Distinctions Produce a Taxonomic Lattice: Are These the Units of Mentalese?

Andrew U. Frank
Institute for Geoinformation and Cartography, TU Vienna, Austria

Abstract. Ontologies describe a conceptualization of a part of the world relevant to some application. What are the units of conceptualizations? Current ontologies often equate concepts with words from natural languages. Words are certainly not the smallest units of conceptualization, neither are the sets of synonyms of WordNet or other linguistically justified units. I suggest to take distinctions as basic units and to construct concepts from them whereas other approaches start with concepts and discover properties that distinguish them. Distinctions separate concepts and produce a taxonomic lattice, which contains the named concepts together with other potential conceptual units. The taxa are organized in a sub-/superclass (better supertaxa/subtaxa) relation and for any two taxa there is always a single least common supertaxon. Algorithms to maintain such a taxonomic structure and methods to combine different taxonomies are shown, using a four valued (relevance) logic as introduced by Belnap (1977). The novel aspect of the method is that distinctions that are only meaningful in the context of other distinctions restrict the lattice of concepts to the meaningful subset.

The approach is restricted to the *is_a* relation between classes; it relates to Formal Concept Analysis, but replaces the "formal attributes" with (necessary) distinctions and uses a four-valued logic. It stresses the focus of recent ontological studies like DOLCE or WonderWeb on qualities; it is expected that distinctions as introduced here for the *is_a* hierarchy influence the mereological aspects of an ontology (i.e., the *part_of* relation) and connect to Gibson’s affordances (1979) and contribute to the classification of operations.

Introduction

Words from natural language or sets of synonyms are often used in ontologies as the conceptual building block. Gärdenfors has already pointed out that concepts depend on context and "we constantly *learn* new concepts and *adjust* old ones in the light of new experiences" (Gärdenfors 2000, 102, emphasis by Gärdenfors). The conflict between the fluidity of concepts and the rigidity of ontological knowledge acquisition results in the observed difficulties with building ontologies and it is difficult to integrate ontologies or similar artifacts like database schemas.

Distinctions between concepts could be the building blocks for the ‘language of thought’ (Fodor 1984). Following Pinker, Gärdenfors, Lakoff and many others (Lakoff 1987; Pinker 1999; Gärdenfors 2000), our concepts of the world are not arbitrary but reflect the physical, bodily, and social constraints of the world: we make the differences that are meaningful for operations we want to carry out and notice distinctions that are relevant for our lives. Distinctions create intensional and extensional sets of entities and differentiate between concepts. They serve as building blocks to construct taxonomies and help with knowledge acquisition.

This paper concentrates on taxonomies, what Masolo et al. (2003) have called lightweight ontologies. In a taxonomy constructed from necessary distinctions, the deduction of sub- and superclass (*is_a*) relations is immediate and algorithm for knowledge acquisition and integration use database operations and do not require logical inferences. The integration of two independently elaborated ontologies requires only the identification of the distinctions—of which there are much less than class concepts; additional identification of common taxa strengthen the integration.

The paper is structured as follows: the next section clarifies the terminology used, linking the work to the DOLCE/WonderWeb terminology. Section 3 discusses briefly the difference between linguistically justified conceptual units and the finer grained concepts addressed here. Section 4 shows how distinctions lead to lattices of concepts and gives the examples used in the paper. The fifth section collects the formal definitions and properties of the taxonomic lattice of distinctions. Section 6 shows how new concepts are added to such a taxonomic lattice and how such lattices can be integrated. Section 7 introduces rules to restrict the application of distinctions and excludes impossible combinations. Section 8 shows some results from a prototypical implementation and section 9 lists future work, especially the connection to mereology and dynamic ontologies with operations.

1. Terminology

It is amazing that the field of ontological studies that pretend to clarify the meaning of words is itself entangled in a confusing terminology. From different terminologies I mostly follow the WonderWeb definitions (Masolo, Borgo et al. 2003). The word *concept* will be used to describe a unit in the mental realm, something in our mind; whereas *kind* describes collections of things in the world that have some commonality (I avoid the often used term *category* to avoid confusion with mathematical category theory (Asperti and Longo 1991; Krötzsch, Hitzler et al. 2005)). The terms *type* and *classes* are used to describe extensional and intensional sets of representations; classes considered only in an *is_a* relationship will be called *taxa* (singular *taxon*). The term *distinction* describes the difference between the individuals in two taxa, based on the observation of a single quality.

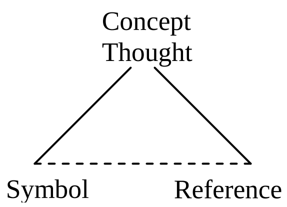
Individuals (for example, my dog Fido) are often called object or entities and described sometimes by proper nouns (whereas classes are described by sortals). Individuals have *qualities,* "within a certain ontology, we assume that these qualities belong to a finite set of *quality types*" (Masolo, Borgo et al. 2003, 16, emphasis in the text). The basic qualities are observable (weight, color, etc.) but other qualities are culturally constructed (Searle 1995). Properties are (unary) universals; I see them as functions that applied at a specific time to a specific individual result in a value from a *quality space* (Gärdenfors 2000) (the *quale* in DOLCE (Gangemi, Guarino et al. 2002; Masolo, Borgo et al. 2003)). I will use the term *word* for linguistic units and *symbol* for the representations in a formal system.

2. Linguistics as a Start for Ontology?

Linguists have studied the vocabulary, the lexicon of languages extensively. Their efforts to understand the semantics of words have often provided starting points for ontologists:

2.1. Words

Words in a natural language are recognizable signs (tokens). They stand for the equivalence class of utterances, written signs, etc., they are *invariant under representations*—written or spoken in different forms and in most languages subject to grammatical transformations (e.g., the addition of a terminal 's' to form a plural in English). The abstract word "dog", which we find in a dictionary entry, describes the equivalence class of all representations of the word.



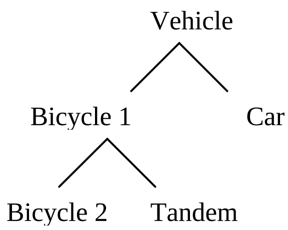


Figure 1. The semiotic triangle

Figure 2. The taxonomy for context 1 and 2

In the semiotic triangle (**Figure 1**) (Eco 1977) the relation between symbol and referent is not direct but indirect through the concept in the human mind. The relationship is influenced by prototype effects and family resemblance (Rosch 1973; Pinker 1999; Gärdenfors 2000).

It is accepted that multiple concepts are associated with a single word. Linguists separate homonymy, two words sounding or written the same but with different meaning, and polysemy, the same word having different meanings. The same words in natural languages often stand for a class and a related super-class, depending on the context. Consider first a legal text in which permitted action for different kinds of vehicles are discussed—*bicycles* are separated from *cars*. The second text describes an encounter of a group of people "there were three bicycles and one tandem". $bicycle_1$ (from the legal context) is the superordinate of $bicycle_2$ (from the second text) (**Figure 2**). In general, the lexicon is not sufficient to mark all the distinctions between concepts; natural language is economical and reuses a combination of words to achieve finer subdivisions.

2.2. Synset

WordNet (Fellbaum 1998) introduced sets of synonyms (synsets), which group words, such that, in a fixed context, the words in a synset can be exchanged against each other. Many research contributions—including papers by myself—have equated synset with conceptual unit and used WordNet as a start for an ontology. WordNet provides a finer and more structured division of meaning than ordinary dictionary entries. In particular, WordNet has a hierarchical hypernym/hyponym structure that is often used to demonstrate ontological processing.

Nevertheless, synsets are not likely the finest grained conceptual units, because they do not translate from one language to another language; they are language specific (EuroWordnet project). Assuming that conceptual units are language specific (but otherwise context invariant) would push the ill-famed Whorfian hypothesis (Carroll 1956) into a new field.

3. Taxonomy as a Set of Distinctions

Consider a set of concepts arranged as a taxonomy. The taxonomy consists of a set of taxa (Krötzsch, Hitzler et al. 2005). These taxa are considered different from each other, they are distinct. In this paper, I consider the taxa and the taxonomy as constructed from a set of distinctions, with the interpretation that all individuals in a taxon have a particular value for the quality related to the distinction. A distinction is related to a particular type of qualities that map from individuals to a small set of values. For example, cars are distinct from bicycles as they are motorized and bicycles not; cars have for the distinction *motorized* the value *True*, bicycles the value *False*. Every taxon in a taxonomy is different from any other by at least one distinction value, the set of distinction is an intensional definition of the taxonomy (Priss to appear).

A taxonomy organizes the taxa in an *is_a* relation, which corresponds to a subset relation between the set of individuals classified in these taxa. If *S* is a subtaxon of *A* then every individual that is an element of *S* is also member of *A*, every (necessary) distinction that individuals of *A* have is shared by individuals of *S*. The discussion here is in terms of the taxa and not in terms of individuals (this is different from DOLCE, BOF, and similar ontologies); the reference to individuals is only a motivation for the formalization. The discussion is limited to *is_a* relations between taxa and I leave the connections with mereology and operations in a dynamic ontology for future work.

Example: Classify vehicles, first by a *land/water* distinction, and then separate bicycles from cars by having a motor or not, and use the same distinction for water vehicles, separating rowboats from steamships (**Figure 3**). Note that we have a word *vessel* to describe water vehicles, but no corresponding term seems to exist for land vehicles. This taxonomy makes sense if we have only to distinguish between these concepts (*bicycle*, *car*, *rowboat*, and *steamship*). To distinguish between *n* taxa at least $log_2\ n$ binary distinctions are necessary; in this sense the taxonomy in **Figure 3** is minimal.

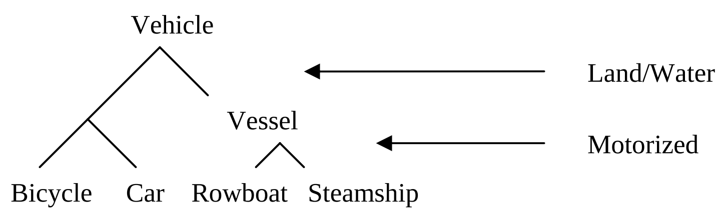


Figure 3. The taxa produced by the distinctions "Land_Water" and "Motorized"

3.1. Boolean and multi-valued distinctions

In general, the property that distinguishes the two taxa are not Boolean values: any (small) set of distinct values can serve. For bicycles, one could ask for number of seats (1,2,3), for vehicles the environment in which they operate (Land, Water, Air). Without loss of generality, the discussion concentrates on Boolean distinctions (in subsection 5.1 treatment of non-Boolean distinctions is shown). In the following diagrams I will annotate the taxa with the distinctions without showing the values not to overload the diagrams. Diagrams are shown as semi-lattices without the trivial bottom element.

3.2. Impediments of hierarchical taxonomies

Current ontologies discuss mostly hierarchical taxonomies, but many systems accept heterarchies, (e.g., OWL). Organizing words in a strict hierarchy (i.e., a structure in which each element has exactly one superordinate) leads (1) to the question of selecting a unique starting point (or several ones) and then (2) to setting the order in which distinctions are applied. WordNet, for example, has selected a small number of unique beginners for the hierarchies—there were 25 for nouns (Miller 1998, 29) and some additional ones for verbs etc. DOLCE classifies a material object by the distinctions Particular, Endurant, PhysicalEndurant (in this order) (Masolo, Borgo et al. 2003, 14). The selection of unique beginners and the order of distinctions influences the structure of the ontology and hinders integration of ontologies that have different unique beginners or use different order. Classifying the taxa from **Figure 3** by first splitting in motorized or not and then in land/water would be equally good for other purposes like regulating the need for a permit to conduct a motorized vehicle on land or water (**Figure 4**); note that no node in this taxonomy describes *vessel*!

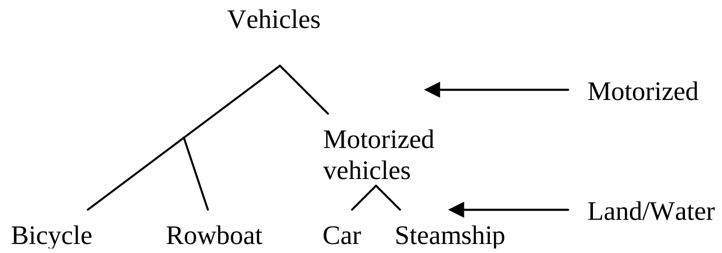


Figure 4. An alternative taxonomy to Figure 1

The extensive debate on inheritance in the object-oriented software community has shown that modeling human conceptualizations in a hierarchy introduces artifacts. Distinctions can be applied in any order and produce a heterarchy, specifically a semi-lattice. This structure represents not only the concepts introduced and named by the user, but also the different supertaxa (land vehicle, motorized vehicle, etc.), which may be meaningful in some related context and are useful when merging different ontologies.

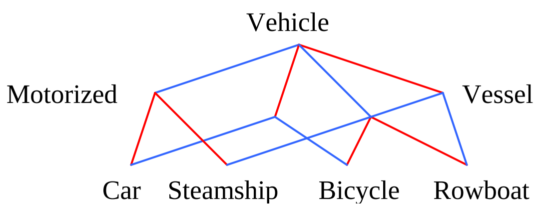


Figure 5. Merging the taxonomy from Figure 1 and 4 to form a semi-lattice

3.3. Dependencies between distinctions

Some distinctions are often not applicable if not another distinction has a particular value. For example, if we distinguish between a taxon of physical objects and one of non-physical ideas, then a distinction *motorized* applies only to the subtaxa of physical objects. Representing such dependencies as rules reveals the intended semantics of distinctions of the taxonomy.

3.4. Difference to Formal Concept Analysis

Formal Concept Analysis (Wille 2000; Priss to appear) was developed to deduce automatically higher level concepts from a description of individuals with quality values. The result of the analysis are concepts that generalize the knowledge found in the individual cases. The taxonomic lattice of concepts is organizing taxa that are defined by distinctions, not simple values (for example, values of distinctions describe regions that partition the quality space). Nevertheless, some of the results from Formal Concept Analysis are directly applicable to the taxonomic lattice, as will be seen in the next section (Burmeister 2003).

4. Formalization of a Taxonomy

A taxonomy consists of distinctions (d_j) and taxa (A_i). Distinctions map from a taxon to a set of distinction values from a domain $D : d_j :: A \rightarrow 2^D$; the cardinality of D is small and 2^D denotes the usual powerset over D. The taxa are characterized by a set of values for the distinctions. Without loss of generality, I start the discussion with Boolean distinction ($D = \{True. False\}$). The formalization here can be seen as a subset of description logic (Brachman and Levesque 1985).

A taxon is described by two sets of Boolean distinctions: the set of the affirmed and the set of negated distinctions, where each distinction appears at most once, either in the affirmed or in the negated set; the intersection of the affirmed and negated set is empty. Between two taxa, a partial order < is defined, extending the ordinary subset relation to the pair of sets; note that the supertaxon has the smaller set of distinction and the subtaxon the larger!

$$\forall a : aff(a) \cap neg(a) = \varnothing$$
$$a \subset b \Leftrightarrow aff(a) \supset aff(b) \wedge neg(a) \supset neg(b)$$
$$a \wedge b = (aff(a) \cap aff(b), neg(a) \cap neg(b))$$

$$a \vee b = (aff(a) \cup aff(b), neg(a) \cup neg(b))$$

The distinction defines a lattice with a top taxon *everything* that has no distinctions and a bottom taxon *nothing*. For any two taxa a unique, least supertaxon exists, called the *join* ($\wedge$) and a largest subtaxon, called the *meet* ($\vee$). The *join* is computed as the intersections of the affirmed and the negated distinctions. The *meet* of two taxa is the union of the affirmed and negated distinctions and if any distinction is in both resulting sets, then the result is *undefined* represented by the *nothing* taxon.

The interpretation of *join* is 'the smallest taxon that includes both of the given taxa'—for example, the *join* of *rowboat* and *Bicycle* is *non-motorized vehicle*. The interpretation of *meet* is 'the largest taxon that has all the qualities of the two given ones'; for example, the *meet* of *motorized vehicle* and *vessel* is *steamship* (**Figure 5**). This construction of a Boolean lattice is an application of Belnap's four-valued logic (Belnap 1977), with the values, {*A, not A, A or not A* (indifferent), *A and not A* (undefined)} (**Figure 6**). It is used in relevant logics and increasingly applied to problems of information science.

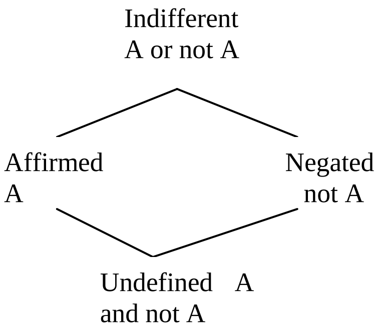


Figure 6. Belnap's four valued logic

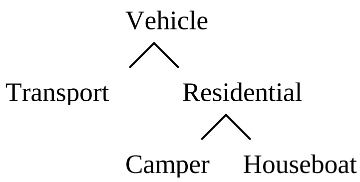


Figure 7. A taxonomy for campers and houseboats

4.1. Multi-valued distinction

For distinctions that have multiple values, a taxon is characterized by the set of the values the distinction can take, interpreted as 'every individual in this taxon will have one of these values'. The *join* is the union of the values for this distinction in both taxa and the *meet* is the intersection of these values; an empty set of values for a distinction represents *undefined* and the set of all values for the distinction the value *indifferent*.

Example: Extend the distinction *Land/Water* to *Habitat* with the values {*Land, Water, Air*}; then the taxon *Steamship* is described by *{Motorized = {True}, Habitat = {Water}}*. The taxon *Seaplane* is described by *{Motorized = {True}, Habitat = {Water, Air}}*. The *join* of *seaplane* with *car {Motorized = {True}, Habitat = {Land}}* gives *MotorVehicle {Motorized = {True}, Habitat = {Land, Water, Air} = indifferent}.*

4.2. Named taxa

All taxa in a taxonomic lattice are created by the set of distinctions and need not be stored; one could say that they are virtual. Some taxa are of particular interest to the ontologist and are associated with a descriptive label and a natural language gloss to indicate the intention. Only these named taxa are stored with the affirmed and negated set of distinctions. Typically diagrams of ontologies show only these named taxa, but the construction of all taxa in the taxonomic lattice makes *join* and *meet* operations produce a super- and subtaxon in all cases (but these are not necessarily one of the named taxa!) and helps with the maintenance and integration of taxonomies.

5. Operations to Manage a Taxonomic Lattice of Distinctions

5.1. Add or delete named taxa that can be expressed with the given set of distinctions

Adding a named taxon to a taxonomic lattice without introducing a new distinction is just adding the label and the gloss to the taxon, because potentially all taxa that can be constructed from the given distinctions are already in the taxonomic lattice. Practically speaking, one checks that not another named taxon with the same values for the distinction has been added before. This allows to detect if a taxon is added twice with different terminology or to identify distinctions that must be added to differentiate two otherwise not differentiable taxa. Example: name the taxon *Wheeler {Motorized, Land}* to complement the taxon *Vessel* in **Figure 3**. Deleting a named taxon from the lattice is just removing the name—the potential taxa remains in the lattice as a combination of distinctions.

5.2. Add a taxon and a new distinction

To add a distinction to a taxonomic lattice is only changing the potential taxa but stored taxa need not be changed—the existing taxa all receive the value *indifferent* for the new distinction. The new distinction can be added to existing named taxa; for example: a new distinction *isResidence* is added (see **Figure 7**) and the taxa *HouseBoat* and *Camper* can be distinguished.

5.3. Split at taxon with a new distinction

Consider the case where an existing taxon should be split in two. For example in **Figure 8** we want to introduce a taxon *Dieselboat* to contrast with *Steamship* in the taxonomy of **Figure 3**. For this we have to introduce a new distinction *SteamEngine* and mark the existing taxon *Steamship* with this as an affirmed distinction (and propagate this to all subtaxa of *Steamship*!). The taxa *Dieselboat* and *Motorboat* can be named.

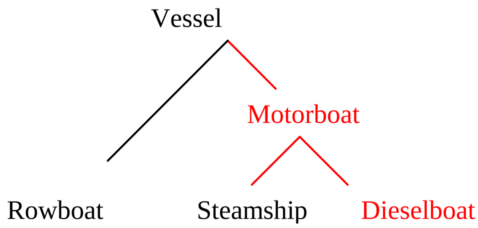


Figure 8. Taxonomy with distinction *steamEngine*

The general procedure for adding a new distinction is: first, identify the sibling of the new taxon and decide on the distinction (**Figure 9**). Second, add the distinction to the two sibling taxa, once affirmed, once negated (and propagate to the subtaxa of the existing taxon). This produces automatically a new supertaxon (the *join* of the sibling and the new taxon).

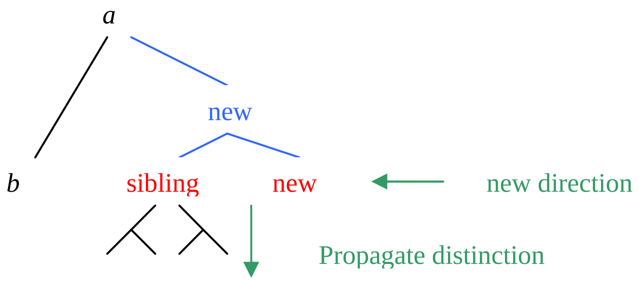


Figure 9. General approach to addition

5.4. Merging two taxonomies

Two taxonomies *A*, *B*, with different distinctions can be combined. Taxa that lack a value for a distinction acquire the default value *indifferent* for this distinction. The resulting taxonomic lattices are much larger but the named taxa remain distinct and keep their characterization by the set of affirmed and negated distinctions (note that taxa are defined as set of distinction values—thus even if the intentions for two concepts are the same, if the taxa are defined by different distinctions, they are considered different). This is possible because the named concepts represent only a small part of the lattice of concepts. The result, however, is a combination without any interaction between the taxonomies. For any combination of taxa from taxonomy *A* and taxonomy *B* the *join* and the *meet* are top (everything) and bottom (nothing)—no new information is generated.

More useful is the combination of taxonomies where at least some distinctions are the same or can be identified. Then the combination of the two lattices shows the interaction between the concepts. Example: Merging the ontology of vehicles of **Figure 3** and **Figure 7** gives a lattice with the distinctions *Land/Water* (shared), *Residential*, and *Motorized*. Relationships between the taxa are established; for example, the *join* from *Houseboat* and *Steamboat* is *Vessel*; the *meet* of *Residence* and *LandVehicle* is *Camper*. These relations are based only on the identified distinctions and result automatically without any changes in the description of the named taxa (except for adding the default value *indifferent* for distinctions that were not originally used).

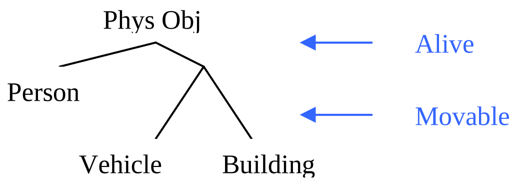


Figure 10. A taxonomy with distinctions alive and movable

Even more integration is achieved when not only distinctions are identified but also named concepts. This is especially important, if the top level distinctions differed between the two ontologies. Assume that the ontology of **Figure 3** is merged with **Figure 10**. Then the distinctions for *Vessel* in **Figure 10** must be added to the distinctions of *Vessel* in **Figure 3** (and reverse) before the two taxonomies are merged by identifying the distinctions.

5.5. Preserving initial taxonomies

Merging taxonomies to make database interoperable leads to a new taxonomy but the relations to the original taxonomies *A* and *B* must be preserved. The concept lattice spans the space of all combinations of distinctions. It is therefore possible to maintain in it the original taxa together with taxa that result from mergers or updates. Changed taxa are given new names and operations to determine sub- and supertaxa can be restricted such that they give the same results as before the merger. It is only necessary to restrict the operations to consider only the distinction available originally in the taxonomy and to select—among the taxa that become equal by this restriction—the ones that are most general.

6. Reduction in the Size of the Taxonomic Lattice

Certain distinctions are only meaningful when other distinctions have specific values. For example, only physical objects have weight—a distinction of objects lighter or heavier than water is only meaningful for physical objects, not for immaterial objects. Adding rules to express these dependencies reduces the size of the lattice by the following interpretation (formulated for the case of Boolean distinctions, but generalizable):

Rule: (aff, neg) -> {distinction}

If the affirmed and negated distinctions are not present in a taxon then only the values indifferent or undefined are possible; distinct values (*A*, *not A*) are mapped to undefined. This prunes the lattice from impossible taxa, e.g., a rule: *{physObj}* -> *{color}* excludes a taxon for *green ideas* because color is restricted as a distinction to physical objects. The rules express the intended semantics of distinctions and serve to communicate these intentions among the ontologist working on a taxonomy and warn the ontologist when attempting to enter taxa with inconsistent distinctions.

These rules do not apply when computing the *join* because if a distinction is justified in both taxa from which we calculate the *join*, then it is also justified in the intersection of the two. Neither do they apply when computing the *meet*, because if a distinction is present in one of the two then it is also justified in the union.

7. Prototype

Software to demonstrate this approach has been implemented in Haskell (Peyton Jones, Hughes et al. 1999) and a set of concepts were entered, separated taxonomies merged and the result interrogated. The operations manage sets of distinctions and use straight forward representations and operations on sets. The most complex operations compute set intersections for the small sets of distinctions! Taxa accumulate distinctions downwards; the number of distinctions is less than or equal to the depth of the taxonomic lattice. In general, a taxonomic lattice with *n* distinctions has at most $3^n + 1$ element.

The prototype produces supporting information for the ontologist about sub- and supertaxa to a given set of distinctions and warns if a taxon with the same set of distinctions as another already existing one is about to be entered. More advanced tools from Formal Concept Analysis may be applied in the future.

8. Conclusion

The formalization is strictly speaking about tokens that are interpreted as distinctions and taxa and for which we establish a small set of rules and relations that respect the interpretation. I assume that the simplicity of the proposed formalization comes from the explicit introduction of the distinctions between taxa instead of inferring these from other types of description of the taxonomy. It seems that describing taxa by giving their distinguishing qualities is not more difficult to alternative methods used in, say, Protégé.

The flexibility in adding new distinctions as a situation requires, the connection between distinction and bodily interactions with the environment and the simplicity of the deduction suggest further investigation whether a definition of fine-grained and adaptable concepts based on distinction corresponds to some aspects of human mental concepts. The formalization shown here gives hints to possible test cases.

8.1. Future work

The application of a fuzzy four-valued logic (Straccia 1997) to taxonomies should be studied to understand how it can contribute to represent prototype effects in taxonomies (Rosch 1973). The mapping between different subsets of a taxonomy may be useful to discuss metaphorical usage, e.g., *heavy thoughts*, *green ideas*, and *flying proposals* correspond to comparable taxa that are just different in one distinction (physical vs. immaterial object).

The work presented here is restricted to taxonomies (*is_a* relation). A promising connection is to mereology (*part_of* relation). It is known that certain qualities carry over from the whole to the parts: if a car is a physical object, then each part of it is a physical object. Other qualities do not carry from whole to part: if a cat is *alive* then the parts of the cat (tail, leg, etc.) are not *alive*—or perhaps alive in different, restricted sense. Further, one must inquire how to express distinctions that are expressed as equivalence classes, e.g., a definition of biological taxa as ‘interbreeding’.

Considering taxonomies of processes with related entities of different types, e.g., "Tom is cutting a loaf of bread with a knife", can be seen as connecting different taxa: person, bread, and knife. Generalization of processes by removing distinctions from the taxa involved can thus be described: Tom is cutting foodstuff with a tool > Tom is separating foodstuff > An agent is moving material. This gives a finer order relation to operations than currently available and shows how to relate taxonomies and processes in a dynamic ontology (Frank 2006).

Acknowledgements

I am grateful for comments from Werner Kuhn and Stella Frank, who have helped me to improve the presentation. I appreciated the suggestions and constructive critique by the reviewers that were useful for preparing the final text.

References

Asperti, A. and G. Longo (1991). Categories, Types and Structures - An Introduction to Category Theory for the Working Computer Scientist. Cambridge, Mass., The MIT Press.

Belnap, N. D. (1977). A Useful Four-Valued Logic. Modern uses of multiple-valued logic. G. Epstein and J. M. Dunn. Dordrecht, NL, Reidel: 5--37.

Brachman, R. J. and H. J. Levesque, Eds. (1985). Readings in Knowledge Representaion. Los Altos, California, Morgan Kaufmann.

Burmeister, P. (2003). Formal Concept Analysis with ConImp: Introduction to the Basic Features. Darmstadt, Germany, TU-Darmstadt: 50.

Carroll, J. B. (1956). Language, Thought and Reality - Selected Writing of Benjamin Lee Whorf. Cambridge, Mass., The MIT Press.

Eco, U. (1977). Zeichen - Einfuehrung in einen Begriff und seine Geschichte. Frankfurt a. Main, Edition Suhrkamp.

Fellbaum, C., Ed. (1998). WordNet: An Electronic Lexical Database. Language, Speech, and Communication. Cambridge, Mass., The MIT Press.

Fodor, J. A. (1984). "Precis of The Modularity of Mind." Behavioral and Brain Sciences 8: 1-5.

Frank, A. (2006). Distinctions - A Common Base for a Taxonomic Calculus for Objects and Actions. Vienna, Institute for Geoinformation and Cartography.

Gangemi, A., N. Guarino, et al. (2002). Sweetening Ontologies with DOLCE. EKAW 2002.

Gärdenfors, P. (2000). Conceptual Spaces, MIT Press.

Gibson, J. (1979). The Ecological Approach to Visual Perception. Hillsdale, NJ, Erlbaum.

Krötzsch, M., P. Hitzler, et al. (2005). Category Theory in Ontology Research: Concrete Gain from an Abstract Approach. Karlsruhe, Germany, Institut AIFB, Universität Karlsruhe: 6.

Lakoff, G. (1987). Women, Fire, and Dangerous Things: What Categories Reveal About the Mind. Chicago, IL, University of Chicago Press.

Masolo, C., S. Borgo, et al. (2003). WonderWeb Deliverable D18 (Ontology Library). Trento, Italy, Laboratory For Apüplied Ontology - ISTC-CNR: 247.

Miller, G. A. (1998). Nouns in WordNet. WordNet An Electronicd Lexical Database. C. Fellbaum. London, England, MIT Press: 23-46.

Peyton Jones, S., J. Hughes, et al. (1999). "Haskell 98: A Non-Strict, Purely Functional Language." from http://www.haskell.org/onlinereport/.

Pinker, S. (1999). Words and Rules, Basic Books.

Priss, U. (to appear). "Formal Concept Analysis in Information Science." Annual Review of Information Science and Technology 40: 22.

Rosch, E. (1973). On the Internal Structure of Perceptual and Semantic Categories. Cognitive Development and the Acquisition of Language. T. E. Moore. New York, Academic Press.

Searle, J. R., Ed. (1995). The Construction of Social Reality. New York, The Free Press.

Straccia, U. (1997). A Four-Valued Fuzzy Propositional Logic. 15th International Joint Conference on Artificial Intelligence, Nagoya, Japan, Proceedings of IJCAI-97.

Wille, R. (2000). Boolean Concept Logic. Conceptual Structures: Logical, Linguistic and Computational Issues. B. Ganter and G. Mineau. Berlin-Heidelberg-New York, Springer. LNAI 1867: 317-331.