CHAPTER TWO

# Socio-Economic Units: Their Life and Motion

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## 2.1 INTRODUCTION

Current Geographic Information Systems (GIS) are modelling static spatial situations. Using Sinton's terminology (Sinton, 1978), they hold time constant and then either vary theme or location—depending if they are vector (object) or raster (field) oriented (Frank, 1990; Goodchild, 1990). The world in which we are interested is in constant change; nothing is ever stable. This has been observed by the Greek philosophers and identified as one of the chief difficulties in understanding the world. We need to identify objects that we can see as (relatively) stable and against which we can compare others.

This is particularly important for socio-economic objects in geographic space, which are typically non-physical. By socio-economic objects we understand areal units that are used to describe social or economic phenomena. They encompass census tracts for statistical data collection, political subdivisions (borough, town, county, nation, etc.), urban and rural zones, areas delimited for demographic descriptions (ethnicity, religion, language, etc.). These socio-economic units are conceptual constructions (see Raper, this volume) and do not correspond directly to physical reality. Change and movement does, therefore, not have exactly the same meaning as with physical bodies.

Our conceptualisation of change is influenced by the perception of change of physical objects, mainly the moment of rigid physical objects. The experience with physical objects, primarily rigid bodies, but also with liquids, melting ice, etc. determines the cognitive categories we use to describe other objects and their movements, using metaphorical transformation (Lakoff and Johnson, 1980). It is thus recommended that the modes of change of the relevant physical objects are studied and formalised in order to transform the results to the socio-economic units and the special properties identified.

Socio-economic units often appear with an ontology similar to 'shadows' (Casati and Varzi, 1994). They are non-physical properties of an area, which can be moved without any movement of material. Shadows and holes are ontological categories that have only recently been systematically studied. The socio-economic units, as abstract objects, are perceived and understood in terms of such ontologies. Clarifying these will be an enormous first step.

## 2.2 CHANGE IN THE GIS

### 2.2.1 Importance of Change for GIS

There are very few applications where only the current situation is important. Most uses of GIS technology are interested in change. This is true for scientific and administrative uses of GIS.

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Sciences in general, and geography can serve here as an example, are interested in processes that transform things. Processes are the general rules, the descriptive data is the particular, and thus of lesser standing. Scientists collect data in order to understand general rules, which are mostly seen as processes. The collection of data, the descriptive part of scientific activities, is necessary to have the foundation on which deductive work is building up. The need for support for time-related data was voiced by anthropologists, architects, atmosphere scientists, marine biologists, planners, urbanists, wild life specialists, etc. The topic has become of even more interest lately with the global change efforts (Mounsey and Tomlinson, 1988), where the object of the study is change itself, as it occurs on a global scale.

Administrative uses of GIS sometimes work properly with the current status only: tax mapping, facilities management for public utilities, forest management can do. But wherever legal aspects of liability, due process or the use of proper administrative procedures are involved, previous states are stored to assure that changes can be reconstructed.

### 2.2.2 Representation of Change

Support for temporal data in GIS software, so-called temporal GIS, has been asked for a long time (Smith, Boyle *et al.*, 1983; Allen, Green *et al.*, 1990). The lack of support for time related data in GIS may be one of the reasons why GIS is often seen only as a tool to help with the descriptive part of scientific work (Goodchild, 1990). A tool for geographers, helping with the descriptive part of science, but not helping with the heart of science, where processes are in the focus.

It is indeed surprising to see how poorly a current commercial GIS deals with data representing objects that change in time. The best we can currently do is to show a snapshot of the data and even this may represent data collected over a period of time (see Cheylan, this volume). Data quality standards demand that this is properly documented—but again, most data collections are lacking in this respect. Neither the software nor the data help with understanding changes.

To simulate change, snapshots of the situation at a specific time are accumulated. What would be required is a representation of change and the events that limit gradual change with the time they occur. To deduce the same information from the differences between snapshots is difficult and limited by the temporal resolution of the snapshots. This is a similar phenomenon as the one discussed in (Burrough and Frank, 1995), where the difference between the capabilities of current GIS software and the requirements was compared. The social sciences need tools to represent and analyse change.

### 2.2.3 Life and Motion as Two Types of Changes

Change comes in two forms: change of the objects of interest and change in the position or geometric form of these objects. For the first we use the heading *life* of objects: objects may appear and disappear (for example, a forest or a residential zone), two objects may merge (for example, two parcels or two towns), an object may split. For the second we use the heading *motion*: objects may move or may appear to move, with or without changing their form at the same time.

The life and motion of physical bodies, especially of human beings in space, are the prototypical notions dominating our experience. The motion of physical bodies in the natural sciences is sometimes complex, but the direct experience with the phenomena and the possibility to analyse the physical movements of particles constituting the bodies gives an approach to their understanding.

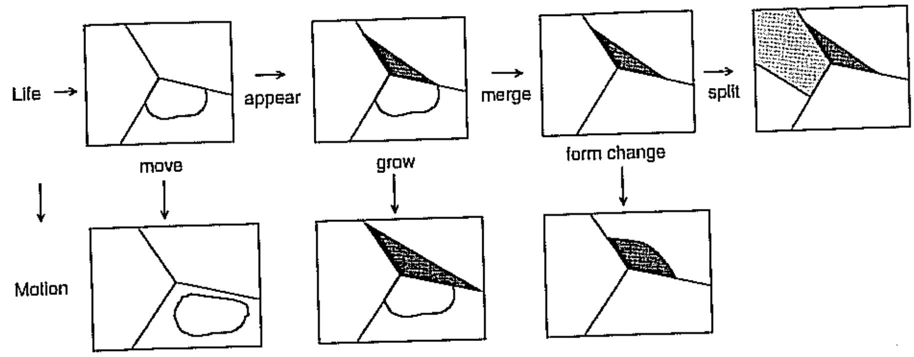


**Figure 2.1** Objects' life and motion

More unusual are the *life and motion* of spatial units in economic and social sciences or administration. Administrative units are moving in space (e.g., Poland is here the best known example, Centennia, 1993) or are merging or splitting—causing enormous difficulties for the analysis of statistical data collected for these (changing) units (Openshaw, this volume). The central business districts are changing in size, form and location over time—even without having clear-cut boundaries (Burrough and Frank, 1996).

### 2.2.4 Approach

The past discussion of time in GIS can be classified in several groups:

a. snapshots and differences between states (Langran and Chrisman, 1988);
b. discussion of work time, data flow and database time (Langran, 1988);
c. formalists' discussion of space/time as a multi-dimensional continuum (Worboys, 1994).

These approaches were comprehensive (or generalising), but did not allow going beyond the obvious because too many dissimilar phenomena were treated at once. What is advocated here is an approach where different aspects of changes are analysed and formally described, starting from the dominant human experience with motion of rigid bodies (but also liquids) and following the cognitive metaphorical transformation of these cognitive categories to describe abstract objects like socio-economic units. It is asked for which real-world situation they are applicable and which application areas use models for *life* or *motion* of objects of this type.

One can differentiate different types of *life and motion* of objects:

a. motion of physical bodies in small scale space, or in geographic space, along a predetermined path or in a field;
b. motion of large physical bodies in geographic space, where the objects follow the rules of rigid body motion or the rules of liquids;
c. motion of collectives in geographic space, where the motion of the collective is the sum total of the motion of the individuals (Cheylan and Lardon, 1993);
d. motion of non-physical objects, e.g., administrative units, which glide shadow-like over the landscape.

It is assumed here that each of these kinds of motion follows its own set of rules—its own ontology (Frank, 1997). Understanding what is similar and dissimilar for these types of changes will be useful, in particular to model the more abstract changes in socio-economic objects. It becomes clear from this analysis that the kinds of *lives* and *motion* objects may have are bound in a set of logical schemata, best described as algebras (or categories in the sense of mathematical category theory, see (Frank, 1996).

Different applications not only differ regarding the models for change they use, but also regarding the scale of time or space they employ. Geological time and space scales are very different from the temporal and spatial scale to describe urban changes. The classification attempted here is then to be combined with these differences in scale.

## 2.3 STATE OF THE ART

The difficulties to include model data with respect to change in time are multiple, some generic and some specific for spatial databases.

### 2.3.1 Temporal Databases

Database theory for temporal data exists, for a review see (Snodgrass, 1992), but none of the current commercial DBMS include extensive support for time varying data. Lotus Notes and other systems support replicated databases with time stamps for any change (Dennig, 1994). This can be used to model the flow of information within the organisation (database time) and thus contributes to supported collaborative work; it does not apply to data describing an exterior, changing world (real-world time).

Temporal database theory covers mostly a static or snapshot view of time, and changes cannot be analysed at the level of user semantics. It can be used to reconstruct a database after data loss, but reasoning about motion and change is limited.

### 2.3.2 Temporal GIS

Geometric models are static. In particular, Euclidean geometry models static situations. Newtonian physics provides a sort of *dynamic geometry*, but it is appropriate only for the table-top object space (Montello, 1993). GIS need support for temporal change in environmental and geographic space. For raster data, the operations of map algebra can be used to compare images from two different points in time (epochs), and to identify cells which have changed. This is not an appropriate model to describe the movement of an object in space in general, but can be used in certain application areas. Chrisman and Langran have investigated land use changes (Langran, 1988; Langran and Chrisman, 1988; Langran, 1989), following a snapshot approach related to the database viewpoint.

A number of workshops discussed support for temporal data in GIS (published reports are available for (Barrera, Frank *et al.*, 1991; Egenhofer and Golledge, 1998)). Generally, these meetings reaffirmed the importance of support for temporal data in a GIS—known at least since (Abler, 1987; NCGIA. 1989). The discussion invariably also shows a wide variety of application areas and possible solutions. Frank has concluded—in analogy to the discussion of the spatial domain—that there are many different types of time, which must be handled differently in a GIS (Frank, 1994). Different situations lead to different experiences of time—walking over a hill is a different experience than observing a city sprawl—which lead to different formalizations.

### 2.3.3 Change in Philosophy and Cognitive Science

Philosophy looks back over two thousand years of discussion of the notion 'time'. The duality between duration and event, which has occupied the best minds since Zenon

(Fraser, 1981) has been very fruitful (Hofstadter, 1979). It attempted to find a uniform and all encompassing explanation of time—to correspond to the human belief that there is a single notion of time as there is assumed to be a single type of space. Time is crucial to science because time is intricately linked with causation. *Post hoc, ergo propter hoc* is not a permissible deduction rule, but temporal precedence implies so often causality that the inverse conclusion has become a common mistake. For scientific analysis, but also for many administrative applications, an ordered time is sufficient because causation implies precedence, lack of precedence rules out causation.

Experientialism (Lakoff, 1987, 1988) takes human direct experience and perception as fundamental. Other domains of human endeavour that cannot be directly experienced are conceptually organised in analogy to the domains that can be directly experienced (Lakoff and Johnson, 1980). There are at least two different base experiences of time and motion: the observation of motion of objects in figural space (Montello, 1993), for example, moving an apple from the left side to the centre of the table, and bodily experience of walking in open space, e.g., over a hill.

The perception of time is dependent on the situation. Resolution of time is according to the task: only differences that can be of importance are observed and recorded. Human perception limits the resolution of two events to few tenths of a second, but in most situations, much larger concepts of instantaneous are used: start points for meetings are understood as five minutes later or earlier; in business, most duration is measured in days. This is similar to space, where resolution depends on the task at hand.

## 2.4 RESEARCH PROGRAM: DEFINE DIFFERENT TYPES OF CHANGES RELEVANT TO GIS

### 2.4.1 Abstract From Scale of Resolution

We start with the assumption that for each description of a process that links causes and effects a specific resolution for space and time is appropriate: a scale on which necessary differentiation can be made and irrelevant details disappear. These scales vary over several orders of magnitude (Morrison, 1982) from the time/space scales for galactic or planetary movement, to those used to describe the daily migration of humans in a city. Fraser assumes that reality is divided in several clusters of interaction, which all have similar time/space scales (Fraser, 1981). Such clusters form the subject matter of scientific disciplines.

Certainly there are a number of combinations of time and space scales relevant to geography (Frank, 1994). The effort here should abstract from these, as they are trivial to characterise; it is sufficient to indicate the resolution in time and space for a process.

### 2.4.2 Abstract From the Particular Type of Space and Time

From a perceptual perspective, there are different types of time as there are different types of space. Perception of space is different for small-scale space (table-top) and geographic space (Montello, 1993). This is the same for time, where time in administrative processes is discrete and structured as containers, whereas time for other social and natural processes has a continuous aspect and can even be cyclic (Frank, 1994).

For the effort here, we do not focus on these differences as they have been dealt with previously. We assume:

a. geographic space, defined as too large to be perceived at once from a single vantage point;
b. a discrete, linear time.

For both, time and space, we assume a resolution fine enough for the process of interest.

### 2.4.3 Separate Change in Life and Motion Aspects

A possible hypothesis to structure change in geographic objects is that the aspects of *life* and *motion* can be separated.

By *life* we understand all aspects of the existence of an object in time. It is *created*, and lives on till it is *destroyed*. It may be *killed* and later *reincarnated*. Objects may *fuse*, *aggregate*, etc. Also the non-spatial properties of the object may change in time (Al-Taha and Barrera, 1994).

*Motion* covers all aspects of the movement of the object or change in the form, i.e., all geometric changes. A change in the form can be seen as a movement of the boundary of the object.

### 2.4.4 Start With Prototypical Situations

The prototypical situation for motion is the movement of human or animal bodies in space, but also the motion of liquids in small-scale space. The best formalization is for movement of rigid bodies, as taught in every high school physics class. For life, the prototypical situation is the life cycle of a person (or animal), but also the life cycle of a rigid body or of liquids.

We assume that the abstract objects of geographical space—in particular the socio-economic spatial units—are perceived and represented in terms very similar to these prototypical situations. Metaphorical transformation allows for the change from small-scale experience to large-scale space and from the physical experience to the general abstract (Lakoff and Johnson, 1980; Lakoff, 1987).

## 2.5 PROTOTYPICAL SITUATIONS

### 2.5.1 Life Styles

The notion of *life* is closely related to persons. A person is identical with himself from birth to death. This requires a notion of identity for an entity, where two things can be tested if they are identical, even if they differ in some descriptive values: a person at age 10 and at age 30 is the same legal person, despite the apparent change and the likely complete change of all the substance (molecules) it consists of. It is proposed to use the operations *create* and *destroy* to start and end an entity with identity (Al-Taha and Barrera, 1994).

Further, one may allow that entities get *killed* and *reincarnated* (Al-Taha and Barrera, 1994)—customary for gods and heroes of the ancient sagas.

Objects can *evolve*, where one object disappears and a new one appears at a specified time.

An object may be *identified* as being the same as another one or two objects may *aggregate* where the identity of the second object is preserved within the first one. Two objects can be *fused* to form a new one.



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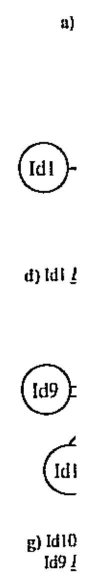


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An object may *spawn* a new one or two previously aggregated objects may become *disaggregated* again. *Fission* breaks an object into parts, which form new objects.

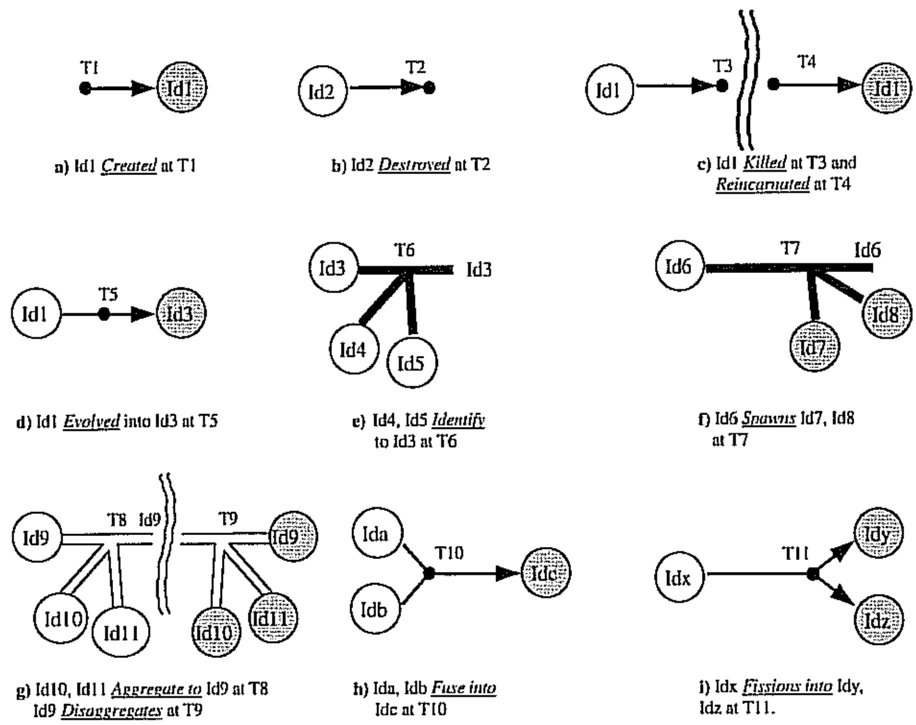


**Figure 2.2** Temporal constructs of identities (from Al-Taha and Barrera, 1994)

Not all these changes can occur to all objects, they form logical clusters and depend on each other. Formal methods can be used to analyse these dependencies and to document them. By lifestyle we understand coherent sets of life operations: cars and similarly manufactured objects are created, parts are aggregated and disaggregated from them and they are destroyed. It is very unusual for cars to be killed and reincarnated, to evolve or spawn new objects. Thus the operations *create, aggregate, disaggregate* and *destroy* form the lifestyle 'manufactured goods'. For lifestyles also see (Medak, this volume).

### 2.5.2 Movement of (Rigid) Bodies in Space

*Movement of Small Objects in Small-Scale Space*

The prototypical case is the observation of a physical body in space. This is one of, if not the primary experience of change as motion. A physical object is found at position a1 at time t1 and position a2 at t2, and at any time ti at a position ai between a1 and a2. It is implied that the size of the object is relatively small compared to the movement and the temporal resolution of the movement. Galton has formalised an ontology of movement of physical objects, which reconciles the event and the duration position (Galton, 1995; Frank, 1997).

It appears that movement of small objects is typically perceived as instantaneous change of position; the path of the change is usually not described nor noticed, probably because it is not consciously planned, but an appropriate path for the movement is left to the non-conscious motor planning.

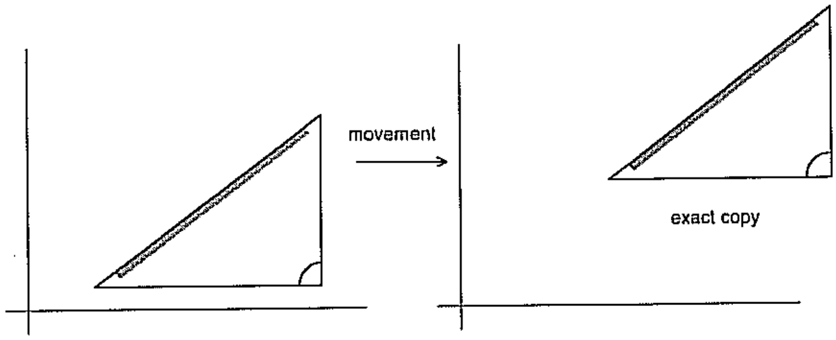


**Figure 2.3** Movement of a small object

*Movement of a Person*

Generally, movement in large-scale space (or space larger than small-scale) of a self-moving body, too large to be moved.

The movement of a person along a path is a fundamental experience. It is experienced by every human as movement along a path with duration.

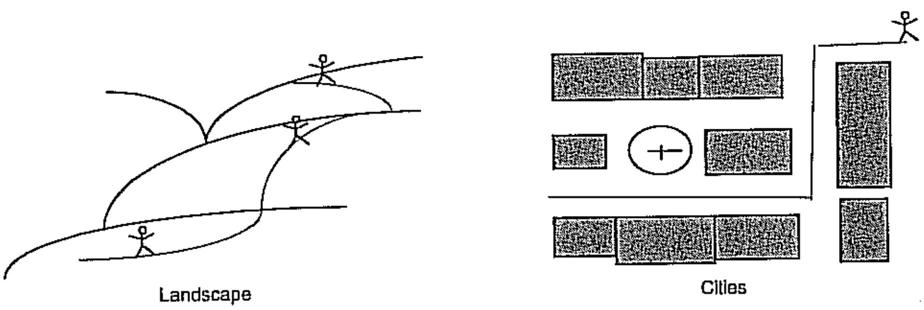


**Figure 2.4** Movement of a person

The movement can be across a field in the landscape, visible from a distance. The standard situation is on a surface in a gravity field, which influences the effort necessary for movement along the path; gives a component of resistance/acceleration along the path and one orthogonal to it. Related is the movement of a liquid in space: it follows the vector field. The movement of water in the landscape is of utmost importance to human economy.

*Change of Geometric Form: Movement of a Boundary*

The change can result in a change in the boundary, which is often seen as a movement of the boundary. One says the forest advances, meaning that the forest boundary changes (the only forest actually moving is the Birnam Wood in Macbeth). It appears as if the boundary was moving—but mind: boundaries are not physical objects, they are limits between physical objects and as such have a complex ontology (Casati and Varzi, 1994).

Change in the geometric form can have multiple origins. It can occur through accretion of the small pieces the object consists of or the loss of components, which leads to erosion. To this the lifestyle of kill/reincarnation fits: a lake (for example, the shallow Neusiedlersee in Austria) can disappear through draught and reappear.

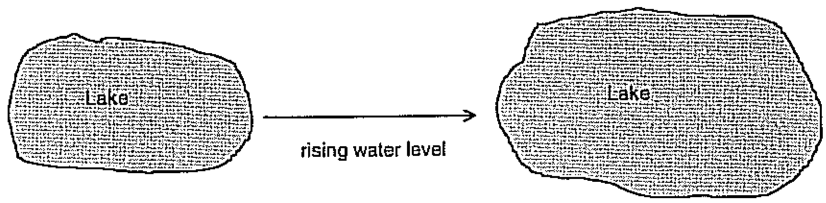


**Figure 2.5** Change of geometric form

### 2.5.3 Changes Which are Understood as Movements

Many changes are understood as movement—e.g., the movement of a forest—even if in reality the forest as an object does not move, and even if no physical objects move at all.

*Collective Bodies*

By collective bodies we understand objects which are composed of individuals that are separated at the next level of resolution (Talmy, 1983; Cheylan and Lardon, 1993). Compare with collective nouns in language (Langacker, 1991; Langacker, 1991).

The movement of individuals in a collective body can be ordered, i.e., the same individuals remain in the advancing boundary (military formation), or those most back advance to the front (flocks of sheep).

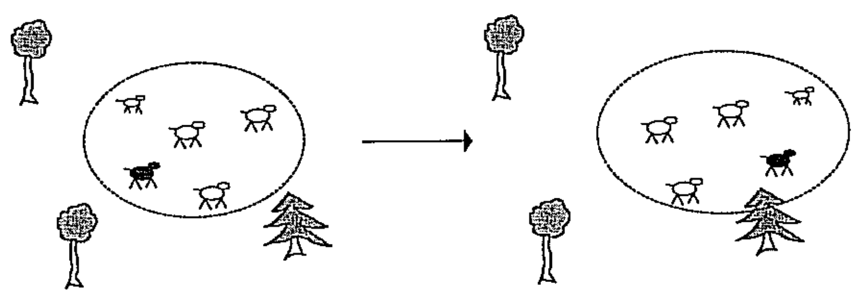

**Figure 2.6** Movement of a flock of sheep

*Liquid-Like Things*

The movement of liquid-like things is similar to an ordered collective movement, but the form of the entity always follows the limits of other objects. In geography, cities seem to flow around 'forbidden areas' (like lakes, forest, if legally protected, etc.).

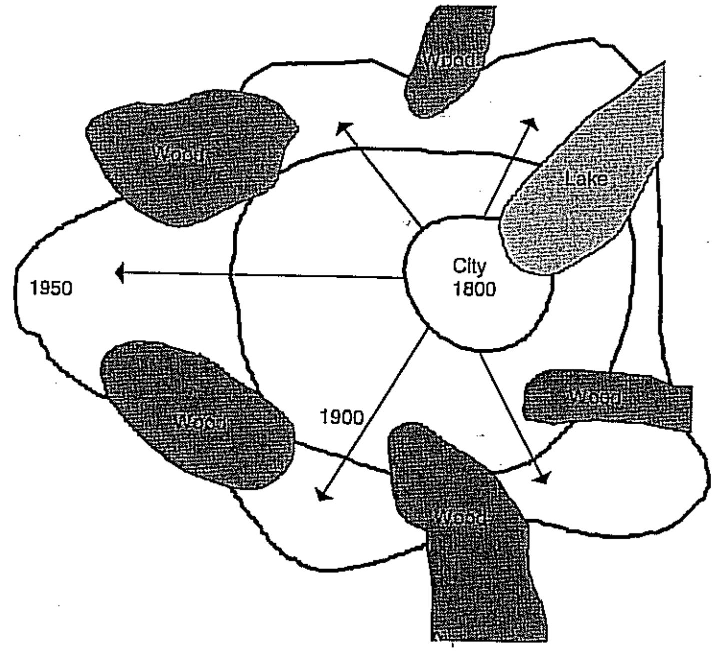


**Figure 2.7** Growing of a city (e.g., Zurich)

The movement may include evaporation (e.g., glacier—where movement is mass movement plus the movement of mass through the boundary (df/dt + integral v x P/dl) or accretion from diffuse distributed material, which is collected at a location and thus increases the object.

### *Apparent Movement Resulting from Individual Changes of Properties*

If individual areas of space change their property individually, then a movement of the area with the same property may appear. A tree in a forest does not move, but trees on one boundary of the forest may be cut consistently and be preserved on the other boundary. Thus the forest recedes on one side and advances on the other, without any physical movement. If the change of an individual cell is strongly correlated to the properties of the neighbours, individual change may appear as a movement. All habitats seem to belong to this group.

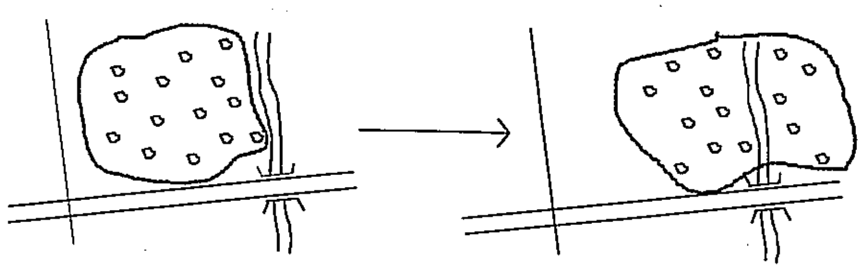

**Figure 2.8** Movement of a forest



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*Movement of Shadows*

By shadows we understand areas of uniform, non-essential properties of the objects which make up space (Casati and Varzi, 1994). Shadows are cast on the object and can move without affecting the object. This is ontologically similar to legal assignments of areas to urban zones, to protected areas, etc. Ownership rights are similar cases or the assignment of a country to an area; in this sense, Poland (or any other nation) is a shadow and as such can move (this is to be differentiated from the area populated by people speaking the polish language, who move as collective bodies).

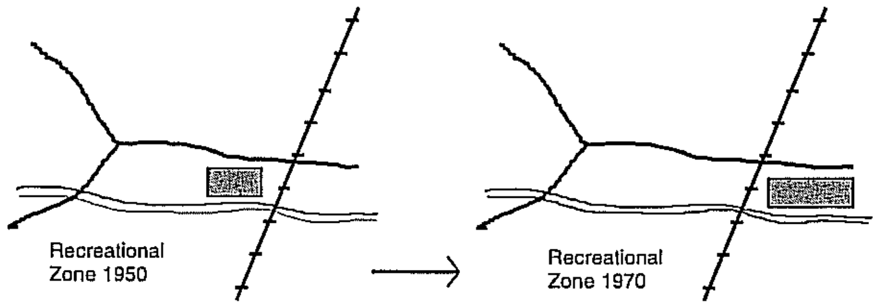


**Figure 2.9** Movement of recreational zone

## 2.6 REPRESENTATION OF CHANGE IN GIS

In a current GIS we cannot describe the changes directly but indirectly: change is the difference between two snapshots, representing states. A direct representation of movement of physical bodies is a vector of their speed (defined as difference in position divided by difference in time). With a starting point one can compute the points this object will be at in future. Other forms of change are very different to describe and no such simple and general method is known (for example, differential equations).

In a GIS we must be able to represent directly the different kinds of change. Each of the lifestyles and kinds of motion leads to its own representation schema. Therefore the classification effort described above is crucial to identify appropriate representations. One may follow the example set by natural sciences: differential equations are a powerful method for a wide variety of kinds of changes in attribute values, which can be described as fields $a = f(x)$ (Goodchild, 1992), and thus are applicable for natural science objects in a GIS. Kuipers (1994) shows how to translate differential equations to the qualitative domain and how to use them in cases where no exact measurements but only qualitative (i.e., more, less, etc.) descriptions are available. These methods could be extended to spatial objects.

Representations are not only necessary for the internal storage in a GIS, but are required over a whole spectrum of methods of communication. Graphical and natural language methods are necessary to communicate effectively with humans, whereas the formal and internal storage methods support the design and implementation of GIS software.

The traditional methods for communication of change used by humans must be studied to understand the cognitive categories humans use to discuss change. Especially natural language expressions for change can be analysed to understand the image schemata (Lakoff, 1987). The cartographic tradition contains a series of examples to represent change on maps.

## 2.7 TOPICS TO WORK ON

From this 'program' a series of specific topics to work on can be identified. These topics appear relevant for today's GIS industry and ready to work on, and small enough that there is a good chance of success within one year's effort.

The research topics can be seen as a set of theoretical questions:

a. formalising the prototypical cases listed (Section 2.4);
b. description of the prototypical cases for natural language expression or graphical expression of change, life or motion;
c. formal representation methods and effective storage methods, including particular data structures;
d. connection between change, life and motion and general description of data quality.

In each case, a specific subset of the total questions should be tried first and justified by a particular real case. For example, the description of sheep movements on a mountain (Alps) could serve as an interesting test case, many different methods could be applied to. The paper by Cheylan and Lardon (1993) could serve as the base description of the case.

In general, work in the area of change of socio-economic units should be motivated by specific and realistic cases. It is far too easy to construct complex cases which cannot be solved in general, but each specific case of which the complex one is an amalgamate could be solved.

## REFERENCES


Abler, R., 1987, The National Science Foundation—National Center for Geographic Information and Analysis. *International Journal of Geographical Information Systems*, **1**, pp. 303–326.

Allen, K.M.S., Green, S.W. and Zubrow, E.B.W., 1990, *Interpreting Space: GIS and Archaeology*, (London: Taylor & Francis).

Al-Taha, K. and Barrera, R., 1994, Identities through time. In *Proceedings of International Workshop on Requirements for Integrated Geographic Information Systems, New Orleans, Louisiana.*

Barrera, R., Frank, A.U. and Al-Taha, K., 1991, Temporal relations in Geographic Information Systems: A Workshop at the University of Maine. *SIGMOD Record*, **20**, pp. 85–91.

Burrough, P.A. and Frank, A.U., 1995, Concepts and paradigms in spatial information: Are current geographic information systems truly generic? *International Journal of Geographical Information Systems*, **9**, pp. 101–116.

Burrough, P.A. and Frank, A.U., Eds, 1996, *Geographic Objects with Indeterminate Boundaries*, GISDATA Series Vol. 2, (London: Taylor & Francis).

Casati, R. and Varzi, A.C., 1994, *Holes and Other Superficialities*, (Cambridge, MA: MIT Press).

Centennia, 1993, (Chicago: Clockwork Software Inc).

Cheylan, J.P. and Lardon, S., 1993, Towards a conceptual data model for the analysis of spatio-temporal processes: The example of the search for optimal grazing strategies. In *Spatial Information Theory—A Theoretical Basis for GIS, European Conference COSIT '93*, Lecture Notes in Computer Science 716, edited by Frank, A.U. and Campari, I. (Berlin: Springer-Verlag), pp. 158–176.

Dennig, J., Ed., 1994, *Lotus Notes—Das Kompendium*, (Markt & Technik).

Egenhofer, M.J. and Golledge, R.G., Eds, 1998, *Spatial and Temporal Reasoning in Geographic Information Systems*, Spatial Information Systems Series, (New York: Oxford University Press).

Frank, A.U., 1990, Spatial concepts, geometric data models and data structures. In *Proceedings of the Conference on GIS Design Models and Functionality*, Leicester, UK, (Midlands Regional Research Laboratory, University of Leicester).

Frank, A.U., 1994, Qualitative temporal reasoning in GIS-ordered time scales. In *Proceedings of the Sixth International Symposium on Spatial Data Handling, SDH '94*, Edinburgh, UK, (IGU Commission on GIS), 1, pp. 410–430.

Frank, A.U., 1996, An object-oriented, formal approach to the design of cadastral systems. In *Proceedings of the 7th International Symposium on Spatial Data Handling, SDH '96*, Delft, The Netherlands, (IGU Commission on GIS).

Frank, A.U., 1997, Spatial ontology: A geographical information point of view. In *Spatial and Temporal Reasoning*, edited by Stock, O. (Dordrecht: Kluwer Academic Publishers), pp. 135–153.

Fraser, J.T., Ed., 1981, *The Voices of Time*, (Amherst: The University of Massachusetts Press).

Galton, A., 1995, Towards a qualitative theory of movement. In *Spatial Information Theory—A Theoretical Basis for GIS, International Conference COSIT '95*, Lecture Notes in Computer Science 988, edited by Frank, A.U. and Kuhn, W. (Berlin, Springer-Verlag), pp. 377–396.

Goodchild, M.F., 1990, A geographical perspective on spatial data models. In *Proceedings of the Conference on GIS Design Models and Functionality*, Leicester, UK, (Midlands Regional Research Laboratory, University of Leicester).

Goodchild, M.F., 1990, Spatial information science. In *Proceedings of the 4th International Symposium on Spatial Data Handling, SDH '90*, Zurich, Switzerland, (IGU, Commission on GIS).

Goodchild, M.F., 1992, Geographical information science. *International Journal of Geographical Information Systems*, **6**, pp. 31–45.

Hofstadter, D.R., 1979, *Gödel, Escher, Bach: An Eternal Golden Braid*, (New York: Vintage Books).

Kuipers, B., 1994, *Qualitative Reasoning: Modeling and Simulation with Incomplete Knowledge*, (Cambridge, MA: MIT Press).

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

Lakoff, G., 1988, Cognitive Semantics. In *Meaning and Mental Representations*, edited by Eco, U., Santambrogio, M. and Violi, P. (Bloomington: Indiana University Press), pp. 119–154.

Lakoff, G., and Johnson, M., 1980, *Metaphors We Live By*, (Chicago: University of Chicago Press).

Langacker, R.W., 1991, *Foundations of Cognitive Grammar—Descriptive Applications*, (Stanford, CA: Stanford University Press).

Langacker, R.W., 1991, *Foundations of Cognitive Grammar—Theoretical Prerequisites*, (Stanford, CA: Stanford University Press).

Langran, G., 1988, Temporal GIS design tradeoffs. In *Proceedings of GIS/LIS '88, Third Annual Int. Conference*, San Antonio, Texas, (ACSM, ASPRS, AAG, URISA).

Langran, G., 1989, Accessing spatiotemporal data in a temporal GIS. In *Proceedings of Auto-Carto 9*, (Baltimore, MD: ASPRS & ACSM).

Langran, G. and Chrisman, N., 1988, A framework for temporal geographic information, *Cartographica*, **25**, pp. 1–14.

Montello, D.R., 1993, Scale and multiple psychologies of space. In *Spatial Information Theory—A Theoretical Basis for GIS, European Conference COSIT '93*, Lecture Notes in Computer Science 716, edited by Frank, A.U. and Campari, I. (Berlin: Springer-Verlag), pp. 312–321.

Morrison, P., 1982, *Powers of Ten*, (San Francisco, CA: W.H. Freeman).

Mounsey, H. and Tomlinson, R.F., Eds, 1988, Building databases for global science. In *Proceedings of the IGU Global Database Planning Project*, Tylney Hall, Hampshire, UK, (London: Taylor & Francis).

NCGIA, 1989, The research plan of the National Center for Geographic Information and Analysis. *International Journal of Geographical Information Systems*, 3, pp. 117–136.

Sinton, D., 1978, The inherent structure of information as a constraint to analysis: mapped thematic data as a case study. In *Harvard Papers on GIS*, Vol. 7, edited by Dutton, G. (Reading, MA: Addison-Wesley).

Smith, L.K., Boyle, A.R., Dangermond, J., *et al.*, 1983, Final Report of a Conference on the Review and Synthesis of Problems and Directions for Large Scale Geographic Information System Development, NASA Report, available from ESRI, Redlands, CA.

Snodgrass, R.T., 1992, Temporal databases. In *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, Lecture Notes in Computer Science 639, edited by Frank, A.U., Campari, I. and Formentini, U. (Berlin: Springer-Verlag), pp. 22–64.

Talmy, L., 1983, How language structures space. In *Spatial Orientation: Theory, Research, and Application*, edited by Pick, H. and Acredolo, L. (New York: Plenum Press).

Worboys, M., 1994, Unifying the spatial and temporal components of Geographical Information. In *Proceedings of* the *Sixth International Symposium on Spatial Data Handling, SDH '94*, Edinburgh, UK, (IGU Commission on GIS).

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