Draft
An Empirical Ontology for GIS

How to achieve interoperability and to integrate data from different sources,

or,

A computational ontology for space, time, matter and information.

409 pages, 132,000 words

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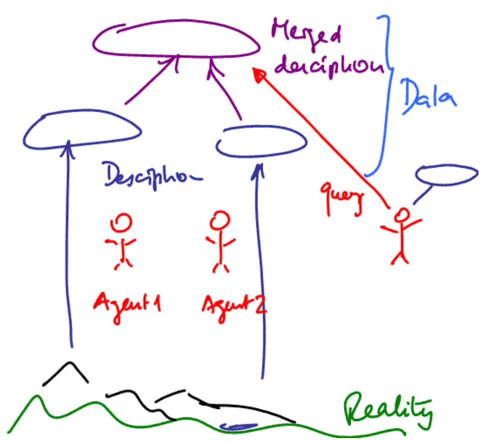
TABLE OF CONTENT

010 PREFACE

Our world has changed a lot since the classical Greeks started to answer questions of ontology in a systematic way; we have moved from a world where the struggle for physical survival was the foremost concern to a world in which wars are fought on information. Only 20 years ago, ontology was a sub-discipline of philosophy, known to few. Now the term ontology figures in official documents of the European Union and industry—specifically software producers and the information industry—starts research projects on ontology. International standardization organizations are busy with defining “Ontology Languages”.

In the information age, the meaning of the information has changed from a "philosophical" debate to a economically important issue. The problem of translation between different languages or professional vocabularies has become important. Different collections of data must be merged to yield valuable information, but this is only possible if the meaning of the data and its encoding is compatible; we observe the differences in vocabulary when we navigate web pages produced by other organisations or ask queries on online databases. In each case, differences in the ontology used and the semantics given to words surface painfully.



Description of the same reality by two agents. How to integrate their descriptions?

It is said that the web contains all the information one ever wants – one needs only find it. To construct automatic search engines, which find the data we need to construct a map, to answer a query etc. formalized methods to translate, understand, and compare the data descriptions, the so-called metadata. The methods to build formal ontologies described here contribute to achieve this goal.

The philosophical debate was mired in the different terminologies of philosophy schools that differed minimally but blow-up the differences to fuel a heated debate. Now the discussion is often buried in the jargon of computer science. Both the specialized terminology and the jargon confuse and obscure the issues. I try here to discuss my understanding of ontology and how it is relevant to GIS and important for all of us in simple terms.

1. Address Practical Problems

My interest in ontology is motivated by the practical problems I am confronted with and I want to justify the theory presented here with real application problems and hope to demonstrate at the end why and how the theory contributes to their solution. The result of the analysis is justified with a computational model that can be tested (in principle). I see this as a step towards a rational, hypothesis and experiment based approach to obtain useful results in ontology.

2. Build Computational Model

I am an engineer—my interest is directed to understand and ultimately improve the environment in which we live. Ontology is not often discussed by engineers (as little as by cooks, carpenters, etc.). The ontology of civil-engineering and other classical engineering disciplines is evident: building parts, loads, building materials, etc. The use of information systems pushes theory further. The engineer constructing an information system is not building primarily with physical objects, but constructs a program that refers to the objects in the world. Thus a clarification and communication how different participants construct the objects in the world, becomes important.

I want to avoid constructing a theory for theory's sake. Theory must contribute to solving actual problems in a predictable way. I hope this book on ontology for geographic information system can contribute to this.

3. Story Telling

The text here should include stories to motivate the discussion, examples which illustrate the concepts and images which relate to real world situations. In summer 2001 I have been on a tour to revive the old tradition of story telling: a group of friends has traveled—with a horse drawn wagon—in northern Austria. The nights we stayed in villages and invited the inhabitants to join us around our camp fire for story telling—stories about the past, loves, ghosts, and also practical jokes. Many followed the invitations and many a funny or sad story was told.

I will try to address the deep questions of ontology with an eye to my personal experience and tell it as far as possible for a scientific topic in the style of story telling.

One of the important lessons I learned from story telling is that one should tell the facts and let them speak for themselves; the interpretation is left to the hearer. I hope the computational model sketched convinces the reader that my initial choices are justified. I am fully aware, that other interpretations of the world are possible, but I hope this interpretation is one that is useful and agrees with much of our everyday observations.

4. Simple Language

Vester has pointed out that text books for schools are not communicating well. They often hide simple concepts behind complicated words of scientific language typically of Greek or Latin origin. Readers fail to grasp the intentions of the writer, but may be impressed with his learnedness. Unfortunately many of the research papers we have to read (and also many I have written) are influenced by this unfortunate tradition that what is scientifically deep must be written in a pompous style difficult to read.

Writing in a foreign language—this was the justification for famous writers like Ionesco and Beckett—slows progress and forces one to consider the meaning of sentences carefully. In the mother tongue one can write and hide behind well sounding but logically wrong sentences.

5. Images

I have learned that our view of the world through images is different from the reality captured in words. Images are perceived in a different way than verbal messages. When we use words, the world is already subdivided into units that have specific names—usually related to a specific way of using the things. I will try to capture some of the immediateness of situations by showing pictures.

Links between images and words

The ontology for pictures should be the same as for words or at least we should understand the links between images and words. This is practically relevant in the spatial context when we convert between verbal instructions to find a place on a map.

Photograph of map and landscape

One of the important methodological differences between this approach to ontology and others is that it starts with direct observations, similar to images. Ample empirical evidence demonstrates that mental processing of optical (image) stimuli is different than processing verbal stimuli –the verbal processing is (mostly) conscious, but images are reacted upon by non-conscious parts of our brain (Roth 1994). It is not an accident that advertisements use images; images can transfer emotions and it is difficult for the observer to assess and control the emotions received [ref].

An image says more than 1000 words.

6. LIMITATION

I finish this book with a clear understanding that not all questions, not even all questions of importance can be answered with the methods I apply here. Everybody knows, that, according to Douglas Adams, the answer to the most important question is 42, but unfortunately, we do not remember the question (Adams 2002). I suggest that the methods used here are sufficient to yield insight that is practically useful for the construction of better information systems for geography, planning, town administration, etc. I hope they are a valuable starting point for others to correct my errors and misconceptions and advance our understanding of the world further. I have left a discussion of imprecisions, errors, and approximations for a separate text that I hope to publish later.

Hamlet says ‘There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy’ (Shakespeare *Hamlet*, Act I SceneV). Not all of them can be known in the way scientists discover and know. Therefore ‘Was man nicht sagen kann, über das soll man schweigen’ (Wittgenstein 1960).

Picture 1 Bar Tahiti panorama

A first draft was written in the summer 2001 in the bar Tahiti in Procchio on the Island Elba.

ACKNOWLEDGEMENTS

The ideas collected in this text have been worked on over the years since my Ph.D. studies at ETH Zurich under the guidance of the late Rudolf Conzett.

The debates in many meetings have influenced my thinking, but the probing questions of my two daughters Stella and Astrid have often forced me to rethink a question till I could explain it in simple terms and my explanation needed not be hidden under the cloak of scientific mumble.

But equally important were my philosophically inclined friends during the years: Susi Michel, Maria Catedra, Irene Campari, Sissi Fels and Christine Rottenbacher

I appreciate enormously the pleasure to work with very gifted graduate students and colleagues all over the world in many research projects over the past years. I have used material from my published papers in this book, most important (Bittner, Wolff et al. 2000; Frank 2001; Sellis and al. 2003). I also used a paper co-authored with Martin Raubal (Frank and Raubal 1998) and with Stephan Winter.

Nearly everybody with whom I had a meaningful conversation in my life has influenced my views on ontology. The discussions during the meeting David Mark and I organized in Las Navas del Marques with Pylyshin and George Lakoff as two contrasting views have influenced my thinking. There is the group of academic friends and sparring partners, Barry Smith, Werner Kuhn, Max Egenhofer, David Rhind, and Peter Burrough, Stephen Hirtle; the colleagues from the National Center for Geographic Information and Analysis NCGIA late David Simonett, late Jack Estes, Ross Mckinnon, Waldo Tobler, Reginald, Golledge David Mark, Mike Goodchild and Helen Couclelis. My graduate students over the years, especially Steffen Bittner, Thomas Bittner, Damir Medak, Alenka Krek, Hartwig Hochmair, Martin Raubal, Gerhard Navratil, Florian Twaroch and Christine Rottenbacher. My secretary Edith Unterweger allowed me long and uninterupted work sessions and Christian Gruber improved the manuscript in numerous ways.

Equally important were everyday discussions with my family and friends: first my daughters Stella and Astrid, then Susi Michel, Maria Catedra, Maria-Augusta Fernandez, Sissi Fels and Charlotte Sühs. I am grateful for my friends in Geras: Robert und Silvia Haidl, Gerlinde and Ingo Hofbauer, Jo Kisslinger. I wrote and though about this in the casa Angelini and in the Bar Tahiti in Prochhio on the island of Elba (Italy). Last but not least, Christine's cats Tiger and Punkti which I adopted in this text and the horses in Wolfsbach: Santana, Stephen and Antares.

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Chapter 1 040 WHY A BOOK ABOUT ONTOLOGY FOR GIS

1. MY BACKGROUND

I have been interested in ontology since my late teenager years. The copies of Kant, Hegel, Husserl, Heidegger, Wittgenstein, Carnap and Sartre on my bookshelf were all bought before I was 20 and I have moved them many times from one apartment to the next. The question philosophers have considered for more than 2000 years "What is really existing?" and "What do we know for certain?" were with me all the time. I have—in different situations—tried to understand the questions better and to provide the appropriate answers for the particular way the question was posed. The standard, common-sense answers our culture provides was sufficient for my daily operations. I saw limitations and internal contradictions of these folk-theories and tried crude formalized discussions of ontology (in the style of Carnap (Carnap 1958)) and later an extensive study in esthetics connecting with the then new literature on cybernetics (Wiener 1961) and computer art (Bense 1982), which lead me to semiotics (Eco 1976). During this time I ventured even to learn Chinese and Finnish, with little success, read Whorf (Carroll 1956) and got acquainted with the principles of production grammars (Chomsky 1980).

After having studied surveying and mapping at the Swiss Federal Institute of Technology (ETH) in Zurich, I was invited by the late Rudolph Conzett to investigate how the new technology of database management systems could be used for storing data for topographic mapping and land registration. (Frank 1983). Despite the fact that my focus at that time was on the solution of technical questions to achieve acceptable performance for spatial databases (Frank and Tamminen 1982; Frank 1983; Frank and Barrera 1990) I found that the difficult questions were not of a technical nature (Frank 1983). What is the correct way of representing real objects in space—and is there a single correct way? How to reconcile two different representations selected by two different persons or agencies? How to define precisely the meaning of data in a database? How to integrate data with different semantics?

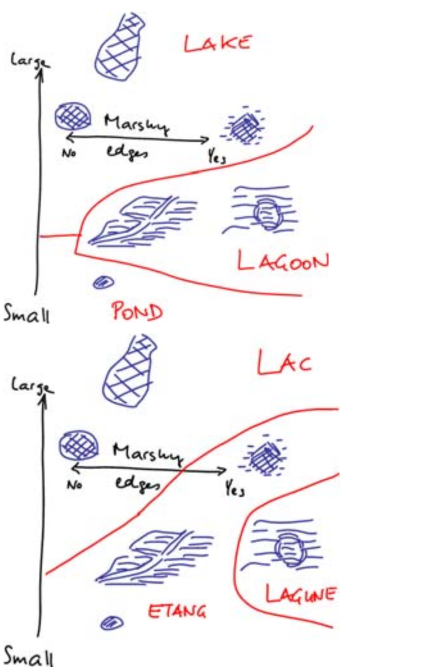
Thaya park?

Often differences in meaning can be bridged over quickly—transforming temperatures in degrees on the Fahrenheit scale to degrees on the Celsius scale is trivial. More difficult is the conversion of spatial position expressed in different coordinate systems, where the assessment of accuracy of relative position is usually impossible (Baarda 1981). The translation of natural language terms, for example the simple concepts of 'lake', 'pond' in English and the corresponding terms in French or Spanish, is not straight forward: dictionaries indicate that pond translates to *etang* in French, but some *etang* in France are much larger than anything that is called a *pond* in English; Mark has pointed out that perhaps the properties considered in one or the other language are different [figure] (Mark 1993).

°C to °F $\frac{f-32}{5} \cdot 9$

°F to °C $c \cdot \frac{9}{5} + 32$

Formulae for Fahrenheit to centigrades



The use of the terms Lake/Lagoon/Pont in English and the French corresponding terms Lac/Etang/Lagune(Mark 1993)

With my newly minted doctorate I had the good fortune to start teaching Geographic Information Systems at the University of Maine in 1982; I was given the freedom to address the questions I felt important and difficult, namely the proper representation of geometry with two foci:

- representation of coordinate geometry with the limited precision of finite computer systems using simplicial complexes (Frank and Kuhn 1986), and
- qualitative representations of spatial relations, specifically topological relations (Egenhofer 1989).

The cooperation in the National Center for Geographic Information and Analysis (NCGIA) http://www.ncgia.ucsb.edu/ (Abler 1987; NCGIA 1989) helped me to better understand the breadth of the fundamental questions and to separate them from technology issues important for the day, but not of lasting impact. In this environment we studied methods for spatial representation and became aware of the fundamental difference between a vector and a raster representation, linking it to the debates by the positions of Descartes—space existing without the objects in it—and Kant—space as an intrinsic properties of the objects (Nunes 1991).

In my work as professor for Geographic Information at the Technical University of Vienna I realized that the hard problems of integration of data from different sources are caused by differences in our concepts of reality: Do we see a road as a line or an area—and if we see it as an area, how wide is it? This question was already discussed during my PhD work (published by my colleague Chevallier as part of his PhD studies (Chevallier 1984) (Figure 1). The same difference we observe in the political process, when opinions from different camps clash; it is difficult to trace them back to different fundamental choices (Lakoff 1996).

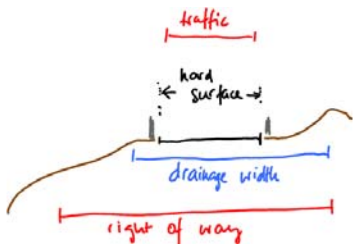


Figure 1: Different definitions of the width of a road

2. THE LACK OF ONTOLOGY IMPEDES THE USE OF GIS

Semantics and the ontological framework used to describe semantics have become the crucial missing piece to achieve better use of information (Masser 1988; Hunter and Williamson 1990; Masser 1999). Numerous research programs, for example by the European Commission, target the infrastructure necessary to use the available information better. We live in a society with abundance of data, but we do not have the tools to make good use of it. It is difficult and time consuming to find information on the World Wide Web. Understanding the semantics of the data is the crucial element; it is at the core of the software crisis, which (Gibbs 1994) is still limiting what we can use from the potential of the computers.

The lack of understanding how to describe semantics impedes the integration of information from different sources in meaningful ways; it limits what efforts like the Open GIS Consortium (OGC 2000) can achieve and how effective tools like 'web mapping' can be: they promise that we can map data from different sources, stored on different computers under different formats, bring together in a single map—if we only can understand what the data means!

Last, but not least, semantics is at the core of methods to describe the quality of data, because quality must be expressed in terms of the fitness for use (Frank and Timpf 1994; Frank and Timpf 1995; Frank and Timpf 1995), therefore the use must be described. Semantics is, essentially as a reflection of the data quality assessment, linked to the economic valuation of data and information, which must be answered before information business can flourish (Krek and Frank 2000; Krek 2002).

3. How ontology contributes to interoperability

Any information system like a GIS contains data which represents some part of reality, but people differ in the way they conceive the real world and how they represent what they see. Most obvious are the differences in the words languages use to describe things or places: a *wood* is a *wald* in german, but a *meadow* is not exactly the same as a *feld.* Language is incredible flexible in the use of a limited vocabulary, as anybody observes with frustration when searching the web for some text and encounters any hits with unrelated items just using the same word for with some other meaning. Wordnet [ref] lists 17 senses for the word *field*!

In order to integrate data from different sources, but also to search for data, the different vocabularies must be related to each other. Practically, groups of cooperating people can agree to use only a limited set of terms with a fixed meaning – technically called a 'restricted vocabular'. Going through university to obtain a degree has much the same effect: one learns the standardized vocabulary of one's trade, for example the vocabulary of lawyers.

To integrate across application boundaries and from different domains of science more fundamental differences in conceptualization surface: a transportation engineers sees ports linked by ship routes, but a marine biologist sees a water volume! Ontology clarifies these fundamental differences in conceptualization and investigates how the different viewpoints can be reconciled.

4. Ontology for Geographic Space and Time

Current ontological investigations related to databases and information systems have been extended into the spatial domain (Egenhofer 1989; Egenhofer 1989; Randell and Cohn 1989; Egenhofer and Franzosa 1991; Casati and Varzi 1994; Stell 1997; Casati and Varzi 1999) (Bennett to appear), but their extension into the spatio-temporal domain (Cohn 1993; Galton 1995; Galton 1997; Hornsby and Egenhofer 1997) has proved more difficult than expected (Smith and Brogaard 2000; Frank, Raper et al. 2001). An overview of Time Ontology for computer science was published by (Schreiber 1994); Montanari and Pernici discusses the different proposals for temporal reasoning

(Gadia and Nair 1993). Missing in the ontology discussion is so far the distinction in administration and database management theory between two time perspectives: the time as events occur in reality and the time as a system acquires knowledge about the events (Snodgrass 1992).

I will investigate the questions that arise when information systems are built for purposes involving the representation of geographic space, time, and processes (Abler, Adams et al. 1971; Couclelis and Gale 1986) . Geographic Information Systems are especially demanding and help to identify the important issues. They model real-world situations including their spatial and temporal aspects, their application area is very broad and extends from the administrative and legal rules governing land ownership and registration (Dale and McLaughlin 1988) to systems built for environmental purposes and for research into global change (Mounsey and Tomlinson 1988). The situation is not substantially different for other spatio-temporal systems, like systems for motor traffic monitoring or tracking airplanes.

Spatio-temporal geographic database are often built from data from many different sources, where ontological differences surface. Data to be integrated differs in their semantics and representation and a meaningful combination requires bridging the gap created by ontological assumptions as well as translations between the representations once their meaning is in the same context. Even for databases where all data come from the same source, the same ontological gap between the ontological of the data collector, the designer of the GIS software, and the users must be bridged.

5. New Approaches Needed

The information age leads to the construction of ever more encompassing information systems in which data from very different sources are integrated. Researchers in Artificial Intelligence have observed early on that different representations of reality are possible, many are just useful for restricted subsets of our interactions with the world and cannot be consistently extended to include a broader view (Hobbs and Moore 1985). It is obvious that human in day to day situations use quite crude but mostly adequate methods to reason about our physical environment. The construction of formal representations of every-day, ordinary man reasoning about the environment, so called 'naïve physics', common sense reasoning (Davis 1983) were attempted and the formalization of how humans think about geographic space proposed (Egenhofer and Mark 1995). It has not been possible to achieve consistent systems for larger subsets of our experience and interaction with reality so far.

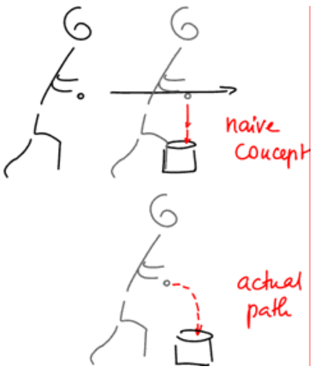


Figure 040-02 and 03: Person walking drops a stone into a basket and misses; Contrast Naïve and Newtonian physics

Despite Aristotle's discussion of processes (Aristotle, Ross et al. 1998), ontology followed his approach to construct taxonomies of nouns (Aristotle, Ross et al. 1998; Aristotle 1999), describing classes of objects. The equally interesting ontology of properties is much less explored (Quine 1977), or the ontology of operations has not been explored—unless one is willing to read Gibson's discussions of affordances as an attempt to consider operations as fundamental (Gibson 1979). It seems necessary to consider all three fundamental aspects of an ontology—namely objects, properties and operations and correspondingly nouns, adjectives and verbs at the same time. It is not surprising to see that even linguists are much more interested in establishing taxonomies of nouns than adjectives or verbs (Fellbaum 1998). The exceptional work by Beth Levin demonstrates how fruitful an investigation in the grammar and the semantics of verbs is (Levin 1993).

6. Hope for Improved Political Decisions

The impetus in writing this book, of which the focus is on information systems, specifically spatial information systems, is to contribute to the understanding of the differences in opinions in a pluralistic world. How can we arrive at a rational dialog between different cultures, languages, and political opinions? It should be possible to relate different opinions to the common reality that we share and then decide on the best course of action transforming this very same common reality—the world—to become a better place for all. In this book I will analyze the causes of these impediments, which are known for millennia. I hope that the theoretical analysis can contribute practically to their solution. I seem to share this viewpoint with George Lakoff [new book].

PART TWO PREPARATION

In this first part, the foundations are laid: I explain the origin of ontology in philosophy and the recent use of the term in computer science, especially Artificial Intelligence and database design. A list of guiding principles I try to follow in developing the topic is made explicite and gives an idea how this approach is different from traditional ontologies.

The approach here is dividing reality in tiers which exist in a similar way and chapter xx gives an overview of these tiers before later parts then discuss them in detail. These tiers are linked by operations which transfer knowledge from one tier to the next. These operations are, in principle, expressable in a formal model and some parts of what is described here has been tested in a computational model. Chapter xx describes the how using formal models helps us defend against the frailness of the human mind. The part closes with a description of small scale space and how it influences the structure of the conceptualization of reality before I describe two geographic scale spaces which I will use as examples, namely city and open landscape.

Chapter 2 020 WHAT IS ONTOLOGY?

Bild – akropolis von athen –

Many good books on the subject of ontology in philosophy exist and I do not want to add to this list. There are excellent books by competent philosophers that review the development of ontology from different points of view (Runggaldier and Kanzian 1989). Such books list a number of attempts to construct a consistent framework for thinking about the world—each labeled as an “-ism”—and show later, why one or the other, and in the end, all of them, lead to logical contradictions.

This chapter reviews different interpretations of the term ontology. It contrasts the philosophical tradition with the novel interpretation of the term among computer scientists, especially database designers and researchers in Artificial Intelligence. I then present my understanding of positions, which impressed me over the years as possible answers to the question of "what is here" (Quine 1977). The few selected positions listed stand prototypically for questions still discussed today and identify some of the questions a practical ontology has to answer.

1. NOTION OF ONTOLOGY

Ontology is a new word—customary since the 17th century (Barry Smith and Welty 2001)—for the very old and fundamental question “what is here?” (Quine 1977). There are numerous occasions where one observes that our concepts of what is real are questionable—for example when watching a magician’s (Gopnik and Meltzoff 1998). The eminent scientist Heinz von Förster was fond of magical tricks, because they seem to blur the dividing line between real and imagined and as such cast a very bright light onto the question "what is real"? What things are real? What is it that makes a thing real? In what way is a thing real?

Philosophy tries to find a single solution to the question “what is”, which fits for all kind of ‘things’; similarly to logic, which applies to all sort of reasoning. The success of this enterprise—or rather the lack of success—seems to indicate that this is quest for an ontology 'one size fits all' is mistaken. The approach selected here intends to separate different kinds of ‘things’ and to outline different ontological regimes for their existence: the cat “Tiger” (Figure 2) exists in a different form than the "commune of Marciano Marina" in Italy (Figure 3), or "democracy" (Figure 4); they have different forms of *existence*. A theory that differentiates different types of existence influences our interaction with them, our expectations and how we codify them.

Figure 2: Tiger

Figure 3: Map Marciano

Figure 4: Wilhelm Tell the inventor of democracy (Friedrich Schiller 1759-1805)

Picture of tiger, map of marciano

The imprecision of human natural language in which philosophical debate is carried out—not improved by the seemingly precise professional jargon of different philosophy schools—makes it difficult to pinpoint the differences. It is difficult to separate reality from the way we talk about reality and the two are often addressed with the same terms. Some philosophers in an effort called ‘ordinary language philosophy’ have tried to deduce the rules governing reality from the use of language (Austin 1988; Grice 1989; Heidegger 1993)—preferably ‘old’ languages, like Greek because no native speakers are left to contradict the speculations as was critically remarked by Eco (Eco 1976). Analysis of language can only yield insight how language describes reality. At best, language embodies the commitments about existence of things people in a certain culture make and the results do not automatically have universal validity.

Some philosophers have attempted formalizations. The few subsets that have been formalized show much more variability than one would like (Simon 1987; Casati, Smith et al. 1998). No single and undisputed solution has been identified and some proposals seem logically consistent but do not correspond at all with the real world as I observe it every day. Philosophers are fond of puzzles, like Zenon’s question how Achilles ever can catch up with the turtle, starting ahead of him, but moving only half as fast as he (Figure 5); (Hofstadter 1979). Such puzzles are fascinating, but not really useful to solve day to day problems.

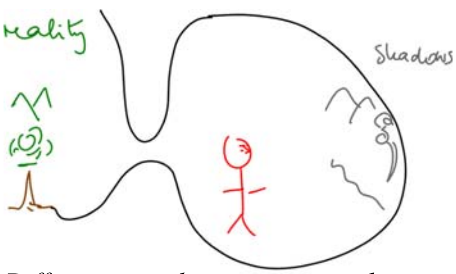
Figure 5: Zenon and turtle

2. The origins of Ontology in Greek Philosophy

The Greek philosophers, especially Aristotle in what he called the ‘primary questions of philosophy’ and what later was referred to as Metaphysics (Aristotle 1999), inquired what the properties of the world and the objects in it are and how we perceive them (Smith and Mulligan 1982) (Smith 2001). Philosophy today uses the term ontology to describe *that which is* (ontos, Greek , to be; ontology, therefore: the science of what is) and in this sense, it is used synonymous to 'metaphysics'. Quine coined the description of Ontology as an answer to the simple question ‘what is here’.

3. Plato’s Cave: Separate Reality and our Thinking of It

Plato has pointed out—around 550 BC—that our knowledge of the world is very limited and must be separated from the world itself: we are in a cave and see only the shadows of the events which occur in reality. We must not confuse reality with our knowledge of it (Figure 6). All our talking about reality is just about our observation, given that we do not have any other way to know or think of reality than what we know.



Difference ontology vs. epistemology

Figure 6: What we see are the shadows on the wall of the cave

Plato’s ‘cave’ metaphor stresses that reality (the things outside of the cave) are the causes of the shadows we see, but they are not the shadows. The connection between the things and our percepts are our methods to observe, which pick some aspects of the things and ignore others. There may be more and different properties in reality than what we see.

Ontology is often used in contradistinction to *epistemology*, which is "the field of philosophy, which deals with the nature and source of knowledge" (Guarino 1995), briefly a ‘theory of knowledge’. It is difficult for us living in the world to separate the description of the world from our knowledge of the world and how it is expressed in languages. Strictly speaking, if there is only one reality, there must also be only *one Ontology* and the human views or conceptualizations of this world are not ontologies in the strict sense. We need another term for the "theory what people believe the world is like"; one could call them 'projected ontologies' or 'epistemological ontologies' (Smith 2002 (draft)) and use a capital O for the single Ontology. The approach in this book is a separation in tiers and the tier 0 for ontology contains what is really in the world, from tier 1 is what we know about the things in the world, etc.

4. Zeno’s Paradox: Achilles and the Turtle—Limits and Infinities

Zenon considered the problem of movement. He discusses the example of a fast runner catching up with a turtle: whenever he reaches the position where the turtle was before, the turtle has moved further and he has again to run to this place and when reached this one, the turtle has moved further. Practically we all know, that the fast runner will catch up with the slow turtle and overtake her, but theoretically he seems not ever to be able to reach the elusive turtle.

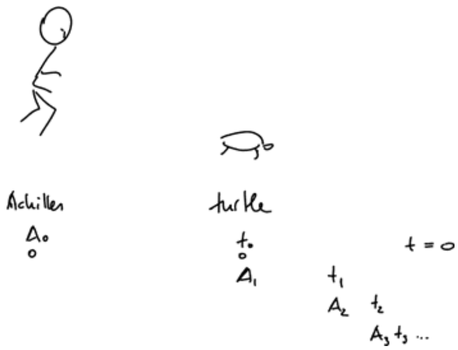


Figure 7: Achilles can never reach the turtle

The modern reader knows that the difficulty is with adding up an infinite number of small quantities. If Achilles runs 10 m/sec and the turtle half as fast, and the turtle starts 10 m ahead of Achilles, then the time it takes for Achilles to reach the turtle is the sum of the infinite series 1/1, 1/2, 1/4, 1/8… 1/ 2**n, which is in the limit of n going to 2. For the Greeks adding up infinitely many infinitely small fractions was confusing. It led them to conclude what they knew from direct experience to be false: That Achilles cannot overtake the turtle.

The underlying question is one of the properties of time and space: is time and space continuous as is assumed for the mathematical theory of limits, or is time and space built from small atoms. The Greeks thought matter consisting of atoms—that, which is not divisible. Modern physics has shown that atoms are built from smaller particles, quants that have a dual interpretation as the smallest units and as continuous waves.

Many modern philosophers were very impressed with quantum physics (Smith 2002 (draft)) and draw conclusions from the model of quantum physics to macro reality. Such arguments are extremely dangerous., I refrain from such arguments, as I want to concentrate on the parts of reality that are directly experienced by mankind. Quantum physics is an interesting and productive theory, but it is not within the realm of direct human experience; I do not believe that commonsense reasoning and the logical structure of our language are appropriate tools to discuss. As the famous physicist Feynman (Nobel price 1965) said: Anybody claiming that he understands quantum physics demonstrates by this very claim that he has not understood it.

5. Aristotle's Metaphysics—Taxonomies

Aristotle attempted a systematic classification of the things in reality. In his Metaphysics—"which goes beyond Physics"—he classified the things into classes and laid the foundations for modern ontology as a taxonomy of what exists. It is instructive to review his classification.

Figure of greek coin demonstrating todays respec for this philosopher

Substances are the things that consist of matter. They are grouped in distinct '*kinds'*—humans, dogs, cats, stones, etc.—which are clearly separated from the individuals (or particulars), which are instance of these classes: me, you, the cat Tiger, my car.

Accidents are things attached to substances. They cannot exist independent of a substance: Barry Smith's headache is dependent on his head (Smith 2001).

6. METAPHYSICS OR ANALYSIS OF LANGUAGE?

As far as Aristotle identified different '*natural kinds*'—the classes of animals—he described facts of biology: animals of different species cannot breed together (or the offspring is sterile) and therefore species are distinct and can be differentiated. They appear as autonomous, clearly identifiable classes. There are not hybrids between dogs and cats, horses and asses (very closely related species) can breed, but their offspring mules are sterile.

This definition is circular, as the definition of species in biology used to be based on the potential of interbreeding. With modern biology, the question how to define species have become less clear and clearly depend on human interpretation: species a.k.a. Aristotle's 'natural kind' are not a fact of nature, but a human construct, namely the classification of animals in classes such that members of a class can breed together. Other definitions of a kind of animal are possible; they are, as human constructs, arbitrary and subject to debate. In certain areas—for example in plant families like 'rubus' (Blackberry) species (Figure 8) cannot be differentiated and all varieties within the family form hybrids. Of practical interest are varieties of whine, like Riesling x Silvaner, and other garden plants, crops, etc. (Figure 9).

Figure 8: Rubus

Figure 9: Riesling x Silvaner

Figure 10: Birds

Picuter of mule – wine glass?

Eleanor Rosch studied extensively the way humans form categories and found that even for well-defined categories like 'birds' there are better and worse examples: raven, robin and sparrow are good examples, but emu, ostrich, and penguin are not quite so good exemplars of the class 'bird' (Figure 10) (Rosch 1973). Rosch could observe that questins like "Is a robin a bird" were faster than to "is a penguin a bird". The prototype effects influence also reasoning:

> "There are typical case prototypes used for automatic inference about common cases. For instance, if someone says that there's a bird outside, we expect to see a small songbird, not a great auk or an ostrich. An experiment was done by Lance Ripps in which he told one group of subjects that all the robins on an island got a certain disease and asked them if they would expect the ducks to get it. Then he told another group of subjects that all the ducks on this island had a certain disease and asked if they would expect the robins to get it. The subjects were more likely to expect the ducks to catch a disease from the robins than vice versa.
> The inference goes from the typical case to the category as a whole, so the typical case stands for the category as a whole." [http://www.icsi.berkeley.edu/~bbergen/cogsci110/lectures/lecture10.html]

It appears that the system of categories proposed by Aristotle is the exceptional case of biological species corresponding to the way human beings form and use categories in daily live.

7. Kant's Ideals: The Ontology of Abstract Concepts

The Greeks were wondering where ideal concepts like perfect squares or circles reside. All realizations are imperfect, but the human mind can imagine the ideal circle. Do ideal concepts exist in the same way imperfect circles exist? This can be generalized to other ideal concepts: the number π (Figure 11), e, mathematical laws like 1 + 1 equal 2. Do they exist independent of human thinking? And if so, where? Closely linked to mathematical truth are the foundations of religion, the credo (which incidentally did change in time!), the existence of god, ethical behavior and similar questions.

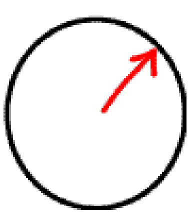


Figure 11: c= 2rπ

Kant assumed that such eternal truth must exist independently and are discovered by mankind through studies. One may assume that the number π (as all real numbers) existed in the same way that all other numbers (e.g., π + 1, or π + e) and were only singled out to have special properties.

I will embrace a strictly realist position, and not posit a transcendental existence of ideas outside of the human. Lakoff and Nunes have demonstrated how abstraction from real experience with the phyisical world lead to the construction of abstract theories which result in the abstract construction of modern mathematics, physics etc. (Lakoff and Núnez 2000). Child psychology (Gopnik, Meltzoff et al. 2001) argues today that learning of small children and construction of abstract theory by science is based on the same principles, making Lakoff's argument all the more plausible.

8. CONSTRUCTIVISM

In my opinion, confusion between talking about what really is and how we think and talk about it, leads to many of the contradictions which philosophers are so fond of. The approach here separates in different tiers what is real and how we think and how we talk about it.

The observation that human construct representations of their reality in their mind and the puzzling fact, that the same physical situation can lead in different people to different representations, led to my approach, in which the human construction of concepts and later their representation in an information system is the primary object of study.

Chapter 3 030 MODERN NOTIONS OF ONTOLOGY

1. ONTOLOGY IN COMPUTER SCIENCE

Building computational models of parts of reality requires a decision what is included in the model and what is ignored. Different scientific theories differ mostly in what is considered and what is left out. Augustine introduced the related notion 'universe of discourse'. As far as a rational discussion is concerned, the notions of ontology or universe of discourse are related to the concept of a system and its boundary. Identifying the minimum amount of aspects to include and to avoid unrelated and often confusing other influences, is the art of an analyst or scientist.

In this sense computer science has borrowed the term ontology to list what is considered within a discussion or an information system (Hayes 1985), database specialists talk about database schema, often with the same meaning.

Occam's Razor:
Entita non sunt multiplicande praeter necessitatem [occam]

Occam has warned of the danger to create new concepts when something not yet completely understood is encountered. Our explanation of ontology—and other parts of science—include non observable, hidden variables. Philosophers are quick to give names to them and then act as if these unobservable 'things' were real. It is a well accepted principle in science—at least in the natural sciences—that from two theories that purport to explain the same observable facts we should prefer the one that contains less hidden variables (Kuhn 1994).

Ontologies are modeled after scientific theories (or the naïve counterparts thereof) especially physics (Hayes 1978) and geography (Egenhofer and Mark 1995), and they generalize the rules found there. Recently philosophical ontologists have begun to study practical problems from law, engineering, and commerce and they have started to identify the limits of ontologies based on empirical observations of physical objects. It was found that not only the AI programs but also many ordinary application programs contain much code that is a representation of the ontology necessary for the selected part of the world. The ontologies are similar, but difficult and time consuming to build. Lenat and others have started collecting the 'commonsense knowledge' and identified a business in selling prefabricated ontologies (CYC 2000; ONTOS 2001).

Ontology is trying to establish a set of consistent commitments (assumptions) about how we see the world and interpret our observations. Analysis of language identifies the assumptions about the world a speaker builds into his sentence; as such, this is relevant for the construction of an information system: it makes clear what meaning a statement has d [frank- in auf an paper].

2. THE NOTION OF 'ONTOLOGY' IN THE ARTIFICIAL INTELLIGENCE AND DATABASES COMMUNITIES

Ontology and the related term '*semantics'* have recently found increased attention in database discussions. Early discussions of ontology issues important for databases (Kent 1979; Frank 1983) were lost in a sea of papers on technical—mostly performance—issues, despite the fact that early database textbooks (Lockemann and Mayr 1978) discussed the relationship between information system and real world. This is different today: in a conference in 2000, two of the three invited talks where concerned with semantics. Ceri discussed the expression of semantics in XML and possible extensions http://www.edbt2000.uni-konstanz.de/invited/talks.html and Reuter dedicated his whole lecture to the discussion of what semantics a database should contain and of how current database structure is not sufficiently flexible to capture it (Reuter 1981). His examples were diverse and ranged from an application providing guidance for tourists moving in the town of Heidelberg to an application from science, where reports about scientific experiments in cellular biology must be organized. Reuter started with the assumption that the ontological categories of Space and Time should be included and proposed History, Topology and Intensions as candidates for categories to be included in the future, a position already advanced by Gadia and Nair in 1993(Gadia and Nair 1993) (Tansel, Clifford et al. 1993).

Information systems and their implementation as databases rest on ontological commitments. The ontological commitments are mostly reflected in the type system: Decisions about the type system used, how identifiers are managed, etc., are derived from a specific view of the world to which the database relates, in other words from a specific ontology (Brodie, Mylopoulos et al.

1984). The ontologies of standard database models make very limited assumptions and therefore the data model is widely applicable, but unspecific; different applications may assume different ontological commitments that lead to difficulties in the interoperability of applications.

Spatio-temporal databases must make stronger commitments to capture the meaning of space and time. This ontology is necessarily more involved and the connection to the application area stronger. The designer of a database application has to reconcile the ontological concepts from the application area with the ontology built into the geographical database.

The ontology built into a DBMS can be insufficient or it can be too restraining. Optimally, a spatio-temporal database involves in its built-in ontology a minimal, but strong commitment on how space and time is structured. A stronger set of ontological commitments improves interoperability. If it is too restraining the ontology commits those who apply it to assumptions that do not hold for novel applications and force them to circumvent the assumptions by complex programming. If it is insufficient the ontological categories necessary for numerous applications are not available and must be reconstructed for each application anew; the resulting incompatibilities will be very costly to correct later. (Frank 1997).

Spatio-temporal databases are typically constructed to integrate the knowledge of many agents and face the problem of heterogeneous environments, a point already raised by Wiederhold et al (Jajodia, Litwin et al. 1993; Tansel, Clifford et al. 1993). Current databases do not allow us to model joint beliefs of groups of agents that do not correspond to similar beliefs of other groups of agents; for example, Reuter works with groups of scientists, who manage terabytes of reports of results from experiments in cellular biology, where the validity of the results and their interpretation are debated among the groups http://www.edbt2000.uni-konstanz.de/invited/talks.html.

3. THE CRITIQUE OF DISEMBODIED ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) had a long tradition of building systems that modeled as realistically as possible an expert's understanding of a situation. These systems represented only the knowledge about the situation, not the situation itself. To include the knowledge of the (physical) world into the reasoning process was found to be difficult. The collection of the necessary commonsense knowledge became unexpectedly a Herculean task (Lenat, Guha et al. 1990); the last reports where that 6 million rules had been collected and an end is not in sight.

Dreyfus in an abstract critique what AI cannot do (Dreyfuss 1972) and later Brooks (Brooks 1991) in a direct comment on the praxis of AI research to build models of the mind only, pointed out, that AI was not connected to the physical (bodily) existence of autonomous agents in the world; humans consist of body and mind. Brooks argued that the experience with the interaction with the physical reality imposed restrictions and gives guidelines for research in AI. He, with his research group at the MIT, set out to construct autonomous robots that can adapt and learn about a simple environment and solve simple tasks in it.

The newer multi-agent theory avoids this mistake by regarding the environment as integral part of the framework (Ferber 1998). In the computational model for ontology to be sketched here, models of autonomous agents in a model of physical reality will be demonstrated.

4. Ontology and Semantics

The current use of the term ontology is closely linked to questions of semantics, i.e., definitions of what is meant with some term (Stoy 1977; Jackendoff 1983; Jackendoff 1996). The description of a program, both when writing the requirements and when writing the user manual, requires an ontology in the sense of a ‘universe of discourse’ and an explanation of the meaning of the terms occurring in this universe of discourse.

In the classical view, ontology and semantics are two completely distinct topics: ontology describes what is and semantics is concerned with the definition of the meaning of signs (for example words). Traditional semantic studies (de Saussure 1995), for example in the form of dictionaries, are limited by the problem of *grounding* (Lakoff 1988). Some words must be accepted as having a fixed meaning in order to be used to define other ones. Wierzbicka postulates a small set less than 100 words that are fundamental and occur in all languages, from which all others are constructed (Wierzbicka 1996). These primes are all related to bodily and direct sensory experience. Wizerbiska claims that this small number of primes is sufficient to explain all other words of natural languages, forming a small (semi-formal) language.

Ontology runs into the same difficulty: the meaning of the terms must be explained. The concepts occurring in classical ontologies: matter, objects, animal, ideas, etc. are part of the list of Wizerbiska's list of fundamental terms. Ontology provides, in this view, the explanation of some of the fundamental terms. Modern efforts where ontologies contain very large collections of terms are often divided in the most basic concepts, from which all other derive and the rest. These so-called 'upper level ontologies' of some 100 terms form the foundations for very large collections (sometimes more than 1 million) of concepts arranged in a systematic manner. In this modern, operational view of ontology, ontology gives the semantics of many terms: there is no obvious limit, where an (upper level, classical) ontology should stop and an ordinary dictionary type of collection of meaning should start. In fact, vastly different projects like CYC, which aimed at collection of common sense knowledge, and wordnet, aimed at a large computerized dictionary, result both in comparable products (Fellbaum 1998; CYC 2000).

It has become evident, that a separate discussion of ontology and semantics is not productive and the integration of the two efforts has the potential for a significant step ahead. This is the approach this book takes.

045 INTERLUDE

The complexity and extension of commonsense reading—and it's essentially spatial part—became evident in the effort to collect the rules. It was hoped that the common sense rules could be identified quickly (Lenat 1982) , but as many other projects in Artificial Intelligence this project was also overly optimistic. Nearly 20 years later and having assembled more than 6 million rules linking more than a million concepts the project is not completed.

Picture from Picasso or Bacon?

The following list of the 'physics of comics' http://www.cc.gatech.edu/classes/cs8113f_97_spring/cartoon.html may help to increase our appreciation of the complexity of the commonsense world. Human art often construct a contrasting, non-realistic 'ontology' for example in fairy tales or science fiction novels; these ontologies are slightly-off and contrast with our daily experience. They sharpen our understanding of the ontology we apply day to day, the regular ontology we have learned through continuous interaction with the world.

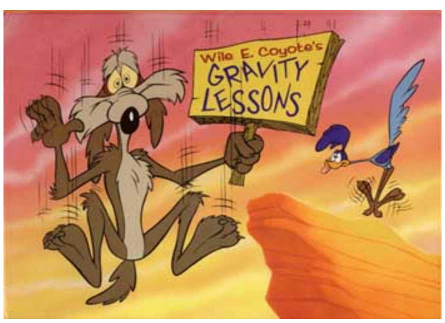


Figure for how to throw a stone into a basket while walking -- earlies

Cartoon Law I
Any body suspended in space will remain in space until made aware of its situation.
Daffy Duck steps off a cliff, expecting further pastureland. He loiters in midair, soliloquizing flippantly, until he chances to look down. At this point, the familiar principle of 32 feet per second takes over.

Cartoon Law II
Any body in motion will tend to remain in motion until solid matter intervenes suddenly.
Whether shot from cannon or in hot pursuit on foot, cartoon characters are so absolute in their momentum that only a telephone pole or an outsize boulder retards their forward motion absolutely. Sir Isaac Newton called this sudden termination of motion the stooge's surcease.

Cartoon Law III

Any body passing through solid matter will leave a perforation conforming to its perimeter.

Also called the silhouette of passage, this phenomenon is the specialty of victims of directed-pressure explosions and of reckless cowards who are so eager to escape that they exit directly through the wall of a house, leaving a cookie-cutout-perfect hole. The threat of skunks or matrimony often catalyzes this reaction.

Cartoon Law IV

The time required for an object to fall twenty stories is greater than or equal to the time it takes for whoever knocked it off the ledge to spiral down twenty flights to attempt to capture it unbroken.

Such an object is inevitably priceless, the attempt to capture it inevitably unsuccessful.

Cartoon Law V

All principles of gravity are negated by fear.

Psychic forces are sufficient in most bodies for a shock to propel them directly away from the earth's surface. A spooky noise or an adversary's signature sound will induce motion upward, usually to the cradle of a chandelier, a treetop, or the crest of a flagpole. The feet of a character who is running or the wheels of a speeding auto need never touch the ground, especially when in flight.

Cartoon Law VI

As speed increases, objects can be in several places at once.

This is particularly true of tooth-and-claw fights, in which a character's head may be glimpsed emerging from the cloud of altercation at several places simultaneously. This effect is common as well among bodies that are spinning or being throttled. A `wacky' character has the option of self-replication only at manic high speeds and may ricochet off walls to achieve the velocity required.

Cartoon Law VII

Certain bodies can pass through solid walls painted to resemble tunnel entrances; others cannot.

This trompe l'oeil inconsistency has baffled generations, but at least it is known that whoever paints an entrance on a wall's surface to trick an opponent will be unable to pursue him into this theoretical space. The painter is flattened against the wall when he attempts to follow into the painting.

This is ultimately a problem of art, not of science.

Cartoon Law VIII

Any violent rearrangement of feline matter is impermanent.

Cartoon cats possess even more deaths than the traditional nine lives, might comfortably afford. They can be decimated, spliced, splayed, accordion-pleated, spindled, or disassembled, but they cannot be destroyed. After a few moments of blinking self pity, they reinflate, elongate, snap back, or solidify.

Corollary: A cat will assume the shape of its container.

Cartoon Law IX

Everything falls faster than an anvil.

Cartoon Law X

For every vengeance there is an equal and opposite revengeance.

This is the one law of animated cartoon motion that also applies to the physical world at large. For that reason, we need the relief of watching it happen to a duck instead.

Chapter 4 050 GUIDING PRINCIPLES

Before starting on an enterprise like this book in a subject area where so valiant attempts have failed before, one must ask oneself, why one believes that one can succeed where others have failed. The following set of guiding principles point out differences to approaches in the past:

1. OCCAM'S RAZOR

Entita non sunt multiplicande praeter necessitatem [occam]

Occam has pointed out that one should not differentiate concepts more than absolutely necessary—which is certainly an important admonition to every scientist. Scientists have a tendency to name something that is unknown, and after having put a name on it, they behave as if it was well-known and its existence assured.

Occam has also warned against too much generality—one must not generalize beyond what is appropriate. Several recent books discussing specific points of ontology demonstrate, that completely generalized concepts of objects, space, time, etc. are leading to contradictions (Simon 1987; Casati and Varzi 1994). The approach followed here tries to give generalized properties for ontological tiers: objects that exist in a similar way and follow similar ontological commitments—but not more general. No attempt is made to define a completely general notion of 'existence' (Smith and Mark 1998).

2. USE EMPIRICAL EVIDENCE

John Searle pointed out in his concluding lecture of the Wittgenstein Symposium 2000 in Kirchberg am Wechsel that "philosophers should be very careful when denying the obvious"—too often I see philosophers discuss areas where I have never experienced a problem and construct ingenious explanations for seemingly simple situations, only to discover deep problems that did not exist before. My favorite example is the often referenced proof that bees can't fly, which emerged from a technical discussion of equations about airplanes given by Sainte-Lague [1934 book by antoine magnan], and demonstrates how quickly a reasonable argument becomes misinterpreted. Famous examples from philosophy are the arrows which cannot move, Achilles and the turtle (xx), Buridan's ass (later xx), the

Chinese room [searle] and the world in which water is gasoline [dreifus?].

Philosophers declaring in a lecture that communication is not possible seem not to believe their own conclusions.

A useful ontology must be in accordance with the empirical evidence of how the world works that we see everyday. Differences in circumstances must be accepted where they are evident from the environment and no misguided attempts on full generality tried.

3. More than Just the rational and verbal

Ontology as part of philosophy concentrates on the rational, verbal representation of the world. Philosophers argue mostly about the factual verbal descriptions of the world. It is evident that this makes ontology dependent on the language one selects for analysis, but there are no arguments why, for example, the classical Greek language should be closer to truth than any other language. Probably traces of a romantic idea of the 'original language' of mankind, before the construction of the tower of Babel, influence such views (Eco 1993).

Philosophy ignores the richness of human emotions and cognitive processes that are not lifted to the rational and conscious thinking. This partial view limits what can be explained.

4. Grounding of Semantics

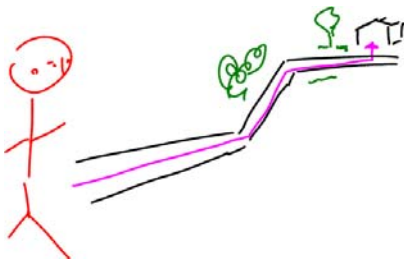
The difficulty with the ontology as an analysis of language is grounding. How do we establish the relationship between the terms in the language and the parts of the environment they represent in our thinking and talking? It is not sufficient to assume that everybody has some basic understanding of what is meant by "mother", "Peter's cat", "my car", etc. If we attempt to give definitions of some notions, for example in a dictionary, then we realize that the terms used must be defined first. This leads to an infinite regress; in dictionaries this is typically broken by circular definitions. To make it somewhat less obvious, the loops in the definitions are typically about 7 entries before the loop closes, longer than what users follow to check.

"circle" is defined as a "round figure" and "round" in turn is defined as "circular".

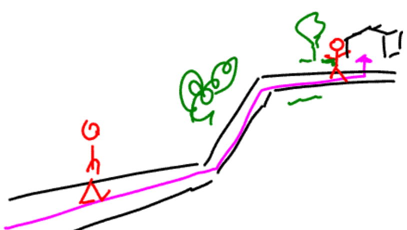
Wieerzbicka (1996) assumed that some notions are universal, i.e., the same for all mankind. She lists around 100 words, which she assumes to be existing in all human languages. She further assumes that these words do have the same meaning in all languages. From this ground, other terms can be defined.

This is a debatable solution for a linguist, but leaves out all the ontological questions: the fundamental ontology is given by these 100 universal notions, which are not further defined and are accepted without definition. They consist of the ‘upper level ontology’ for the enterprise of Wierzbicka. If we do not restrict ourselves to definitions of terminology, then a solution based on interaction with the world is possible.

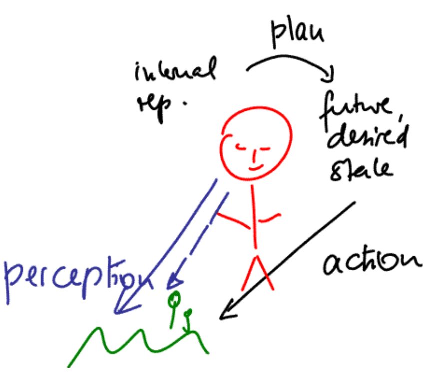
5. Closed Loop Semantics



Perceiving a situation



Action in the situation: leads to perception of changed situation



The loop from perception to action to perception of the change effected by the action

A stack of plates

Cognition and language must describe the environment in a realistic way—realistic in the sense of being effective in day to day operations. If our concepts of the environment were arbitrary effectiveness of our activities would suffer (Hartmann and Janich 1996). Consider a situation like (Figure 024-01): we see a path to a location and decide to walk there. The result of walking is that we are at the desired location. The observation and conceptualization of path and location must correspond to the later observed physical effects of the conceptualization of walking (Figure 024-02). This independence of the concepts we are using, even if we are not using words in our mind; (cf. the ‘minds language’ (Jackendoff 1996)). The concepts in our mind—independent of their internal representation—must be connected such that ‘path’, ‘location’, and ‘walk’ have a structure that corresponds to observation; in mathematical terms, we could call this a morphism, a structure preserving mapping between outside reality and mental representation (Frank submitted 2005). Mental disordered people come to have difficulties to connect their observations and activities in a realistic sense; (Sachs; Sacks 1998) such disorders reveal much about the inner workings of our brains.

Closed loop semantics is based on the assumption that humans have repeated interactions with the environment and learn through these repeated interactions about the environment and how it is structured. One can imagine that the child builds gradually theories about the combination of observations and activities (Piaget and Inhelder 1967; Gopnik and Meltzoff 1997; Gopnik, Meltzoff et al. 2001). Such simple theories link some observations and some activities in the same sense that an algebra links observer and change operations (Twaroch and Frank 2004). The structure of the observations is capturing the meaning of the concepts interlinked—all of them, not just one.

The stack of plates from figure x with one plat put on top

The concept of a stack (Figure 024-03) is learned from the behavior of physical stacks, e.g., a stack of plates. The observation of a stack with a single plate and the action to place one more plate on the stack (automatically on top) results in the observation that the stack has 2 plates and the new plate is on top. This can be described as algebra

top (push (p, s)) = p
height (push (p,s)) = height s + 1,

the concept of 'stack' is in this algebra, which is grounded in the actions with plates, books, sheets, etc.

6. Bodily Intereaction

Most of the philosophical debate is concerned with factual description of the world, with rational thinking and communication of facts between humans.

Example sentences are: Socrate is mortal, the tail of the cat is part of the cat.

Only a small part of the human communication is directed towards the exchange of factual information. Most of human communication intends the exchange of emotional consideration (Savage-Rumbaugh, Shanker et al. 1998). It is estimated that more than 90% of our cognitive activities are not controlled by conscious thinking and only a small part of what we are conscious of is related to facts (Roth 1994). There is increased interest in emotions (Picard 2002; Trappl and Payr 2002), but it is evident that the discussion of emotions is hindered by the lack of shared terminology.

The ontology presented here follows the critique of Brooks:(Brooks 1991) (Brooke and Kubik 1991) the artificial intelligence research concentrates on rational reasoning and leaves out the human body and its interaction with the environment. Inserting the body and the non-conscious part of human cognition, using new research results from neurobioglogy (Roth 1994; Damasio 1995; LeDoux 1996), will change the way ontologies look.

The use of references to the human body are numerous in language, for example to describe cardinal directions (Mark, Svorou et al. 1987). Johnson has discussed the role of the body in language (Johnson 1987) . With Lakoff he studied the use of body parts in metaphor (Lakoff and Johnson 1980). We can accept the frequent references to the body in language in many contexts as evidence of grounding in the body.

7. Applicable

My interest in ontology was rekindled when I observed that ontological questions are important for the design of geographic information systems, and, in general, to the design of all information systems that must represent some data describing physical reality(Frank 1983). This implies limiting the topics treated here to ontological issues relevant for geographic information systems as they are used for science, administration, and planning.

8. Processes and Objects

The ontology cannot succeed if it is only a taxonomy of objects; constructing taxonomies is well-understood and already international standards for languages to describe ontologies are underway (OIL 2000; Dieckmann 2003) [OWL reference]. Taxonomies alone cannot ground basic terms (Lakoff 1990) of link to body interactions and contribute to grounding [ref to actor conference in maine 2002].

9. Ontology with Agents

The model of ontology I want to construct is an ontology for humans—it takes into account the view of the world of human beings. This is generalizedto a most general abstract view of what is the minimal set of properties an agent must have to construct a world-view, at whatever primitive level. Agents must have at least the ability to observe the environment, to build a minimal representation of their percepts that are used to decide on actions to change the environment.

10. Observations Based

The approach considers observations of the physical environment as the only source of knowledge we have. Observations are a first class part of the ontology and the connection between abstract ideas about objects and the fundamental observations are constructed through cognitive porcesses.

11. Separation of Physical and Data Realm

Much confusion arises from mixing the discussion about the physical world with the discussion of the representation of physical objects in our thinking, our speaking and writing about the world. It is often difficult to differentiate between the cat

Punkti that eats its meat from its plat (Figure 12) and our description of this observation. Any discussion is always in terms refereeing to Punkti and does not contain Punkti itself. Sometimes the discussion is one level more abstract, terms that refer to the words that refer to Punkti. This is further complicated by the fact that the mechanism to process the data—our brains or the computer—and the physical representation of the words are again physical objects.

The concept of closed loop semantics is stressing the separation of the two realms and how they are linked together by observations that transfer from the environment realm to the data realm and actions, which in turn link the data realm with the environment realm (Figure 13).

Figure 12: Punkti

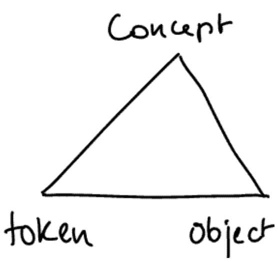


Figure 13: Eco p.30

Figure 050-01

12. TOKEN ONTOLOGY

The ontology must recognize the difference between an object and the sign that describes it (Eco 1977; Pierce 1980). I will use *token*, which stands for all sorts of signs we use to reference objects in the environment. Tokens can stand for words of natural language, for records in computer memory, or also for concepts in human minds. Tokens are always dependent on a physical substrate to which they are attached, but the important aspect is the reference to a concept not their physical existence (Figure 14). The introduction of tokens contributes to separating the physical realm and the data realm: tokens reference to the physical realm and exist in the physical realm, but their signification have special meaning only in the data realm.

13. ACKNOWLEDGE IMPERFECTION OF KNOWLEDGE

Errare human est.

The ontology constructed takes into account the limitations of agents what they can observe, know and act on. It is always understood that agents are finite systems that have imprecise observation systems, limited memory, and apply incorrect reasoning, make decisions under incomplete knowledge and are not capable of accurately executing their decisions.

Figure 14: Closed loop semantics separates physical data realm

Taking into account the imprecision of our knowledge of the world includes respecting the difference between the world and our incomplete and imprecise knowledge of the world. Understanding that our knowledge is always limited reduces at the same time the potential for some philosophical puzzles with arguments about the finite and infinite; for example, Zenon's argument that an arrow cannot move, or that Achille cannot overtake the turtle.

14. COMPUTATIONAL

The goal of this book is to construct an ontology for matter, space, time, and information that is useful for the design of geographic (spatio-temporal) information systems (Bennett 2004). This ontology must be usable for constructing computerized information systems. The ontology presented here leads to the construction of a consistent computational model, which is expressed in a formal language and checked for consistency and completeness by an automated tool. The computational model can be tested on small cases to check if the results agree with our observations of the world (Bittner 1999; Medak 1999; Bittner 2001; Raubal 2001; Krek 2002).

A comprehensive treatment of different aspects of imperfect knowledge is not available yet; I hope to publish a separate text later, expanding on earlier work (Goodchild and Gopal 1990; Burrough and Frank 1996).

Chapter 5 060 OVERVIEW OF FIVE TIERS

bilder fuer die tiers:

1. OVERVIEW OF TIERS

Ontological Tier 0: Physical Environment: - the existence of a single physical reality, - determined properties for every point in time and space, - space and time as fundamental dimensions.

Ontological Tier 1: Observations of the Environment: - properties are observable at a point in space, - real observations are incomplete, imprecise, and approximate.

Ontological Tier 2: The World of Objects: - objects are defined with uniform properties as regions in space and time, - objects continue in time.

Ontological Tier 3: Information Realm Tier 3a: Socially constructed reality - social processes construct external names, - facts and relationships between them, - social facts are valid within the social context only. Tier 3b: Subjective Reality of Cognitive Agents: - agents use their knowledge to derive other facts and make decisions, - knowledge is acquired gradually and lags behind reality,

I propose a multi-tier ontology, where different rules apply to each tier. The approach is empirical and starts with the observation of physical properties for specific locations and instants. Objects are formed as areas of uniform properties that endure through time as identical. Cultural conventions link names to objects and construct objects of 'social reality' (Searle 1995; Berger and Luckmann 1996), which are meaningful within a set of culture dependent rules. For example, the legal system of a country gives meaning to concepts like 'parcel' and 'ownership'; the corresponding objects do not have physical existence. They are social artifacts tied to a physical object, in this case a piece of land.

The proposed tiers are ordered from data for which data collections from multiple sources are more likely to agree to data for which disagreement is common. The tiers help with the integration of data from different sources to understand the processes that result in agreement or disagreement between data because they can account for the differences in different view points.

Knowledge is typically only as precise as necessary.

The level of detail and accuracy in the description of a situation is both related to the observation method and to the accuracy necessary for the action. Humans are extremely able to collect just enough information necessary for a decision and do not spend time and effort to obtain irrelevant detail. This can be used to design methods to deal with uncertainty in geographic data (Burrough and Frank 1995; Burrough and Frank 1996).

A multi-tier ontology allows integrating different philosophical stances, from an extreme realist or positivist view to the current post-modern positions (Derrida 1978). The multiple tiers recognize that various approaches contribute to our understanding of certain aspects of the world around us and take the philosophically unusual position, that none is universal (Rhoads 1999).

2. Physical Reality Seen as an Ontology of a 4-Dimensional Field

Physics often operates with a simple 4 dimensional model of the world: space has 3 dimensions and 1 dimension for time. The physical laws that describe the behavior of the macroscopic world can be expressed as partial differential equations, which describe the interaction of a number of properties in the space-time continuum. These equations give the values for properties in each space-time point.:

$$f(x, y, z, t) = a.$$

Abstracting from the temporal effects, a snapshot of the world can be described by the formula that Goodchild called 'geographic reality' (Goodchild 1990)

$$f(x,y,z) = a.$$

Giving space and time a special treatment results in simpler formulations of the physical laws that are of particular interest to humans. For example, the mechanics of solid bodies, e.g., the movement of objects on the tabletop, is explainable by Newtonian mechanical laws, which relate phenomena that are easily observable for humans in a simple form.

The formula $a = f(x,y,z,t)$ describes a regular function which yields only single value. This is equivalent to the assumption that there is only one single space-time world and excludes 'parallel universes' as part of reality.

3. Agents Observe the Physical Reality

The physical reality is populated by autonomous agents.

without cognitive agents no ontology!

Agents can—with their senses or with technical instruments—observe the physical reality at the current time, the 'now' (Franck 2003). Results of observations are measurement values on some measurement scale (Stevens 1946), which may be quantitative or qualitative.

An ontology is always an ontology of an agent or a group of similar agents. The ontology is determined by what is relevant for the agent, what can be observed and has an effect on his decisions to act. In particular, the frequency of observations and actions, the spatial extend that is observable or can be influenced with actions and finally the spectrum of what is observable (colors, heat, etc.) all determine the details of the ontology the agent uses (Lettvin, Maturana et al. 1970). It is obvious that the ontology of animals that cannot observe colors or animals, like bees that sense ultra-violet light that is invisible for humans must be different from a human ontology (Sacks 1996) that.

The ontology of the agents is equally influenced by the actions that are possible for the agents. An ontology for agents that can travel in time as easily as in space (Adams 2002) would be different from the ontology for human agents who can travel in space, but not in time. Speculations in fiction and fairy tales about populations of agents with different ontologies are attractive (Carroll 1960; Abbott 1992; Adams 2002).[flattland II]

The observation with a technical measurement system comes very close to an objective, human-independent observation of reality. Many technical systems allow the synchronous observations of an extent of space at the same time, e.g., remote sensing of geographic space from satellite (COLWELL 1983).

Figure 15: Remote Sensing Image

The same observation method can be used in other situations, the objects on my table as well as the city, including moving objects. They are used for robots, where TV cameras, which sample the field in a regular grid, are used to construct 'vision' systems to guide the robot's actions manipulating the objects on the table(Horn 1986) or guiding the robot's movement in hallways of buildings (Kuipers 1998).

4. Operations and Ontology of Individuals

Our cognitive system is so effective because it identifies in the array of sensed values objects, and we reason with objects and their properties, not with the multitude of values sensed. Thinking of tables and books and people is much more effective than seeing the world as consisting of data values for sets of cells. It is economical to store properties of objects and not deal with individual raster cells. As John McCarthy has pointed out:

Add a figure?

> ".. suppose a pair of Martians observe the situation in a room. One Martian analyzes it as a collection of interacting people as we do, but the second Martian groups all the heads together into one subautomaton and all the bodies into another. .. How is the first Martian to convince the second that his representation is to be preferred? He would argue that the interaction between the head and the body of the same person is closer than the interaction between the different heads. .. when the meeting is over, the heads will stop interacting with each other but will continue to interact with their respective bodies." (McCarthy and Hayes 1969p. 33).

Our experience in interacting with the world has taught us appropriate subdivisions of continuous reality into individual objects. Instead of reasoning with arrays of connected cells, as it is done in finite element analysis for, e.g., strain analysis or movements of oil spill, direct reasoning with individuals is selected: The elements on the tabletop (Figure 16) are divided in objects at the boundaries where cohesion between cells is low; a spoon consists of all the material that moves with the object when I pick it up and move it to a different location.

Figure 16: Tabletop

Finite element figure

The cognitive system is very fast in identifying objects *with respect to typical interactions*. We see things as chairs or glasses if they are presented in situations, where sitting or drinking are of potential interest (Figure 17). Under other circumstances, the same physical objects may be seen as a box and a vase (Figure 18). The detection of 'affordances' of objects is immediate and not conscientious. The identification of affordances implies a breakup of the world in objects: the object is what we can interact with (Gibson 1979).

Figure 17: Glass for drinking

Figure 18: Vase

Cognitive science has demonstrated that small infants as early as 3 months have a tendency to group observations into objects and to reason with objects [.. pinker has quote]. It has been shown that animals do the same(Savage-Rumbaugh, Shanker et al. 1998). Most of the efforts of our cognitive system to structure the world in objects are conscientious and not possible to scrutinize. Similar to the interpretation of the image as cube or a corner, but not both at once (Figure 19); in Figure 20 the decision what is foreground and what is background is arbitrary, but we can see alternatively only the two faces or the vase, again not both at once. In the same way, the decision of how to group an observation in objects does not permit doubt and insecurity.

Figure 19: Necker Cube: A cube or a corner? -

Figure 20: Two Faces or a Vase?

Efforts to explain the categorization of phenomena to common nouns based on a fixed set of properties lead to contradictions. Dogs are often defined as ‘barking, having 4 legs, etc.’; from such a set of attributes, it does follow that my neighbor's dog, which lost a leg in an accident (Figure 21), is no longer a dog, in stark contrast to common sense. Modern linguistics assumes generally that prototype effects make some exemplars better examples for a class than others (Rosch 1973; Rosch 1978). (See earlier chapter 020) Linguistic analysis suggests that the ways objects are structured are closely related to operations one can perform with them (Jackendoff 1983; Fellbaum 1998).

Figure 21

Humans have a limited set of interactions with the environment—the senses to perceive it and some operations like walking, picking up, etc.—and these operations are common to all humans. Therefore the object structure at least at the level of direct interaction is common to all humans and it provides the foundation on which to build the semantics of common terms (Lakoff 1988; Wierzbicka 1996). The way individual objects and object types are formed varies with the context, but is not arbitrary.

The viewpoint of physics, where space and time are just different dimensions of a continuum is an abstraction from human experience: Time is experienced by all biological systems as a vector and processes are not reversible—energy is used and dissipated and entropy increases by the laws of thermodynamics (Couclelis and Gale 1986). All observation of the world is limited to the observation at the time 'now'. 'Now' is not only a difficult philosophical problem (Franck 2003) but also a practical problem for temporal query languages (Tansel, Clifford et al. 1993).

Ontological time and space are not just similar dimensions of a 4-dimensional space-time continuum.

Humans experience the direction of gravity as most salient 'up-down' axis, which leaves the plane orthogonal to gravity as space that is experienced isotropically—what is in front of me is behind me if I turn around (Tversky 1996). Objects can move, nearly without effort, in this plane and these movements are reversible. The geometry of the object—especially the distance between two points on the object or angles—remains the same, independent of my movement.

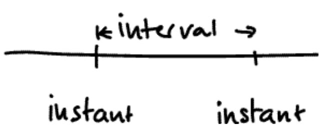
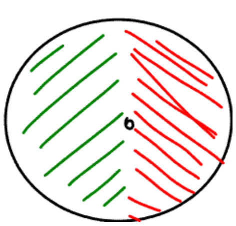


Figure 22

Points in space seem natural, despite the fact that they are abstractions, which cannot be materialized. The corresponding time-points appear much less 'real'. They are necessary to mark boundaries between intervals (Figure 22) (Galton 1995).

Spatial objects have boundaries, which are lines and surfaces, which bound volumes. The physical objects of the tabletop are modeled as solid volumes, most of them with fixed form. Their surfaces can touch, but the volumes cannot overlap.

Everywhere, where a boundary is introduced, puzzling questions similar to Zenon's can be introduced: Meinong asked what is the color of the center of a disk, which is exactly half red and half green(Smith 1982). There are eventually effects of discretization. The general question: "what is special about spatial?" (Egenhofer 1993; Meixner and Frank 1997).


What is the color in the center?

5. SOCIALLY CONSTRUCTED REALITY

Human beings are social animals; language allows us to communicate and to achieve high levels of social organization and division of labor. These social institutions are stable, evolve slowly and are not strongly observer dependent. Such fixed names for objectscan produce complex social arrangements that are partially modeled after biological properties, for example, the kin system [ref anthropology], or legal concepts like property rights derived from physical possession.

5.1 NAMES

The common names in language are clearly the result of a social process: words as names for individuals. Socially agreed identifiers seem to be part of the individual, e.g., my name is Andrew (better would be to state that I am called by the name Andrew).; the choice of "Fido", "Bello", or "Rex" as a name for a newly born dog is an arbitrary decision. Examples for proper names and similar identifiers reach from names for persons and cities to license plates for cars; there are also short-lived, socially agreed names created, like 'my fork' during a dinner.

Names are meaningful only as far as they can be used to refer to something in a discourse and then they must be expressed as a physical realization to be exchanged between agents (Figure 23).

Names for classes are equally arbitrary. Pointing out that 'chien', 'Hund', and 'cane' are equally good words to describe what in English is called a dog, should make it clear that neither of these names is more natural than the other [eco – natural language of men]

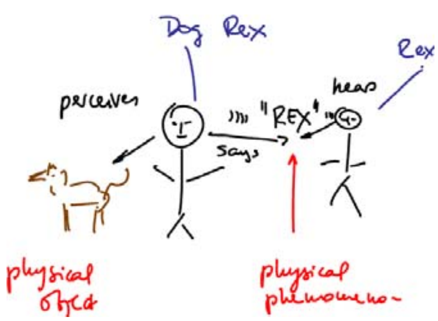


Figure 23: The use of a name in a communication

5.2 INSTITUTIONS

Social systems construct rules for their internal organization (Berger and Luckmann 1996), for example, laws, rules of conduct and manners, ethics, etc. Such rules are not only procedural ("thou shalt not kill"), but often create new conceptual objects (e.g., "marriage" in contradistinction to cohabitation without social status), adult person (as a legal definition and not a biological criterion), etc. Institutions, (North 1997), are extremely important in our daily life and appear real. Who would deny the reality of companies like Microsoft Corporation but there is no physical object one could point to.

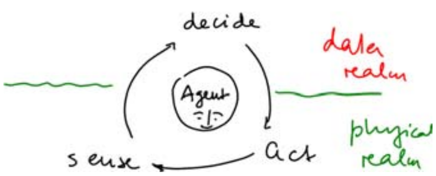
Much of what administration and therefore administrative databases deal with are facts of law—the classification of reality with the categories of the law. The ontology of these objects is defined by the legal system and is only indirectly related to the ontology of physical objects.

6. ONTOLOGY OF COGNIZANT AGENTS

Cognizant agents—persons and organizations—have incomplete and partial knowledge of reality, but use this knowledge to deduce other facts and make decisions based on such deductions.

Agents are aware of the limitations of the knowledge of other agents; social games, social interaction and business are to a very large degree based on the reciprocal limitations of knowledge. Game theory is exploring rules for behavior under incomplete knowledge (Morgenstern and Von Neumann 1980; Davis 1983; Baird, Gertner et al. 1994).

In this context, we equate organizations with persons . Organizations today have similar internal structures than other agents: they perceive the environment in which they are embedded through the sensors of their personnel, they accumulate knowledge and experience which is used to make decisions; these decisions are eventually carried out as actions of the personnel.



The sense-decide-act loop

The knowledge of a person or an organization increases over time, but the knowledge lags necessarily behind the changes of reality. Decisions are made based on this 'not quite' up-to-date knowledge. Social fairness dictates that actions of agents are judged not with respect to perfect knowledge available later but with respect to the incomplete knowledge the agent had or should have had if he had acted carefully. Modern administration follows the law and administrative acts must be open to inspection [max weber]. Such audits must be based on the knowledge available to the agent, not the facts discovered later. For audits it must therefore be possible to reconstruct the knowledge an agent, i.e., a public administration, had at a certain time.

7. Summary

The tiers of this ontology separate different types of existences. The structure leads from observations to the construction of physical and social objects. In the following part, the processes that connect the tiers will be detailed.

In this treatment, we have not included a detailed treatment of error, imprecision and uncertainty in our knowledge, but always accept that knowledge is imperfect. We have also left out a comprehensive treatment of emotions. It seems evident that the two topics are related, but very difficult to explain how.

Chapter 6 080 COMPUTATIONAL MODEL FOR ONTOLOGY

> “Philosophy is written in this grand book - I mean the Universe - which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles and other geometrical figures, without which it is humanly impossible to understand a single word of it.” **Galileo Galilei**

I learned the concept of a stack as an abstract concept of computer science when I used the HP45 scientific pocket calculator. Only much later I realized that computer science concept of a stack is an abstraction from the "Tellerstapel" (stack of plates) encountered in the kitchen (Figure 24).

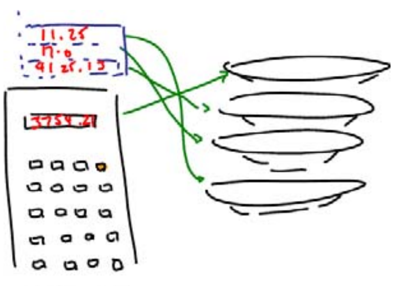


Figure 24

1. NEED FOR FORMALIZATION

Philosophers work traditionally with and in natural language, from the Socratic dialogs (Kahn 1998)[ref] to the teaching at the Greek academies and modern universities. Over time, a shift from the spoken word to the written word—today processed and communicated electronically—is observed, but has not changed substantially the structure of arguments and counter-arguments expressed in natural language. I wonder if the technical ability to add pictures to a text substance will change the arguments in the future.

Frege suggested that natural language is not precise enough to advance ontological studies and introduced his 'Begriffsschrift' (Frege 1964). It gave a precise, mathematical expression to logical statements. The translation from rational arguments to formal logical expression should free the reasoning from the imperfections of language. Russel and Whitehead, later Carnap, Wittgenstein and Gödel all treated philosophical, primarily ontological and epistemological question using formal logic. The difficulty with the use of formal languages is the grounding—how to agree on the meaning of the symbols in real world terms. For some objects, like a dog, we may point to and state that 'dog' means that, but how to point to abstract concepts like 'three' or 'democracy'?

1.1 Human limitation in checking logic

Natural language is an extremely flexible tool to communicate between humans in practical situations; it works surprisingly well most of the time, but we all know of its limitations. Attending a philosophy conference and paying close attention to the arguments exchanged, one quickly finds a list of figures of speech that passes as logically correct, but is not. Two most important and drastic examples should be sufficient:

- Drawing general conclusion from an example. It is logically correct to conclude from a general rule to an individual case; but even this logically justified conclusion may be factually wrong

all dogs have four legs and Rex is a dog; conclude rex has four legs (figure).

Where do I get a picture of a dog or cat with 3 legs?

The reverse conclusion from the particular case to conclude the general rule is logically not admissible, but common:

my cat Tiger has black spots conclude that all cats have black spots.
from all birds have wings and Tweaky is a bird one can conclude that Tweaky has wings

- Ignoring polysemie: many words have multiple meaning, or a broad field of meanings. It is logically correct to conclude from two statements as above, that Tweaky has wings—but only if the term 'bird' is used with the same meaning. If Tweaky is a young girl, which is sometimes called a 'bird', one must not conclude that Tweaky has wings.

Figure

1.2 Unchecked assumptions in the foundations

In general, philosophical arguments, like mathematical proofs, build on arguments previously discussed—not every philosopher starts all over again. The arguments dependent on the assumptions one builds into the theory, and many theories have become so complex, that it is difficult to see, if the assumptions are consistent. In a natural language text we cannot check systematically that all the assumptions that are imported with the references to previously demonstrated facts are consistent.

For example, Strawson (Runggaldier and Kanzian 1989) claims that a person consist of 'res cogitans' (mental ego) and 'res extensa' (physical ego). Given the implied assumption of Cartesianism, a substance can only be one thing, not both mental and physical ego, this leads to a contradiction, therefore a person cannot consist of mental and physical ego. Despite the seemingly logical argument I am not convinced and believe that I have a body and a mind.

1.3 DOUBTFUL PROOF BY CONTRADICTION

A second limitation comes from the use of a proof by contradiction: A thesis and some additional assumptions lead to a contradiction, therefore the starting thesis cannot be correct. This method is especially debatable if used to prove the existence of some concept. Such proofs follow the schema: 'given the theory A and assuming that B do not exist, leads to a contradiction; therefore, B exist.

Some schools of mathematics will not accept proofs by contradiction to demonstrate the existence of things and insist on constructive proofs. This skeptical position is even more justified today: constructive proofs are useful to write computer programs that compute values of the desired kind. For example, one can proof by contradiction that a value for the square root of 2 must exist or one can give a rule how to find an increasingly better approximation for the value for square root of 2. The second, constructive proof is directly usable for programmers.

formulae

1.4 CIRCULARITY OF THE DISCUSSION

Discussing ontology—which is essentially the meaning of some words—in other words leads to confusions. The ontological debate should clarify the status of the very same debate that is carried out. This must lead to circularity in the arguments.

1.5 DISCUSSION OF ONTOLOGY IN NATURAL LANGUAGE IS LIMITED

Given the complexity of the ontological discussion and the limited power of human cognition to logically analyze complex arguments, I distrust some of the conclusions, especially if they are in contradiction with daily experience. Computational models are a method to avoid the possible tangles of the limitations of natural language arguments. Their consequences can be checked against empirical observation and their internal consistency is—within the limits of the formalization—controlled.

2. FORMAL MODELS

Only parts of an ontology have been formalized. Much effort of mathematicians and analytical philosophers to formalize ontology was concentrated on particular problems of logic (Whitehead and Russell 1910-1913), mereology (Simon 1987;

Casati and Varzi 1994; Casati and Varzi 1999), modalities and temporal aspects (Kripke 1963; Galton 1987). The set theory on which Aristotle's categories are built, is formalized.

In general, difficulties were encountered. Important aspects of reality—especially space and time—have not found a consistent, widely applicable and fully general theory (Blumenthal 1986). For example systematic investigations to build a theory of space built on mereology and topology (Casati and Varzi 1999) lists a large number of axiom systems that each cover some interesting cases, but do not achieve integration. Formalization of the ‘part-of’ relation—mereology (Simon 1987)—and the connection with topology—mereotopology lead to similar partial solutions. The efforts to formalize time conclude with a list of possible concepts and formal rules for deduction but not with an argument for one preferred one(Galton 2000).

Unfortunately, these efforts to formalize parts of an ontology are not completely trustworthy: critical reviews of formalization in articles always reveal a number of inconsistencies, errors in the arguments, etc. Again, we learn that human cognitive abilities are not very good to apply logical rules without error—human intuition leads the way towards a plausible goal, often ignoring faults in the arguments. Many such errors can be fixed, but not all.

It is notoriously difficult to understand the implication of a formal system provided in a text. What are possible conclusions from it? How does it interact with another formal system, described elsewhere? It is tedious to check that the desired consequences are achieved, and more difficult even to ascertain that no undesirable interpretations are possible. Bennett has suggested that only small parts of an ontology should be defined axiomatically, preferably using well-known mathematical structures. This reduces the potential for unintended consequences of a set of axioms—a problem with axiomatic definitions in particular. Bennett advocates that most of the ontology should be formalized as definitions using the few algebraically defined base terms (Bennett 2003).

Cartoon laws would fit here

In any case, formalization does not warrant blind trust. for some types of formalization, computerized tools to guard against some types of errors exist. In this book I will sketch the elements of a computational model for the ontology, because I believe that formal models for the proposed ontology can be built in languages that can be checked for completeness and syntax and that can be executed to test that the consequences are the desired ones.

3. Computational Models for Ontology

Is it possible to construct a computational model how ontology 'works'? What would be a model of an ontology? Ontologies are models of reality, but what is a model of the model? Most ontologies cover only a small part of reality—can we construct computational models that demonstrate how reality and knowledge about reality are linked? What would such a computational model contribute to the current discussion?

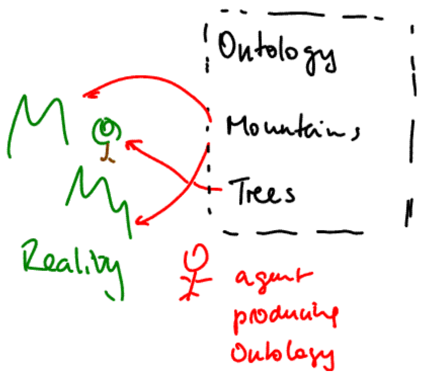
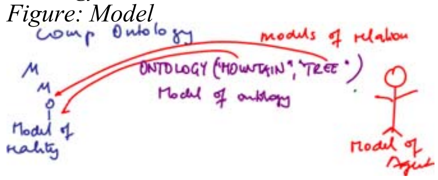


Figure 25

Ontology

Figure: Model



Computational model of ontology

Figure 26: Model of model

The effort to build a model of an ontology poses—surprisingly—difficult questions and requires more precise responses to the question 'what is an ontology' than the current widely cited definitions (Gruber 2003).

Many practical ontologies are computational models—from database schema to the data descriptions in AI programs (Figure 25). They are used to describe how a certain subset of reality is conceptualized, usually in a software application. These are not computational models of an ontology, they are just computational models of some application domain.

A computational model for an ontology (Figure 26) must bring together reality and the knowledge of this reality as it is used in, e.g., a computer program. The model must include a modeled reality, and the persons who use the ontology to understand and communicate about the reality. It must include the objects in the modeled reality as well as the description of these in the mental systems of the persons.

In this book I describe computational models of reality and cognitive agents and trace the different aspects of the ontology, from reality to the beliefs of agents. In such a model, we can precisely determine what terms like 'reality', 'Cognitive Agent', data, beliefs (Knowledge), etc. mean. The distinction between ontology and epistemology could be drawn exactly, but I will not make this distinction explicit because it does not appear useful.

A computational model of an ontology is a model of a model; this double reflection is very difficult to capture for the human mind and equally difficult to express in natural language. More reason for a computational model, which demonstrates that the desired properties and the behavior is achieved. Remember: It is for human beings very difficult to identify errors and contradictions in a static description; it is, however, easy to identify errors when observing a process, a set of actions that do not lead to the desired consequences.

4. What Is a Model

Models are widely used in practical arguments, technical and scientific discussions. In day to day experience, we use maps and sketches to explain the hiking path through the woods, we depict on a piece of paper the layout of the furniture in our living room and how we want to rearrange it. Many of the striking advances of technology, for example high rising buildings, are only possible, because we can construct models and explore different aspects of the building to be constructed ahead of time. Crucial are models to explore technical systems where experiments are not possible—nuclear plants for example.

Models consist of a real system *R* with states $r_1, r_2, \ldots r_n$ that is modeled as *M* (with corresponding states $m_1, m_2 \ldots m_n$), such that operations op_1, op_2 at the real system and the corresponding operations op_1', op_2',.. in the model have corresponding results. The function *model* that maps from reality to the model is a functor (Frank submitted 2005).

Formula for homomorphism model(op(r))=op'(model(r))

– and ontology

$$\begin{tikzcd} R \arrow[r, "model"] \arrow[d, "op_1"] & M \arrow[d, "op_1'"] \\ R \arrow[r, "model"] & M \end{tikzcd}$$

Figure: Reality R on model M

Mathematically we say that a homomorphism obtains between the system and the model. This is the relationship that Tarski introduced as the correspondance between a situation in the world and the statement about it, the *correspondance theory of truth* (Tarski 1995). Wittgenstein used a similar approach as the *picture theory of meaning*: a sentence is a picture of a real situation and is true, if there is a correspondance between the elements in the sentence (the words) and the objects in reality (Wittgenstein 1960).

5. Ontology of a Model

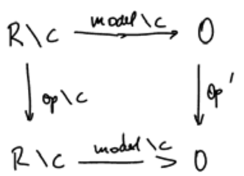
A cognizant agent is an agent that is capable of constructing a symbolic internal representation of the external world (Figure 27). The symbolic representation is used as an internal model of the external world; it must be 'true' in the sense that prediction of future states of the environment constructed with the model must correspond with the observations of the state observed later.

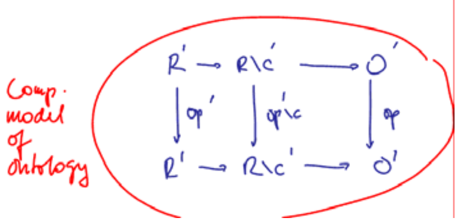
An ontology must be reasonable; it must be beneficial in day to day use.

Figure 27

The ontology provides the structuring principle for this symbolic representation. The difficulty is the circularity of the modeling effort: the cognizant agent is part of the environment and my symbolic representation follows the same rules of ontology that I am constructing. (See subsection 10).

Where





6. WHAT IS A COMPUTATIONAL MODEL

Models can be constructed in many ways—architectural models are often from plywood, foam, etc. (Figure 28). Maps are models to scale where the features of the landscape are shown graphically (Figure 29). The behavior of technical systems is described by formulae, such that the relationship between some physical properties and the numerical magnitutes are known. For example, the maximum bending of a beam under a load is (Figure 30).

Figure 28: Architectural model

$$\frac{wl^3}{8EI} = \frac{wl^3}{4Elh^3}$$

Figure 29: Map

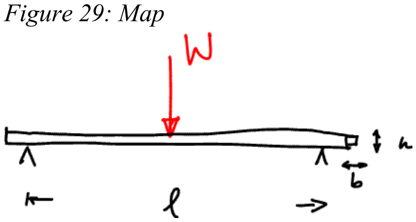


Figure 30

One can compute what load a given beam will carry or one can design a beam with a tolerable bending.

Figure

Computational models have become important since complex situation can be represented with formulae that are then programmed. It is possible to simulate the behavior of complex systems. For example, the statics of large buildings are described numerically and the resulting stresses in the structure are then depicted graphically. The result obtained from the model is used to determine the size of the structural members of the building, to design a building that will resist all loading that the engineers assumed. These are typically fixed in standards and not let to the individual choice of the designer!

Figure

Computational models are not restricted to technical system and models of physical properties. Computational simulation is increasingly used for non-technical applications. Social systems can be simulated—the simulations are sometimes crude, but they help to understand mechanism (Epstein and Axtell 1996; Portugali 1997).

In general, a computational model is a model where the simulation of a real world situation is carried out in a computer. The properties of the object in reality are translated to values which can be represented in a computer and the behavior is described as a program; the actual response of the real system is then simulated as computation and the results of the computation interpreted in terms of the real system. Output is often transformed from collections of numbers that are difficult to interpret to a visual display [visualization lit, debiase].

7. Models of Models

One could argue that constructing models of models, leads to an infinite regress and demonstrates nothing. This argument was for example raised by Pylyshyn against the analog model of spatial representation advanced by Kosslyn (Pylyshyn 1973; Kosslyn 1980). Pylyshyn argued that a homunculus would be necessary to inspect the analog representation of the scene and then the homunculus would require a smaller homunculus to inspect the scene in his mind, etc. (figure). In “Gödel, Escher, Bach” an explanation ….(Hofstadter 1979)

This is a popular and somewhat convincing argument, but it does not apply. The objections:

1. infinite regress is not a fundamental problem:
2. we build only once a model of the model, a model and a model of the model.—There is no further regress.

Figure 31

Figure 32

The issue of infinite regress—the model is built using the concepts in the model (“turtles all the way” (Figure 31))(Hofstadter 1985)—is not a fundamental limitation: it is a problem of our thinking not of principle. The previously discussed paradox by Zenon is caused by this faulty reasoning: we know from empirical observation, that any runner, even less speedy than Achilles, will eventually pass the slow turtle. We can construct a series of approximations how long it takes for Achilles to reach the turtle (Figure 32). The next approximation is always better than the previous one and we accept the limiting case – the perfect approximation—as the true value. This has not only been demonstrated for numerical calculation, but also for axiomatic definition of semantics. It is so called ‘fixed point semantics’ (Stoy 1981).

Sometimes it is permitted to pull oneself out of the mud.

8. Computation Models of Ontology

A computational model approach starts always with the question, what aspects of what objects should be modeled—in an AI problem often an 'ontology' (in the sense of 'universe of discourse') is given. What is the ontology of an ontology? What are the elements to be included?

An ontology discusses what is in the real world—the real word must be included in the system and represented (substituted for) in the model.

In ontology (or epistemology) objects in the world are described in mental or textual representation by persons. The model must include objects, people, mental and textual representation and relations between them.

Do this in a table

The difficulty in building computational models of ontology is the nearly 'self application' of the concept: to model the modeling of the world. The model must contain representations for objects and representations for the representation of object in a mental system or in a text—and these representations are not the same (but very closely related).

Figure 33

A computational model of ontology clarifies the *metaconcepts* used for the discussion and description of ontology (Figure 33); it is helpful for the clarification of assumptions in a formal debate and contributes to reduce confusion. It points out the ontological commitments made and shows what they entail in terms of real world experience. It contributes to identify what are the smallest set of realistic ontological commitments to construct a useful ontology.

9. How to Build Computational Models: Formal Language and Execution

The computational model is constructed in a set-up with multiple agents, i.e., multi-agent framework (expalined later xx), where it is possible to model an external reality and agents that interact with this reality in a systematic way. Simple interactions with the model are possible to demonstrate that the formal construction performs as expected from real world experience. The methods of formalization are based on higher order language, because we need to formalize not only the static concepts—this is the usual approach to formalization of ontology—but also the dynamic processes in the world.

Computational models are helpful as they combine formality with practical control (Frank and Kuhn 1995). We can see on one hand, how they are formally constructed and what the individual components are and how they interact, but we can also see, that they describe some interesting parts of reality in accordance with our daily experience. Computational models are used in different scientific fields; I propose here to use the tool to advance our understanding of ontology. The computational models we have built were very useful to advance our understanding (Bittner 1996; Frank 2000; Raubal 2000; Bittner 2001; Bittner and Frank 2002; Navratil and Frank 2003; Navratil and Frank 2004).

10. General comments to models

The term model is used in many ways. Models can be bult with different obligations:

- The models built here are mostly functional – they predict behavior of systems and there is an homomorphism between the model and the real system. The reaction of the real system corresponds to the reaction predicted by the model for the same inputs.
- Models can also be built to explain not only the current function, but also give a plausible description of how the mechanism did evolve. This is in general not attempted here (despite that evidence to this end is collected and presented)
- Models can also be constructed to be structurally equivalent – not only the function of the model, but the inner construction of submodels is comparable with the system modeled. For example, in a cognitive model, one would have to model not only the translation from inputs to outputs, but also to check that the known brain parts with their functions are each indivually represented in the model and the overall function is explained with the structural composition of these parts. This again, is often done in neuroscience [book advances], but not attempted here either.

Chapter 7 090 Example Domains

Picture – for each domain one

The example domains selected should make the use of the word *environment* clear—it means the physical environment that is existing outside of us. Often the term 'reality' is used for the physical environment in which we live, but there are numerous other uses of this word and I will therefore avoid it.

The environment is not only nature and the physical structures like buildings etc. The environment includes the cognizant agents—us—and it contains also the physical representation of information. Information must always be represented in some physical medium; this can be the neural matter in the brain, in human readable text or in computer internal representation— Three environmental situations will be used several times in the book.

Ontologies are influenced by the examples the designer uses. Classical ontology studies, from Aristotle onwards, are based on material objects, preferably solid bodies or the human body or other organism as well as the actions and events in which such objects are engaged. There are a small number of gedankenexperiment that philosophers discuss again and again: Darius' arm, Burridan's ass, the cat Tibbles and its tail, Socrates, who is mortal, etc. They are prone to subtle errors; for example, different assumptions and interpretations are used at different times in the argument.

Studying other cases reveals how much the example has influenced the outcome: Hayes has studied the ontology of liquids and found it to be very complicated (Hayes 1985). Different domains lead to different ontological foundations.

Three quite different application domains are used here to assure that the ontological base for geographic spatio-temporal information systems does not include commitments that will exclude its application to other domains:

- a tabletop situation, with solid and liquid material objects, as they are customarily found on a dinner table; these objects are moved around by humans;

- a city environment, where persons or cars move between buildings and along streets, similar to examples found later, (Raubal 2001; Pontikakis 2004);
- a geographic situation, with plots of rural land, forest, roads and rivers, where people and animals move unrestricted across the land.

The different examples should demonstrate the breadth of applications requiring spatio-temporal ontologies and the differences in their conceptualization of reality. The examples are selected such that they cover three different cognitive situations of space, according to the classification introduced by Zubin (Couclelis and Gale 1986; Mark and Frank 1991; Montello 1993).

1. Upper Level Ontology

I have recommended that particular ontologies be developed for specific applications areas (Frank submitted 2005). For example, an ontology for farming is highly desirable to connect the rules for data collection, calculation of agricultural subsidies in the EU and the integration of the resulting database for policy (Frank 1998). Bernasconi has documented an ontology for the sewer systems of a commune (Bernasconi 1999). We need concrete ontologies for land registration to build the base software usable in several countries with different legislation (Bittner 1998; Navratil 1998). Last but not least, an ontology of transportation, private and public, would be very useful in the exchange of data between different traffic guidance systems, transportation schedule services and car navigation aids[ref cost book by stuckenschmidt].

picture

The foundation ontology incorporated in the GIS must be open to integrate more than one of these domain ontologies in it. The discussion in this book constructs the foundation, the upper level ontology, in which different ontologies for particular domains can besituated.

The currently available upper level ontologies are different from each other. This makes the connection between concepts defined in one and the other ontology very difficult. The work presented here gives a rational for a specific top level ontology, which is constructed from observable properties of the world.

2. Tabletop Situation

A well-researched abstraction of the situation on a dinner table was one of the first examples of a computer science ontology: the block world (Winograd 1979). It consists of solid blocks that can be stacked on top of each other (Figure 34). This has served as a fruitful example to discuss the meaning of ontologies (Guarino 1998) and to discuss the formal definition of the semantics of spatial relations (Hornsby and Egenhofer 1997; Frank 1998).

Figure 34: Blocks

More complex is an environment that includes liquids in bottles or cups (Hayes 1985). Liquids do not have a fixed form, but fill the holes in container objects (only specific kinds of holes can be used to contain liquids (Casati and Varzi 1994)). Liquids can be poured and mixed, but it is generally impossible to separate two pieces of a liquid once they are merged (Medak 2001).

Take picture from summer 01 used in agelonde

Figure 35: Tabletop Situation with Solid Objects and Liquids

The objects on a table are under control of a person manipulating them (Figure 35). The primary manipulation is to move physical objects around; secondary operations are pouring a liquid, cut a piece in two, etc. Important operations are the eating and drinking of food and drinks. Possession of an object by a person may signal legal ownership; in other instances, possession signals a temporary association with an object respected by others (e.g., my fork during a dinner), which is given up at the period.

One can see that objects are conceived such that important invariants are maintained. The regular laws of conservation of matter apply and material properties, e.g., color, specific weight, remain invariant under a large number of operations. Solid objects on a table, maintain their size, volume, and form. More complex ontologies apply for cooking, where less invariants are maintained: neither form, nor color, nor volume, nor weight is preserved.

Similar to the tabletop situation is office space, with desktops, papers, pencils, and computers, but also work benches with tools, car repair shops etc.

A special kind of tabletop object is a model of some other situation (Figure 36). The physical objects then are signs, stand for other objects (which may be physical or not). Good models assure that the rules for manipulation of the representations compare directly with the manipulation of the real objects.

Figure 36: Picture model railway

3. CITYSCAPE

A city contains buildings and streets (Figure 37). Buildings we can understand as containers, which are further subdivided into rooms. Persons can move between them or to these rooms. Doors between the rooms allow people to leave the buildings. Streets are formed by the empty space available for movement between the buildings (Lynch 1960). Streets and plazas can, again, be seen as containers, but for navigation in a city, a linear conception of a street as a path between doors is a more effective conceptualization (Hillier 1999). For most purposes, the details of the movement of a person in a street is irrelevant, important is only that the person follows the street from intersection to intersection (Remolina, Fernandez et al. 1999).

Figure 37: City situation with buildings, streets and people

Not only a container and a linear model of space are applicable, we find also an areal one: Considering the rainfall on buildings, the amount of rain running off a roof is proportional to the surface. The runoff then follows the streets and in modern cities disappears in the sewer network (Campari 1996).

Buildings, streets, plants, etc. can not move from their location and the processes of creation are slow. Persons, cars, and other vehicles move among them rapidly; their movement is restricted to pathways. The important operation is to navigate from building to another building, traversing streets and plazas. An important application and rapidly increasing business are applications that assist people in navigating, especially while driving a car, when movements are not only restricted by physics, but also by the legal rules of car driving.

This example shows how different tasks lead to different conceptualizations of space: the same cityscape is seen in terms of volumes, areas and lines. But even within a single type of geometry, for example, the linear network structure of a street network, different levels of detail are used depending on the specific task: planning a trip uses a less detailed representation of the street network than the description of a path to take, where every intersection must be mentioned. Finally driving in lanes and changing between lanes is yet a third level of detail in a street graph (Timpf, Volta et al. 1992). A hierarchy is useful to produce maps at different levels of cartographic generalization for (Timpf 1998).

Physical possession is not sufficient to indicate ownership of land. Legal institutions, often called land tenure, are necessary to transfer and publicize ownership and other rights in land (Twaroch 1999). The registry of deeds or a registry of title is maintaining public knowledge about these rights (Zevenbergen 2002).

Picture of registry book and the corresponding property

4. Geographic Landscape

The first object of the geographic world is the surface of the world and its form (xx). The landscape is seen as an undulated surface (a *2*-dimensional geometrical object) embedded in *3*-dimensional space. The geological processes create this surface, in the temperate zones mostly through erosion caused by ice or water flow. Measuring height as potential with respect to a reference potential assumed as 'sea level' stresses the general importance of water and water flow for our lives. Water flows under the force of gravity over surfaces and forms rivers at the bottom of valleys. Streams form a linear network and watersheds form a functionally defined subdivision of space—for every point along a street network there exists a corresponding watershed, namely all the area from which water flows to this point (Figure 38) (Frank, Palmer et al. 1986; Paiva, Egenhofer et al. 1992; Paiva and Egenhofer 2000). Operations are the flow of water over surfaces, but also the operations of agriculture (tiling, bringing out seeds, harvest, etc.) and grazing of animals, erecting buildings and navigation.

Replace with picture from hohentauern (moscher)

Picture from agelonde vortrag

Figure 38 Landscape with hills and valleys

Figure 39

Couclelis has pointed out the contradiction between objects and fields: 'people manipulate objects but cultivate fields' (Couclelis 1992). The surface of the earth is divided into parcels, which are manipulated like objects, bought and sold like books or shoes. Fences divide the fields and streets link fields to populated places.

Remote sensing allows observations of large areas and permits the classification of actual land use. Areas of uniform use, e.g., forest area, do not necessarily correspond to the areas of land ownership. The maps in planning offices show the intended use of some area, but this does not always correspond to actual use.

All objects in the geographic world change and move, but some move much faster than others (Cheylan, Libourel et al. 1997). Most geographic processes are so much slower than most other human activities that geography seems to be the 'stable' backdrop against which other processes are played out. Mountains and rivers do not move; people move between them. Considering a geological scale, mountains rise and are eroded, rivers change their courses; changes in land use are relatively rapid and woods can appear or disappear within a few decades. Movements of geographic objects are qualitatively different from the movement of persons along a street or across a field, they are also different from airplanes moving in the skies (Frank, Raper et al. 2001).

Man-made objects in the landscape are sharply delimited, but most natural objects do not have sharp boundaries. Various methods have been discussed - from fuzzy logic to qualitative reasoning - to deal with objects with undetermined boundaries, from forests to geographic regions like 'the north sea' (Burrough and Frank 1995; Burrough and Frank 1996).

5. Cognizant Beings in the Situations

People, animals, etc. are part of the physical situations. The people sitting at the dinner table, the people in cars moving in the city and across a field are part of the physical ontology. We have a tendency to describe landscapes, cities or even a table set for dinner without the people; this is not appropriate: a dinner table is set for people to eat there, to use the silverware to cut food and to move it to their mouth, the glasses to drink from, etc.

Make new photographs which have sheep in the landscape, people in the street (try kaernerstrasse) and people at the table.

Figure 40A landscape and a picture of a landscape

Picture of a memory chip

The cognizant agents in the world are part of the physical environment, but they also produce a (mental) representation of the situation. Even this representation of concepts is part of the physical world, embodied in some of the grey matter in the brain of the agent. In fact, even the model of the ontology built here is attached to some physical, material objects and exists only as an '*accident'* (in the same sense as in chapter 020) of this—for example, text printed on pages is an *accident* to the page; the existence of the text depends on the existence of the page. If we build a computational model in a computer, the model is physically represented in a discrete, non-analogous form, in computer memory, which is a physical object. The fact that we cannot see the model in the computer chip is not making it less physical. That the model of the physical object is again a physical object seems to be circular and will require attention.

PART THREE 100 TIER 0— THE ENVIRONMENT, THE PHYSICAL REALITY

Ontology, in a naïve view, should describe what is. In this chapter, the necessary minimal assumptions about the environment, the ***physical*** reality are described.

- A single shared physical reality exists, which is the same for all cognizant agents,
- it has determined properties at any point in space and time,
- agents can observe some properties of the environment and construct internal representations (data, information) of them.

This gives a minimal ontology of points in space and time. Property values at each point in space and time are quantitative or qualitative values. Agents can observe these properties and act based on internal representation of these observations.

Tier 0 is the ontology that is assumed to exist without agents—it is independent of the observing agents; tier 0 describes what is in the world, without us or any other agent observing. There is very little we know about the physical environment other than our observation of it. All what we know comes through observations and is therefore knowledge of observations, not knowledge of the environment. In consequence, this part of the ontology is short. It is not constructive and consists entirely of assumptions, selecting a small set of consistent assumptions, following Occam's admonition.

1. What Can We Know?

We know little about the physical reality independent of observations. All we know follows from our observations, but even from millions of empirical observations no deductive knowledge about the world ever follows.

Philosophers have tried to deduce how reality must be. For example from our way of talking about reality one can deduce which commitments partners in a communication share; the observation that communication between persons is usually effective. Therefore people must be using a common set of ontological commitments, shared by all humans. These are often called universals. Three points can be raised:

- Shared commitments of all humans do not reveal the ontology of reality, but only the shared understanding of reality by people. This differentiation will be explored further in the construction of the tiers, where later tiers are explicitly dealing with the shared understanding of humans of reality (not to be confused with assumptions about reality, as discussed in this chapter).
- There is no indication that we can observe all properties of the environment. Our ontologies are always restricted to what we can observe; the discovery how to observe electromagnetic waves (radio waves) added to the Ontology; Newton's Ontology is different from Hertz's, but reality has not changed.
- Reconstructing a complex structure as it is revealed from the multiple forms we talk about reality is logically impossible or extremely difficult —it has lead to many different schools of thinking, which produce contradictory theories.

All we know about the world is based on observation. A photograph shows what was observable—not all of reality. This limitation does not imply that our knowledge of the world is wrong; it is useful in our daily dealings with the world and the myriads of objects in it and must therefore be ‘right’—but this ‘rightness’ is functional, is empirical and partial to what is relevant for us and does not allow the conclusion that ‘this is the way the world is’. It is, at best, the way the world is for us.

To conclude that the efficiency of our interaction reveals the true nature of reality is based on a subtle logical error: our knowledge of the world is useful to conduct our daily activities, but any other model, which is isomorphic with respect to our interaction with the world, is equally true. It is not possible to state more than what is observable and any model that is isomorphic with respect to all observations is equivalent; this excludes many models, but cannot identify a single true one. Any model with commitments that do not contradict what we accept as physical laws and that are the abstractions from myriads of observations, is faithful. If two persons have different models that are equally effective to guide their day-to-day activities then they are both faithful. Additional observation may reveal a difference and confirm one as faithful and the other not.

There is no privileged knowledge about the environment!

2. Physical Space-Time

For the abstract (non-constructive) level of ontology, space and time are continuous such that positions in space and time can be observed and mapped to real numbers. This is the classical model of space and time of physics, where both real world space and time is mapped to an *n*-cube of real number.

*Any continuous space of n-dimension is isomorphic to R**n*

The abstract field model of physics is described with a function for each kind of observation for a given point in space and time yields a single value. The temporal and spatial coordinates are formally equivalent.

The laws of entropy give the processes in the environment a direction and make most processes not reversible; time in this model has an oriented axis.

$v=f(x.y.z.t)$

There is no special treatment of natural constants—they are understood as varying in time and space, and most of the 'natural constants' are indeed varying in time or space (see 5.2).

Space and time form together a *4*-dimensional space in which other properties are organized. This is a purely syntactic device, a method that helps our imagination. Other organizations would be equally valid. Giving space and time a special treatment results in simpler formulations of the physical laws that are of particular interest to humans. I see no observation possible, which would substantiate the claim, that this is the 'only true' model; philosophers and theologians may differ. For example, the mechanics of solid bodies, e.g., the movement of objects on the tabletop, is predictable by Newtonian mechanical laws, which relate phenomena that are easily observable for humans in a simple form.

$s = v * t,$

Other sciences, for example astrophysics, prefer other coordinate systems in which mass and gravity is included (Einstein 1995). The preferences are justified by obtaining simpler rules for certain interesting relationships. Our focus here is on the macroscopic everyday environment.

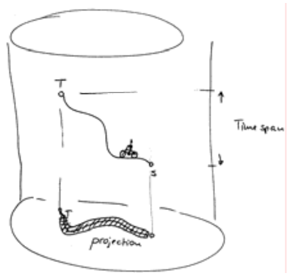


Figure 2: Timespan and projection of a region, depicted following Hagerstrand's Time Geography (Tom bicycles from S to T) [hagerstrand ref fehlt]

3. Physical Reality Seen as a *4*-Dimensional Field

For each point in space and time a number of properties can be observed: color, the forces acting at that point, the material and its properties at every point like mass, melting temperature, etc. The interactions of objects—the physical laws in general—can be described in terms of local properties and result in changes in local properties (Figure 41).

$$\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y} = 0$$

$$\frac{\partial^2 v}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 v}{\partial t^2} = 0$$

$$D\frac{\partial^2 v}{\partial x^2} - \frac{\partial v}{\partial t} = 0$$

Figure 41: …., wave, and diffusion equation

The world can be described as a set of partial differential equations, but this is not to say that the natural laws are differential equations, only that point properties are in a continuous *4*-dimensional space are sufficient for a physical theory. Quine would have accepted this as an argument for the existence of point properties (but Quine himself argued strongly against properties).

A field model can be observed at every point in space and time for different properties:

$f(x, y, z, t) = a.$

Abstracting fromtime, a snapshot of the world can be described by the formula that Goodchild called 'geographic reality' (Goodchild 1990)

$f(x,y,z) = a.$

Figure 100-02: Differential equations and load on a plate

The processes occurring in physical reality have spatial and temporal extensions: some are purely local and happen very fast, others are very slow and affect very large regions (Figure 42). The processes of objects moving on the tabletop are fast (m/sec) and the spatial extent is small (m); movement of persons in cities is again fast (m/sec) and the movements of the buildings very slow (mm/a); geological processes are very slow (mm/a) and affect large areas (1000 sqkm). One can associate processes with frequencies in space and time (Fraser 1981). Each science is concerned with processes in a specific spectrum of space and time that interact strongly; other processes, not included in this science appear then so slow or so fast that they can be considered constant.

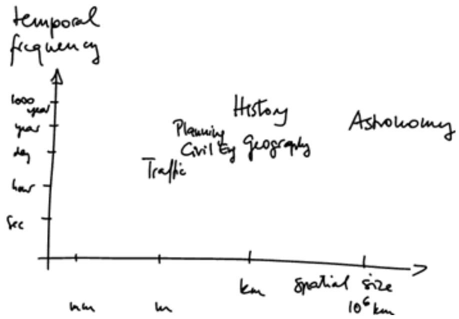


Figure 42

The function $a = f(x,y,z,t)$ describes a regular function that yields only single value. This is equivalent to the commitment that there is only one single space-time environment and excludes 'parallel universes' as part of physical reality.

4. Properties and Property Values

I imagine the world as such that each point has some properties; this corresponds to my experience of the environment in which I live: The environment I see is the collection of the properties that we can observe in time and space. Observations of properties at points are values on a continuous scale, isomorphic to real numbers. Some properties can be observed and the property values are transformed by the observation process into measurement values.

The environment has many, possibly infinitely many point properties, of which some can be observed by an agent. The assumption that only the observable properties exist, would be logically equivalent, but reality would be changed if a new property becomes observable. For example, the electric and magnetic fields have only become of concern in the 19th century and observation methods invented, but these properties of the physical reality have always existed. It is entirely possible, that other, new physical properties will become observable in the future.

There are different properties at every point of reality. The properties at a point in time and space are determined, i.e., multiple observations will always yield the same property value. But the actual observation result obtained may vary, due to imperfections in the observation process, (see next chapter 230). The same properties obtain at different points in time and space and have different values. Each property yields a set of values, which are of the type of the property. Typing rules avoids nonsensical operations (Frank 2001; Frank submitted 2005).

The property (type) and the property value are of two different types; the property type indicates what property is observed and the value gives the intensity. Ordinary language is polysemous and the name of a property can be used in conjunction with a property value to describe a property type but can also be used alone to indicate a (usually high) property value.

The height of the mountain is 10,000 feet

The height of this table makes it difficult to reach for children

figure 100-01 new cuyama [is already in gis theory

Properties are assumed to obtain at points, but practical observations are limited to observations of very small regions, over which the property value is varying very little and averaged (see chapter 230). An argument could be raised that infinitesimally small (geometric) points cannot possibly have physical (material) properties, but this is just yet another example of the difficulties to deal with infinitely small quantities in abstract thinking and smacks of the ridiculous argument of philosophers past on how many angels can dance on the head of a pin! We will in the next tier restrict physical observation to extended regions, avoiding the problem.

Properties are always physical point properties, not properties of objects

5. Continuous Change and Movements

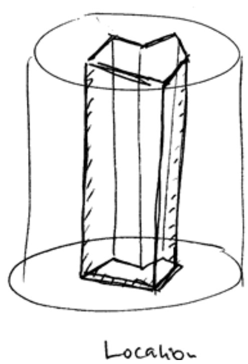


Figure 6: Location

The properties at a given point can change in time. It makes no essential difference if we imagine the environment as a *4d* space in which property values along the lines that represent fixed locations change (figure) or we imagine a changing *3d* environment.

Movement of objects can be described as changes in these properties; even the movement of solid objects can be described as the result of point properties, namely the cohesive forces in the body maintaining shape. The description of reality by differential equations Is effective in engineering and natural sciences (see 060). For example the reaction of a beam or a plate to load is a propositional bending. The effects of multiple concurrent loads is the sum of the individual loads. Reactions to causes are, however, not always proportional and small changes may have large effects (Abraham and Shaw 1983). The interaction of changes (for example forces) writes the environment (mostly the geometry) is often continuous within some margins and then at once a change occurs. Consider filling a container with water: the water level raises till water overflows (Figure 43).

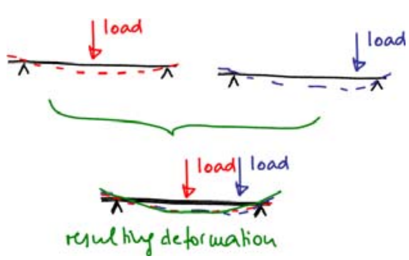
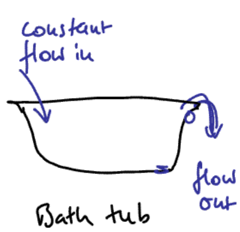
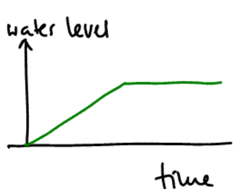


Figure 43: two causes have the addition of their individual effects





A constant cause has a non-constant effect

6. Spatial and Temporal Autocorrelation

The rules of physics, specifically the description of processes as differential equations result, for many important domains, in gradual changes. In general, there is strong spatial and temporal autocorrelation, at least at some scale on the spatial and temporal axis. Values near to a value are similar, the nearer the more likely.

Goodchild has pointed out that a world without spatial and temporal autocorrelation would be uninhabitable; it would be impossible to understand it and to organize one's actions to achieve certain goals.

7. The Environment is Observable

The values of the properties in the environment are observable: The environment contains special objects that have the property to be able to observe the environment, construct internal representations of the observed properties and take actions based on the internal representation of the observations. Agents can be individuals of extremely simple biological species, can be mechanical devices that expose similar behavior, or very complex computerized systems or human beings. We will generally use the term *agent* for them.

Braitenberg has written an adorable small treatise on “vehicles” (Braitenberg 1984); it describes autonomous agents constructed from simple observation devices combined with simple actors. The crucial element in such agents is the ability to transfer observations of the environment into internal representations, which are used to decide on actions (Figure 44). Ontologically important is the link between the internal state of the agent and the external state of the environment.

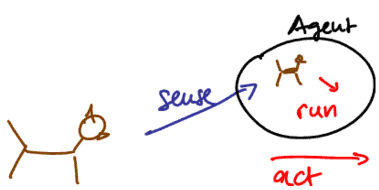


Figure 44: Agent observes and acts

8. Single Environment, Multiple Similar Observers

One can assume that all the world is my private imagination—this position is not very useful but I believe that one can construct a—admittedly absurdly complex—set of beliefs that is consistent with my observations. It will be necessary to believe that not only I have invented all the books I have ever read—and I am particularly proud that I have invented all of Shakespeare’s plays!—but have also to invent all other people I see and their actions, etc., etc.

In this *Solipsist ontology*, there is only one cognizant being and all other human beings he sees are figments of his imagination. This can be logically consistent, but does not agree with basic assumptions built into all our ordinary understanding of the world: I prefer to assume that I am basically similar to all other humans I see and that no privileged observer exists: all humans have essentially the same abilities with a large variability between individuals and understanding myself allows—with a large margin of error—to predict what others could and would do. This is crucial later for every communication between humans. The grounding in observations and actions must be very similar in every communicating agent for communication to work; and it is not deniable that people do communicate, not always perfect, but usually effectively.

All human agents are fundamentally similar in their abilities to observe, process, and act on the environment.

9. A Single Universe, Not Parallel Universes

Science Fiction stories sometimes assume that there are parallel universes—all the same than ours but different in some detail—for example in a story by Asimov, there is a parallel universe in which Hitler won World War II(Asimov 1957). Such constructions can be logically consistent but no empirical evidence is available to justify such assumptions and with our observation methods also not available.

No privileged observer

A quantum physics argument about indeterminacy—which is counter to the assumption of a single universe—is not relevant for an empirical, macroscopic level description of reality. Omnès has shown that any kind of macroscopic interaction forces the quantum indeterminacy to a single value—the value obtained in the single reality (Omnes 1999).

The assumption that there is only a single reality in which many cognizant beings interact and of which we are all part, which we observe and change is simpler. In science, typically the simpler assumptions are to be preferred (Occam's razor), but that does not make them true!

This formal model of reality as a function, which has a single value as result, expresses the ontological assumption of a single reality as observable ($f(x,y,z,t) = a$); if we had allowed multi-valued functions here, then we would permit 'parallel' universes.

10. Computational Model

For the computational model we retain only that there is a single reality—we will use the term environment to describe it, in which all things, including the cognizant beings, exist. There is nothing outside of this.

```
reality:: world -> observationKind -> spacePoint ->
timePoint ->  value  (xx)
```

Nothing exists outside of the environment.

The environment evolves in time and to retrieve that state of the environment at a specific time, there is a function

```
at :: environment -> time -> state of environment
```

and an (internal) function

```
step :: environment -> environment
```

that evolves the environment by one time unit and makes the history of the environment longer.

Agents are part of the environment.

We have not assumed any particular knowledge about the internals of the world, just that there is one. How the world is represented is not part of the model as little as the internals of how the world evolves are not part of the computational model of the ontology, and we can therefore use any knowledge we have in it. It must only simulate as closely as possible the observable behavior of the real, physical world. It will therefore be necessary to include the known physical laws—from Newton's mechanics to electricity and thermodynamics—as far as such aspects are simulated in the ontology.

We assume further that there are agents that can observe some (not all) properties of points in space and time.

Agents observe properties of the environment.

11. Conclusion

The logical consistence of a Solipsist ontology—all what seems to be reality is a figment of my thinking—demonstrates that logical arguments cannot reveal much about reality, strictly speaking, nothing. The assumptions listed here could be left out and added to the next tier, where the conditions for observing reality are discussed. It would, for example, be completely consistent to assume that many parallel universes exist, but all agents are restricted to observe always the same one.

> Commitment: there is a single physical environment and there is nothing outside of it.
>
> There are agents within the environment that can observe the environment and form internal representations of it.
>
> This environment is the same for all cognizant beings considered.
>
> Nothing is known about the internal workings of the world.

There is little we can know about the environment and therefore this part of the description of the ontology remains very brief. All what agents—and human beings are agents in the sense defined before—can know about the world derives from observations and any number of observations will never yield a true understanding of the nature of the world.

Most philosophical debate on ontology wants to concentrate on this tier, but ends in speculation and bold assumptions. I cannot see how one can claim that from studies of human thinking, natural languages (preferably old ones, where no native speakers exist—as Eco has pointed out with reference to Heidegger [eco]) one can intend to derive knowledge about the world. All what is possible is to understand what we can observe, as some philosophers, mostly phenomenologists [bergson, merlau ponty, husserl] have concentrated on. This will be discussed in the next tier.

PART FOUR 200 TIER 1 – OBSERVATION OF THE WORLD

Ontology in the wide sense is a human activity—a discussion of the methods humans use to understand how the world appears to them, how they see the world. All what ontology can really be is a discussion how humans construct their image of the world. Ontology is the ontology of a cognizant agent, typically a human being. We can muse about the philosophy and the related ontology of a frog (Lettvin, Maturana et al. 1970) or our dog, but serious discussions of ontology are carried out by humans, considering primarily their view of the world. Ontology is therefore an ontology of human agents in the first place.

A principled discussion of ontology must consider the way the agents observe physical reality and interact with this reality. This tier 1 "Observations" introduces the minimal properties of the agent that forms his ontology; we will see that even simple systems with at least one feedback loop from observations to actions have the most minimal structure required for an agent and therefore have an ontology in an unusually loose sense; what becomes evident is that there is not a strict boundary between humans, living organism, and less structured systems. The boundary is gradual; one may argue that the boundaries between the tiers are important. One could even argue that tier 1 includes as agents very primitive systems and organism, whereas the tier 2 agents conceptualize the world as populated by objects and are closer to vertebrae, and tier 3, which includes some level of abstraction and communication points to primates, with a possible sub-tier reserved for the cognitive abilities of humans. This seems speculative, but interesting contribution to the old discussion how human beings are different from animals (Savage-Rumbaugh, Shanker et al. 1998).

The first tier is, for example, the ontology pertaining to Braitenberg's vehicles (Braitenberg 1984). The vehicle shown in Figure 45 is a small autonomous car with four wheels and two sensors—for example light sensitive photo-voltaic elements—in front. The left sensor controls the speed of the right rear wheel and the right sensor the speed of the left rear wheel. If the left sensor senses more light than the right one the vehicle curves to the left, if the right sensor senses more light, it swears to the left (Figure 46). The autonomous vehicle demonstrates phototropic behavior, like a moth. The "ontology" of this vehicle contains at least observations of light and the actions of turning a wheel. That is of course not the common concept of ontology, which considers only rational thinking.

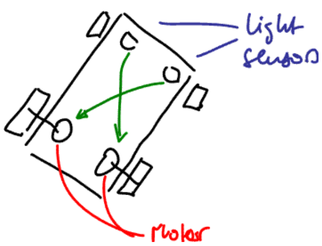


Figure 45: A phototropic vehicle

Photograph of moths around a light
Marlene Dietrich (Blauer Engel)
"...Männer umschwirr'n mich, wie Motten um das Licht..."

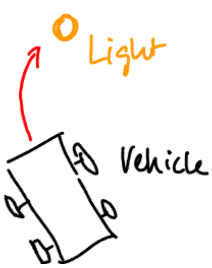


Figure 46: Path of a phototropic vehicle

If we were to wire the vehicle differently, for example connect the right sensor with the right wheel and the left sensor with the left wheel, then the vehicle would show a different behavior, viz. would turn away from the light, which in biology is known as photophobic behavior. Exchanging the light sensitive sensors for sensors detecting some chemicals (for example a pheromone) would result in a vehicle that approaches or runs away from a source of this chemical; such behavior is often encountered in insects, where surprising sensitivity to chemicals exists; some male moths are reported to find a female over several kilometers of distance.

Ontology is not necessary restricted to the ontology human beings use, but could be applied to the ontology used by some animals or the 'ontology' of the vehicle sketched above, which is extremely simple, having only one sensor sensing a single property of the environment. Understanding the ontology of foxes or birds might be valuable to model wildlife behavior. Watzlawick has posed a puzzling question: how could we communicate with whales. He did not wonder about the technical issues of frequency and medium, but as a question of 'understanding the semantics' of whale-speak (Watzlawick 1976; Watzlawick 1981). There are extensive observations of whale 'songs' and it is believed that they are a highly developed system of communication; one can observe that a message is relayed by groups and can quickly travel around the globe. But what are the whales talking about? What are the things—if there are "things" in whale ontology—of interest to them? Not likely the result of the recent football game of Juventus against Milan or the closing quotes of the New York Stock Exchange. Perhaps whales talk about family or food? Could whales talk about love?

We can ask what is the influence of the agent on the ontology he constructs. To produce ontologies for special agents might be useful for the theories about behavior of non-human agents. This is of interest, for example, if we study wildlife behavior (Church, Gerrard et al. 2003) and must model the "ontology" of the animals we study. Likewise, agencies and companies act as a collection of cognitive agents, and the organization as a whole demonstrating behavior similar to individual agents, based on the “ontology of the organization.

Large organizations, companies, and government agencies observe, through their independent, but coordinated, agents specific aspects of reality of importance to the organization. They store the results of observations and use their stored data to decide on actions, which are then carried out by humans acting on behalf of the organization. A large part of the ontology of such organizations becomes the database schema of the central database: what are the objects of interest, how are they described and how is the data used for decision making. This similarity of ontology of persons and ontologies for agencies and the directly identified need for ontologies to organize the databases of organizations shows the practical applicability and importance of an improved understanding of ontologies and the place where computational ontologies can be directly applied.

The novel theory of multi-agent systems (Ferber 1998; Weiss 1999) establishes a framework in which properties of agents and different types of agents can be discussed. Cognitive spatial agents are required to construct ontologies. The first chapter in this tier discusses agents and how they observe or act on the world based on their observations of reality. The following chapter then discusses observations and their limitations of the observations. The prototypical cognitive agents we are interested in are humans.

I give up here the distinction of ontology and epistemology and follow the tradition where ontology is a discussion of human conceptualization of the world [Guarino, gruber] All what is ontology in a very narrow sense was discussed in tier 0— suggesting to read the 0 as O for Ontology *sensu strictu*.

The difficulty in the discussion of this tier 1 ontology is the limitation to observations of physical properties in points. The human cognitive apparatus is so predominantly geared towards the formation of objects, which will be discussed in tier 2, that it is very difficult to restrict the discussion to this limited view.

Tier 1 is limited to the observation of physical properties at points.

The confusion in the discussion of tier 1 is that we discuss the observations of agents that are clearly objects, thus pertaining to the discussion of tier 2. The focus of the discussion here is the observations of the environment, of which the agent is a part, and the action of the agent on the environment in terms of properties of points, i.e. the physically existing world of tier 0.

Commitments:

There are cognizant agents that observe the world and form mental representation of it

All human cognizant agents are essentially the same

Agents have a body and are part of the physical reality (matter)

Local knowledge of an agent is separate and not observable by other agents.

Agents act on the environment and effect observable changes in it.

Chapter 8 210 An Environment with Agents

Terminology:
observation – action
Object – activity

Humans are prototypical autonomous agents as defined by multi-agent theory. The concept of agent used here is very simplistic and contains the minimal structure necessary for us to understand how agents observe and act on the world. This description follows very much Braitenberg's account in "Vehicles", but extends it with the framework of the now developed multi-agent theory (Braitenberg 1984). Multi-agent theory deals with systems of (autonomous) agents acting in an environment (Figure 47). It is a very recent new development in science, with roots in systems theory (Ferber 1998; Weiss 1999). There are many areas of application, from systems to control large machinery, robotics and cognition.

Figure 47: Agents in the environment

Different authors from different fields have different understandings about agents, but a coherent multi-agent theory is emerging (Weiss 1999) (Russell and Norvig 1995; O'Hare and Jennings 1996; Ferber 1998) (Bond and Gasser 1988). This section gives a short introduction to the current state of this theory as it is useful to understand ontology and its applications. It introduces the concepts and definitions we found applicable for our work. An agent is just a system with internal state in a system that consists of the agent and the environment; the agent can observe the environment and change it through its actions. It is worthwhile to note that a description of an agent without considering the processes and the time these require is pointless.

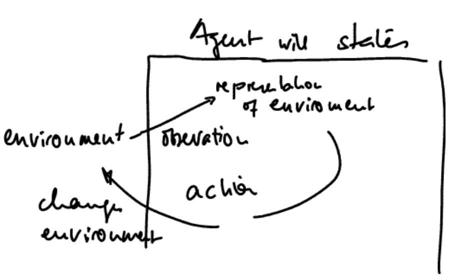


Figure 48: Schematic of agent

In some sense, multi-agent theory is rediscussing biology and general systems theory are the properties of systems that make us call them 'alive' (Bertalanffy 1973). It debates the limits between dead matter and live and follows in the tradition that ontology is a discussion what is human .[Ref to shirley turtle?]

1. Cognitive, Spatial Multi-Agent Systems

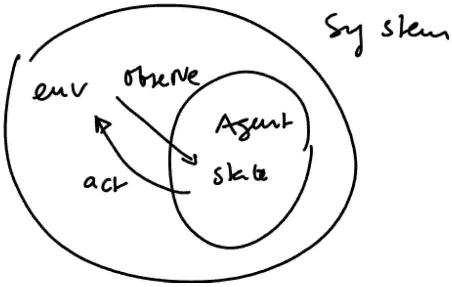


Figure 49: Agent and environment as a system

The intention to construct a computational model of an ontology requires that we construct software agents that act in artificial environments, representing real agents acting in real environments (Figure 50). These environments are intended to represent parts of the real world we are interested in for the simulation of cognitive, spatial processes. Consider the vehicle sketched before—it can be seen as a model for a moth which exhibits phototropic behavior. a computational model of the vehicle allows us to observe its behavior in a computational environment without actually constructing a physical model.

Real World Situation	Multi-Agent Model
World	Environment
Time	Computational Cycle
Person	Agent

Figure 50: Mapping from reality to model (from (Frank 2000))

Mark and his co-authors (Mark, Freksa et al. 1999; Mark, Smith et al. 1999) present a hypothetical information flow model for spatial and geographical cognition, which consists of four stages: acquisition of geographical knowledge, mental representation of geographical knowledge, knowledge use, and communication of geographical information. They, and most other scientists, leave out the decisions and actions. Scientists collect information to produce knowledge, but do seldom think of the practical use of the knowledge and information to decide on actions, which change the environment and influences thus the geographic knowledge acquired (cf. the discussion of social responsibility of scientist after Hiroshima and Nagasaki [ref schwebe, in the shadow book]). We focus on all *four* of these processes: the agents perceive their environments, form beliefs about the environment, use these beliefs to decide upon actions, and communicate with other agents (Figure 51).

Ontology for

- *observation*
- *representation of environment*
- *decision*
- *action*

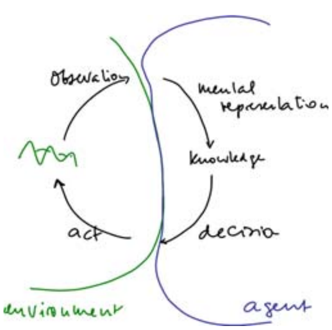


Figure 51: The 4 processes

Agents with internal state are necessary to provide sufficient capabilities for the representation of cognitive processes, but these internal representations can be extremely simple, like Braitenberg's vehicle demonstrates.

The function *decision* provides a general definition of cognitive processes describing these processes as a mapping from percepts and internal world representations of the agent (the internal state) to activities the agent performs in its environment.

Communication between agents is important but does not alter the picture: knowledge acquired can be transferred between agents through communication, what the first agent has observed, the second agent uses to guide his actions (see tier 3).

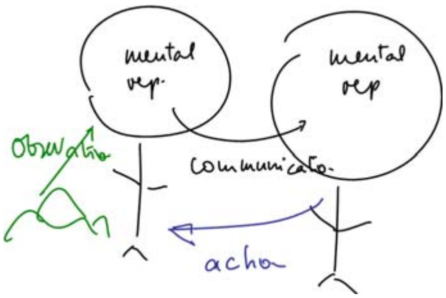


Figure 52: Two agents communicating

An explicit representation of space is provided by the set of locations *L.* Agents can change the location of objects in space by their actions. The function *runEnv* represents reactions of the environment to the agents' modifications. It defines the general rules change in the environment follows (the laws of the universe *U*). A cognitive spatial multi-agent system defines a qualitative notion of time represented by the change of the system from one world state to the next. The transition is realized by the operation *runEnv*.

The model must take into account that observation and action are limited to extended regions and otherwise influenced by the limited capabilities of agents. In this tier 1 the universe consists of small regions, approximated by points, which can be observed and acted upon (see chapter 230).

2. What Is an Agent?

There is no common agreement about a definition of the term agent. We regard an agent as *"anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors"* (Russell and Norvig 1995, 31). Agents are situated in an environment and capable of autonomous action {Wooldridge, 1999 #682}. Animals and human beings are prototypical agents.

Agents are embedded in an environment and autonomously perceive and act upon the environment.

Agents interacting in a multi-agent model are the basic concept for the model of ontology. We use the term 'agent' as design model, i.e., we do not focus on the technical means for representation or reasoning mechanisms. Real agents can be constructed using very different technologies. Biological systems, which exploiting the oxidation of material as an energy source as well as electrical-energy systems like robots are agents.

Agents act autonomously. They have control over their actions and internal state, i.e., the agent can act based on its own knowledge and perception. A system lacks autonomy if its behavior is completely determined by its build-in knowledge and does not need to perceive its environment to decide about its activities (Russell and Norvig 1995, 35).

A technical system which does not have perception and action and no internal state is not an agent, but can be used by an agent to extend its reach—either as an extension to perceive where its own sensors are not sufficient, or to control actions to which it would not be capable. Telephones permit to hear what is spoken at places to distant to hear it directly; bulldozers are convenient to move large amounts of earth which a single human could not do without their use.

3. The Environment in Which the Agents Are Embeded

The environments must allow observation to the agent and that the agent performs actions. Actions must change the observations.(Figure 53). The agent is physical part of the environment but forms—using the same physical matter it and the environment consist of—percepts which represent the environment. The agent is part and is not part of the environment at the same time: it is physically a part, but it internal structured representation of the environment is not part of this. We separate mater and information. More details follow in tier 3 where information as a special kind of existence is considered.

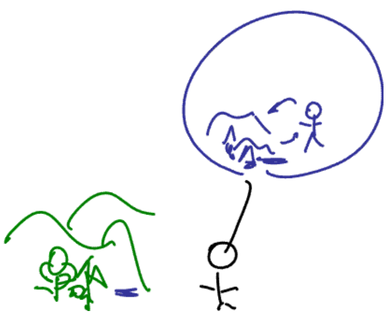


Figure 53: An Agent is part of the environment and represents in this environment the environment and itself

Multi-agent theory regards the environment as an integral part of the framework. Artificial and real environments can be distinguished (Russell and Norvig 1995, 36). Ontology is discussing a real environment in which real agents act, but the computational model is an artificial environment in which artificial agents act. The computational model of the ontology is constructed from *software agents* that are computer programs and exist in artificial software environments. .

3.1 The laws of the Universe

The general rules governing the behavior of the environment are determined and represented by the laws of the universe. They define the reaction of the environment to the actions of the agents. If we model reality then the laws of the universe are the laws of physics for example the law of preservation of mass, energy, momentum etc.

For a purely physical universe, it seems to be sufficient that all changes are the effect of exchanges between adjoining points. Stress or heat is propagated from point to neighboring point, sometimes fast (stress) or slow (heat). These exchanges are described by partial differential equations (see…).

3.2 The environment is spatial

A model of the real environment is spatial; it consists of a set of locations L, which together form space compare with in point-set topology where an infinite number of infinitely small points form space (Frank submitted 2005).

3.3 TIME: THE ENVIRONMENT HAS STATES

The state of the environment is the set of all observables. The environment changes in time from one state to another. The reaction of the environment to the agent's actions changes the current state. The focus of this tier are not the objects perceived and the actions executed but the effects on the points of which space consists.

Figure 210-03

3.4 ASSYMMETRY OF SPACE AND TIME

Agents can observe and act only at the present time, the ever changing 'now'. (Franck 2003), agents can however travel in space and move to arbitrary locations, to observe or act there.

The conditions of our physical existence convert the symmetric four dimensional space-time universe of physics into an asymmetric situation, where space and time is treated differently. Further, for all biological process and all agents time is directed and operations can only progress from past to future (Couclelis and Gale 1986).

Figures compare 4d to 3d + directed time

Commitment: movement in space is possible, but perception and action are only possible at the time 'now'.

Time advances during all operations uniformaly in the direction from past to future, moving the 'now'.

The time 'now' is the same for all agents—independent of their local time system(Franck 2004). All perceptions of all agents in the world are synchronously at the same (physical) time—even if the local times are different. If I call a friend in the USA, my time is 19:02 and his time is 11:02—but our communication by phone is only possible, because the time point 'now' is he same for both of us (18:02 in GMT)

Ref franck

4. AGENT PERCEIVES ONLY A SUBSET OF THE ENVIRONMENT

The interaction between the agents and the environment defines the dynamics of the multi-agent system. This interaction is determined by the decision making process of the agent about the actions to perform and the reaction of the environment to these actions.

Different agents have different abilities for spatial and temporal resolution (Figure 54).

Figure 54

The agent has a goal and observes parts of the world that are relevant to achieve these goals. The assumption of a general principle of economy, namely that processes are purposeful and irrelevant observations are avoided can be justified from evolution; systems that are more effective in their methods to achieve their goals are more likely to survive.

The wayfinding model (Figure 2) integrates the agent's cognitive schema and perceptual structures within a Sense-Plan-Act (SPA) approach {gat 1998}. It focuses on external knowledge to explain actions of the agent performing wayfinding tasks.

Information and *affordances* describe the kinds of knowledge agents derive from the world by means of visual perception. Affordances (Gibson 1979) are possibilities for action for the agent. Information is necessary for the agent to decide upon which affordances to utilize. The environment provides percepts (i.e., affordances from cognizing agents and non-cognizing objects) to the agent; the agent decides upon and performs actions in the environment, which in turn provides new percepts; and so on (Figure 55). Affordances of the same situation for different agents are different, affordances are not abjective.

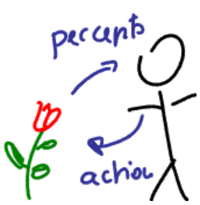


Figure 55

4.1 Interdependence of Perception and Goals

The internal cognitive schema (Neisser 1976) guides the agent's processes of perception, decision, and action during the wayfinding task. Information about the task and goal, and a minimum of wayfinding strategies and commonsense knowledge are necessary for the agent to perform the task. The task description directs visual perception in such a way that the agent samples only task-relevant information and affordances (therefore only a subset of all affordances present in the environment). The wayfinding model concentrates on the actual information needs during wayfinding and does not focus on learning a spatial environment. Its fundamental tenet is that all information must be presented at each decision point as "knowledge in the world" (Norman 1988).

4.2 Time Scale of Agent Actions

The time it requires for the agent to execute the sense-plan-act cycle (Figure 54) once is not the same for all agents. Some biological agents act much slower than others—e.g. a sloth acts slower than a human, and flies are even faster (what anybody trying to swat a fly can ascertain!). It seems useful to differentiate agents by the speed of their sense-plan-act cycle given as the frequency with which their sense-plan-act cycle is executed. This frequency is related to the minimal time separation to obtain two different observations. Complex agents can be seen as multiple subsystems, which have different sense-plan-act cycle frequencies; hand-movement coordination is on a much faster cycle than the cycle from hunger to eating.

4.3 Spatial scale of agent actions

The agent has limited ability to separate observations in space and to act precisely on points in space. This gives the agent a spatial resolution for perception and action. For example, the human eye can differentiate points of about 1/10 of a mm (under specific circumstances we can see differences closer to 1/100 of mm) and we act on objects with about equal precision.

5. Different Types of Agents

An agent has at least an internal state and one method to observe the state of the environment and one operation to change the state of the environment.The main criteria distinguishing agent architectures is the question of how much internal representation of previous operations and world states the agents have. Reactive systems have no internal representations of previous states, whereas systems constructed according to the deliberative approach have extensive and symbolic representations.

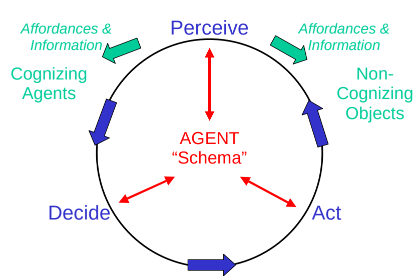


Figure 56: Process model for agent

6. Sense-Plan-Act Paradigm

An agent constructed after the reactive approach purely reacts to its current percepts following condition-action rules. Deliberative agents follow the classical AI approach (the Sense-Plan-Act paradigm {Gat, 1998 #709}) that decomposes the control system of an agent into three elements: the sensing system, the planning system, and the execution system. The agent plans his actions based on his percepts and knowledge. The control flow between the three components is unidirectional from the sensor to the effector.

The operation of the agent can be divided in three steps, which are repeatedly executed (Figure 56)

- Sense: observe the environment

- Plan: decide on the next action
- Act: execute this action

These three steps, which are repeatedly performed in an agent, are broken up in five processes, which a multi-agent system executes repeatedly (Figure 57):

- Sense (Perceive)
- Fusion of new and previously available information
- Plan (Decide)
- Act
- Reaction (of environment)

Only if we look at the processes in the physical and the information realm the control loop is closed and the feedback for stabilization available. The sense and the act process translate between the physical and the information realm, the reaction of the universe is completely in the physical realm, the plan process is completely in the information realm (Figure 57).

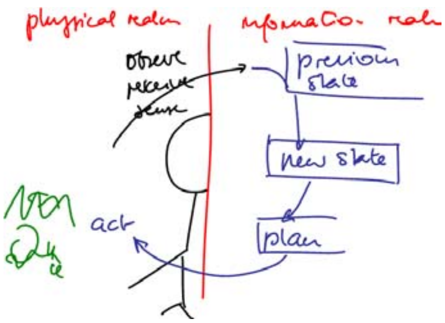


Figure 57: The five processes, two connecting the physical to the information real, three in the information realm

7. SYNCHRONIZATION OF AGENTS

The connections between the actions to the perception through the reaction of the environment is responsible for the synchronization of process of multiple agents; they all sense the actions of one of them at the same time (exactly some minimal delay Δ t between the action and the perception later). For example, yesterday night in my Italian vacation spot a car hit a parked car (parked where it is always parked under a "No Parking" signs, of course!)—everybody in the neighborhood heard the noise and a very large number of people gathered immediately to assess the damage, speculate about the cause … The unusual, loud bang synchronized their behavior!

(photo would be nice?)

8. AGENT ARCHITECTURE

The structure of the decision making separates three agent architectures. The differences are in the functions *perceive* and *decide*:

8.1 PERCEIVE

$perceive: E \rightarrow P^*$

$p: E \rightarrow P$

The function *perceive* represents the perception process of the agent. It maps the environment to a set of percepts.

8.2 DECIDE

Different agent architectures are distinguished by their *decision* function:

- reactive agents and
- agents with internal state.

For an autonomous agent, the *decision* function maps a set of percepts and the current internal state *I* of the agent into an action *A*. The decision function consists of two steps. The first step (the function *fuse*) updates the internal state of the agent based on his percepts; the second step (function *act*) selects an action based on the updated internal state.

$fuse: P^{*} \times I \rightarrow I$
$act: I \rightarrow A$

If the agent improves his knowledge based on his own selected action, the internal state of the agent will be again updated afterwards.

$fuse: A \times I \rightarrow I$

The function *env* represents the reaction of the environment to the agents' actions.

$env: E \times A^{*} \rightarrow E$

It maps the environment *E* and a set of actions performed by the agents to a new state of the environment. This mapping function realizes the changes on objects (including agents) caused by the agents' actions.

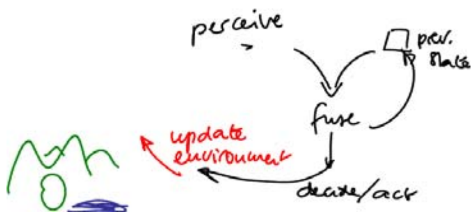


Figure 58: The cycle in a computational model

8.3 Reactive Agents

Reactive behavior of an agent does not require information from previous states using the currently stressed states of the world are sufficient. A purely reactive agent is characterized by a decision function, which directly maps input to output, i.e., percepts to actions.

$decision: P^{*} \rightarrow A$

8.4 Deliberative Agents

To allow higher-level internal capabilities of the agents, such as, planning, goal directed behavior and collection of experiences, a kind of internal representation of the world is necessary. For deliberative agents the decision includes the former experiences of the agent, into the decision making process.

$decision: P^{*} \times I \rightarrow A$

9. Physical Agent—BODY

The agent must have a body, which is extended, has physical properties and is located in space. An agent has all the same physical properties that other objects have. In very simple models, which do not reflect spatial aspects, the only part in the agent is the mind. For spatial models an agent has at least a location in space, but may also have body geometry and other physical (material) properties.

The computational model of the agent includes of a model of the physical body part, which determines the physical properties of the agent, its location and the location of all the body parts. The body determines which operations the agent can perform. The body is the locus of the execution of actions which change the world state. The body eats food, grabs objects (with the hands, as part of the body), walks to a new location etc.

The body contains also the brains (and other internal organs). The brain can only indirectly affect the world and change it, namely by inducing actions in the muscles to move body parts, which then produces grabbing, eating, speaking, walking etc.

The body contains sensors, which inform the agents mind about the environment and its own position in space. The primary sensors of humans are the eyes, ears, etc. Additional sensors inside the body inform the mind about position of body parts and the state of internal parts of the body (propriosensors).

10. COGNITIVE APPARATUS—MIND

The mind contains the internal 'mental' state of the agent. It is a store of data that result from observations. The state of the mind represents previous observations, actions, etc. Real, physical agents with bodies have internal states in the physical situation of their bodies as well as in their brains.

Internal representation = internal state

10.1 AGENT MIND

The agent has a mind, which contains representations of the percepts the agent body. It uses the visual and other spatial perceptions to construct a world image of physical objects, as useful for th ecurrent goals. In this worlf view, objects which are part of the body and other objects are dealt with alike – they are all physical objects, which are visible (can be felt,..)

In addition, the mind receives proprioperceptive data that leads to an internal representation of the body as felt by the agent. This contains models of the internal state of the body and also information about the physical location of body parts. The correspondance between the perception of body parts and the proprioperceptive information about the same parts are unique for the self (Figure 59). Only for the body 'self' proprioperceptive information is directly available.

Figure 59The body and the internal representation of it

10.2 Representation

The term *representation* is here used differently than for example in neurobiology where it is u restricted to a symbolic stored representation. (Gibbson stresses that certain mental functions do not need an internal representation (Gibson 1986)). I include in representation even transient phenomena, for example the current in the wires of the vehicle in figure XX is a representation of the amount of light sensed by the corresponding sensor or the signals sent from the frogs eye to its brain (Lettvin, Maturana et al. 1970). This is transient, but it is a representation in the sense that the current *represent* the amount of light sensed. I think that restricting the term representation to the symbolic, stored representation constructs a confusing distinction where there are rather gradual differences.

10.3 Computational models of perception

The agent has operations which simulate the functions of the senses of humans. The result of perceptive operations are internal states.

```
See :: environment -> agent -> visualForm
```

Perception is the only way for the agent to acquire data describing the environment. Other agents are part of the environment and perception of their physical body properties is possible, similar to observation of physical properties of non-agent bodies. Perception of internal states of other agents is excluded (we do not include mind reading in the ontology!). Communication between agents is only by one agent producing physical signs which can be perceived as ordinary physical objects—for example an agent can draw a map on a sheet of paper, or produce audible sounds in the environment, which other agents then can perceive (Figure 60).

No perception of internal states of other agents.

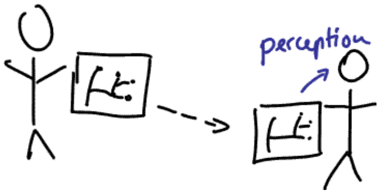


Figure 60

11. Actions

Agents have a selection of actions which they can perform to change the environment or their position in the environment. If the intended actions are possible—i.e. consistent with the Laws of the Universe—then they have effects and change the physical environment accordingly. These changes are perceptible to other agents. The changes are not necessarily the ones planned by the agent carrying out the action.

Communication is a special kind of action and all communication between cognitive agents is through the production and perception of physical signs.

Commitment: all communication through physical signs

All agents can observe the changes in the environment they have caused. As agents observe the effects of their actions, they have to update their expected state of the environment with the actual state of the environment resulting from the actual execution of their operations.

Agents have control over their body

The model of the agent consists of two parts—the model of the physical body of the agent and the model of the cognitive apparatus. This reflects the commitment that all cognitive activity is bound to some physical properties. The changes of the physical body are controlled by the law of the universe (typically Newtonian physics).

Agents have the possibility for acting on the environment. Activities by the agent change the state of the environment and these changes are then observable.

Activity is selected as the most basic notion; actions are composed from activities. An activity is for example exerting pressure on something, which will eventually move it. Moving something would be an action, consisting of several activities some of which extended over periods of time, others just momentarily.

Terminology: Activity changes properties of a point

Despite the discussion of agents in this chapter, the focus is on the change in the point properties of the environment that are the result of the actions of the agent. Activities of agents are primarily effects of exercising forces (typically pressure) on the environment.

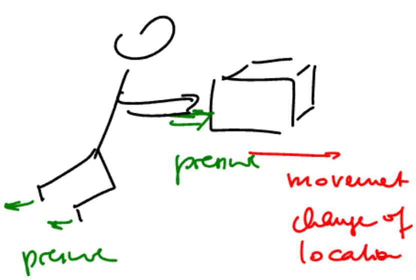


Figure 61: An agent acting on the environment

Wordnet gives the following definitions for activity (Laboratory 2005):
2. the state of being active,
3. bodily process,
7. the trait of being active.
This justifies the selection of this term for the notion of the tier 1 concept that is later used in contradistinction to action, which describes the tier 2 concept of a sequence of activities that has some internal coherence. The distinction between activity and

action corresponds to the distinction between properties of points and attributes of objects.

Tier 1	*tier2*
point	*object*
property	*attribute*
activity	*action*

12. ACTIVITIES CHANGE THE PROPERTIES OF SOME POINT

The physical processes an agent controls can effect a change in the properties of some points adjacent to the agent. Humans can control primarily pressure exercised through muscle tension (active) and the skeleton (passive), they can also produce air waves observable as sound and their body heat can increase the temperature of objects they come in contact with.

13. PLANNING

Commitment: no mental activity without a body

The decision for action and the corresponding actions are only possible for the self—the agents cannot decide directly on actions for other bodies: I can stretch my arm, but I cannot stretch another persons arm.

Predictions of future states of the agent's body (especially the positions of body parts) are meaningful—the agent has control over the actions, but activities can be hindered by the laws of the universe, for example physical barriers may impede an intended move.

Image schemata force – barrier

The construction of possible worlds following from action of the self is meaningful and is part of the planning operation. Planning means the execution of an intended action in the mind, such that a new, desirable state of the world is projected.

As an example may serve the plan to move the body to achieve better visibility. From a given position, not all other points in space are visible. The agent may predict that after a specific move, e.g., climbing a tree this location may become visible; the result of the action may or may not be the planned one, depending if other obstacles impede the view or not. The same mechanism can be applied to other agents and one agent can predict what another agent can see and cannot see. Chimpanzees can understand that they are not visible for others

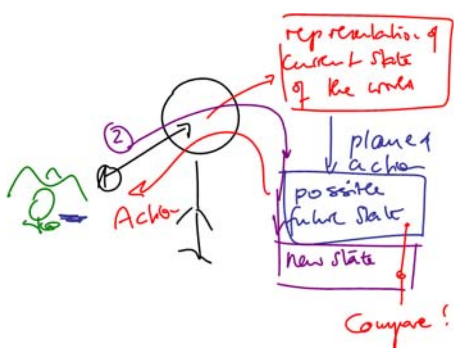


Figure 62 Compare planned and achieved state

14. DEFINITION OF A MULTI-AGENT SYSTEM

Adapting the definition of Ferber (1998) the term 'multi-agent system' refers to a system consisting of the following parts:

> The environment E consisting of the following elements:
>
> A set of *observable regions* O. Point properties can be perceived, created, destroyed and modified by agents.
>
> A set of *agents* A. Agents are a subset of objects ($A \subseteq O$) capable of performing actions - the active entities of the system.
>
> An assembly of *relations* R which link point properties.
>
> A set of *operations op* for agents to perceive, manipulate, create, destroy point properties off O, in particular representing the agents' actions.
>
> A set of *operators* U with the task of representing the application of the operations from *op* and the reactions of the world to this attempt of modification. The operators from U are called the *laws of the universe.*

The physical world in tier 1 consists of small regions, represented by points. Activities are forces applied to these points. The points are small regions, not geometric points (see next chapters).

The minimal physical system which can be considered an agent must have some minimal form of perception, some internal representation of at least the current state of the environment, a decision function and a way to act on the environment.

Figure or photograph

The formulation of a computational model of the agent is (nearly) a complete description of the tier 1 ontology: what can be observed, what activities are possible. The computational model makes clear what commitment we assume about the physical world. Unfortunately, the description is not possible without the agent, which is an object (see tier 2).

15. Affordances on the Field Level (Tier 1 Affordances)

Gibson argued that humans see potential for activities directly (Gibson 1979; Gibson 1986). His example uses optical flow to detect an opening in a wall, a door, through which one can move. Optical flow is an observation of solid surfaces and the changes of these observations through motion of the body (and therefore the eye).

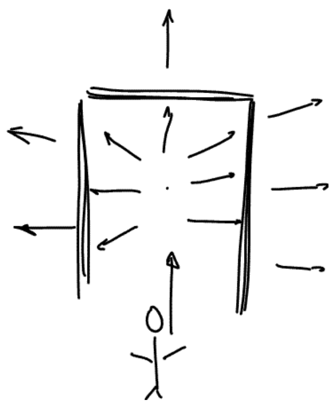


Figure 63: Optical flow (after [gibson])

Figure 250-01: Optical flow when looking through a window

Figure 64

Affordances seem to operate on basic physical laws, e.g., the impossibility that solid matter can be moved to a place where there is already solid matter, the rules for flow of liquids, the effects of gravity on objects, and geometric arrangements of solid matter to stop movement, etc.

Cognizant agents that can observer the environment and effectuate activities have learned which activities are possible in which observed situations, respective which ones are not. We see a liquid and see it in our minds eye flow, see how it can be poured, etc. Seeing a pencil, you immediately conceive of making marks on paper with it. Seeing an apple, you conceive of taking a bite…(Figure 64)

Gibson makes a strong argument that affordances do not rely on a symbolic representation of the world in the agents mind—beyond the internal representation of the observations—and this is justified in this sense of tier 1 affordances. The observation of open space is equivalent to observing 'here matter can move to', learned by repeated experience and internalized such that the connection is not a conscious thought.

Affordances are very often associated with operations that can be carried out with objects (Raubal 1997; Raubal, Egenhofer et al. 1997; Jordan, Raubal et al. 1998; Raubal 2001; Raubal 2001); these affordances will be discussed in tier 2.

16. Close Loop Semantics of Data

The question posed initially about the meaning of data can now be partially answered. The meaning of data representing observation values in a reactive agent is determined by the sensors and the actor's connection to reality. The sensor determines what physical property is observed and the actors determine which physical property of reality is influenced. If we observe a vehicle that reacts to light (phototropic 200.1) the sensors must observe light intensity and the internal state must represent the light intensity—whatever the words used to describe this—light, luce…. Alternatively, we can argue that if moving towards light is important for an agent, it will learn to use sensors that report light intensity, because only with these sensors, his situation improves. Over time it will adapt its internal processing of the observations of the sensors such that it will use the light sensors to guide its movement in a phototropic pattern. The wiring of the frogs eye to the brain is optimized to detect prey (small moving) and to escape predators (Lettvin, Maturana et al. 1970).

From 'inside the reactive agent' semantics is not defined with relation to the exterior world, but with relation to an internal processing model. The meaning of a sensor in this internal processing model is based on the linkage the value of this sensor has to the actor's control.

Figure

The semantics of the values are determined by the processing model, which is homomorphic to the actual system controlled—but the reactive agent does not know about the world, it knows only about inputs and outputs and connections between them. The concept of temperature is sufficiently determined by the connection between 'temperature sensor' and 'heating switch' (Figure 65). A similar control to stabilize the water level in a tank links water level sensor with open/close valve control—again the semantics of 'water level' is determined by the sensor/actor pair and their linkage through the control process, which is isomorphic to the one for temperature control.

Figure 65

17. COMPUTATIONAL MODEL

The agent has observations and represents the results internally. The meaning of these results are related to the activities the agent can perform (i.e., the data processing part of the agent can cause).

Activities change properties in the environment; these changes can be observed again. This connects the internal semantics of observations, i.e., a signal on wire from sensor x, to the internal semantics of activities, i.e., activate actor x.

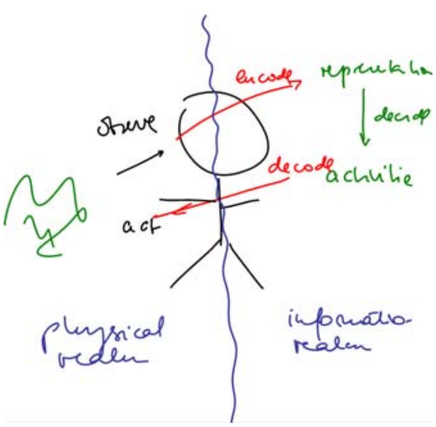


Figure 66: The physical and the information realm

Chapter 9 220 Agents Observe Reality

Commitment—linkage between observations and operations/decisions?

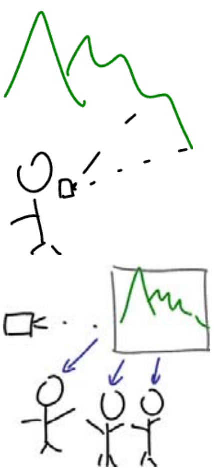


Figure 67

Figure from Hohe Tauern

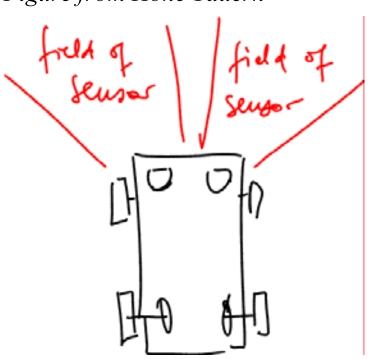


Figure 68: The field of "vision" of the two sensors

We observe reality. Our visual impressions are similar to the photographic pictures our cameras produce, or at least, observing the photograph produces very similar sensations in our eyes than the direct observation of reality: watching Figure 67 I can clearly remember the sunny summer day I was hiking up the xx valley and took the picture. It shows, in my opinion, truthfully the meadows, trees, buildings and mountains. But we all know that cameras take pictures by sensing the light energy in different bands in different directions in an array of pixels. The camera does not see mountains or trees; the camera records only point observations. The objects we see are produced by our mental processing of the image and will be discussed in the following Tier 2.

Two questions are important here:

- What can be observed?
- What is separated (distinct)?

Braitenberg's vehicle serves here as an example. It observes reality through its (two) sensors; it observes the intensity of light for two regions of space (Figure 68). The observations are limited in what wavelength the sensors are most sensitive to, the direction light is sensed from and how little difference in light energy results in two different observations (which then make the vehicle turn).

1. Observation of Physical Reality

Agents can - with their senses or with technical instruments - observe the physical reality at the current time, the 'now'. Results of observations are measurement values on some measurement scale (Stevens 1946), which may be quantitative or qualitative.

The observation with a technical measurement system comes very close to an objective, human-independent observation of reality. A subset of the phenomena in reality is observed. As humans are ‘visual animals’ [ref] the observation of light and visual sensors dominate, but the other senses (haptic, hearing, taste and smell, etc.) must not be forgotten.

Technical systems may extend the range in space, time, or frequency spectrum we are capable of observing. They translate observations that would not be possible to an agent to phenomena that the agent can directly observe; for example, optical devices like binoculars, enlarge distant phenomena that would be too small for direct observation.

Many technical systems allow the synchronous observations of an extent of space at the same time, e.g., remote sensing of geographic space from satellite. Typically a regular grid is used and the properties observed are energy reflected in some bands of wavelength (typically the visible spectrum plus some near infrared bands) and encoded on a scale from 0..255. (COLWELL 1983)

Figure Remote Sensing Image

Photograph of man with binoculars

Sampling light energy in a regular grid can be used in many situations, the tabletop world on my table as well as the city, including moving objects. TV cameras, which sample the field in a regular grid are used to construct 'vision' systems to guide the robot's actions manipulating the objects on the table (Horn 1986) or guiding the robot's movement in hallways of buildings (Remolina, Fernandez et al. 1999).

2. Our Limited Knowledge of the World through Observations of Reality

The observations of reality are necessarily limited: we can only know a (very small) subset of the reality and with very limited precision. We can only observe at specific locations and at specific times, and human observers are restricted to observations of the property for the moment 'now'. Continuous observations are actually rapid samples at discrete points. Measurements are observed with unavoidable error and are expressed only with limited resolution (see next chapter).

One must also accept that some observations humans make never reach the conscious level.. We do not notice that we noticed, for example, a faint smell. On the other hand, technical systems increase what we can observe, but do not fundamentally alter the process of observation.

3. Objective Observations

Theory of science has bestowed much attention to the concept of 'objective knowledge' which comes from 'objective observations'. It has been shown that a purely objective knowledge of the world is not possible (Hartmann and Janich 1996) as was pointed out in the discussion of tier 0—all what we know is knowledge obtained through sensors, which are limited in their truthfulness.

It is often assumed that technical sensors are more objective; they produce the same result, independent who operates them—at least in principle. The operator influences the result through small differences in the handling of the sensor, the routine steps in preparing for the measurement or order in which some manipulations are done. For highly precise leveling work, not only the calibration of the sensors is critical, but also the order of observations must be controlled. It has been observed that the bases that are used to pose the leveling rods on slowly sink into even hard surfaces (Figure 69)—and this accumulates over the course of a long measurement chain noticeably; careful ordering of the readings can cancel this effect.

Figure 69

Figure

Objective observations means in principle: observations that are not dependent on the person obtaining it. If another person observes the same property at the same time and location, she obtains the same result. This cannot be empirically verified, because it is impossible that two different observations are made at exactly the same location and time—but for properties that change slowly in time or space, it can be verified that observations are very similar.

The truth condition for point observations is that the observation is in relation to the intensity of the property of interest at the location. Unfortunately, exact duplication of measurements is typically impossible, but within the error bounds selected, one can repeat an observation within a very short delay, or perform synchronous observations at very close positions. Such parallel observations give us an indication for the precision of a measurement method.

4. Observation Types

Different sensors observe different properties—in general, each sensor observes in a particular way a particular property.

- My eyes observe light energy directed at the eye from different direction. The lens produces on my retina a picture similar to a photograph and my retinal cells translate the light energy into a nervous signal (the details of which is not relevant here).

- The sensors in my fingers inform me about pressure on my finger tip, the heat at the contact point, etc. There are different sensors in the skin of my finger.

Figure

In principle, each technical or biological sensor translates a physical property at the location of observation into an encoded value. The sensor system selects the property (or a mix of properties) and the instant field of vision, i.e., the region over which the value is averaged and also the transformation to a continuous value in a representation appropriate for the system. This may be firing of axons or an analog or digital signal produced by the sensor. Technical sensors often work in two steps: first a sensor translating a physical property in an analog electric signal, where the voltage varies as some known function of the physical property and then an analog digital converter, which converts the voltage in a digital signal (a number in some representation usable in a computer system).

Photograph of volt meter

These technical aspects are interesting but must not distract from the principle that sensors translate a physical property into a value. The observation type determines the rules for this translation.

Give a sensor picture (geodesy)

Sensor type = observation type

5. OBSERVATIONS OF CONTINUOUS PHENOMENA

Some observations are following a property as it changes in time. If the change in the property and the observations are frequent enough, the observations seem continuously following the signal. In practice, the observations are sampling the continuous signal in a regular interval. They seem continuous, but are discretized (see next chapter xx).

6. OBSERVATIONS AS TRANSFORMATIONS

Observations translate the value of a property at a specific point in time and space into a measurement value. Observations are realized as physical processes that translate the intensity of some property into an observation value, expressed on some measurement scale; observations are always made at the present time ('now'):

```
observation:: world -> observationTypes -> location ->
value
```

The domain of this function is composed of:

- the types of observation agents are capable of; different methods to observe the same quantity are not necessarily equivalent;

- the location of the observation.

The range of the function are values on some measurement scale. These scales need not be numeric and definitely not symbolic. The frequency of firing of some axons is as good a representation of an observation as the voltage level in a wire or the digitally represented values.

7. MEASUREMENT SCALES

Steven has, in a landmark article (Stevens 1946) shown the fundamental properties of the measurement scales. He listed four measurement scales, namely the

- Nominal scale: only the equality between values can be tested (example: names of persons)
- Ordinal scale: values are ordered (example: grades in school, rank in a race)
- Interval scale: differences between values are meaningful (example: temperature in degrees Celsius, height above sea level)
- Ratio scale: ratios between values can be computed and an absolute zero exists (example: temperature in degree Kelvin, population counts, money in a bank account).

These measurement scales correspond to algebras; we often find the roughly corresponding algebras of equality (=, =/), order (<,>,>=, <=), integral (+, -) and fractional (+,-, *, /) (Frank submitted 2005). Other measurement scales exist but are not as prominent or well-researched (Frank 1994; Chrisman 1997). The nominal and the ordinal scale are often called qualitative [spacenet book], especially when the number of different values is small. For example, the size of a garment can be expressed on an ordinal, qualitative scale with the values 'small', 'medium', 'large', 'extra large'. Additionally, one could separate a cyclic scale (for example for measurement of angles) and a logarithmic scale (Frank submitted 2005).

The assumption about the physical properties of the environment in tier 0 result in observations which can always be expressed as continuous value on a interval scale (because we did not make assumptions about the existence of a true 0 for physical properties).

Properties in reality are assumed to vary continuously; therefore the measurement values must vary continuously.

Physical point properties can always be expressed as rational numbers on an interval scale. Post processing of measurement of point properties can convert these to ratio scale by calibrating.

Thresholding may convert measurements to ordinal scales and other operations—often compounding several measurements, translate to a nominal scales (which will be important in tier 2).

8. MEASUREMENT UNITS

Measurements describe the quantity or intensity of some properties at a given point in comparison with the intensity at some other, standard, point or standard situation. Well known is the former meter standard, defined as the distance between two marks on a physical object manufactured from precious metal and kept in Paris. It is superseded today by a new definition, which links to a physical process which can be reproduced in any location, namely a number of waves of light of a defined frequency. The temperature of melting ice is used as the reference point for the ºC scale.

Table 1: The mutually independent SI base quantities

meter (length) m
kilogram (mass) kg
second (time) s
ampere (electric current) A
kelvin (thermodynamic temperature) K
mole (amount of substance) mol
candela (luminous intensity) cd

Observation systems are calibrated by comparing their results with the standard. They are expressed as a quantity times a unit, 3 m, 517 days or 21 ºC. The Systeme International d'Unites (SI) is founded on seven SI base units for seven base quantities assumed to be mutually independent (Table 1). Today, the base units are increasingly connected to constants in nature, especially constant in quantum physics (speed of light, frequency of changes in atomic state [ref heintz]. Before, the cgs-system (centimeter-kilogram-second) was used. For example, the unit of gravity in the cgs-system was Gal, named after Galilei (1 Gal = 1 cm s-2), but newer books refer to the SI standard (m s-2).

For the same kind of observation, different units are used; most important the metric units and the Anglo-Saxon units (which come in imperial and U.S. variants). Practically, conversions are a problem, and a source of many errors, but these are not ontological problems as long as exactly the same property is measured.

The observation of seemingly the same property but suing different methods result in different values, for example the "loudness" of a motorcycle measured in two different countries gives different numeric results. These are indeed observations of different properties. Remember: sensors and measurement procedures define the properties observed. Conversions can be achieved approximatively, as the two observation methods can be applied at the same location and time and the results compared. From sufficient comparable observations a conversion formula can be deduced.

9. Observations of Tier 1 Are Observations of Properties at a Point

Point observations can only yield measurement values for properties at a specific location; they are properties at a point. This excludes many properties used in daily operations: properties of extended objects, for example volume, weight, or value that are not point properties and not directly observable. The same goes for the so called Cambridge properties. A Cambridge property is a device to amuse philosophers [ref]; it is a property of a thing that changes without any noticeable action occurring to the thing. For example, I become a grandfather in the moment my daughter gives birth—without any action on my part. Practically important is that under Swiss civil law, you inherit in the moment of the death of the person you inherit from—and typically you learn only later, that you have become the owner of a large farmhouse your uncle left to you.

The assumption here is that non-point properties are derived from point properties. This tier is only concerned with observable physical properties observable at a point. The points are identified by real numbers, which can be read as indices, names or addresses for points with no assumptions about a structure like a coordinate (vector) space.

10. Observing Change and Causation

The point properties in the physical world are not all independent of each other. Changes in one property can have effects on other properties nearby; this is the foundation for Toblers "first law of geography" [ref]. The laws of physics establish relations between them.

First Law of Geography:
All things influence all things; nearby things influence more.

The phrase "Action X causes Y" can have many meanings: physical (the load caused the bridge to crash), social (a speed limit causes people to drive slower), personal (her request cause me to arrive earlier). Considering tier 1, we focus on the physical causation. For example, a force, which is observable as a point property, "causes" an object to move, i.e. it first causes an acceleration which "causes" the moving, which then causes the effects of the moving, namely a change in location.

10.1 Classification of Point Properties in Static and Derived

The point properties can be classified by considering how they interact. Some point properties affect others or are changed by others.

10.1.1 Static properties

These values do not change in time and do not affect other point properties to change. Example: mass.There are no operations included in the ontology to change this property within the temporal and spatial frequencies in focus. In a relativistic ontology, the conversion of mass into energy according to $e = mc^2$ would be such an operation.

The mass points have an identity, invariable in time; they can change location.

10.1.2 derived properties

Property values can change. For example, the temperature. The rate of change per time unit is a derived property: *dc/dt*. The value of a changing property at *t1* is

c1 = c0 + integratl t0 .. t1 dc/dt

There is a series of derived properties: the flow of heat is the rate of change of the temperature. The laws of physics are preferably expressed in partial differential equations, which connect derived quantities.

10.2 Control

In non-uniform spatial arrangements, a small effect can "cause" a large change. This may connect effects of different spatial or temporal frequency. For a geographic example: an ice dam can melt and release large amounts of water to flow through a valley.

It is difficult to think of such situations as fields – we cast them automatically into an object (tier 2) structure. They are nevertheless physically described by partial differential equations. The conversion to objects brings discretization effects, which often appear as inconsistencies.

10.3 Conservation Laws

Much of what we see as causation can be stated as rules of conservation:

- Mass is conserved (unless a relativistic conversion of mass into energy is included in the ontology)

- Energy is conserved (as well as impulse, but this is seldom necessary to include in the ontology). Different ontologies are constructed when more or less states of energy are considered and what transformations between them are included.
- For most common-sense reasoning, materials are preserved. Not only the amount of mass, but also the type of material is invariant. This excludes chemical transformations and the transformation of chemical energy into other forms (and reverse).

Chapter 10 230 LIMITATIONS OF OBSERVATIONS AND REPRESENTATION

Observations do not give us full, unbiased, and precise information about the world. They are systematically influenced by random errors and technical limitations. This chapter discusses these effects and is of quite technical nature.

Humans need to know the state of the environment around us only with a limited precision and can tolerate errors, incompleteness, and imprecision in the observations. Numerous methods to adapt the level of precision of observations to the need to know. The technical systems that sensors are limited and influenced by:

- Errors of an essentially statistical form, so-called random errors. If the exact same situation is observed multiple times, the results vary slightly.
- Bias and gross erros in the observation system
- Discretization and classification effects in the representation of the results of the observation,
- The measurement is not a point measure, but an average over a certain region,
- Influences of sampling of continuous signals.

1. OBSERVATION ERROR

1.1 UNCERTAINTY PRINCIPLE

All observations are imperfect realizations and imply error. This is in the limit a fundamental consequence of Heisenberg's uncertainty principle, but most practical observations are far removed in precision from the fundamental limits. The uncertainty relation says that the product of uncertainty of position and impulse are larger than h (the Heisenberg constant 6.62×10^{-23} J s/(2 π)), but for objects with macroscopic mass, this is essentially 0; "this is the reasons, that the uncertainty relation is without effect in the macroscopic physics" (Heitz and Stöcker-Meier 1998, 24).

Measuring with precision better than 1 part in a million is generally difficult. Distance measurements with an error of 1 mm per kilometer are demanding, few centimeters per kilometer are standard performance of surveyors today. The best observations are for time intervals, where a random error as small as 10^{-15} is achieved, but the theoretical limit as predicted by the Heisenberg uncertainty principle, would be 10^{-23}. This substantiates the exclusion of quantum effects in our practical approach to ontology: the measurement errors of most precise observations are 10 million times larger!

1.2 Random error

Parts of the error of real observations are the result of random effects and can be modeled statistically. The random errors are assumed to be distributed with an expected mean of 0—any realization deviates from the true value, but if one repeats a measure often enough, the mean should approximate more and more the 'true value' of the sensor (not the true value of the unknown physical point property). The distribution is characterized by the standard deviation, which assumes a Gaussian distribution (Figure 70). Surveyors report measured coordinates with the associated standard deviation, which represents—with some reasonable assumption—an interval with 68% chance to contain the true value.

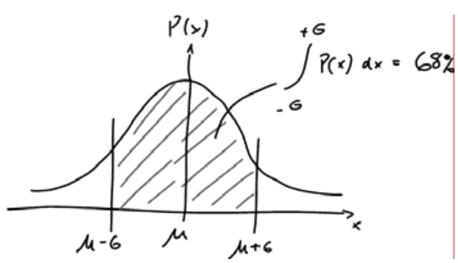


Figure 70: Probability of encountering a value in a certain interval (Kreiszig 1979)

1.3 Gross errors

Observations can be effected by accidents—in biological and technical systems—and errors of the human operator. Such effects are not the result of random process and do not even out when we compute the average of more observations. They can be detected and eliminated through comparison with other independent observations.

1.4 Bias

Bias is a systematic error in the observations; for example if we use a meter measuring rod of 1.005m length all our observations will be less than an unbiased measure. Repetition of observations with the same sensor does not reduce or eliminate the bias but if the calibration of the sensor is known, the bias can be compensated.

1.5 Error Propagation

Error propagates through the computation. The Gaussian law of error propagation approximates the *propagation of random and non-correlated error*; it says that the error propagates with the first derivation of the function of interest. Given a value $a = f$

(*b,c*) and random errors for b and c estimated as *e.b* and *e.c* (standard deviations), then the error on a is following Gauss:

$$e.a = sqrt\ (df/db * e.b^2 + df/dc * e.c^2)$$

An arithmetic system can be extended such that every value is associated with an error estimation. Numeric operations on values are lifted to calculate not only the result but also the estimated error on the result using Gauss' formula (Frank 1998).

1.6 Integration of Measures from Multiple Sources

Observations are often in bundles of measurements, some repeated measures with the same sensor of the same property, but other measures of other properties that are in a functional relationship with the first ones. The functional relationships may then be used to calculate a more accurate value, using the method of least squares adjustment [ref]. Surveyors typically measure more distances and angles between points than necessary to determine point locations. They use for example that the sum of angles in a triangle is 2π to adjust their measurements.

2. Finite Approximation

The results of observations are expressed as finite approximation to real numbers, often called floating point numbers. Geographers often use the term 'resolution' to describe the smallest discernible difference between two intensities, not necessarily one unit of the last decimal. For example, measurements are often read out to mm, which must not be interpreted as precise to the millimeter.

Terminology:
Resolution: the smallest difference that can be differentiated by an observation.
Precision: the standard error on the measurement caused by random error.
Repeatability: the difference between repeated observations with the same sensor.
Xx: unit of the smallest difference after the conversion of an observation to digital values.

3. Instant Field of Vision

A sensor—as a real physical system—cannot observe the property of interest at a geometrical (dimension and extensionless) point, but observes the value for a typically small region—the instant field of vision IFV—and the result is dependent on some (possibly weighted) average in this region.

This averaging is generally beneficial, because it counteracts the effects of discretization of continuous properties in space and time (the so-called aliasing effects see next section). The Instant Field of Vision has the same effect of a low-pass filter, which cuts away all signals with frequency higher than corresponding to the wavelength twice the size of the IFV.

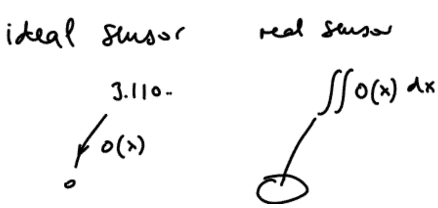


Figure 71: Ideal and real sensor

However, the averaging effect changes the result in a non-predictable way. In general—i.e., without more detailed knowledge about the distribution of the signals in space (or time)—one cannot transform a signal of one IFV to a signal of another IFV.

Figures 230-01 Same figure at different resolution

The effects of instant field of vision are not only in space but also in time. An observation is always taking a small amount of time—in a photograph a fast movement is not frozen, but results in a "smear"—and the result is the average over this time interval.

4. DISCRETIZATION AND SAMPLING

An observation yields different values, depending where and when we observe reality. Some processes change rapidly (in time or in space), others vary very slowly: Observing the height of a mountaintop is (nearly) independent of the time as the value changes only very slowly. Light energy at a point may vary rapidly. Measuring gravity gives very similar results, independent of time or location.

Figures 230-02 230-03

Space and time can be treated equally: some properties change quickly if we move in space (e.g., elevation) and others change very slowly (geology). One can speak of a temporal and spatial frequency in a signal.If we observe a process, then our observations must be made with twice the frequency of the highest frequency in the process of interest, the minimum density to avoid misleading 'aliasing' To avoid erroneous observations, so called aliasing, higher frequencies must be filtered out before the signal is sampled (Figure 19). The averaging in a sensor over the instant field of vision is just such a filter. For example, data collection by remote sensing (figure 9) takes the average value over the area of the pixel and applies therefore at the same time a filter, which eliminates too high (spatial) frequencies.

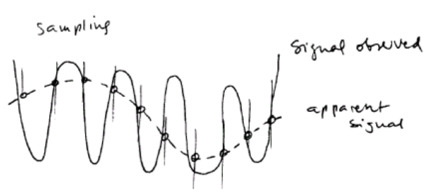


Figure 72 A low frequency signal emerges from a high frequency signal not correctly sampled

5. CONCLUSION

The observations of properties we can make are not perfect. We have seen that the uncertainty principle of quantum physics does not affect directly the macroscopic world with which we deal, but that a number of other influences make it impossible for us to have perfect knowledge:

There are non-avoidable random errors in our observations, but observations can also be influenced by bias in the measurement process and gross errors. Observations are never reporting the property at an infinitely small point, but give the average for a (small) area, the instant field of vision of the sensor.

The transformation of the observation in a digital approximation to a real number introduces further effects that make the result deviate from the true value describing the property at this point.

Chapter 11 CAUSATION

First Law of Geography:
All things influence all things; nearby things influence more.

The point properties in the physical world are not all independent of each other. Changes in one property can have effects on other properties nearby; this is the foundation for Toblers "first law of geography" [ref]. The laws of physics establish relations between them.

The phrase "Action X causes Y" can have many meanings: physical (the load caused the bridge to crash), social (a speed limit causes people to drive slower), personal (her request cause me to arrive earlier). Considering tier 1, we focus on the physical causation. For example, a force, which is observable as a point property, "causes" an object to move, i.e. it first causes an acceleration which "causes" the moving, which then causes the effects of the moving, namely a change in location.

1. CLASSIFICATION OF POINT PROPERTIES

The point properties can be classified by considering how they interact. Some point properties affect others or are changed by others.

1.1 STATIC PROPERTIES

These values do not change in time and do not affect other point properties to change. Example: mass.There are no operations included in the ontology to change this property within the temporal and spatial frequencies in focus. In a relativistic ontology, the conversion of mass into energy according to $e = mc^2$ would be such an operation.

The mass points have an identity, invariable in time; they can change location.

1.2 DERIVED PROPERTIES

Property values can change. For example, the temperature. The rate of change per time unit is a derived property: *dc/dt*. The value of a changing property at *t1* is

c1 = c0 + integratl t0 .. t1 dc/dt

There is a series of derived properties: the flow of heat is the rate of change of the temperature. The laws of physics are preferably expressed in partial differential equations, which connect derived quantities.

2. CONTROL

In non-uniform spatial arrangements, a small effect can "cause" a large change. This may connect effects of different spatial or temporal frequency. For a geographic example: an ice dam can melt and release large amounts of water to flow through a valley.

It is difficult to think of such situations as fields – we cast them automatically into an object (tier 2) structure. They are nevertheless physically described by partial differential equations. The conversion to objects brings discretization effects, which often appear as inconsistencies.

3. CONSERVATION LAWS

Much of what we see as causation can be stated as rules of conservation:

- Mass is conserved (unless a relativistic conversion of mass into energy is included in the ontology)
- Energy is conserved (as well as impulse, but this is seldom necessary to include in the ontology). Different ontologies are constructed when more or less states of energy are considered and what transformations between them are included.
- For most common-sense reasoning, materials are preserved. Not only the amount of mass, but also the type of material is invariant. This excludes chemical transformations and the transformation of chemical energy into other forms (and reverse).

4. 240 DATA—REPRESENTATION

We started with the fundamental assumption that only a *3*-dimensional, temporal physical world exists. Therefore the results of observed values—data—must be represented as *physically observable structures*, within the agent's "mind", or outside of it for communication to other people recording the results as ordinary printed letter forming words on paper are physical signs. These are observable the same way we observe flowers or mountains. It is less evident from our daily experience that the memories in our heads are similarly physical structures of neural tissue that can be observed in very special ways by other neurons.

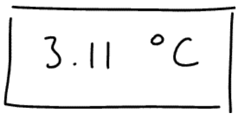


Figure 73: The representation of the result of a temperature measurement

The approach used here is based on the assumption that observation and processing of information in a human mind or in an electronic system is essentially similar: in both cases, observation values are represented internally in some physical form and transformation of such physically observable signs into other signs and eventually into actions of the agent. Cybernetics as a science introduced the belief that human minds and computer systems are comparable over 30 years ago (Wiener 1961), but for various reasons, more efforts concentrated on demonstrations why this could not be the case (Dreyfuss 1972; Fodor 1984) than explorations of the obvious similarities. This is not to claim that no differences exist, that differences where minor, or that the computer model could explain all of human thought. After all, computers are very fast (mainly) single stream processors, whereas the brain is a relatively slow but massively parallel process. I am only assuming that all thought processes are connected with physical (neural) processes in the brain and that all storage of previously observations must be connected with matter.

Observations transform physical properties of the real world into data, but what are data? Data are representation of measurement values encoded in some physical form. Data cannot exist without a physical substrate onto which it is encoded and a context in which it is meaningful. In this chapter the concept of data, signs, and information is discussed—always restricted to the results of observation of physical point properties. It concludes with a first answer to the question that for me started this investigation 30 years ago: Why do signs mean something? How do signs carry meaning? What is information?

5. Sensor Systems Transform Properties to Data

A classical physical instrument—now only found at a museum—observes two properties of the ambient environment: it measures temperature and humidity of the air and translates the measurement values into a blue mark on a roll of paper. The individual measurement value is encoded continuously as a distance from the base line (Figure 74). Similar modern instruments are electronic, which observes some environmental variables, e.g. temperature, humidity, and visibility on an airport

(Figure 75) and translate the result into a digitally encoded value stored in electronic memory chips.

Figure 74

Figure 240-01

Figure 75

Photo of air condition sensors – or something similar – e.g. from a museum?

The recording devices attached to the sensors transform different physical properties—the properties they are supposed to measure—into a single set of physical properties. The apparatus from the museum transforms the properties of the ambient air into two signals each represented as a black line on paper (fig x2). Modern instruments translate the observed properties into digitally readable changes in a computer memory. In both cases, different physical properties at one location are transformed in a single type of signs, which can be observed and act upon in the same way, independent of the specifics of the physical properties they represents. This permits to act on multiple different properties with a system that combines physical signals of only one kind, makes observation.

Recorded measures make them available for later inspection.

Representation of observations allows the inspection at a time later than when the observation was made!

6. Encoding of Data

The result of observing (sensing) a property of the environment is translated into some other physical property where there are fixed rules for the translation from value to physical signs. Corresponding rules must be used while encoding and decoding of signals. To understand what a stored value means I have only to see what property is current—observed with some other sensor—when the actual reading of the sensor is the same as the one recorded before (Figure 76).

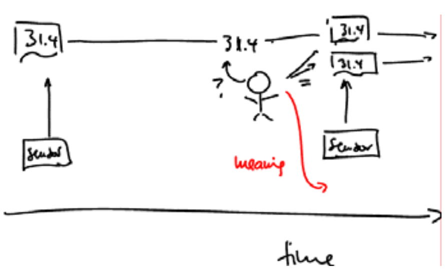
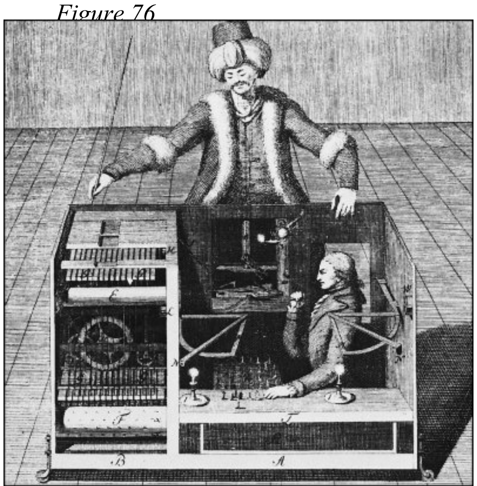


Figure 76



7. Data Processing Mechanism

The standard view of computers science sees information processing mechanism (computers) as systems that have data inputs and produce data as output (Figure 77). The internals of the computer are not important, except that we know that they consist purely of physical process and no human mind is hidden in it; there are no dwarfs hidden, as they were in the famous chess playing automaton of the 18th century (Figure 78).

The encoding and decoding of measurement values is independent of the processes that transform values according to some rules into other values. The transformations are preserving all important properties of the measurement scales (point of zero, order, proportion, etc.). This independence of data processing from the measurement process and the encoding makes it possible for computer programmers to understand the workings of the computer at a very high, very abstract level. Hardly ever do questions of encoding and translation between encodings enter in their focus. In practice, data is converted many times from different representations during simple operations: from the magnetic encoding on a disk to a time sequence of voltage signals on a wire to a parallel multi-bit signal on a bus and then goes into an encoding in a solid state memory etc. etc. For the purposes of data processing, the encoding and decoding steps can be neglected; the result is as if there was only one single encoding as floating point numbers.

The processing of data is guided by programs that determine the connection between inputs and outputs. Taken in isolation, data processing is useless; it is only of interest if the data processing is connected to the environment, for example in an agent

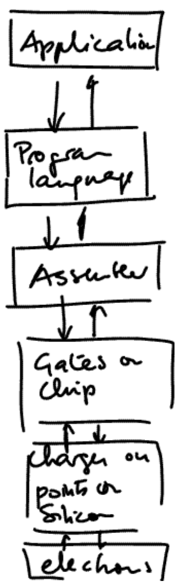


Figure with layers
Figure 79

8. Integration of Data Processing with Sensors and Actors

Simple examples for a system that uses sensors and some (minimal) data processing and is connected to the words are temperature control systems in rooms (Figure 79). The goal of the system is to keep the temperature constant; they sense the actual temperature in a room and switch on the heating system when the temperature drops below a limit. If the inputs indicate that the temperature is lower than desired, the output gives a signal that heating is necessary. This is a simple reactive agent.

Simple animal reaction to stimuli can be discussed in terms of simple reactive agents, which are agents that have some sensors to observe properties in the environment and actors to act on the environment, but do not have extensive internal states. For example, the process of reaching with the hand for a fruit by a chimpanzee or human, relates an observation of the distance and direction between the hand and the target.

A simple reactive agent can be realized with an analogical or a digital processing of the measurements obtained by the sensor. The vehicle (xx) can be constructed by direct wiring of light sensors to the motors. Most temperature sensors before 2000 were analogous. Today, they are replaced by computational systems, because the production of digital components is today less expensive than the production of analogous devices.

9. MEMORY—STORING OBSERVATION VALUES

Humans can remember observations made before and combine previous observations from different epochs and compare these with current observation values. Cognitive agents that model capabilities of humans must be able to store observation values and retrieve these when necessary. These operations are not problematic and technical implementations abound. The exact nature of the neural counterparts—memory function in the brain—is less well-understood. It seem to be divided into at least short term and long term memories [ref].

The ability to store results from observations (remember: observations are only possible at the current point in time) is a first crucial step to agents that can adapt better to their environment.

The computational model of memory requires that the measurement value obtained from an observation is stored, together with the context in which it was taken. Measurement values devoid of context are useless! Only when we know when and where an observation was made and what sensor was used, it can be used to make some decision about an action.

```
Store:: obsValue -> obsType -> time -> location ->
store - > store
Retrieve :: obsType -> time -> location -> store ->
obsValue
```

For such functions, there need to be internal representations of location and time; no particular assumptions are required except that all observations made at the same time (with a resolution appropriate for the case) are stored and retrieved with the same time value. The time values are also ordered, such that memory preserves the order in which entries were made. All observations made at the same location at the same time are coded with the same location code. It is not necessary that observations made later while revisiting a location are given the same location value than the observations stored during the previous visit.

Time as a succession of events (ordered—single order for an agent) Location along the path the agent takes (it can be only one place at any given time).

10. LEARNING REQUIRES MEMORY

The ability to acquire new information and to store it for later use in decision making can be seen as a form of learning: agents with complex internal states change in time. Previous observations may influence later decisions. This is a form of learning—information about the environment is accumulated.

This simple form of learning as acquisition and accumulation of observations is a fundamental aspect of memory. It must be clearly separated from any form of abstract learning, where from multiple observations general, abstract rules are deduced. Such advanced learning is essential to use memory capacity better and to improve decision making: many detailed observations are replaced by a single rule. How it is achieved in the brain is presently unknown; a possible model will be described later (xx theory theory).

Memory gives perdurance in time

11. TWO TIME PERSPECTIVES

Memory is not representing changes in the outside reality instantenously; some time passes between a change in the world and the change in the internal representation. (time lag). This introduces two time perspectives (Codd 1991; Snodgrass 1992)

- World time: when did a change occur?
- Memory time (database time): when did we learn about it?

12.CONCLUSION

The ability to transform observations to representations together with indications of the context in which the observation was made is a crucial step.

We have seen that representation of observation values is physical process that produces physical artifacts in the environment. These are observed with the same physical processes we use to observe other parts of the environment.

Representation of observations allows to escape the tyranny of the *now*. Observations are only possible at the current time and the current location, strictly speaking (the observation of the light here gives often the illusion that we observe at a distance).

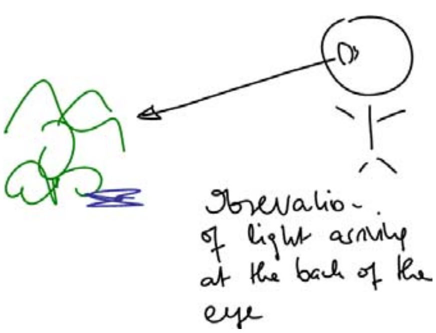


Figure 80

PART FIVE 300 TIER 2: OBJECTS

The construction of objects with which we interact from the field of observations is *the* break line in the ontology. The physical reality operates by local interactions between neighboring material elements, but this is not how we see reality. Humans perceive the world as a world of objects; we understand ourselves as distinct, separate objects from other people and from other things. We see relations between and interactions with these objects. This tendency to form objects we share with most higher animals. The conversion from the observation of properties at points to our perception of objects occurs mostly without conscious efforts; it is fully automatic. This tier 2 analyzes in detail how we construct material objects from point observations.

This part describes first objects in small scale space, which is defined as the subset of space-time in which humans move objects around (see def. xx). The prototypical example is a table set for dinner. Montello has labeled this space as figurative, stressing primarily the perceptive situation (Montello 1997); my focus here is on the interaction.

Picture Figure with the tree - 4 versions (stomp, table, chair, outlook)

The situation in small-scale space is simpler than large scale space which will be discussed next part. The rules constructed during interaction with small scale space serve as prototypes from which specific rules for geographic space are derived.

This focus on a specific situation and the applicable operations is necessary to deal with the temporal aspects of ontology. The chapters build different subdivision of the world as relevant for certain operations; we consider each of those as a special ontology.

Figure 81: Photo of neighbor's dog, cat Tiger, horse Antares

Tier 2 assumes no communication or coordination between agents; the next break line in the ontology is when agents communicate and cooperate (see tier 3)!

1. The Two Viewpoint of Tier 2:

It is possible to construct a 'vehicle' in the style of Braitenberg that forms concepts of physical objects. Braitenberg did not consider such models but concentrated on tier 1 agents, which observe properties at points in space. The tier 2 agent is patterned after a small rodent, say a mouse: Micky, which feeds on red colored round fruit and escapes from smelly, black cats in small black holes (Figure 82). The visual system of Micky cannot just react to red light, but must consider the red color and the form to identify a fruit. To detect cats it uses a combination of color and smell. Micky must also detect the holes in which it can hide and which protect it from cats.

Figure 82: Environment and mental map of Micky

It is possible to explain such behavior and to build a model directly from the observations of properties of points, but it is more economical (Sen 2000; Roth 2003) to organize the internal knowledge of the rodent in terms of fruit, cat and holes and locations where such are found, how cats move and how it can move. This example shows the two perspectives:

- The objects of the world Micky identifies.
- The rodent Micky as an object (seen from others) and from himself.

The following chapters will discuss how the agent conceptualizes the world. The discussion in this part is limited to the operations performed and excludes intentions. The question why Micky does this or that; i.e. goal directed behavior, decision making, and free will will be addressed in the next part.

2. Objects as Areas of Uniform Properties

Physical objects are extremely real for the human cognition. They are manifest in very similar form in different modalities of our sensing the world. We can see, feel, move, sometimes smell and hear objects; this plurality of confirming observations gives the impression of reality.

The philosophical tradition assumes the existence of objects in the environment. To connect object formation to the observation of point properties is important to the analysis of error and uncertainty (Burrough and Frank 1995; Burrough and Frank 1996). Pragmatically: objects are defined as areas of uniform properties and constructed in the agents mind.

The properties that must be uniform for an object are related to the possible ways of interaction with an object. Depending on the property, which is uniform, and the operations that are considered, very different types of objects are formed and these objects follow then different ontological rules. The properties, which are fixed to determine uniformity, can be used to define a topological, a morphological, or a functional unity (Guarino and Welty 2000). This permits that a given piece of material is part of or forms different objects: a tree trunk is (1) a tree trunk, (2) a table to serve drinks, (3) a seat to rest on, etc. etc. (Figure 83)

Figure 83: Photographs

In analyzing the ontology of objects, I will first concentrate on solid objects on a tabletop and consider only movement as an operation. This is essentially the ontology of AI toy systems like SHRDL (Barr and Feigenbaum 1981), a world of blocks on a flat support and corresponds to the ontology of the robot, used to manipulate the blocks.

Picture of robot

3. VERBAL DESCRIPTIONS NEED OBJECTS

Insert a repro of some art which shows this (expressionist?)

It is difficult to speak about reality but not to assume that it is divided into objects. The text describing the tier 1 ontology is stilted, always talking about properties observable at points and carefully avoiding the term object. It also required the introduction of the observing agent, which is clearly an object and described in the terminology of tier 2. This problem does not appear for the visual arts or for music, dance, etc. It indicates that *language* presupposes this 'objectivication' of the environment that an objectivication occurs when we discuss a situation verbally. The properties and the observation of properties in the world were relegated to a separate field, the discussion of "qualia" {Heckmann, 2005 #836}.

Language leads to objectivication.

Traditional ontology was primarily concerned with the ontology of the things we speak about: the cat Tibble and its tail, Burridan's ass, etc. Tibble and Buridan's ass are objects. Aristotle assumed that ontology 'cuts the world at its joints' into natural kinds, which exist independent of the observer (Smith 2001). This division of the world in objects is 'objective', there seems only one way. This is not justified for geographic objects: the same location can be in a watershed and a forest, but watershed and forest have different boundaries. Multiple ways to subdivide the world are used in geography, but as well in medical ontology (Grenon, Smith et al. 2004) see (xx).

Different agents can 'see' different parts of the physical reality, observe different properties, but if they observe the same properties they obtain the same result. The observation of physical properties in tier 1 was in principle ‘objective’ and order between property values was preserved. Two agents may differ in the name for a property, but not in their quantitative ordering of observations values. This is the foundation for integration of different ontologies.

This is not the case for the ontology of physical objects in tier 2: different agents have different forms of cutting the world in objects. Different agents can construct different tier 2 ontologies from the same physical observations. The ontology of the rodent Micky above is different from the ontology for a cat in the same environment: the cat will not differentiating red fruit from other similar objects and identify human bodies, some of which are friendly (and are useful to open cans of cat food!).

Picture a farm with animals?

4. Objects Are Visible and We Interact with Objects

Humans carve reality into objects according to the current needs. The task a human agent tries to complete at this instance determines how objects are identified and classified. An ordinary tree stomp can be seen as a table, a seat, or platform to stand on (figure 3) depending on current needs. The effect is like the one with the Necker cube (after the Swiss crystallographer L.A. Necker): one can see a cube or a corner, but one at a time. Humans 'see' objects with respect to their potential for interaction with them (Gibson calls this 'affordance' (Gibson 1986)).

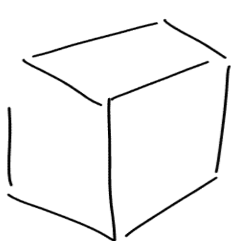


Figure 84: Necker cube: A corner or a cube? (see also http://www.cut-the-knot.org/Curriculum/Geometry/Necker.shtml)

Agents, especially in the normal tabletop environment, act on the environment by exerting pressure on a point. The effect is a change in the location of the object; and this is the change intended. We usually do not say 'I will press on this handle' but state 'I close the drawer' (Figure 85). The actual forces exercised on an apple to lift it off a table and to move it to a different location is quite complicated—but we fortunately need not think of it and become aware of the details. All the transformations from tier 2 operation 'move apple to the plate' to muscle tension and pressure applied (tier 1 activities) are automatic and do not enter conscious thinking. When we program a robot to execute the same operation we discover how much detail isimplied.

5. Physical Objects Have Properties

Figure 85: Photo drawer

Figure person grabbing apple

Properties create theories for object classification

The combination of seeing objects and interacting with objects confirms their 'existence' in multiple ways through different senses. This increases the feeling that 'objects are real'.

Objects have properties and most of these properties do not change with time. This makes reasoning about objects so much simpler! Objects preserve invariants in time and object formation is therefore a method of human cognition to reduce the complexity of the world. Areas of uniform properties are grouped with respect to potential interactions. The most salient examples are solid bodies, which preserve form, volume, material, weight, color, etc. Point observation is transformed to object attributes of objects, typically integrating specific properties (e.g., specific weight) over the volume of the object. The geometric form of a solid object remains invariant under movement. It is best represented in a coordinate system fixed with the object, a vector that indicates the location of the object, and an angle of rotation; from this coordinates in an exterior system can be deduced for any position of the object (figure) {Frank, submitted 2005 #809}.

We will use abstract concepts, like boundary, centroid, etc. to describe conceptual aspects of physical objects. These abstract concepts do not have physical existence and are not subject to the laws of physics. For example, the intersection point of two straight lines may move with speed higher than the speed of light without violating a rule of relativistic physics.

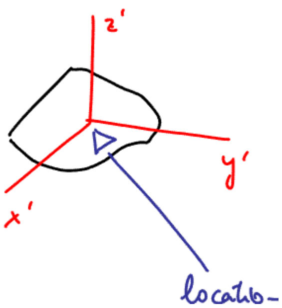


Figure 86: The geometry of an object is described locally

6. Focus of this Part

In this tier 2 the discussion concentrates on objects of the physical world and how they are constructed. We are concerned with carving the space-time fields in some pieces, for which we will use the term '(physical) object' and discuss the properties of objects and their perdurance and identity in time. This excludes abstract ideas, social construction, etc. are not included; 'headache', 'democracy', or 'marriage' etc. are discussed in tier 3.

The approach here is dynamic: operations change the state of the world, therefore change properties of objects. The operations induce a subdivision of the world in objects; operations subdivide the world in sets of objects to which these operations apply. These groups of objects are called classes.

These small theories can be combined. The approach to define objects simply as *areas of uniform observable properties*—avoids the difficulties in the foundation classes of ontologies. Guarino and colleagues have compared several ontologies and found conflicts and hidden assumptions, which made comparison between the ontologies and transfer of knowledge integrated in one ontology to the other difficult (Guarino and Welty 2000).

Traditional computer science and AI approaches to ontology are mostly taxonomies (Latour 1987; CYC 2000; ONTOS 2001). They describe a static world and produce a taxonomy of objects based on their (static) properties. Properties of objects determine their affordances, which connect object classes to operation.

Figure 300-02 ball identified on grass (photo)

The part is divided in a first set of 5 chapters that discusses the prototypical object formation situation, namely small objects with sharp boundaries on a tabletop. The human interactions with the solid bodies in the tabletop environment are ubiquitous and prototypical for our understanding of objects.

The large class of geographic objects, which are typically unmovable and not physical themselves, but constituted by other physical objects (a road or a forest is an area of space, not a physical object) will attract our attention in the next 3 chapters. The concluding two chapters summarize the approach and show how it is used to construct formal ontologies.

Chapter 12 310 Prototypical Object Formation in Small Scale Space: Solid Objects with Sharp Boundaries

Figure 87 picture – table top space

In this initial chapter we discuss the prototypical situation for the concept 'object': small objects that can be grabbed with the hands, moved and put on a table (Figure 87); these are the kind of objects with which small children have initial contact and which serve to inspire a theory of objects (Gopnik and Meltzoff 1997; Gopnik, Meltzoff et al. 2001).

Picture of children and toys (ask twaroch)

The central question for objects is how they are delimited and how their identity evolves in time. Consider the tabletop space (Figure 87): The applicable operations to change these situations are used to construct mini-ontologies (theoritas as Casati called then (Casati 2001)). For each mini-ontology the:

- definition of objects by uniform properties,
- properties of objects,
- identity of objects

are different. We will see that the selection of an attribute and how it is changed determines the ontology. Mini-ontologies combine to model complex situations.

1. Small Scale Space Experience

Human experience can be divided into experiences in small scale space and experiences in large scale situations (Zubin 1989). Small scale space is characterized by a layout that can be perceived with a single glance; objects are smaller than human beings and can easily be moved (Figure 88).

Figure 88 table top with fruit bowl

Experience in small scale space primarily takes place with movable objects that have sharp boundaries; other types of objects, without well-defined boundaries, exist, e.g., fluids, grains, balls of cotton but are not considered as prototypical. The generic properties of prototypical objects and the interactions with them can be analyzed, e.g., the handling of a fruit. What operations can be performed? What attributes of objects change and which remain invariant?

In small scale space we observe the effects of gravity on objects as weight, but the mass of the objects is typically small enough that we have the impression that acceleration is immediate and movement is with uniform speed. This is a substantial simplification from Newtonian physics to a naïve physics.

2. OBJECTS ON A TABLETOP

A table set for lunch, but before food is served, contains numerous objects. Objects are lumps of material that hang physically together when moved, which form rigid bodies and are not attached to others. We will use the term *solids* for such objects. The boundaries of these solids are identified when we move the object—all what goes with the object is part of it. The form of rigid objects remains the same independent of their position in space. The solids on a lunch table, before any food or drinks are served, have all well-defined sharp boundaries.

Figure 89Picture of object moved

Figure 90- some addition

The discussion here is always in terms of *individuals*, the fork (meaning this fork here on this table), the plate and the glass here; sometimes 'a glass', meaning any glass, but again, an individual (Figure 91). Classes of objects will be discussed in the chapter 320.

Figure 91 breakfast table

3. OBJECTS ARE DEFINED BY UNIFORM PROPERTIES

Objects are defined as spatio-temporal region of some uniformity in a point property. The uniformity can be in the material type, in what moves jointly, etc. Tabletop objects are typically delimited by what forms a solid body, what moves together. This often (but not always!) coincides with uniformity in color, texture. The frequent coincidence of material and visual uniformity in point properties permits to identify objects on photographs. The expectation of coincidence of visual and mechanical uniformity can be used for tricks: solids can be hidden from visual detection by blending in in the environment. Animals and plants use mimicry (camouflage) to disappear visually, and people use it to hide secret doors (Figure 92).

Detection of uniform property values gives objects

Figure 92animal with mimicry

Examples for objects on the tabletop are the glass, knife, piece of bread, etc. We will see that the 'objects formed by uniform property' rule applies as well in other situations: In the cityscape, objects are the buildings, the persons, and the cars. In the landscape: forest, lakes, mountains and roads are all objects with some degree of uniformity in a property and boundaries of varying degrees of sharpness (Burrough and Frank 1996). A TV camera observation of a limited field of vision produces about 200,000 observations of light intensity in compression algorithmus (e.g., JPEG) reduce the redundancy due to autocorrelation. The observations of the environment are strongly *spatially autocorrelated*. Observations near to a given observation are most likely similar, both for observation spatially near or temporally near (Goodchild 2001). Most of the world remains the same and only few things in the world are changing, and these require our attention—both in our cognition as in a geographic information system (a restatement of Tobler's first law of geography) (Frank 1998).

4. Classification of Property Values

In order for things to have uniform properties, the properties must be classified and small variations in reality or by the errors in the observation process ignored. The classifications can be applied to values that are the result of some computations, combining multiple values; for example, to detect areas that are connected, one can observe direction and speed of movement; the same result would be obtained with a static analysis of the resistance to stress and strain, which indicates where a collection of material bodies will separate. Ultimately, the classification results in a binary result—a point in space or time is part of or is not part of an object but there are many classifications possible which yield different objects.

5. Attributes of Objects

Objects have attributes. For the object on a lunch table, attributes like weight (measured in grams), length, width, height are important.

One or more point properties (i.e., properties that are observable at a point) are used to identify the region of uniformity in this property (or properties). Other point properties can be summarized for the region of uniformity and result in an attribute value of the object. For example, the weight of an object is the sum of the weight of its material. (Egenhofer and Frank 1986). Attributes derive from point observations by integration: integrate along a path, integrate over an area or over the volume included in the boundary. Purely geometric attributes are obtained by integrating a constant function; for example the volume obtains by:

$$Vol = \int_{obj} 1dx$$

The word property is used for the physical properties observable at a point and the word attribute for 'properties' that objects have. Properties integrated over the volume of the object give object attributes

Example for object attributes:

- Mass is the result of an integration of the specific mass over the volume of the object.
- The weight is the integration of the product of local gravity times local mass; for practical purposes, the weight is the mass times the gravity;
- Properties integrated over the surface area, for example, the heat loss of an object is the sum of the heat loss over the surface.
- Moments of inertia, which we experience as a feel for the way the object sits in our hand when we move it, are integrals over the volumes.
- Surface is the integration over the boundary of the object.
- Color is the light reflectance value at the boundary.

Figure

6. PROTOTYPICAL OPERATIONS

Operations change the state of the world; they change point properties in some spatial region over a determined interval in time. Other properties remain invariant during such changes.

Operation determines which properties are selected for object formation.

The objects on a lunch table afford the operation of *moving*, *grabbing*, *picking up*, and *setting down*. They have a sharp boundary which is a *2d* surface in *3d* space, whereas the object itself is *3d* in *3d* space. The boundary of rigid objects does not change when the object is moved.

Some solids, but not all support other objects, which can be set on top of them (Figure 93). Most of the objects on a breakfast table have a determined base on which they rest in a stable equilibrium; this base determines the upright axes of the object (going through its center of gravity).

Figure 93: Plate of strawberries

Some objects have holes, they can be filled and a liquid can be poured from them and can serve as containers; glasses for example.

Figure 94: Photo of three types of holes

Sketch with holes – Casati and Varzi holes

Operations that are linked together affecting the same properties form theories (theoritas (Casati 2001)); they are represented in the computational model as algebras. Operations that are not affecting the same properties are not directly related. They may be related when one of the properties in the first set through some physical laws affect a property in the second set. (See causation xx).

7. OBJECTS ENDURE IN TIME

Physical objects endure in time (Figure 95). Physical objects maintain their identity from begin to end—even a grain of salt has an identity, which is lost, when it is dissolved in the soup. The objects are initially created and have then a fixed form and a number of other physical properties, which they preserve till they are destroyed and stop existing. Objects may undergo slight alterations, for example a cup may be chipped and therefore some of the properties are changed (less volume, less mass, different form), but the essential aspects—a gravity container—remains. If a glass shatters in many pieces, we say it is destroyed. A plate can brake in two pieces and the pieces glued together again.

The law of preservation of matter applies: objects are created from matter available in some other form and the matter becomes available again after they are destroyed. The ordinary ontology considered does not include the creation of physical matter! We call the conditions under which objects emerge and disappear—only the object, the form emerges, not the material—the object lifestyle {Medak, 1999 #393} (see later xx).

Figure 95

The concept of physically observable object is a generalization of the material object, which endure in time: the piece of bread on my table now (figure xx) will remain a piece of bread even 5 minutes later and many of its properties remain the same (they are invariant with respect to short intervals of time but over longer time periods the bread will dry out and lose weight!). The stable identity of objects is modeled in an information system with a (stable) identifier, which replaces the combination of properties which make each individual physical object different from all others.

Objects are "worms in four-dimensional space" (Quine 1977). Objects can be seen as functions from an identifier, an observation type and time to a value (formula xx). Objects are formed such that many properties remain invariant, primarily invariant with respect to time but also with respect to other operations.

```
attribute :: id -> time -> obs -> value
```

In the computational model, the objects are represented by their unique identifier.

8. Euclidean Geometry Follows from Small Scale Space Experience

Experience in small scale space leads directly to the abstraction in Euclidean geometry (Lakoff and Núnez 2000). Euclidean geometry is structured after the experience with rigid, movable objects, i.e., objects that allow solid body motion. The classical geometric instruments, ruler and compass, are rigid objects, which are moved in space to produce marks where they are placed. Theoretical investigations demonstrate that the requirement of 'rigid body motion', meaning that material objects can be moved around without change of shape, leads to a class of geometry of which the Euclidean geometry is the simplest case (curvature 0) and respects our daily experience with relatively small objects at rest (Adler, Bazin et al. 1965) .

Small scale space is by itself static—nothing moves until a force is applied and our perception is primarily one of static situations. Changes are brought about swiftly, nearly instantaneous, things are moved from one place to the other without consideration for the path nor the time the move requires.

Of particular interest in our context is the aspect of a sharp boundary: if an object can be moved, its boundary is determined by lifting it up. What is moved is the object, what remains is not part of it. The boundary that might not have been clearly visible at first is sharp and becomes determined when the object is moved and can be measured with any precision desired.

9. Non-Solid Objects

There are also experiences with other things that have not all properties of solids. Some classes of unbounded objects are so fundamental that they have found expressions in language, for example liquids and other 'mass nouns', like 'sand', 'flour', etc. They do not identify objects but an indefinite or measured amount from a particular material. Words like 'water', 'sand', etc. usually do not have a plural form and languages often have particular constructs to indicate an amount (linguists call it partitive). Objects that are not solid do not have a determined form; they fill containers and assume the form of the holes.

Liquids are materials with viscosity around $10^{-3} Pas^{-1}$ (Hayes 1985)
From an experiential point of view, objects are a basic experience of small scale space. Object identity and sharp boundary, invariance of shape and properties under movement etc. are the most salient characteristics of objects.

10. Measurement of Distances and Angles

The distance between two objects relates to the experience that another object may fit between them, or the experience of failing to move an object between them. The distance between two objects is equal to the size of the largest object fitting between them. When we measure the distance, we integrate along a path, an imagined linear movement.

Distance is additive: if an object fits between two other ones, then the two pieces resulting from splitting the object in two still fit. The length of the two pieces together is equal to the length before the splitting (Hartmann and Janich 1996). Angles measure turning, another movement.

11. Instances of Objects and Actions

Human language does not clearly separate between object classes and object instances. If confusion is possible, I use *class* for *object class* and *individual* for an *object instance*. Only individuals exist physically—the horse Antares is a physical object (Figure 97), the class horses is a general concept, describing physical objects, but the class is not a physical object itself.

Figure 97: Picture Antares

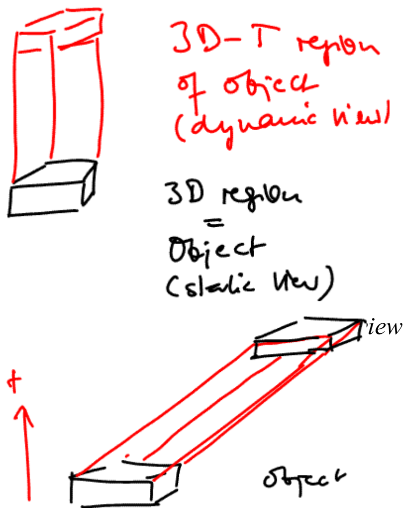
For actions, only the single instance of carrying out an action to a specific individual at a specific time and location is physically occurring. I can move on June 29, at 12:13 the spoon from the small plate into the coffee cup (photo), this movement is an instance of the action movement.

Instance of a move

Languages typically mean an instance if we report about actions: "Peter walked this morning to the office" or command somebody "Walk to the blackboard!" The general action "walk" is meant when we make general statements ("walking is good for your health"). Objects have only one kind of instantiations: horses in general and then Antares, but actions can be partially instantiated: "I walk to the office every morning" is neither fully general, nor completely instantiated—it describes a set of 'walking to the office' occurrences past and future; again, this set is not a physical object.

	Instance	*General*
	Physical	*Abstract*
Object	*Individual*	*Class*
Op	*Instance*	*Operation*

Instances of objects and actions are spatio-temporal regions. Objects that continue unchanged and unmoved in space are the result of an action 'do nothing' that projects the current spatial, *3* dimensional, region of the object into time, leaving location and everything else constant (figure).



Movement of object is uniform regions

The spatio-temporal region of an object at rest is a *3D-T* region with uniform property. Other actions are defined similarly as *3D-T* regions with some uniform property. For example, the region in which an object continuously moves is a *3D-T* region in which the translation vector is everywhere the same. Other actions are uniform in some other properties, for example heating gives an approximatively uniform increase in temperature per time unit.

We see that objects and actions are at this level of abstraction *3D-T* spatio-temporal regions. Objects are in a sense special kinds of operations, namely the continuation of identity in time.

12. Summary

- The object has an *identity*; each object is an individual and is differentiated from any other. The identity of an object is immutable during the lifetime of an object (Al-Taha and Barrera 1994). We typically speak of classes of objects that have similarity, but this is already a second level of abstraction.
- The object has some properties; attributes are not dependent on its current location (*invariance of properties* under movement).
- A solid object has sharp boundaries and a *geometrical form and size*, which are invariant under movement.
- A solid object *can be moved* around and remains where it is until it is moved (this is known as the 'frame problem' in artificial intelligence (Hayes 1985))
- Solid objects can be joined: Two similar objects are twice as long (or high) as a single one.
- Solid object cannot be placed at the same location where there is already one.

Chapter 13 315 THE FIRST SMALL DYNAMIC ONTOLOGIES

In this chapter, three small ontologies for physical objects in small scale space are described. The focus is first on movement of objects (m-ontology); then the effects of gravity are considered (g-ontology) and thirdly, merging objects or cutting objects in two is studied (l-ontology). (Figure 98).

Figure 98: Loaf of bread

ontology	operations	image schemata
s-	(physical) is existence	object
m-	move	path
g-	gravity	surface, support, platform, contact,(gravity) container
l-	merge	link
c-	open/close	blockage, part-whole

These ontolgies build one upon the previous one in a defined way. They relate to image schemata, structures that linguists have found to be fundamental for our thinking (Lakoff and Turner 1989) (see chapter 340). The chapter is based on two types of commitment:

Tier 0: the commitment to a space-time continuum and observable point properties for each space-time point.

Tier 1: agents can observe properties and change through activities these properties.

Tier 2: the commitment to a concept of physical object with permanence, identity and invariant and changing attributes.

1. SPATIO-TEMPORAL ASPECTS OF SOLIDS

The static view of the tabletop world divides spatial regions of uniform properties into objects. This is a useful and statically valid simplification and can be used to establish taxonomies of objects based on some of their properties; this static view has been called the SNAP ontology (Grenon, Smith et al. 2004).

A dynamic view, a view that considers the world as a space-time continuum with changing properties and active agents needs a different definition of object, namely as a region of space-time with uniform properties. This gives objects (solids) which continue to exist in time and at any moment of their existence occupy a spatial region. Objects seen as continuing in time are spatio-temporal worms. This can be called the SPAN ontology (Grenon, Smith et al. 2004) [more refs missing]..

Figure

There are a myriad of different ways to identify a property and to define objects as uniform regions. Depending on the property selected, different objects result. Most of them would not be considered as objects in a common-sense view (see story of Martians xx). We construct ontologies such that many attributes of objects remain *invariant*.

2. Attributes and Operations to Change Them Create Theories

There is a theory of weight and a theory of color. The theory of weight of an object is the theory of the rule of preservation of mass combined with the theory of (nearly) uniform gravity in the world, which predicts that (roughly) *mass x gravity = weight*, which then leads to theory of preservation of weight: if we divide an apple in four pieces, the sum of the weight of the pieces is the same as the sum of the apple before cutting (fig).

Figure 99

The theories of attributes are mostly quite simple; they predict preservation of an attribute over time: the weight of an apple will be the same as now in the (short) future, color of the bread will be the same in the (short) future. For longer periods, more complex theories are necessary: the apple will slowly dry up and evaporate water and become lighter; bread may be attacked by mold and change color (Yuk!).

An example for a more complex attribute theory is the theory of the geometric form of an object. Axioms for the relations between points, lines, angles, etc. were originally stated by Euclid (Fuller and Prusinkiewicz 1988).Operations are functors preserving attribute theories: for example, the movement of an object leaves its weight or color invariant. The operations are transformations from one state of the world to another state of the world such that the axioms of the theories of weight or color remain. Mappings that map objects and operations, such that the axioms of the operations are preserved are called functors (see {Frank, submitted 2005 #809}{Goguen, 1991 #837}). Different ontolgoies can be merged, because the attributes derive from observable point properties, for which physics gives an exhaustive list of independent scales on which Rule about overlap from space time to snapshot: (gis theory)observations of point properties can be expressed.

3. Universe for the Small Ontologies

In the ontologies (focus) the universe considered is a delimited part of space-time. The space is fixed and the time is also fixed; the space-time block is the Cartesian product of the two (Figure 100).

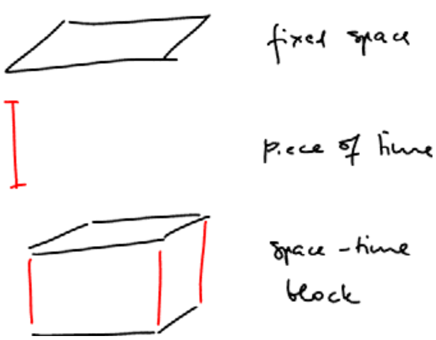


Figure 100: Space time universe

The space-time universe has observable properties for each point in space-time. The properties of interest for the present discussion are the values of the material constants: (specific mass, elasticity, viscosity, color, etc.).

For simplicity we assume in the examples that only the material wood, copper, iron, and air are present and that the universe is closed, i.e. nothing enters or leaves through its boundaries. The initial conditions are Figure 101. The iron cube, the wood block, and the copper plate are solids and cannot overlap (following commitment xx). The air is the residual object, not a solid; the solids and the air are all material objects.

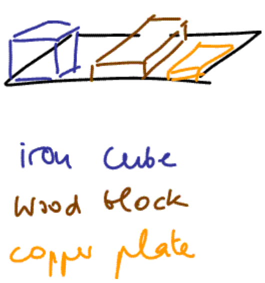


Figure 101: Initial condition

4. Static View: The Ontology of Solids at Rest

A projection of the space-time block gives a snapshot in space (Figure 102). In it we can identify regions of uniform property, which we will call m-objects (or objects when the reference ontology is obvious); a 2-d cut through them is (Figure 103) (formally this is a projection of a projection) and we identify the four regions of uniform properties cube, block, plate and air (note that the air region is connected, only in the *2d* cut it appears in two pieces).

The subdivision of the snapshot in areas of uniform properties gives non-overlapping objects in space-time and therefore in any snapshots.

In the universe considered, the subdivision in regions can use any of the point properties listed above as material properties, because these properties are assumed here as fixed for a material (i.e. we assume time-invariant functions from material to property values).

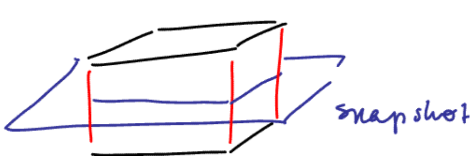


Figure 102: Snapshot

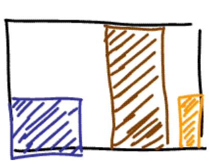


Figure 103: A 2d cut through the snapshot

Quantity is the result of a measurement process. It is typed The world of solids is a single subdivision of objects floating in empty space.

No two solids can occupy the same space.

4.1 Objects have a 3D-geometry

Objects resulting from a classification of some property values and delimiting areas of uniform value have a closed boundary and they form a partition, i.e., they are jointly exhaustive and pairwise disjoint. Solids have a very high elasticity module (> 10^5 Nm^{-2}) which gives them a fixed geometry, which we observe as a boundary. For each moment in time (i.e. each snapshot) there is a closed boundary. The boundaries are identified when forming the regions of uniform property.

```
Property :: env -> time -> propertyType -
> value
getObjBoundary :: env -> time -> objectID ->
boundary3D
```

Actions are *4D* volumes and have also boundary, volume, etc. Boundary and the centroid point are geometric objects, have properties and identity, but they are not the same kind of objects as solids: they are 'abstract objects' of the ontological construction.

From the boundary derives a centroid point, determined by geometric rules alone and a volume, which is a quantity value. Both are functions of time and can be determined for each snapshot.

```
GetObjBoundary :: env -> spatobj -> boundary
Centroid :: env -> spatobj -> point
Volume :: env -> spatobj -> quantity
Volume e i = volume' (getObjBoundary e i)
Centroid e i = centroid' (getObjBoundary e i)
Position :: point -> env -> coordinate
Area:: boundary -> env -> areaValue
Length :: boundary -> env -> lengthValue
Geometry is not ontology!
```

4.2 Actions have a 3D-T geometry

Region of uniform properties in the spatio-temporal universe have also closed boundaries. For the do-nothing action this gives parallelepipeds (in 4D, Figure 104 shows a projection in 2D-T space). The geometry resulting from forming the regions of uniform properties is an action, not a solid.

4.3 Do Nothing Ontology

To convert static description of a world to a dynamic one we introduce a do-nothing (null) operation, which leaves everything the same. This converts the *3D* volumes of an object to a *4D* (*3D-T*) volume of an action, this *4D* region is again uniform as it has everywhere the change $\frac{df}{dt} = 0$ (Figure 104).

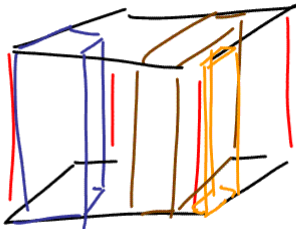


Figure 104:Space-time regions for solids

5. MOVE: THE ONLY OPERATION IN THE M-ONTOLOGY

The m-ontology is constructed from solids and the operation move and the do-nothing (null) operation; in the current discussion there is no question to what causes a move. A move changes the position of an object at t_1 to another position at t_2 $(t_1 < t_2)$ (t_1 before t_2).

The move does not change the geometry of the object, only the centroid (it does not even rotate the object; this would be another very similar ontology left out for simplicity).

Formulae

The laws for solids of this universe permit moves only if the resulting space-time regions of the solids do not overlap (i.e., all space-time regions are pairwise disjoint); indeed, the space-time regions of material objects (solids and residual object air) do not overlap. This law of this universe is a result of the classification of objects in regions of uniform property: if every point in space-time can have only one value for a property then the resulting space-time regions as well as their snapshots cannot overlap.

5.1 VARIANT AND INVARIANT ATTRIBUTE

The only attribute move changes is the location of the centroid (rotate would rotate the geometry, but leave the centroid invariant). Every other aspect included in this ontology remains the same: the (snapshot) 3d volume of the object remains the same, but its location is changed.

5.2 PATH

Solids move along a path in space time. At any point in time they are at one location.

Arbitrary movement along a path can be separated as a movement along a path of the center of gravity and a rotation around this point (excluded here Figure 105).

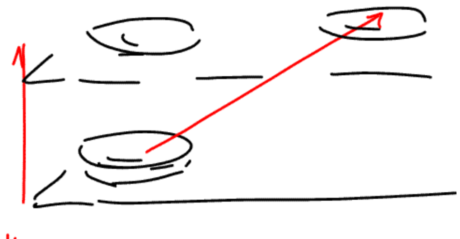


Figure 105: Move a plate from the stack to a different location on the table

Material objects: uniform material properties
action: uniform change of properties of objects

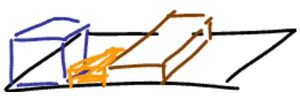


Figure 106: Situation at t_2 when copper plate is moved between iron cube and wood block

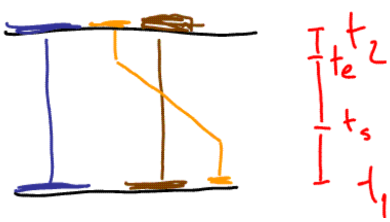


Figure 107: Projection in x and t

Move: space time areas of uniform change of location (dl/dt= const).

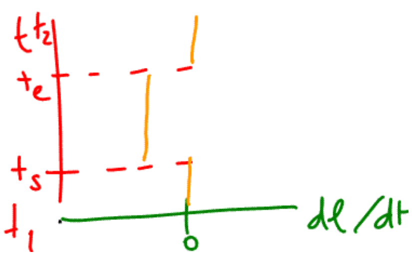


Figure 108: Temporal regions of uniform change

5.3 Move Actions

Actions are intervals of time in which a uniform change occurs. In the development from t_1 (Figure 4) to t_2 (Figure 9) we can identify three intervals (Figure 107)

- t1 to ts : the null action which results in no change
- ts to te: change of location of copper plate
- te to t2: null action.

Actions are change in time—the uniform property is the rate of change, the first derivative of the attribute and related property. The operation is move, the changes the location of the center of gravity of a solid. For the iron and wood solid the rate of change in all three intervals is uniformly 0, for the copper plate, it is zero in the first and third interval, but not for the second one. It is different from zero and (approximatively) constant. This shows that actions are intervals of uniform change.

point property velocity at p.t

$\Delta l = \int v \, dt \qquad v = \frac{dl}{dt}$

The path of the centroid is a continuous line (no interruption, no jumps, no missing intervals) this fallows from the continuity of existence of solids (commitment xx).

6. Relations between Point Properties

The point properties are connected through differential equations. From these corresponding equations for attributes of objects follow.

Some properties are static and do not change within the scope of the ontology. Some properties describe change for example an inflow of energy results in an increased temperature in an object. And others are changing under the influence of the active properties. For example, location is a static property, the movement (vector) property is active, because it changes the location.

Physical objects have boundaries
Physical objects are formed as uniform areas of some material properties.

7. The G-Ontology Includes Gravity

In the real world an approximatively uniform force of gravity applies to each mass element. The actual force found at a unit volume element is the product of mass per unit volume times the gravity force. For small scale spaces, gravity is constant and parallel (which is not the case for geographic space, see later).

- Solids have unit masses which are close to 1000 kg m^{-3}, the residual object air has negligible mass 0.5 kg m^{-3}.
- Solids in the g-ontology have a weight. It is computed as $ms * v * g = w$ and is invariant under moves (in small scale space). Weight is force and therefore has a direction. All weight vectors are parallel.
- Solids exert a force on the object supporting them (action = counteraction).

Image schema: counterforce
this gives the spatial predicate AUF

7.1 Movement caused by force

If the weight force is not countered by a support then the object is accelerated and moves. The acceleration is constant, the velocity is linearly increasing.

$$\frac{d^2 l}{d^2 t} \cdot k$$

Acceleration is the second derivative of location.

Space in g-ontology is not isotropic
Time in g-ontology is not reversible.

8. The Ontology of Existential Events

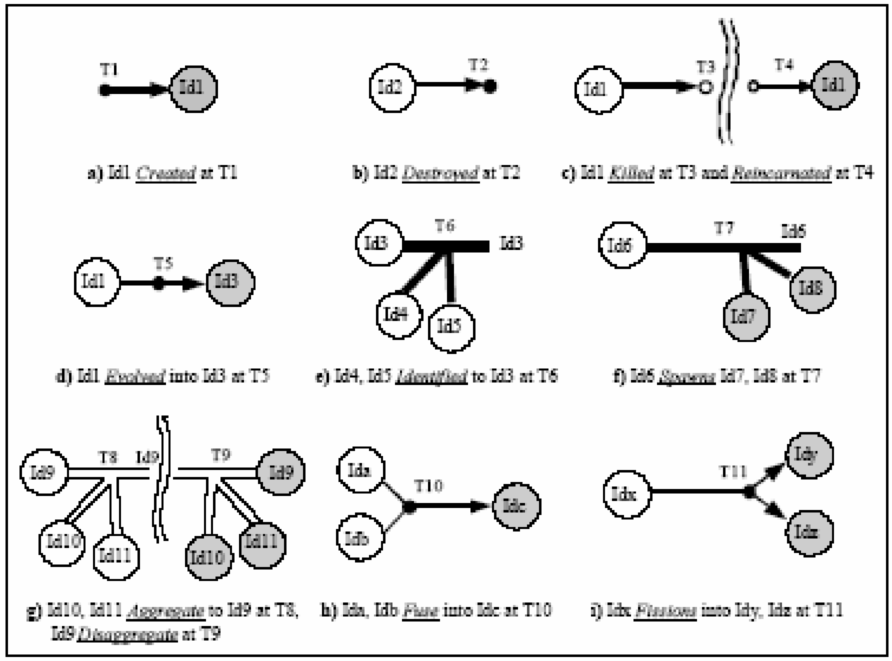
Some operations change the object in a fundamental way: we cut a piece of bread from a loaf (Figure 98) and create a new object this 'piece of bread', or we let a glass drop and it breaks: the object glass stops to exist and a number of pieces of broken glass exist.

Remember: a solid object is defined as uniform single connected region.

Event = point in time where change happens

An object comes into existence or ceases to exist. The time during which the object exists is its live span.

Figure 109: The 11 lifestyles (Al-Taha and Barrera 1994)



Catastrophic changes are affecting the 'existence' of the object and these changes follow different rules: The solids on the desktop can be glued together such that two objects become one and later this connection can be broken again and the two original objects reemerge. If we pour the water from one glass into the wine in the other glass, the two liquid objects water body and wine body have ceased to exist and a new 'water-wine-body' emerged. This operation cannot be undone and the two original liquids cannot be restituted. Considering the life of an object in time, we observe that different objects have different 'life styles'. Solids can be glued together and reemerge, but the liquids mixed cannot be separated again.

Existential events change the identity of an object. For solids, the existential events are

- Separation, which creates a new solid. Example: cut a piece of bread from a loaf (photo xx).
- Divide, which creates two (or more) new solids and the previous object ceases to exist. Example: cut an apple in 4 pieces (photo xx)
- Glue: a solid is attached to another solid; the first ceases to exist. Example: attach a post-it note to a book (photo).
- Aggregate: one or more solids are connected, such that a new solid emerges and the previously existing ones cease. Example: bind a book from pieces of paper (photo book).

The operations that change the objects define interactions between the ontologies. After an aggregation, a move changes the location of all the previously independent objects. The weight of an object after a separation is less than its weight before the separation. Weight of an aggregate is the sum of weights of the pieces, the volume is the sum of volumes, and the center of gravity is the weighted means of the center of gravity of each piece.

The way objects emerge and later change the modus of their existence differs for different categories of objects. *Lifestyles* are sets of special, identity changing operations applicable to object identifiers of different kinds of objects. Beside the inevitable *creation* of an object and possible *destruction*, the concept of temporary loss of identity for an object has been introduced with operations *suspend* and *resume* with the same meaning as kill and reincarnate in {Clifford and Croker 1988}. An object may change its identity keeping track of its predecessor through *evolution*, modeled as a composition of a creation and a deletion. Thus, the concept of part-whole is described as *aggregation* (parts are suspended) whereas the melting of objects is described as *fusion* (parts are destroyed). The fundamental difference is that the inverse of the former process (*segregation*) is reversible while the inverse of the latter (*fission*) is not: the contents of a glass of water and a glass of wine poured into a carafe cannot be restituted.

The change of identity in objects produces many side effects: e.g., topological relations change. Thus, the investigation that relates lifestyles and the change in topology of emerging objects [Hornsby and Egenhofer].

Lifestyles are a special case of small ontologies; they include only operations which affect the identity of the object; different lifestyles group operations which apply to different kinds of objects.

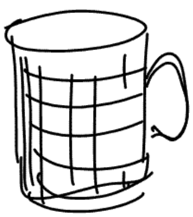
9. THE ONTOLOGY OF CONTAINMENT AND LIQUIDS

Some solids have a special form which can be used to contain other objects; they have holes (of different types, see xx). Most important are holes that can be classified. Holes of type 1 may be filled with a liquid (if the hole points upward—it is a "gravity container"). Holes of type 2 afford putting something through them—e.g., a finger to handle the object (tea cup) (Figure 94) and holes of type 3 enclose their interior completely (wine bottle). This classification clearly relates to operations: fill and pour for types holes, flow for type 2 holes and contain for type 3 holes.

Physical objects are connected (but not necessarily simply connected)

An object is said to be convex, if the boundary of the object and the convex hull of it is the same. If the object is not convex and the concavities, which are the areas not part of the solid but within the convex hull (Figure 110) of it are such that other objects do not move out of them under the influence of gravity, we can use them as containers; they afford 'containment' and are in ordinary language called container (type 1 holes).

The form and orientation of an object in 3space may be suitable to contain a liquid or similar movable object. A procedure to identify gravity containers is: Triangulate the surface of the solid and determine for each triangle the flow direction, which are the lines of maximal descent (gradient) in the gravity field. The rim of a container are the boundary lines of the triangles where the flow directions go away from the line on both sides. Sinks go from points where all flow direction merges up to the rims (Figure 111).



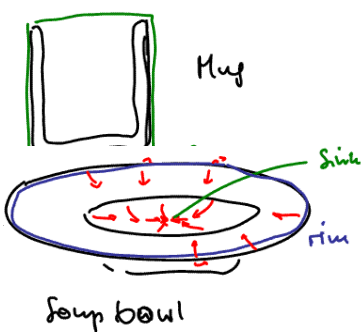


Figure 111: a deep plate and its flow lines
Figure 112: Jar with lid

9.1 OPEN AND CLOSE OF CONTAINER

Some containers have elements which can be moved such that a container (typically a gravity container) can be closed, i.e., the type 1 hole is converted to a type 3 hole (see xx). The operation to close is inverse to open (Figure 112).

9.2 POURING LIQUIDS, MIXING LIQUIDS

Mixing liquids is a catastrophic event of type fusion (Figure 109). A (part of) a liquid in a container can be poured into another container; this may be a fusion for the liquids in the container from which is poured and may be a fusion if the target container already contains a liquid. It is not possible to undo a fusion. Liquids can be separated arbitrarily with fusion events.

The material properties after the fusion are the weighted averages from before the fusion. The properties of the material after a fusion are the same as before the fusion.

for mixing liquids. Liquids which do not mix (oil – water) special case

Notice that this ontology of containment and liquids does not include an operation to increase or reduce the temperature or pressure and therefore liquids cannot change their state (phase): they do not freeze solid nor evaporate.

10. Summary

Selecting a property and the activity that changes it leads to small theories for regions with uniform values for them. These theories for objects are what our commonsense knowledge of the world starts with. They are interconnected and increasingly more operations can be included. This gives a small granularity ontologies that combine (Frank 1997). If we include another attribute and operations to change we construct a new ontology, which may be separate and combines with the first or is a refinement of the first one (see 385xx).

Chapter 14 320 CLASSES ARE THEORIES

picture – small children with experiment a la gopnik

All important things I learned in kindergarten (book title by Fulghum 1993)

The previous chapters have argued that agents can conceptualize the observation of the point properties of the world in terms of objects; the last chapter gave examples of ontologies that construct the interaction with small solids. Grouping the myriad of observations of point properties and their permanent change to objects which have attributes invariant under many changes in the world reduces the cognitive load. It is a first step in structuring our observations of the world to compact forms and is a particular form of learning. This chapter first gives an account of experimental work with very small children to understand how they build their structured knowledge of the world to form theories about certain classes of objects.

Aristotle has observed that people form classes of similar objects. We talk about dogs in general (not only of Fido, Bello, and Cesar), of students (Peter, Marlene, and Kate) and of horses (Antares and Steve). For many objects we use only the class terms and have not even names for the individuals, for example, forks, plates and glasses on a table.

pictures

The approach here is quite different from the ordinary approaches where the objects classes and their linguistic counterpart, namely nouns are assumed. Observations of toddlers before they develop language reveal the mechanism that produces classes. It is an attempt to arrive at a balanced treatment of properties of objects, operations with objects, which cannot be achieved when the structure of the language is already imposed on the situation.

I start here with an empirical description of knowledge acquisition of small children and the so called ‘theory theory’ suggest by two experienced child psychologist (Gopnik and Meltzoff 1997). They give evidence for a theory that very young children learn about the environment by constructing from the evidence they accumulate by forming (small) theories like the ones described in the previous chapter, which are models for the accumulated evidence. Children then observe attentively situations which are not explained by their theories and over time accumulate sufficient evidence to replace the initial theory with a better one—more or less what scientists are supposed to do (but don’t (Kuhn 1962)).

1. THEORIES

The theory theory of learning suggest that the representation of common sense theories of the world are in form of theories—which can be described as algebras (Goguen 1991). By theory I understand here a system of rules which connect observable states to prediction of future observable states; theories of interest are falsifiable (Popper 1984). Theories are abstraction from evidence collected and are used until they are falsified by new evidence which contradicts the prediction a theory makes.

Theories can be seen as compact expressions of the accumulated experience, forming objects from point properties was a first step in structuring and compacting the observations from the world. Theories are another method to reduce the cognitive load. Classifying individual objects and having theories for these classes reduces further the amount of knowledge we must store and consult to regulate our behavior in the world in the most effective way. The theory of solid indicates that they can be moved and the theory of liquids predicts that grabbing water will not really work and we have to form a type-1 hole with our hand to scoop some water in our palm (Figure 113).

Figure 113photo of hand and water

The word theory may sound too pompous for so simple parts of our common-sense knowledge. Guarino has proposed to call these theoritas (small theories) to differentiate them from real theories. But then, 'real theories', like gravity or the Lorentz transformations, which are at the foundation of relativity theory are also very small; theories need not be complicated or baroque to be important:

*For vertical falls: v = g * t, where g is the gravity constant g = 9.81 m s-2*

Lorentz transformations: $x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$, $t' = \frac{t - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$

Theories connect current observations with observable future states and can be wrong (falsified).

2. THE THEORY THEORY

How do children learn from the experience they make? How can one deduce general knowledge from empirical repeated evidence? Inductive reasoning in an open environment is not acceptable: a principle deduced from the evidence accumulated so far can be falsified by the next observation. Induced information is never certain—but we all take for granted that, for example, objects without support will under the influence of gravity fall. There has never been an observation to the contrary! This justifies that this rule is referred to as a *natural law* (as if nature would obey the laws people have established in the same way people follow the state laws or violate them; more about this in tier 3).

How are such laws expressed? How are such laws deduced? Gopnitz and Melkoff, two child psychologists, collect evidence from experiments and suggest that little children as young as 3 months to 9 months try to summarize the evidence they have accumulated into theories – long before language in any way is developed! This reduces the amount of storage required for memorizing the evidence and the time necessary to search for stored to apply to the current situation (Gopnik and Meltzoff 1997; Gopnik, Meltzoff et al. 2001). A small rule like: "objects remain where they are" is a first approximation to a theory about object, object location and movements. This theory is not general enough and counterevidence accumulates. It can be improved to

Objects – except for people and animals – remain where they are

and later add a rule

objects without support fall towards the ground

All these rules are much more compact and useful than the collection of thousands of experiments the toddler has carried out before she arrives at this level of knowledge (Figure 114).

Figure 114

Picture of toddler experimenting with gravity

3. Experiments with Toddlers

The psychologist carried out experiment with toddlers (Gopnik and Meltzoff 1997; Gopnik, Meltzoff et al. 2001): they showed them a scene with an object, e.g. a red ball, covered the scene with a screen so the object was not visible and then removed the screen. In some cases the object was where it was before, in others it was removed.

Then they asked the toddlers of 3 months to answer some simple question in a questionnaire of 2 pages length? Obviously not, but how do you investigate with toddlers so young? They observed the eye movement and facial expression: did the toddler express interest in a scene or was a single glance enough to understand it? They found that toddler’s interest in scenes where the object was removed was significantly higher. If the object was where it was before the screen blocked the sight, a single glance was enough to ascertain that nothing extraordinary or interesting was happening.

Gopnik and Meltzoff interpret this result as follows: the toddler has a current theory (objects remain where they are) and if the situation is in accordance with the theory then nothing interesting is happening, a single glance is sufficient to understand it. If the observation however contradicted the prediction of the theory—i.e., the object is not there where the theory predicts it should be—attention is high and interest is expressed with multiple glances and facial expressions. The assessment when a toddler was interested and when not was made by a person observing the toddler but who could not see the scene the toddler was looking at to avoid bias in the observation.

They found, that after accumulating sufficient evidence toddlers constructed a new (improved) theory. The change from one to an improved theory was again accompanied by an amused, laughing face, as if the toddler was proud that he had ‘understood the trick’.

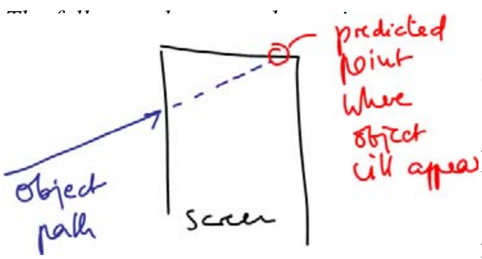


Figure 115: Theory about moving objects

This is learning.2: learning of abstract rules from the observation of the world. – not just accumulation of facts (as was learning.1)

Toddlers were surprised, if the object did not appear where expected, but it did not surprise them, if it had changed color or shape! (Gopnik and Meltzoff 1998) This indicates that toddlers had initially no theory of “the color of an object remains the same”. In another experiment, they presented the toddlers with a moving object disappearing and reappearing behind a screen. The Toddlers expected the movement to continue behind the screen and the object to appear as shown in Figure 115.

4. Theory as Algebra

Some aspects of the theory of solids should help to understand the point of view. Objects that are not influenced by other forces follow straight trajectories with uniform speed. We simplify to leave away the influence of gravity, friction, etc.

```
class Movable o where
isAt :: t -> o -> l
speed :: t -> o -> v
Axiom:
IsAt t2 o1 = isAt t1 o1 + (t2 – t1) speed (t1 o1)
```
[1]

A simple theory of weight was given before (see 315). A theory of visibility and occlusion states that from 2 objects in the same direction the one closer to the observer is visible, the other is occluded (formulae are given in most texts for computer graphics (Newman and Sproull 1981))

Classes group objects that have the same behavior.

5. CLASSIFICATION OF OBJECTS BY THEORIES

These theories predict the behavior of an infinite number of objects. All solids are grabable; all balls on a flat surface follow more or less the rules of uniform movement. It seems useful to group the objects we see into classes of things which follow the rules of these theories.

Some of the attributes necessary that an object falls into one class are visible. For example: Balls are round; from the form of objects we deduce their behavior and the applicable rules. Gibson called these visible properties of an object, which indicate that some operations apply to it the *affordances* of the object (Gibson 1986). Humans *see* immediately if an object has the necessary properties for an action—and thus classify objects without conscious effort. Observations in neurophysiology demonstrate that the mirror cells in the frontal lobe identify objects which can be acted on, for example grasped. They fire, when such objects appear in the visual field – confirming Gibson's claim (Roth 2003) [ref to mirror cells-rizzolati].

Categories of things - classes are constructed as 'the object x can be part of the operations in this class'. An object can be in several classes.

Algebras form a lattice of classes, not a simple hierarchy.

Figure 116

From this viewpoint, the common nouns that describe sets of objects are classes: Forks, plates, glasses (Figure 116). Consider for example each of these classes has a set of applicable operations. Forks have different operations (pick-up semi-solid object) than plates (put thing on) or glasses (pour liquid into, drink from). This gives an *intentional* description, which describes the infinitely large set of potential objects, existing or perhaps existing in the future, falling into each class. The *extensional* description is given by the attributes required for an

[1] In axiom, individuals of a type have the first letter of the type and a number as identification. o1 is the first object t2 is the second time point.

object in this class: forks, plates and glasses must have specific form, and many objects with these forms can serve as a fork, plate or glass.

Figure 117

Figure 118

In this classification scheme, the intention when producing the object does not enter. The plates on photo (Figure 117) were manufactured as 'plates' but this is not decisive. In a pinch a sheet of paper may serve as a plate to eat a piece of cake from (not to speak of the famous 'fish & chips' of olden days, which had to be served in a piece of newspaper! Figure 119). A physical object with a single identity can belong to different classes, depending on what operations its physical attributes afford. The actual need of the observer decides which of these potential affordances are important and classify the object accordingly. A single object can belong to many classes.

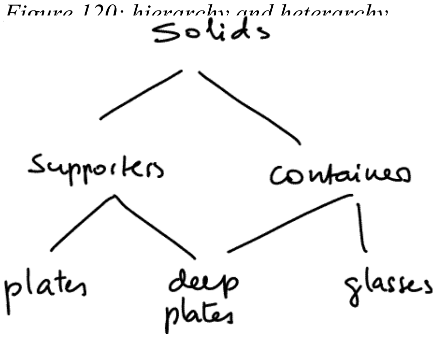
Terminology: nouns in the plural are used for class names

Figure 119

6. SUB- UND SUPER-CLASSES

Forks, plates and glasses are all special instances of the class solids. This seems to suggest a hierarchical structure, but indeed this is too restricted (Figure 120). Plates are supporters that are solid, glasses are containers that are also solids. But the deep plates used to serve soup are plates providing support and containers at once. The structure is a heterarchy (Figure 121). A heterarchy is like a hierarchy, except that a class can have more than one superclasses. We can imagine that the construction of new clauses *B* and *C* from a superclass *A* follow a simple process. Observe for situations s_1, s_2, s_3, … s_n; the outcomes o_1, o_2, o_3, …o_n; the theory *A* predicts p_1, p_2, p_3, …p_n. Test the prediction gives Boolean values t_1, … t_n. Separate the situation is set *T* for which t_i= time *T* and in set *F* for which t_1 = False. If *F* not empty, i.e., we have found cases where *A* does not correctly predict, determine a property *C* that is time for all situations in *T* and not time for all situations in *F* (for example, all objects in *T* are solid, all objects in *F* are liquid). Construct a new theory *B* that is if *C* then apply *A* and a theory *C* that is if not *C* then apply $\bar{A}$. Extract the common parts of *A* and $\bar{A}$ into *A'*. The result is hierarchy of clauses:

Figure 120: hierarchy and heterarchy



The heterachy of plates and glasses
Figure 121Tree stomp as a table

7. CONCLUSION

This theory of objects classification is compatible with the known interdependence between objects and the observer. Only after one has seen the first snake, other snakes become visible (and similar for strawberries and mushrooms in the woods). The process to digest the visual observations is guided by the current focus, the interest of the agent. If the interest is to put a class somewhere, which is an operation for objects in the class table, then the corresponding attributes required of objects to allow 'posing something' are activated and the object recognition system explores the inputs to identify objects having the desired affordance, i.e. have the physical properties of flat, horizontal surface, rigid material and stable support, etc. (Figure 121).

A formal object theory was published by Arbial and Cardelli (Abadi and Cardelli 1996). The typically concepts of object-orientation used in programming languages result in very complex theories which cannot be expressed in lambda calculus. The approach using verbs and to separate intensional and extensional classification results in a theory which is compatible (and implementable) in a Hinley-Milner type inference system [milner ML, Haskell report].

Chapter 15 340 Image Schemata

1. Introduction

Human beings describe with natural language terms spatial situations with enough precision for most day-to-day operations. Guests on a table can indicate where the salt shaker is on the table, a friend can describe to us the way to his home; communication is not perfect but usually successful. This chapter compares the experienced accumulated in natural languages with the approach to object ontologies described in the previous chapters.

Natural languages provide a small number of words to express a spatial position, typically described as a relation between objects. These words belong to the 'closed class' of the vocabulary of a language: it is not possible to invent a new spatial relation term; we have to do with *in*, *between*, *in front of*, *behind*, *around* etc. (Talmy 1990). There are typically 100 words for spatial relations. Compare this with the open class, for example nouns and verbs, where language is productive and has added new verbs like 'to google' or nouns 'lego', 'fridge', etc. We say 'I got this *over* the internet', where internet is a newly created noun, but the spatial relation over is not replaced by a new word like 'overnet' or 'oner'! Linguists have described the semantics of the small number of spatial relations people identify and have words to describe it (Lakoff 1988; Talmy 1990).

"rose is a rose is a rose" (Gertrude Stein)

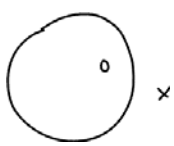
The observation that only few spatial terms are available and that the myriad of real world situations can be expressed with a small number of patterns has lead to a search for these patterns. One approach is based on a concept of image schemata. Image schemata describe high level, abstract structure of common situations, most of them expressing spatial relations {Johnson, 1987 #223}. It is widely assumed that image schemata ({Johnson, 1987 #223; Lakoff, 1987 #254}) are the fundamental experiential elements from which spatial meaning is constructed. They are somewhat similar to Gibson's affordances (Gibson 1986). Understanding image schemata is, part of the quest for naïve or commonsense physics {Hayes, 1978 #390; Hayes, 1985

#391; Hobbs, 1985 #400} and “Naïve Geography” (Egenhofer and Mark 1995).

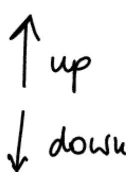
2. EXPERIENTIAL REALISM AND SPATIAL IMAGE SCHEMATA

Experiential realism (Lakoff 1988) posits that human cognition is based on practical experience. The physiological similarities of human bodies lead to the similarity of basic aspects of human life and thus to similar experiences - independent of culture or language (Montello 1995). All children have essentially the same experiences in the first years (eating, grasping things, letting things drop etc.) and cultural and individual differentiation follows later.

Many of these early experiences common to all human beings are spatial, leading to the fundamental spatial relations for example '*in*' /'*out*', '*up*'/'*down*' etc. (fig). In the framework of experiential realism meaning is associated with abstract concepts through repeated experience. The concepts of space that humans construct are thus dependent on the physiology of the human body in a similar way that the value of the primary colors dependent on the physiology of the retina (Rosch 1973; Whigham, McKay et al. 1992).



A region with a point inside and point outside



The salient direction up/down

The spatial experiences are aggregated to image schemata, which abstract the essence of a prototypical situation, many of them spatial.

> "... Much of the structure, value, and purposeness we take for granted as built into our world consist chiefly of interwoven and superimposed schemata... *My chief point has been to show that these image schemata are pervasive, well-defined, and full of sufficient internal structure to constrain our understanding and reasoning.* [Johnson's italics] To give some idea of the extent of the image-schematic structuring of our understanding (as our mode of being-in-the-world or our way of having-a world), consider the following partial list of schemata, which includes those previously discussed:

Container	Balance	Compulsion
Blockage	Counter force	Restraint Removal
Enablement	Attraction	Mass-Count
Path	Link	Center-Periphery
Cycle	Near-Far	Scale
Part-whole	Merging	Splitting
Full-empty	Matching	Superimposition
Iteration	Contact	Process
Surface	Object	Collection" (Johnson 1988p. 126).

The name *image schema* stresses the situation primary as an image but this is too narrow an interpretation. In the previous chapters we have considered operations and patterns of interaction of humans with the environment, which includes the visual observation. I want to show here that a close connection between image schemata and small theories exists.

3. Classification of Image Schemata

Image Schemata are mostly independent of the scale of the space in which an experience is situated (Talmy 1990). A detailed analysis shows that the specifics of a spatial situation influence the meaning of preposition. The *in* in "The apple is in the bowl" stresses the restriction from movement whereas in "The island in the lake" the stress is that the island is surrounded by water.

The two major situations for spatial experience have different prototypical image schema associated (Mark 1989; Kuhn and Frank 1991):

- small scale space with movable objects smaller than human beings: container (in/out), object, link, surface, support, part/whole, contact
- moving in large scale space: place, path, near/far, centre/periphery

image schemata are scale invariant (Talmy)

The same words are used to describe spatial situation of different scale (e.g. "the apple is in the fridge" and "the island is in the lake"); metaphorical transformations are applied, which transfer the essence of the concept from one space to the other, and even to definitely non spatial situations (e.g. "the idea presented in this context") (Turner 1996; Fauconnier 1997). A single schema can appear in multiple, closely related situations. For example, "in" is used for a bowl of fruit ("Der Apfel ist in der Schale."—"The apple is in the fruit bowl."), but also for closed containers ("Das Geld ist im Beutel."—"The money is in the purse."). The single image schema is not a precise, well defined entity but "prototype effects" as described by Rosch (Rosch 1973; Rosch 1973; Rosch 1978) seem to apply. For example, a different level of detail can be selected to describe the same image schema. (Rosch 1978).

To make progress with formalisation, a specific environment must be fixed (Rodriguez and Egenhofer 1997). In this chapter I use tabletop space. I assume that for the spatial Image Schemata listed above, the figural space situation is the primary experience and other uses, e.g., for geographical space, are secondary (which will be discussed later 360-xx).

4. Components of Image Schemata

Researchers in the past have used a working definition, which implied that image schemata describe spatial situation and relates physical relations between objects, related to direct human experience in interacting with the world. Most have concentrated on spatial prepositions like *in*, *above*, *over* between an figure and a ground (Langacker 1987). They assume that these relate directly to the image schemata (Lakoff and Johnson 1980; Johnson 1987; Lakoff 1987). Other image schemata reflect prototypical aspects of actions, for example *blockage.*

A detailed discussion of Image Schemata uses direction and other simpler spatial concepts, like horizontality or verticality (direction of gravity) of a surface (Regier 1996). One could think of these components as semantic atoms, especially spatial semantic atoms. Cross-linguistic studies have demonstrated that different languages combine these components differently to arrive at different subdivision of spatial situations which are described with a word (Bowerman 1996) but that the same components are found in all languages, they are universals.

5. Formalizing Spatial Meaning

The spatial domain—in which GIS facts are situated—is fundamental for human living and one of the major sources for human experience (Barrow 1992). Space seems extremely real to us, probably because there are multiple senses informing us jointly about the single reality around us. Human language exploits the communality of spatial experience among people and uses spatial situations metaphorically to structure purely abstract situations in order to communicate them (Lakoff and Johnson 1980; Johnson 1987). The formalization of spatial relations has, therefore, been an active area of research at least since 1989 {Mark, 1989 #235; Mark, 1988 #2767} and is most likely important to arrive at methods to integrate ontologies from different sources. Kuhn has pointed out the importance of image schemata as a tool to build “natural” (i.e., cognitively sound) user interfaces for GIS(Kuhn and Frank 1991; Kuhn 1993).

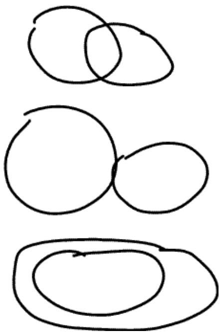


Figure 122: overlap, meet and inside relations between two geometric regions

He gives formal definition for relations like overlap, meet, inside etc. (**Error! Reference source not found.**). His definitions are in terms of intersection of interior and boundaries of the two geometric figures, using as a foundation point set topology (Alexandroff 1961; Frank submitted 2005).

Topological relations between simply connected regions were treated in {Egenhofer, 1989 #305} and extensive work has followed from this (Egenhofer; Egenhofer, Clementini et al.; Egenhofer, Clementini et al.). Metric relations between point-like objects, especially cardinal directions (Frank 1991; Frank 1991; Freksa 1991; Hernández 1991) and approximate distances (Frank 1992; Hernández, Clementini et al. 1995; Frank 1996) were discussed. Other efforts dealt with orderings among configurations of points (Schlieder 1995) and formal descriptions of terrain and relations in terrain {Frank, 1986 #4427}. Linguists have made systematic efforts to clarify the meaning of spatial prepositions ((Herskovits 1986), {Lakoff, 1987 #254}). However, it remains an open question how to combine these interesting results within a uniform ontology.

6. Formalisation of Image Schemata

Image schemata cannot be defined in isolation, but define relations between a set of objects and their development in time. The situation will be called scene: with a figure and a ground and different successive states of the same scene will be numbered (*scene*1, *scene*2, etc). This is similar to Langacker's method to describe the semantics of other aspects of language (Langacker 1987; Langacker 1991; Langacker 1991). Efforts are made to identify aspects which are time invariant to avoid the complications of temporal logic (Galton 1987).

6.1 Image Schemata Defined With Predicate Calculus

Lakoff gives a definition of a CONTAINER using predicate calculus:

> *"For all A, X, either in (X,A) or not in (X,A).*
> *For all A, B, X, if Container (A) and Container (B) and in (A,B) and in (X,A), then in (X,B)." (Lakoff 1987p. 273)*

In theory, predicate calculus has all the expressive power necessary, but it is practically limited by the frame problem, which makes succinct definition for changes impossible (McCarthy and Hayes 1969; Hayes 1977; McCarthy 1985). in a predicate calculus formalization it is necessary to add formulae, which link facts in two consecutive states of the situation and state, which these aspects do not change. This is the logical equivalent to completing the sentence "Harry left the room" with a long list of statements, which assert, that the table and the chair remain in the room, the window remains open or closed, etc., etc. Reiter gives a new formalisation of situation calculus and provides also some tools for the simplification of formalisation (Reiter in preparation).

6.2 RELATIONS

The behavior of topological relations {Egenhofer 1994; Papadias and Sellis 1994}, but also cardinal directions and approximate distances (Frank 1992; Frank 1996) can be analyzed using the relations calculus {schroeder 1895; maddux 91}. Properties of relations are described as the outcome of the combination of two relations relations from a category (Barr and Wells 1990; Asperti and Longo 1991; Walters 1991; Pierce 1993) specifically an allegory (Bird and de Moor 1997). The description abstracts away the individuals related (in comparison to the predicate calculus) and gives a simple algebra over relations. This leads to succinct tables, as long as the combination of only few relations is considered.

aRb and bSc ==> a (R;S) c.
for example: North;NorthEast = {North or NorthEast}
meet;inside = {inside, covered, overlap}

6.3 FUNCTIONS

To capture the semantics of image schemata with respect to operations, functions and algebraic methods are more appropriate. Relation composition is replaced by function composition. In order to use this notation flexibly, a "curried" form of function writing must be used (Bird and Wadler 1988; Bird and de Moor 1997).

$f \, . \, g \, (x) = f \, (g \, (x)).$

6.4 MODEL BASED

A model of the scene is constructed and used for reasoning (there is some evidence that this is also one of the methods humans apply (Schlieder 1995). A fundamental set of operations to construct any possible state of this model and a sufficient number of observe operations to differentiate any of these states are provided.

Models can be ontological—modeling some subset of the existing world—or they can be epistemological—modeling exclusively the human conceptualization of the world.

Model-based specifications have the advantage that the difference between the ontology incorporated in the model and the epistemology of the observers can be clarified. On top of the same ontology, multiple epistemologies may be constructed by combining the spatial atoms. For example, it is possible to use the English prepositions '*in*' and '*on*' in lieu of the German '*in*', '*auf*' and '*an*'.

7. SPECIFICATION OF IMAGE SCHEMATA

7.1 *OPERATIONAL DEFINITION OF IMAGE SCHEMATA*

There seems to be in any language a large number (perhaps 100) spatial relation terms: which ones should be investigated to find the spatial atom? We identify a spatial situations image schemata if it is usable as a source domain for metaphorical transfer to some target domain; this demonstrates that a commonly understood structural content, that is independent of the specific situation, exists.

7.2 *ASSUMPTION OF POLYSEMY*

A spatial relation terms may have different meanings, depending on the circumstances. One could assume that spatial relation terms are polysemous: one word is used to describe different situations. We assume that polysemy helps to initially separate what are potentially different meanings of a word for formalization. If the meanings are the same after formal description is achieved, the assumed polysemy can be dropped.

The apple is in$_1$ the kitchen (indirect inside) in$_2$ the fridge (directly inside).

7.3 *PARTIAL SPATIAL RELATIONS*

Spatial relations may be partial: a pen may be partially on a sheet of paper, a city boundary partially in one, partially in another state or country (e.g., Niagara Falls is a city both in Canada and the U.S.A.). Egenhofer has studied such cases {Egenhofer 1997} characterizing the degree of overlap etc.

Figure partial inside, partial coverage, partial on.

7.4 *RESTRICTION TO A SINGLE LEVEL OF DETAIL AND ABSTRACTION*

The level of abstraction differs depending on the requirement of the situation (Timpf, Volta et al. 1992){Voisard, 1997 #6986; Voisard, 1994 #7549}. These multiple levels of detail play an especially important part in geographic space and make the specification of image schemata difficult. Level of detail may be spatial subdivision, may be more rule considered or may be the subdivision of categories into subcategories (Giunchiglia and Walsh 1992; Frank and Raubal 1998).

8. Conclusion

Image Schemata and possibly even smaller atoms of (spatial) semantics can be identified and formalized. The next chapter will give a worked out example.

Chapter 16 330 Three Spatial Relations between Objects in Tabletop Space

1. Introduction

Having defined objects—at least for the small scale, table top environment (chapter 315)—we may ask about the relations between objects, in particular spatial relations. This chapter gives a systematic description of the semantics of three spatial prepositions in tabletop space. It demonstrates how a formal approach to ontology can link to linguistics and their methods of investigation.

Natural language sentences are given which describe a common spatial situation and suggest an interpretation or logical derivation, which is not directly expressed. Linguists call this entailment. The logically implied and tacitly deducible conclusions from a description—most often centered around the assertion of a spatial preposition (e.g., *in*)—are taken as the content of the image schemata, i.e., the abstract structure expressed in it. A number of restrictions and assumptions are necessary to make progress with this investigation. Topological relations between simply connected regions were treated in (Egenhofer 1989; Egenhofer, Clementini et al. 1994) using relation calculus. This is useful to give definitions for geometric situations but not to explain what spatial relations between solid objects mean. If we consider solids, we must exclude that they overlap and are only concerned with touching and distances between objects.

Ontological commitment for solids: no solid can be where another solid is

Most discussion of Image Schemata is concentrated on English language examples. The work here reported uses three German spatial prepositions 'in', 'auf' and 'an', which represent a case, where the German (and Dutch) language make a finer division than the otherwise closely related English language. The German *auf* and the German *an* are both describing situations, where in general English uses *on*. Etymologically, German *an* is related to English *on* and Dutch *aan*; German *auf* is related to English *up* (not used as a spatial relation today) and Dutch *op* (with similar use as German *auf*); German *in* is related to English in and Dutch *in* [etymologische woerterbuch dtv–].

2. THE SITUATION STUDIED

To understand the logic of the natural language terms, sentences or groups of short sentences, which could be spoken by a native speaker, are used. They describe a situation and give entailments of the initial description: what follows from the description, what is implied and understood by a competent speaker about the situation. This combines grammatical and common-sense knowledge of the world, as typical for 'cognitive linguistics' (Langacker 1987; Langacker 1991; Langacker 1991; Fauconnier 1997).

(1) Du musst die Schachtel zuerst aus der Tasche nehmen, bevor du die Münze hineingeben kannst.
You must take the purse out of the pocket to put the coin in.

(2) Teller und Gläser sind auf dem Tisch. Wir müssen den Tisch zuerst abräumen, bevor wir ihn auf die andere Seite des Zimmers bringen können.
Plates and glasses are on the table. We have to remove all objects from the table, before we can move it to the other side of the room.

(3) Der Apfel kann nicht aus der Schale rollen, aber du kannst ihn dir herausheben.
The apple cannot roll out of the bowl, but you can take it out (lift it out).

(4) Du musst die Büchse öffnen, dann kannst du die Würfel herausnehmen.
You must open the box. Then you can take out the dice.

(5) Er hat das Bild mit Klebeband an die Wand geklebt.
He taped the picture to the wall.

(6) Ich habe das Papier auf das Buch gelegt, jetzt klebt es dar**an**.
Wenn du das Papier mitnehmen willst, musst du es sorgfältig lösen.
I have put the paper on (auf) the book, now it is glued on (an).
If you want to take it with you, then you have to carefully remove it.

(7) Wenn du den Beutel mitnimmst, so hast du auch die Schachtel mit der Münze bei dir.
If you take the purse, then you have the box with the coin with you.

(8) Sogar wenn du die Schachtel bis ans Ende des Tisches schiebst, wird die Etikette daran sein.
Even if you move the box to the other end of the table, the label will still be on it.

(9) Du kannst das gelbe Buch nehmen, es liegt auf dem Tisch.
You can take the yellow book; it is on top of the table.

The entailment of the box being in the bag (Example (1)) demonstrates that an object cannot be put into the box, while it is in the bag (Figure 123). The example sentence (2) demonstrates how objects which are place one on top of another are hindering the movement of the later (Figure 124). In example sentence (3) from the apples being in the fruit-bowl follows that they cannot roll of or cannot be slid out, but can be lifted out of the bowl (Figure 125). Similarly, a box blocks the movement of an object unless the box is opened (4) (Figure 126). Example (5) is the prototypical case for the use of *an*: a picture is hanging on the wall, because it is taped there (Figure 127). In example (6) , an is used because there is a stronger connection than the force of gravity (as in example (4)) and only a qualified movement to undo this connection can move the object (Figure 128). The entailment in example (9) demonstrates that the position described by *an* does not restrict movements (except for gravity, against which the table provides support Figure 129)

Figure 123

Figure 124

Figure 125

Figure 126

Figure 127

Figure 128

Figure 129

pictures

3. FORMAL DEFINITION OF *IN*, *AUF*, *AN*

To understand the common-sense semantics of the relations *in*, *auf*, and *an* between an object and a relatum (figure and ground), we describe their implications for (what linguists call entailment) operations to establish such relations (*moveIn, moveAuf, moveAn*). The axiomatic approach defines semantics by describing the observed results of an operation; this corresponds to operations defined in terms of changes in attributes (chapter 315xx).

The scene is a tabletop of unspecified objects, which are moved from the outside. The ontological commitments are:

- In this world objects can be moved, unless the relation the object participates in blocks the move.
- An object can be moved to (*in*, *auf*, *an*) a target, unless access to this target is blocked by a relation this target participates in.
- Every object can enter in any relation with any other object, i.e., all objects can serve as containers or support; objects are not differentiated.

This is a closed world, (Reiter 1984) no other forces or events than the ones described are assumed to exist. Moves are not blocked by other considerations. This means, for example:

- No other objects exist.
- The number or size of other objects, which can be related to an object, is not limited. Moves are not blocked by size considerations (for example, objects too large for container, surfaces completely covered, etc.).
- A scene remains the same unless a changing operation can be executed.

4. POLYSEMY OF *IN*

'in' can mean *directly in* or *indirectly in* and its semantics should be differentiated. *'in'* here means 'directly in' and is differentiated

from *'in*'*, which generalized *'in'* to include indirect containment.

Die Münze ist im Beutel und der Beutel ist in der Tasche. Die Münze ist in* der Tasche.

The coin is in the purse and the purse is in the pocket. The coin is in* the pocket.

5. FORMALIZATION

An initial effort to formalize the container and the surface image schemata resulted in two isomorphic algebras (Kuhn and Frank 1991); this shows that more than just the change in the relation must be investigated.

5.1 TRANSITIVITY

The semantic difference between the image schemata is in combination of movements and the blocking of operations; all three relations are transitive. The combination of twice the same relation gives the corresponding transitive closure:

In; in = in and generalize to r;r= r* (for r elem {in, an, auf})*

the apple is in the bowl and the bowl is in the fridge. Entails: the apple is in* the fridge.

Der Zettel klebt an der wand; das bild ist an der wand. Entails: der Zettel ist an* der Wand.

Das Buch ist auf dem Heft; das Heft ist auf dem Tisch. Entails: Das Buch ist auf* dem Tisch.

5.2 'IN' BLOCKS TARGET OF MOVEMENT

An object cannot be moved to a target if this is already in another object. This is justified by situations as:

x 'in' y (in scene) => blocked (move z into x (in scene))

Du musst den Beutel zuerst aus der Tasche nehmen, bevor du die Münze hineingeben kannst.

You must take the purse out of the pocket to put the coin in.

5.3 CONVERSE OF 'AUF' BLOCKS OBJECT OF MOVEMENT:

'Auf' blocks the movement of the supporting object. It cannot be moved unless the object 'auf' it is removed.

x 'auf' y (in scene) => blocked (move y in scene)

Teller und Gläser sind auf dem Tisch. Wir müssen den Tisch zuerst abräumen, bevor wir ihn auf die andere Seite des Zimmers bringen können.

Plates and glasses are on the table. We have to remove all objects from the table, before we can move it to the other side of the room.

5.4 'IN', 'AN': BLOCK MOVEMENT OF OBJECT

'In' and 'an' create a link between the object and the relatum which resists movement (a particular 'break link' operation would be required to break it: unglue, takeOut etc.).

'In' does restrict the movement of the object.

x 'in' y (in scene) => blocked (horizontal move x in scene)

Der Apfel kann nicht aus der Schale rollen, aber du kannst ihn dir herausheben.

The apple cannot roll out of the bowl, but you can take it out (lift it out).

x 'in' y and 'closed' y (in scene) => blocked (move x in scene)

Du musst die Büchse öffnen, dann kannst du die Würfel herausnehmen.

You must open the box. Then you can take out the dice.

'An' presupposes a physical connection between the object and the relatum (stronger and more permanent than gravity support) which is typically established intentionally (verbs like to nail, to glue, to stick, etc. and not just plain 'to put'). 'An' with this definition could be seen as a 'Link' image schema. Movement is restricted unless the link is broken.

x 'an' y (in scene) => blocked (move x)

Ich habe das Papier auf das Buch gelegt, jetzt klebt es dar**an**. Wenn du das Papier mitnehmen willst, musst du es sorgfältig lösen.

I have put the paper on (auf) the book, now it is glued on (an). If you want to take it with you, then you have to carefully remove it.

5.5 'IN', 'AN': INVARIANCE UNDER MOVEMENT OF RELATUM

Corresponding to the blocked access to the object for *in* and *an* relations (rule 6.4), these relations are invariant under movement. If x is 'in' y and y is moved, then x is still 'in' y (and the same for 'an').

x 'in' y (in scene) => x 'in' y (in move y in scene) = True
x 'an' y (in scene) => x 'an' y (in move y in scene) = True

These rules will not be expressed explicitly, as they are subsumed by the 'stable world property' (nothing changes unless specifically indicated).

5.6 A MOVE UNDOES A PREVIOUS RELATION OF OBJECT: 'AUF'

'Auf' does not restrict the movement of the object:

x 'auf' y (in scene) => move x in scene

Du kannst das gelbe Buch nehmen, es liegt auf dem Tisch.

You can take the yellow book; it is on top of the table.

The effect is, however, that the previously established relation is false and a new relation is established:

scene2 = move x Rel y (scene1)
a Auf z (in scene1) = True
a Auf z (in scene2) = False
a Rel y (in scene2) = True

5.7 SUMMARY

Table 2 Application of different moves to different situations

	move a in c	move c in a	move a auf c	move c auf a	move a an c	move c an a
a in b	in blocked: a in	in blocked: a in	in blocked: a in	in blocked: a in	in blocked: a in	in blocked: a in
a auf b	a in c,	c in a, a auf b = c auf* b	a auf c,	c auf a, a auf b = c auf* b	a an c,	c an a, a auf b = c auf* b
a an b	an blocked: a an	c in a, a an b = c an* b	an blocked: a an	c auf a, a an b = c an* b	an blocked: a an	c an a, a an b = c an* b
b in a	a in c, b in a = b in* c	c in a, b in a = {b,c} in a	a auf c, b in a = b auf* c	c auf a, b in a = b auf* a	a an c, b in a = a an* c	c an a, b in a,
b auf a	auf blocked: a covered	c in a, b auf a,	auf blocked: a covered	c auf a, b auf a = {b,c} auf a	auf blocked: a covered	c an a, b auf a,

The rules can be described as a table. In the top row the moves are described, in the leftmost column the starting situation. The cells give then the result of applying the move to a situation, in all possible combinations. The same information can be expressed as rules. The operation 'move' with the arguments: relation type, object, target, scene are shown below.

```
move i a b s =
      if fRel In b s   -- rule 6.2 : in blocks target of
      movement
         then error ("in blocked: already in")
      else
      if fRelConv Auf a s -- rule 6.4: (conv auf) blocks
      movement
         then error ("auf move blocked: already covered")
      else
      if fRel In a s   -- rule 6.5 (1): in blocks movement of
      object
         then error ("in move blocked: already in")
      else
      if fRel An a s   -- rule 6.5 (2): an blocks movement of
      object
         then error ("an move blocked: obj already an")
      else
      if fRel Auf a s -- rule 6.6: undoes previous 'auf' of
      object
         then move i a b (takeOff Auf a s)
      else
      Move i a b s
```

This is a refinement of the m-ontology (see chapter 315), where the move is qualified by the relation that is achieved. The rules for moving objects which are connected by an *an* relation follow the l- and the c- ontology of links and containers.

6. Conclusions

Formal descriptions of spatial relations as they are encountered in everyday life are an important part of the ontology for GIS (Egenhofer and Mark 1995). It is assumed that image schemata lead to the identification of the universal atoms for the conceptualization of spatial situation. For interoperability of GIS software, it is necessary to formally define query language predicates, such that they same query executed on different computers have the same result.

In this chapter a methodology for a systematic effort to define spatial relations was outlined. It progresses along the following steps:

1. Identify a simple environment in which the spatial relations of interest are important. List the types of objects and the relations between them, which are of interest.
2. In natural language (preferably the investigator's natural tongue) list a number of sentences which describe a concrete situation, for which pictures are given. For the sentences identify the entailments.
3. Identify the rules form the entailments and formalize them.

Ich sitze nicht auf dem Boden, ich habe mir eine Zeitung untergelegt.
(I do not sit on the ground; I have put a newspaper under.)

It achieved essentially the same result than the algebraical approach earlier (xx315).

Chapter 17 350 OBJECTS IN GEOGRAPHIC SPACE

> Q: What goes uphill and downhill and always stays in the same place?
> A: A road.
>
> Children's riddle

The typical experience in large scale space is one of moving around in a landscape which is only partially visible. The most important operation is navigation, to find the way back and to enter the 'cave' after a day of hunting or collecting nuts and berries. Extensive psychological literature exists about how people navigate, mainly relating to an artificial environment (Kuipers and Levitt 1990) (Freundschuh, Mark et al. 1990; Gluck 1991; Hutchins 1995; Werner, Krieg-Brückner et al. 1997). [werner keynote cosit 2000 stade]. Additionally important is to recognize places where water could be found, either for plants, other animals or for drinking.

The previous chapters discussed objects in figurative (small scale) space, taking its example from a table set for lunch. It was argued that direct experience and interaction with these objects influence our understanding of spatial relations. Image schemata are the abstraction of this commonsense knowledge. In this part I show how same principles are applied to objects in geographic space. At tier 0 or 1 geographic space is seen as a space-time continuum in which observations of point properties are possible is not different from figurative space. The conceptual organization of large scale space is different from the conceptualization in small scale space:

- Geographic space is experienced primarily as a 2d surface, on which we move. This 2d surface is embedded in a 3d space.
- *Figure* There is not a single subdivision of space which is uniformly preferred (like the subdivision in movable objects): geographic objects may overlap and have often boundaries which lack a crisp definition (Figure 130).
- Geographic objects can change their dimension depending on the scale we use: a town can be seen as a point or an area; a road can be a line or an area. Operations apply accordingly.

Figure 130

Folk agriculture and geography discusses forest, ponds, pastures and fields. We speak of individual objects like the Hufnagelstrasse, my backyard, the pond in front of the abbey and the Kottaunerwald. How are these delimited? How are these objects related to operations? A field is the unit for farming operations like tilling, sawing, harvesting. A street serves for movement between two nodes. A street is (usually) not tilled nor is a field used for moving between towns. Hunting and cutting trees etc. are operations typical for forest, not for fields or streets and fishing and swimming takes place only in ponds and other water bodies.

Four types of objects seem to be the foundation of the conceptualization of large scale space: Places, Paths, and Regions. Very different are fields, which describe some property varying in space. This ontological breakdown is similar but not the same as presented by (Lynch 1960) who investigates the object classes NODE, EDGE, REGION, PATH, and LANDMARK. Lynch was interested in the description of city form and not large-scale geographic space and the set of objects and relations considered are, therefore, slightly different.
figures

1. Metaphorical Transfer of Image Schemata

Figure 131

Figure 132

Experiences of small scale and large scale space are substantially different, but with a strong tendency to carry over the experiences gained from one to structure experiences in the other one. Most obvious is the application of the 'container' image schemata in tabletop space applied to landscape elements like lakes, swamps, good hunting areas, fields for planting and finally territory. Even if the areas in the landscape lack the 'clear boundary' property they can be used for metaphorical transformation, because not all the properties of the source domain must be present in the target domain {Martin, 1990 #199} (Couclelis 1992; Couclelis and Gottsegen 1997; Fauconnier 1997). Forests, fields, and lakes are treated as objects, despite the fact that they are imagined mostly as 2D surface not 3D volumes and without concern where exactly the boundary is. For example one says 'the deer is in the wood', not implying that the wood has well defined boundaries or is a 3D volume (Figure 133).

Figure 133

2. Geographic Objects Are not Solid Bodies

Figure 136 Three different classifications for urban land use (with 4, 7 and 24 classes)

The classical concept of object is a generalization from the physical objects on the tabletop; such material objects are exclusive: where one object is no other object can be. This is correct only for solid body objects and not the case for other physically observable objects: in most applications, more than one classification is possible [smith and brit]. In the city environment the classification can be based on a pedestrian viewpoint or a legal-ownership viewpoint: a pedestrian is interested in the areas which are uniformly 'not-obstructed' whereas a bank is interested in seeing what areas have a uniform ownership. The boundaries typically do not coincide (Figure 134).

Figure 134

This gives more than one object at a single location. Similar differences in the classification of land for planning purposes can be observed: Classify for natural habitat, for car traffic, for pedestrian traffic, for residential constructions, all are examples of objects of different types which overlap and coexist. The division of the world in objects is not unique and depends on the observer and his intentions.

Figure 135 Subdivision of space in building objects and ownership objects which overlap

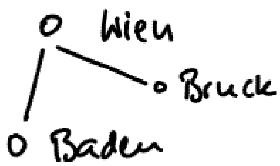
3. Places

Places are locations, which can be recognized, but they are neither objects with definite boundaries, nor abstract points from Euclidean geometry [ref couclelis], but can be small or large. They seldom have a defined boundary (Burrough 1996). We speak of downtown [montello couclelis], determine the distance between towns as if they were points, etc.

Wien is a point for the determination of distances, but also an area where people can be located in

4. Path

Places are connected by *paths*, which can be followed to get from one to another. A water course from lake to the sea, a street or a footpath between two places are all example of a path. Path typically facilitates some form of communication. Paths and links are examples of two very similar image schemata, one from the small scale, the other from the large scale space.



Path connect places

Along a path there are intermediate locations which are not sharply determined and not even named. The path also goes up and down gradually, with highest and lowest points which might qualify as places, but all intermediate points are just relatively higher or lower than others.

Movement of humans or animals in the landscape is slow enough that gradual movement along a path is perceived. This links path in geographic space to the same notion in small scale space (xx-315). The temporal sequence can be deduced later from spatial clues; we know of the famous Indians reading from marks on the ground which animals or humans have passed and when (for the application of the same concept to geology see {Flewelling, 1992 #52}).

5. GEOGRAPHIC REGIONS

The concept of region is most general: watersheds are regions, so are forest, fields in agriculture, urban areas etc. Both places and paths can be regions, when considered at a more detail.

5.1 IDENTIFICATION OF REGIONS SUITABLE FOR AN ACTIVITY (AFFORDANCE)

Activities possible in space require certain properties—similar to the situation for table top objects. Consider the case for agriculture: Soil type, exposition, climate etc. all must contribute to make a piece of land suitable for agriculture. One can often use the signs of agricultural activities (e.g. tilling) to see where farmers have decided that the area is suitable for agriculture and delimit the field based on their judgment.

To determine regions, we select areas with uniform values on one observable property (Figure 136). Sometimes a function of several properties must be used, e.g., to determine suitability for agriculture and the maximally connected regions that have values in a range are identified.

Figure 137 Classification of the remote sensing image from figure xx

Figure 138

Figure 139

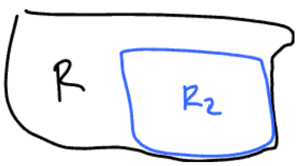


Figure 140Region R is contained in R2

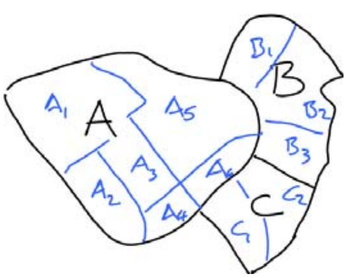


Figure 141Three regions with one level of subdivision

In many cases, specific observation systems are organized to find the boundary positions directly in the terrain and not from the point-wise observation of the environment. Surveyors go out and measure the boundary of the forest by detailed observation in the field (equation from 8xx) and then measure the location of the boundary.

Figure

5.2 Size of Regions

Regions come in a variety of sizes. A geographic region is always a subset of the earth surface (the southern hemisphere is a region). The smallest regions in geographic space must be at least large enough for a human (or other agent) to enter it, thus a small garden plot is a human sized region (Figure 138) and the burrow of a fox is region when considering foxes as agents (Figure 139).

5.3 Regions Have Boundaries

Every region has a close boundary (Figure 138), but these boundaries need not be determined [couclelis – montello business district; more refs from the burrough frank book]

5.4 Places Can Be Contained in a Region

A place can be located in a region. This is very similar to the *in* relation in small scale space.

5.5 Containment Relation between Regions

A region can be contained within a larger region. This is closely related to the 'in' relation of a point (location) in a region, but not the same. A region is contained in another region if any point in the first region is also in the second region.

5.6 Hierarchy of Regions

In many situations, regions are structured hierarchically, which means that the 'contained in' relation between regions is a tree. Several subregions are contained in a super-region.

5.7 General Case of Containment: A Lattice

Different observations or different classifications lead each to a different formation of regions. The same point in space is included in different regions: A point can be in a forest area, in a region of south exposition, in a region with 800 – 1000 mm rainfall annually, 1000 m above sea level etc. If regions are constructed from different properties, for example land use and height, then regions based on one property are in general not fully contained in regions based on the second property.

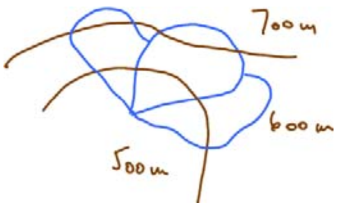


Figure 142 three watersheds and 3 height regions

The containment relation gives a (semi) lattice induced by the classification of point properties. It starts with smallest regions, which are uniform in all properties and gives the following diagram of containment (Figure 142). This is the same mathematical structure as the heterachy of classes—but applied once to classes once to individual regions.

Figure

6. FIELD: LANDSCAPE

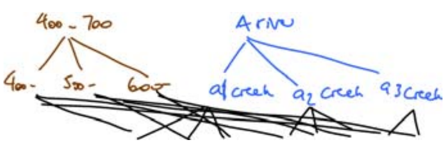


Figure 143 Containment lattice

The surface is a boundary of a material object (solid), namely the earth.

The landscape is a surface undulating in 3d space. It has a structure imposed by the process of water raining on it, flowing down over it and being stored at some locations. Water and the effects of gravity, together with the irregular form of the surface of the earth produce a structure which can be seen as objects (lakes, watersheds, mountain peaks).

This is an application of the ontology of liquids to large scale space; the behavior of the liquid is independent of the scale (at least at the level considered here; the detailed formulae for flow of liquids do not scale directly.).

6.1 GRADIENT

The flow of water on the surface follows the gradient, the lines of maximal descent. They are also called Falllinien. These are determined for each point of the surface.

Formulae

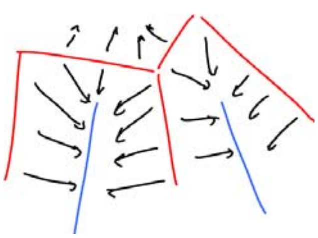
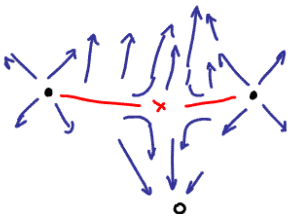


Figure 144 ridges and channels

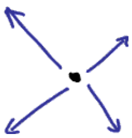
6.2 RIDGE LINES AND CHANNELS

Ridge are lines where the direction of the gradient go away on both sides channels (also called Talweg) are lines where the gradients come together on both sides. (Figure 144) break lines are lines where gradients are incoming on one side and outgoing on the other side. These lines are 1-dimensional lines embedded in the surface of the earth, which is a 2-dimensional geometric object. Channels are not necessarily streams, but they indicate where water would flow.

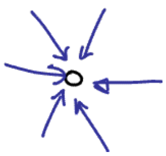


6.3 Peaks, sinks and Saddles

Peaks are points where ridge lines come together. They are points where all lines of maximal descent go away. Sinks are points where the channels come together and all the lines of maximal descent come together. Saddles are the places where ridges and Talweg cross.



A peak

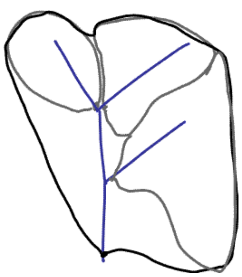


A sink

6.4 Watershed

For every point on a channel, the region from which water flows to this point can be identified. It is convenient to do this for junction points, where a watershed for each tributary to the junction is determined (Figure 145). Watersheds are 2-dimensional regions of the surface of the earth. Watersheds for all points upstream to a given point are hierarchically included in the watershed for this point.

Figure 145 A junction with three watersheds



Two level of watersheds

6.5 Lakes

Searching on the surface for gravity containers identifies the lakes. Inside a lake is at least one sink. The so identified gravity containers are not necessarily filled with water. In arid climates, rain may not be sufficient to fill a sink with water at all times (dry or intermittent lake).

6.6 Secondary effects

The form of landscape is often caused by the effect of water flow (or glaciers, wind erosion, etc.). The objects formed are as well conceptualized in terms of their genesis through water flow as their current effect on water flow. More details in (Frank, Palmer et al. 1986).

The structure imposed on landscape from water flowing over it is the same as in small scale space, because the physical laws are the same. But the flow of water is influenced by the form of the landscape. A hen and egg problem? [scheidegger]

In the landscape we can separate primary and secondary effects: long time flow of water over a surface erodes the surface and this leads to specific forms. These effects are the same in small scale and large scale space, but are very seldom observed in small scale space, due to the small time scale: water erosion is usually so slow that the effects are not visible in a human lifetime and thus seldom visible in a small scale environment.

6.7 ATTRACTION AND OTHER FIELDS

Geography (and other sciences) also uses fields to model influences, often in the form of a 'gravity law' where attraction spreads out from a center towards a periphery. These are essentially special types of fields of point properties (xx--).

$$F_{12} = g \frac{m_1 m_2}{r_{21}^2} \bar{r}_{21}$$

$$\bar{r}_{21} = unitvector$$

$$\textit{for a point in the field} \quad g(r) = g \frac{m_2}{r_2} \hat{r}$$

$$\bar{r}_{21} = \frac{r_1 - r_2}{|r_1 - r_2|}$$

7. LINEAR VS. AREAL OBJECTS: GRAPH THEORY

The contrast between movement along lines and working a field is strong but the two views coexist in our understanding of space. Fields are limited by boundary lines, which serve often as path. The abstract formulation for the relations between places and paths is found in graph theory, which deals with a bipartite set of objects (nodes and edges) and the relations between them (adjacency) {Deo, 1974 #167}.

Graph theory does not capture all experiences of large scale space (Figure 131) but retains the essence; it abstracts from the actual path that may go through a wood or across a field and retains only that the path starts in Geras and ends in Kotaun (Figure 132). This is most often expressed in language using 'fictive motion' describing as if a person actually would walk along the path: “the path winds along the valley” (Talmy 1983). Fields, woods and other areas which extend to the right and left of a path are visible, but they need not have boundaries and can gradually change from one to the other (from wood to grazing area). The experience of the local neighborhood, as it is experienced in large scale space, is leading to the theory of topology (Alexandroff 1961){Spanier, 1966 #168}.

Between the regions and the places exist a duality. The neighborhood relation between regions is dual to the connection between the places. A special case of this duality is the Pfaltz graph, the special graph structure which relates peaks, saddles and sinks to the ridges and the channels. The discretization, which fixes the scale at which ridges and talweg are identified must be kept constant (consider also the relation between ridges, talweg and contour lines!) (Frank, Palmer et al. 1986).

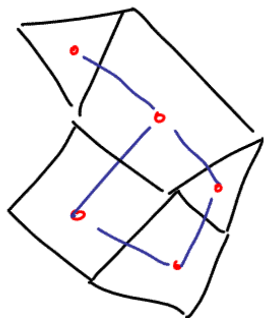
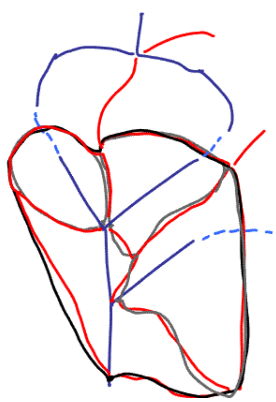


Figure Duality



Ridge lines and talweg

8. GEOGRAPHIC OBJECTS HAVE OFTEN UNDETERMINED BOUNDARIES

Only few objects in geographic space have natural boundaries which are sharp and well determined (Couclelis 1992; Smith and Varzi 1997). Most geographic objects seem to be an abstraction of things which have unclear, fuzzy boundaries (Burrough and Frank 1995; Burrough 1996). The list includes most natural phenomena, from biotope to mountain range; extensive research efforts center around soil type data (Burrough 1986) and often use the techniques of fuzzy logic (Zadeh 1974). Nevertheless, many practically used GIS model reality in terms of crisply delimited objects. This is appropriate for modeling tier 3 objects like, for example, cadastral systems, but soil, and land use do not have sharp boundaries and to produce a fiction of sharp boundaries contradicts experiences of reality.

9. GEOGRAPHIC OBJECTS ARE STABLE

The objects of geographic space are mountains, forest, and streets remain stable in time. Natural change in landscapes is usually slower than human experience. Changes in vegetation or even snow cover or light changes are slow in comparison to movement in small scale space and we typically use only landmarks that are not changing with seasons. Social progress (see tier 3) creates places through conventions, selecting landmarks that do not change rapidly [Lynch, 1960 #169]. Topographic maps depict stable objects in the landscape that are useful for navigation.

10. TERMINOLOGY: MOVE VS. LOCOMOTION

Sometimes, it will be necessary to use a different word for moving an object in small scale space and to move around objects in large scale space. Wordnet (Laboratory 2005) gives

> (130) travel, go, move, locomote -- (change location; move, travel, or proceed; "How fast does your new car go?"; "We travelled from Rome to Naples by bus"; "The policemen went from door to door looking for the suspect"; "The soldiers moved towards the city in an attempt to take it before night fell")
> 2. (60) move, displace -- (cause to move, both in a concrete and in an abstract sense; "Move those boxes into the corner, please";

"I'm moving my money to another bank"; "The director moved more responsibilities onto his new assistant")

I will use *locomote* for the move operation in large scale space if it is necessary to differentiate it from moving objects in small scale space, which will be described by *move*.

11. THE OBJECT VS. FIELD DEBATE

We have seen in large scale space the coexistence of a field conceptualization that relates directly to tier 1 and an object conceptualization. This connects to the object vs. field debate in geographic information science. Initially, the choice between raster and vector representation of geometry was considered a technical issue of implementation (Dutton 1979). The early discussion often mixed conceptual and implementation considerations (for an early and extreme example see (Corbett 1979), where fundamental mathematical considerations from topology are expressed in the assembler code of a particular computer).

It was restated as a debate between GIS with an object concept (not to be confused with object-oriented as used in software engineering; (Egenhofer and Frank 1987; Worboys 1994) uses the term object based GIS), where objects have sharp boundaries delimited by vectors and the GIS which model the continuous variation of attributes over space using a regular tessellation, e.g., a raster (Frank and Egenhofer 1990).

The vector vs. raster debate has been fruitful, because it has forced us to consider and reconsider the epistemological bases of our work and has led to an extensive discussion of fundamental questions (Chrisman 1987; Mark 1991; Mark and Egenhofer 1994). The debate has promoted the development of ever more powerful software, achieving a nearly complete integration of vector and raster data (Herring, Egenhofer et al. 1990).

Chapter 18 360 Formalizing Image Schemata For Geographic Space

In this chapter a linguistically based analysis of spatial terms, similar to chapter 330xx, is undertaken. The subset of reality considered here consists of objects classes in geographic space with the relations between them. The image schemata are:

- LOCATION: This image schema is missing in Johnson's list but seems to be important for geographic space (Johnson 1993). We use it as a position in space.
- PATH: A PATH connects locations and consists of a starting point, an endpoint, and points in-between these two.
- REGION: This image is the geographic space equivalent to Johnson's CONTAINER schema. A REGION has an inside and an outside.
- BOUNDARY: This image schema is similar to Johnson's CENTER-PERIPHERY schema. A center is separated from its periphery by a BOUNDARY.

These objects cannot move and their relations are fixed accurately but not completely known. Particular properties of these objects that would depend on subcategories, for example highway as a particular type of path, are not considered,. The immediate relations are relations that exist without the interference of another object. In addition, movable objects such as PERSONs and their location in this space are included. This part of the ontology is applicable to model Location Based Systems (LBS) and car navigation systems. The concrete examples are taken from the Eastern European environment (Figure 146).

Figure 146: map of example geography used

1. Relations

We first treat the relations between the geographic objects and then the movement of persons between them. The relations of objects are static and can be formalized with predicate calculus. For the formal model, a set of base relations are singled out which are recorded and other relations are derived from them.

This world is logically closed in the database sense (Reiter 1984): everything is known about the scene and what is not known can be assumed to be false. In particular, there are no unknown objects, all objects have different names and all relations are known or inferred from the image schemata.

1.1 Base relations:

A scene is represented by a number of facts, which seem to be cognitively salient and basic and are formally simple and without redundancy. In particular, we prefer relations that are simple (i.e., which are partial functions from a to b) (Bird and de Moor 1997; Frank submitted 2005). There is no cognitive justification for these choices of base relations—other relations could be selected and the base relations deduced. For the scenes considered, we use two simple relations, i.e.,

- location in region, and
- region inside region

and two non-simple relations which are symmetric (only a set of non-redundant facts is stored), i.e.,

- location directly connected to location, and
- region borders region.

1.2 Location and Relation between Places

A path connects places. We differentiate between the simple "direct path" and the indirect path, which consists of a sequence of "direct paths."

1.2.1 Direct Path

Connects places directly, without any intervening place. A direct path has a start and an end location. There is, at this level of detail, no need to model path as an object, just as a relation between two places. Different kinds of paths are not differentiated (e.g., highway, railroads etc.).

"Es gibt einen Weg von Wien nach Baden."
"There is a way from Vienna to Baden."

The path relation is symmetric:

a "direct path" b => b "direct path" a

It is derived from a non-redundant base relation as the symmetric completion.

"Du kannst von Baden nach Wien fahren und am Abend wieder zurück."
"You can drive from Baden to Vienna, and back in the evening."

Particular path relations, e.g., in the case of a one-way street, are asymmetric.

1.2.2 Indirect Path

An indirect (transitive) path connects two locations through a sequence of direct path relations, such that the end location of one direct path is the start location of the next path. A sequence of paths exists, such that the start point of sequence is the start point of the first path and the end point of the first path is the start point of the second one etc.

a gp b = [a P a1, a1 P a2, a2 P …. P bn, bn P b] *Formula*

The generalized path is derived using transitive closure. The details of the algorithm are particular to deal with cyclic and bi-directional graphs, well known as shortest path algorithm (Dijkstra 1959)[dijkstra, sedgewidge].

1.2.3 General connection: "über" or "durch"

"Wenn du von Wien nach Budapest fährst, dann fährst du durch Gyoer. Der Weg von Graz nach Wien führt über Baden."

("If you drive from Vienna to Budapest, you will drive through Gyoer. The way from Graz to Vienna goes through Baden.")

A generalized path goes "via" its intermediate locations from the source to the target (a1…an, b1… bn)

1.2.4 Umweg

A path has a length and generally there are several paths between two locations, some of them shorter than others. A detour is a path that is longer than a shorter path, a round about way (Laboratory 2005).

"Der Weg von Wien über Sopron nach Budapest ist ein Umweg. Der direkte Weg führt über Gyor."

"The way from Vienna to Budapest through Sopron is a detour. The direct route goes through Gyor.")

Formally path x from a to b is a detour if

path yand y from a to b exists and length x > length y.

1.3 Relations with Region

1.3.1 Region inside region

A region can be inside another region. This relation is asymmetric (Soja 1971).

"Die Steiermark ist in Österreich."

"Styria is in Austria."

1.3.2 Indirect inside: (in*)

Inside for region is transitive: if region 1 is in region 2 and region 2 is in region 3, then region 1 is indirectly in region 3.

"Die Steiermark ist in der EU." Styria is in the EU.—because Austria is in the EU

Indirect inside is the transitive closure for inside.

1.3.3 A location is within a region.

"Wien ist in Österreich. Graz ist in der Steiermark. Budapest ist in Ungarn." "Vienna is in Austria. Graz is in Styria. Budapest is in Hungary."

If something is within a region and this region is within another region, then the thing is in the enclosing region as well (transitivity of the "in region" relation).

"Graz ist in Österreich." "Graz is in Austria." Because Graz is in Styria and Styria is in Austria.

A location can be indirectly in a region, if the location is in a region 1 and this region 1 is indirectly in region 2 then the location is indirectly in region 2:

loc1 in region2 <=> loc 1 in region 1a and region 1a in* region 2*

1.4 Relations with Boundaries

Regions have boundaries, which can be conceived as determined, sharp lines, or one of the different types of undetermined boundaries (Burrough 1996; Burrough and Frank 1996) (Smith and Varzi 1997)

1.4.1 Neighbor

"Ungarn grenzt an Österreich und die Slowakei."
("Hungary borders upon Austria and the Slovak Republic.") (implies that Austria borders Hungary)

Neighbor is a non-simple but symmetric relation. A region can have several neighbors but if a is neighbor of b then b is neighbor of a. It is constructed from the non-redundant known relation, "region borders region".

1.4.2 Island

"Das Land Wien ist vollständig von Niederösterreich umgeben. Großbritannien ist eine Insel."
("The territory of Vienna is completely surrounded by Lower Austria. Great Britain is an island.")

A region is surrounded by another region (is an island) if it has only one neighbor.

1.4.3 A Path crosses a Boundary

If a path leads from a location in one region to a location in another region, it passes a boundary:

"Wenn du von Wien nach Budapest fährst, musst du die Grenze in Hegyeshalom passieren."
("If you drive from Vienna to Budapest, you will have to cross the border at Hegyeshalom.")

The same is true for a generalized path.

"Die Strasse von Graz nach Udine passiert die Grenze bei Tarvisio."
("The road from Graz to Udine crosses the border at Tarvisio.")

The issue of the level of boundary; state boundary vs. country boundary, is considered later (see xx).This follows from Jordan's curve theorem (Frank submitted 2005).

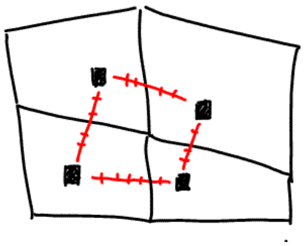


Figure 150

A path crosses a boundary if its start and end point are not in the same region:

a crossesBoundary b = not (a inSameRegion) b
a inSameRegion b = a in r and b in r

1.4.4 Boundary towns

A location is a boundary location if there is a direct path to a location in another region:

"Sopron liegt an der Grenze."
("Sopron is at the border.")

loc a OnBoundary => exist directPath loc a to loc b and loc b notInSameRegion loc a

1.4.5 between

A boundary is between two locations if the direct (or indirect) path from one to the other crosses the boundary:

"Die Grenze zwischen Ungarn und Österreich liegt zwischen Eisenstadt a und Sopron."
("The border between Hungary and Austria is between Eisenstadt and Sopron.")

Between loc a loc b => exist direct path loc a loc b and loc a notInSameRegion loc b

1.5 Persons

Persons and other autonomous and movable objects are the focus of attention considering move operations as they are important for navigation. For the analysis we construct a sequence of scenes. Assume scene n is at t_n, e.g., scene 1 is at t_1. Time points are ordered t_1 is before t_2, etc.

1.5.1 at

Persons are at places and remain there unless they move.

"Peter ist in Graz. Max ist in der Steiermark, er kann nicht in einem Café in Wien sitzen!"
("Peter is in Graz. Max is in Styria, he cannot sit in a coffee house in Vienna!")

A person can only be at one place at a time. The relation is a function from person to location: for each person there is exactly one location. The location may not be known and, therefore, the relation is partial.

1.5.2 move

Persons move to places and are then at the place, unless they move further:

"Er ist nach Gyor gefahren, jetzt wartet er dort auf dich."
("He went to Gyor, now he is waiting there.")

scene2 = Move p l scene1 => isAt p l in scene2

If a person is found at place p1 at time t1 and place p2 at time t2 one can deduce a move:

"Simon war letzte Woche in der Steiermark, jetzt ist er wieder in Wien.—Ist er am Samstag oder am Sonntag nach Hause gefahren?"
("Last week Simon was in Styria, now he is back in Vienna.—Did he drive home on Saturday or Sunday?"—move inferred in the time in-between)

1.5.3 at unspecified locations

A person can be at an unspecified location within a region:

"Er ist in Ungarn auf Urlaub."- Simon ist in der Steiermark, aber ich weiß nicht in welchem Ort.
("He is on vacation in Hungary.")- Simon is in Styria, but I don't know at which place.

A person can be moving along a path and the current location is not specifically known:

"Er fährt jetzt gerade von Wien nach Salzburg, ich weiß nicht wo er genau ist."
("He is driving from Vienna to Salzburg right now, I don't know where exactly he is.")
"Peter ist auf dem Weg nach Graz."
("Peter is on his way to Graz.")

1.5.4 Deduce "in" region from "at" location

If a person is at a location and the location is inside a region, then the person is in the region:

A ist in Budapest => A ist in Ungarn

If a person is on a path and the path is in a region, then the person is in the region:

"Simon ist in Österreich, er ist auf dem Weg von Graz nach Wien."
("Simon is in Austria, he is on the way from Graz to Vienna.")

1.5.5 Conditions for move

To move requires for a person some preconditions, unestablishes some facts and establishes new facts; in order to move from a to b, one has to be at a and there must be a path from a to b. Te result from moving from a to b is that one is at b and not at a anymore.

Move p from a (i.e., location) to b:
p is in a, path a b
unestablish p in a, establish p in b

Unless there is a path, a person cannot move from one place to another:

"Du kannst von Baden nicht direkt nach Schwechat fahren, du musst über Wien fahren."
("You cannot drive directly from Baden to Schwechat, you have to go through Vienna.")

If the person is at an unspecified location within a region, then it is only required that there is a path from some location in this region to b.

1.5.6 Position on path:

"Er ist auf dem Weg zu dir. Er ist zwischen Wien und Salzburg."
("He is on the way to you. He is between Vienna and Salzburg.")

X auf dem Weg von A nach B ==> X isAt A in scene 1, path A B in scene1, X is between A and B in scene2, X isAt B in scene3,
X kommt in B an ==> X war auf dem Weg von irgendwo nach B

This is a hierarchical decomposition of the single move in two steps, to leave and to arrive (see xx).

1.6 Checks for Inconsistencies

The set of base relations contains minimal redundancy. Nevertheless, inconsistencies can be introduced: For example, a person cannot be at a location in a region a and on a path that is not (at least partially) inside a. In a formal model, guards against the introduction of such inconsistencies can be built in; in the database literature, these are called consistency constraints (Frank submitted 2005).

2. FORMAL EXECUTABLE MODEL

A formal, executable model for inferences with the relations presented here has been written in a functional programming language (Peterson, Hammond et al. 1996). If a suitable set of support operations to deal with relations is available, the content of the image schemata is expressed in about 80 lines of code. Most rules can be written as equations between relations and relation transforming functions (i.e., point-free in the categorical sense [bird- de moore].

The use of a typed relation calculus with polymorphism allows to overload relation names; for example "a location in a region" and "a region in a region" can be reduced to a polymorphic in:: a -> b -> Bool (with two type variables a and b) and instantiations in: Location -> Region -> Bool and in: Region -> Region -> Bool. This is not only "syntactic sugar", but leads to the identification of commonality and connects to the use of the relation prepositions in natural languages.

3. METHODOLOGICAL OBSERVATIONS

The method used here is borrowed from linguistics. For linguistic demonstrations, a single utterance which is acceptable by a native speaker is sufficient to demonstrate the existence of a construct. Is a single commonsense reasoning chain as given here sufficient? It documents that at least a situation exists where the suggested spatial inference is made—thus it demonstrates at least one aspect of a spatial relation in (one human's) cognition. Are these common sense rules valid for all languages?

3.1 INTERACTION OF IMAGE SCHEMATA WITH OBJECT PROPERTIES

Image schemata interact with object's properties. For an object to move along a path, it must be of the appropriate kind (only trains run along railway lines, cars cannot follow a foot path, etc., and similar restrictions apply in other cases). The current approach to capture image schemata with the definition of spatial prepositions may be too simplistic; {Raubal, 1997 #423} semantic atoms (see 315) are like affordances and structure a spatial situation in order to know what to do {Gibson, 1979 #403}.

4. METAPHORICAL USE

This geographical space is very fruitful as a source of metaphor. For each of the concrete usages given here a corresponding metaphorical usage can be suggested {Lakoff, 1980 #13}, {Lakoff, 1987 #254}, {Johnson, 1987 #223}. Geographic space is typically used to structure the space of ideas—one could posit an overarching metaphor “the world of ideas is like geographic space”: ideas are connected (by logical path), people have arrived at some position, but not yet moved on to a new understanding, in order to move from one camp (political party) to another, one has to cross a boundary… "life is a journey" metaphor {lakoff, johnson] is also using geographic space as the source domain. The journey metaphor is used to structure a large number of aspects of the understanding of our lives. Dieberger has explored the city as source domain to structure the web and organize navigating it (Dieberger 1994; Dieberger 1995; Bird and de Moor 1997).

In this domain the relations are static because geographic objects do not move, only people move among them. This lets us at conjecture that geographic space is selected as a source domain for the metaphorical discussion of ideas, because ideas are seen as unmovable, only the position people hold can change, not the ideas themselves (this may not be accurate truth, but is the conceptualization of ideas). x

5. CONCLUSIONS

This restricted set of objects from geographic space leads to a rich set of relations between them. The commonsense knowledge of this environment is captured in a set of logical implications following from individual relations. It may be surprising how much deduction is actually possible at this high level of abstraction, where neither form nor location of individual objects are considered (except excluding physically impossible situations, e.g. the regions are considered connected or composed of few pieces, reasonable compact etc. (Pratt, Zyda et al. 1995)).

Most previous efforts to analyze spatial relations have used relation calculus and have concentrated on spatial relations which are amenable to this treatment. To include aspects of people moving in geographic space, we used functions. The two tools are not as different and their conceptual merging is in category theory (Barr and Wells 1990; Herring, Egenhofer et al. 1990; Asperti and Longo 1991; Walters 1991). Function composition tables can be used similarly to relation composition tables; they show patterns which can then be succinctly formulated as rules.

The conceptual organization of the large scale space follows the same principles of theory building which we have introduced for the small scale space. Operations change properties and connect to the observation of properties which are changed but also to properties which make it difficult or impossible to perform an operation.

Chapter 19 380 Methodological Summary for Objects in Tier 2

We have seen that an ontology for a changing world cannot simply be a taxonomy of objects based on some arbitrary differentiation between conceptualizations of objects, but must consider operations as a primary approach. These operations must correspond to operations on the physical continuum of the physically existing and observable world (tier1).

- Physical operations in tier 1 allow the observation and change of point properties. Change means difference between point properties at the same spatial location but different times.

- Physical objects and actions are regions of uniform properties. This gives for objects and actions a closed boundary in 3d snapshots and the 3d-t space-time continuum. Boundaries abstract geometric objects.

In this chapter geometric reasoning in *4D* (*3D-T*) space is used to derive some properties of the relation between objects and actions {Pigot, 1992 #6452}(Worboys, Hearnshaw et al. 1990). Geographic space is often conceptualized as a *2D* surface; a dynamic view gives then a *3D*(*2D-T*) space-time continuum in which the same rules apply as to the *4D*(*3D-T*) continuum.

1. Regions of Uniform Values

Picture 1 apple tree

2. Static properties of objects and their geometry

2.1 *Classification of property values*

2.2 *Attributes of objects*

2.3 *Entities endure in time*

Figure 151

Photos

2.4 *Geometry of Objects*

Figure with Nuts and figure from timpf

3. Objects resulting from Classification form Topological Complex

The boundaries of a set of objects coming from a single classification form a complex [ref to cell complex, algebraic topology or homology]{Frank, submitted 2005 #809}; each boundary bounds an object on each side. All the objects form a partition, i.e., they jointly exhaust the space and are mutually disjoint (often described as JEPD, jointly exhaustive, pairwise disjoint). Sometimes a residual object has to be added, e.g., air, open space.

Given a classification to determine what is a 'uniform' object one can ask for a list of all objects within an area:

```
Get id's back = of course time determined.
ObjectsInView env -> classifcation -> view -> [soid]
```

For a geometric object in a complex, functions give the boundaries of the object. For cell or simplicial complex, these operations from algebras with well defined properties. (Frank submitted 2005)

A spatial database for which objects have such a structure is often called a topological GIS or a topological data structure. (Corbett 1975).

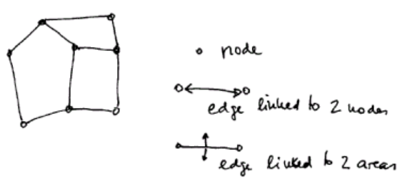


Figure 152 Simplicial complex of nodes, edges and areas with boundary and co-boundary relations

4. Relation between Objects

Objects resulting from a single classification are either neighbors or not; they cannot overlap. Comparing objects from different classifications of properties can overlap.

The topological relations between objects are usually described by the set of topological relations which were proposed by Egenhofer in his dissertation [xx, other refs]. They are a generalization of Allen's relations for temporal intervals for two (and more dimensional) regions. They are similar (but differently defined) than the relations the RCC calculus proposes (Burrough and Frank 1995)[comparison in Baden ??]

Overlay operations to determine such relations between objects from two classifications are the construction of a refined simplicial complex in which all regions are uniform in both properties. The original object then consists of several refined regions.

Figure 153

5. REFINEMENT RELATION BETWEEN PARTITIONS

If we divide the values of an observable property into a ranges, completely covering all values (a 1D partition), then the corresponding division in areas is similarly a partition (2D) (Volta and Egenhofer 1993; Frank, Volta et al. 1997). A division of the attribute space leads to a spatial subdivision; the finer we divide attribute space the smaller the regions in the spatial subdivision become. There is a function leading from a division of the attributes in classes to a spatial subdivision, which has no inverse (Frank, Volta et al. 1997).

This gives containment of objects with different granularity: One object may be part of a larger object and the larger object contains a number of smaller objects.

```
Contains :: obj -> env -> [objs]
Contained:: obj -> env -> obj
```

Containment relations may form hierarchies, for example, for the political subdivision of a continent in countries, regions, provinces, communes, etc. (for example, the European NUTS, National Units of Territorial Subdivision, subdivision form a hierarchy of partitions, where each higher level of NUTS forms a refinement of the previous one). Timpf has investigated how such containment hierarchies are formed, how they relate to other hierarchies (e.g., functional), and how they are used for cartographic generalization [Timpf diss].

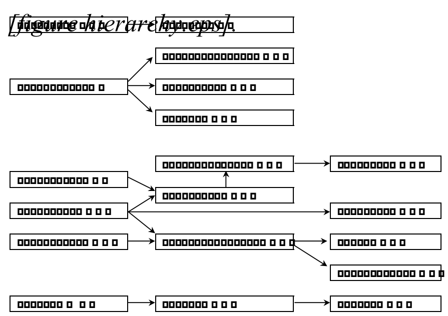


Figure 154 The subsummtion-graph of Lifestyles

6. DYNAMIC OBJECTS

6.1 *PHYSICAL EVENTS AND PROCESSES*

Events are changing some of the observable properties of the space continuum over time: a property observed at a location *x* at time *t1* and *t2* differ. Events result in space-time regions of different observations for some specific properties. The movement of a solid object results in a space-time region with a uniform vector of movement; other properties may change non-uniformly. I do not differentiate between instantaneous changes, e.g., switching the light on and slower changes, e.g., heating a room. The difference is in the scope of the observation: switching the light on is also a gradual process, only much faster than heating.

Events change the state of the world in a uniform way.
Events are not necessarily short.

Tokens that are names for events map to spatio-temporal regions, which we interpret as physical events. Not all of the *3d-t* regions that have such properties have an event name.

The difference between entities and events—endurants perdurants (Bittner and Smith 2003 (draft)) or continuants and occurants (Simons 2000)—does not map immediately to space-time region and its properties; It is the result of a complex classification based mostly on expected life span. From a single observation, e.g., a snapshot made photographically, we cannot identify events, or objects; common experience allows often to deduce material objects and the occurring events, but it is not possible to differentiate between a picture showing a car to say if it is in movement or not (photo). Objects are always part of an event, possibly the null action, which changes nothing

6.2 EVENTS ARE UNIFORM CHANGE

Regions with no change have for all observed properties the differential of zero; areas of change have differential observations different to zero.

Consecutive observations are filtered for temporal autocorrelation – values, which remain the same, have no novelty – and regions of uniform changes aredelimited. Comparing two observation close in time gives difference observations, which are a discrete case of 'differential observation' *dv/dt*, the rate of change of the observed value in time at the same location.

Material entities: Assume a set M of tokens m, which map to spatio-temporal (3d-t) regions, with a uniform value for a property

The most important example for such a 'differential observations' is the speed and direction of movement of points, which is uniform for a moving, non-rotating, object. There is evidence for neural structures in our visual system that change is necessary for observation and movement, as difference between consecutive time points, is detected early in the processing of visual signals (Gibson 1979; Marr 1982; Regier 1996).

Figure with space-time region (for 1d-t points)

Formulae: f (x, t1) /= f (x, t2) t1 /=
8

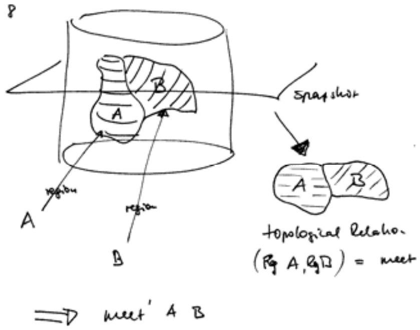


Figure 155: Space-time regions

6.3 MOVING AND CHANGING OBJECTS

Objects have permanence in time and can move position or change shape. The observation of movement or change of shape for table-top objects which are under our permanent scrutiny is easy. Solid objects move but maintain their shape, other objects on the table may change form as the result of actions.

How to recognize moves and changes inobjects in geographic space which are observed infrequently. What can be stated about the sand dunes of figure 76, where we have observations which are half a year apart? (Stein, Dilo et al. 2004) One might conclude that the sand dune X in spring 99 is the effect of margin the two dunes A and B from fall 98, but this is not necessarily the correct interpretation.

The generalized question: Given two observations t1 and t2 of an environment with two snapshots of objects i1 and i2 which have properties can we construct a changing object o1, such that the value of object o1 at t1 is i1 and, with reasonable assumption about applicable operations the change from i_1 at t_1 given i_2 at t_2. Note that a number of very strong assumptions are necessary to draw such conclusions (for example conservation of material). The argument becomes circular if we later determine the man of i_1 and i_2 and interpret the difference as a gain or loss of object o_1. Tricks of magicians rely often on abusing our experience to deduce from few observations that some region in space is one and the same material object.

o1 (t1) = i1 and o1 (t2) = i2

In this case, we are justified to label the two observed snapshot objects with the same identifier and consider them as snapshots of the same object.

Figure 156 Wandering Sand Dunes

7. THE GEOMETRY OF SPACE-TIME REGIONS

The assumption of a four-dimensional continuum in space and time implies the existence of parts of this continuum, which are spatio-temporal, four-dimensional regions; which we interpret as events. For a fixed point in time, *snapshots* from a 3d-t-region are possible and give spatial regions. Geographic projection separates the two space coordinates in the plane parallel to the surface of the earth from the height and results in geographic (2d) spatial regions or geographic space-time (2d-t) regions.

Projections and snapshots are topological transformation that preserves topological neighborhood and topological relations.

7.1 METRIC AND TOPOLOGICAL PROPERTIES OF SPACE-TIME REGIONS

The space-time continuum is metric, i.e., it is possible to measure distances between points in space and time with the ordinary axioms of distance functions (D1- D3). For most purposes, ordinary Euclidean distance extended to R^4 is sufficient (Pigot and Hazelton 1992). This gives definitions for neighborhoods, and induces a topology in this space.

Axioms for distance: D1 – D3

Assumption: Space-time is metric.

There are (exist) regions in space-time (3d-t regions) for which we have topology, separating interior, boundary and exterior of regions. Note: Space-time regions "exist" in a different way than material objects "exist".

Egenhofer: disjoint, meet, overlap, covers/covered by, inside/contains, equal
RCC: disconnected, part, proper part, identical, overlaps, discrete from, partially overlaps, externally connected, tangential proper part, non-tangential proper part.

For practical purposes, algebraic topology seems sufficient; regions have interior, boundary and exterior. Topological relations are defined as intersections between interiors, boundaries and exteriors of the two regions following Egenhofer and Franzosa (Egenhofer 1989) comparable to the RCC calculus (Cui, Cohn et al. 1993) . The terminology of Egenhofer for the relations is preferable, because these terms stress spatial aspects and do not mix the spatial with the part_of aspects. Linguistic evidence indicates that 'in/inside' and 'part' are two independent primes, and suggest that both are universal, i.e., are found in all human languages as separate units (Wierzbicka 1996).

7.2 PROJECTIONS

Projection is the operation, which reduces the dimension of a region by leaving away one of the 'coordinates'. Projection takes a region of *n* dimensions and produces a region with *m* dimension, where *m* is strictly less than *n*. Projection preserves the neighborhood (topological) structure of regions: a simple connected region projects to a simple connected region. A projection to space is not a usual operation, but projection from 3d-t space to time is useful: it gives the *timespan* (life) in which the region *exists* (figure 1) (Goodchild 2001). Geography and related sciences and technologies consider often the surface of the planet earth as a 2d surface (Goodchild 2001); a *geographical projection,* separates the *height* from the other 2D coordinates. Geographic projection applied to 3d-t *space-time regions*, give 2d-space-time regions (2d-t) and height regions. Geographic projection applied to snapshots (3d regions) gives 2d regions.

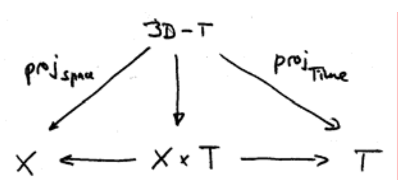


Figure 1: Category diagram

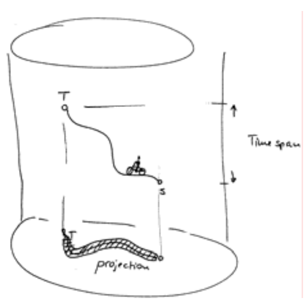


Figure 2: timespan and projection of a region, depicted following Hagerstrands Time Geography (Tom bycicles from S to T) [hagerstrand ref fehlt]

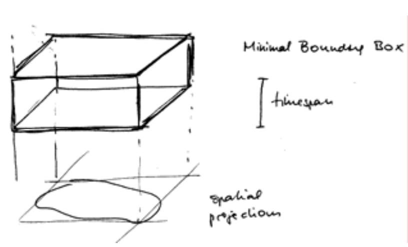


Figure 3: Minimal bounding box from projections in 2 spatial and 1 temporal dimension

7.3 SNAPSHOTS:

Snapshots are an alternative method to convert a 3d-t region to a region with fewer dimensions, by *fixing* the value for one or more dimension and determine the region for the remaining dimensions (figure 3). As the name indicates, *snapshots* are typically a restriction from 3d-t regions for a fixed time point t to a spatial 3d region (Pigot and Hazelton 1992).

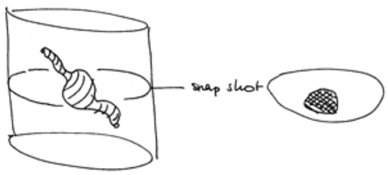


Figure 4: snapshot

7.4 Topological Relations between regions, projections and snapshots

Projection and snapshot operations are topological mappings and preserve neighborhood. Regions (in particular connected regions) map to (connected) regions. Do they preserve topological relations? The answer is unfortunately, not completely.

Interior points project to interior points and boundary points of projections are boundary points of the original, but not all boundary points project to boundary points (fig 5). For snapshots, boundary points map to boundary points and interior points map to interior points.

Topological relations as defined by Egenhofer (Egenhofer 1989) are not preserved, but some relations are maintained: for example, if a snapshot of a region A is inside of the snapshot of another region B, then region A is inside, covered or overlapping region B. A systematic account how projection and snapshot transform topological relations would be very useful.

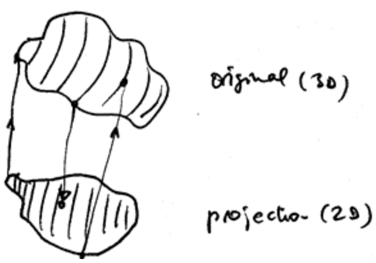


Fig 5 The boundary points of a 3d volume do not all project to boundary points of a 2d projection

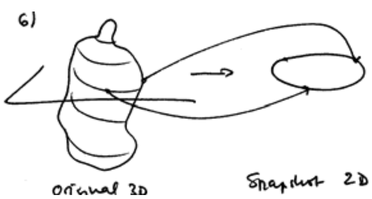


Fig 6 Snapshots map boundary to boundary and interior to interior

8. Stable Reference Frames: Locations and Times

We need stable reference frames against which changes can be observed, reported and discussed. Locations are fixed regions in space, which do not move (at least not relative to some larger frame of reference) and occupy therefore peculiar space-time regions. Similarly, fixed regions in time are used as references independent of spatial location; their space-time regions are across all space. Stable location objects are those that do not move, e.g., to their location only the null action applies. Bittner has in his PhD. thesis investigated how the location of arbitrary objects can be described with respect to a fixed frame of spatial subdivisions (Bittner 1999); the results extend naturally to temporal relations.

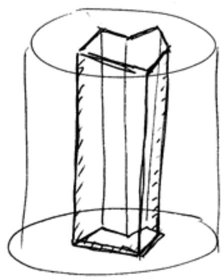


Figure 6 Location

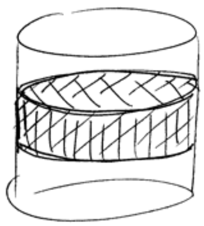


Figure 7 Time

Locations are very often named: England, USA, Gascoigne. Not all the named locations have well defined boundaries (Burrough 1996; Burrough and Frank 1996); sometimes human actions construct exact boundaries (Smith 1995; Smith and Varzi 1997), but these should be discussed together with socially constructed reality (Searle 1995) and are not covered here.

Fixed regions in time – here dubbed ***times*** in analogy to *location* – have conventional names, using references to the calendar: March 15, 2003, the year 2000. Boundaries are often not well defined as for "spring 2003"; *times* have seldom proper names.

Locations and *times* are with reference to a fixed frame – the part of the environment, which does seemingly not change. Change of the 'frame of reference' may be too slow to be noticeable – continental drift between Europe and America is for most human activities negligible (it is actually xxcm/year)– or the frame of reference is large enough that all meaningful activities are inside. This applies to the use of the earth as a frame of reference, ignoring the earth rotation and orbit around the sun etc., but applies also to the use of say an airplane as the local frame of reference to describe the activities inside the plane, ignoring the planes movement in an outer reference frame.

9. MEREOLOGY, PART_OF RELATION

The discussion of part_of relations is prominent in the current ontology discussions and has been used to classify spatial relations. Casati and Varzi (Casati and Varzi 1999) explore the relation between topology and mereology; the INSIDE relation for spatial regions has very similar properties to the PART OF relation, but it seems impossible to find a coherent and simple set of axioms covering both [Casati and cohn 2001]. "An account …involves mereological as well as topological aspects, and neither can be reduced to the other." (Casati and Varzi 1999) p. 197. Wierzbicka has pointed out that the 'part' relation is a semantic prime and universal; it is found in all human languages (Wierzbicka 1996); the word 'part' is polysemous and has 3 meanings (Fellbaum 1998):

- an identifiable part,
- a part which is separated from a whole, but was not identified before the separation,

- some objects of a group.

Only the first meaning is the prime concept of part_of - the other two meanings are expressed with the prime 'some of'. The core properties of the part relation are a partial order, which is reflexive, antisymmetric and transitive; this is the strict subset relation of mathematics. Additional axioms are discussed by Simons (Simons 1987).

I suggest here to restrict topological relations (inside) to regions that are abstract objects and mereological relations (part_of) to relations between material entities.

For material objects *inside* can be derived from *PART_OF*, but not the reverse: if A is part of B then A is inside B, but one must not conclude from A inside B that A is part of B: the ring is not part of the box (Figure 157) people inside a building are not part of the building (Figure 158). *PART_OF* requires *more* than just a spatial situation; the parts together must form a whole. This moves the question to the definition of wholeness. Casati and Varzi list four vague justifications of wholeness:

Figure 157

Figure 158

- causally unitary, i.e., operations performed on some parts have effects for the whole;
- functionally unitary, i.e., the parts contribute to an overall function;
- teleologically unitary, i.e., the parts contribute to an overall goal;
- unitary by dependence meaning that a part is dependent on some other parts, but there are others (Casati and Varzi 1999)

A decision about *INSIDE* is strictly geometrical but a decision about *PART_OF* depends on the context.

Note: If part_of is applied to spatial, temporal, or spatio-temporal regions then it obtains only between two locations, two times, two material entities or two events, but not mixed: This is an argument for typed formalization of ontology.

10. INVOLVEMENT OF ENTITIES IN EVENTS

The term '*involve*' describes the relation between an event and the entities it relates to, since the entities involved in an event are certainly not *part of* the event. Many entities can be *involved* in an event and they can be involved in different ways. Different types of involvement are possible and rely on specific relations between the space-time regions. Processes can involve locations and times, i.e., spatial snapshots and temporal projections.

For example, assuming that the individuals are all completely determined, “Punkti moved from my house to my garden today at 12:15”

```
Move (t1215, punkti, house, garden)
H = snapshot 1215 – dt,  house
G = snapshot 1215  + dt, garden
P1 = snapshot 1215- dt punkti
P2 = snapshot 1215 + dt punkti
Inside H p1, inside g p2, notInside H p2, notInside G
p1
```

House and garden are spatial locations and only the cat Punkti moves. This is the general pattern for *moving* events. In general, the space-time region of a process is of little interest – the entities involved are sufficient indication of the locus of the process. Specifically spatial processes list the involved regions as locations.

10.1 CAUSATION

Of particular importance are actions which cause other actions: pushing a button in the wall causes the light to go an. The switch in the wall is connected by wires to the light bulb and to a source of electrical energy; the laws of physics (at the level of differential equations) connects the different pieces and their interaction (see xx). Physical causation requires that the space-time regions touch; chains of causations are worms of connected space-time regions.

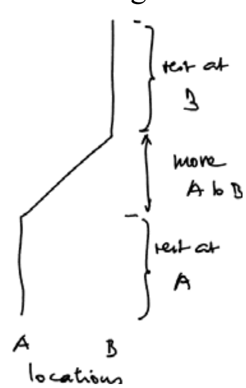


Figure 159: move of an object

10.2 SIGNATURE AS CLASSIFICATION OF INVOLVEMENT

Processes are described by what kind of entities are involved and the classification of entities relates these to the processes they can be involved in. Algebra describes these relations as ‘signatures’ and uses a notation, where the process name is followed by an ordered list of the kinds of entities involved.

```
Move :: Time -> Material Object -> Location ->
Location
```

A description of an event must complete the schema, provided by the signature. For example, above we had

```
Move (t1215, punkti, house, garden)
```

which is only well formed if *t215* is a *time*, *Punkti* is a *material object*, and *house* and *garden* are *locations*. An event is correctly typed, if for all the entities involved have the appropriate types. Formulae which are not properly typed are meaningless; there is no discussion what it means to state *move (house, t1200, Punkti, garden)*, which would translate to: “at the time ‘house’, noon moved from Punkti into garden”.

The use of operations which have multiple paramters which combine several object types into a single type achieve in the single coherent theory of typed function what is usually introduced as a *frame* [refs].

11. Classification of Entities and Events to Kinds and Processes

Classes like things collect things that are kind of a universal prime (Wierzbicka 1996). For example, different types of entities result in different space-time regions: solid bodies give space-time regions, which have congruent snapshots. Non-compressible liquids give space-time regions where the volume of the snapshot is constant etc. The same goes for events: an event of dissipation of heat gives a space-time region, which has the form of a cone.

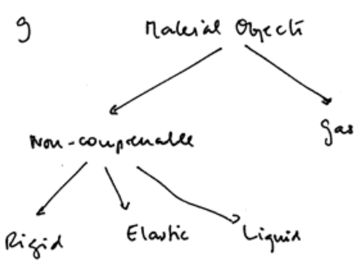


Figure 9 Classification of material objects

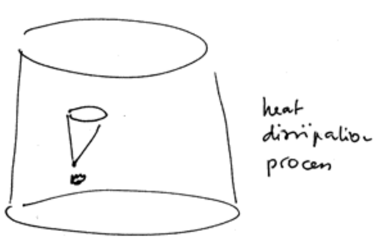


Figure 10 Heat dissipation in space-time diagram

12. Classification of properties to materials

Bennett has proposed tokens for materials; I consider materials’ classification of observed properties which occur often: a certain combination of physical properties is encountered wherever water, or gold, etc is. It is often sufficient to have a value for one of the properties to determine the others, based on previous experience.

13. Classification of entities

The invariants of space-time regions are useful to classify entities in classes. For example material objects can be classified in non-compressible and compressible ones. The non-compressible ones are then separated into liquids and rigid bodies, just by describing the space-time region they can occupy.

For non-compressible materials the volume of any snapshot is constant. For solids, even the form (boundary) remains the same.

We assume a set of tokens k and a function kind, which maps each entity to a kind (token): kind :: entity -> kind

Assigning a kind to an entity is an ontological commitment: an entity has the same kind for all its life. If it changes the kind, it also changes the entity identity. An ontology where material quantities are considered, which are sometimes liquid, sometimes solid, must use '*substance'* (in the sense of Aristotle's metaphysics) as a kind and have an attribute '*phase'* with the values *solid*, *liquid*, *gaseous*. In the same ontology, objects, which are solid and remain solid can have kind '*solid'*, e.g., the tubes in which the liquids or gases are transported.

14. CLASSIFICATION OF RELATIONS AND ENTITY ATTRIBUTES

Relations between entities like the topological relations and attributes of entities, e.g., the weight or volume are given classes of relations.

Some identity as long as the same kind

15. CLASSIFICATION OF EVENTS TO PROCESSES

Similar to the classification of entities to kinds, events can be classified to processes; different types of movement by people using their feet can be described as the process of 'walk'.

We assume a set of tokens p and a function process, which maps each event to a process (token). Process :: event -> process

An event cannot change its classification as a process; if an event changes its characteristics so much that its signature changes then we also have a new event. Different processes result in different kinds of space-time region. Figure 160 gives a sketch of the space-time region occupied by a movement and a diffusion process; the difference is crucial for the classification.

Figure 160

The types of involvement can be classified (causation, resistance, time, location, agent….), suggestions by linguists are either the schemata of Lakoff (Lakoff 1987) or Universal Primes (Wierzbicka 1996). Most fundamental verbs, as to be, to go, to do etc., can be used to identify the basic relations of involvement which are encoded in natural language grammar, often the case system (Langacker 1987; Langacker 1991; Langacker 1991). For example, Latin and Finnish use case markers to indicate the time, the location at which an event occurred or the destination of a movement, etc. Most modern languages use prepositions.

16. FORMALIZING THE ONTOLOGY

it is necessary to identify what foundational theories with axioms are used here and what definitions are used to extend them (Bennett 2001). The foundation is an algebra with equality. From set theory we include *element* of and *subset* relations and restrict the sets to finite sets given by extension. Integers with the regular arithmetics are assumed and topology can be dealt with the methods of algebraic, combinatoric topology (Henle 1994) with *interior*, *boundary*, and *exterior*, which is sufficient to define the topological relations. Time is based on an order relation. Space and time are combined using product and projections from category theory.

These mathematical foundational theories are combined in a categorical setting (Barr and Wells 1990; Asperti and Longo 1991; Walters 1991) and use an algebraic approach (Loeckx, Ehrich et al. 1996). The functional programming language Haskell (Peyton Jones, Hughes et al. 1999) which separates – as Bennett desires – the axiomatic small theory from definitional extensions and the model. The algebraic approach does not make the proof of completeness of an axiomatization simpler, but gives good guidelines to find the axioms necessary for completeness (Goguen 1991).

17. CORRESPONDENCE WITH LINGUISTIC RESULTS

Wierzbicka has listed a small set of words, which she considers to be

- primes – i.e., all other human concepts expressible in language can be expressed in these – and
- universal – i.e., they occur in all human languages (Wierzbicka 1996).

The ontology constructed so far (Bennett 2001), covers all the linguistic primitives Wierzbicka lists as necessary to describe the environment of humans (Wierzbicka 1996). Not included are all the expressions of mental states, of communication etc, which will appear in tier 3.

Some of the primes are included in the algebra used to describe the ontology: NOT, THIS, THE SAME, OTHER follow from equality, ONE, TWO, from integers, ALL, SOME, MORE are constructed as second order functions.

The ontology proper covers entities: SOMETHNG, events and processes: DO, HAPPEN, time: WHEN, BEFORE, AFTER, A LONG TIME, A SHORT TIME, NOW, space: WHERE, FAR/NEAR, SIDE, INSIDE, HERE, (and for geographic space: UNDER, ABOVE), partononomy: PART OF and taxonomy KIND OF, movement and existence: MOVE, THERE IS.

What is not included? The following primes are neglected: I, YOU, SOMEONE, PEOPLE; mental predicates: THINK, KNOW, WANT, FEEL, SEE, HEAR, speech: SAY, WORD; life: LIFE; evaluators: GOOD, BAD, imagination: IF...WOULD, CAN, MAYBE; interclausal linkers: IF, BECAUSE, LIKE. The completion of the ontology to include abstract concepts will have to include with these 'left-overs'.

Chapter 20 385 Top-Level ontology and a Method to design an Application Ontology

The description of a conceptual schema or ontology for an application is subject to inconsistencies. The human mind is infinitely flexible and conceptualizes the world according the needs of a task – which changes quickly; even while speaking or writing a few sentences (this makes all sciences which do not use formal methods difficult). To reach consistency in a logical description of the ontology is difficult, because a conceptualization used in one part does not necessarily agree with the conceptualization used in other parts. A word used in one place has not alwasys the same meaning as the same word somewhere else.

The usual approach is to describe only a taxonomy of nouns, typically hierarchically organized with every word just having a single hypernym (e.g. wordnet). This

- leaves most of the interesting information in the commentary, justifying the taxonomy,
- equates words with concepts, which is not justified (see polysemy), and
- breaks symmetric situation in an asymmetric way: a houseboat is a house and a boat – what is the concept that defines its place in the taxonomy, "house" or "boat"?

An improvement would be to link a houseboat to both, "house" and "boat" – but that will not differentiate it from boathouse; it is necessary not only to construct a network of relations between concepts, but to tag the relations: the connection between houseboat and boat is different than the connection from boathouse to boat.

Concepts are differentiated because our interaction with them is in some way different. These differences can be used to separate the concepts: what are the operaions objects of the one or the other can be involved in. The differences are related to verbs, i.e. operations; these are written as algebras (classes, categories).

The design of an application ontology is hardly ever started from scratch, it uses a top level ontology with a number of the fundamental theories already included which is then suitably extended. We start with a review of the top-level ontology constructed so far. Then we compare the combination of the small ontologies constructed with the process of blending [fouconnier] or metaphor [lakoff, johnson].

A 'cookbook' recepie will be given to construct the ontology to separate boat house and house boat in the context of other similar object classes. The example is due to Goguen [ref] and Kuhn [GIScience 2002]. The example is small enough that it can be described and complex enough that it exposes (hopefully) all the constructs necessary. The method can be translated to code in a functional programming language and uses an extended hinley-milner type inference system to make inferences about the applicability of operations to objects (this is comparable to the inferences which are possible in an ontology language based on descriptive logic [owl]).

1. UPPER LEVEL ONTOLGY

What are the fundamental concepts we have introduced so far?

1.1 TIER 1

In tier 1 we assumed the domains of *space* and *time* to produce a 4 dimensional (3D-T) continuum. *Properties* are fields. For each point in this continuum, properties can be observed and yield in a value: *observation* :: property -> space -> time -> *value*.

1.2 TIER 2

Classification gives connected regions of the 3D-T continuum which have uniform values for some property. We call these regions *events*; if base properties do not change in them, the null-action is encountered and we have a (physical) object. From events, *projections* and *snapshots* can be derived.

Events and their snapshots and projections have

- geometry. *Geometry* is represented by *abstract objects* (not physical) to which geometric operations apply: determine volume, area, centroid, length etc.
- other *attributes*, which are typically integrals over some point property values. This gives weight of material objects, moments of inertia, etc.

It is useful to introduce a concept of *material*, which is an abstraction of a bundle of point properties typically for objects made from this material (specific mass, mechanical properties like elasticity, viscosity, etc.).

Material objects have an extended, continuous life span. In general, objects are formed, such that interesting properties remain invariant; this will be used to drive the classification later. Two material objects cannot be at the same location: snapshots are always jointly exhaustive and pairwise disjoint (JEPD). Material objects are transformed by catastrophic events; different types of material objects allow different sequences of operations, which we call lifestyles.

For geographic space, which is often conceptualized as the 2D projection of 3D space, we have, location, path and regions. The 2d projections of geographic objects lack in general precise boundaries.

1.3 SOLIDS

Non-compressable objects are those, for which the volume in all snapshots is the same, solids are objects for which the form in all snapshots is the same.

1.4 LIQUIDS AND GASES

Liquids in glasses form temporary objects which can be merged to form a single new object, but the two initial objects can never again be recreated. The law of conservation of mater applies however. Consider for example coffee and milk, which is poured in a cup: not even a Vienna Ober can separate the coffee from the milk again, if the person wanted its coffee black (Figure 161). Liquids must always be contained in a container as they do not have a fixed form; they fill the hole of a container guided by gravity (or flow away, when spilled over a table, "searching" for containment).

Figure 161

Give figures for the liquid lifestyle

Gases behave much like liquids; under the influence of gravity, they either sink like a liquid or rise. Even for gases, the rule that no two material objects can be located at the same place is valid: gases mix and become a new object!

1.5 NON-RIGID OBJECTS

Food typically is prepared and appears on a table as pieces which are not solid and can be divided with the silverware into smaller pieces, moved to the mouth and eaten.

The form of non-rigid objects is not determined, but objects are delimited by the boundaries which appear when an object is moved; boundaries are often not visible and surprisingly long pieces may appear when one tries to roll spaghettis on a fork (figure?). The pieces have fixed material properties but not form: form changes as gravity acts on the material – with much variation from one kind of food the next.

2. COMBINING SMALL ONTOLOGIES

2.1 BLENDING

Blending is the conceptual merging of distinct properties of two objects to form a new conceptual object. From house and boat one blends the concept houseboat and boathouse, keeping different aspects of the boat and house in the two combinations. Blending is the foundation for metaphor [Lakoff Johnson] and for social construction [Searle]. Blending or metaphor are extremely powerful methods of human brains, which have not been observed in animals; perhaps this is the distinct differentiation between humans and animals?

Blending is a method always at work: new concept are formed from existing ones. Methods to construct ontologies should include it to allow the ontology to evolve and grow without explicite construction.

2.2 AFFORDANCES AND IMAGE SCHEMATA

The small ontologies reflect what Gibson has introduced as affordance. affordance describes the possible operations a thing offers to us [Raubal]. Examples: to observe the color of a thing and the operation painting the thing with a color is linked by the axiom that the color after painting is the color the thing was painted with:

color (paint (thing1, color1)) = color1

Affordances are closely related to image schemata [Lakoff, Johnson]; they are one of the many attempts to capture the semantics of operations.

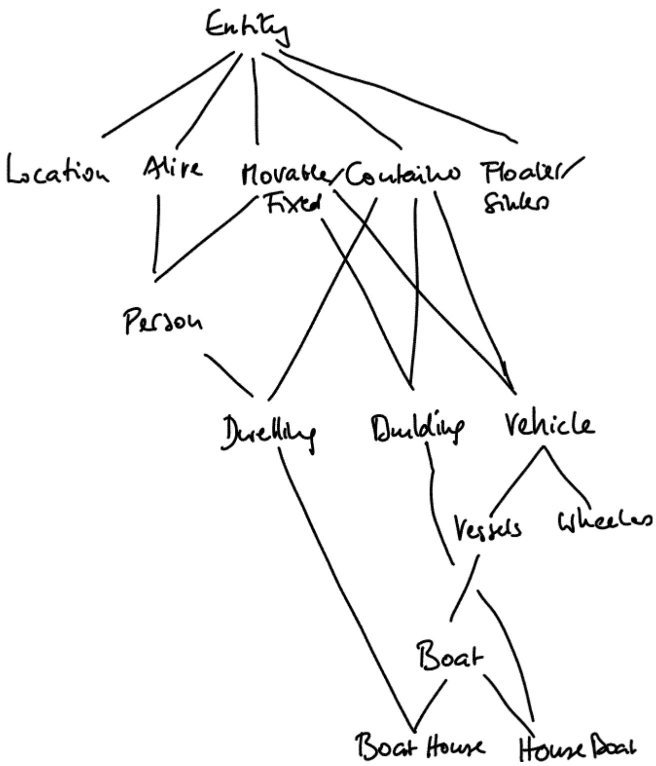
3. FORMALIZATION BY TAXONOMY

Taxonomies just order nouns. Nouns are understood as describing sets of objects (classes) and the taxonomy gives the subset relations between these classes. They describe an 'is-a' relation between classes: a boat is a vessel, a vessel is a vehicle. In wordnet additional glosses indicate what is meant.

boat -- (a small vessel for travel on water)
=> vessel, watercraft -- (a craft designed for water transportation)
=> craft -- (a vehicle designed for navigation in or on water or air or through outer space)
=> vehicle -- (a conveyance that transports people or objects)
=> conveyance, transport -- (something that serves as a means of transportation)
=> instrumentality, instrumentation -- (an artifact (or system of artifacts) that is instrumental in accomplishing some end)
=> artifact, artefact -- (a man-made object taken as a whole)
=> object, physical object -- (a tangible and visible entity; an entity that can cast a shadow; "it was full of rackets, balls and other objects")
=> entity -- (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))
=> whole, whole thing, unit -- (an assemblage of parts that is regarded as a single entity; "how big is that part compared to the whole?"; "the team is a unit")
=> object, physical object -- (a tangible and visible entity; an entity that can cast a shadow; "it was full of rackets, balls and other objects")
=> entity -- (that which is perceived or known or inferred to have its own distinct existence (living or nonliving)) – usually by subset relations of the objects they describe

house -- (a dwelling that serves as living quarters for one or more families; "he has a house on Cape Cod"; "she felt she had to get out of the house")
=> dwelling, home, domicile, abode, habitation, dwelling house -- (housing that someone is living in; "he built a modest dwelling near the pond"; "they raise money to provide homes for the homeless")
=> housing, lodging, living accommodations -- (housing structures collectively; structures in which people are housed)
=> structure, construction -- (a thing constructed; a complex construction or entity; "the structure consisted of a series of arches"; "she wore her hair in an amazing construction of whirls and ribbons")
=> artifact, artefact -- (a man-made object taken as a whole)
=> object, physical object -- (a tangible and visible entity; an entity that can cast a shadow; "it was full of rackets, balls and other objects")

Use of semi-formal tools like UML or logic-based languages like OWL captures not much more than is given in wordnet. Notice, that most of the important aspects of the semantics is captured in the informal glosses, not in the taxonomy.



The Lattice of sub-classes

3.1 ENTITIES

Boathouses and houseboat are entities, which have properties. They have identity and this differentiates them from each other.

entity -- (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

```
create :: EntType -> GIstate o
id' :: o -> ID
```

3.2 LOCATIONS

Locations are entites , which have a property to be land, water or beach/shore, which seem relevant for boathouses and house boats.

1. (992) location -- (a point or extent in space)
2. (2) placement, location, locating, position, positioning, emplacement -- (the act of putting something in a certain place or location)
3. (2) localization, localisation, location, locating, fix -- (a determination of the location of something; "he got a good fix on the target")

```
class Xentities l => Locations l where
    setSupportable :: LocKind -> l -> GIstate l
    getSupport :: Env -> l -> LocKind
```

3.3 MOVES

The difference between buildings and boats is (among other things) that boats move and buildings do not: Introduce the verb move and separate the physical objects in those which move and those which remain fixed:

motion, movement, move
-- (the act of changing location from one place to another;
(WordNet)

Movables and Fixed are entities. The operations are to move something from one location to another location (it must be at the first location!).

3.4 CONTAINER

Containing things is important to differentiate between houseboat and boathouse: a boathouse contains boats, a houseboat not.

container -- (any object that can be used to hold things

hold, bear, carry, contain -- (contain or hold; have within;
(WordNet)

Containers and Containable are both entities.The operations are to put something in a container – which is an affordance of the container and the things contained.

3.5 PERSON

Persons are necessary to define boats (as vessels for people) and dwellings: a person is a physical object, which is movable. None of the specific properties and abilities of humans enter here, therefore this quasi-affordance stands for all of them:

person, individual, someone, somebody, mortal, human, soul
-- (a human being; "there was too much for one person to do")
(wordnet)

3.6 FLOATERS AND SINKERS

Boats float. We therefore introduce a difference between objects which swim and those that do not. This will interact with a corresponding differentiation in the location in land and water:

3.7 DWELLING

With the differentiation we have introduced so far, we can not describe the difference between a boat and a house boat – both are entities which swimm.

1. houseboat -- (a barge that is designed and equipped for use as a dwelling)
dwelling, home, domicile, abode, habitation, dwelling house -- (housing that someone is living in; "he built a modest dwelling near the pond"; "they raise money to provide homes for the homeless")
=> housing, lodging, living accommodations -- (housing structures collectively; structures in which people are housed)
=> structure, construction -- (a thing constructed; a complex construction or entity; "the structure consisted of a series of arches"; "she wore her hair in an amazing construction of whirls and ribbons")

Kuhn has already pointed out, that a dwelling is not a building [ref]; it meets the taxonomy of building only at the structure level. To separate dwellings from other containers, we have to make them livable for persons only, which will be done later as *Homes*.

3.8 The Rest Missing

Check the figure

Vessels are vehicles which swim, land vehicles use wheels – it seems that there is no term in English, so I make up Wheeler (which has several other meanings, which will not likely confuse here).

vessel, watercraft -- (a craft designed for water transportation) (wordnet)

4. Boathouse

There is here a difference between the terms for affordances and the terms for objects (data types, representations); this is the distinction between intensional and extensional definitions.

A boathouse can be defined in these terms as a building to store Boats

1. boathouse -- (a house at edge of river or lake; used to store boats)

Moving boats into the boathouse require that a new location type is inserted: LandWaterEdge.

4.1 Houseboat

With the differentiation we have introduced so far, we can only see that a houseboat is a boat, because we do not have a notion of dwelling.

1. houseboat -- (a barge that is designed and equipped for use as a dwelling)
dwelling, home, domicile, abode, habitation, dwelling house -- (housing that someone is living in; "he built a modest dwelling near the pond"; "they raise money to provide homes for the homeless")
=> housing, lodging, living accommodations -- (housing structures collectively; structures in which people are housed)
=> structure, construction -- (a thing constructed; a complex construction or entity; "the structure consisted of a series of arches"; "she wore her hair in an amazing construction of whirls and ribbons")

Kuhn has already pointed out, that a dwelling is not a building; it meets the taxonomy of building only at the structure level. To separate dwellings from other containers, we have to introduce people as different from non-people physical objects (using the affordance personable – a quasi affordance to summarize many of the affordances of persons).

```
class (Dwellings b, Vessels b loc) => HouseBoats b loc
where
```

To move a boat into a boathouse is with the described typing not possible – boats can only move to water locations, but the house can only be built on a land location. The connection between types and classes in Haskell is flexible enough to describe this network structure – languages which can only describe hierarchies must fail here!

Note: there seems not to be an English word for land-water-edge; beach implies sand and slope!

beach -- (an area of sand sloping down to the water of a sea or lake)

5. TYPING

5.1 UNTYPED UNIVERSE

With these affordances and their semantics given by the axioms, an untyped universe is defined and operations apply to any combination of arguments, for example, locations could be moved to boats (and not only boats to locations). This is the view of the database, where everything is an entity represented by an ID. In this universe, locations can be moved to a boat and similar nonsense; typing can restrict what operations are applicable.

5.2 STATIC TYPING

Static typing is used in programming language, where processes last for a short time. A program is checke at compile time and we are guaranteed that no type errors will occur during the execution[Cardelli]. Errors are detected very early, error detection is exhaustive and does not depend on the thoroughness (or lack thereof) of the programmer. Using an extended form of Hinley-Millner type system – as implemented in Haskell [report, ghc 6.4 user guide] much complex type inference can be done during compilation.

5.3 DYNAMIC TYPING

Dynamic typing is often used in connection with databases because entities in databases last long and conceptualisation may change in this time. Dynamic type checking controls before the execution of an operation, that the argument has the appropriate type. This is

- difficult, because an operation can be applied to many types (one can move persons, ships, cars...) and needs powerful type inference at run time,
- wasteful, because the tests would be repeated at each function call in a nested set of functions anew,
- errors are detected too late – namely when a user is running a program, not when the programmer is working on it.

5.4 Ontological typing

The issue is the connection between the affordances (classes) and the object types. Affordances are (sort of) verbs, types are (sort of) nouns. Affordances are observations and actions, which are carried out in the world and succeed or fail. Nouns describe sets of objects which can participate in some affordance. What we need is a flexible connection between the classes and the types: we must be able to use a tree stomp as a seat, a table and a outlook post (see figure xx in xx). So far we have defined the classes.

The point is therefore to connect types with affordances. First we define types for objects (as data types) and then connect the classes to the data types with instance declarations. These say that the operations of a class are applicable to instances of a data type. With powerful type inference mechanism, this can be organized that the applicability of an operation depends on other operations applicable to an object, leading all the way back to the physical properties.

For example: A person is a located, movable, and containable entity. Or: a building is a fixed structure not swimming which can contain something:

6. Natural Kinds for Animals

Animals are an important part of human experience – biologically, humans are part of the animal kingdom. Animals were also economically very important for people and were used since Aristotle as examples for ontology discussion.

6.1 Animals are 'moveables'

Animals are moveable (and can even locomote, i.e., move by themselves) and thus have natural boundaries where all what goes with the animal is part of it. Again, hierarchical considerations may apply: is the loose hair in the fur of a dog part of the dog? (Figure 163) Are hair in general part of the animal? – But these are questions of object resolution and can be dealt with the 'supertruth' method [smith, boegard?].

Figure 163

6.2 Animal lifestyle

Animals are born and die, they exist from birth to death. Again, animals are matter and the matter is existing before and after death a corpse of the animal still exists. Animals constantly eat and transform matter into energy and body material, they also excrement the remainder of the metabolism process.Important for (higher) animals is procreation: two adult animals of different gender unite to produce a new individual, which is born by the female parent.

6.3 Lifestyle of live agents

Life animals have an identity from birth to death, despite the changes in the mater they consist of. Their state of liveness cannot be suspended, if they are killed they are dead forever. A rule like agent a1 in t1 is identical with agent a2 at t2 (t2 immediately after t1), if a1 is live in t1 and a2 is live in a2 and most of the material of a1 and a2 is the same. Such a rule assures continuity of the biological memory, and is therefore pragmatically the same than what was discussed under agents.

6.4 Species: natural kinds of animals

Only similar animals can procreate and the offspring belongs to the same similarity class (mathematically this is an equivalence relation:

From two individuals of opposite gender a potentially infinite number of individuals can follow, which are all of the same type. This principle of folk biology is already mentioned in the bible, when Noah was instructed to load a pair of each species onto the Arche Noah.

Rule of folk biology: Any two individuals of a species can procreate and the offspring is of the same species.

Biologists know of exceptions to this rule, especially changes in the genetic code over time, which can lead to the creation of new species etc, but this is not of concern here.

This rule of folk biology defines the meaning of species – it does not explain something about the world!

6.5 Properties of species

Species are not physical things and do not have physical, material properties as such in the ontology created this far; they are an abstraction; each species is an abstract concept.

What is then meant when we say that dogs (the species) eat meat? Certainly not that the species, the abstract concept, eats meat. The properties of species as discussed in biology texts are properties which all individuals of the species have. It is evident that animals of the same species have typical form, which makes it possible for us and for them to recognize each other such that they can select appropriate partners for procreation. The process of procreation passes forward not only outside form properties, but many other details of the internal organization of the animal. This information is contained in the genetic code and represented as sequence of amino-acids forming the DNA; biologically one may define an individual by its particular DNA code.

6.6 Additional rule for property of animal in procreation.

Species are a convenient device of cognitive economy: in lieu of remembering the details for all animals of a species we have ever met, we just store one generalized description. Cats have tails is the sum of all observations of Tibble, Tiger and Punkti (and numerous other cats, of which most had a tail) and biology suggest that all other animals of this species cat – even the ones we have never seen and those not yet born, have tails.

7. Summary

A method to capture the semantics of classes based on the operations applicable is presented. This solution is flexible. The use of a functional programming language permits the formalization and produces executable code, with which we can test, whether the compiler rejects non-intended operations. No new tools had to be constructed.

Examples: it is not possible, to move a boat into a house boat, or to move a person into a boat house (a boat house is not a dwelling!). Semantics fixed in axioms in the affordances are, of course, always checked!

Does this scale? Wordnet demonstrates that the number of levels of hyponyms is not very large (even if more levels need to be differentiated than listed in wordnet), meaning that the number of affordances per base type is not growing very much (assume that each level of differentiation introduces a new affordance).

Achieving type checking statically is difficult and perhaps not always achievable. It seems not possible, if two different levels of detail in the conceptualization exist. (Example Location and Land/WaterLocation).

PART SIX 390 TIER 3: THE COGNIZANT AGENT

1. Tier 3 in General

Tier 3 deals with cognition and the use of cognition in agents and in their social interactions. The world of tier 3 is populated by multiple cognitive agents, which interact, observe, and manipulate the physical world. The cognitive agents coordinate their behavior.

Preview of parts:
A single agent and his internal representation of the world (including his own body)
Communication between agents to improve cooperation
Social constructions to organize social processes

Specifically spatial aspects are found in each part: the internal representation of spatial situations and specifically the foundation for qualitative spatial reasoning, the communication of spatial situation with maps and verbal instruction for, e.g., wayfinding, and finally all the socially constructed methods to manage land as a resource: ownership, political subdivisions, census, etc. One can argue that spatial cognition is in many cases where methods originate to be applied more generally to non-spatial situations as well.

Geographic Information Systems are part of human society, culture, and technology. They report about the physical world of mountains, glaciers, and lakes, but they also include the social constructions humans have arrived at during their evolution and history. This part attempts to differentiate the kinds of existence that these constructions and conceptualizations of the real world have.

Language and social constructions are not representations of single physical objects with their undeniable reality of material realness, but appear nevertheless as real: who would deny the reality of say a company like Microsoft, despite that there are no real objects: there are people that own, manage, or work for the company, there are buildings, but there is no physical thing "Microsoft Company". How do such constructions exist, compared to the existence of a dog?

It has always puzzled philosophers how language and social constructions came to existence: they work only if a general agreement is present, but to construct them the same agreement must exist already. This is in a way the same puzzle that confused Zenon, when he argued why Achilles cannot reach turtle, despite that he runs twice as fast (see xx). The solution is to look at the process that leads, in steps of decreasing length and time, to the point where Achilles and the turtle are only an infinite small distance apart. Similarly, the social constructions that are effective only when they are based on a general agreement, are arrived at in a process of continuous improvement which ever decreasing differences between agents. Mathematically we speak of a recursive process with a fixed point and use this to define, for example, semantics (Stoy 1981).

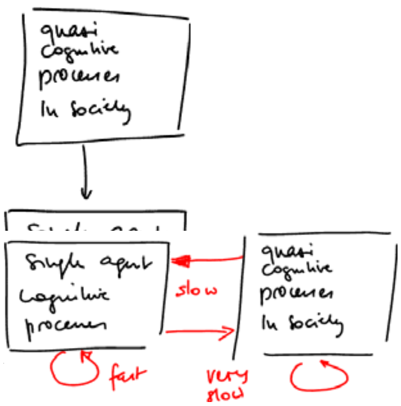


Figure 165: Interaction and speed of processes

It needs to be stressed that the connection between a single agent and the cognitive processes he uses and the quasi cognitive processes in groups are not two layers, one operating on top of the other (Figure 164), but there are strong interactions over extended periods of time between the two (Figure 165).

Some species of vertebrae, primarily primates, have learned that life in social groups is—despite the potential for internal strive—more beneficial; some authors argue, that only social organization made it possible to populate the niches at the border of the Savannah for primates and social development, especially language, emerged in an effort to acquire new territories by primates.

Similarly, newborn babies identify early with other humans and become involved with emotional communication—smiles and tears—at about the same time they develop a theory of objects (see previous part). Babies all over the world learn to speak a human language (and there is much speculation about what is inborn as a language instinct (Chomsky 1980) and what is acquired in contact with the environment and others).

The tier is divided in three parts:

- Cognitive agents,
- Communication and language,
- Social Construction of Reality.

The first part describes the abilities of cognitive agents, which have memory of previous states and can construct theories about the world, predict the outcome of their actions and plan them.

Human agents can communicate and use communication to act as a group more effective than as single individuals;

communication is used to coordinate actions. Communication uses signs (words) to refer to the entities of tier 2 (de Saussure 1995). A book is first a physical thing, but then the text communicates ideas about the world; the book belongs at the same time to the physical and the information realm.

Using language we can construct theories about the world, but we can also construct abstract, new concepts, which are useful to organize society but do not have a reference to a physical (tier 2) entity. Examples are marriage, property, or democracy: socially constructed concepts, which seem as real as physical objects ring, tree, or the parliament building (Searle 1995; Berger and Luckmann 1996). Constructions, like political subdivisions and owner ship in parcels are important for GIS, indeed they dominate the administrative applications of GIS.

The discussion here is often using linguistic arguments: Language is easily observable and we are justified to assume that language expressions are closely linked with the internal processes in the brain. With language we can describe (some of) our observations of the world and other agents and how they are interpreted. Language over the thousands of years of development of human society has developed structures that represent these observations and makes it possible to exchange such observations; but language may also affect how we observe the world (the famous Whorfian hypothesis (Carroll 1956)). .

This tier 3 spans the gulf between the more objective expressions of the law—as a socially constructed reality, which is nearly as objectively real than objects—and the purely subjective concepts in the agent. The subjective knowledge of an agent seems not consequential to a GIS—the data stored in a GIS are always externalized signs, which may represent the internal knowledge, but typically 'objectivized' in some way. However, the 'subjective concept' level may be useful to understand interoperability and the connection between different GIS. A GIS is constructed for an agency—an organization that is to a certain level autonomous (sometimes called authority, to express its autonomy). It can be seen as an agent, and its local memory—its GIS—seen as internal concepts, which are meaningful in its context.

Chapter 21 THE ONTOLOGY OF A COGNITIVE AGENT

Cognitive agents have a memory to remember previous states. They do not only react to the stimuli they receive from the environment like reactive agents, but their reaction to the environment depends on their internal state, including the memory of previous situations. This part will show how adding memory to an agent's computing capacity changes the behavior of the agent in a radical way. It leads, at least in human agents, to generalization of situations and actions; memory is not only useful to record previous situations but also to imagine future ones, which is necessary to plan actions.

Memory to accumulate experience but also to imagine future worlds.

Cognitive agents build internal representation that corresponds to the external reality. The operations cognitive agents—primarily human beings but also to some degree animals—must take into account the particulars of the interaction between the agent and the world. This part discusses the operations of a single cognitive agent, the internal processes that link the observations to their activities and what objects result from this. Humans have the possibility not only to observe the current situation, but to imagine past and future states of the world; Johnson has pointed out that this imagination is crucial for the highest and most difficult to explain aspects of human society, e.g., ethics (Johnson 1993).

The cognitive abilities of agents, in particular humans, are remarkable:

- the cognitive agent builds a model, which is structurally and operationally similar to the perceived reality.
- the model is not physical analogous (like a model train) but consists of internal representations in the brain.
- the model is not identical to the world, but deviates

- it is partial, as only the aspects perceived by the agent are represented

- the representation has less detail

- it contains errors, imprecision, and other artifacts introduced by the limits of the perception apparatus combined with shortcomings of the memory (recording).

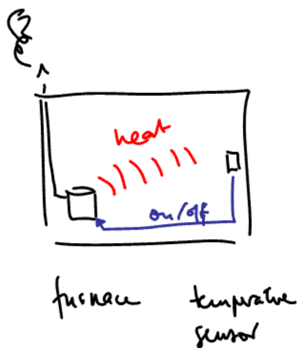


Figure 166: A simple feedback loop: the furnace is controlled by a thermostat

Any apparatus that includes a feedback loop has some form of internal representation of the exterior world, which is in a form data. The switch in the temperature sensor, which switches the furnace on and off 'represents' the state of the furnace, the temperature sensor the state of the room. This is the basic element of representation, but is trivially simple with only two elements modeled. The power of cognizant agents—humans and animals—results from the combination of many such small models including their connections and a massive, nearly unlimited, memory to store previous state. They can build complex models of the environment they are embedded in and—as we will see later—construct social artifacts on top of this tier 2 model of reality to achieve more efficiency in their interaction as groups with the world. Humans have emotions, which help them use the memory of previous states to use memories effectively to make decisions.

This part introduces the ontological dichotomy between

- physical (material) objects, forces, and activities and
- percepts and concepts in the human mind

which is further confused by the observation that all information is bound to the physical structures of the brain. Data can represented outside of the brain in data files and documents.

To speak about "free will" is absurd, because freedom is defined in terms of will (Hobbes).

The assumption that actions follow from decision that follow from reasoning leave the question open, where the actions come from {Searle, 2003 #10717}. We have connected actions to the observations of the environment (closed loop semantics). One might still ask: where does the action to perceive come from? This infinite regress is broken with assuming a 'desire to survive' as part of the agent; agents that lack such a desire die. This is observable in people, who lose with age their desire to survive and quietly fade away.

Assumption: Agent has a desire to survive.

Agents have first to understand themselves as objects in reality and interacting with reality and to see other agents of the same kind as similar. Each human is specific and unique and has a unique view of reality, but we know that other humans have essentially the same properties than we have ourselves, some of these properties we can observe (e.g., their physical appearance and the physical manifest actions they perform) and we conclude that other properties that we cannot observe are also similar to our own.

Chapter 22 ACTIVITIES OF COGNIZANT AGENTS

The cognitive agents that operate in the world are physical objects. They are capable of actions that lead to the particular (mini-) ontologies we have seen (see 315 xx). The actions of the agents come paired with operations to observe their results.

In this first chapter, the ontology of the world is presented from the perspective of a human being; animals have some but not all of the same capabilities and have some of the capabilities to a lesser degree.

Knowledge of the past is partial, incomplete and faulty.

1. THE PERCEPTION OF TIME BY AN AGENT

Agents carry out all their activities in the present time and can perceive the environment only at present time (the 'now'). We cannot know the future and it is not possible to make an observation in the past: our knowledge of the past is always partial and I cannot return to last year's Christmas party and see what color the tie of Uncle Peter was (but I can inspect a photograph if one was taken at the party).

Agents cannot freely move in time—time advances regularly without interaction with the agent. This directedness of time is—assumedly—the same for all macroscopic systems, biological and electronic, and follows from the second law of thermodynamics or law of entropy.

Agents are always at a specific time that advances without their involvement.

The agents perception of time is dominated by the 'time of the day', which is related to the rise and setting of the sun, which influences activity patterns of humans and all higher animals. The universal time is moving uniformly. It is conveniently represented by the Coordinated Universal Time UTC and translates at each location differently into a local daytime. For practical reasons, day-time is structured in zones, which have conventional relations with universal time.

Photo sunrise

The relation between the dominant local day-time of the agent and the universal time requires knowledge of the location of the agent. This makes the decision whether two actions are concurrent or not depending on knowledge of local time and location to translate both into the same universal time.

Formulae

Autobiographic time: the agent's concept of a single time line through his life, a single sequence of events making his life.

Time is for each agent a singular linear ordering for all his experiences, actions, etc. This is *autobiographic time*. It is not experience uniformly; experienced time advances sometimes faster and sometimes slower. Compare your experience of how fast time passes when waiting for a boring lecture to conclude or having fun at a party.

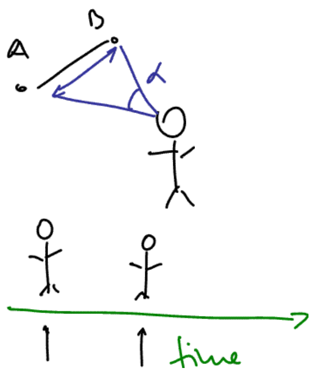


Figure 167: Only in space the distance between two points can be observed, not in time.

Time points where important events occurred have an identity and can be referred to without using the numerical characterization of a time. Unlike for space, we cannot 'see' the difference between two time points; the time elapsed between two events can only be examined by inspecting memory. It is perceived longer or shorter, depending on the amount of intervening other events. [ref montello]. Time is the most often used structure for ordering recording of actions in diaries, calendars but also in biographical accounts, curriculum vitae, etc. because it is easy to add new events at the end of the text.

2. Agents Are at a Location

The agents are—like all physical objects—at all times at one specific location; the location may not be known or the agent may not know the relation of this location with other locations, but the agent is always at a location. We can be lost, but we cannot be nowhere!

Every agent is always at a specific location, which may change.

Agents can change their location and move (locomote) to another location. Agents may be moved by other agents or moved as part of the movement of another objects, e.g., a car moves (locomotes) with all its passengers and content. Movement of agents is, as for any physical object, continuous in space. There is no teleportation!

Agents have no absolute sense of location; they can observe visually their current position relative to other locations they were at a short time ago. They have also a proprio-sensoric observation of the distance they have moved—(Golledge 2005) and accumulate this information while moving. This can be used to find a direct way back and is called a "homing vector" (). Agent's can recognize a path when comparing the actual sequence of observations with the observations stored in their memory (Kuipers and Levitt 1990).

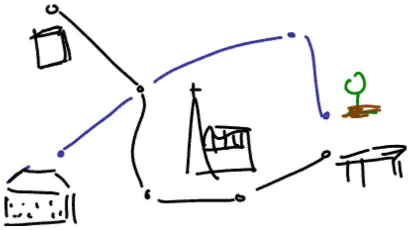


Figure 168: Two paths that cross

Agents can identify a location and recognize that they have arrived at a location they have visited before. This is mostly based on visual memory, combined possibly with tracking of position and the proprio-sensoric experience of moving. For cognizant agents location has an identity, similar to the identity of objects. The recognition that two locations on two paths are actually a single location Figure 168) is sometimes described as achieving *survey knowledge* (Montello 2001).

3. Perception of the Environment

Scene: the collection of percepts made at a location at a time.

Agents can perceive their environment, at the time *now* (only now) and within a certain distance from their location. This organizes perception into *scenes*, which group the observations made from one position before moving to another one. A scene consists of the perception of the physical environment at the location, the movable objects present, including other agents.

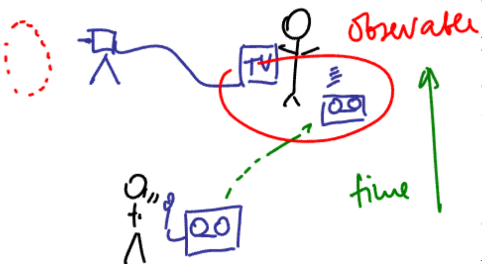


Figure 169: Technical means make observations at a distance possible

There are a multitude of technical devices to make observations at a distance or in the past possible, e.g., photographs, TV. They all translate past or distant situations such that they become locally (space time) observable.

Figure 170: Naive concept of the brain as a uniform place of integration of all sense data

The agents observe their environment with their senses. The classical five senses are: Vision, hearing, taste, smell, taction (haptic), to which we have to add thermoception, nociception, equilibrioception, and proprioception, which inform us about the temperature, pain, our position in space and the state of our own body. These senses deliver data to the brain, but not in a uniform way (Figure 170 and Figure 171).

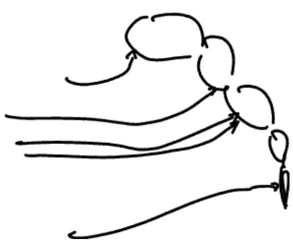


Figure 171 Different senses relate to different parts of the brain

4. Action in the World

Agents can exert some forces on physical world at the time ‘now’ only: they can, e.g., push on objects. The way an agent can apply forces and how much force to an object is determined primarily by their body; differences between individuals of a species exist. Some agents can grab an object and push on it from all sides at once (squeeze), objects that are grabbed can be pulled, etc.

Actions can be applied only at the time 'now and to objects within the *reach* of the agent; the reach of the agent, considering different modes of movement and different time frames structure what is reachable in a hierarchical fashion, which corresponds with the organization of scenes (above). If I move to another location, different objects are within my reach and I can see different scenes (Figure 172).

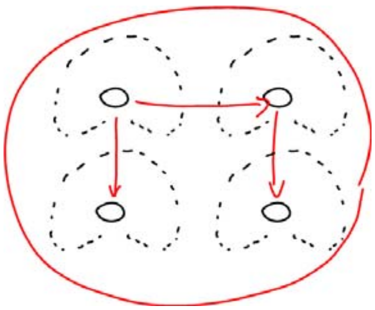


Figure 172: The reach of the agent by moving consists of the reaches from a location

4.1 AGENTS CAN ACQUIRE, GIVE AWAY (SMALL) PHYSICAL OBJECTS

Humans and most animals have the ability to pick up objects and carry them to a new location. Agents can acquire physical objects, which are small enough to be handled, inserted in some container attached to the agent (the mouth, a pocket). They can also give away small physical objects they have acquired before. Physical objects can be used as tools to amplify and change the effects of action of the agents. Acquiring objects is only possible within the physical reach of the agent.

4.2 USE OF TOOLS

Agents can use small objects they have acquired as tools to change the effects of the forces they exert. A screwdriver is useful to turn a small screw, which is hard to do with fingers only. The screw is shaped to insert itself into a material and acts eventually as a fastener.

4.3 BODY FUNCTIONS

The body of the agent needs a form of metabolism to gain the necessary energy from the environment. For humans and higher animals most important and visible are eating and drinking; but also breathing and the more 'shameful' disposal of excrements. A special function is related to procreation.

Agents can sleep; they have periods of rest, where activity level is reduced. One may include within body functions also the operations to wash, comb, etc. Natural agents (humans, animals) must procreate to produce new individuals.

4.4 COMMUNICATION ACTIONS

The agents can produce physical events that are used specifically to communicate between agents. There are several channels, with special activities to produce a communication and special sensing operations to receive a communication:

- visual channel: signs made by moving body parts, permanent traces of body movements to be understood as signs, writing, etc.
- aural channel: voice and other sound effects; often structured as verbal messages

The resulting signs can be transitory and exist only for the moment or leave permanent marks in the environment, such that they can be observed at a later time.

Communication is the sending of a physical object or a physical event and the sensing of such an event.

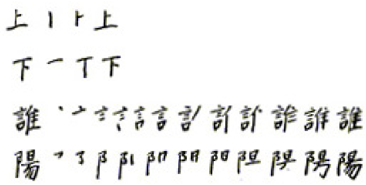


Figure 173: Instructions how to draw Chinese characters (two simple and two complex characters given first and then the details how they are gradually constructed from Tchen (Tchen 1967)

Marks found in the environment are 'read' by reconstructing mentally the action necessary to produce them. This is evident in the teaching of Chinese characters. They are not learned as figures but as a sequence of strokes (Figure 173). This is not only important for production, but also for recognition of signs created at different levels of fluidity. Westerners often copy Chinese characters as a picture and produce images, which are difficult to recognize (the same applies to western writing when copied by analphabets, e.g., small children).

5. SUMMARY

Cognitive agents are physical objects, existing in physical space-time at a specific location and have an internal representation of their bodies, their location in space and time, etc. The mostly hierarchical structuring of their observations in scenes and along a time line follows from the properties of their bodies. It is the body that limits observations and actions to scenes and makes a hierarchical structure by location and time points at which they were experienced, economical.

Chapter 23 REPRESENTATION, MEMORY, AND ABSTRACTIONS

Cognitive agents acquire through their senses percepts about the current state of the world and their body and construct in their memory long term, generalized knowledge about the world in which they exist. The knowledge they construct is not necessarily corresponding to reality. Cognitive agents use the accumulated knowledge to make decisions using derived knowledge about actions (see later chapter 400 xx).

Memory is the general term for the internal state of an agent. In computers, we separate the longer term memory (RAM, hard disk, etc.) from the ever changing states of the operating elements (CPU, registry, cache, i/o devices, etc.). This subdivision, which goes back to John von Neumann (Neumann von and Morgenstern 1961) is not appropriate for the description of human agents but has influenced it. Some authors understand by 'memory' (and correspondingly 'representation') only the long term memory and further limit it to the consciously retrievable. The internal states that are automatically changing with time and the storage of snapshots of these states, what we call our autobiographic memories, are separated and have different uses. I include in this chapter the discussion of internal states related to emotions.

1. STATES OF THE BODY – EMOTIONS

Agents have proprio-sensor for the state of their bodies. This does not only include the sensors for the position of the limbs, which we know consciously about, but also for the state of inner organs, of which we have not the same direct conscious knowledge of. There are feelings of hunger and thirst that are known to all humans (and likely also to animals). Simplifying, I take the feelings related to the internal organs as primary sensations.

The nervous sensation I have when my stomach feels empty is the meaning of the named feeling 'hunger'. Probably several sensations, which could be differentiated, map to 'hunger' (e.g., blood sugar level low or emptiness of stomach). Many of the body feelings are not directly accessible to a conscious introspection, others are. Language has incorporated many of these feelings and the association with the body parts is considered a 'poetic metaphor' but it could be understood as a direct expression of body sensations.

Intelligence is in the head,
love is in the heart, etc.
Vor Angst in die Hose scheißen.

For present purposes, the simplest model of emotions is sufficient: emotions are either positive or negative. Positive emotions are associated with states the agent tries to achieve, negative emotions relate to situations the agent needs to avoid. The literature differentiates between several emotions, but no agreement has been reached yet (Trappl and Payr 2002). Some emotions are short time—e.g., being frightened—and others have longer duration—e.g., being depressed; the later are sometimes called *moods*.

Emotions are necessary for a discussion of planning and intentions. Sachs reports a case of a patient with a mental disorder: the man had lost the part of the brain that controls emotions. Did this completely emotionless person become a most shrewd business man or poker player? No, all the contrary: he was so much overwhelmed by all the possibilities open for him that he could not ever make a decision (Sacks 1998). This shows that emotions are closely related to the evaluation of plans.

2. MEMORY

There are at least two types of memory: an episodic memory, where experienced episodes are stored and an abstract (semantic) memory (Roth 2003). Other memory types include visual memory where imagistic percepts are stored and a procedural memory for motor skills, where sequences of actions are stored but not accessible to conscious recall. We can swim and ride a bicycle—but can you explain how it is done?

The episodic memory stores observation of the environment, action of the agent, and emotional state. The units in the episodic memory are emotionally evaluated.

Episodic memory: emotionally valued memory of previous states. Fundamental non-convertible categories of our experience!

2.1 EPISODIC MEMORY

Episodic memory structures experiences by combining

- Events—time points,
- physical objects,
- locations,
- actions, and

- emotional state.

These are fundamental types and cannot be transformed from one into the other within the operations we have experience with. We can imagine to have the ability to be at two places at once (the novel 'les sabines' in the book 'passe muraille' by Marcel Aym'e), or move in time and space effortless (despite logical confusions resulting). The conversion of one object into another is regular magic, but I know of no example, where a location in space becomes an action. The episodic memory is related to narratives in the past tense—stronger emotional impact seems to make the event easier to recall and longer to be memorized. The semantic memory stores knowledge that has been separated from individual experiences and is held to be generally valid.

2.2 SEMANTIC MEMORY

Semantic memory generalizes from single events in episodic memory. We use generalization to arrive from individual objects and action to classes of objects, actions, etc. (see 320 xx). Note that neither the abstract operation 'to run' nor the abstract type 'horse' exist in the same way as Antares exists (photograph page xx) and I was running this morning (photo).

Figures

The abstract memory relates to sentences that start with "I know" and express facts that are held to be valid independent of the time.

The theory theory (see xx) gives a plausible description how the transfer between episodic memory and semantic memory could be functioning.

2.2.1 Generalization of actions

Each individual action is an entity; it is characterized by location, time and agent, and unique. The execution of an action and a later execution of the same sequence of movements are experienced as similar: it is a single pattern that is executed repeatedly. The low level patterns are stored in procedural memory.

Agents form a concept of action type, which is the generalization of many similar actions. An action type can be instantiated to become an action at a specific time (and location).

The no-action makes only time advance (tick).

2.2.2 Generalization of objects: classes

The generalization of single actions to the general concept of an action type calls for a similar generalization for objects: all objects that can be used with a specific action type are of a single type, a class. For example, to the action type to sit belongs a type of agent that can sit and an object on which the agent can sit.

Natural kind: set of entities that are identified by natural laws (e.g., breeding).

Photo

2.2.3 Generalization of observations: attributes

The generalization of an observation activity gives a type of observation that then leads also to a generalization of the observation. The observation of a temperature here, and yesterday, and last year, etc. gives the abstract concept of 'temperature observation' (and activity) that has as a result an observation—generalized to an observation type (attribute) and related semantically to the sensors for temperature.

2.2.4 Typed universe

This viewpoint of classes is transformation to a computational model: Objects and actions are all typed, and only type consistent expressions are permitted. Operators combine objects and produce new objects at the entity level. The entity level is the level of real objects and real activities in the physical world. At the generalization level, we have operator types and types of entities (classes).

3. Logical Deduction

Cognitive agents are capable of logical deduction. They can inspect episodic memory and semantic memory to deduce knowledge as help to make decisions on future actions.

The closed world assumption says, that we know all what is there and what we do not know is false;
The domain closure assumption says that all the individuals are known; and
The unique name assumption says that distinct names relate to distinct individuals. Check with Reiter's text

Logical deduction can be very simple; just to search if a person has ever been seen before. This is like a database lookup to check if a person is a client of a bank. A database uses typically the close world assumption (and related axioms (Frank submitted 2005)) to conclude from not finding an element that it does not exist. Humans must cope with their incomplete knowledge of the world and conclude from not recognizing a person only that they have never met the person, but not that it did not exist. They are also aware of the limitations of their memory and cautiously qualify the result of a 'memory search' by 'as much as I can remember'.

There are three assumptions invoked:

Humans use often modus ponens for deductive reasoning, which gave rise to the formalization of logic. Human reasoning is very often inductive, where one concludes from many examples a general rule; one can never be certain that not a counterexample

It is not likely that agents use closed world assumption in their reasoning!

surfaces and therefore the induced rule is not absolutely true—it is valid, till revised (see theory theory 320 xx).

Modus ponens: from A follows B and we have A therefore B

Chapter 24 395 INTEGRATION OF VISUAL PERSPECTIVES

Moving through space produces changing perceptions of the objects and their location (fig or photo). Agents are capable to compensate for these changes in perspective and to integrate the different viewpoints.

Photographs of same situation after moves

It is assumed that the integration of multiple perspectives in memory requires a unified spatial frame of reference, but it is not yet known, how this spatial reference frame is selected. The linguistic expression of spatial positions of objects in order to communicate world knowledge gives some indications; one can assume that the methods used to express a spatial situation with words (see 500) is related to the methods used to store spatial situations (Frank 2000).

1. OVERVIEW OF THE OVERALL COGNITIVE MODEL USED

The overall cognitive model assumed here follows Jackendoff's 'coarse sketch of the relation between language and vision' (Figure 3). The linguistic viewpoint is used, because verbal communication of spatial situations can be observed, knowledge of internal representation is only indirectly deduced for the discussion here syntax and phonology are merged, because this difference is of less interest here (Figure 175).

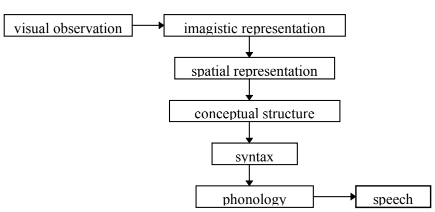


Figure 3: Relation between language and vision (after (Jackendoff 1996figure 1.3?))

The model in Figure 176 merges transformations from Figure 175 where a distinction is not definable, and adds a transformation from the propositional representation of the environment to a perspective representation (following (Levelt 1989)[Levelt, p. 96, figure 3.11]). The transformations between perspectives in Figure 175 are the linear transformations to translate, rotate and mirror geometrical configuration (Frank submitted 2005).

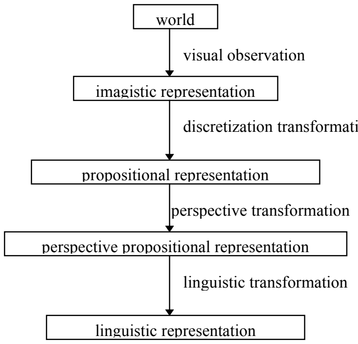


Figure 175: The relation between language and vision used here

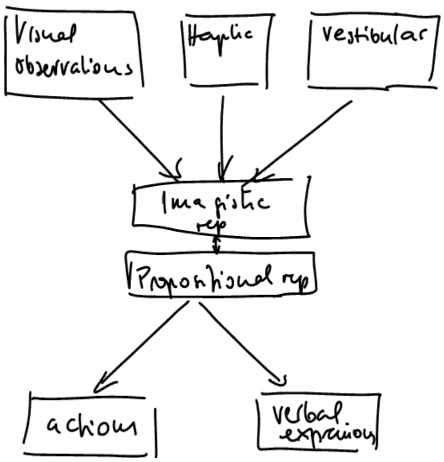


Figure 176: Assumption of full integration in a single internal representation

Figure 177: A room with horizontal and vertical planes

The model in Figure 176 is simplistic as it assumes that all inputs from different sensors are integrated in a single internal representation and then used to control actions and verbal expression (a special case of action). Psychological experiments demonstrate that actual processing in the human mind is certainly more complex and multiple, competing systems exist. Unless good evidence for a more specific more complex system is available, this simplistic model must suffice.

In such a model the question of *intermodal* transfers can be discussed (Bloom, Peterson et al. 1994): what are the transformation functions, which translate from one to the other modality. The visual channel dominates our spatial experience, but the propriosensors informing about movements and position of our limbs and haptic experiences of touching things can replace or add to the visual. Of particular importance are the sensors for acceleration in the vestibular system (in the inner ear region) that give us a sense of turning and moving. It helps the eye to compensate head movements but its signals are also available for other tasks of orientation in space by (double) integration of acceleration over time produce a sense of position and heading relative to a previous position (Klatzky 1997).

The discussion here will assume that the intermodal integration for spatial position perception results in a percept that can be structured as shown in Figure 178 again a gross simplification, but sufficient for present purposes.

2. PERCEPTION OF THE SCENE: THE IMAGISTIC VIEWS

The imagistic view gives the location of the objects in the scene from the position of the observing agent. This is a translation of the coordinate system to the location of the agent, a rotation of the axis to his heading and finally a transformation from a Cartesian coordinate system to a polar one (Frank submitted 2005).

The horizontal plane and the direction of gravity are the most important, salient axis and for most purposes the spatial relation between objects can be separated in relations in the horizontal plane and in the vertical (Figure 177). Remember: objects must be supported against the force of gravity, but in the horizontal plane no gravity forces apply. This suggests that an imagistic projection of the objects to the horizontal plane is sufficient for many purposes.

The same separation of height and location in the plane can be observed in language. Further the location and the extension (form) are separated. (Levinson 1996). Most objects are 'axial' (Landau 1996) and for each object an orientation as an angle between their 'natural orientation' and the axis of the model is recorded (see figure 5). The natural orientation for agents and other objects that have a moving direction is their heading, for other objects it is often their longest extension (e.g., rooms) or a direction that is salient when they are used (e.g., desk). Some objects are *OmniDirectional* and have no orientation angle ().

The example scene used here to construct a computational model (and later in 500 xx) consists of a collection of material (tier 2) objects that are identified by a name (fig 5). Some of the objects are other agents.

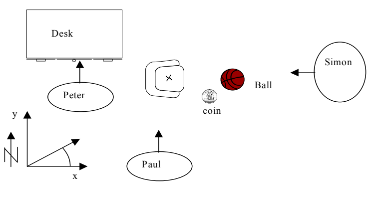


Figure 5: The example world

```
Simon     (12.0, 4.0)       (180)
Peter     (1.0, 4.0)        (90)
Paul      (5.0, 0.0)        (90)
desk      (1.0, 5.0)        (270)
drawer    (0.0, 5.0)        (90)
chair     (5.0, 4.0)        (0)
coin      (8.0, 3.0)        (Omni)
ball      (9.0, 4.0)        (Omni)
```

Figure 6: The internal representation of the example world

3. Perspective Taking

The discussion of perspective can be subdivided in two issues:

- prediction of perspective from another location, and
- integration of multiple perspectives of a spatial situation.

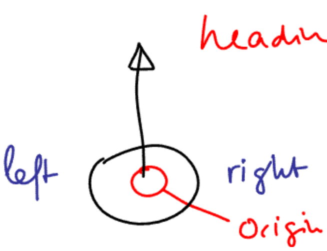


Figure 178: The perspective of a single agent: origin, heading and left/right

3.1 Single perspective of a single observation

The world is always visible for an agent from his particular position, his *perspective*, determined by his body *location* and *heading*.

Terminology: percepts are the result of a multi-sensor integration [http://en.wikipedia.org/wiki/Multimodal_integration].

3.2 Perspective changes through Movement

Movements are closely related to perspective: What an agent sees before and after a movement is different. The agent integrates a new perspective with the perspective he has acquired before the move. One customarily assumes that most objects in the visual field are fixed; the changes in his visual field are (mostly) the result of the movement of the self or few other objects.

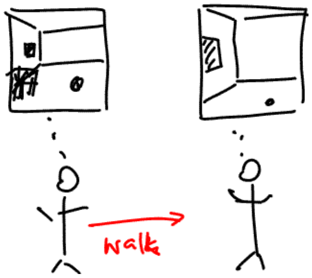


Figure 179: Walking connects the visual difference in two perspectives

Body movements connect the visual observations (Kosslyn 1980) with the propriosensoric observations; they relate visual sensations to the feeling of movement in the inner ear and the use of muscles to achieve a movement. This connects the observation and the action in a close loop (see xx) (Figure 179). The interpretation of a visual percept connects with body sensations and does not lead to the infinite regression suggested by Pylyshyn (Pylyshyn 1973).

3.3 Transformation of perspectives

The ability to transform their perception from one perspective into the perception from a different point—Levelt's 'perspective taking'(Levelt 1996). Is fundamental to integrate perspectives an agent acquires over time.

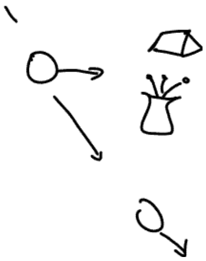
The agent deduces the imagistic 3D perspective or a perspective deduced from a 2D top view. Computationally, this requires projections, translation between the origins and rotations to account for a possible change in heading between the two positions (Frank submitted 2005). The transformation from the perception at a location 1 to the location 2 is the same as the perception directly at location 2.

The experiments reported the internal structures of the imagistic representation in the human mind are not clear (Kosslyn 1980). Probably more than one representation is used for different tasks.

3.4 Predicting perspectives

In order to predict the effect of operations, in particular movements, the agent must be able to predict the perspective as seen from another viewpoint. If seeing something is important, then the agent may move to a place where he predicts that the observation is possible: if I want to see where a car is parked on the road, I move to the window, because from there I can likely see if the car is parked on the street or not.

Figures



Two consecutive perspectives while moving

3.5 Integration of Multiple Perspectives

Human memory is not likely storing all the different views one has observed, but creates an integrated representation (perhaps similar to the episodic and the semantic memory). It is not demonstrated empirically what perspective humans use to accumulate the different views they have acquired (McNamara 1991; Wolff v. 2001) but unless there is better evidence, the most plausible assumption is that a perspective aligned with a salient reference frame anchored in the environment is used (see xx) and separated for position in the horizontal plane and height.

3.6 Changing Perspective

Formulae

4. Definition of a Frame of Reference

The computational model shows that a frame of reference must be specified with few characteristics (Frank 2000):

- the origin of the coordinate system;
- the orientation of the coordinate system, given by the direction of its primary axis (secondary axis between primary and the angle);
- the handedness of the coordinate system (i.e., the relations of the axis).

Usually, a right handed orthogonal coordinate frame with a right angle is assumed; *then origin and orientation are sufficient to determine the coordinate frame.*

Figure 180: Right handed coordinate axis

Handedness is the orientation of the vector space, where conventionally the turning of the first axis (x) in direction of the second axis (y) as seen from the third axis (z) is positive; this is equivalent to say that the axis x, y, z form a triangle similar to the thumb, index and middle finger of the right hand (Figure 180). Converting between a left handed and a right handed space is a mirror transformation.

The conversion from one orthogonal frame of reference to another, i.e., perspective taking, consists of 3 steps:

1. The origin (or ground) indicates the new point with coordinates 0/0. A translation with the vector from the location of the self to the new origin gives the new coordinate values (*translate*).

2. The orientation gives the rotation between the new coordinate system and the coordinate system of the ego (*rotate*).

3. The change in the handedness of the coordinate system, with a mirror transformation, if necessary (not for conversion between agent viewpoint; see 500 xx).

5. Egocentric Frame of Reference

The result of perception is first in an egocentric frame. The origin is the observer; the orientation is given by his heading. Humans project the orthogonal structure of their bodies (front-back, right-left) and use a right handed orthogonal reference frame.

6. Environmental Frames of Reference

The egocentric frame of reference is constantly shifting with every movement of the agent or the agent's heading. Consecutive percepts of the spatial position of objects are integrated. This is not likely a single frame for all percepts acquired during a lifetime, but integration occurs in groups that have some experiential coherence, e.g., a room, a garden, but also in geographic space a village, a part of a city (see above xx); Tversky uses the term cognitive collage (Tversky 1993) (Figure 181)

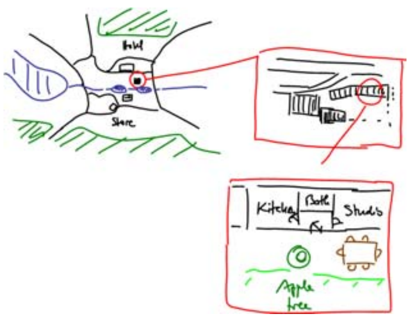


Figure 181 Cognitive Collage

What frames are useful? It is reasonable to think that later percepts are integrated in the frame of reference used initially. For example, the organization of a room may be organized as seen when one enters the room (Figure 182); this gives a narrative of fictive motion when explaining somebody an apartment (Fauconnier 1997) (the observed alternative is a birds-eye description of the layout). Observable conventions are used when verbally expressing of spatial relations (see 500 xx). The resulting hierarchy is comparable to the hierarchy that is the effect of different modes of action (see *reach* 390 xx).

Environmental frames are anchored with some object in the world and take from it the origin and the orientation.

These frames of reference are fixed environment; a movement of the self does not change the spatial relations, only the position of the self in the reference frame changes (note: the position of the self is not explicit in an egocentric frame; it is implied as the origin).

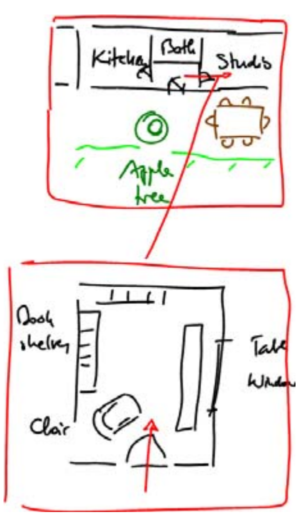


Figure 182: The refinement is oriented in direction of entry in the room

The anchor (origin and orientation) of an environmental frame may be

- the geographical environment with the cardinal directions environmental and an origin assumed at a salient point (capital of the country, village center, etc.);
- a valley, with an ist up/down directions and the sun and shadow side,
- a slope, as for example in the city of Tehran, where up is approximately north,

- the "Hawaii" system, with orientation towards the sea/towards the mountain [ref].
- a ceremonial room (church, theater, lecture hall), which has a front determined by usage,
- ordinary rooms, where conventionally the window is front and the door (if at the opposed side) the back,
- vehicles, where the direction of motion determines a front, etc.

Environmental frame: spatial relations remain invariant under movement of self.

For the self the transformation of its egocentric perspective to the environmental frame is comparable to other transformation of a perspective only that the viewpoint used is determined by the selected reference frame and the self needs to know its orientation in this environmental frame.

7. Discretization of a Perception

From an imagistic view discrete relation between objects can be deduced; this is a discretization of the continuous observations of the continuous world into a discrete representation, which is suitable for the production of verbal descriptions and perhaps used for long term memory, given that the discrete representation is much more compact than an imagistic one. Observations of human performance in solving spatial problems indicates that at least for some tasks an imagistic representation is likely (Pylyshyn 1973; Kosslyn 1980) but for verbal communication, discrete representations are necessary. The conversion between different viewpoints is possible in both representations (fig). Later (xx-10) we will compare the results.

The model of Jackendoff (Jackendoff 1996) deduces from the imagistic representation, but little is known about its encoding, an abstract propositional representation (Levelt 1996; Levinson 1996).

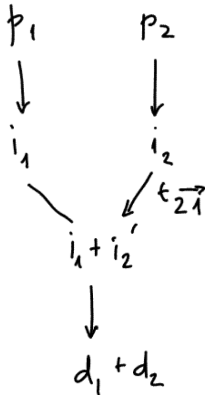


Figure 183: Two observations and integration at the imagistic representation

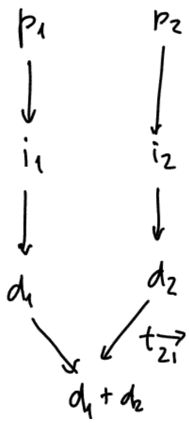


Figure 184: Two observations and integration at the discrete representation

8. DISCRETIZATION OF SPATIAL RELATIONS

Verbal expressions of spatial relations require a discretization—most prominent in the discretization of directions: front, left, right, behind. Such expressions are used very often and in many contexts, in the tabletop space and in geographic space other spatial relations relate to operations (see 340, 330, 360, xx). More difficult are the distance relations, because distances between objects of interest vary enormously: from a few centimeters between a glass and a spoon on the dinner table to thousands of kilometer between my office in Vienna and a meeting place in Brazil. How to reduce this range of 10**9 to a few discrete values? Many languages have expressions to differentiate between *very far, far, medium, near* and *very near*, but most often only three discrete values are used: *far, medium, near* (note that *medium* is often expresses with the absence of a specific distance marker).

The objects in a scene create a complex configuration, which in verbal expression reduces to a collection of relations between two objects, described with respect to possibly a speaker and an observer. More complex descriptions of scenes, e.g., of multiple objects at once, are rare and limited to a few fundamental geometric configurations that are often functionally important, e.g., objects that form a triangle, a square, a circle, etc.

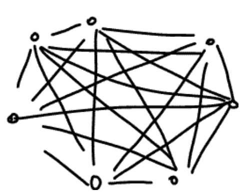


*Figure 185: N**2/ 2 relationships between n objects*

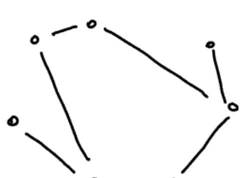


Figure 186: Few relationships between 2 objects

The expression of a relation between two objects involves

- an object of interest (called figure)
- the object to which it is related (called ground), this is typically the observer.

For verbal expression in a communication, the speaker and the observer or listener may be important and be different from the ground (see 500 xx).

9. HIERARCHICAL SUBDIVISION

There is a strong empirical evidence that human agents subdivide space approximately hierarchically. Hierarchical decomposition of space separates environments according to what actions are possible: I can reach only within a meter without walking (tabletop space), my nearly instantaneous range of access is a few meters (a room), the realm of daily activities is restricted by the distance I can walk forth and back (a village), etc. (above xx). Experiments show that humans systematically commit the same errors in spatial reasoning, which point to the use of hierarchical decompositions (Tversky 1993; Mark, Freksa et al. 1999). Hierarchical decomposition reduces also the number of relations that need to be stored and helps to organize memory of location of objects economically. Hierarchical subdivision makes discrete (qualitative) spatial reasoning more precise. Technically the organization is more likely a *heterarchy* as the same object occurs in neighboring scenes and gives the connection between them.

9.1 Reduction in Spatial Relations That Need to Be Stored

A hierarchical organization of spatial locations reduces the number of spatial relations one needs to memorize in a systematic way; most of the $n**2/2$ relations between n objects can be deduced from the relations in a hierarchical arrangement with only $b * log\ b\ n$ levels. If we assume, for example, that each hierarchical decomposition contains 7 +/- 2 elements, then we can take the log of base 7 and 100 noticeable objects in a room do not require 5,000 pairwise relations, but only <1200 relations.

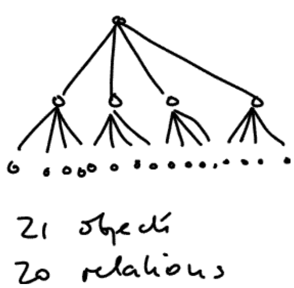


Figure 187: A hierarchical organization reduces the number of relations to remember

The rule to determine which relations are preserved is not purely geometrical, but relies on a decomposition of objects by type and function. One can think of an application of the method described by Nystuen and Dacey:

1. order objects by importance.
2. identify for each object the nearest other object of higher importance.
3. An object is central if all its nearest objects are of less importance; an object is subordinate if its nearest object is more important.

This gives a tree structure as shown in (Figure 187)

9.2 Reduction of Variation in Distances Through Hierarchical Organization

The organization of objects in hierarchically structured containers reduces the variation in distances such that a discretization of distance relations is possible. If a region is subdivided in 7 +-2 subregions then the centers of these subregions are all about the same distance from the center (assuming a regular subdivision of space).

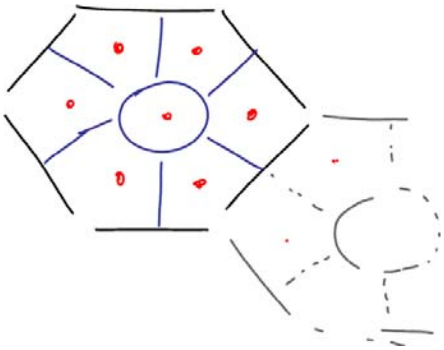


Figure 188: A regular hierarchical subdivision of space

9.3 Effects of hierarchies in spatial reasoning

Spatial reasoning in the propositional representation gives useful results only if the objects are distributed in a small region of space and the distances between them somewhat similar. The ability of people to use a propositional spatial reasoning in situation where the only information they have is propositional is a strong indication that a hierarchical decomposition of space is used.

9.4 Empirical evidence

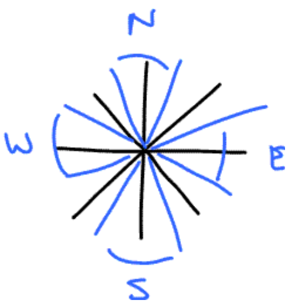
Steven and Coupe have shown in experiments systematic errors in human spatial reasoning; these errors point to a hierarchical structure used. Subjects were asked to decide questions like "Which city is more to the west: San Diego or Las Vegas?" and they found systematic errors that are best explained by assuming a reasoning chain that argues hierarchically: San Diego is in California, Reno is in Nevada, California is west of Nevada, therefore San Diego is west of Reno, which does not take into account the detailed geometry of California and Nevada.

fig

Similar effects are found for cities like Munich and Vienna, where Vienna is assumed to be south of Munich, probably because Austria is South of Germany, but actually Munich is a tiny bit south of Vienna. This effect is confirmed in many experiments but Portugali and Omer point out, that hierarchy is not the only possible explanation and suggest an alternative explanation proposing an effect of alignment of edges {Portugali, 2003 #10718}).

10. Discretization of Directions and Distances

Fig.



The eight directions—with cones?

10.1 Discretization of directions

A system, which differentiates 8 equidistant directions seems ecologically plausible (Frank 1992; Hong, Egenhofer et al. 1995). This system Human performance gives approximately the same level of errors as a model with 8 direction cones (Montello and Frank 1996).

For directions between extended objects, a different discretization may be used, where the object size indicates the size of the 'directly' front, left, etc. zone (Figure 189); this discretization gives 9 direction relations, to the ordinary 8 a neutral direction 0 is added (Frank 1996).

Simon says: Der Paul steht links vor mir. (Paul is to my front left),
Der Ball liegt gerade vor mir. (The ball is in front of me),

Egocentric coordinate system: The self is at the origin and its heading gives the direction 'front'. Seen from above, the turn from front to right is positive (anticlockwise).

From a discretized set of relative directions the perspective of another agent cannot be produced; but the application of transformation after discretization is only for few cases the same as discretization after transformation (Figure 183 and Figure 184).

San Franzisco west of St. Louis; St. Louis west of Washington DC => San Francisco west of Washington DC.

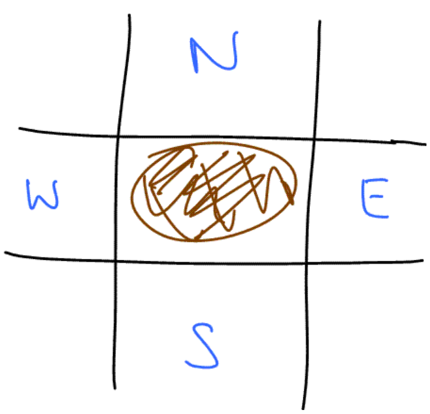


Figure 189: Division of space in 9 direction relations

10.2 Discretization of distance

A discretization of the distance relations is necessary to allow quantitative reasoning: in a subdivided space one could use 4 values for distances (fig 9): the zone up to 1 unit is *here*, between 1 and 2 units is *near*, 2 to 4 units is *far*, and further is *very far*. This gives together with a discretization of direction figure 9.

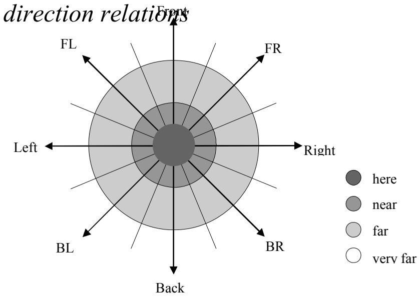


Figure 9: The qualitative distances and directions

10.3 Qualitative spatial reasoning

Relations calculus with these discretized values for distance and direction gives approximate values for the combination of two relations (Frank 1992). The result of a logical deduction gives all possible relations that could obtain and for many combinations of relations, the result is 'everything' (Freksa 1991; Hernández 1993). Later, I have proposed an approximate mode for the composition operation, which gives always a single relation for the combination of two relations—the most plausible or most likely one (Frank 1992; Hong, Egenhofer et al. 1995; Frank 1996). This agrees with the observed 'preferred model' tendency of human subjects.

10.4 Production of Other perspectives from the Discretized Observations

The transformation and discretization can be applied in any order and the same result should obtain approximately (Figure 183 and Figure 184) :

trans . discretize ~ = discretize . trans

from the expression in an egocentric frame (Figure 190)

Paul says: Der Ball liegt rechts vor mir.

people can produce the perspective of the addressee, as in:

Paul speaking to Simon: Der Ball liegt vor dir. (The ball is in front of you).

using another person gives a ground (relatum)

Paul speaking to Peter: Der Ball liegt vor Simon. (The ball is in front of Simon).

Simon says to Paul: Der Stuhl steht vor dir! (The chair is in front of you).

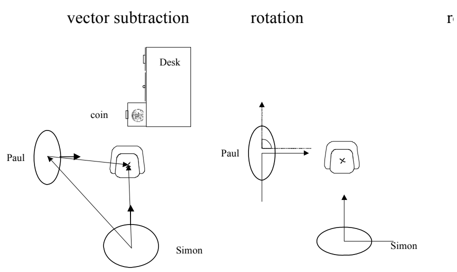


Figure 190: Steps in Simon's reasoning

Combined qualitative reasoning of distance, directions and orientations Gives these expressions: if the chair is in front of me and far and Paul is front-left of me and very far then the chair is in (Simon's orientation system) left and near from Paul. The transformation to Paul's orientation gives: if the chair is in Simon's orientation system left and near from Paul and Paul is facing left (in Simons system) then the chair is in front (and near) from Paul.

The comparison of the precision of the results of the deduction in an imagistic with the one obtained in discretized representation could be used to gain some insight of the procedures humans use. If the error in qualitative reasoning with the discretized values is comparable to human error in spatial reasoning, the use of a discrete representation becomes plausible.

11. Multiple Competing Representations and Reasoning Methods

Experiments with human subjects show varying results, depending on the specific experiments. So far we have followed a linguistically influenced line of argument, assuming a qualitative spatial reasoning with discretized values for distances and directions comparable to verbal expressions.

If one sets up experiments where stimuli and responses were strictly non-verbal, for example presenting a scene and asking for its memorization and later asks subjects to imagine standing with a specific orientation and then point with the hand in the memorized location of one of the previously shown, results are different. They seem to be better explained by an imagistic memory, but results are not clearly excluding other interpretations (Wolff v. 2001).

Experiments where subjects are blindfolded and turned or translated and then asked to point towards objects they had seen before, and the results compared with the same experiments except that the subjects are asked to imagine the rotation or translation, different results obtain for translation and rotation. Subjects can imagine a translation and the precision of pointing after a real or an imagined translation are similar, but the imagination of a rotation produces considerable error compared to a real rotation. This is evidence that the simplistic schema of a single pathway for processing spatial information, as suggested in Figure 176 is a gross simplification and different competing mechanism are at work in the human brain.

12. CONCLUSIONS

Cognitive agents that can move must have a method to integrate the consecutive observations of the world in a uniform, probably single, reference frame. Each individual observation is relative to the location and orientation of the agent. Agents must be able to predict the view they will have from another position to plan their moves and integrate observations from different positions.

Each reference frame is characterized by:

- its origin (ground),
- the orientation (orientation of the observer, orientation of ground or externally fixed), and
- the handedness of the coordinate system (which remains fixed for an agent).

With these parameters, the transformation of observations is possible, if the position of the self in this reference frame is known.

We have identified egocentric, i.e., agent relative, and environmental reference frames. Environmental reference frames are relative to some outside object of a size to include most of the objects of interest (see next chapter). They can be geographic space with a prominent location as the origin and the cardinal directions, a valley with an up/down direction or the axis of a room, where the front is determined by convention and intended use of the room.

Chapter 25 400 IMAGINATION, VALUATION, AND PLANNING

Human Agents exert control in the physical world through their cognitive abilities. Agents are using physical laws to cause large changes through smaller actions; they can counteract the general trend towards more entropy by directing parts of the energy to produce order. This requires planning, something primates other than humans can only achieve to a limited depth.

With the different affordances the objects in the environment make available to an agent and the activities possible for an agent, an overwhelming number of different actions seem possible at a given time. How to select the next one? Agents—even very simple ones—must have a method to generate possible plans for action, evaluate plans and to decide on actions. Agents must have long term goals, which are related to the continuation of existence, survival and the survival of the species. From these complex goals the concrete immediate actions are selected.

Assumption: Agents want to survive!

This chapter proceeds from the production of possible actions and the corresponding imagination of the world state resulting from carrying out the action. The world state is then evaluated with a scale of values. The action promising the highest value for the imagined resulting world is selected for realization. This does not guarantee that this was the optimal choice; it is only optimal with respect to the current knowledge and assumptions the agent uses.

The law of the universe are the physical laws, where there are no exceptions and agents have no perfect knowledge of them.

I try here something similar to the efforts of Epstein and xxx (Epstein and Axtell 1996) in that I try to construct the simplest mechanism exposing some of the visible aspects of human and animal decision making. In this chapter the word 'value' means a simple internal variable, corresponding roughly to goal fulfillment, feeling of pleasure, etc. of the agent, expressed on a simple scale and directly linked to the state of the body, interpretable as emotions (see 390 xx). Value is comparable to the 'sugar' in the models of Sussmann (Sussman 1977).

The computational model is simplistic and achieves only to demonstrate that a computational solution is possible. As we link mental actions (planning, deciding on an action) with the actions, it is necessary to have a "first" plan, from which all other start—

otherwise the infinite regress is not stopped. The empirically observable "first goal" of survival is sufficient to start the planning and thus the actions.

1. GOALS OF AGENTS

Agents need a first, fundamental goal to get them going; survival is certainly a plausible goal; observable strategies indicate that there could be an additional goal of survival of the species (the genes).

The overall goal of survival of the self can be subdivide in subgoals

Maslow pyramid

- Physiological needs: Food and drink, air;
- Security: Shelter , bodily security and protection;
- Love and belonging needs: Sex for procreation.

Maslow (Maslow 1970) adds do these 3 *deficiency needs* also an esteem need, which describes the relations between an agent and others (will be addressed in the next parts xx). In addition to these deficiency needs, Maslow adds a *being need*, which includes *self-actualization* and *self-transcendence*; these later seem vague and not defined enough to be included in a formalized system, whereas the first three deficiency needs are empirically observable, even when the ranking among them is debatable.

In the model, an internal state describes how much a goal is currently satisfied or not. This makes the ordering of the goals dynamic, changing in time: after having a good meal with enough to drink, the goal "food and drink" is lower on our priority list. This assumption results in an ever changing, dynamically ordered list of goals, which derive from a 'first goal', namely survival. This does not imply that only satisfaction for the highest ranking goal is sought; if another goal, nearly as highly ranked becomes easily satisfiable, it may receive preference.

The emotions described before (see 390 xx) are part of the feeling of 'goal fulfillment'. The relations between body parts, goals of the agent to survive and our concepts of emotions are strong but not explored scientifically sufficiently.

2. PLANNING ACTIONS

Planning in an ever changing world by an ever changing agent with ever changing needs is a difficult problem; most approaches in AI have ended with a combinatorial explosion: the number of possible actions, considering only a few steps into the future, is immense. For the reduced set of actions in games, for example chess, there are 10^{50} legal positions (and many more arbitrary arrangements of chess pieces on an 8 by 8 board), computers can today compete with humans using brute force approaches (i.e., evaluating all possible outcomes for a game with only 5 pieces for each player). Such brute force approaches have however not been fruitful for other games, e.g., the Chinese Go, which uses a large board and has a much larger set of possible states.

It was initially thought that playing chess would be a good choice to learn about human planning; after "solving chess" with brute force methods—computers play routinely better than good human players—the focus has shifted to more complex games. Where brute force methods do not help with selection of actions. One has to admit, that most humans are not very good at playing chess, Go, or any similar game, which can be taken as an indication that a different process than optimizing chess playing is at work. Emotions and the valuation of goals are plausible suggestions for how humans plan their lives. Remember the case reported by Sacks where a person without emotions was unable to plan their daily life.

2.1 *WHAT ACTIONS ARE POSSIBLE?*

Consider the top goals from Maslow's pyramid: What operations would contribute to their fulfillment? To answer this question quickly, the operations classes must be ordered in a lattice that indicates to which needs they contribute.

organize the verbs with respect to the human needs!

The objects within reach provide some affordances. The type system of actions restricts the possible actions to the affordances of objects present; this selection must be made in a hierarchical structure, to avoid combinatorial explosion.

2.2 *PLANNING OF ACTIONS IS ONLY PARTIALLY A CONSCIOIUS ACTIVITY*

Planning is often seen as a conscious operation, where we rationally consider possibilities and ponder their outcomes till we identify the best one. This is only part of the story; the part that we are conscious about, but there is more to it (Roth and Mattis 1990).

It is known from imaging brain activities, that emergence of (bright) ideas in the rational part of the brain are preceded (!) by activities in the non-conscious part of brain, close to areas where emotions and episodic (emotional) memory sits. One may assume that the current situation is compared with previously experienced similar situations and the actions performed then. The emotions associated with such a past activity and the current level of need together identifies the currently optimal action. This interpretation of planning in the emotional brain is at least consistent with the observed tendency of humans to follow the same patterns again and again.

Optimal for current need level + (emotions associated with past experience)

Such a selection among previous situations and actions can be done without 'combinatorial explosion': there are less than a dozen needs, which are ordered. Consider the affordances of objects that relate to the top need (if these are few, consider other needs that are close in neededness); this gives again a small number from which to consider the optimal. This occurs obviously at a high level of aggregation.

It is assumed here, that plans are structured hierarchically (Timpf, Volta et al. 1992): the plan to spend my vacation time on the island of Elba consists of several subplans, which include renting an apartment, packing, moving to Elba and back, etc. This subdivision of a single idea in an elaborate plan is what we are then conscious about.

The emotional brain has, according to recent observations of brain activities, a last say in the step from planning to execution. It can reject (block) the plan if it does not fulfill the needs, which are not conscious; everybody experiences that some nice plan we were decided to carry out unexplainably are not done. The standard example is the decision to stop smoking, which is rationally easy to take but emotionally difficult to realize. The emotional brain (amygdyla region) can approve of a rational plan and we might use the term *'intention'* to describe the plan that is selected among other plans to be executed (this is not the meaning that philosophy, especially Brentano, has given the term *intention*. Brentano used intention to describe the connection between the mental acts and the outside world {wikipedia.org, 2005 #10719}).

2.3 INSTINCTS AND CONDITIONED REFLEXES

Most animals are seemingly selecting their actions based on some fixed patterns—often called instincts and assumed inborn. Reflex patterns can be observed in human babies shortly after they are born: the reflex to close one's eye if something is approaching fast, a reflex to cry when not comfortable.

Animals learn over time particular reaction to a stimulus, if this reaction was enforced with a reward or other reactions punished. I think that these observations—going back to Pavlov and his dog—are compatible with the above account but do not need to predict outcome of actions.

Figure of dog?

3. IMAGINATION

In order to plan one must be able to imagine how the world will look after some action. This is somewhat comparable to predict what is visible from a different point of view; it is a transformation of the perception we have of the world (or at least one part of this) to a different state. Imagination requires more than just change the viewpoint, but imagine a future state that is related to an operation that could change the current state to this future state.

3.1 IMAGINATION OF FUTURE WORLD

The agent has to produce in his imagination the state of the world after the execution of the intended action. This means, it is carrying out the transformation of the world resulting of the execution of the action in his mental space. The result of this execution is not exactly the same than when executing the action in the real world and observing the results. The imagined future is based on the current knowledge of the agent about the world state and his theories of how the world works.

3.2 PREDICT THE OUTCOME OF AN ACTION

For each action available the self can imagine the situation of the world after this action is carried out: if I grab the apple, I have the apple in my hand.

```
Iws1 = imagine action an kws0
```

This is a very different thing than when the action is carried out: I imagine the action being carried out and use my knowledge of the world at state 0 as a starting point. The result is an imaginary world, in which the effects of the action are present—this world state is of the same form than my current knowledge of the world.

The imagined world in state ivs1 after the action is carried out may not correspond to the actual world state ws1 resulting from executing the action in reality. I may imagine that the ball is lying 100 m from here after my throw, but the actual execution gets it only 20 m far. The limitations of my physical abilities or actions of others, my incomplete knowledge of the world state and the rules of the execution may change the outcome from what I imagine to something quite different.

photo – drawing

Experience with our abilities helps us to predict the outcome of many daily actions quite precisely, but not always. In unfamiliar situations, we may make substantial errors and improve our theories about the world (see 320 xx).

3.3 Causation (in the sense of tier 3)

The connection between my action and the future (expected and later observed) state of the world can be seen as my action causes the observed change. This is a different concept of causation than what we have identified in tier 1, where causation were the linkages between different point properties. Tier 3 causation can be explained in terms of tier 1 causation: the agent exerts some forces, i.e., changes some point properties, which then cause other point properties to change (e.g., by acting a lever) till the desired effect occurs.

Tier 3 causation is the connection between intention and outcome

Tier 3 causation is generally connected to an understanding that a mental activity of the agent has controlled the first physical action (i.e., exerting a force on something exterior, e.g., pressing a button to connect two wires that 'causes' the explosion).

There is a strong connection between temporal and causal ordering of events. Causation in the sense of physics restricts the effects of actions to cause effects at the same time or later. The agents (tier 3) causation is therefore restricted that effects of actions are later than their causes. An organization of events by causal order is therefore also an ordering of events by temporal order, but not necessarily the reverse; despite the convenient conclusion to identify a cause in an action earlier: post hoc ergo propter hoc.

3.4 Possible actions—possible worlds

The agents can (usually) select between many possible actions. Grabbing the apple, writing a letter, etc. For each action the world will possibly take a different course. The interpretation of possible worlds—as purely mental or formal constructs—fuels imagination of authors, especially of science fiction. It is certainly true, that if I would decide on a different action than the one I decided to do, the consequences in the real world could be enormous: if the heir to the Habsburg empire had decided otherwise than to drive through Sarajevo on June 28, 1914, then he would not have been killed and the first world war would not have broken out …

Modal logic, necessary, possible
Interpretation reachable from state x to state x1
Creates possible worlds
Statements if any possible world…

Kripke has described a logic to consider possible world states and allows statements what is true in all possible worlds.

The construction of 'future' or 'possible' worlds is a purely mental construct and necessary for the planning and selecting actions to carry out. It is not a statement about reality. Mark Johnson (Johnson 1993) has pointed out that the possibility of agents to imagine the outcome of their actions is crucial for anything related to ethics.

3.5 Shared data

The implementation of representations of future worlds—in the formalism used here, but likely also in the mental system of humans—uses extensively 'sharing' of values that have not changed. The deduction of s_1 from s_0 means that all elements of s_0 that are not changed in s_1 are referenced directly and not copied—and our mental plans are often wrong, because we assume incorrectly that other things than what we actively change will remain the same as they are currently.

4. Hierarchical Structure of Actions

The actions can be seen at different levels of resolution. They are connected to a hierarchy of goals and subgoals (not to confuse with the order of goals described by Maslow as a hierarchy (Maslow 1970)).

The difference between these different types of hierarchization is likely the core issue of this ontology.

4.1 Scripts

A sequence of actions that each achieves a small goal is often together achieving a larger goal. These actions are repeated often together and form more complex, composite actions. Neurophysiologically, scripts can be seen first as these learned, often repeated sequences that we execute without control of the conscious brain: walking, eating, etc. Other scripts are then constructed analogically, but with more conscious thinking involved: preparing a meal, eating a meal.

5. SELECTION OF ACTION

A model of actions requires a formalization of the selection of actions. Ordering possible actions by some criteria—here called value—and selecting the first one achieves this. The remaining question is how these values are assigned to the actions:

5.1 VALUE

To select a particular course of action among many possible ones requires a method to evaluate them and to express the result of the assessment on some common measurement scale. The measurement scale must be at least ordinal, i.e., it must be possible to compare two values and determine which one is bigger.

Epstein in “The construction of artificial societies” (Epstein and Axtell 1996) introduces a neutral ‘sugar’ of which quantities are used for movements, for living during a period, moving, etc. and which can be harvested from ‘sugar trees’. I think this is an appropriate metaphor. One can think of the value as ‘energy’ that is dissipated during live processes and is collected in actions of eating and drinking. It is an abstract resource, which stands for the many different types of resources actually necessary for living. It must include the emotional benefits as much as physical ones—following Maslow's pyramid; in this sense the metaphor of 'sugar' is misleading, as it suggest a purely physical value measure; equally misleading is the concept of 'money' that seems to ignore non-commercial values.

Value is the most general measurement scale to assess benefits that will incur to an agent.

The integration of all available resources to a single value is necessary, because decisions between different goals that would increase or decrease different specific resources are made; nobody has seen Buridan’s ass starve to death, and people make routinely difficult decisions between having lunch in a restaurant or going to the cinema. This can be taken as an indication that at this moment, a comparison between the expected value for the two actions (going to the restaurant and going to the cinema) was possible.

Figure of Buridan's asses here?

The approach here does not assume anything more than that:

- It is not expected that the valuations would always be the same—the valuation function is clearly dependent on a large number of influential factors (how much have I eaten for lunch? When was I last in the cinema? Who would join me for lunch or the cinema? etc.).
- It is not expected more than an ordinal scale on which the different actions considered in this decision are projected. This does not assume that other actions could be integrated in the scale.

The customary argument that indicates that people do not have transitive preferences is not counterevidence: it is only assumed that from a set of actual actions possible at a given moment, the best (preferred) one can be selected. The standard tests, where pairs of actions are compared, in imaginary situations, leads automatically to comparison of each pair in a different environment. I can easily imagine a situation in which I prefer the cinema over lunch, and situations in which I prefer lunch over the cinema. If I must declare my preference in three cases:

- LUNCH vs. Cinema;
- Cinema vs. Preparing for lecturing;
- Lunch vs. Preparing for lecturing.

It is most likely that I select cinema over lunch, preparing over cinema and lunch over preparing: considering lunch vs. cinema: if these are the options (and no preparing for a difficult lecture tomorrow is on the horizon), I go for the cinema. As I am a xx person, I will prepare for a lecture before I go for fun; therefore, the cinema comes first. However, if I have to decide if I eat first and then do the preparation, then I may have a quick lunch first. The result is one of the typical intransitive choices.

Needs figure

- The scale on which the preference is measured is only ordinal—only comparisons for 'greater than' are meaningful. A distance between choices should not be deduced from the values.

5.2 VALUATION FUNCTION

The valuation function is simply a function from a mental world state (typically a possible state) to a sugar value.

```
Evaluation :: worldstate -> sugarValue
```

In the simplest case of an action like 'eat' the value of the action is the increase in the energy level of the agent. The evaluation of actions within a higher level goal is of course affecting the assessment: grabbing an apple is an interesting subgoal IF I want to eat the apple, but if I am not interested in eating apples, then grabbing it is not worth the effort.

6. CONCLUSION

A mechanism to select goals and actions to carry out is necessary for an autonomous agent. A small number of actions that can contribute to improve the state of the agent are selected based on previous experiences. Rational planning is needed to subdivide a high-level goal in individual steps and connect them, it uses the semantic memory.

The selection of a plan for execution is based on the evaluation of the outcome of the plan in light of the current emotional state that is reflected in the evaluation function. This includes physical and emotional benefits that would accrue to the agent if the plan is executed. The evaluation is done in parts of the brain that are not accessible to conscious inspection and uses past experience, stored in the episodic memory.

Planning of actions is full of uncertainty: the agent does not have perfect knowledge of the state of the world and the rules in it. Human agents often plan with assuming that everything else than what caused to change by their action remains the same, which makes reasoning simpler, but increases the risk that a plan will not succeed.

Chapter 26 500 Other Agents

In this chapter, the observation of other agents and the conceptualization of other agents in the self between multiple agents are discussed. Indirectly the observation of other agents leads to self-awareness, which is part of consciousness.

Introspection tells an agent that other agents are similar:
Other Agents can perceive the world and have Internal States:
Other Agents can cause change in the world.

1. Recognize Other Agents

A crucial step is the development of an understanding of the agent itself as an independent unit separate from the rest of the world he observes; this is the Archimedean viewpoint, which liberates: "Give me a place to stand on and I will move the world". The development of perspective in the 14th century both as a technique to draw pictures as well as to theoretically analyze the world were important. All modern thinking is only possible if we see the world as separate from us as an object. Most important in this view of the external world are other agents, for which we can observe their physical behavior; we must accept them as similar to us and assume that they have a mind, which we cannot observe.

Assumption: other agents have a mind similar to my own.

Picture from Dürer on perspective

In this chapters the agent is recognizing that other objects are agents like himself and distinct from him. Using introspection—understanding the self—agents can understand and predict actions of other agents: they can predict their visual perspective, but also their intentions. The representation of the agent in his own mind has unique properties. We call it here the self (ego would be an alternative). Once agents have functional models of their own self, they may recognize other agents as similar, with the same self (their self) and the corresponding functions.

We first consider what is observable from other agents and then list projections an agent may make to deduce internal states, intentions etc. of other agents, based on these observations.

2. Observation of the Bodies of Other Agents

The bodies of other agents are observable like the body of the self, because agents have physical bodies, of which physical properties are observable.

Other agents have, like all physical objects, a location at all times. Each agent has a perception of his own location and also a perception of the location of other agents. These perceptions are not equal, but the agent understands—through reflection—that the result of his own understanding of his location and the observation of a location of another agent is similar.

3. Time of Other Agents

All activities I perceive concurrently are at the time *now*. The *now* is the same for all agents I can observe and interact with now. The action I perceive them execute is at the same time than my perception of actions I carry out.

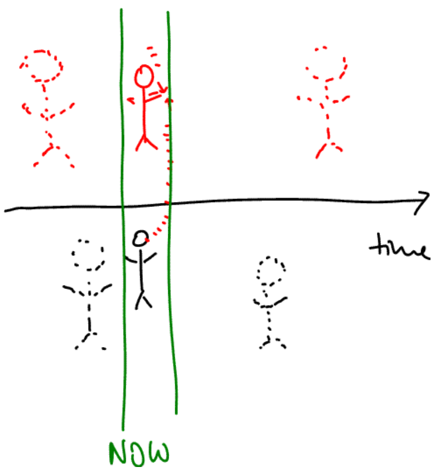


Figure 191: I can only observe actions of other agents at the same time than mine

4. Internal States of Other Agents Are Not Accessible

Other agents have likely internal states similar to the states of the self. Other agents have observations of the world, but also desires, needs—some conscious, some not known to the conscious thinking and learn that other agents have similar, but distinct desires and goals.

Agents understand that the cognitive processes of other agents are not directly accessible and that, in details, other agents may have different goals and desires than them. Agents lean to observe other agents and understand their behavior in the same terms they understand their own behavior. This gives semantic grounding of observations of actions of others in the same actions I could execute.

5. Visual Perspective of Other Agents

Agents see of other agents only their bodies and movement of their bodies (including sound produced, etc).

Other agents have a different perspective view of the world: I see certain things from my perspective and other things are occluded. Another person in the scene has a different view of mostly the same things, but some others may be occluded. My experience of different viewpoints by moving leads to understanding that others have different viewpoints and also different internal states, different intentions, etc.

photographs

The most directly observable effect is that agents understand that other agents do not see exactly what they see, and they can transform their perception of reality to the perception that they assume other agents have. They can transform from their perspective to the perspective of others and realize that each agent has a special and separate perspective of the physical reality.

6. Mirror Neurons Interpret Actions of Others

Understanding the action of others is crucial for cooperation in society. It is not surprising, that special brain structures are contributing to this: Neurophysiological studies report, that the same neurons in the frontal lobe become active when we carry out an action or see another human carry out the same action. I will say that the action type related to an action of mine and an action I see another human carry out is the same.

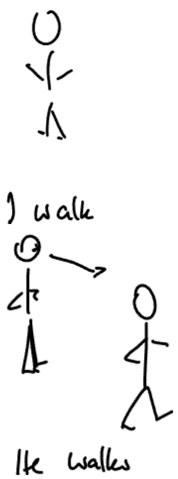


Figure 192: Two instances of action type 'walking'

These neurons react not only when we see another human carry out the operation, but also when another agent carries out a similar operation; the recognition is not restricted to human agents, but we interpret operations of animals immediately as comparable to our operations; even actions of machines are identified with human actions. We use immediately the same terminology to describe them.

7. Emotions Are Reflected in Body Language

The internal states of an agent, especially the emotions an agent feels are connected to external signals of some of these emotions. This is a wide field including what is often called 'body language' or non-verbal communication.

There are likely to be more channels that make internal emotional states observable to other agents than what we are conscious of. There are not only signals that are visible, but probably other signals that are communicated by odor (pheromone), etc. For example, many emotional states are divulged when we speak.

Details are not important for the ontology; relevant is that the agents can 'read' the emotions of others, probably with the help of mirror neurons. These 'readings' of the internal states of others are never perfect; some people are better to hide their goals and to lie more convincingly than others, some are more attentive and pick up more of the signals and interpret them better. Differences in degree aside, empirical observations confirm that we can understand the (hidden) internal states, the emotions of others.

8. Assigning Emotions, Moods, and Intentions to Other Agents

Agents assign to other agents the same fundamental goals, which they have. They assume that other agents want to survive (the background for all crime movies) and the subgoals

- Food and drink;
- Shelter, bodily security, and protection; and
- Sex for procreation.

9. Interpretation of Observation of Other Agents

Agents learn to interpret actions of others as indications of their intentions, their desires and goals. They learn to interpret exterior signs as indications of internal—invisible—state, this all in analogy of their own internal understanding of their own wants and actions to achieve these goals. Important for the ontology is only that the agents have goals and that one agent can recognize the goals of another when observing the actions of it. (Gopnik and Meltzoff 1998).

10. Projections of Intentions

If the self understands itself as a mechanism to decide on action based on goals, it may assign the same potential to other agents. The difficulty is that actions of other agents are observable, but not the goals or all emotions they have. The agent must deduce from observable actions of the other agent what emotions and goals she has.

It may assume that other agents have a similar valuation function and determine their action based on them. It may even assume some characteristics of the valuation function of others. This may lead to a prediction of future actions of others—or reactions for actions the self decides.

11. Folk Theory of Causation

Agents seem to construct theories regarding the functioning of other agents in analogy of the object theory. They learn, for example, that action of one agent can cause actions of another agent and that these connections are very similar to the causation of effects through actions in the object world; we will call this process ‘metaphorical transfer’ observed in language (Lakoff and Johnson 1980), because it explains something new—in this case the causation of changes by agents—through something that is already known: causation of change through physical action. The self can cause changes in the world. Other agents (selves) can affect changes in the world. A folk theory of changes is perhaps:

All changes in the world are the effects of agents' actions.

Humans have a strong inclination to find explanations for all changes they observe; this is important to construct predictive theories that can be used to improve living conditions. This strong drive for explanations (young children go through an age, where they ask 'why', wanting to understand the causes) constructs explanations where there are none (or none yet)—in a pantheistic world view the world is populated by gods that are responsible for the actions that have no other obvious explanations: weather, thunder, good and bad years.

12. Mental Construction of Other Agents

A crucial step was the development of an understanding of the agent as an independent unit and to assign to other agents the same independence. This leads to constructing images of other agents that have the same abilities—including having local knowledge and following inferences. The primary example for understanding other agents as similar to myself is visual perspective (see xx above): from a given position, not all other points in space are visible. The horizon in a landscape limits what part of the geographic space is visible. One can predict what will be visible after a possible move—climbing a tree will enlarge the space visible (see previous) and this ability is the foundation to predict what is visible to another agent.

Other agents are constructed as similar to oneself.

If an agent understands itself as having internal states, which are for example emotions, moods, and intentions, then it assigns such states to other agents as well.

13. Theories about Self

Constructing general theories about others makes it likely that the same theories are used to understand oneself. Such theories may be simple, like:

Eating now will reduce hunger in future.

These theories include knowledge about life and death—from observation of others—and form part of self-consciousness: the agent knows that he is an agent, similar to other agents, together with a theory about agents, which applies to him and to others. This can be seen as a justification for the Golden Rule:

So in everything, do to others what you would have them do to you, for this sums up the Law and the Prophets. Matthew 7:12 (New International Version).

14. SUMMARY

We have new abstract concepts:

- Self, emotions, proprioperception and perception of the self;
- Projection of perspective, projection of goals, and action selection mechanism;
- Folk theory of causation, pantheism;
- Theory of free will.

The single agent in a group of agents conceptionalizes and can recognize physical objects as manipulated by himself or by others. The way objects are formed is related to the operations and how they interact with the continuous world. Operations identify objects—different operations may identify different objects.

Agents have concepts for the simple operations they undertake and can recognize these operations in others.

Agents have internal states (emotions and moods) and can recognize from exterior signs and behavior of agents what internal states they are in.

PART SEVEN 540 COMMUNICATION NECESSARY FOR SOCIAL BEHAVIOR

Agents have concepts in their mind; these concepts represent their understanding of the world. Social cooperation would be much helped if their ideas are exchanged: instructions in coordinated actions, warnings, etc. Communication tries to achieve this: transport of ideas from one mind to another one. Because direct access of ideas inside an agent's mind is excluded (as an ontological commitment based on empirical evidence) the ideas must be translated (encoded) in a physical form, which the next agent can decode. Communication is effective if the structure in the sender's mind and the structure in the receiver's mind are comparable with respect to actions they carry out in the world.

The goal of the ontology here developed is to explain the operation of Geographic Information Systems and information systems in general; these systems are a form of indirect communication. The prototypical communication is verbal communication of facts from one agent to the other: 'the book is on the table' as a response to a question 'where is the book?' but information systems, like other devices that can store information and make it available later, allow indirect communication between agents that are not at the same location or the same time (Figure 194). Information a first agent has can be encoded as for direct communication but the codes (message) stored in form of a text (book), picture (painting), or electronic form (information system) and the message later retrieved and decoded by another agent; the result is like a communication between the two agents, despite the distance in space or time.

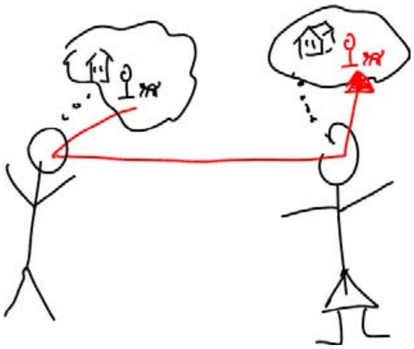


Figure 193: Communication of ideas from one mind to another

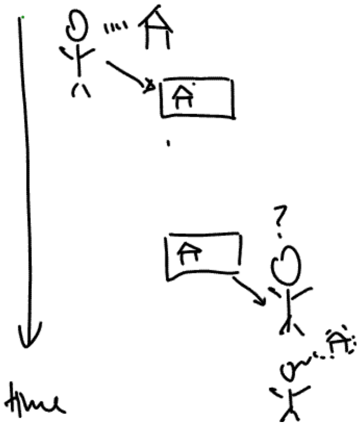


Figure 194: An agent learns from an information system about observations in the past

Any observation of actual communication between people reveals that most of our day-to-day conversations are not of this type of factual communication. It is however the type of communication that a GIS can provide today, at least at the current level of technology. The focus of this part is therefore on factual communication about physical objects through information systems.

Communication is a social activity and emerges from the need for coordination in groups of agents; the next chapter introduces the ontological assumptions and their empirical background.

Communication is first an exchange of physically manifest signs. The mathematical communication theory by Shannon and Weaver describes the reproduction of a message through a channel and defines a measure for the information. The important aspect of communication however is the transfer of ideas from an agent to another agent; this requires an interpretation of the message in terms of the experience of the sender and the receiver; the chapter xx gives an algebraic model. Repeated experience tells us that a long message is not necessarily more informative than a short one; in chapter xx a method to measure the relevant information content, termed pragmatic information content, is presented. It combines the information measure from Shannon and Weaver with the algebraic model of communication between agents.

The following chapters then look at communication with signs, especially cartographic maps and communication with language, especially the communication of spatial relations.

Chapter 27 SOCIAL BEHAVIOR

Humans are social animals, we life in communities together, specialize in our work and share or exchange the results. This is part of the human evolutionary achievement that gives us a competitive advantage to fill our ecological niche. Communication is necessary to help to keep the social structure intact and to construct social, cultural, and legal rules (see next part xx).

In this brief chapter we establish the base concepts to discuss simple social behavior and its goal.

1. DEFINITION SOCIAL BEHAVIOR

Society, noun (pl. societies)
***1** the aggregate of people living together in a more or less ordered community.*
***2** a particular community of people living in a country or region, and having shared customs, laws, and organizations.*
***3** (also **high society**) people who are fashionable, wealthy, and influential, regarded as a distinct social group.*
***4** an organization or club formed for a particular purpose or activity.*
***5** the situation of being in the company of other people. [OED, web]*

A group of similar (cognitive) agents that can interact form a *society* (similar to (Epstein and Axtell 1996)). This definition is more focused than the concept used in sociology, where a common culture is included. This seems unnecessary as culture emerges from the interaction of the agents.

By social behavior we understand here in general all behavior where actions of agents are coordinated to achieve results that they could not achieve individually. Different types of social behavior use different forms of coordination, different kinds of actions. Social behavior translates to advantages for the group or some of the individuals in it.

This is definition applies to all groups of agents of similar type. One can speak of social behavior of robots or even software agents like the ones used by Sussmann (Sussman 1992); in sociology the term behavior is contrasted with social behavior and means an animal-like behavior without any social meaning [wikipedia social behavior].

Society: group of cognitive agents, which interact
Social behavior: coordinated actions by agents in a society

The most fundamental and inevitable social behavior of higher animals is mating, the exchange of genetic material necessary for sexual procreation. Many animals connect to this minimal social behavior more or less complex behavior that improves the chances of survival of the offspring.

2. SOCIAL BEHAVIOR IS ECONOMICALLY ADVANTAGEOUS

The argument or social behavior is an economic one: coordinated behavior, division of labor, joint use of installations or skills is useful if the result of the action is larger than what the individuals could produce. It is a form of economy of scale: in many cases, cost increases less than proportional to the number of pieces produced.

Coordinated behavior of a group of agents is more effective and can overcome limitations of individual behavior in many ways:

- Defense of a group against a common enemy (e.g., of chimpanzees against a lion). A coordinated attack may be effective, but individually the agents cannot defend themselves.
- Coordinated Hunting for large animals of prey is effective when individual actions are useless.
- Development of expensive skills or machinery that could serve large groups is only economically feasible, if the cost and benefits are shared among the group.

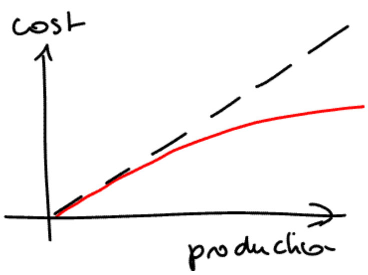


Figure 195: Cost of production increases less than proportional - economy of scale

3. Development of Coordinated Behavior

Coordinated behavior can emerge over time from refinement of repeated situations. Assume a hunting situation—a prey escapes easily a single attacker—but if there is a circle of attackers, then the prey is trapped and will be culled. If such successful situations are repeated, agents learn to produce them intentionally as a coordinated response (see 320 theory theory). This is a further development of the scripts to handle situations individually, an agent by itself.

Other such situations exist: e.g., escaping a predator. Groups that develop effective coordinated responses improve the survival chances of the individuals in the group and of the group as a whole. In conflicts between groups, the group with better coordinated behavior will—ceteris paribus—win; other groups will adopt similar methods over time or disappear.

4. The Economy of Division of Labor

The subdivision of activities among several individuals increases the productivity of each—one assumes that individuals get better in performing an activity to achieve a goal with repetition and that individuals are assigned activities for which they have a natural inclination or ability. Thus a division of labor increases the productivity, i.e., more can be produced or achieved using less inputs. Inputs to an activity are time, muscle power, other energies, land, raw materials, etc.

Division of labor leads to higher productivity.

Nothing can be achieved for free: division of labor does not only increase the productivity but increases the need for communication. Groups must spend time to coordinate their activities, which requires communication. In classical economy as well as in the fold economy today, communication is free. Adam Smith assumed that all participants in a (farmers) market had perfect knowledge of all transactions (Smith 1993). Only recently has the cost of communication entered the discussion: Douglas North received the Nobel price 1993 for his description of an economy where not everybody has all the information and communication is at a cost [xx]; Mesarowich has deduced that

TANSTAFL principle:
There ain't no such thing as a free lunch!

5. Elements of Coordinated Behavior

Coordinated behavior consists of several elements:

- A group of agents coordinating their actions.
- A goal of the action (i.e., hunting a game animal).
- A role for each member of the group.

Coordinated behavior can be learned by imitation—watching other do it and then picking up one role and playing it. I suggest the term *dance* for a set of coordinated behavior of a group. Dances are like scripts, but organize a group, in which several roles (which are scripts) are available for the participants. It is important that each role is fulfilled.

Ritual dances are among the oldest elements of human culture!

A '*dance'* is based on a theory (theorita, see 320 xx), which justifies the dance as a successful action in a specific situation. There is a common goal that the action achieves and this gives therefore rise to an ontology for group actions, very similar to the emergence of ontologies from individual actions; this will lead to social constructions of concepts, discussed in the next part.

6. Game Theory: Need for Enforcement

Coordinated actions are beneficial, but only if the members of the group cooperate. If one defeats, then all the effort of all the others may be lost, and, in certain dances, the defector may win for himself big. A famous example is the dilemma of two prisoners:

"Two suspects A, B are arrested by the police. The police have insufficient evidence for a conviction, and having separated both prisoners, visit each of them and offer the same deal: if one testifies for the prosecution (turns King's Evidence) against the other and the other remains silent, the silent accomplice receives the full 10-year sentence and the betrayer goes free. If both stay silent, the police can only give both prisoners 6 months for a minor charge. If both betray each other, they receive a 2-year sentence each".[wikipedia prisonner's dilemma].

Game Theory gives a systematic analysis of cooperative situations, reduced first to the simplest case of cooperative behavior of two agents, with two possible actions each: the actions of the two players are written as a matrix with the cell giving the result obtained by the actions:

	Prisoner A Stays Silent	**Prisoner A Betrays**
Prisoner B Stays Silent	Both serve six months	Prisoner B serves ten years; Prisoner A goes free
Prisoner B Betrays	Prisoner A serves ten years; Prisoner B goes free	Both serve two years

[wikipedia pr dill].

Game theory (Morgenstern and Von Neumann 1980) gives rules how to describe situations as games and how to find the optimal plan. Many situations are such that cooperation wins for both partners and these lead to stable behavior. For example, hunting leads to a stable cooperation if the chances of getting an animal alone are less than half of getting it when working as a coordinated group.

Hunting as a game	A cooperates	A does not cooperate
B cooperates	Half an animal each	A small chance, B nothing
B does not cooperate	A nothing, A small chance	Small chance to get an animal each

The extension of Game Theory from single games to continuous games makes game theory much more useful to analyze social behavior.

A group can inflict a punishment on a player who does not cooperate; this changes the game matrix and may convert a situation that has no stable optimum to a game in which cooperation is optimal. Enforcement can be physical power, but it can also be more subtle—e.g., excluding a defector from future cooperated actions, which excludes him from the advanced benefits, which may be sufficient punishment.

To allow multiple roles in situations where the payoff for the roles is different, rules to distribute the result evenly (or after a certain scheme) among the group members is necessary. For example, in group hunting, many members are used to drive the animals into a convenient spot where few then kill them; obviously the killed animal had to be distributed among all (including the dogs!)

7. FAMILY AND KINSHIP

Biology leads to the physical experience of procreation, parenthood, etc. This gives rise to concepts like: parent, child, family. In the next part, these physical experiential concepts are translated to social constructs.

Groups are typically formed by agents that share the same gene pool and it is often posited that behavior is—without explicit intention of the participating agents—directed towards the preservation of the agents genes. It seems possible to assume that animals can recognize their offspring—or their common ancestors—by observing chemicals emanating from an agent. There are at least apparent parallels between the human rules about kinship and inheritance and similar efforts of transfers between generations in the animal kingdom.

8. ROLES: GROUP AND LEADERSHIP

The need for methods to enforce the discipline (the game plan) may be seen as a foundation for the election of the strongest group member as the leader: he can enforce discipline.

In a band of apes the strongest individual—as demonstrated in fights—has primary sexual access to the females. In herds of horses a dominant female is leading the group; this leadership is exerted first by dominating other members of the group by fights, attacking, etc. that asserts the position of the agent and then by other agents following the "leader" by imitation of its behavior. This has the effect that the group remains united and does not disperse.

9. Groups Behave like Individuals

Groups have goals; they perceive through the individuals the environment and have jointly knowledge of the world that they use in decision making. In many respects, groups behave like individuals. The hierarchy of individual, group, and super group can continue for town, county, state, etc.

10. Conclusion

Social behavior is improving the efficiency of actions; the group is more effective in achieving special goals, e.g., hunting a large animal, than is an individual. The rational for social behavior is economically: the benefits of cooperation are larger than the cost of coordination and enforcement of discipline.

It is customary to assume that all coordinated action in a group; in general group behavior is the result of verbal communication. This is not necessarily so and a sufficient number of mechanism is known to achieve a coordination in a group without verbal communication (the concept will be defined more sharply soon, cf xx).

The position argued here is rather the reverse: the development of structures that are based on direct observation of behavior of others is sufficient for a simple form of social behavior and group organization. From this modest beginnings, the development of communication means were possible and can be seen as a logical evolution.

Chapter 28 610 Communication as a Transport of Signs

At the physical level, communication is connected to the transfer of physical markings, signs. The communication theory of Shannon and Weaver describes the exchange of signs through a channel. It is the foundation the theory of communication. It does not cover meaning in any sense (which will be discussed in later chapters), but is restricted to the reconstruction of a message after communication; where message is defined as an arrangement of markings (signs) and communication as transport through a channel. For this theory of communication, it does not matter, whether the message is intentional or a random product of some physical process without any meaning in the human sense.

Technical communication: exchange of signs

The discussion by Eco (Eco 1976) indicates how difficult it is to find a general and comprehensive definition of sign. When Winnetou reads the markings left by some enemy passing through a forest hours ago, he reads and interprets signs. Is this communication? Can we say that the enemy communicates with Winnetou, despite that the enemy had no intentions to leave marks to inform Winnetou of his whereabouts.

Figure

On the other hand, all communication using meaningful signs must rely on physical marks; this is part of the ontological commitment not to assume any non-physical existence.

No transcendent things!

1. What Is Communication?

Communication is the intentional transfer of information from one person to another (directly or indirectly).

Communication *intends* the transfer of information an agent has to another agent. It is an ontological commitment, that there are no direct methods for an agent to perceive the internal states, including the memory of another agent. When we mention communication we mostly mean verbal communication, but much of human exchanges are non-verbal and much is not even conscious.

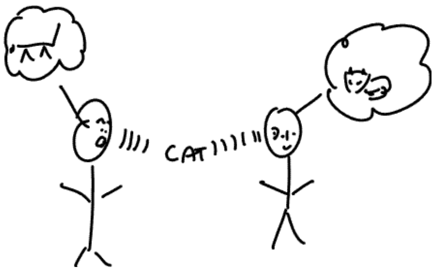


Figure 196: Communication using aural channel

Communication in its usual sense requires that physical marks mean something in a context for some participants, but this is not objectively observable. It is not easy to know if some physical mark is the result of a communication act or just an arbitrary marking in the environment. Such questions are discussed when investigating historic monuments (e.g., Menhirs, the Stonehenge circle of stones)—are the marks we see intentional marks of humans in order to communicate or are these just arbitrary markings or just physical erosion processes, leaving essentially random marks? The same questions crucial in the debate for communication with extraterrestrials: are the signals we detect intentional encodings from intelligent agents somewhere in the galaxy or is it the signal of some physical process with no intention to encode knowledge (Frank 2003)[ref stella paper on web, books on eti].

Communication is always based on physical marks that are produced by the sender and read by the receiver, but not all signs are part of an intentional communication. The focus of this chapter is on the transport of a message that consists of signs, not the communication of meaning (which will be dealt with in the next chapter).

2. SIGNS

Signs are marks in the environment, which can be observed by others and indicate the presence (or past presence) of some other entity or activity. Signs must not necessarily be material, but always physical (e.g., pressure waves in air count as aural sign). This corresponds to the first meaning of the word according to wordnet:

> (19) sign, mark -- (a perceptible indication of something not immediately apparent (as a visible clue that something has happened); "he showed signs of strain"; "they welcomed the signs of spring") (Laboratory 2005)

How to recognize an elephant in the elevator? The peanut smell in the breath is a giveaway!
How to notice that an elephant was in the fridge? Footprints in the butter!

Signs as physical marks is a broad definition, including non-intentional signs; linguistics and philosophy, in a tradition that goes back to de Saussure (de Saussure 1995), restrict signs usually to "…something that stands for something else". This definition introduced the difficulty, that something is a sign only if it is interpreted by some human, which is not an objective detectable property.

2.1 PROPERTIES OF THINGS

Signs are often observable properties that are directly linked to other properties that are not as easily observable. The red color of apples indicates that the apple is ripe.

2.2 SIGNS INDICATE THE PRESENCE OF THINGS

Most visible properties of things indicate their presence. The mirror surface of a lake indicates the presence of water.

2.3 SIGNS INDICATE OPERATIONS IN THE PAST

The markings Winnetou reads are signs that indicate the occurrence of an operation (action) in the past.

This class of signs can be subdivided further:

- Signs that were the effect of some action without an intention to communicate meaning.
- Signs that are the result of actions that were carried out with the intention to communicate meaning.

2.3.1 Non-intentional signs

Activities in the world leave markings, which can be read to understand the activities that have taken place.

This is important as it explains how we can collect information about previous states of the world. In every Western story I read in my childhood the Indians could 'read' from the markings left by animals, horses, and people when and with what intentions they passed. The same applies to geologists: they read the cues they can find and deduce past geological processes (Flewelling, Egenhofer et al. 1992).

2.3.2 Intentional signs

Signs can be caused by an agent with the intention to communicate something to another agent. This is the prototypical case of communication with signs.

3. THEORY OF SIGNS

An intentional sign has two or three parts, depending on the semiotic theory used (Eco 1976).

Figure 197: A two part definition of sign

Pierce and Frege introduced (among others) a three part definition of signs, where we differentiate between the sign:

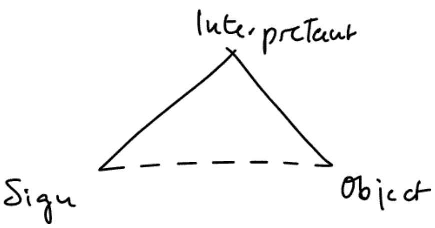


Figure 198: Triadic definition of sign

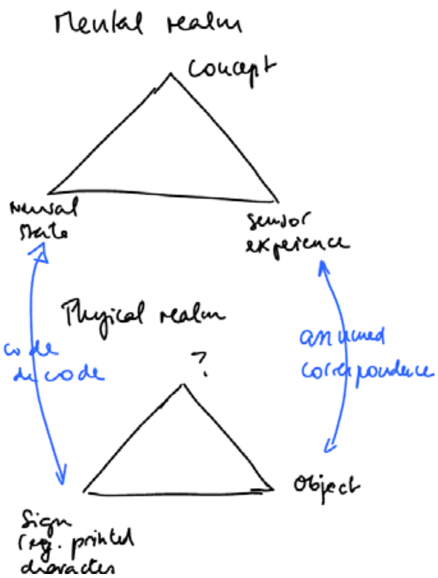


Figure 199: The incomplete correspondence of the triad in the mental and physical realm

- the object the sign should refer to,
- the representation: the sign in its material representation,
- the interpretant: what the sign means.

The connections between sign and interpretant and the connection between interpretant and the object exist in a persons mind; it is not a relation between physical objects. The connections between sign and interpretant (mental concept) and the connection between concept and object is direct, the connection between sign and object is only indirect. Note that neither of the relation sign-interpretant nor interpretant-object are bijective (1:1), and their combination is therefore not bijective either. The relation between sign and object is between physical objects, but it is only the combination of two 'in the mind' mappings and is therefore dependent on the person's mind. In the general case there are many objects which one person may link to a sign and many signs the person may link to an object and the relation—despite the fact that it is between physical objects—depends on a persons mind.

The difficulty with this triad is that the objects 'exist' in very different realms. Counterparts for the three elements of the triangle exist in the mental realm, but not in the physical. What would be the counterpart of the mental concept? Our ontological commitments rule out the existence of Aristotelian (or Kantian) ideals; no ideal dog or ideal circle exists physically.

4. The Mathematical Theory of Communication

Shannon and Weaver in their landmark contribution have analyzed the transmission of messages over channels and how the message is affected by noise. A message is a collection of sings (physical marks) and the goal of technical communication is to recreate the message at the other end of the channel.

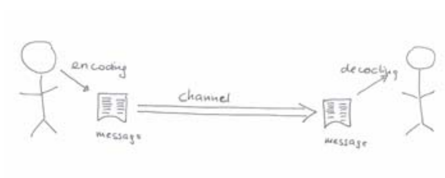


Figure 200: Transmission of a message through a channel (Shannon and Weaver 1963)

4.1 Message

A collection of marks, arranged in a fixed order are a message. A message usually represents some concepts, but that is not necessary. A random collection of marks, no mark at all, etc. are all valid messages.

4.2 CHANNEL

A communication channel must be able to transmit physical signs. Air can carry airwaves to allow communication with audible signs; electrical wires can carry signals as electrical potential, etc. Today channels that differentiate two states are preferred, but signaling with a semaphore uses a visual channel and a set of arms and flags to allow a total of 196 positions (Figure 201).

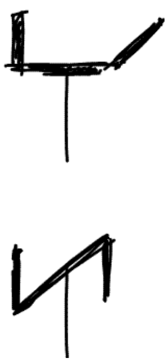


Figure 201: Two Semaphore Signals

Communication requires the manifestation of the signs that are intended for communication in a physical medium. It must be possible to create and detect the different states reliably. The different part of the sign can be organized spatial or temporal.

Possible channels:

- Aural—encoding by voice, instrument to make noise, observed with ears,
- Visual—marking on some surface,
    a. (many visual communications are not intentional; becoming red in the face as a sign of emotional uproar).
- Tactile/haptic—seldom used,
- Chemical—not intentionally controllable but important for non-verbal communication between human agents.

4.3 ENCODING

The signs in the message must be translated in the signs, the channel can transmit. The code must be established as a convention between sender and receiver. The channel must provide for a set of discrete states that can be used to signal a specific sign.

4.4 PROTECTION AGAINST TRANSMISSION ERRORS

The signals are distorted when they travel over the channel. The probability that the signal that is detected incorrectly is the error rate of the channel. To guard against errors in transmission over noisy lines, *redundancy* is added. Redundancy can be used to reconstruct a transmitted text and to correct transmission errors. Typically natural language text contains considerable redundancy, estimated for English at about 50%. A text where every other character is left out can be read without much trouble (example).

A message can be encoded with different redundancy—usually the redundancy will be matched such that the signal and the redundancy are less than the capacity of the channel.

4.5 Measure of information

Shannon's method to measure the 'information content' of a message is based on the amount of binary decisions necessary to reconstruct the physical message as it is in the channel and does not measure the information content of the message, as it is understood by a human.

This measure of information is applicable to the technical level of communication. It measures the size of a message in binary decisions necessary to reconstruct the message and suggested 'bit' as the fundamental unit to measure information content. This measure is widely used today and the unit bits and its multiples, i.e., Byte = 8 bits, and kilobytes, megabytes, etc. have become household words to measure the size of storage devices and the transmission capacity of communication channels, measured as information per second (bit/sec).

A message of one bit is transmitted over a channel from a sender to a receiver if the sender informs the receiver about a decision between exactly two choices of equal probability; the prototypical case the sender transmit the result of throwing a coin as 'heads' or 'tails', which are equally probable. The required message has 1 bit length. To decide between more choices—e.g., the selection of a candidate in an election out of 8 requires three binary decisions (first to select the first or the second 4, then the first or second 2 out of the four and then one out of the two—figure). In general, the information content in bits is the logarithm to base 2 (logarithms dualis, ld) of the number of choices. For practical purposes the result is usually increased to the next entire number.

(entropy) $H = - K \text{ Sum over } i \;\; p_i * \log p_i$

figure

If the choices are not of equal probability, then the information *H* is the weighted sum of these probabilities (entropy formula). The negative sign is necessary to convert to a positive value; notice that the probabilities p_i are all less than 1 and the log p_i therefore negative. *K* is a positive constant Shannon pointed out the relationship with similar measures in physics and suggested the term '*entropy'* (or uncertainty) for this property of a source of messages.

5. CONCLUSIONS

Communication in the usual sense requires that a physical situation means something. Technical communication however is concerned with the transmission of messages over channels, where a message is a collection of signs. Whether a sign 'means' something or not cannot be observed objectively.

The length of a message—its technical information content—is the number of binary decisions that are necessary to transmit the message as sequence of bits and to reconstruct it. This measure of information is independent of the meaning of the message for a human—a sequence of random numbers has, according to this measure, a high information content.

To overcome the noise added by imperfect channels that distort the signal, redundancy can be added to messages. Human communication methods are usually highly redundant; for example, a text in English language has at least 50% redundancy and can be reconstructed even if some letters are lost in the transfer.

Chapter 29 COMMUNICATION AS TRANSFER OF MEANING BETWEEN AGENTS

Communication between agents is the most common situation where integration of data from two different sources is performed—not always perfect, but in general with sufficient success. It is therefore valuable, to analyze this transfer of meaning between two agents very carefully and to construct a computational model (Frank 2000).

The analysis here discusses communication first in terms of mappings between reality, the two agents' mind and the data realm. Then a computational model is described that has been implemented and run to model a situation where one agent observes a part of a city and draws a map, which is then used by another agent to navigate to a given address (Figure 202). The example uses communication with graphics, but the same considerations apply to verbal communication; differences between communications with verbal or graphical signs are discussed in later chapters (xx).

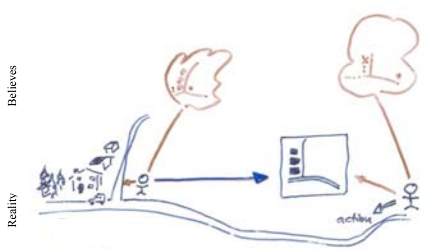


Figure 202: An agent producing a map and another agent using a map for navigation (Frank 2000)

1. MAPPINGS BETWEEN REALITY AND SIGNS

Abstracting from the particulars of Figure 202 we arrive at Figure 203, which shows the two sets reality *R* and data *D*. Reality contains objects (say an intersection or a street segment) and a function *a* that maps between two objects. One might think of this function as 'follow street x' that leads from one intersection (*p*) to the next (*q*). The first agent observes these objects and the function between them and construct his mental model *A1*, which is—in the ideal case—isomorphic to reality. The mental model of agent *A1* is the base for him to produce a graphical representation of the objects *p* and *q* and the relation between them as physical signs in the set of data *D*. Ideally again this mapping is isomorphic.

The second agent reads the data and produces his mental model (set *A2*) that he then uses to decide on his actions that he performs in the reality *R*. In the ideal situation, the mappings between data and reality are all bijective mappings that preserve the function *a*. This means, that when agent reads from the map that Main St. connects two identified intersections, then in the real world, Main St. connects these two intersections. An operation carried out on the data must have the same effect as the corresponding operation carried out in reality; mathematically a homomorphism must exist between real world and data (Hodges 1997; Guarino 1998; Goguen 1999):

$F (g.r (d.1)) = g.r (F (d.1)).$

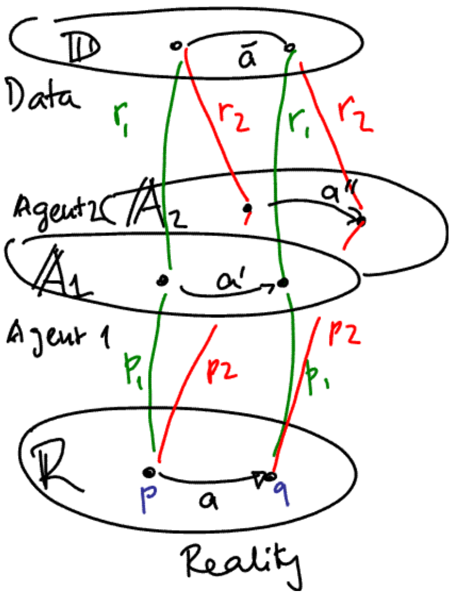


Figure 203: The two mappings of the agents from reality to data

The Figure 203 shows clearly the three different realms involved in communication:

- Reality,
- Beliefs (knowledge) of agents about reality, based on their observations, and
- structured representations (data).

Following an AI tradition, the agent's knowledge is called 'belief' to stress the potential for differences between reality and the agent's possibly erroneous beliefs about reality (Davis 1990).

2. Limitations of Communication and Errors

Communication is never complete. Eco says that in translation one must make a choice what one wants to preserve in the translation and what can be sacrificed (Eco 2003), is true of communication in general: we have to select what we want to preserve—it is impossible to be completely true to reality. Errors can be caused by the encoding and decoding process: if the mental concepts are not mapped in the same way to physical signs by sender and receiver of a message, then errors result. Further, the channel, through which the message is transported, may add error.

3. Correctness and Effectiveness of a Communication

Correctness of the communication is judged as the success of the second agents in navigating in the environment. *Effectiveness* of the map can be judged by comparing the size of different representations to communicate the same information between agents. One might ask are two equally correct representations of the situation in a town, one given as a map and the other given as a verbal description, equally effective. The answer is, not surprising, that the verbal description is effective to communicate a single route, but is inefficient to communicate a complex spatial situation, e.g., the street segments in a downtown area. When multiple routes must be followed, a map is more effective. In the simulated environment, it is possible to define what it means that a map is correct and how to compare the effectiveness of map communication with verbal communication.

4. COMPUTATIONAL MODEL

The model formalizes the processes involved (Figure 1); I use here a simple task to make the discussion concrete; namely, the production and use of a small street network map for navigation. The model constructed simulates:

- The environment, which is constructed after the example of a small part of downtown Santa Barbara (Figure 4);
- A map-maker who explores the environment and collects information, which he uses to construct a map of the area; and
- A map-user who acquires this map to gain knowledge, which he uses to navigate in this environment.

The environment represents the world in which persons live and the agents represent the persons who make and use maps (Figure 2). The simulation includes multiple agents—at least one map-making agent and one or several map-using agents—and demonstrated how insight can be gained from a fully simulated (synthetic) model. The agents used here are nearly as simple as Braitenberg's "vehicles" (Braitenberg 1984); they are sufficient to contribute to our understanding of correctness and effectiveness of maps. The model constructed here is—to avoid misunderstandings—not intended to support navigation in a city.

Fig.2. Mapping from reality to model

Real World Situation	**Multi-Agent Model**
Real World Situation	Model
World	Environment
Person	Agent
Map-maker	Map-making agent
Map user	Map using agent
Fact	Belief

Each agent is located in this set of streets and can perceive streets and intersections and can move along the streets from one to the next intersection; the intersections are identified.

Agents perceive their environment and act in it. The first agent observes reality by moving through the environment and memorizing the possible connections between the intersections – for example in an area of downtown Santa Barbara (step 1 in Figure 204).

The *map-making agent* is exploring the modeled reality and constructs knowledge of each segment traveled and accumulates this knowledge in its memory. From this knowledge, a map is produced as a collection of lines and labels, placed on paper. This map, which looks much like Figure 4 as well, is then given to the agent that represents the map user.

The task *the map-using agent* is carrying out is to navigate between two named street intersections. The agent is constructing knowledge from the map drawn by the map-making agent and then plans the shortest path to the destination using the knowledge gained from the map.

Errors in the agent's perception of reality or errors in the production or reading of artifacts like maps, representing and communicating an agent's (possibly erroneous) beliefs can be modeled. It is possible to include imaginary or contrafactual maps in this computational model!

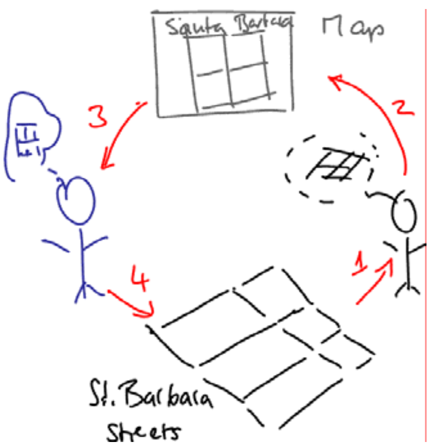


Figure 204: The different kinds of representations

5. Implementation of the Computational Model

The model was designed in an algebraic way and implemented using Haskell (Hudak, Peyton Jones et al. 1992). The description here should give more details about how such models can be implemented and tested.

The computational model is separating the four realms: the representation of *reality*, the *beliefs* of the agents, and the *map* are each separated data structures to which the agents have limited access. For example, each agent can only access the representation of his mind, but not the mind of the other agent. The representations are different, representing errors and incompleteness in the knowledge the agents have and the imperfections of their perceptive apparatus and their faulty execution of their intentions.

5.1 *Static Street Environment*

The environment, which represents the world in the model, is encoded by a data structure, which represents the street graph and the locations of the intersections with coordinates. The *environment* is maximally simplified to focus attention to the relevant aspects. The model of the environment is static, as no changes in the environment are assumed to occur while agents collect data and use the data.

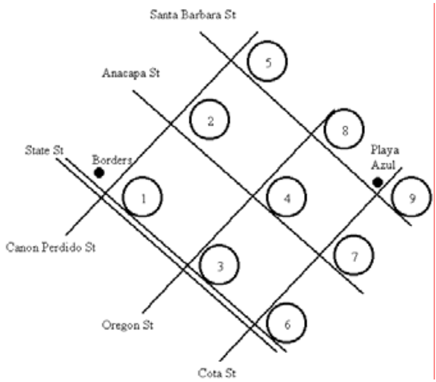


Figure 205: A small subset of streets of downtown Santa Barbara (with node Ids as used in the code)

The street network consists of street segments (*edges*), which run from an intersection to the next. The intersections are called *nodes* and the street network is represented as a graph. The algebra for the street-network must contain operations to determine the position of a node as a coordinate pair (*Vec2* data type), test if two nodes are connected and find all nodes, which can be reached from a given node (operations *connectedNodes*); the shortest path algorithm requires to find all nodes and to get the distance between two nodes. Two operations to add a node and to add a connection to the network are also included.

```
class Streets node env where
     position :: node -> env -> Vec2
     connected :: node -> node -> env -> Bool
     travelDistance :: node -> node -> env -> Float
     connectedNodes :: node -> env -> [node
     allNodes :: env -> [node]
     addNode :: (node, Vec2) -> env -> env
     addConnect :: (node, node) -> env -> env
```

Nodes are just numbered (Figure 4) and Intersections consist of the Node (the node number as an ID), the position (as a coordinate pair) and a list of the connected node numbers.

```
data Intersection = IS Node Vec2 [Node]
data Position = Position Node Vec2
data Node = Node Int | NoNode
data Vec2 = V2 Float Float
```

5.2 *AGENTS*

Agents are located in this environment at a street intersection oriented to move to a neighboring intersection. They can turn at an intersection to head down a desired street segment and can move forward to the end of the street segment they are heading. Agents recognize intersections and street segments connecting them. This is roughly a simplification of the well-known TOURS model (Kuipers and Levitt 1978; Kuipers and Levitt 1990).

The agents have a position at a node and a destination node they head to. They can either move in the direction they head or can turn to head towards another destination. They are modeled after Papert's Turtle geometry (Papert and Sculley 1980; Abelson and Disessa 1986).

The agent constructs knowledge about the environment while it moves. The operation learnConnection constructs the belief about the last segments traveled (start and end intersection and its length) and accumulates these beliefs about the environment. The operation exploreEnv lets an agent systematically travel all connections in the environment and accumulate complete knowledge about it. Agents can determine the shortest path (here simulated with the algorithm given by Dijkstra) to a destination based on their knowledge and move to a desired target following the planned path using moveAlongPath (using single steps of moveOneTo).

```
class Agents agent env where
     pos :: agent -> env -> Node
     destination :: agent -> env -> Node
     move :: agent -> env -> env
     changeDestination :: agent -> Node -> env -> env
     moveOneTowards :: agent -> Node -> env -> env
     learnConnection :: agent -> env -> env
     exploreEnv :: agent -> env -> env
     moveAlongPath :: [Node] -> agent -> env -> env
     pathFromTo :: agent -> Node -> Node -> env ->
[Node]
     moveTo :: agent -> Node -> env -> env
```

A possible data structure for agents contains the beliefs as a list of edges and position recordings, which are used only by map-makers:

```
data Agent = Agent AId Node Node [ConnectionCost]
[Position]
data AId = AId Int deriving (Show, Eq)
type ConnectionCost = Edge Node
data Cost = Cost Float | CostMax
data Edge n = Edge n n Cost
```

An ordinary agent after having traveled over some segments has a knowledge, which is represented as (using the codes from Figure 4):

```
Agent A1 at Node 4 destination Node 2 beliefs
     Node 4 to Node 2 dist 3.20156
     Node 2 to Node 1 dist 1.41421
```

5.2.1 Map making agent.

The map-making agent is a specialized agent and explores first the environment and then draws a map. In addition to the observation of connections, any agent is capable; it can observe the coordinate values of his current position. The map-maker can draw a map based on his current knowledge or can draw a sketch of a path between two nodes (used in section 9, Figure 10).

```
class MapMakers agent environment where
   isMapMaker :: agent -> environment -> Bool
   getCoords :: agent -> environment -> Vec2
   learnPos :: agent -> environment -> environment
   drawMap :: agent -> environment -> environment
   drawPathMap :: Node -> Node -> agent -> environment ->
environment
```

A map-making agent after having visited node 1, 2 and 5 has also coordinates for these nodes (using again the codes from Figure 4):

```
Agent A1 at Node 5 destination Node 8 beliefs
   Node 8 to Node 5 dist 3.60555
   Node 3 to Node 5 dist 5.09902
   Node 5 to Node 2 dist 2.5
   Node 4 to Node 2 dist 3.20156
   Node 2 to Node 1 dist 1.41421
   Node 3 to Node 1 dist 3.20156
 visited
   Node 5:(5.0/8.0)
   Node 2:(3.0/6.5)
   Node 1:(2.0/5.5).
```

5.2.2 Map-using agents.

The map-using agents have the task of moving from the node they are located at to another node in the environment. Their locomotion operations are the same as for all agents. They intend to travel the shortest path (minimal distance). A map-user first reads the map (using *readMap*) and adds the knowledge acquired to his set of beliefs about the environment before he plans the shortest path to his destination node.

```
class MapUsers agent environment where
   readMap :: agent -> environment -> environment
```

5.3 MAPS

Maps are artifacts, which exist in the environment (for simplicity, only one map is present in the model at any given time). The map-making agent produces the map after he has collected all beliefs about the environment. The map represents these beliefs in a (simulated) graphical format.

Maps in the model are a list of line segments (with start and end map coordinates) and labels at the intersection coordinates; one can think of this as suitable instructions for drawing a map with a computerized plotter. The map is then read by the map-using agent and translated into a list of beliefs.

Maps can be drawn and read, as well as sketches of a path (Figure 10):

```
class Maps aMap where
     drawTheMap :: [ConnectionCost:] -> [Position] ->
aMap
     drawAPath :: [Node] -> [Position] -> aMap
     readTheMap :: aMap -> [ConnectionCost].
```

They are represented as

```
data Map = Map [Line] [Label]
data Line = Draw Vec2 Vec2
data Label = Label Node Vec2.
```

6. BENEFITS OF COMPUTATIONAL MODELS

Constructing a functional model bridges the gap between mathematical analysis and trying out the model. The formal notation helps to test a model for logical consistency, but it does not reveal if the model is an adequate representation of "how the world functions". Observing behavior of the model for some cases helps to check that a formal system captures correctly our intentions.

The following test starts with two agents “Jan” and “Dan” (more would be possible) in an environment with the streets from the center of Santa Barbara (with the coding shown in Figure 4). Jan is a “map-maker” and explores the environment. We can ask him for the path from Node 1 to Node 9 and get the shortest path. The same question to Dan gives no answer, as he has no knowledge yet. If Jan draws a map (*env2*) and Dan reads it (*env3*), then Dan can give the correct answer as well. This answer is the same as if Dan had explored the environment himself (*env1a*). The simulated system exhibits this behavior and confirms that our intuition about maps and the formalization correspond as explained in section 5. The following text shows a sequence of `code` and the *`responses`* from the system:

```
-- readable names for the agents:
jan = AId 1
dan = AId 2
-- create two agents at node 1 destination in
direction of node 2
jan0 = Agent jan (Node 1) (Node 2) [] []
dan0 = Agent dan (Node 1) (Node 2) [] []
env0 = Env santaBarbara [jan0, dan0] emptyMap
--the two agents with the streets of Santa Barbara
(figure 9)
env1' = learnPos jan env0
env1 = exploreEnv jan env1'
-- the positions of jan and dan
janpos1 = pos jan env1
danpos1 = pos dan env1
     test input> janpos1
          Node 3
     test input > danpos1
          Node 1
-- the path from 1 to 9
janpath1 = pathFromTo jan (Node 1) (Node 9) env1
danpath1 = pathFromTo dan (Node 1) (Node 9) env1
     test input> janpath1
          [Node 1,Node 2,Node 4,Node 7,Node 9]
     test input> danpath1
          []
-- jan draws map and dan reads it
env2 = drawMap jan env1
env3 = readMap dan env2
danpath3 = pathFromTo dan (Node 1) (Node 9) env3
     test input> danpath3
          [Node 1,Node 2,Node 4,Node 7,Node 9]
-- this path is the same as
--     if dan had explored the environment itself:
env1a = exploreEnv dan env0
danpath1a = pathFromTo dan (Node 1) (Node 9) env1a
env2a = drawPathMap (Node 1) (Node 9) jan env1
env3a = readMap dan env2a
danpath3a = pathFromTo dan (Node 1) (Node 9) env3a
     test input> danpath3a
          [Node 1,Node 2,Node 4,Node 7,Node 9].
```

Constructing a model and check its adequateness by implementation focuses our attention to important points. The investigation is focused with a specific set of tasks in a concrete environment, communicating the data necessary to finding a path between named intersections in a city street network. Research in cartography usually concentrates on transformations applied to maps—mostly discussions of map generalization (Weibel 1995)—situated in a diffuse set of implied assumptions about the intended map use and the environment represented (Lechthaler 1999). The focus results in an abstract definition of correctness and efficiency of a map.

7. Cognitive Models

Computational models in the information domain are more difficult than computational models of physical processes. The model takes into account many of the often-voiced critiques against formal models of cognition. In terms of Warfield and Stich (Stich and Warfield 1994, p. 5ff) models of cognition must have three properties:

- Naturalness: The semantics of the mental representations are linked to the operations of the agent observing the environment and acting in it. These observation operations are part of the model and their properties described.
- Misrepresentation is possible, as the model contains separate representations for the data, which stand for reality, and the data, which represent an agent's beliefs. The models of observation processes may produce errors; the actions may not use the information the agent has correctly represented.
- Fine-grained meanings are achieved, as concepts and what they are linked to in reality are separate. It is possible that the agent maintains beliefs about two different concepts, only later to find out that the two are the same.

The model constructed here has these properties:

7.1 Naturalness

The semantics of the mental operations on the beliefs are directly connected to the person's bodily actions (Johnson 1987): mentally following a street segment's mental representation is given meaning through the correspondence with the physical locomotion of the agent along a street segment. This correspondence is kept in the model; the simulated mental operations of the agents are linked to the simulated bodily actions of the agents. The model is therefore not disembodied AI (Dreyfuss 1998) because the linkage between bodily actions of the agents and their mental representation is direct and the same as in persons (Lakoff and Johnson 1999).

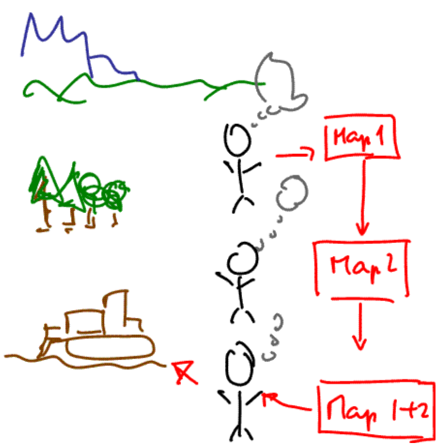
Naturalness results in an implementation where polymorphic operations are used to code related operations: the structure of the operations for locomotion along a street segment, for drawing a street segment or for following a drawn street segment and for mentally following the belief about a street segment.

7.2 MISREPRESENTATION

Persons—both the map-maker and the map-user—can make errors in the perception and form erroneous beliefs about the environment. The maps produced can also have errors or the map reading operation can include errors into the beliefs map-users form about the environment. Such errors or imprecision can be modeled in the beliefs of the agents. Eventually, agents are prohibited to achieve 'impossible' states of the environment and are stopped in the model from executing impossible actions; e.g., to travel along a street not present in the environment.

7.3 FINE-GRAINED MEANING

Concepts can have various levels of detail—they can be 'read' from a map and therefore have no experience, e.g., a visual memory associated, or can have a partial knowledge, e.g., a street segment can have a known start but a not yet known end. It is possible to realize later that two different concepts are linked to the same real object, e.g., the intersection where 'Borders' is and the intersection of 'State Street' and 'Canon Perdido Street', which is the same in Santa Barbara (Figure 4). This is possible in multi-agent models, but not included in the simple model presented here.



8. CONCLUSIONS

Communication is the prototypical case of integrating data: the data produces in the conceptual frame of one agent must be interpreted (integrated) in the conceptual frame of the other agent. The Figure 202 shows all the important aspects that are the core of the GIS data integration problem: data from different sources should be integrated and used.

Chapter 30 PRAGMATIC INFORMATION CONTENT

1. ABSTRACT

Shannon and Weaver published 194x a breakthrough book on how to measure the information transferred over a channel. This measure of information necessary to reproduce a message does, however, not assess the *pragmatic information* content of a message. Everyday experience tells us, that two messages of very different data and size may communicate the same message; they have the same information content. We also observe that the same message may have very different information content for different users. Shannon and Weavers information measure (as reported in the previous chapter) does not cope with this situation.

We are interested to measure the information that flows from sender to receiver (Figure 207: InfoTrans in red). This is not directly observable, because this is the virtual flow between the mind of the sending and receiving agent; it is achieved through the data channel, which is the measure Shannon and Weaver defines, which does not measure how much of the information on the channel is received. What can be observed is the actions that follow from the information received—the pragmatic results in the environment; the pragmatic information content measures this using an abstract model of the receiver (comparable to the algebraic models introduced in the previous chapter).

Pragmatic information content starts with the definition of pragmatically equivalent messages, i.e., messages that lead to the same conclusion. To determine pragmatic information content, the receiver is modeled as an algebra. If two receivers differ in the action they consider, their algebras differ and therefore the information they deduce from a message differ from them, the information content of the same message is different.

The analysis necessary to understand and measure pragmatic information content is very useful for the sender to structure the information he wants to convey to the receiver in a form that is useful for the receiver to follow.

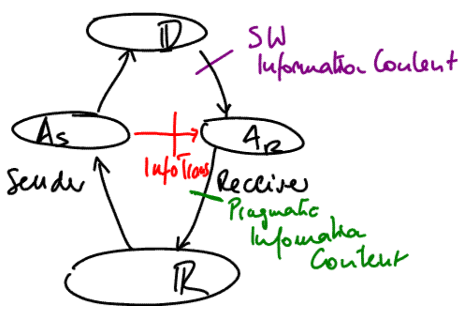
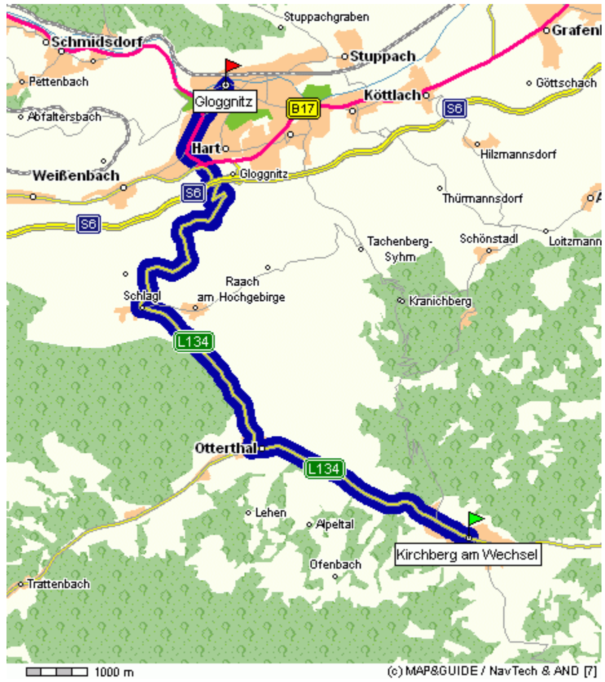


Figure 207: Different Information Measures

2. A Practical Problem

A friend tells me how to drive from *Kirchberg am Wechsel* to *Gloggnitz*—two small towns South of Vienna (figure 0):



Follow the road to Otterthal In Otterthal turn right towards Gloggnitz Follow the road through Schlagl and Graben Cross under the Semmering highway Follow the road into the town of Gloggitz

I do not fully trust his information and check with a routing service on the web, which produces the following route description:

Ihre Route von Kirchberg am Wechsel-Außen nach Gloggnitz
Die Gesamtstrecke beträgt 13,1 km.
Für diese Strecke werden Sie voraussichtlich 00:21 (hh:mm) benötigen.

Strassenname:	Fahrzeit:	Wegbeschreibung:	Länge:	Entfernung vom Start:
LH134\Markt	00:00	auf LH134\Markt	4,1 km	4,1 km
LH134\Otterthal	00:06	rechts abbiegen auf LH134 \Otterthal	6,6 km	10,6 km
LH134\Graben	00:16	rechts abbiegen auf LH134 \Graben	430 m	11,0 km
LH134\Graben	00:16	rechts abbiegen auf LH134 \Graben	770 m	11,8 km
B27 \Semmeringstrasse	00:18	rechts abbiegen auf B27 \Semmeringstrasse	650 m	12,5 km
Hoffeldstrasse	00:19	rechts abbiegen auf Hoffeldstrasse	500 m	13,0 km
Sparkassenplatz	00:20	rechts abbiegen auf Sparkassenplatz	50 m	13,0 km
Sparkassenplatz	00:21	links abbiegen auf Sparkassenplatz	128 m	13,1 km

Is this the same route as described by my friend? My curiosity is started and I check two other descriptions:

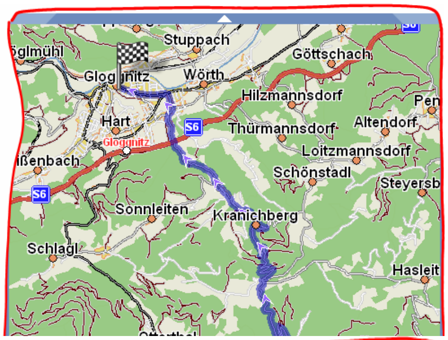
Start:	A	2880	Kirchberg am Wechsel
Ziel:	A	2640	Gloggnitz

Nr.	Nat.	Knoten	Richtung	Straße	km	km ges.	Zeit
1	A	Kirchberg am Wechsel	.	.	0.0	0.0	00:00
2	A	Ramssattel	.	.	2.7	2.7	00:05
3	A	RS	links auf	B27	6.5	9.2	00:16
4	.	Gloggnitz	.	.	1.5	10.7	00:18

Entfernung ges.: 10.7 [km]	Fahrzeit ges.: 00:18 [hh:mm]

and

Zeit	km (ges.)	Beschreibung	abbiegen	Strecke	Richtung
00:00	0,0	A2880 Kirchberg am Wechsel-Mark	auf	-	
00:13	6,2	-	halb links auf	-	
00:16	7,8	-	links einordnen auf	-	
00:22	11,7	-	rechts auf	B17	
00:22	12,0	A2640 Gloggnitz			



Beschreibung		
01	Sie starten in der Straße Markt in Kirchberg am Wechsel.	
02	Sie verlassen Kirchberg am Wechsel.	2 min 1.04 km
03	Verlassen Sie die Straße Markt und fahren Sie weiter geradeaus auf die . Folgen Sie dem Straßenverlauf für 2.41 km.	4 min 3.45 km
04	Sie passieren jetzt die Ortseinfahrt von Otterthal.	4 min 3.45 km
05	Folgen Sie der Straße Otterthal für 932 m.	6 min 4.38 km
06	Sie verlassen Otterthal.	6 min 4.38 km
07	Verlassen Sie die Straße Otterthal und fahren Sie weiter geradeaus auf die . Folgen Sie dem Straßenverlauf für 5.04 km.	11 min 9.42 km
08	Sie passieren jetzt die Ortseinfahrt von Gloggnitz (Graben).	11 min 9.42 km
09	Folgen Sie dem Graben für 66 m.	11 min 9.49 km
10	Sie verlassen Gloggnitz (Graben).	11 min 9.49 km
11	Bleiben Sie auf dem Graben und folgen Sie dem Straßenverlauf für 1.89 km.	13 min 11.38 km
12	Verlassen Sie den Graben und fahren	

Figure 0: – a map of the area

I realize that I have received three times information to drive between the same locations—encoded in three different formats. Is it the same information? Following the different routes on a map shows that the last two descriptions give a different route (route B in figure 0), perhaps quicker, and only the first one describes the same route given by my friend (route A in figure 0).

It is evident, that the instructions can contain the same information but presented in different forms. How do we measure *pragmatic information content* of messages of different size that lead to the same actions?

Unfortunately, actual route descriptions as given in the examples leave many questions of a driver open. They are difficult to use and it is not clear, what their intended semantics are. This is necessary to clarify before we can measure their information content!

3. How to Measure Pragmatic Information Content

The theory of Shannon and Weaver (Shannon and Weaver 1963) is widely used to measure the size of messages; it measures the amount of data that is stored or transmitted over a channel in 'bits', i.e., a unit of a single binary decision (previous chapter). It does not measure how much of the information has been picked up by the receiver. The examples show that the amount of information transmitted is quite different but they have—if correct and correctly followed—the same effect to guide me from my start to my destination.

It is not possible to measure the information created inside the receivers mind; we can only observe his actions and derive what information was necessary to decide on them. The

	Km	Ort	Beschreibung
START	0.0	Kirchberg am Wechsel	L134\Markt
	4.0		in Otterthal rechts abbiegen auf L134\Otterthal
	11.2		L134, **Beschilderung Trattenbach/ Kirchberg Am Wechsel/ Otterthal/ Raach/ Wechselgebiet**
	11.3		Folgen Sie dem weiteren Verlauf der B27\Schlaglstrasse (Beschilderung beachten)
	12.3		B27\Semmeringstrasse
	12.3		am Kreisverkehr auf Hoffeldstrasse
	12.9		Sparkassenplatz
	12.9		Sparkassenplatz
	13.0		Doktor-Karl-Renner-Platz
ZIEL	13.0	Gloggnitz	

pragmatic information content depends on the *message* and the situation (receivers *context*) in which the information is used to make a decision. For example, a receiver that has already most of the knowledge necessary will gain much less from a message than a receiver with less previous knowledge. It is therefore necessary to model the receiver of the message and the decision the message is used for making.

The message itself is assumed to be a fixed artifact produced by the sender. The sender may adapt the message to his assumptions of what the receiver may already know; this influences the content and form of the message, but it does not influence the information included in the message, once this message is produced: the content of a message after production does not depend on the sender anymore.

Decisions are the only use of information

When a message is used to decide on some action, then the message becomes information (in the sense of pragmatic semantics) and the pragmatic information content of a message can be identified and measured—with respect to this decision context. This use of information in a decision situation gives value to the information, following modern economic theory (North 1997); to measure information used is therefore related to the value drawn from the information.

Service providers, for example the route planners initially shown, want to measure the information they provide to know how to charge for it (Krek and Frank 2000). How should such services charge for the information they provide? Current solutions are to measure the length of the measure, by the character transmitted or by connect time? This is using the Shannon and Weaver measure of the information in the message; users are not willing to pay for more verbose messages! They are (at best) willing to pay according to the value of the information for them that they have used.

4. Pragmatic Information Content

Pragmatic semantics and pragmatic information content of messages must be investigated not in transmission situation as described in Shannon and Weaver (fig 1), but in a decision situation (fig 2). This includes the receiver and measures his use of the information. The connection between the information in the message that is used to make a decision about some actions and the decision needs to be considered—Shannon and Weaver's method stops when the message is correctly received.

A measure of pragmatic information content is different from the measure of data size of messages using the theory of Shannon and Weaver. In numerous situations it has been observed that the measure of Shannon and Weaver is not adequate for information content. For example three of the route descriptions given initially have the same pragmatic semantics, but different message sizes. A widely held opinion wants to restrict the formula xx to technical circumstances and declares it inappropriate as a 'real' information measure.

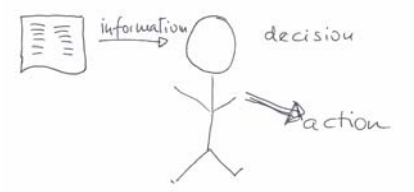


Figure 2: The decision context

5. PRAGMATIC EQUIVALENCE OF MESSAGES

Theory of pragmatic information content:
(eq) Two messages are equivalent when they lead to the same actions.
(p1) Equivalent messages of different size have the same pragmatic information content.
(p2) The same message has different pragmatic information content when used in different decisions contexts.

Assuming a fixed decision situation, messages that lead to the same action have the same pragmatic semantics and the same pragmatic information content. If I have to drive from Kirchberg to Gloggnitz then a series of decision situations are fixed: at each intersection I have to decide which way to turn. Three of the instructions given initially, if properly interpreted, lead at these intersections to the same decisions. These instructions are therefore *pragmatically equivalent*.

5.1 DIFFERENT MESSAGES FOR DIFFERENT DECISION CONTEXTS

Pragmatic equivalence—leads to the same actions

If we give instructions, we adapt them to the person to whom we give them. Route descriptions assume that drivers have certain abilities. Some route descriptions refer to cardinal directions, most web-based ones use distances. Not all drivers are certain where the cardinal points are while driving and many ignore the odometer that would give them distance information. They cannot effectively use such instructions. Some drivers can follow a named or numbered highway through many intersections; others need instructions at each intersection. Many route descriptions from the web require additional information gathered from the road signs and knowledge about the location of places mentioned on road signs and in the route description.

I once went in Virginia from Lee Highway 2000 to Lee Highway 10620—14 miles of winding road through many tricky intersections where I got lost more than once! I was hours late!

An instruction type is geared towards a specific decision situation, where the decision maker has determined ability and knowledge. Users with more knowledge can often use instructions prepared for less knowledgeable users. For example, users with a general geographic knowledge of the area can use detailed descriptions, ignoring a large part of the message.

5.2 EQUIVALENT MESSAGES HAVE SAME PRAGMATIC INFORMATION CONTENT

If two messages are pragmatically equivalent—i.e., they lead to the same decision—they have the same pragmatic information content. Even if their size, measured as size of data to be transmitted using the entropy formula (chapter xx) is different, the measure of pragmatic information content must be the same. In Figure 208 the amount of information extracted from a given message is shown for three different agents with different amounts of information they have already or they can acquire directly from the environment.

For a knowledgeable user (agent C in Figure 208) a succinct instruction is sufficient with a low pragmatic information content. If the same user is given a more detailed one, for him, the more detailed instructions have the same pragmatic semantics and therefore the same (low) pragmatic information content. For a user that requires a detailed instruction (agent B in Figure 208), the same message has a higher pragmatic information content. Other agents acquire information from the environment and need therefore fewer instructions (agent A in Figure 208). For the knowledgeable user, much of the detailed message is redundant and not contributing to pragmatic information content—in the extreme case, where somebody knows the way from Kirchberg to Gloggnitz already, the message does not contain any new information, i.e., no pragmatic information content. The decisions taken without the instructions would be exactly the same!

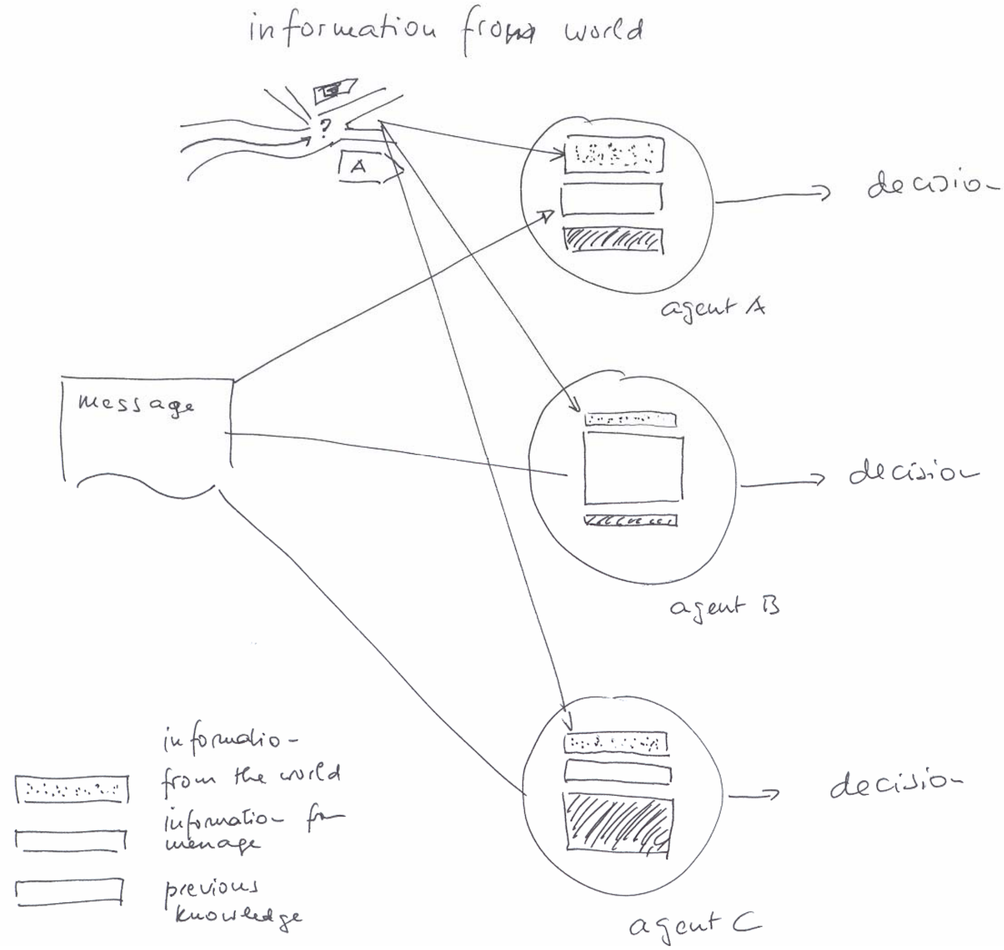


Figure 208: Three different agents with different previous information

Drivers with different levels of knowledge are in different decision contexts, the way they make their decision is different. The pragmatic information content is the least amount of information necessary to make a decision in some determined context. If the context changes then the information necessary changes and the pragmatic information content of a message changes as well.

Using the same driving instructions for the determination when I have to leave Kirchberg to reach a train in Gloggnitz at 08:55 is an entirely different decision context. In this context, I am only interested in the expected driving time and the remainder of the route description is lost on me. The pragmatic information content of a message that only contains the driving time and one that also contains the full route description is the same.

6. Integrate Earlier—Redundancy

Data in the instruction that is not required is considered redundant. The driver reaches her target without this data as well—only the necessary part is translated to information and used to make the decision. In practice, redundancy is crucial, to respond to unexpected situations, missing street signs, errors in the data used to produce the route description, etc.

In this article only the role played by the necessary information is investigated. The value of redundancy in the instructions needs a separate assessment.

7. Formal Description of Use of Information in Decision Required

Pragmatic information content can only be measured with respect to a determined decision situation and decision process. It is therefore crucial to define the decision context precisely and to assess instructions with respect to the decision context. In this section, a formalization is shown continuing with the model of agents navigating in a city situation.

For modeling the street network and the basic agent, we use the same algebras as in the previous chapter.

7.1 A decision context is modeled as an Algebra

To determine information content a description of the decision situation must come first. This description explains how the instructions can be understood by a driver, i.e., the semantics of the instructions for the driver. The agent with the operations to move in the street network is modeled as an algebra; the instructions must identify the operation the agent must take and provide the necessary parameters.

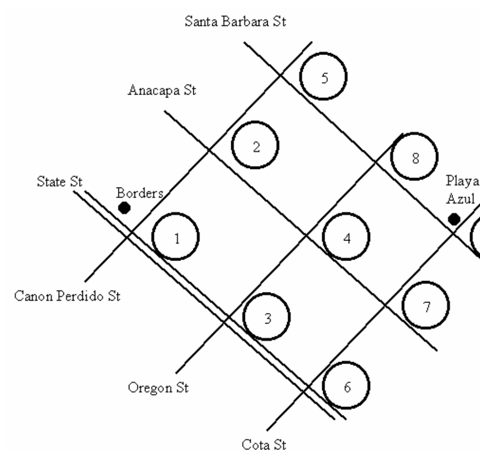


Figure 209: A small subset of streets of downtown Santa Barbara (with intersection identifiers)

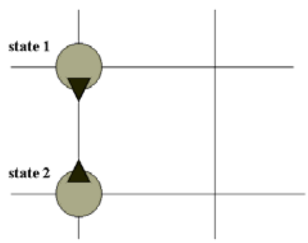


Figure 210: The position of an agent before (state1) and after a move (state2)

```
class BasicDrivingAgent agent env intersection where
    startAt :: intersection -> state -> state
    isAt :: state -> intersection
    headsTo :: state -> intersection
    move :: state -> state
    turnTo :: intersection -> state -> state
```

Agents are located in this environment at a street intersection and are oriented to move to a neighboring intersection. They can turn at an intersection to head towards a desired neighboring intersection and they can move to the intersection they are heading towards. They are modeled after Papert's Turtle geometry (Papert and Sculley 1980; Abelson and Disessa 1986)). After a move, the agent heads to the node it came from (Figure 6). This—not quite natural—behavior leads to the smallest set of axioms for its definition; it can be defined with only four axioms (the operation *connectedIntersectoins* returns all nodes connected to the node given as an argument):

1. *Turning does not affect the position:*
   isAt (a, (turnTo (a,n,e)) = pos (a,e)
2. *Moving brings agent to the node that was its destination:*
   isAt (a, move (a,e)) = headsTo (a,e)
3. *The destination after a move is the location the agent was at before the move:*
   headsTo (a, move (a,e)) = isAt (a,e).
4. *Turning (changeDestination) makes the agent's destination the desired intersection:*
   headsTo (a, turnTo (a, n, e)) =
   if n elementOf (connectedIntersections (pos (a, e) e) then n
   else error ("not a connected intersection")

This model is the model of the actions a driver can take on an 'intersection by intersection' level and which are checked against the available street segments; drivers are restricted to advance along existing streets. The implementation of the algebra as part of an agent system together with a representation of the street network checks the legality of all moves and calculates the result of such actions. It is a model of a physical agent moving in a street network and is not intended as a model of the human decision process. I call it therefore *'basic driving agent'*.

7.2 TYPE OF INSTRUCTIONS

The algebra of the agent defines the instructions this agent can follow. Instructions are here understood as messages that translate 'piece by piece' into actions. Route descriptions are presented as a sequence of instructions, each containing an action word, which translates to an operation, and the appropriate parameters for this action. The algebra with the axioms gives the semantics of instructions and defines which instructions are meaningful for a given agent.

For example, the basic driving agent requires the following instructions to drive from Borders (intersection 1) to Playa Azul (intersection 9) (see figure 5):

```
StartAt 1, turnTo 2, move, turnTo 4, move, turnto 7,
move, turnto 9, move.
```

All instructions that are meaningful for an agent (defined as an algebra) are of the same type. Typically, all instructions prepared by one web service are of the same type; some web services offer two different instruction types—often including sketches of the intersections in the more detailed one. The four initial route descriptions are all of different types and it is therefore difficult to compare them.

7.3 Instruction equivalence is path equivalence

The result of carrying out a sequence of instruction for driving between two locations is that the agent has traveled through certain street segments and has arrived at the goal location. The instructions describe the path through the network. Two sequences of instructions are equivalent, if they describe the same path through the network.

A path is a sequence of location, starting with the initial location and the listing all the locations a driver passes through.

A path is a sequence of locations the agent has passed through. Two paths are equivalent, if they contain the same location in the same order. Route descriptions of different types can be path equivalent, when carried out result in the same path.

Equivalence of messages is defined as homomorphism between the algebras of the receivers; homomorphism between algebras establishes equivalence classes. All messages in the same equivalence class define the same pragmatic information. All messages that produce the same path are equivalent; they must have the same pragmatic information content.

8. Differences in Agents Modeled as Different Algebras

The instructions given by my friend and the instructions downloaded from the web do not consist of instruction to move from one location to the next one, as suggested by the 'basic driving algebra'. For example, my friend assumes that I am able to carry out the operations:

```
followRoadTo :: location -> state -> state
turnTowards:: left/right -> locatoin -> state -> state
follwoRoadThrough:: location -> state -> state
cross :: streetId -> state -> state.
```

This assumes substantial commonsense reasoning, reading, and interpretation of street signs; if street signs with the location names indicated are not present, I will have difficulties to follow the instructions.

For example the 'basic driving algebra' of moving from location to location can only be used by a person knowing the locations that are mentioned and is clearly not realistic for route information giving. Other methods to give driving instructions rely on street names (example 2 falk) on location names on signs on intersections (example easy tour) and most use turn directions.

To each instruction (type) belongs a corresponding algebra that explains how to follow these instructions. Trivially, such an algebra contains an operation 'follow one instruction line' with the data in an instruction line as arguments. In this section, different algebras, which each represent a different decision environment, are formalized.

For the following examples, instruction for a path from Borders (Intersection Canon Perdido St and State St, #1) to Playa Azul (Intersection of Santa Barbara St with Cota St, #9) is used (figure 7). A human could give the following 'natural' route description:

Follow Canon Perdido Street to the East for one block,
Turn right and follow Anacapa Street for two blocks
Follow Cota St to the East for one block,

which results in the path

```
[Intersection 1, Intersection 2, Intersection 4,
Intersection 7, Intersection 9].
```

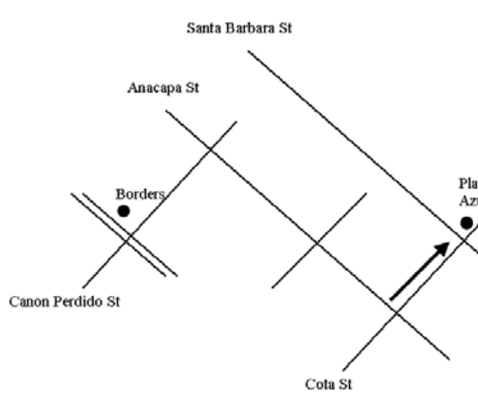


Figure 211: Sketch for path from Borders to Playa Azul

8.1 DRIVER "TURN AND MOVE"

In regular instructions using the Basic Driving Agent every turnTo instruction is followed by a move instruction. Merging the two to a single instruction gives ('.' is the composition operation for actions, 'a . b' means do a then b):

```
turnToAndMove : intersection -> state -> state
turnToAndMove n = headsTo n . move.
```

The instruction for the path in the initial example is now:

```
Initialize at 1, turn to and move 2, turn to and move
4,  turn to and move 7, turn to and move 9, ->
(reached 9).
```

Information content for such a description of a path, not including the information about the start node, is per segment traveled an information about the turn.

8.2 DRIVER "TURN LEFT/RIGHT AND MOVE"

A driver that responds to instructions to turn left or right and then move for one segment

```
TurnAndMove :: LeftORRight -> state -> state.
```

The instruction for the same path is for such a driver:

```
Initialize at 1 heading to 4, turn left, turn right,
turn straight, turn left -> (reached 9).
```

8.3 DRIVER "TURN LEFT/RIGHT AND MOVE STRAIGHT FOR N SEGMENTS"

A driver that responds to instructions to turn left or right or to proceed for a number of segments

```
MoveFor :: Integer -> state -> state
Turn :: Left_Right -> state -> state.
```

The instruction for the same path is for such a driver:

```
Initialize at 1 heading to 4, turn left, move 1, turn
right, move 2, turn left, move 1 -> (reached 9).
```

8.4 DRIVER "TURN AND MOVE DISTANCE"

A driver not familiar with the environment will pay attention to the indications of the distance and use the odometer to check his movements. He can determine the cardinal directions, perhaps using a small compass. His algebra is

```
TurnAngle :: Angle -> state -> state
MoveDistance: Distance -> state -> state.
```

8.5 DRIVER "TURN AND MOVE TILL"

This driver is familiar with the environment; in particular he recognizes some street names and is able to read other street names from the signs often found. His algebra is:

```
Turn :: Left_Right -> state -> state
MoveTill:   Streetname -> Turn :: Left_Right -> state
-> state.
```

The interpretation by the driver "Turn and move till" requires information, which is either known to him—"information in the head" in the terminology of Douglas Norman []—or information he perceives from the environment—"information in the world".

8.6 Equivalence of instructions

A set of instructions is equivalent, if they result in an equivalent path, i.e., when an agent following the instructions touches on the same locations in the same order. This can be achieved with simulated execution of the instructions against the street network.

Alternatively, we can translate the different types of instructions listed above into operations of the basic driving algebra (an example is given in 5.1??). It is then possible to show directly that two instructions are equivalent if they translate to the same instruction sequence of the basic driving algebra.

Some translations are purely formal and do not require additional information. Another needs information from the street network—for example to translate left or right turns into ‘headsTo intersectionID’ operations or to translate moveDistance in simple moves along street segments from intersection to intersection.

8.7 Conclusion

The algebra that represents a decision situation defines methods how information is used pragmatically. Different decision makers with different knowledge encounter different decision situations. Instructions for them must be adapted to their knowledge and ability, the instructions must relate to the algebra of which describes the decision context; the instructions must use the operations and their parameters according to this algebra.

9. Pragmatic Information Content

9.1 Determination of pragmatic information content

The information content in an instruction of a given type follows from the algebra. The information content in an action

```
op :: param1 -> param2 -> state -> state
```

is estimated as

H = ld (cardinality domain param1) + ld (cardinality domain param2).

To this, we have to add the information to select this operation from all the operations in the algebra (*Ho = ld (number of operations in algebra)).* There is very often only one operation and therefore *Ho* is 0 (*ld 1 = 0*).

This estimate assumes that all combination of input values are of equal probability (and none illegal—i.e., the function is a total function); if only for some values a valid state change is defined, then the information content is less and must be computed using the formula for entropy (in section 2).

The information content per instruction for the different algebras given can be computed easily. We assume that there are 1024 intersections in the street network and that distances are given with 3 meaningful decimals (i.e., values between 10m and 9990m) and directions are given with a resolution of 1/100 of a circle.

Basic driving agent:

turnTo h1 = ld 2 + ld 1000 = 1 + 10 = 11 bits
move h2 = ld2 = 1.

Turn and move:

TurnToAndMove h3 = ld 1000 = 10 bits.

Turn left/right and move:

h4 = ld 8 = 3 bits.

turnLeft/right and move n segments

h5 = ld 8 + ld 16 = 7 bits.

Turn and move distance:

turn h6 = ld 100 + ld 2 = 9 bits
move h7 = ld1000 + ld 2 = 11 bits.

9.2 PROPERTY 1: DIFFERENT MESSAGE, SAME INFORMATION

A particular agent with a determined algebra expects instructions in the corresponding form. Most humans are versatile and can follow instructions of various types. The algebra of such a decision situation contains the 'basic driving operations' plus some additional ones, this agent knows how to translate into the basic operations.

The size of the instructions this agent can use varies (see xxx) and if the agent can respond to a number of instruction types, these form equivalence classes of instructions leading to the same actions.

The pragmatic information content for all equivalent instructions an agent in a given situation can use must be the same. Therefore, the information content is the size of smallest instructions in this equivalence class, i.e., the instructions that contain no redundancy (with respect to this agent definition). The beneficial effects of redundancy are not considered in this paper and the question is left for future work.

The pragmatic information content is the size of the instruction without redundancy for this agent algebra.

Different messages this agent understands may have different data size, but have the same pragmatic information content, namely the data size of the smallest message. This measure is completely dependent on the abilities and knowledge of the agent (modeled as an algebra).

9.3 Property 2: same message, different information

The same message used by two different agents with different decision context may lead to very different assessment of the pragmatic information content of the message. Compare the agent above that intends to drive, with another agent, which

```
whenToLeave:: expectedArrival time -> lengthOfDrive ->
departureTime
lengthOfDrive :: [dist&dirInstructions] ->
lengthOfDrive.
```

For this agent, a specialized message that contains only the expected driving time is pragmatically equivalent with a set of instructions, which contains the distance, which he sums and divides by the expected average speed to calculate the driving time (a figure between 5 minutes and 2 hours). The pragmatic information content is therefore *ld 120* = 7 bits.

10. Information business

In this section I sketch how the theory developed here can be used to advance the information business, in particular the business with Geoinformation. In many decision situations, spatial and geographical information plays a role; it is often estimated that 80% of all decisions are influenced by or influence space [ref?]. In ongoing research we develop methods to assess the value of geographic information in different decision situations as the contribution it makes to improve the decision (Krek 2002); the assessment of information value is using the same algebraic concepts to model the decision situation as described here.

1. The description of the decision context as an algebra is first helpful for the design of the presentation of results and explanations for the user on how to interpret a route description. The ones found on the web leave considerable guesswork to the intended user. The pragmatic value of the information is therefore greatly reduced and the user will not trust information difficult to interpret.

2. The measure of pragmatic information content can be used to determine the charges for instructions provided, identifying what is information and what is redundant. For different street network parts (in town, highway, local streets

between small towns) different information is necessary for navigation and what is redundant is not always the same.

3. Differential pricing is key for an effective information business. For uses of information in decision situations that have a higher value, higher prices should be charged, but users will tend to buy information designed for other, lower value uses, if they contain all necessary detail.

For example:

If one user must sketch a path for somebody in a map-like way, then instructions with cardinal directions and distances are very useful and other forms of instructions cannot be used. This user takes full advantage of the rich content and deduces higher value from the data. Another user that just uses these instructions to follow a route in familiar territory would translate the instructions in turn and move *n* segments, and extract only much less information (most of the metric data is just redundant when one moves actually in the physical street network, which keeps drivers on the prescribed roadways). To avoid cannibalism—i.e., that high value users buy the data intended for low value applications—the route descriptions for driving should contain only very approximated cardinal directions and distances, whereas a higher value instruction for drawing sketches of path contains cardinal directions and distances with sufficient precision for the task.

11. Acquisition of Information before It Is Used

Information is used to make decisions between actions—it is difficult to see another use of information. Often, we acquire information ahead of time and store (learn) facts for which we expect later a use in a decision situation. It is not possible to evaluate the information acquired unless it is used—again: observation of what is inside an agent’s mind is not possible. But a similar issue arises with information used once and measured by and paid for this use: the receiver keeps the information and can use it again.

From a business perspective, information selling over the web is useful when users need a small part of a large data collection, typically combined with some additional 'smarts' (e.g., the selection of the shortest route). Then reuse is very unlikely and pricing for a single use is advised. A higher price is not feasible, because most clients use the data once only and the effort to make it impossible to store the data cause more cost on the side of the vendor and on the side of the client!

12. SUMMARY

12.1 PRAGMATIC INFORMATION CONTENT IS DETERMINED WITH RESPECT TO A DECISION CONTEXT

The theory by Shannon and Weaver defines a size measure for the transmission of data, pragmatic information content defines a measure for the amount of information used in a decision context.

Two messages are pragmatically equivalent—in a determined decision context—when the decision taken is the same.

A decision situation is modeled as an algebra, where the details of the message lead to decision.

The information content in an action

```
a :: param1 -> param2 -> state -> state
```

is estimated as

H = ld (cardinality domain param1) + ld (cardinality domain param2).

The pragmatic information content for a given decision situation and user is the least amount of data necessary to make the decision. If instructions contain more data, this is redundant, either formal redundancy, or already known by the agent or extracted by him from the real situation.

But if the same message is used in different decision contexts, then the above method, using a different action for one and the other context, results in different pragmatic information content.

12.2 SEMANTICS OF INSTRUCTIONS DEFINED BY MODEL OF HUMAN USER

The semantics of instructions is defined by the decision context, which is a model of the human user. Agents are models of human users of information and can be modeled using algebra. The algebra defines what instructions lead to the same decisions (i.e., what instructions are equivalent). This article concentrates on the general principle of measuring the pragmatic information content and the decision contexts are used only for illustration.

12.3 OPEN QUESTIONS

Formal description of realistic human drivers as algebras

In this article, the algebras were selected for simplicity. It is an important task, to determine what are good models of human drivers? What are the abilities of drivers to follow route descriptions? Route descriptions given in natural situations, are quite different from the route descriptions listed in this article initially. Route descriptions produced by humans contain much more landmarks:

Drive down Reinprechtsdorferstrasse till the Gazelle (a bright blue colored chain store)

Drive along the Taborstrasse till you pass the church.

How many landmarks are useful to provide the tranquility of mind to the driver?

12.4 Redundancy:

Messages that are larger than the minimum required for pragmatic actions contain redundancy. This is useful to guard against transmission errors, but also necessary when carrying out the instructions to cope with errors in the instructions and missing information in the world. The assessment of the value of redundancy is an important question, left for future investigations. Small differences between pragmatic information content are certainly overshadowed by the contribution produced from redundant data in unexpected situations.

Different strategies of giving and following route descriptions react differently to errors:

- some fail completely if a minimal error in the instruction is encountered
  example: list of turns—one error and a completely different path results that do not lead to the destination
- some rely on the receiver picking up some additional information from the world
  example: relying on street names posted at each corner—fails if these signs are missing
- some rely on the receiver having specific knowledge of the world

Figure

Chapter 31 650 Verbal Communication

Verbal communication is the prototypical communication for human beings: uttering a sentence constructed from words is the primary form of communication between humans. The vocal tract and the human ear is a perfect channel for communication: the vocal tract is a very flexible, highly coordinated system that can produce a wide variety of sounds and change them quickly. Audio signals carry easily in air to reach people that are close enough for interaction. We may say that audio communication is ideal for humans, but one could also argue, that human society has perfectly adapted to the abilities of the vocal tract and the physics of audio-signals—a classical question of 'what was first: the hen or the egg?"

Fixing verbal utterances to paper is an important step to achieve communication not only between people present at the same location, but to communicate across time and space: a sentence written can be mailed to a different location and be read at a later time.

Figure

For GIS, communication with language, mostly verbal language, is central. Most facts stored in a GIS are encoded words and communication to and from the GIS is verbal, mostly written but increasingly also spoken, e.g., instruction in car navigation systems. This will be discussed in the next chapter (xx).

Language is infinitely extensible and humans have developed powerful methods to use language beyond the simple naming of things visible and the direct interaction with them, this chapter will focus on communication of physically grounded facts with spoken language, written communications will be discussed in the next chapter, construction of abstractions is discussed in the next part.

The system of verbal communication, a.k.a. natural languages, is structured in a hierarchical fashion: sounds (phones, allophones, and phonemes) are combined to form words, words are combined to form sentences, and sentences combined to form texts, conversations, etc. For each layer, the rules of combination are different. This flexibility produces an infinite variation in texts. Adding new words adds to the adaptability of the system to new situations.

One of the often overlooked abilities of natural languages is the ability to be as precise or imprecise one wants to be with a communication. Language has a large variation of methods to describe only the part of a situation that is necessary or interesting, the part, which the speaker is willing to divulge, etc. In this respect, language is more flexible than images—it is difficult to make a picture of a person (not a specific person, not a man or woman). Language can not only state facts, but it is possible to express a question (important for GIS query languages).

Interesting is how language expresses temporal and spatial relations. Natural spoken language has a linear organization in time, but how to describe spatial relations?

This chapter starts with the methods to construct words and the relation between words as special audible signs with concepts. Spoken words and written words are linked, comparing an iconic with a phonetic approach.

The combination of words to sentences is addressed; the special interest of GIS is here with the expression of spatial relations (see xx) between objects.

The verbal communication system

- can be communicating different channels (the audio or the visual channel as spoken or written language),
- has an infinite number of combination of words and new words can be constructed,
- can express partial information.

The focus of this chapter is the communication of situations in terms of tier 2 objects, the construction of abstract concepts is left for the next part. Important is the observation that language is not restricted to truthful communication of a situation (as are cameras), but imagined worlds can be communicated (so called ‘contrafactual’ expressions); this is necessary to communicate plans.

Maps are a special kind of language and will be discussed in the next chapter.

1. Words and Meaning

Verbal communication is based on the combination of words to sentences. The meaning of a sentence follows from the meaning of the words and the exact structure of the combination. Linguists stress this property as the 'combination requirement'. This first section describes the construction of words.

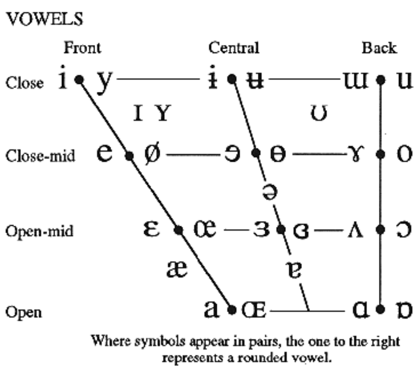
1.1 Phones

The human vocal system is able to produce a large number of different sounds, perhaps 250 are differentiated by phonetics as 'typical' and not just personal variations of the same sound. The voice has attributes that identify the person; most people can recognize the voice of their friends easily and without conscious effort as quickly as you identify a person from seeing her face.

Natural language use some (perhaps 50) sounds to construct words from the 250 possible ones; this adds redundancy: in one language, only these 50 sounds must be differentiated, which makes the recognition much more robust. Ambient noise does not disturb a conversation that much!

1.2 Combinations

Languages have rules how the phonemes are combined; these rules are influenced by what is easy to produce and avoids combinations of sounds, which require difficult changes in the vocal tracts. For example, in Finnish, a word can only use vowels from the front [ɛ, œ, y] and middle part [ɜ, ə] of the mouth, or vowels from the middle and the back part [*a*, o, u]: vowels; in German, no word starts with the combination s – z. In Italian, words should end on a vowel and combinations of consonants without intervening vowels are seldom. Chinese words are monosyllabic and constructed from xx consonants and xx vowels, combined with 4 tones (for mandarin); this gives a total of xx pronounceable words.



Vowel square from the International Phonetic Association website (IPA) published 1993 (1996 updated) http://www2.arts.gla.ac.uk/IPA/ipa.html .

The rules for possible combinations reduce the vocabulary from the infinite number of combinations to a finite set of combinations of maximal length (non-compound words seem to be limited in length in all languages to a few syllables; any language with more than 3?), further restricted by combination rules. This again, increases redundancy.

1.3 Representational character of words

Words stand for concept—but one should not assume a one-to-one relationship. Unfortunately, this is—often only implicitly—assumed in many discussions, including the descriptions of the terminology used for classification of geographic units. The mapping between concepts and words is many—many:

1. Polysemy: There are spoken words that have multiple meanings: a bank can be a river bank or an institution to keep money. One word—multiple concepts.

2. Synonyms: There are words that have (nearly) the same meaning: a river and a stream. Lists of synonyms were used to help enrich writing, but modern linguists do not assume that there are perfect synonyms; words that are considered synonyms are often different not in their 'objective' meaning (cheap is the same as inexpensive) but in their connotation (cheap is negatively, inexpensive positively loaded).

Organizing words by synonyms has a long tradition—Roget's Thesaurus perhaps the best known (Donald 1996). The revolutionary concept in wordnet was to arrange words in synonym sets (synsets), but to include a word into more than one set of synonyms (Fellbaum 1998).

It is a reasonable simplification to assume that the assumed mental concepts correspond closely to such symsets (note that this is not a claim that mental concepts exist in some fixed representational sense in the brain!). Between words and symsets are clearly a many to many relation!

Figure

1.4 Proper names

The vocabulary consists—from an ontological point of view—of:

- Proper names of agents (Tiger, Tom);
- Proper names of things (the car ZH 512 421, Afghanistan);
- Names for property value;
- Class names,

- Property names;
- Verbs;
- Particles (prepositions, articles, etc). (in, an, auf, therefore, etc.).

Names will be discussed here and the rest of the vocabulary is dealt with later.

Proper names stand for the object they represent: there is a 1: 1 relation between the object and the concept (at least in a context). There is only one Andrew Frank (photo) and the name “Andrew U. Frank” (at least all reference to this name found on Google seem to point to me).

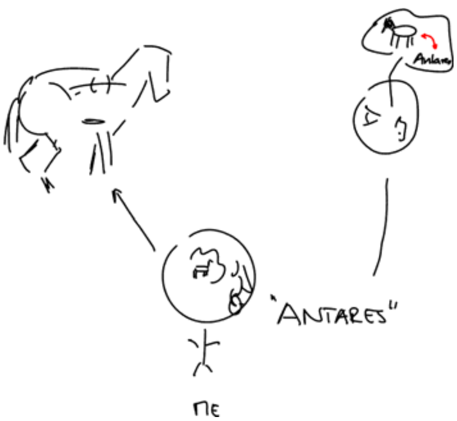


Figure 212: An entity and a word

There is no direct connection between a word, including names, and an object: this connection is only established through a cognitive agent observing the object and connecting it with a word. The realm of the objects and the realm of the words representing them are completely separated, but must expose a certain isomorphism (figures xx before)

It is culturally necessary that names of things are stable. It is improper to change one’s name (except for women when they marry in most of Western Europe) or use multiple names (only criminals and artists do this) and everybody has to have a name (including ‘the artist formerly known as Prince’).

Culture assumes for many important things (but not all) that there exists a function.

```
Getname :: env -> obj -> name
FindObj :: name -> env -> obj
```

Names are a first example of a social construct in the sense of Searle (Searle 1995). They are only useful if a group of individuals agree on them.

Names can come in many forms, as strings of characters, as numbers (e.g., the names of the days of a month) or arbitrary strings (social security numbers, license plates of cars, serial numbers, etc.). Names are always on a nominal scale—only comparison for equality is a relevant operation—and often a lexicographic ordering is exploited for searching (e.g., in telephone directories). Some names, especially person names, are structured such that they hint to relationships between people: Peter Smith maybe the father of Paul Smith (or his brother, or completely unrelated).

Many uses of names rely on a small context, in which the name is likely unique. The best example is the use of Christian names to identify people, there are thousands of 'Rudi' living in Vienna, but within the context of my department, 'Rudi' is unique (not so for 'Martin'). Usually the context of a situation is sufficient to disambiguate a statement and identify the person. One should not be tempted to think that the usual combination of Christian name and family name *is* the person: there are 3 persons with the same name 'Martin Staudinger' listed in the Vienna phone directory!

1.5 Names for the results of measurement observations

The results of measurement observations are expressed with numbers that are then translated to words, based on the ordering of words: one, two, three, four… Occasionally other words are used: very small, small, medium, large, very large.

1.6 Verbs

The actions human agents are capable of are restricted. We have seen that generalized concepts for human actions are necessary for planning. The walk yesterday and the walk today and my future walking are all instances of the same verb 'to walk'.

People can recognize actions of others and connect them mentally to the same action they would carry out. Words to describe these concepts are thus grounded in the personal experience and are recognized based on the same grounding in others. The possible human actions are the same for everybody. Some are more apt, some are so inept, that one says, they cannot do it. Not everybody can play the piano well (but anybody can in principle touch the keys and make some 'music'), everybody can learn to swim and therefore can swim, but some have never tried.

1.7 Nouns

All instances of things that can be part of an action form a class (intentional), the extension of which can vary with the situation (example: a tree stomp may become a table or a seat, fig xx). Agents construct such classes and properties based on the abilities to perceive properties, etc.

Names for classes of objects can be divided in 'base class' and others. Base classes are the names of classes that are perceived directly; one of the simple tests is the question "Can you imagine an object of this class?“ We can imagine a sheep, a dog, but we cannot imagine an animal; we can imagine a chair, a table—but not ‘a furniture’.

Figures
Why is this relevant—less variability? Directly related to properties?

Base classes seem to be older strata of a language. In English, base class are short (typically monosyllabic) and of Germanic origin. In German, base class nouns are also short and have masculine or feminine gender—non-base class has neutral gender.

Die Maid, der Knabe, (not base class: das Kind)

Die Stute, der Hengst, (not base class: das Pferd).

1.8 Productivity in vocabulary

A language is only working if the vocabulary is agreed in the community—to a large degree, but not perfectly. Language and communication between humans accept differences in the vocabulary, if they are limited: I may call a wood what you would call a field with some trees (photos), and you may refer to my friend Werner as “Herr Professor”—this does not confuse us. If you, however, change the meaning of all words or speak in a language that I do not understand, communication breaks down.

Tolerance for differences in the vocabulary allows the introduction of new words in a language: everybody knows what radar is (it was originally an abbreviation) or what the verb ‘to google’ means (the name of a service on the web). New words can be introduced into the language of a community for a number of good or bad reasons (“Freedom fries”!), but not unlimited: certain parts of the language are closed to new introductions. These are first the small words in the language that are part of grammar, the so called ‘closed class’, but other restrictions apply: in English, all new verbs must have a regular form of the past (to google, I have googled, I googled, not to google, I have googt, I gogt).

1.9 Closed Class Particles

Closed class is this part of the language, which evolves extremely slowly. Individuals cannot produce new elements. Includes all particles that are closely linked to the grammar, which evolves also very slowly (meaning slower than the vocabulary). The description of spatial relations uses closed class particles extensively.

1.10 Computational model

The verbal token (the word) is linked to each mental concept in an agent. These are relations, not functions. There is no guarantee that these relations are the same for all agents, but effectiveness of communication makes it likely that over time usage conforms in areas where it is important. There are constant possibilities for feedback—life is a repeated game: if I do not hit it the first time, I might do better next time.

There are mechanisms, which translate names into spoken or written form. The internal representation is not determined, and probably not of ontological interest.

2. From Words to Sentences

Words carry some meaning, but only in the combination in sentences, complex situations are described: language combines a restricted set of words with rules to produce an infinite variety of sentences (it is reported, that ordinary, everyday language uses only a few hundred to less than 1000 words—some hope for learning a foreign language!).

2.1 Grammar

Grammar describes how words can be combined to form sentences that have a compound meaning, constructed from the meaning of the meaning of the words (de Saussure 1995). Grammar restricts the possible combinations of words in sentences and increases, again, redundancy: most grammars separate actions, objects, properties of objects, and actions (verbs, nouns, adjectives, and adverbs).

For verbs, grammar gives in most languages methods to indicate the person executing the action, the time and sometimes aspects of the mode; English differentiates between actions in the present time (‘now’), finished action in the past and actions in the past continuing. Other languages use different marks.

For nouns describing a countable thing, English can indicate whether we have one instance of this class and differentiate if the instance has been referred to before (the dog) or not (a dog), or if there are several instances (dogs). Again, other language use different methods, but very similar differentiations are made.

The operations to carry out an action can be also used to describe the actions—polymorphism.

2.2 WORD ORDER

Grammar restricts word order in language like English. Other languages have case markers that are added to the words and permit more flexibility in the word order:

Ein Apfel ist auf dem Tisch

Auf dem Tisch liegt ein Apfel.

It is often assumed that such sentences are exact paraphrases, having the same meaning and differing only in the order of words. Current linguistic theory attributes to different sentences different meaning, even if the factual information is the same (as above—where the connotation difference is subtle.

Gentlemen prefer blondes. - Blondes prefer gentlemen.

„hast du Hunger, ein Apfel liegt auf dem Tisch und Brot hat es im Kasten“

contrasts

„Auf dem Tisch liegt ein Apfel, was soll ich damit/darf ich ihn essen…“,

2.3 PRONUNCIATION OF SENTENCES

When words are combined to sentences, the pronunciation of the words in the sentence are influenced by the words before and after but also sentences have an intonation that influences and is compound with the pronunciation of the word. The high level of redundancy is necessary to achieve recognition of sentences pronounced in noisy environment and to separate emotional aspects, which are often carried in the intonation from the factual information.

2.4 METHOD TO AVOID SAYING SOMETHING

Passive voice and others

Beth levin

2.5 MODALITIES

Language can not only describe facts, but indicate what could be true, what I think is true or ask what is true—there are flexible ways to construct non-factual statements.

Of particular importance for GIS is the ability to state questions: information systems answer questions of users.

2.6 PRODUCTIVITY OF GRAMMAR

Grammar evolves very slowly—similar to close class. One can observe that U.S. English has added the rule “you can verb everything”, which is not present in U.K. English. The use of ‘like’ in NYC seems to be also an addition to grammar…

3. STORIES, SITUATIONS, ETC.

The expression of complex situation requires more than one sentence. These are connected, either using grammatical tools to structure sentences in main and subclauses or just vocabulary (in languages that allow only main sentences, e.g., Swiss German that knows only main and relative clauses).

Communication of stories follows rules—Fauconnier. How much?

There is a correspondence between

There is a path, a turn
Go this path, take this turn
You go, you turn

For the description of an apartment, two methods are often used: describe the rooms as a static description

In the entry hall are three doors, the first on the left leads to WC, the second to the store room. The door in front of the entrance goes to Stella's room. There is also an opening leading to the hallway, where on the right hand side are the bookshelves…

Or the alternative gives a tour of the place:

When you enter the entry hall, you see three doors. The first gets you into the toilet, the second on the left into the store room. Through the door in front of you, you enter Stella's room….

Fouconnier has a theory of 'moving focus'—each part of a sentence moves the focus and lets the reader at a new place…

Connect to possible worlds,

How to deal with counterfactuals.

4. COUNTERFACTUALS AND IMAGINARY WORLDS

Language can describe actual situations as a person sees it or it can describe situations a person imagines. A sentence is not automatically making a true statement or stating something does not make it true.

The discussion of counterfactuals and other descriptions of imaginary worlds cover a large part of the linguistic and philosophy discussion.

If we use a simple truth condition for a sentence (or a communication in general), for example Wittgenstein's correspondence theory then a morphism between the world and the sentence must obtain for a sentence to be true. Such a correspondence does not obtain in the case of counterfactuals; it is exactly this lack of correspondence, which makes a sentence a counterfactual. Nevertheless, counterfactuals are part of our conversations and communicate effectively something.

The condition for effective communication defined here is directly extendable for counterfactuals and similar descriptions of imaginary worlds.

5. Condition for Effective Communication

5.1 Truth of statement

The truth condition a la Tarski or the correspondence theory of Wittgenstein are concerned with the truth of a sentence. They establish truth of a sentence (a statement) if a morphism between the world and the sentence can be established.

This reflects a position, where sentences are put in an objective situation and are compared to the objective reality. In the approach taken here, sentences are part of the communication process between agents. They must be interpreted by agents before one can determine via a test of agent actions on reality, if the sentence carried correct or incorrect information to the receiving agent.

The truth conditions for sentences cannot solve the grounding problem—why is Tiger the cat on figure x? In the approach suggested here, the grounding problem is solved, but at the cost of not pronouncing on the truth of a statement, but only discussing effective communication.

5.2 Instructions

The simplest case is the communication of instructions—agent A tells agent B what to do—for example following a route. The communication is effective, if the exchange of encoded signs from agent A to agent B leads agent B to make the same decisions along the route as agent A.

This is empirically testable and does not rely on a comparison of the internal mental structure of A and B (which is excluded by ontological commitment).

5.3 Descriptive statement of the world

The effective communication of statements describing the world—e.g., a description of a road system, but also…—is achieved if the receiving agent makes in all situations the same decisions than would be made by the sender.

This is again empirically testable, but requires extreme care to restrict the situation such, that the sender does not use other information than what was communicated in his decisions.

Typically humans do not communicate all what is relevant in a situation and routinely violate rule xx from Grice's conversational implicature (Grice 1989).

5.4 PLANS, FUTURE ACTIONS, IMAGINARY SITUATIONS

The same condition can apply to sentences explaining situations that are not real and that are difficult to assess with a correspondence theory of truth—that assumes a correspondence between the world and the sentence. These sentences are not true, they are descriptions of what could be true in the future, or would be desirable, if it were true, etc.

Again, the effectiveness of communication is testable: does the receiver draw the same conclusions (in actions or sentences expressed) as the sender.

6. COMMENT

One can argue that this condition of effective communication is trivial and is a souped up version of the question 'you understand?'. This is indeed correct—we only establish that the (observable) effects of the change in the receivers mind are corresponding to the observable effects the same information has in the sender's head.

The alternative assumption, that words stand for fixed classes of objects with determined properties, agreed by everybody is untenable. It is observable in any meaningful communication between humans, that words have multiple meanings and people switch between these meanings at will and sometimes in the middle of a sentence.

Time flies like an arrow, fruit flies like banana.

Chapter 32 RELATIONS BETWEEN OBJECTS OR ACTIONS

Language not only combines words in sentences organized around a verb: who does what with what object, but can describe static relations between objects and actions.

1. TEMPORAL RELATIONS BEWTEEN OBJECTS

Spoken language is organized in time and it is simple to list actions in the same temporal order as they are occurring: radio reporting of a sports meet describes in present tense the actions as they are occurring. Prepositions are used to report spatial order between past events:

I saw him enter the room and then he started yelling at me.

The prepositional phrase *y then x* says that *x is later than y.* The converse relations are expressed by *after*.

He started yelling at me after he had entered the room.

Three relations are possible between two actions conceived as single event: *a* before *b*, a at the same time as *b*, *a* after *b*. If an event occurs with respect to an enduring action, then the action can be at the start, at the beginning, in the middle, etc.

The murder occurred in the beginning of the play.

Two enduring actions can have in principle 12 relations (Allen 1984). They can be expressed linguistically, but the interpretations of the terminology are not as precise and unambiguous as the mathematical definitions.

Spatial relations are transitive. From a statement that *a* before *b* and *b* before *c* the entailment *a* before *c*.

2. SPATIAL SITUATIONS

Language must provide predicates and other grammatical methods to describe spatial relations; the *2*-dimensional space cannot be mapped directly to a *1*-dimensional sequence of words.

There are three methods identifiable:

- Fictive motion (Talmy 1990),
- Spatial qualification of locations with respect to actions,
- Spatial relations.

2.1 FICTIVE MOTION

Talmy has pointed out that we often use a transformation of a spatial situation in a temporal one; a static spatial situation is described as an imagined action, typically a motion along the spatial object.

The path follows the valley.

This can be used to translate a spatial situation in a temporal one. In stead of describing the spatial relation between towns, I tell you the order in which you encounter them along a road:

On your way from Vienna to Budapest, you come through Gyoer and Eszetergom.

Figure

Figure 213

2.2 SPATIAL QUALIFICATION OF LOCATIONS WITH RESPECT TO ACTIONS

Actions can have spatial qualifications, describing for example the destination of a move:

Put the spoon on the table.

In many languages that have flexion (declination) of nouns, special cases are used to describe a location (differentiated between a static situation and a location as a destination of a move) and others.

In English and other languages without flexion, spatial qualification of actions relies on preposition. The prototypical meaning of a preposition is its meaning in connection with verbs of being, moving, or putting. The use of preposition is often influenced by the verbs, i.e., a specific action requires a specific preposition, which seems quite independent of the prototypical use of the preposition. (see 330 xx).

2.3 SPATIAL LAYOUT

We have argued before that binary spatial relations are sufficient for the internal representation of spatial relations. The layout of a group of objects is represented as relations of the objects with respect to a reference frame; we have discussed an egocentric and an absolute reference frame (395 xx). How are these internal representations translated to language?

The question is difficult to answer with certainty as the internal representation is not observable directly and language was used extensively to identify probable internal structures; it is difficult to avoid circularity in the arguments. Important for a GIS is primarily how we can produce verbal description of spatial situations—for example in a car navigation system or in response to a question—and how spatial situations that are described verbally can be translated and integrated with other spatial data.

Two questions must be answered if an automatic transformation of a spatial situation to a verbal description is attempted:

- What are the words used to describe the relations and what is their semantics?
- How does language signal which reference frame the description is based on?

The two questions are intertwined: the vocabulary is often used to identify the reference frame as well; we therefore start with an analysis of the reference frames and then go on to discuss issues of vocabulary, which are, of course, highly varying in different languages.

2.3.1 Reference frames

A taxonomy of reference frames must be sufficient to define mechanism that is sufficient to produce and differentiate the different verbal descriptions of spatial location using different reference frames. The formalization shows that the current taxonomy is not sufficient for this purpose. Levinson differentiates for English 3 cases: intrinsic, absolute, and relative (Levinson 1996). Levelt combines this with a differentiation between egocentric and allocentric, to give 6 different cases; he uses the term *deictic* to mean *relative egocentric*, intrinsic to mean *intrinsic allocentric*, and absolute *absolute allocentric* (Levelt 1996). (A detailed discussion how these terms are used by the authors is delayed till section 11, when the geometric foundation has been laid). The current taxonomy is not sufficient to differentiate the use of left/right for another person or a stage (both are *intrinsic* in the standard terminology) (figure 1) or with respect to a person or an object (both are *deictic*) (figure 2):

- > from the observers perspective right of Peter

Der Ball ist auf der linken Seite der Bühne. (The ball is on the left side of the stage.)

- > from the observers perspective on the left side.

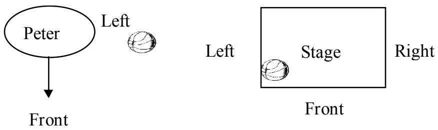


Figure 214: Two different uses of 'left' (right-handed and left-handed coordinate system)

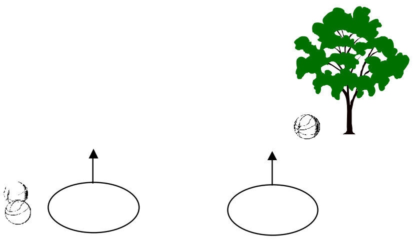


Figure 215: Two different forms of deictic reference frame (egocentric and retinal)

Der Ball ist links von mir. (The ball is to my left).
Der Ball ist links vom Baum. (The ball is to the left of the tree).

The formal model presented must be the classification of reference frames by 3 values (see 395 xx):

- The reference object (ground): the speaker, an observer or another object;
- The orientation of the reference frame (which implies the selection of the frame type): speaker, ground, and direction from speaker to ground, or one of an externally fixed system (cardinal directions, up/downhill, etc.);
- The handedness of the reference frame (right- or left-handed).

For English, 4 different situations using the 'front, left, back, right' terminology (in subsection xxx) and 2 using the cardinal direction terms 'north, west, south, east' (in subsection xxx) are characterized. The classification scheme is deduced from a formal (mathematical) model. The formalization can be used as code, which is sufficient to produce acceptable English descriptions for all cases. The classification can be used for other languages as well. The model is not intended to explain the pragmatics of the selection of one or the other perspective, the use of default values and ellipsis in general, etc.

2.3.2 Representation of the World

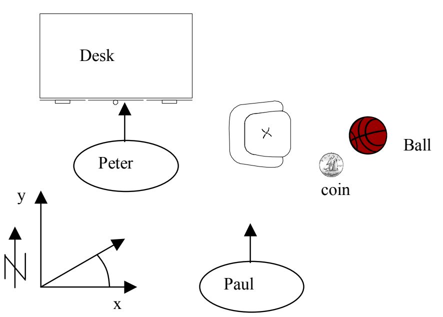


Figure5: The example world

The objects in the world are seen as points in a *2*-dimensional plane without extension. We follow Levinson (Levinson 1996) in confining the discussion to the horizontal plane, as this is sufficient to reconstruct and clarify the current discussion in the literature. The objects are 'axial' (Landau 1996) and for each object, the location is given with 2 coordinates (location of the centroid) and an orientation. The orientation for things that have a natural orientation (e.g., persons) is the azimuth for the 'front direction' (i.e., the angle with the positive x coordinate axis, measured clockwise) (see figure 5). Objects that do not have a natural coordinate frame are marked with *OmniDir*. The extension and shape of the objects are not considered (this is sufficient for reconstructing the discussion in (Levinson 1996) but would need extension to capture the work of. The model of the world could be more complex, for example space could be *3*-dimensional, the objects could have a spatial extension and more extensive properties, but this is left out here, to present the core of the modeling concept without additional complications.

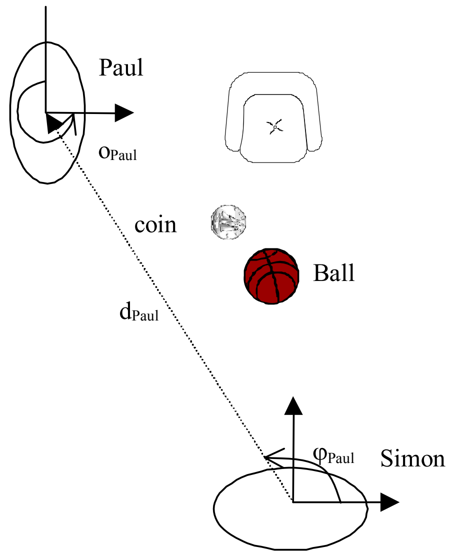


Figure 7: The construction of the ego-centered representation

It is assumed here that the observer builds first a representation in which he uses himself and the organization of space as it emanates from himself as ground and represents the other objects on this ground (egocentric view). Since Piaget, there is an extensive discussion how allocentric representations of space are built from such an egocentric representation, but the observations reported in the literature are not sufficient that a formal description was possible. For the model here, an egocentric representation is sufficient.

2.3.3 Discretization

Following the model of Jackendoff (Jackendoff 1996) an abstract propositional representation is deduced from the imagistic representation.

We assume here qualitative representation in an egocentric system, which differentiates 4 distance relations, where each successive range reaches twice as far as the previous one and 8 equidistant directions, following the schema proposed in (Frank 1992; Hong, Egenhofer et al. 1995). This system seems ecologically plausible; reasoning with directions, human performance gives approximately the same level of errors as a model with 8 direction cones (Montello and Frank 1996). Distance is encoded in zones: the zone up to 1 unit is *here*, between 1 and 2 units is *near*, 2 to 4 units is *far*, and further is *very far* (see figure 9).

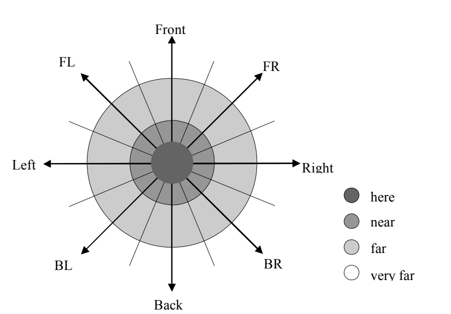


Figure 9: The qualitative distances and directions

The transformation discretizes for each object the distance and the direction value in 4 levels for distances and 8 values for the direction and replaces the quantitative representation in the imagistic representation by a qualitative representation (”Ball” 3.2 45) becomes (”Ball” Far FrontRight). The propositional representation of the world by the EGO is a propositional, qualitative encoding of the imagistic one. This means that the vectors are discretized (i.e., distances encoded as far, near, etc. and directions as front, left…, directions by 8 cardinal direction values). Jackendoff’s model assumes that in the propositional representation sufficient information is available for the production of the linguistic code. Sentences like

Simon says: Der Paul steht links vor mir. (Paul is to my front left),
Der Sessel steht gerade vor mir. (The chair is in front of me),

etc. can be produced. This produces the most direct representation of a spatial situation. It is often called intrinsic (Levelt 1996), but Levinson shows the difficulty of this label.

We propose the term *egocentric* for this. In Levinson's characteristic, it is described as an intrinsic coordinate system, with origin at the speaker and using as relatum (ground) the speaker.

2.3.4 Descriptions of spatial reference frames

Every spatial reference frame can be characterized by three values: the selection of ground, orientation, and handedness of the coordinate system. Here descriptions of the 4 constructions used in English in conjunction with body-centered terms (front, left, back, right) and then the 2 constructions used with external frames are given. The following section compares these characterizations with the descriptions found in the literature. The characterizations listed here are sufficient to produce the corresponding expressions.

For each method of perspective taking, the object that determines the origin of the coordinate system (ground), the object that gives the orientation of the coordinate system (orientation) and the handedness is given as three parameter values.

English allows the following constructions:

2.3.5 Using the body-centered direction terms (Front, Left, Back, Right):

The following 4 relations between point-like objects are used:

- egocentric
  ground = speaker, orientation = speaker, right-handed

Peter says: 'The desk is before me, the chair is to my right.'

- intrinsic - right-handed (mostly used for persons, but also animals, vehicles)
  Ground = person, orientation = person, right-handed

The ball is in front of Simon.

- intrinsic - left handed (objects like a stage, desk, etc.)
  ground = oriented-object, orientation = object, left-handed

The left drawer of the desk.

- retinal
  ground = object, orientation = towards the observer, left-handed
  (note: the observer is not necessarily the speaker)

Paul says: 'The ball is to the right of the chair.'

For Peter, the ball is behind the chair.

For path, English allows:

ground = current-position, orientation = direction of movement, right-handed

2.3.6 Using cardinal directions (North, West, South, East)

in English only used for geographic space

- egocentric

ground = speaker, orientation = cardinal, right-handed

Paul says: 'The chair is to the north, Simon is north-east.'

- allocentric

ground = object, orientation = cardinal directions, right handed

Acity is north of Btown.

2.3.7 Using other direction terms

ground = speaker, orientation = hill-side, right-handed—only used in geographic space

The tree is above the house.

Examples from other languages

German allows, but only for geographic space in valley:

ground = speaker, orientation = valley, right-handed (down is the primary axis)

AStadt ist oben, BDorf unten (im Tal).
BDorf ist auf der rechten Seite.

ground = object, orientation = valley, right-handed

AStadt ist weiter oben als BDorf.

This seems to be similar to the system used by Tzeltal ([Levinson 94] quoted in (Levinson 1996).

Haussa allows (probably among other methods to express relative location):

ground = object, orientation = observer, right-handed

This is defined for situations where the observer is oriented towards the ground object (and then the same as the English 'retinal' case, except for the handedness of the coordinate system). If the observer faces in another direction, two interpretations are possible (figure 17)

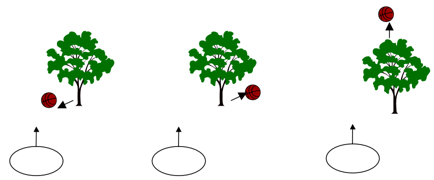


Figure 17: English retinal and two interpretations for the reported use in Haussa (Hill 1982 quoted after (Pederson 1993))

2.4 CONVERSENESS AND TRANSITIVITY

The properties identified by Levelt for the combination of reference frames follow from the above description (Levelt 1996). Converseness $(R (a,b) = R^{-1} (b,a))$ and transitivity $(R (a,b)$ *and* $R (b,c) = R (a,c))$ holds for all cases when the orientation is the same, but not when the orientation (or the handedness) for two expressions differs (which is the case for his 'intrinsic' case: ground = person orientation = person). One can therefore construct more transitive relations: for an intrinsic case: if persons Simon, Peter and Paul all face me, then Simon is left of Peter and Peter is left of Paul allows the deduction Simon is left of Paul.

2.5 COMPARE TO USUAL TERMINOLOGY

The usual terminology for English sentences can be characterized in these terms and we propose some (minor) restrictions to make the regular terminology more precise.

- Absolute reference systems

All systems where the orientation is given from the outside (cardinal direction, valley up-down, monsoon, inland/seaward, direction of a landmark, local landmark (Pederson 1993), etc.) are called absolute (Levinson 1996). For all methods of absolute orientation, the individual must know its own orientation relative to the fixed reference frame (but it need not know the speaker's orientation for understanding a description). Absolute systems are invariant under rotation of ground, but not invariant under rotation of the whole configuration (figure and ground).

We differentiate between egocentric and allocentric absolute systems:

egocentric absolute: ground = speaker, orientation = {an absolute reference frame}, RH

Simon says: 'The ball is to the west;'

allocentric absolute: ground = object, orientation = {an absolute reference frame}, RH

Paul says: 'The ball is to the west of Simon.'

- Egocentric

A frame of reference, which is centered in the speaker and with the speaker's orientation (or the assumed observers).

Ground = observer, orientation = observer

Paul says: 'The chair is before me (= in front of me).'

This is obviously also a case of intrinsic reference frame (in Levinston's definition), but a further differentiation, as proposed by Levelt, is appropriate.

- Intrinsic

This is used to describe spatial reference frames where the orientation is taken from an object. We propose to exclude the case where the reference frame is the speaker serving as the ground (we call it egocentric).

Ground = an oriented object (not the speaker), orientation = from the ground object, RH or LH

Paul says: 'The ball is in front of the chair.'

This agrees with Levinston's characterization that intrinsic frames of reference are invariant under rotation of the viewer, but not under rotation of the ground object.

- Retinal

The relative position of an object with respect to another, as it presents itself in the eye of the speaker (this is often described as deictic):

ground = object, orientation = arrow from observer to ground, RH.

Simon says: 'The coin is left of the ball.'

Paul says: 'The coin is in front of the ball.'

Levinston would characterize this among his group of relative frames, which are not invariant under rotation of the speaker. This is not completely accurate, as the orientation of the reference frame is taken from the arrow from observer to ground, not the observer's orientation (Levinson 1996).

- Deictic

This is used for relations where ground and observer are not the same and the orientation is taken from the observer.

Ground = object, orientation = observer

Precisely this definition it is not often used in English. There may be situations—for example, in military situations—where two observers discuss the relative placement of objects in a landscape, the observers facing the same direction and use their (nearly common) reference frame. Usually the retinal frame of reference is meant when a frame of reference is described as deictic (e.g., in Levelt).

A description in a deictic frame of reference would be invariant under rotation (and translation) of the viewer, but not under rotation of the ground (this is Levinston's characteristics of his class of intrinsic frames of reference).

- Relative vs. absolute

We propose to use the term relative term for all 'body-centered' (or generally object part related) reference frames—these are the ones that in English are based on the 'front/back, left/right' lexical terms. All these are invariant under translation or rotation of the full configuration (speaker, ground, and figure), but not under rotation or translation of either speaker or ground. This is different from Levinson's usage, where 'relative frames' are invariant under rotation of the ground.

The term absolute should be used for frames of reference, where descriptions are invariant under rotation of the ground or speaker, but not invariant under rotation of the complete situation (figure, ground, and observer).

		egocentric ground=speaker	allocentric ground=object
relative	orientation= speaker related	egocentric	retinal (orientation= speaker-object)
	orientation=object		intrinsic (RH or LH)
absolute	cardinal	egocentric cardinal	allocentric cardinal
	up/down-hill	…	…

Table 3: Summary of Frames of Reference used in English

This table classifies the frames of reference in the English language. It differentiates first between relative and absolute reference frames and differentiates the relative then in those where the orientation is taken from the speaker and those where it is taken from the object. Absolute frames of reference can be separated in those using cardinal directions, and those using other, e.g., up/down-hill, as reference frames. It further differentiates each case in egocentric (speaker serves as ground) or allocentric (another object serves as ground). In English, it seems not to occur that the orientation is taken from another object, but the speaker serves as ground (Haussa?). Other languages may use other frames of references, which are best classified using the characteristics of ground, orientation, and handedness of the coordinate system.

2.6 FORMALIZATION

Perspective taking consists of 3 steps:

1. The origin (or ground) indicates the new point with coordinates 0/0. A translation with the vector from the ego to the new origin gives the new coordinate values (operation *translate*).
2. The orientation gives the rotation between the new coordinate system and the coordinate system of the ego (operation *rotate*). (In the literature, the term *Origo* is sometimes used for the orientation only and ground for the origin).
3. The selection of the orientation of the coordinate system. In most cases, the handedness of the coordinate system is the same as that of the observer (by convention called right-handed). If one observes a person, then the person's left seems right to me (this is often characterized by *intrinsic* and *deictic* (Levelt 1996)). For some objects like desks, which have a front, but their left side is to the left of the observer, left and right are exchanged compared to the coordinate system in comparison to the observers. This we call a 'left-handed' coordinate system.

Peter stands in front of the desk and opens the left drawer.

The handedness of the coordinate system differentiates the system of a person, where anti-clockwise follows: front, left, back, right, front, from the system used for objects like desks, where again anti-clockwise follows: front, right, back, left, front. Mathematicians call a coordinate system right-handed, if the three primary axes (front, left, up) are in the same situation as the thumb, index and middle finger of the right hand (otherwise it is called left-handed).

In principle, these three steps are performed for all perspective taking. To understand a verbal description, the parameters for all three steps must be indicated. Default values, customary choices, but also vocabulary is used to indicate these choices. In English, different terminology is used to describe absolute references (cardinal direction terms) or relative references (terms like: front, left, etc.). Some situations remain ambiguous: English allows to call an armrest of a chair its 'left' or 'right' one, depending on the conceptualization (it may be influenced if the chair is occupied or not, which influences if the right handed coordinate system of the person sitting in the chair is used or if the left handed coordinate system of the chair is used).

2.7 Transformation steps

In this model, the outside world is first transformed in an imaginistic (ego-centric perspective) representation. This imagistic representation can be discretized and transformed to a propositional, qualitative representation. The propositional, qualitative representation contains all data for the transformation in a verbal expression.

In order to produce and understand verbal descriptions from other than the ego-centric perspective, specific perspective taking transformations are necessary (for which the parameters were described in the previous sub-section). These perspective taking transformations can be performed either on the imagistic representation (with a discretization following) or on the qualitative representation. The available experimental data is not sufficient to differentiate between these two alternatives.

For the verbal expression, the following language 'instructions' are necessary:

- the expressions to identify ground, orientation, and handedness;
- the lexical terms used for the direction;
- the distance terms; and
- the position of the observer.

Pragmatic rules must explain, when ellipsis is possible and which default values can be assumed and which expressions are to be preferred. I assume here that these rules can be applied after perspective taking has been performed (Levelt's results are not conclusive to this point (Levelt 1996)).

2.8 Signaling which frame of reference is used

Vocabulary is an important indication: the words front, back, left, and right reference the human body for definition of the reference frame (origin, orientation, and handedness).

Words like North, South, East, and West, or terms to described location on a vertical scale (sur, sous, Ober- and Unter-) indicate an absolute frame, either the geographic (which leaves the question where the origin is placed) or one with reference to a geographic feature. If more than one person is available as a reference frame, then the person is sometimes named, sometimes tacitly assumed.

Objects have conventional handedness of the reference frame,.

3. Conclusions

A formalization of the operations necessary to produce from a visual observation of the environment the propositional descriptions to verbalize spatial relations between objects has identified the necessary parameters for the description of the spatial reference frames used. A reference frame should give all geometric properties for this transformation and is therefore characterized by:

- its origin (ground),
- the orientation (orientation of the observer, orientation of ground, or externally fixed), and
- the handedness of the coordinate system.

With these parameters, all spatial frames of reference for all languages can be characterized. Pragmatics when to use which frame of reference is not considered here, but it is noted that some parameter combinations are meaningless or not used. The English language uses only some combinations, which are best characterized as:

- relative (front/back, left/right) with the reference frames: egocentric, intrinsic, and retinal and
- absolute (cardinal, up/downhill, etc.) with egocentric and allocentric reference frames.

Precise definitions for these terms were given.

Other languages use different spatial frames of reference and the current terminology is not adequate for their description. The characterization with the parameters for origin, orientation, and handedness, however, capture easily all examples given in the literature. The formalization has also helped to understand assumptions built in this classification schema and may lead to discoveries of mechanisms in languages that are not covered.

The formalization and the computational model produced show that:

- All forms of relative spatial descriptions can be deduced from a single observation of the world, which results in a representation of distance and directions (in the egocentric reference frame) to the other objects in the world; to postulate such a primary representation is thus justified.
- A propositional, qualitative representation can be deduced from an imagistic representation by discretization (e.g., distance-directions for each object).
- The translation of the ego's representation to a representation as seen from another person either requires

the construction of a translated and rotated (imagistic) representation, using the subtraction of vectors in 2D space, or composition operations for the propositional representation. Observation of error characteristics of human performance may allow identifying one of these possibilities as the one used by humans.

- For objects (at least for persons), the internal representation must include the orientation of the object. This is required for the translation of one's perspective to the perspective of others or to understand another person's description of a scene.
- Knowledge of the ego's orientation is only required to produce spatial relations in an absolute reference frame.

All absolute frames are invariant under rotation of ground or observer, thus the relative position of the parties involved in an exchange does not affect the understanding of the spatial relations. For geographic space, if the observers are relatively close to each other and the objects described are further apart, the description is even invariant under translation of the observers. These properties apply to cardinal directions as well as to up/down-hill, up/down-wind, etc.

All relative frames are invariant under rotation or translation of the full configuration (speaker, ground, and figure). They are thus easier to use inside buildings or town, where the absolute orientation is not so easily detected.

For future work the following hypothesis seems to be reasonable:

An expression using the speaker as ground and a way to express relations using another person as ground, with an absolute orientation or the body orientation of the person serving as ground is likely a universal (or at least that if a language has the first, it has also the second: one is necessary to understand the other, spoken by another person). The opposite hypothesis would be a language, which can only express spatial relations with respect to an object.

It is an open question, how different languages indicate which perspective is taken; many acceptable ellipses further complicate the situation. Both in English (Levelt 1996) and in Tamil (Pederson 1993) misunderstandings based on errors in the perspective taken to produce the verbal expression are common. Lexicon seems to separate the body-related (relative) and the absolute perspectives.

It is further interesting to analyze the preferences in certain languages for certain expressions. Pederson gives an example where two Tamil speaking populations are differentiated by one preferring a cardinal orientation (and the corresponding vocabulary) and the other body axis (relative) expressions (Pederson 1993). Is this correctly related to the invariants of absolute and relative frames of reference, which make absolute reference systems better suited to rural and relative reference frames easier to use in urban situations?

Chapter 33 FIXED COMMUNICATION: WRITING AND DRAWING

Spoken words exist only at the time they are spoken and at the place where they are spoken (today's communication systems have largely overcome this limitation); recording a spoken sentence for later review is important for human society: it is desirable that we not only rely on our memory to remember what we or somebody else promised, but write it down.

Writing makes a sentence available for later reception (or reception at a different location than where it was said.

Fixing actions of communication in some material form preserves it for later use: a written text can be read later, by many people. Graphics as marks on some carrier material, preserve the actions of the author and communicate to later recipients.

There are two paths from a concept to a written word, either going through the spoken word and fix the pronounced word to paper or to assign a graphical mark (icon) to the concept. Western languages use primarily the first, Chinese is the best example for the second. Maps are even more direct, as they represent space by space in a direct—not human—conceptualized form.

figures

This chapter discusses a situation of non-language based communication, namely communication with maps. We will give here a fully worked model of communication, using maps. The connection between action in the world and the actions to draw and read a map are close, which makes it 'natural' to communication with a graphical mode–natural meaning here, that no particular convention must be pre-established as the conventions follow in analogy of the real actions. Verbal communication requires, as we will see in the following chapter, strong conventions for the meaning of signs.

Maps are very efficient to communicate spatial situations. A theoretical framework for a formal discussion of map production and map use is constructed using a multi-agent framework. Multi-agent systems are computerized models that simulate persons as autonomous agents in a simulated environment, with their simulated interaction. A model of the process of map production and map use is constructed based on a two-tiered *reality and beliefs model*, in which facts describing the simulated environment and the simulated agents' beliefs of this environment are separated. This permits to model errors in the persons' perception of reality.

A computational model to this example exists (Frank 2000). It includes computational models for all operations: the observation of reality by a person, the production of the map, the interpretation of the map by another person and his use of the knowledge acquired from the map for navigation, are simulated as operations of agents in a simulated environment.

1. The Connection between Concepts and Written Language

Western languages have developed a form of writing, which translates the spoken word into a written form. It is based on a transformation of the phonemes in a word to a sequence of signs (characters); most languages today use the Latin alphabet, with some special characters, additional marks, and other conventions for the representation of the sounds.

1.1 Phonetic words

The internationally standardized phonetic description (using an alphabet of xx signs) is seldom used—typically for the set of sounds in a language a set of Latin characters are selected. The transformation from a character to a sound is therefore dependent on the language.

The translation of a written word to a sound is further complicated by

- Language specific rules of pronunciation, for example, the sound associated with a character is changed depending on the character before or after.

Italian: capistrano, civita vechai, chiavenna,
explain rule

- The written form is not a representation of the current pronunciation of a word, but represents a historic form

Night (German Nacht) new nite; trhough (durch) thru

Languages like Finnish, Italian, French can be read if the pronunciation rules are known, languages like English require a pronunciation guide for each word.

Languages have a tendency to construct complex rules for writing—this has probably mostly a social end: differentiate the 'learned' from the 'unlearned', differentiate social strata by who can write.

1.2 ICONIC WORDS

Each concept is mapped to a written sign (icon). Old Chinese characters represent this stage, but also some of our alphabet letters seem to go back to direct representation of an object.

sun, moon, field in Chinese—lambda—gimel (kamel)

For an iconic language, the pronunciation for each icon must be learned. In Chinese there are less pronounceable syllables than icons (and each icon represents a monosyllabic word), therefore massive homonyms—the same pronunciation for different words. This allows for complete different pronunciations of the same icons; the different Chinese languages (Mandarin, Kanton, …) use different spoken words, but write (close to) the same language.

This is comparable to the standardized signs we see for example in airports and railway stations:
Exit sign: pronounces: exit, ausgang, sortie, uscita etc, etc.

Modern Chinese language has undergone multiple transformations and often pronunciation based influences have been include (for example, signs sometimes consist of two basic icons, one gives the meaning, one gives the pronunciation at a specific historic time).

Written language

The iconic method is not as strange as it sounds: there was a popular method to learn to read English, based on words, not the spelling.

2. TRANSFORMATION OF TIME TO GRAPHICAL MARKS

Spoken language is happening in time—recording a spoken message requires the translation to marks (via the translation of the sounds or the words to icons) and then fix these to a graphical surface.

The western tradition arranges the signs from left to right in rows and the rows follow from top to bottom. Other cultures (Arabic) order from right to left and also top to bottom (which pages of longer texts bound in reverse order compared to the western method). Chinese texts are often using a top to bottom, left to right ordering.

3. Move?? The Interpretant: The Meaning of the Sign Non-Verbal Communication

There are substantial channels between agents other than the channels used for intentional communication. It is customary to call communication that is not intellectually controlled as non-verbal. This terminology is unsatisfactory as several non-verbal channels are clearly intentional, intellectually controlled, e.g., an ad-hoc sign language to invite some boy to sit down or to signal that somebody should please leave the room or similar. This is non-verbal, but intentional.

Aside: ordinary sign language for the deaf is clearly verbal, but not using a different channel.

The communication treated as 'non-verbal' uses channels as minute and non-consciously emitted signals from the body: inflection of the voice indicating mood and emotions, body position that seem to signal empathy [ref], but most likely also chemical (odor) as channels. Common to all what is typically subsumed as 'non-verbal' is that it is not intentionally emitted and most people cannot control the production of such signs; a 'poker-face' expression is an attempt to block the signaling of emotional states to confuse the opponent and to win a game of poker. Intentional lying is difficult for most people and can be detected because the so-called non-verbal signals belie the verbally expressed lying. The receiver detects the incongruence and interprets the verbally transmitted factual information as 'not reliable' or 'not believable'. This is all non-conscious.

4. Other Examples of Communication Using Analogous Signs

Communication uses analogous signs, if here is a direct morphism between the signs or the operations to produce the signs and the communicated situation or actions.

There are numerous examples of dances, which demonstrate planned strategies for the hunting of animals. Dances are models of actions and sequences of actions. They communicate through the induction of analogous body feelings than those associated with the corresponding poses and movements.

Diagrams, where time is one dimension

Maps are space -> space maps

Pictures are visual space -> visual space

Dance is a reduced model of action sequence

Music – sound sequences in nature -> sound sequences

4.1 General theory:

What else is possible, what dimensions can be mapped to what.

4.2 Limitation

Analogous signs—diagrams in particular—must be complete in the dimension selected for expression. It is in general not possible, to avoid making a statement.

By the way: counterfactuals, imaginary worlds, etc. can be expressed with analogous signs.

The conditions for successful communication can be formulated as

5. Spatial Communication with Maps

5.1 Introduction

Daily experience tells us that maps are a very efficient and natural way to communicate spatial situations. Small children produce maps spontaneously and maps are among the earliest human artifacts. However, we seem not to have a good understanding how maps communicate spatial situations. Formal models for the processes of map production and use are missing. This leaves judgment of map quality to a large degree subjective, as map construction and map reading are both implying intelligent human interpretation. A person using a map knows the general morphology of the terrain and uses this knowledge to draw appropriate conclusions from the graphical signs on the map. Unfortunately, this general assumption of intelligent interpretation breaks down in unfamiliar terrain when a map is most needed. A more objective measure for correctness of a map, which does not rely on additional knowledge, is required. So far, we can only define consistency of a database as the absence of internal contradiction in a data quality. A formal definition for correctness, i.e., the correspondence between data and reality, cannot be constructed, as it would need to bridge between reality and the formal representation.

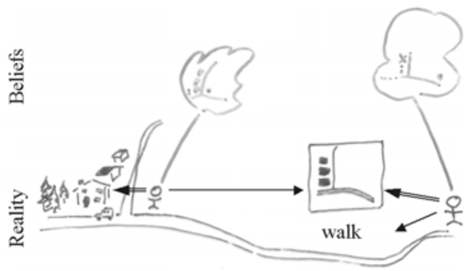


Figure 216: An agent producing a map and another agent using a map for navigation

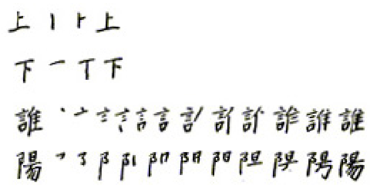


Figure 217: Instructions how to draw Chinese characters (two simple and two complex ones from Tchen (Tchen 1967)

6. NATURALNESS AND SEMANTICS

The semantics of the mental operations on the beliefs are directly connected to the person's bodily actions (Johnson 1987): mentally following a street segment's mental representation is given meaning through the correspondence with the physical locomotion of the agent along a street segment. This correspondence is kept in the model; the simulated mental operations of the agents are linked to the simulated bodily actions of the agents. The model is therefore not disembodied AI (Dreyfuss 1998) because the linkage between bodily actions of the agents and their mental representation is direct and the same as in persons (Lakoff and Johnson 1999).

"Information itself is nothing special; it is found wherever causes leave effects" (Pinker 1997, p. 65-66). The map product can be seen as the sequence of drawing steps (the causes) the map-maker follows to produce it and the map-reader does retrace these steps in his map reading process. It is instructive to observe that Chinese characters are not learned as figures but as a sequence of strokes (Figure 3). This is not only important for production, but also for recognition of signs created at different levels of fluidity. Westerners often copy Chinese characters as a picture and produce images, which are difficult to recognize.

In the multi-agent model, the structure of the operations for locomotion along a street segment, for drawing a street segment or for following a drawn street segment and for mentally following the belief about a street segment can be coded as the same polymorphic operation, applicable to different data structures; e.g., maps, real streets, etc. (not stressed in this presentation).

7. DEFINITION OF CORRECTNESS OF A MAP

In this environment, a formal and stringent definition for a map to be a correct representation of reality is possible. A map is correct if the result of an operation based on the information acquired from the map is the same as if the agent would have explored the world to gain the same information. The proof is in two steps: completeness and correctness. Completeness assures that all relevant elements—here nodes and segments—are transformed between the respective representations. Correctness requires that the transformations preserve the properties important for the decision (here the determination of the shortest path).

7.1 Completeness: Collecting all observations into beliefs

The operations to explore the environment and gradually learn about it or the exploration of a map are a repeated application of an operation '*learnConnection*', which is applied to all segments in the environment, respectively, the map. The construction of the beliefs of an agent about the environment can then be seen as a transformation between two data structures: the data structure that represents the environment is transformed into the internal structure of the beliefs. Similarly is the construction of the map a transformation between the data structure of the agent's beliefs into the list of drawing instructions; reading the map is the transformation of the data element of the map into beliefs.

We have to show that these transformations are applied to all elements and nothing is 'overlooked'. The *exploreEnv* operation is quite complex. It explores a node at a time, learning all segments, which start at this node, and keeps a list of all nodes ever seen. The environment is completely explored if all nodes where completely explored.

Drawing the map is a transformation procedure; coded with the second order function *map*, which applies a transformation to each element in a list. The transformation changes the belief into a drawing instruction. Reading the map is a similar function, taking line after line from the map and building a list of beliefs.

7.2 Correctness: Transformations preserve the important properties

The different transformation for individual objects must preserve the properties necessary for the correct determination of the shortest path.

- A street segment is added to the beliefs after it is traveled; having traveled the segment ensures that the segment is viable and the cost is the cost just observed. Surveyors correctly observe the coordinate values for intersections.
- Map-makers translate each segment into a line drawn. The positions are based on the observed coordinate values for intersections.

- Map-users read the drawn line as viable segments and use the length of the line as an indication of the cost.

These operations guarantee that beliefs about viable street segments by the map-maker are communicated to the map-users. The (relative) cost is communicated correctly if the cost function is based on distance only. These transformations could be more realistic and include systematic and random errors and we could then observe the effects on the determination of the shortest path.

7.3 DISCUSSION

In this example, where the observation and the use of the map are based on the same operation, nothing can go wrong. The model, however, indicates the potential for errors in communication. Here two examples:

7.3.1 Problems with the classification of elements.

The world contains different classes of pathways, which can be driven, biked, or walked, and not all segments can be passed with all vehicles. The classification of the road must be included in the map to allow use of the map for car drivers, bikers, and persons walking. These problems seem trivial, but some of the current In-Car Navigation systems recommend paths, which include segments of a bike path!

In the simulation, if the exploring agent uses the same mode of locomotion as the map user, then correct communication is assured. If the exploring agent rides a (simulated) bike and the map using agent drives a (simulated) car, one may discover that the shortest path determined is using segments of a bike path the car driving agent cannot travel on or may find that a shorter route using an interstate highway is not found, because the map-making agent could not travel there and did not include it.

In general, the map-makers are not using the same operation that the map-user executes. The correctness of the map then depends on the composition of the transformation functions from observations of the map-maker to beliefs in the map user. The same criteria must be used during observation when the coding of an object is fixed. For example, while classifying roads using air photographs only road width, but not police regulations, are available to decide on the coding. This may classify some wide road segments that are closed for traffic as viable.

Users with different tasks may require different maps (or at least careful coding). A map for a hiker must be different from the map for driving—and indeed road maps for car driving are published separately from the maps for bikers or hiking maps. If a geographic database should be constructed for multiple purposes, then the properties that differentiate uses of objects must be recorded separately: the physical width and carrying capacity of a road must be recorded separately from the traffic regulations for the same road. It becomes then possible to establish the particular combinations of classifications, which simulate the intended type of use.

7.3.2 Problems with the transformation.

If the function to draw the map is using one of the many map projections, which do not preserve distances, then the representation of distances on the map is not representative of the distance between the nodes (but systematically distorted). The map-reader's naïve approach to link the distance between two nodes on the map with the cost for travel is then wrong and can lead to an error in determining the shortest path. More questions arise if the travel cost is a complex function of distance and other elements, e.g., the Swiss hiker's rule:

time (h) = distance(km)/5 + total ascent (m)/300 + total descent (m)/500.

8. Effectiveness of Maps to Communicate Spatial Information

In this context, one may address the question why maps are so effective to communicate information about a complex environment in comparison to verbal descriptions. Take the small part of downtown Santa Barbara in Figure 4 and imagine communicating the information verbally: it would read as a long list, describing each segment, with the intersection it starts and ends:

The first segment of State St runs from Canon Perdido St to Ortega St, the next segment runs from Ortega St to Cota St. The first segment of Anacapa St runs from Canon Perdido St to Ortega St, etc., etc. This list contains a total of 12 segment descriptions, is tedious and does not communicate well. Alternatives would use the naming of 9 nodes and 24 incidence relations.

For areas where streets are regularly laid out, abbreviations could be invented. For example, in large parts of Santa Barbara, it is sufficient to know which streets run (conventionally) North-South and which East-West and to know the order in which they are encountered. This does not work for areas where the street network is irregular and a detailed description, for example, for areas, where an Interstate highway or a railway line intersect and distort the regular grid.

A verbal description for a street network is tedious and verbose, because it must create communicable identifiers for each object; for example, a name must be given to each intersection, such that another street segment starting or ending at the same location can refer to it. A graphical communication uses the spatial location to create references for the locations and does not need other names. The incidence is expressed as spatial position on paper and picked up by the eye. The information retained is the same, but the communication is more direct, using the visual channel. It is curious to note that American Sign Language, which is a well-documented natural language, uses a similar device of 'location' used as references. The speaker may designate a location in the (signing) space before him to stand for a person or place he will later refer to. A later reference to this person or place is then made by simply pointing to the designated location, using the location as a reference to the objects (Emmorey 1996).

The situation is different when only a specific path should be communicated. The list of instructions is shorter and simpler than the sketch (Figure 10). The instructions for a path from Borders (Intersection Canon Perdido St and State St) to Playa Azul (Intersection of Santa Barbara St with Cota St):

Follow Canon Perdido Street to the East for one block,
Turn right and follow Anacapa Street for two blocks
Follow Cota St to the East for one block

In the language of the agents, a list of nodes as the shortest path is communicated as:

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[Node 1,Node 2,Node 4,Node 7,Node 9].
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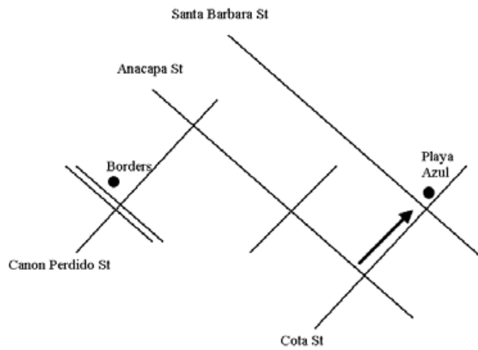

Figure 218: Sketch for path from Borders to Playa Azul

Each of the representations is short and can be communicated using a linear channel, e.g., verbally). A sketch map would be somewhat more complex as the following example of a simulated map demonstrates

```
env4 = drawPathMap (Node 1) (Node 9) jan env1

line:(2.0/5.5), (3.0/6.5),line:(3.0/6.5), (5.0/4.0),
line:(5.0/4.0), (6.0/3.0),line:(6.0/3.0), (8.0/4.0),
label Node 4 (5.0/4.0),label Node 7 (6.0/3.0),label Node 9
(8.0/4.0),
label Node 2 (3.0/6.5),label Node 1 (2.0/5.5),.
```

9. Conclusion

A framework for the formalization of the production and use of maps and cartographic diagram is described. The model is two-tiered; it contains a representation of what stands for *reality* and what stands for the *beliefs* of multiple, simulated agents about reality. The model is natural, allows misrepresentation and is fine-grained. It goes beyond current models, as it permits to model the observation processes of the agents and the agents' actions, which use the information collected. It can include errors in these processes or in the information stored.

The production and use of maps or diagrams for navigation can be described in this computational model, which includes processes for exploring the environment while traveling, casting the information collected by the agent into a graphical form, which can be communicated to and be used by another agent. The semantics of the map is directly related to the processes that observe reality or use the data. Correctness of a map can be established in this formalization. It is directly related to the connection between the operations used for observing and representing reality and the operations the map users intend to perform.

In this multi-agent framework, other related questions can be explored. For example, the effects of incomplete street maps on navigation can be simulated and tested, how much longer the path traveled becomes and what are the best strategies for users to cope with the incomplete information. One can also explore different strategies for map users to deal with observed differences between the map and the environment.

Chapter 34 GIS AS A COMMUNICATION PROBLEM

GIS is an information system: the goal is a flow of information from a human agent that has observed and another human agent that requires this information to make a decision. The GIS is the channel, through which the two agents communicate—across time and space, often without knowing each other.

The issue is to establish a connection between the observed world and the action about which a decision must be made. (In this chapter restricted to the physical world).

We have seen that numerous transformations occur:

List and figure

Figure 219

These transformations are based on relations (many-many mappings) they are not functions. If they were functions—this is what we tend to assume, no problem occurs.

1. INTEGRATION

Several conceptual worlds have to be integrated:

- Concept of observer—
- Concept of db in which he stores his observations,
- Concept of the db which a person consults,
- Concept of the asker,
- Concepts in which results are presented.

The focus of the discussion is mostly the integration of two data sets, which are described as ontological descriptions (e.g., using OWL).

What is necessary? Finding a grounding in common terms.

Where is that found?

Professional training—but does not work across professions.

2. TRANSLATION OF CONCEPTS?

What is possible?

Link to correctness discussion?

Chapter 35 660 Information Systems and Communication—Move?

In this chapter we discuss the role an information system plays with regards to communication. One can see an information system as a form of communication channel between two agents, the sender putting the information into the repository (the databases) and the receiver taking the information out. Alternatively, we can see the information system as the memory of the larger agent, which contains all the individual agents as employees.

1. Two Time Perspectives

A cognitive agent must separate two time perspectives: there is the time in which the world evolves: trees grow, buildings are constructed, people die at certain points in time. Second, there is the time at which these facts are entered into the database: Trees are observed and entered in to the database, buildings are surveyed and shown on maps and death records are filed; these acts of 'knowledge acquisition' occur at a certain point in time - measured along the same time line, but different instants: for each event, two instants are relevant: when it occurred and when knowledge was acquired.

From an agent's perspective, the database (or his own collection of knowledge) is a time varying value – chaging in discrete step at each transaction. Therefore, the semantics of a temporal database can be understood as a function from time to a snapshot database and 'as of time t' queries can be expressed as atemporal queries to the snapshot database valid at t.

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database -> time -> snapshot database
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There are a number of difficulties arising from the combination of a time varying collection of facts with a deduction system:

The result of a deduction from a snapshot database is - sound deduction rules assumed - a single result. The result becomes time varying for a time varying database: depending what data are collected, a deduction yields a different result: the request to withdraw $500 from my account is denied today (balance only $150), but after I received a $1000 reimbursement from a company, the same request to withdraw $500 is granted. If we ask could I withdrwoa $500 we have to state a time because the answer is different for different times.

If the results of deductions are stored then a later acquired fact can make the result invalid and the stored result of the deduction must be identified and corrected. This is usually described as 'belief maintenance problem', when agents deduce believes from their knowledge and knowledge added later requires a revision of these believes. From simple observation in an environment one may deduce that green fruits are unripe and not edible, and red fruits are ripe and sweet; this empirical rule must be revised after tasting of ripe, green figs or grapes and a more sophisticated rule for ripeness must replace the simple one [theory theory book].

Photo of figs or grapes

Social fairness leads often to rules, where not the date of a fact but when an agent learned about it is important. The social system does not punish honest 'not-knowing' if the agent has made all reasonable efforts to discover the facts. For example, the knowledge of the law is assumed, but only after it has been officially published. A case can be brought before a court within a certain deadline and the deadline is counted not from the offending act, but from the time the plaintif has learned (or could have learned if diligent) of the act.

2. SOURCES OF KNOWLEDGE

Agents acquire much knowledge through communication with other agents and not from direct observations. This knowledge is 'hearsay' in legal terminology [Blackwell] and considered of much lower reliability than what is directly and immediately observed by an agent. Human beings are extremely well equipped to keep information from different sources separated and maintain a mental link from the information to the source. Reuter has pointed out, that databases are not prepared to keep track of collections of facts which form areas of consistency, but are not overall consistent. [edbt 2000]

Human can construct abstract knowledge; other primates have a limited facility for this [rimbough – shimps]. The essence of this tier of the ontology is the construction of conceptual units independent of a physical reality, but which are experienced very similar to objects. These are logical, abstract generalization to capture higher level knowledge of the world. The ontology of constructs will be discussed in part xx.

The cognitive system of human beings is very similar to the aggregated cognitive behavior of organizations: They acquire collectively knowledge, which is subject to similar effects which result in only partial correspondence between reality and the knowledge accumulated. The treatment here, which deals mostly with the effects and does not concentrate on the processes and the influences on processes which lead to non-conformance of accumulated knowledge does not differentiate between single cognitive agents - mostly humans, but to some degree also animals - and organizations seen as cognitive agents.

PART EIGHT 710 SOCIALLY CONSTRUCTED REALITY

This part discusses the parts of reality which are socially constructed: Communes, Real Estate, Marriage and Companies. These things appear to us as real as physical objects and only when questioned, we realize that they are not existing physically in the same way that the objects on our table, the trees and ourselves. These socially constructed objects are important as they are used to organize our society, but they exist only in the conctext of society and are constructed by society. They form together the cultural reality, explaining, controlling and often overtaking the physical reality.

The first chapter in this part gives the general background and suggests a possible origin for the first social construction and demonstrates how the meaning of socially constructed objects and processes is linked to the ontology of the physical world. Every socially constructed object or process is directly or indirectlyh related to a physical object or process. In Searle's formula "X counts as Y in context Z", where x is a physical object or process, Y is a social object or process and Z is the cultural or social context. In western societies, small pieces of metal (the physical object) count as money (the socially constructed object); the validity of money is limited to the context of a nation, across the border, other coins count as money (photo).

Photograph of coints

The second chapter focuses on a special case of socially constructed reality, namely the realm of ownership, contracts and other legal constructions. This is extremely important for GIS: ownership of land, planning for the use of land and the legal protectiono of natural resources are all important themes for the application of GIS today.

Chapter 36 MOVE – METAPHOR

The communication of emotions and moods is different from the communication of observable facts in the physical world. The observation of facts in the physical world can be shared in the sense that I have a continuous experience that my observations of the physical reality are mostly the same as yours. This experience of similar observations of the world is confirmed by concludent actions of others.

This is not the case for emotions and moods. We have indicated that moods and emotions have a bodily reality—they are real observations of internal states of the body and as such equally real to our brain as observations of the outside reality – but they are not shared: I can never have the same feeling or the same hurt than another person and I can never see the feeling of another person. This makes communication about emotions and moods more difficult.

The approach mankind has selected is metaphor—communication about emotions is in terms and analogous to the communication of physical reality. Natural language shows this clearly: we run away from .. ,

In this chapter the use of one realm of experience—here the physical world—to describe and communicate another one—here the world of internal (private) emotions—is explained. It will be used immediately for the construction of other types of realities, which are also not shared, physical reality, namely the socially constructed realities.

Metaphor is not only used socially but can be used to help people understand other domains that they do not have a direct experience with. This is primarily used recently to communicate the internal operations of a computer, which are to most observers not available to direct observation, in terms of some objects where the user is already familiar with the operation. The most prevalent example is the desktop metaphor, which has become so real that it seems sometimes to take over and dominate over its physical origin.

1. What is metaphor

Restriction to explain domain *A* in terms of domain *R*.

2. Metaphor as Morphism between Domains

2.1 Desktop

2.2 Emotions

3. Metaphorical Objects

Metaphor constructs objects, which inherit real-ness from the source domain.

3.1 Emotions are objects

Feelings become objects, which we can have (possess, hold). In many languages, we 'have hunger' (in Spanish even the strong physical possession indicating form of 'have' tener).

To what degree can emotions be given away…

3.2 Operations for emotions

Example: anger spread in the audience—using the fire metaphor: it distributed like fire—from an angry person it made people nearby also angry and so on.

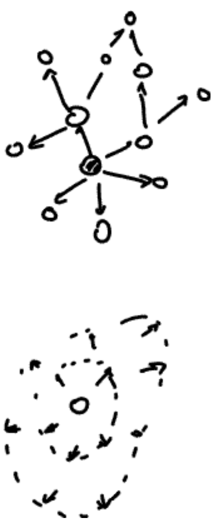

Figure 220: Spreading a rumor

4. Source Domains for Metaphor

5. Limits of Metaphor

Not all the rules (axioms) of the source domain are applicable in the target domain.

6. Metaphor for communication

Metaphor is used to communicate: the source domain is assumed to be shared.

7. Effects of Metaphor

The metaphor we select to frame an unknown situation influences how we understand it. There is a strong tendency of the human mind, to believe the verbal—and thus metaphorical—construction of the sensuous information received.

A novel situation for which we have no precious experience is framed in terms of a metaphor to make it comprehensible and allows communication about it. Metaphor gives an 'explanation' and leads to expectations even where there is no information for this situation available. The metaphor transfer the experience from the source domain to this novel target domain, even if the transfer is not justified.

This is clearly evident in psychology. Emotions are not directly accessible and explanation how the psychological and emotional system of humans works is still today mostly unknown. Different source domains are available to 'explain' the human psyche. A traditional Chinese medicine explanation is in terms of yin and yang—the male and female, the warm and the cold. Indians use often the flow of liquids that carry energy. Western psychology in the 19th century used extensively the terminology of the then fashionable thermodynamics and we often frame psychological effects in terms of friction, simple machines and energy. It is expected that increasingly the source domain to frame the human psychology will become computers and their to the lay-person equally marvelous behavior.

My batteries have to be recharged;
Ich muss Stille tanken

Equally important is the effect of metaphor on ethics. Johnson [ref] has discussed extensively the differences in how ethical questions are answered in different cultures and has linked these differences to differences in the metaphorical construction of the interaction between human body and brain. The western (Anglo-American) tradition talks about faculties of humans and differentiate ratio from .. This is in contrast to an Islamic tradition, where …

Metaphors are not 'true' and their applicability is to be questioned—but this is very seldom done and the human brain seems to believe what the metaphor suggests.

Chapter 37 SOCIALLY CONSTRUCTED REALITY

In the last part objects were constructed with respect to the human interaction with the world in which they exist The physical reality includes a large number of things we interact regularly with, from fruits and other small objects to land, lakes, and weather. This is the world children learn about first and only after they have built sufficient experience with and are familiar with the vocabulary to describe physical reality they learn about the social construction of reality – first again, about the social world of their family (Gopnik, Meltzoff et al. 2001).

A concentration on the ontology of physical things is leaving out a very large part of the reality humans perceive. Naming things and using the names to communicate with others is one of the most important cultural achievements. names are just social conventions, as we have found (see xx). But names are not all that social conventions fix. Social constructs, from marriage to ownership all appear as real to us as physical forces or electricity, but are meaningful only in a social context. The limitation to the context is important to remember: definitions for socially constructed objects are valid only with respect to this context! One must not assume that the definitions valid in one context are valid also in another one. International conventions exist to define some term, mostly in the legal domain, but in general, socially constructed terms are valid only in the small context in which they are used – and the same term, used in another country does not necessarily mean the same thing! This makes international statistics very difficult! Innocent locking terms like 'adult' are social constructions and the age with which somebody is an adult, vary from country to country.

1. SOCIAL REALITY EMERGES IN SOCIAL INTERACTION

Human beings are social animals and social interaction is extremely important. To organzie society by physical force and allow the most powerful individuals control seems to be the usual solution in the animal kingdom. Humans have found methods to organize their interaction in ways which are more economical, creating institutions (North 1997) which regulate social conduct. For example, the institution ownership is more economical than just possession: possession requires personal presence and a readiness to defend my possessions at any time against intruders, bars and locks to keep the thieves out of my home and armed cowboys to secure my cattles. Legal ownership reduces these cost: the "law" in the person of the sherrif must defend me and my property against cattle thieves and other criminals – as any Western shows convincingly.

Social reality includes all the objects and relations that are created by social interactions.The reason to separate physical reality, object reality, and socially constructed reality is the potential for differences in observations and classification: within errors of observations, the results of observations of the same point in time and space should be the same. The construction of objects can be based on the uniformity of various properties, and thus objects may be formed differently—for example, the definition of forest can be based on various criteria and thus leads to different extensions of a 'forest' (indeed one should speak of different forest-kind: legal forest, land-use forest, forest as physical presence of trees, etc.); differences for object formation can be traced back to different methods in classification if enough care is applied to the domain specific interests and procedures.

For socially constructed reality, agreement between different agents from different contexts in the construction is not to be expected. Objects are named with different names in different languages and only naïve persons assume that there are exact translations between terms. Not even countries using the 'same' language, use the same terms with corresponding meaning; well known is the motto "England and the United States are separated by a common language" based on various examples of differences in vocabulary; the same applies to Germany, Switzerland, and Austria. Each country, specifically each cultural system, creates its own 'conceptualization' of the cultural organization. The results are quite different conceptual systems, and one must not expect that the same concept in different cultures has the same meaning. There is a European attempt to extend the WordNet dictionary with 5 European languages to make it multi-lingual.

2. Socially reality is important in GIS applications

Many applications of GIS concentrate not on the physical reality, but on the structure humans impose through social interactions on it. Ownership of land is the most visible social construction, which transforms land into pieces, which we call garden, field or meadow and claim to own, not always remembering that ownership and all similar constructions are only socially constructions.

Our interest in socially constructed reality is justified, because most of what an administrative spatio-temporal database contains are not the physical properties of the world, but the legal and administrative classification of the world; classified and named within the context of social, especially institutional, rules. In the city, building lots, street names, and building zones are administrative facts; in the landscape, county boundaries, right of way and areas of nature parks are administratively constructed facts. These areas created by administrative rules are further simplifications of the complexity of reality to the restricted view of the law. These administrative constructs are valid only within a legal context.

3. Sources of Social Reality

There seem to be three sources for the emergence of socially constructed reality:

3.1 Causation of natural phenomena

Humans have the experience that they can cause events and that changes in reality occur only if they are caused—intentional or non-intentionally. Phenomena in nature, like weather, drought or floods, thunderstorms, etc. do not have an apparent causing agent.

The pattern of agents causing actions is so strong that humans tend to search for causing agents for such natural phenomena. Invisible causing agents are constructed: god or gods, which cause these events. These agents are constructed as 'human like' with emotions, rational thinking, etc.

3.2 Explain nature as populated by gods

The observable behavior of nature is somewhat explainable as the acts of invisible agents with their own internal states—commonly known as gods. If some agents in a society have privileged communication (or at least pretend to have) with the gods, they are important.

3.3 ROLES

We have seen that subdivision of labor leads to higher effectiveness and cooperation and collaboration in groups increases general well being. Roles of agents in a social group are differentiated. These roles are social constructs.

3.4 PROMISES OF FUTURE ACTION

Human agents are capable of planning future actions and to carry them out. They can communicate such intentions and commit to others to perform such actions (or refrain from doing so).

From a promise of A to do X in which B is interested follows that A has an obligation to carry out X and B has a right to expect that A does X. Society is better served if B can rely on X and may construct systems to enforce that A does X as promised.

3.5 CONSTRUCTION OF LAWS AS THE RULES OF GOD

Is that the place to construct the social reality—construct new terms?

Are all abstract terms socially constructed?

How does mathematics and physics (natural sciences in general) work?

Argument—some arrangements of rules are more effective/efficient than others (in the economical sense)

4. SOCIAL REALITY IS VALID IN A SOCIAL CONTEXT ONLY

The names and the concepts are only meaningful within the defining social context. They are not binding outside of this context. What is quite easy to accept with regard to different languages is more difficult to understand with respect to smaller cultural communities: public agencies, administrations, etc.; each creates its own vocabulary and logical organization of the part of reality and cultural institution it is concerned with. It is surprising to see how different the terminology and the concepts of law in Austria, Switzerland, and Germany are; neither the terms correspond, nor do they have the (exact) same meaning. What Austrians call 'Cadastre', a map and a list of the parcels, is the "Liegenschaftskarte" in Germany. Even smaller communities create their own terminology: the laws for urban planning are in the competence of the Land in Austria; there are therefore 9 laws, each creating its own set of terms that have meaning within this set of rules, but do not correspond to the same or other terms used in another Land. And nobody assumes that the different branches in the administration of a town relate the same concept to the word 'building'; the prototypical case, a single family dwelling, may be included everywhere, but the treatment of special cases—very small utility constructions, underground constructions, etc.—will vary. Using the concept of radial category (Rosch 1973), one can say that agencies create radial categories, which partially overlap.

This makes construction of databases, or the integration of databases from different origin very difficult and the smallest common denominators must be found by human specialists; attempts on automatic database schema integration provide at best helpful tools.

5. Example: Money

We have already seen that agents are capable of constructing other agents as similar to themselves and in analogy (or metaphor) to construct as agents things that are not. Such metaphorical constructions are always following an algebraic structure of direct experience and apply it to construct a theory about something that is somewhat different.

6. Instantaneous Changes

Actions change reality. All actions in physical reality take some time to change, because all changes are gradual—changes my be very fast in comparison with other changes, but they are never instantaneous (not even the light bulb is instantly on or off if we move the light switch: the electricity heats the metallic wire and it takes a small fraction of a second to reach the temperature to glow).

Changes in the socially constructed reality are instantaneous, they are on or off, there are no intermediate states as in physical reality. One is either married or not married and the change is at the very moment of the closing of the ceremony (after the last word of the marriage formula has been spoken and the ceremony completed). Similarly, from a position of civil law, a person’s death is constructed as an instantaneous moment; in this moment the inheritance starts. Usually the abstraction from the natural processes, e.g., dying to the legal concept of instant change in state, does not pose problems, but one becomes aware of this difference. A really occurring case: a wealthy couple dies in a plane crash. The legal question—debated in court—was: who died earlier, husband or wife. This was important and made much difference to the division of the inheritance under Swiss law and their wills: if the husband died earlier then the wife inherits all his belongings; after her death, her heirs get it. If the wife dies first, then the husband inherits all her belongings and his heirs get it (figure).

Over the years the construction of the law has become such that boundaries are put at natural break points (night as division between days, birth and death as boundaries of life), therefore the fine point of abstraction usually does not matter.

7. INSTITUTIONAL REALITY

Much of what seems very real is, at a second glance, far from real. Neither status, marriage, nor ownership is physically real. A large number of the constructions of social reality are related to institutions, especially the legal system. We concentrate here on legal concepts, as they are the most important for the construction of spatio-temporal databases, e.g., about land ownership and the planning of the use of space.

Administration and law has a need to simplify the infinitely complex world to general rules that can be applied uniformly and impartially. The complex judgment if a child is mature enough to act as an adult person is replaced by a summary rule that links the age of the person to its classification as a minor, not capable of making legally binding decisions, or an adult. Such rules are important for an efficient functioning of our modern world, where we deal with a large number of strangers and regulate our interactions based on few, typically quickly observable, properties: instructions given by a person in a police uniform are followed when we drive a car, but the same signs made by a non-uniformed person will go mostly unobserved.

Searle observed that some speech acts are not descriptive of reality like 'the forest is green', which can be true or not depending on the color of the forest, but are constitutive—they create the described fact. The most famous example is certainly

"I declare you husband and wife", which, if spoken by a duly authorized person and after the property interrogations create the fact 'marriage'. (Searle 1969).

Often institutions (agencies, laws...) associate specific treatments—fixed in rules and laws—with such constitutive acts. Incorporation of a company, marriage or submitting a letter of resignation constitute legal facts; these legal facts have then well-defined consequences, which are evident, when the constitutive act is made. The institutions typically keep registries of these constitutive facts, a registry of deeds is an example, or provide a document as evidence of the fact, e.g., a driver's license or a marriage certificate. Confusing are 'birth certificates' where the certificate does not constitute the fact that somebody was born—this is an ontological problem of tier 3—but constitutes the legal acceptance that birth was given at a specific location and time, which has consequences like conferring nationality—for example, a birth certificate from a U.S. registry is sufficient for entry into the USA.

Searle in his theory of institutional facts starts with the observation that paper money is nothing else than printed paper, but that this special kind of printed paper has a particular function within the context of a society. He sees that 'special printed paper' serves as 'money' in the context of a national economy. In the theory provided by Searle to explain institutional facts the formula 'x serves as y in the context of z' is very important, but not likely to cover all aspects of social reality (Smith and Searle 2001).

This 'x counts as y' assigns to the physical object x (from ontological tier 3) a specific function y. The meaning of the function x and the rule that x counts as y are both part of the context, for example, the legal institution. The function x, for example 'ownership' is then defined in the context of the legal system: ownership links a person to a piece of land, the owner of a piece of land can sell this land or can use it to secure a debt, etc., etc. The meaning of ownership is fully defined within the legal system of a country. The German Grundgesetz says "ownership is guaranteed within the limits of the law…", clearly pointing out the social and legal context in which the term must be understood. On the other hand, some Reform Country has defined new institutions, avoiding the term 'ownership' for land; in the opinion of experts, if a piece of land can be owned, sold, and mortgaged, there is not substantial difference to 'ownership' (in the meaning of the context of European or American law), independent of the word that this country uses.

Important for the application of spatio-temporal databases to land registration is the separation between the physical properties of things in the world, e.g., boundary markers, buildings, streets and rivers, and the legal facts. Competent surveyors can measure the positions of boundary markers and there should not be cause for debate about the result. Similarly, the reconstruction of a boundary using the documented measurements in the registry is a (mostly) physical process and not dependent on a legal context.

Smith has separated fiat and bona fide boundaries (Smith and Varzi 1997). Bona fide boundaries exist in reality: they may be natural boundaries, like those enjoyed by an island, watersheds, etc. or clearly monumented; the physical reality constitutes the boundary, the registry only points out that these physical elements are the boundary and may contain measurements or other observation values, which can be used to reconstruct the boundary. For fiat boundaries, the registry gives the exact location in terms of observation and competent surveyors are required to indicate the location of the boundary in the real world. In this case, the registry constitutes the boundary and its location. Practically, this difference is important, when the location of a boundary in the registry and the boundary in reality do not correspond—which one is the ruling one? For bona fide boundaries, reality wins; for fiat boundaries, the registry wins.

Confusion in databases of institutional facts may arise from an incomplete separation what are recordings of constitutional facts, which cannot be wrong by definition, and which are facts based on observation of physical reality, which can, obviously, be incorrect descriptions of reality. One can demonstrate that a value does not describe a real property correctly—by inspection of the appropriate place; one cannot demonstrate that a constitutive registration is wrong. However, one can prove that the process that led to its constitution was not following the prescribed rules and therefore the registration void.

8. Computational Model

Construction of algebras in laws.

X counts as Y in context Z

See Bittner's thesis

9. LEGAL OBJECTIZATION

Management in the widest sense requires the manipulation of objects and action applied to objects. The human social interaction calls for rules pointing out what is permitted and what not. Most cultures have developed a concept of ownership of a single individual (or of a small group) on small scale space objects: fruits collected, tools prepared are 'privately' 'owned'. The owner is free to determine what to do with the objects, even to destroy them or to give them away. Every culture has developed its own rules what can be owned, how ownership is established and what rights it grants. Ownership is linked to the 'container' image schema: I own what I have in my hand and I can exclude all others from using it.

From this simple ownership relation between a person and an object many other legal relations can be deduced. Ownership of a (mobile) thing is the fundamental concept of Roman Law, which is uniformly used by analogy for ownership of animals, slaves, and real estate. Similarly, civil law in continental Europe is based on the concepts around ownership of things (and similar rights). From this prototype the extensions for ownership in real estate are made (called 'Immobilar-Sachenrecht' in German, 'vastgoed' in Dutch, always betraying its origin from ownership of things). Other extensions of the concept of ownership of things lead to rights of immaterial 'things', e.g., intellectual property (patent, copyright), etc. In all cases a 'metaphorical' transformation of the basic concepts of ownership of small scale objects to a new situation is used to structure the legal situation of, say, ownership of a piece of text.

In order for this metaphorical transformation to work, the fields and woods must become objects, so they can be dealt with like tools or cattle—sold as individualized pieces: I sell you this parcel of land, this head of cattle. Alternatively, land can be seen as a mass and is sold by quantity: I sell you 10 acres of land.

It should be noted that the original German law, as found in the "Sachsenspiegel", was having particular provisions for the ownership of land and how land is sold, different to the rules for buying and selling movable goods. But even then the thing had to be individualized and bounded. There have been extensive and detailed descriptions how boundaries are to be created—an obviously difficult thing and the details (religious ceremonies, wars, etc.) indicate how 'artificial' (i.e., man made) these boundaries are. Similarly, the Roman mythology reports in detail, how the original boundaries of the town have been created with a plough and admonish respect of the boundary, even if it could have been physically easily crossed.

As ownership rights are the 'fundamental' schema of law, all administrative law relates to objects and relations between objects. For any legal decision, a person or an individualized object must be determined—if the administrative action applies to land, the land must be an 'object' with an identity and a clean boundary. Thus any GIS relating to administrative action affects bounded land-objects; application areas like planning, where phenomena without clear boundaries must be dealt with, incur problems in the administrative process.

10. Assessment

Socially constructed reality is very flexible and can lead to many different arrangements. It seems that in very general terms, a large part of the social construction has to deal with giving justification to the distribution of wealth in society (or more general: access to goods for consumption).

We can see in history a succession of constructions, from priests and kings that have received their power (and privileged access to goods) directly from god or the goods.

Photo

Over time more effective systems have been devices—systems to distribute and control access to goods such that overall production is higher. Economists have studied conditions for a situation to be better than another one, such that some individuals are better off than before and all the other are at least as well-provided than before; this is called a Pareto-optimum.

War is a classical method to change a distribution of access to goods (mostly land), but very expensive for looser and winner.

Social constructions that reduce cost and increase production, i.e., outperform other social constructions, will dominate eventually (or at least that is what a rational person hopes for).

Chapter 38 THE LEGAL SYSTEM: ROLES, RIGHTS AND OBLIGATIONS

A large class of socially constructed reality are rights and obligations. These are crucial to understand ownership in general and land ownership as represented in a cadastre in particular, but also other aspects, e.g. planning.

1. ROLES

Persons can act. Certain actions are reserved for certain roles.

1.1 *ROLE ACQUISITION*

Roles are acquired

2. PROMISES, RIGHTS AND OBLIGATIONS

Give this as an algebra. The constructions are related..

```
Promise
Right
Obligation
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3. CONTRACTS

the cost of contracts:

measurement cost, enforcement cost

4. PROOF OF ACTION

Promises are established by actions; it may be difficult to demonstrate to others that the action was performed by the person.

4.1 *DOCUMENTS AS PROOF*

Documents establish proof that an action was performed.

4.2 *DOCUMENTS ARE PHYSICAL OBJECTS*

A document can be constructed such that the physical object is necessary to execute a right.

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Chapter 39 730 Socially Constructed Subdivision of Space

The continuous surface of the world is subdivided into connected pieces. These subdivisions are the result of some processes, sometimes natural, sometimes man-made physical (artifacts) and sometimes socially constructed.

Natural processes that result in subdivisions of space have been discussed in part 2 when we described objects; examples of spatial objects are the catchment basins that are subdivided by the watersheds (figure there?). Humans create fields—or take natural subdivisions and use them as fields; fields are spatial objects comparable to small scale artifacts.

The subdivisions are used to separate the regions that are assigned to the use by one agent from regions assigned to others. They serve to separate parts of geographic space and make objects, which can be subject to rights of agents.

Figure 730-01:

Only limited objects can serve as xxx in a social construction; it is therefore necessary for land to be delimited—this is today the task of the surveyor, it was before work of priests (roman times) and indicates the 'sacred' aspect of the construction of the social reality parcel from ordinary land.

Testimonies, 'chlapf grenze', bad spirits

1. Boundaries

Natural boundaries delimit land and make land objects that can serve in social constructions.

This is not always sufficient and new boundaries can be constructed—either physical (fence) or—more modern—abstractly by fixing locations with monuments in the corners and declaring the straight line between the monuments as the boundary, or even more abstract, by just fixing the boundaries in abstract coordinate space.

The difference between

- Bona fide
- Fiat

2. Boundary Has a Function

3. Types of Subdivisions

There are multiple types of controls over space and correspondingly many different subdivisions. Modern nation states have multiplied the different ways that control over space can be exerted and then simplified that many aspects of control are assigned to the same subdivision.

Ownership rights (general civil law rights)

Most administrative and political rights: a hierarchical set of constructions (commune, county, province, state, nation) and a corresponding set of spatial subdivisions.

As of lately, special areas are set apart. Some are authorities that must deal with some natural resources and the areas of control are in consequence delimited by the natural boundaries of these resources.

Example: Watershed authorities (baccino hidraulico)

Chapter 40 740 CADASTRE AS AN EXAMPLE

The cadastre can serve here as an example of a complex social construction. It motivates the abstract description given at end.

We see that social constructions can be cascaded, a social construction can be built on top of another social construction, but there is always a physical object at the foundation (no 'free-standing Y terms

We discuss the structure of reality in a cadastre as part of social reality in general. We investigate the embedding of a cadastral system into its environment. The philosophical foundation of the analysis is Searle's theory of institutional reality (Searle 1995). He describes how the physical and social part of reality are linked and how institutional concepts are based on phenomena existing in physical reality.

The research questions we pose are the following: Is it possible to construct a computational model of (social) reality in a cadastre? Does Searle's theory give the appropriate theoretical framework for this task?

1. THE SITUATION

The foundation for efficient cadastral systems is the understanding of the reality, which the system should correctly represent. It is not sufficient to investigate only the cadastral registry with its content and input and output operations. The registration process in the cadastral registry captures only a part of reality. The complexity of phenomena involved makes it necessary to widen the scope to the more general view of reality in a cadastre that comprises the cadastral registry as well as people acting in the real world. This allows representing a more comprehensive view of the cadastral domain. It allows the discussion of the information system cadastre embedded into its environments.

We regard reality in a cadastre as a part of social reality, which is highly determined by institutional concepts. Searle's theory gives the theoretical background to represent reality as consisting of physical phenomena and generally accepted institutional status assigned to physical phenomena (e.g., human beings and the status 'owner of a parcel' assigned). Rights and duties are assigned to status and determine the dynamics of the system. The people act according to the rights and duties defined by the legal system. There are complex relationships between institutional concepts and physical phenomena. The institutional status defined by the legal system is always based on the physical situation in reality. For instance the status ‘owner of a parcel’ is always linked to a physical foundation, i.e., a human being, a piece of land, and the physical possibility to use the piece of land, which is the content of the ownership right.

2. THE COMPUTATIONAL MODEL

In the computational model the world is represented as consisting of agents and land pieces and a message history (the system of documentation). Agents communicate by exchanging messages. Agents have an internal state that comprises three elements. First the agent’s internal state represents beliefs about the status assigned to objects (e.g., this piece of land is a parcel; this agent is the owner of a particular parcel). Second the internal state of the agent represents the current goals the agent has (e.g., an agent can have the goal to sell a parcel.) The third element of the agents internal state are the duties an agent currently has with respect to his own institutional status (e.g., the seller of a parcel has the duty to transfer ownership to the buyer by registering the transfer in the land ownership register).

The execution model of the agent-based model follows the architecture presented in section 2. We distinguish the world level and the agent level of the execution model. On the agent level there are the activity functions of each agent representing the perception, decision, action cycle of the agents. The world level represents the reaction of the environment to the agent’s activities (i.e., to the physical and communication actions of the agents).

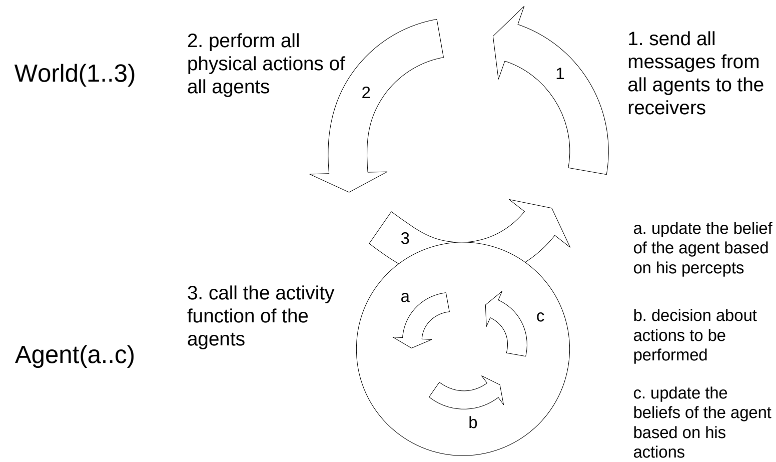

Figure 221: The execution model

The simulation consists of two parts. The goal is to show typical cases of processes in reality of a cadastre. The two parts of the simulation are chosen as case studies for the validation of the model.

First the transfer of ownership on a parcel between two persons will be modeled. The computational model consists of three agents: the seller, the buyer, and the registry agent representing the work of the cadastral registry. Buyer and seller conclude a sales contract. The seller applies for ownership transfer and the registry agent performs the transfer by registering the new owner in the land ownership register.

The second part of the simulation describes reality in a cadastre in the situation that conflicts between people occur in the case of unauthorized land use. It simulates a legal action and a judgment execution process. The simulation comprises four agents. One agent represents the legal owner of a parcel; one agent represents the unauthorized user of the land. Two other agents represent the court responsible for the complaint and the sheriff who has the physical power of the state to force judgments. The legal owner of a parcel recognizes that a person unauthorized uses his parcel (we use an abstract notion of land use, which is exclusive). He sues against the unauthorized user. The judge agent will pronounce a judgment creating the execution title for the legal owner of the parcel to apply for judgment execution. During the execution the sheriff agent will evict the unauthorized land use.

3. THE REPRESENTATION OF REALITY IN A CADASTRE

We have found that it is possible to construct a formal, computational model of a cadastre based on Searle's theory of institutional reality. This result has three aspects. First Searle's theory allows computational model construction. Second Searle's theory is sufficient and powerful enough to represent a complex part of reality, a cadastre. Third the fact that we successfully constructed and validated the model allows the conclusion that a theory of the institutional part of social reality is sufficient to explain the structure of reality in a cadastre.

The extension of the scope from the cadastral registry to reality in a cadastre was helpful for the analysis of the cadastral domain. We were able to discuss a broader variety of issues, because change often occurs outside the scope of the registry but nevertheless with strong impact on the cadastral system.

It was necessary to model social reality in an agent based framework. The model construction based on Searle's theory was only possible with an appropriate representation of human intentions and behavior. The agent-based model was the conceptual framework used for this purpose. We have shown the potential of agent based models for the investigation of social reality.

With agent-based simulation we were able to validate the model with respect to the reality it represents. We developed a framework for the simulation of social processes of reality in the model and tested it by representing two nontrivial cases of processes from cadastral reality. This framework is extensible to represent more comprehensive parts of the legal system.

4. BOUNDARY RECONSTRUCTION AS AN OPERATION CONNECTION BETWEEN PHYSICAL REALITY AND CADASTRE

Chapter 41 750 THE MODEL OF SOCIALLY CONSTRUCTED REALITY

Here the abstract model is presented as summary

Chapter 42 ASSESSMENT OF SOCIALLY CONSTRUCTED REALITY

The representation of the physical reality is not arbitrary—we are constantly checking the agreement between our observations of the physical reality and our constructions. This is not only done when designing new objects and engineers check with prototypes if the behavior of the real object corresponds to what they expect based on their previous experience, but such checking is done constantly and with every interaction we have with the world. There would be enormous surprise if ever a solid, heavy object would float in mid-air and not fall to the floor when we let go—people would call it a miracle and some of the nearby persons could become saints!

Despite the apparent 'relativism' of our constructed representation of the physical world, it is not arbitrary and the practical observations insure correspondence with reality. The construction of social reality seems to be more arbitrary, which opens the door to unlimited relativism [refs]. This is fortunately not so:

The socially constructed institutions organize human society. The effectiveness of these institutions can be observed and assessed. In the historic struggle between kings, nations and countries we can see struggles between different constructed institutions. In the long run—not in short periods—more effective institutions seem to win over less effective ones.

Examples: development of capital markets in the 16th century to 20th

Tax system of UK versus Spanish/Austrian/French

The assumption here is a human nature, which is constant in its base makeup and the institutions work more or less effectively with this human predisposition and how it interacts with others and interacts with the environment.

Example: Japanese steel industry wins against competition because it was forced to modernize and become efficient to avoid environmental pollution.

The socially constructed reality is not completely relative.

PART NINE 800 ONTOLGOGY IN USE

Ontolgoies are used in many situations—they are crucial for the construction of all information systems. Indeed any Information System contains an ontology—even if the designer has not thought of it; he has just built in his own or more likely, a conglomerate of ontologies contributed by all the designers of the system. The result is certainly inconsistent and baroque constructions are required to work around the shortcomings of the actual ontology, which is unknown, but programmed.

In this part, three areas where ontologies are important when designing and building a Geographic Information system are discussed. They are:

- Integration of data and interoperability
- User interface design
- Setting the price for information

It should not surprise that these are three areas where Geographic (and other) Information systems today are often defective and engineers are at a loss to give concrete rules for successful design.

Chapter 43 INTEGRATION OF DATA AND INTEROPERABILITY

Chapter 44 USER INTERFACE DESIGN

Chapter 45 SETTING THE PRICE FOR INFORMATION

PART TEN APPLICATIONS

In this last part I want to show that the ontology here constructed is useful and answers some of the questions applications pose.

Difference between GI and GIS (GIS is in the GIS Theory book!)

1. Part Overview

General structure of these chapters

- Target (what are the systems built for)
- Data collection and data use for decision making
- What defines 'reality'?
- What spatial and temporal concepts are used and what is problematic?
- Integration with other applications

Chapter 46 810 170 GIS FOR SCIENCE

Geographic information is extensively used for the collection of spatial data, the organization and integration of data from different sources and over time to analyze and visualize the data. What are the ontological questions relevant here?

For science, reality is defined by formulae, which connect observables; many hidden variables are constructed, to simplify the theory, the semantics of these hidden variables are defined by the formulae, which connect them to the observable properties.

The major problem is the connection of the observable properties at a location with other observable properties at the same location. Not always the area for which an observation is valid varies and two different properties are defined with respect to different spatial reference objects:

1. SCIENTIFIC REALITY DEFINED BY FORMULAE

For scientific research, we introduce interesting—but not observable point—properties. Sometimes these properties are integrals over spatial regions of point properties and are of a nature that makes observation simple.

Example weight

Chapter 47 820 GI IN ADMINISTRATION

Administration contributes enormously to make our society more effective—see D. North.

Administration is an extensive system of treatment of data or information: inputs in form of data lead to outputs in form of data

(Other parts of administration can be privatized, separated from administration sensu strictu: education, police, health service are production systems)

Max Weber pointed out that administration must make all decision following the rules set forth in law. The law gives the ontology for the administrations treatment of data:

There are some fundamental physical classes—persons, land,—which are predefined for the reality of the law. The rest is defined in the law.

1. DUPLICATION OF DATA COLLECTION

One of the standard arguments for GIS is that the same data are collected numerous times by administration and this is a waste of public funding. This is just one of the topoi of administration bashing…

Administration applies laws, all activities of an administration must be authorized by law and follow the law. Different parts of the administration carry out different specialized laws. They must classify the world according to these laws. If the definitions of the objects in the laws are different, then obviously different data collections result.

The origin of the apparent duplication of the data collection efforts is the legislator, where minor (often inconsequential) differences in definitions of objects creep in and force administration to maintain multiple data collections, which is indeed costly.

Example: definition of forest in Austria

Chapter 48 830 GI FOR CONSUMERS

The use of GI in the production process, the use of GI for consumers:

A process is improved by information. GI is used, if the improvement of the process is more than the cost of acquiring the information.

Concept of usability—closed loop semantics

Issue here is user interface design

Searching the web

Chapter 49 840 GI FOR PLANNING

Geographic information is often used for planning, indeed, urban and rural planning (physical planning) was one of the original forces that led to the concept of GIS.

Planning is difficult; its legal status is somewhere between legislation, where general abstract rules are formulated, and administration, where these general rules are applied to specific cases. It is typically process oriented, meaning that a determined succession of administrative steps are necessary to arrive at a final, binding, result. In each step, certain groups can make suggestions and oppose proposals of other groups. In the U.S. tradition of planning administration, public hearings simulate a court situation, where the parties have to bring forward their points and the planning board makes a decision based on the merits of the case made by the parties. In the European tradition that is more an administrative process based, the planning boards have to consider all aspects 'ex officio', but parties must be heard as well. In both traditions, invitations for all people affected by a plan to voice their concerns at a specific meeting are necessary. In both traditions, the resulting decision is made public and can be opposed with a prescribed process of …

There are difficulties with the process and the decisions do not always reflect the best interest of the population affected by the plan. Indeed, the population affected are often not heard, sometimes there are hints, that the planning boards try to avoid their participation. There is a feeling, that the professional planners and the experienced planning boards 'know better'; the planners believe they can produce better plans than the amateurs, the people affect belief, that the professionals do not want to find solutions that respond to their needs.

Public participation in the planning process is the current watchword—everybody intends to do it, but very seldom the process is really changed from the 'non-participative' practice.

In this chapter, I will show that some of the difficulties can be understood as ontological and demonstrate, how attention to questions ontological and semantic can contribute to improve the planning process to include public participation and to achieve results, which satisfy the interest of more people affected by a plan.

1. A Small Planning Situation

2. Who Is Involved

Different groups are involved in planning actions

Affected population living in the area
Professional planners and the administration
Elected Politicians (town government, planning board)
Public at large living in other areas

Waldo Tobler's first law of geography makes it impossible to identify exactly who is affected by a planning decision. The people living in the area are typically singled out and invited to participate, including owners of real estate who do not live there (absentee landlords), but not including people working in the area or using the area for recreation. One might already question this division between people living and owning, but not other actions.

The population of the region around the area under planning is clearly affected—nobody lives on an island. If a town sets the zoning regulation such to attract a shopping mall or a business strip just right to another town, it may substantial affect the economic viability of the existing shops and other infrastructure in the other town.

The affected population and the public at large have a direct interest in terms of possible interaction with the result of the planning process—the situation as constructed and how it further develops. The politicians should in principle represent the interest of the public at large (which is typically not involved) but their interest is one of popularity for being reelected and the terms are short such that long term effects of the planning process are not important for them. The interests of the planners are varied—some follow particular believes, other are just interested in getting the planning process done without difficulties.

3. The Standard Process

The intention of the process is to find an optimal situation, where the interests of the affected population and the public at large are best satisfied.—pareto optimal?

The process should arrive at this optimal solution. This could take more resources (time) than available. Actually, the legal substitute for optimality is process: the different interests can be made known and argued for and against a prescribed time period. Then an initial decision is made, which can be appealed if one of the parties feels strongly against it.

This allows to achieve a definite decision within limited time and resources. As a process, it favors usually the party that is better organized (owners before population before public at large).

4. Characterization of the Decision Situation

The planning process as currently executed, leads to a decision of subdividing space in some (non-overlapping) regions and assigning to each some rules for the use of the land; typically prescription of the building types and occupation acceptable.

The precise semantics of such land use rules are not important, as the regions are a JEPD subdivisions of space and the land uses are exclusive for one type of land use.

Objections of people affected by a plan are:

the land use leads to emissions, which are disturbing them in their current use (within one region or at the boundaries of regions)

the land use leads to emissions along some communication axes

for example a land use of 'waste dump' creates heavy truck traffic on the roads leading to it

The arguments of people affected are sometimes based on actual situations, but usually are fears based on developments the plan will allow or even advance.

The different parties in the process use a technical vocabulary—jargon—that reflects poorly the individual experiences made. The technical terms are not defined with respect to actual experiences in the situation at hand, but are theoretical constructs of planning practice and administrative regulations.

These abstract discussions hinder actual communication—the exchange of statement does not satisfy the condition of effective communication—

It allows effective planning communication, but this leads to an inefficient real situation.

4.1 Ontological problems

4.1.1 Description of the current situation
The description of current land use is again in terms of planning jargon and does not connect to the experiences of the groups that should 'participate' in the process.

4.1.2 Definition of future land uses:
If the definitions of the land uses permitted are reconsidered, one can find that the uses are not exclusive and can coexist either in space or time.

Example: the clash between the interests of mothers with toddlers to have a quiet area in a park and the interest to establish a zone for teenagers to hang out does not clash, because the mothers need the area mostly in the morning and early afternoon, before school is out and teenager can hang out. The two uses can easily coexist.

4.1.3 Fear and insecurity
The process does not contain methods to express fear and insecurity of the participants: all contributions must be made in the most definite (scientific) terms. Emotions are not acceptable.

5. Improved Process

5.1 Analysis of the problems:

The different groups see (construct) reality quite differently. The professional planners apply concepts to the situation that have been tried elsewhere and are meaningful within the planning methodology and the planning laws; they are not necessarily the concepts that fit with the concepts the affected population or the public at large uses. The standard complaint is that the jargon of professionals does not communicate, assuming that a translation of the jargon into plain English (or German) would help. This is not likely, because the underlying conceptualization is different.

Communication is not happening—the planning process becomes an exchange of formulae which are only meaningful within the process, but do not link to real world situations. The decisions are made on the basis of compromises between opposing interests, expressed as such formulae.

5.2 *Intention*

Connect the words used in the exchange to meaningful real world experience. Create a shared image of reality for the full group in which a meaningful compromise can be sought. Reduce expected or feared inferences.

5.3 *Go on*

Joint activity to form a group with a joint, not opposing interest

Walking to give a common experience base—all participants share the same experience

Discuss problems within the area—avoid abstraction and link to concrete situation

Play out potential conflicts to see if they are actual and how they can be avoided

Review actions

Cognitive spaces—discuss based on Montello and Couclelis.

But add the spaces of the planning law (cultural, institutional space)

6. Reducing the Effects of Natural Hazards

It appears as if natural hazards are occurring more often; there is clearly more publicity for natural hazards in our 'global village' and we have more information about natural 'catastrophes' occurring anywhere on the world.

Even more than for urban and regional planning, decisions for efforts to reduce the negative effects of natural hazards are asking for our image of nature and men.

PART ELEVEN 900 CONCLUSION

What is achieved? What is useful for the practitioner? What are the open questions for the researcher? In this final chapter I want to review the major achievements.

1. ONTOLOGY AS A COHERENT SYSTEM OF UNDERSTANDING THE WORLD

The major goal of this endeavor was to construct a coherent ontology that covers all the aspects that typically occur in the construction of Geographic Information Systems, covering different conceptualizations of space and time and combining them with a field and object view of reality. It was important, to cover physical reality, but as well-connected to the social reality, which—as institutional reality—is crucial for all administrative usage of GIS.

Current ontologies attempt more generality than I think is warranted, the division of the ontology in tiers with different rules has helped to address most of the questions I encountered in the practical implementation of GIS.

The concepts in the tiers are comprehensive and connect from tier to tier the concepts. They can serve to bridge between different realms of application (as was shown in 170 to 200). Because the concepts used are defined formally and connect either among them or connect at least back to the fundamental concepts of point observation in the space-time continuum of physical reality.

1.1 SPECIAL CASE: ONTOLOGY OF SPACE AND TIME

The

1.2 Field and object view

1.3 Social, especially institutional reality

1.4 Information

2. Closed Loop Semantics

Semantics of concepts and data in a GIS are a serious practical problem; every GIS practitioner encounters constantly the problem of integrating data with unknown, different or conflicting semantics.

The discussion in the application chapters justified the concept of closed loop semantics: the connection from the data collection to the decision and action shows if the GI is usable or not.

Usability as an overarching quality concept

2.1 Usability

Usability links the information system back to the real world—what contributes the GIS (or other information system) to improve our physical existence. This is where the rubber hits the road.

No other discussion of quality?

3. Discussion What Defines Reality for Each Use of Geographic Information

The ultimate test is always if decisions applied to reality have the predicted outcome. Internal to the process of collecting information, preparing decisions, various methods exist to introduce ‘hidden variables’ (abstract concepts) that summarize, transform, or otherwise relate to observable properties.

Science: formulae, which link observable and hidden variables

Administration and law: law texts that define new concepts in terms of physical reality.

Consumer GI: the day to day life defines reality (combined physical, social/cultural and legal/administrative).

Planning: People define reality with respect to their interest.

4. Form of Theories to Make Them Composable

Theories described as algebra can be composed.

Theories are small, much smaller than we expected.

Folk theories are as important as scientific theories. Administrative and legal theories (i.e., laws and rules and regulations) are more important.

Algebra provides a common format.

5. Status of Formal Sciences

The ontological status of formal sciences—mathematics, logic—is clarified:

6. Overarching Concept: Linkage between the Information and the Physical Realm

How to link the information realm to the physical world. The links are multiple and different:

mental representation to real world (observation and action link)
information system to real world (usability in decisions)
institutional terms to physical objects (x counts as y in context z)
mental concepts to physical signs (encoding – decoding)

7. Philosophical Problems

We have also seen that many of the problems discussed in philosophy are not of much relevance to the GIS practice. This is not to say that the contributions of philosophy are useless, but to point to the limits of abstract thought. It is not meaningful to split hairs and to discuss questions of how many angles may stand on the point of a pin; I have tried to concentrate on questions that I have found relevant for the practical use of Geographic Information Systems and the information contained in them.

- Limited resolution—this makes questions of how Achilles ever catches up with the tortoise (fig xx) or the question what color the boundary between a red and a green half of a disk has (Brentano 1988).
- Classes are defined by practical operations—this reduces the interest in the discussion of natural kind and questions whether tomatos are fruit of vegetable.

- Operational efficiency as test for usefulness—this leaves the quest for absolute truth to those who look for the Holy Grail.

PART TWELVE 910 POSTFACE

1. DEEPER INTEREST POLITICS

I write this book not the least with an eye to politics. The discussions sometimes paint a situation as if Orwell's 1984 had become a reality, in which government or multinational companies could combine all sort of knowledge about a person and construct the 'gläserne' (transparent) citizen. Designers of information systems know how limited our abilities are and how difficult it is to integrate in a meaningful way data from different sources. The dangers are not in what can become known but are rather with the erroneous conclusion one can draw from inappropriate combinations of data. It would serve our political discussion better, if politicians and the press would rather concentrate on the difficulties and the errors that occur than to fantasize about unlimited, but not yet achieved and perhaps never achievable possibilities of data integration. The dangers of erroneous conclusions are real and affect the individual—citizens are detained at borders, bank accounts are blocked when errors in data processing occur. The dangers are equally real when we observe political decisions of far reaching consequences, e.g., on social programs (Lakoff 1996) or the current debate on war against Iraq.

2. REALISM VS RELATIVIST

The cultural constructivist point out that the concept we use must survive the test of practical life.

Nonsensical constructs—the philosophers loved example of the mereological sum of my car and Barry Smith's headache—are not useful and are not occurring.

Similarly, political constructions, which are not leading to long term optimal satisfaction of human needs (with the given level of technology) are not likely to survive in the long run.

Communism has disappeared, Lenin's doctrine of Pravda (truth) does not lead to proper understanding of the situation and therefore leads to inappropriate reaction of administration to problems occurring. This is wasteful, i.e., less efficient than political systems where an assessment of the situation is better aligned with physical reality.

3. FINAL WORD

The fundamental question of enormous importance which ontology and ethics try to answer is how to separate human beings as a special ‚natural kind’ from other things. How to differentiate humans from animals—especially animals with cognitive abilities as highly developed as chimpanzees (Gill 1997). This is a classical question, necessary to explain why we can slaughter cows and sheep and eat them, but are usually forbidden to kill our fellow men (and women), let alone eat them! But this question can also be asked in a new guise: how to differentiate human beings from artificial life forms—things that live ‘only’ as artifacts, computer programs, and robots. Nevertheless, some of the newest construction enter in a dialog with humans and seem alive—‘as alive as something with a battery gets’.

I think that the ability to use metaphorical transfer and to construct social reality is a uniquely human ability. I wait to hear from observations that animals are capable of such cognitive actions.

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