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Building Objects in Time

The world is composed of “things” that we conceptualize as objects “with the purpose of building knowledge from it” [DEB 04]. Information is increasingly more abundant. It is also available at more diverse granularity levels due to technological progress in the field of acquisition and storage. In such a context, the possibilities of observation are multiplying for the researcher. From this multiplication of possibilities arises the need to *choose*, and especially that of clarifying the choices made: reflection first on the objects that we consider as relevant relative to the problems posed (conceptual dimension); choice then of the observable entities that will allow us to study these objects of interest (empirical dimension); choice finally of what we will observe about the characteristics and behaviors of these objects (heuristic dimension). Therefore, the purpose is to build objects from observable “things” in the empirical world, and to give them a meaning relative to the problematics at stake. This path is not always as immediate as we would like. Two concrete examples can illustrate it effectively :

EXAMPLE 1.1.– Let us suppose that the decision to build a commercial establishment X in a city A depends on the growth of the population in this city during the last decade. The decision maker requests three consultancy firms to estimate the evolution of the population of city A. The first concludes with a decline, the second with a stagnation and the third with a growth. The decision maker is then perplexed, wondering about the respective competencies of the three consultancies, and in total uncertainty as his/her decision. A more thorough examination of the work carried out showed that each of the three consultancies had adopted a different definition of what a city *is*: – the first consultancy firm based its measure on a political–administrative criterion and used the evolution of the population of *municipality* A; – the second used population data corresponding to the *urban unit* A as the French National Institute for Statistics and Economic Studies (INSEE) defines it, that is an entity made up of a central commune and neighboring communes, according to a

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morphological[1] criterion; – finally, the third used the population statistics of the "*urban area*", an entity constructed by the INSEE according to a functional criterion. According to this criterion, a city incorporates the totality of the communes of which part of the active population works in the urban unit. The conceptual object on which the decision maker poses its questioning is, therefore, *the* city A of which he/she wishes to know the population evolution. In the empirical domain, each of the three "observables" (all three supplied by INSEE, but each corresponding to a different delimitation of city A) referred to in this example is *a priori* relevant to answer the question. The ambiguity comes from the fact that the city concept has not been sufficiently specified. Depending on the nature of the establishment X and the targeted customers (the inhabitants of the central commune of A or the active population working in the urban area of A), one of these "observables" will be more appropriate than the others.

EXAMPLE 1.2.– in the fields of geosciences and environment, this type of question arises with the same sharpness. In a similar way to the previous example, let us raise the question about monitoring the evolution of glaciers. Indeed, it is essential in order to evaluate the associated risks. The dynamics of glaciers is an indicator of climate fluctuations. It is associated with a number of events that are sources of risk for the surrounding human activities: avalanches, flash floods, inundations and mudslides. In addition to these disasters, a number of consequences also affect economical activities such as that of mountain tourism. Even if the expert agrees on the conceptual definition of a glacier, irrespective of his disciplinary training, glaciologist, geomorphologist or geophysicist, the specialist does not use the same approach to analyze its dynamics and displacement. The points of view will differ both in the choice of information sources and in the methodology for dynamics monitoring: some will favor the monitoring of field measurements as that of glaciological beacons; others will use high-definition satellite images to delineate the glacier at different dates and observe the evolution of the surface; get others choose not to start from the delimitation of the glacier, but to build an indicator whose monitoring in time provides information about the movement of the glacier, for example, the glacier equilibrium line altitude (ELA)[2] [COS 11]. All these approaches allow apprehending the same question (the dynamics of the glacier), but the quantitative results will be different, since they correspond to different measures, each appropriate to a particular scale, the fine-scale of the glacier for the glaciologist, and more often the regional scale for the geophysicist.

The first example illustrates how an insufficient specification of the city entity leads to the observation of different empirical objects (the commune, the "urban

1 In this framework, the morphology of a city is defined from the built up area. A morphological criterion is then based on the continuity of the built up area.

2 "The glacier ELA refers to the altitude of the theoretical line between the zone of glacial accumulation and the zone of glacial ablation" [COS 11].

unit" and the "urban area" depending on the case), which lead to conflicting results. The second example illustrates the possibility of a variety of points of view on the same phenomenon. In both cases, the challenge consists of choosing the scales and observable empirical objects that are the most relevant relative to the questions asked. The keywords of this chapter are thus *objects* on the one hand, and *construction*, *representation* and *change* (of/in these objects) on the other hand. The sense that will be given to these concepts throughout the book, with the objective of modeling phenomena embedded in space and happening in time, has to be defined. Several points of view are to be taken into account, each with its own specificities. That of the domain expert[3] (geographer and archaeologist in the context of this book) differs from that of the formal sciences (computer scientist, geomatician[4] as well as philosophers). The objective of the former is to represent, describe and understand a social or environmental phenomenon, for example, the strengthening of educational inequalities, the growth differentials between cities, the dynamics of a glacier, the changes in soil occupation, the evolution of the interaction scope of a city during the middle ages or the practices and rhythms of individuals' mobility in different spatial contexts (for example, a train station or a touristic place). The objective of the latter is to build generic representation or modeling media, independent of the types of questions and the studied objects. A geographer and a geomatician will, therefore, have different points of view on geographic objects: for example, in an analysis of the public space, a street may be defined as "a system of places close to each other, connected through practices" [FLE 07]. This design just overthrows the representation that is generally made in geographical information systems where the street is most often represented by a line connecting places.

In addition, faced with the same empirical question, the points of view of domain experts from different areas, for example, archaeologists and geographers, will also differ, notably on how to apprehend time and space. In parallel, at the heart of the formal sciences, including philosophy and information technology, the ways to specify objects and processes at stake differ.

This diversity of points of view, rather than being a source of misunderstandings, can be considered as an asset to the extent where the research for consistency that it requires, constitutes in itself a step forward in the reasoning of the domain expert. Furthermore, the precise conceptualization of the object of interest is necessary to obtain an interpretable formal description that can be implemented on a computer

3 We will call "domain expert" the specialist of a field in the social sciences, raising questions about a given thematic and having an expertise about the domain considered [LIV 10]. The examples raised in this text will mainly fall under the fields of geography and archeology.
4 We will call geomatician the specialist in the science of geographic information, who raises issues of formalization incorporating geographic reasoning. He/she is a specialist of computer developments structured for the acquisition and implementation of geographical databases, for information processing in dedicated systems and for the representation of this information.

system with the least possible ambiguity [PHA 14]. This chapter focuses on two large questions: (1) on the identification, construction and categorization of the objects associated with the posed question; (2) on how to apprehend change, either at the level of the objects themselves or at that of the attributes that characterize them, of the relationships among them, of the processes that underlie them. The categories of objects will be discussed from an ontological approach situated at the interfaces of philosophy, computer science and geomatics (section 1.1). We will then discuss the different ways of dealing with change of objects in time (section 1.2). The main objective is to show the interest of an approach that allows moving from a sociospatial, historical or environmental problematics to a conceptualization in terms of objects. Most considerations are anchored in the operational area of management and analysis of geographical information, but the objective is not to address the operationalization of these designs in formal representation languages.

1.1. Different points of view on ontology

The first step consists of a start from an ontological point of view to discuss "things" at stake during the description and modeling of a spatio-temporal question, whether it is a social or environmental one. Ontology, the study of "the being as being" according to Aristotle, must, therefore, allow specifying "things" that we wish to study, whether from the conceptual or the empirical point of view (whether database, statistics or simulation are considered). Before giving the definition that will be adopted in this book, we conduct a quick review of some definitions put forward in the fields of philosophy, information technology and information sciences, stressing the specificities that belong to each one of them. Different categorizations that can be made about the "things" that we are studying are then discussed, and an example of object construction concludes the first part of this chapter.

1.1.1. *Defining ontology*

Smith, a philosopher of Aristotelian inspiration, suggested the following definition of ontology: "the science of what is, of the types and objects structures, properties, events, processes and relationships in every reality domain .../... of what *could* exist" [SMI 03]. The use of this conditional, referring to "things" that have not necessarily been observed, is essential when we place ourselves in a modeling and simulation perspective involving artificial worlds. In computer science, Gruber defines ontology as a "specification of the conceptualization of a given domain" [GRU 93]. This definition is consistent with the previous one in the sense that this "specification" consists of clarifying the objects, properties and relationships mentioned in Smith's definition. While the latter refers to world "things" ("in every reality domain"), Gruber's definition falls under the framework of knowledge-based systems. What *is*, what *exists,* relates therefore to what can be *represented* [GRU 93].

In the field of information systems, Chen [CHE 76] relies on an ontology made up of three fundamental elements, entities, attributes and relationships in order to develop what he calls an "entity-relationship modeling". For him, the entities designate "things" that are identifiable, distinguishable from their environment and that correspond to "objects" in Smith's terminology. In order to illustrate the different terms of this ontology, let us consider the example of the school domain in which students and schools represent two types of "objects-entities". The attributes describe the characteristics of these "objects-entities" (for example, for junior high schools, the public/private status, the results from the French "brevet" national exam). These attributes correspond to Smith's "properties". The relationships concern on the one hand the links between the "objects-entities" and their attributes (schools are, for example, public or private, have such number of pupils, etc.), on the other hand between "objects-entities" of different nature (such student attends such school), or even between different attributes (the results of the French "brevet" are better in such type of school) and finally the links between "objects-entities" of the same nature (exchanges between same class students, proximity between schools or flow of pupils changing schools).

These different points of view formulated, respectively, by philosophers, computer scientists and information systems specialists, converge in their ambition to describe the world/a world using a generic conceptualization, but it is interesting to point out the nuances in their approaches. In this way, differences of opinion exist between philosophers and computer scientists about the ontologies. The fact that the objects do not necessarily constitute the favored input for philosophers when it is often the case in computer science is an example. Indeed, for philosophers, processes, for example, could replace them [LIV 09]. Smith [SMI 98] for his part, clarifies the difference in point of view between philosophers and "information scientists" by distinguishing a "reality-based" ontology that has an objective to describe the world in its "reality" and an ontology that he qualifies as epistemological and that is associated with a particular conceptualization of the world (among others). In addition, Peuquet [PEU 02] points out that Chen [CHE 76] presents his three fundamental concepts and their articulation at the center of his entity-relationship model without making reference to the philosophical literature on ontologies. This approach was then developed in a progressive and autonomous manner in the field of computer science to build a "theory of database model design". This perspective of the *model design,* representative of computer science, implies a *bottom-up* approach, while the philosopher falls instead under a *top-down* perspective by seeking to identify the most general categories possible to respond to the largest range of questions possible [LIV 14].

The field of geographic information science ("GIScience") is more recent and benefits from the maturation of these ontology issues, allowing us to take account at the same time of the aspects developed in philosophy and in computer science, by seeking to integrate the advantages of each point of view. From a computer science perspective (*bottom-up*), the objective of implementation involves constraints that may cause excessive simplification of the higher level abstractions that tend to be favored by the philosopher. The risk is then to reduce the interest and the scope of the elaborated ontology not taking into account, for example, its evolutionary character [PEU 02]. Conversely, if we systematically privilege the principle of generality, the risk is that the ontological framework is too general to allow the domain expert to operationalize it to answer his questions. Consequently, the challenge consists of finding a middle ground between these two risks.

Further in this book, we will adopt the definition proposed by Livet [LIV 10] that is situated at the intersection of these different approaches: the ontology consists of analyzing a domain, by identifying the *relevant entities* (objects, properties, relationships, events and processes), and *the operations* that can be carried out on these entities. We will explain what are these entities and operations with regard to a geographical problematics:

– The *entities* are of five types: (1) the *objects*[5], whether they are geographical objects such as rivers, roads, plots or spatial units such as municipalities and cities or even localized objects such as individuals, households and dwellings; (2) the *properties* that characterize these objects; they refer in the empirical practice to the "attributes", which may be of a quantitative nature (length, surface area or number of inhabitants) or qualitative nature (type of land use or political color of the municipality); (3) the *relationships* between these entities, which relate, in the sense described above [CHE 76], different attributes between themselves, the objects and their attributes or even different objects between them, for example, the proximity relationships (inclusion, adjacency and distance) and exchanges (migratory flows and information flow); (4) the *events* that characterize the appearances, disappearances and abrupt changes of these same entities; (5) the *processes* that refer to what cause these entities (objects, properties and relationships) to change over time.

5 There is no consensus in the literature on the difference between entity and object that are sometimes considered as synonyms. This is not the case in the definition adopted in this book where the entity refers either to objects (human beings, spatial units such as communes or towns), properties, relationships or processes. To avoid any confusion further in the text, we will use the term entity for this generic sense and we will use that of spatial unit to designate an administrative or spatial entity.

– The *operations* related to these entities allow modeling their structure, functioning and evolution. We can distinguish three main families of operations: (1) the measurements that allow specifying the properties of objects (for example, size and density measurement); (2) the functions that allow characterizing the relationships between objects, whether they concern proximity (in terms of similarity or genealogy) or interactions (for example, trade, hydrologic flows and access time); (3) the rules and functions that allow linking an event to a change or generating a series of successive changes. In a model on the growth of cities, for example, the evolution of a city population may consequently be formalized from a differential equation (logistics equation, for example, expressing an exponential kind of growth when the population is far from the carrying capacity of the city and slowing down as it approaches it) or from a rule that can be formulated in the following way: "if the potential of interaction with other cities is of a given intensity, then the growth rate of the population is so much".

This categorization has proved fruitful when frequent moves to and fro are made between the empirical question, the associated information system and the modeling. Faced with the same empirical question, multiple ontological choices are possible as a result. For example, let us suppose that we are concerned with the evolution of a settlement system in the long term and that we want in particular to model the change from villages to cities. The following two ontologies are possible:

– first case: we consider the existence of two types of objects, cities and villages, which are then apprehended as two different "things"; each one will be characterized by *properties*, and we will be able to define *relations* between these two types of objects, for example, relationships of functional dependency, as well as *operations*, for example in the form of a transformation rule from one type of object to the other;

– second case: a single object, the settlement unit, is considered, and the distinction city/village is then understood through the properties of this object: it can be a property captured directly by a simple attribute with two modalities or several properties related to quantitative attributes such as the number of inhabitants, the economic profile, the level of services or the range of exchanges. In the latter case, the purpose will be to define the operations, usually from recurring rules to thresholds, which will allow characterizing the city or village property of the settlement unit.

The researcher will choose one or the other from these ontologies on the basis of his assumptions on the differences between the objects *city* and *village* and on the possibilities of transformation from one to the other. If the assumption is that there is a semantic difference between city and village, with properties and relations associated with the village being qualitatively different from those associated with the city, the first case is to be considered. This is, for example, the point of view of

Garmy [GAR 12] in his work on settlement systems during the Roman era. The variety of their profiles and functioning modes thus leads him to characterize the settlement units of the Languedoc according to a precise functional typology that cannot be reduced to a simple city/village dichotomy. However, the second case is adequate for the hypothesis of a semantic continuity between these two types of objects, i.e. if it is assumed that the objects are of the same nature and characterizable by the same types of properties and relationships. Simple differences in the properties (for example, the hierarchical level measured by the size of the population or the level of the existing trade) are enough then to account for their differences. This is often the case when geographers or economists aim to model the emergence of cities and systems of cities from an initial situation in which only agricultural villages with few differences existed [AXT 06, BAT 01, SAN 97, SCH 13].

1.1.2. *Qualification of the objects from an ontological perspective: "bona fide" versus "fiat" objects*

Facing the question of falling under the scope of spatial analysis, the challenge is to ensure consistency between the entities of interest in "reality", those that are observable in the empirical world, and those that are appropriate to introduce in the information system that is implemented to respond to the questions raised. These entities can be *simple* (an individual, a road, a parking or a river) or *composite* (a household, a subdivision, a city or a hydrographic system). This distinction between a *simple* or a *composite* object depends on the thematic domain or may be discussed. The composite object is composed of simple objects, themselves having a meaning relative to the question asked (note that from the theoretical point of view, it would be always possible to decompose down to the atom; the position adopted here consists of adapting the level of decomposition to the objective and in discussing the choice made). The information allowing building these entities often originates from various sources.

Any object mobilized during a research is a *built* object in the sense that it is conceptualized to meet an objective. Some of these objects are close to the common sense, in the sense that they are concepts used in everyday life, corresponding in general to physical entities, for example, individuals, buildings, streets, rivers and lakes [PEU 98], whereas others correspond to more abstract concepts referring to more elaborated constructions. Households, cities and countries are some examples. We propose to start with the distinction proposed by the philosophers Smith and

Varzi [SMI 00], between *bona fide*[6] objects and *fiat*[7] objects, by adapting them to the objects encountered during spatial analysis works:

– *bona fide* objects correspond to "natural" objects of common sense [SMI 00]. They have a material and physical anchorage, and the authors evoke "genuine objects", i.e. "real", "authentic" objects. These objects exist and are distinguished from their environment regardless of what Galton named "human partitioning activity" [GAL 03]. They correspond, therefore, to a "reality" that can be described as objective [PEU 98];

– *fiat* objects are constructed objects, which exist according to an administrative, social or political convention [SMI 00], or in the imaginary, as a concept [HOR 00]. These objects are, therefore, derived from a human partitioning activity, and it is useful to distinguish two cases: – the objects corresponding to a political or administrative convention, for example, such is the case of countries and administrative regions; – the objects constructed by "expertise", with a scientific or operational objective. The dichotomy proposed by Terrier [TER 98] between "power zoning" and "knowledge zoning" illustrates this distinction from the point of view of domain expert well. The first term refers to a splitting of the space in zones corresponding to the exercise of a power (typically the municipalities and departments). The second corresponds to a splitting of the space made by institutions and researchers with the purpose of answering a question (for example, the mobilization of census tracts to study at what rate urban sprawl increased).

Of course, the distinction between *bona fide* and *fiat* categories is not always immediate and intermediate cases can appear. A forest, for example, can be viewed from both angles: it is distinguishable in the landscape, but its delimitation is not always unequivocal. As an island, the group formed by the space bringing together the two departments of Corsica is of the first type; as an administrative unit, each of these departments taken separately corresponds to the second. The benefit in explicitly discussing the ontological nature of the object that is being worked upon is in first place epistemological. This reflection helps to ensure that there is no ambiguity in the definition of the objects, to control any potential gap between the object as it was designed and the object as the empirical approach allows observing and analyzing it, and finally to give meaning to the results of any processing carried out. We think it is also clarifying to combine this categorization corresponding to the point of view of the philosophers, with the methodological categorization on the

6 The Latin phrase "bona fide" meaning "in good faith" is used to characterize what is authentic in English as well as in French texts.

7 "*Fiat Lux*" is a Latin phrase present at the beginning of the Genesis. It is the first word of God, order given when he creates light during the creation of the world, translatable into English by "*let there be light*". This formula that experiences a great success since the 18th Century is used nowadays to mention slightly pompously an invention or a discovery." (Wikipedia).

simple or composite character of the objects at stake. This combination defines four cases (Table 1.1) that establish a first classification of the objects that are manipulated during spatial analysis. The examples are presented for information purposes, and some positions in the table could be questioned, such as the case of the forest (mentioned above) or even of the river. As a matter of fact, the latter may be viewed as a simple object making up a whole, elementary entity of the landscape, or as a composite object, composed of a sequence of river stretches delimited by some relevant features of the landscape (for example, change of direction).

	Methodological point of view		
Ontological point of view		Simple	Composite
	"bona fide"	Individual being, housing, building, tree, river...	Family, copse, river, forest, flock...
	"fiat"	Municipality, country, farm, university...	Household, city, forest, built area...

Table 1.1. *Combination of two categorizations of objects with a few examples of each case*

1.1.3. *Specification of ontologies in the field of spatial analysis and geographical sciences: objects versus fields*

The ontological conceptualization will help to impose consistency between conceptual objects responding to the problematics posed and empirical objects, observable in the reality of the field. This step is essential in the path that leads from the facts to be described and understood to the data structuration to be mobilized to achieve this. The conceptualization and observation of empirical phenomena can be done in different ways. We will discuss in particular the dichotomy between the ontologies in terms of *objects* (discrete perspective) and in terms of *fields* (continuous perspective), opposition that also flows through other sciences, notably physics.

When focusing on spatial phenomena and performing spatial analysis, actually a first distinction is to be made between an ontology of the *discrete* and an ontology of the *continuous*. In the geographic information sciences, the first refers to an approach "object-based" and the second refers to an approach "field-based". In this domain, the dichotomy object/field (object based/field based) is a matter related to data and data models developed to store, manage and represent geographical information. Couclelis [COU 92] establishes a parallel between this dichotomy and the discussions conducted within physics on the opposition between the theory of elementary particles (making reference to the atomic and quantum properties of bodies) and a continuous field approach, also called plenum, supposing the continuity of space and time. This paradigm is useful to define a conceptual framework, and here we are recalling it to distinguish between two points of view on geographical space:

– the “discrete” or “object-oriented” point of view is more easily conceptualizable because it is well-anchored in common language [GAL 03]: individual beings, buildings and roads are objects of common sense, relatively easy to identify in the sense that they are “distinguishable” from their environment and associated with an identity. Once built, objects of the “fiat” type, such as cities or countries, share these properties and can be conceptualized by an object approach, of the atomistic type. The totality of these objects exists independently from their attributes, and they retain their identity when manipulated;

– the “continuous” or “field-oriented” point of view is often the work of geoscience or environmental science specialists. As a matter of fact, such approach is appropriate for geographic information that is presented in continuous form, for example, about land use or temperature. Space can then be conceptualized as a set of localizations to which attributes are attached (“a spatial field is a mapping of spatial locations to values”, [GAL 04]). The nature of the information associated with localizations can be of any kind, qualitative (land use) as well as quantitative (for example, temperature and hydrometry degree). The most important thing is that the *field* perspective refers to a coverage of the space.

The adoption of one of these two points of view rather than the other depends either on the *a priori* position of the researcher or on his choice in front of a specific objective in which he considers one of the approaches more appropriate than the other. Most of the spatial phenomena can effectively be conceptualized from either an “object” or a “field” perspective: thus, a vegetation cover can be apprehended as consisting of objects, such as prairies or woods at the landscape scale, or of trees and shrubs at a finer scale or as a continuous field covering a given space [PEU 88, PEU 98]. Another example is forest fire that can be formalized as an object moving in space, or as a continuous field of fire intensity. The two perspectives are associated with different conceptions of space. In one case, the object is autonomous, it has its own attributes and space is a support, a referential frame in which the objects are positioned: “imposed upon” underlying fields according to Galton ([GAL 03]). The objects become to some extent the inhabitants of a space that would be otherwise empty. In the other case, the field forms a “plenum”, where each localization is attached to a property: we are then faced with what Couclelis [COU 92] called a “continuous fabric”. In practice, it is possible to extract objects from a “field-based” approach: the objects are carved out from the properties attached to localizations. These objects can then be characterized in turn by the appropriate attributes. Thus, Plewe [PLE 98] gives the example of the hill. It may be represented as a field of altitudes and is not delimited by a sharp border in nature; there is a gradation. On the other hand, if we want to represent it as an object, one is led to determine an altitude threshold and then delimit the hill with a clear and sharp line. Galton considers that the objects constructed following such an approach correspond to a higher level of abstraction than those related to a direct "object" approach. From the cognitive point of view, an observer can move from a plenum view, consisting, for example, of watching from a train the spatial organization of a landscape that is passing by to an object view where he identifies relative localizations (for example, the tree next to the church) or concentrations (for example, several juxtaposed silos) as illustrated in Figure 1.1. From the point of view of the computer system, it is, however, not easy to manage such round-trips instantaneously [PEU 02].

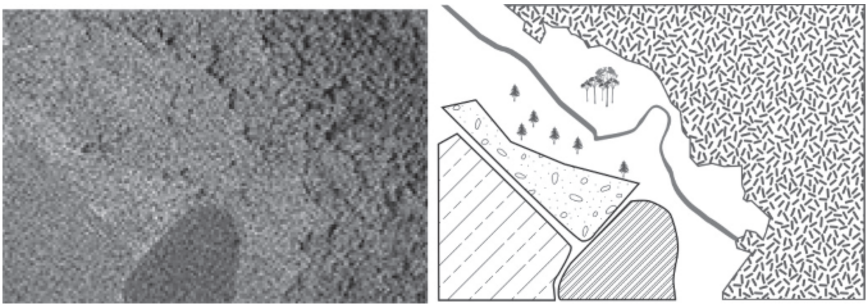


Figure 1.1. *Field-based and object-based approaches: two points of view on the same observable (source: UMR5600 EVS-ISG – ENSL K. Michell). For a color version of the figure, see www.iste.co.uk/mathian/spatiotemporal.zip*

These two perspectives are considered as dual, and some phenomena can be described according to each of these perspectives [PEU 02]. This depends on the phenomenon, of course, and on the scale at which it is considered: a tree will naturally be conceptualized as a discrete object and the temperature in field form. In contrast, the choice is to be made for vegetation coverage, and a number of other phenomena call for further discussion. As a result, Plewe [PLE 98] proposes a categorization into four conceptual models of space: – (1) the plenum is something that fills space, and the properties that matter can be measured at each point (for example, temperature, the nitrogen content of the soil etc.); – (2) The *regions of the space* delimited from the data that the author calls "*categorical coverage"*; it means, for example, built-up areas, green spaces, water surfaces etc. – (3) The *regions of the space delimited in a formal manner*, and not necessarily from the properties of the space. Such is the case of countries, or even of the whole set of census tracts making up an urban unit in official statistics definitions; – (4). The *object perspective* finally, in which the objects are thought as existing by themselves. Such is the case of the city of London, for example, which can be apprehended without reference to the way in which its delimitation has been established. Therefore, Plewe introduces two intermediate models that allow nuancing the fields/object dichotomy, but nonetheless a same phenomenon can fall under different categories depending on the point of view adopted.

Brogaard [BRO 98] for her part uses granularity as a filter to distinguish between two types of fields, one refers to a complete continuity while other refers to objects at a certain level of scale. She illustrates this latter case with the example of population densities. A density field is extrapolated from regions sufficiently thin for the density to be either 0 or 1, depending on whether an individual is present or not on these portions of space. Thus, the existence of this field is subject to the existence of individuals who serve as the basis for the measurement of the density, and which are "material objects". She opposes this type of field to the one where the subject of interest is the salt concentration of a lake: there is only one portion of space where this concentration has a meaning, that of the lake, and the lake as well as the distribution of the salt in the lake are of a field kind. Brogaard proposes consequently to distinguish two types of geographic fields: – the fields that depend on the objects located in this field ("object fields"), the example being that of the population density; – the fields that depend on fields ("continuity fields"), the example being that of the salt concentration.

In general, we can also distinguish two types of objects: – *fixed* objects, whether they are clearly distinguishable from their environment (a tree or a building) or whether they are part of it (example of the hill above, or even of a river); – *mobile* objects, which move in space (for example, pedestrians, automobiles and ships), space playing then the role of support. Here again, going from an object type to the other can be a question of observation granularity. The spatial envelope of a demonstration, for example, may, therefore, be captured as a fixed object from an aerial photo, and this envelope can have fixed contours while the demonstrators, mobile objects, move in all directions.

1.1.4. *An example of empirical objects' construction: the case of cities*

Here, we propose to illustrate the different stages that are associated with the passage from the conceptualization of objects to their concrete construction (this passage corresponds to the operationalization), mobilizing observables in the framework of databases. The "city" is a good example, and it even constitutes a quasi-iconic case in geography, of a built object[8] [BRE 13]. The passage from the conceptual object to the empirical object is not generally done directly and needs giving account of the construction process.

8 This example is drawn from multiple experiments led by Anne Bretagnolle: ANR Harmoni-cities http://www.parisgeo.cnrs.fr/spip.php?article38&lang=en) and ESPON DB program – urban data (http://www.espon.eu/main/Menu_ToolsandMaps/ESPON2013Database/).

Conceptually defining the city as a place of concentration of inhabitants, jobs, services, etc. allows making a mental representation of it. The aim is then to formalize this representation in terms of observables, and the path is still a long one before having made the whole construction process explicit that then leads to a representation in computing terms. This process is based on the categories presented above. Among the possible choices, a city can be defined as a political entity (municipality, metropolitan region, agglomeration community...), or as a morphological entity (dense space and/or built in a continuous manner), or even as a functional entity (employment center, area drawn by daily commuters...). If we rely on the first design of the city, there are only few questions to ask: indeed, the city in this case is an object of the *fiat* type, defined by convention or politico-administrative decision. In the case of the morphological definition, the first question that arises concerns without doubt the conceptualization of space: can we apprehend the city and its dynamics through the bias of a density field (Figure 1.2), where the city appears as a "spatial singularity", distinguishable from its environment, and introducing a "discontinuity" in this environment, as in the example of a hill in an altitude area? Or is it preferable to envisage the city from an object perspective? In this case, it concerns an object of the *fiat* and *composite* type, constructed from lower level objects or fields (Figure 1.2). It is then important to recognize the type of relationships and criteria that will be taken into account in the case of a morphological definition to identify where in the built space are located the discontinuities that allow demarcating the city.

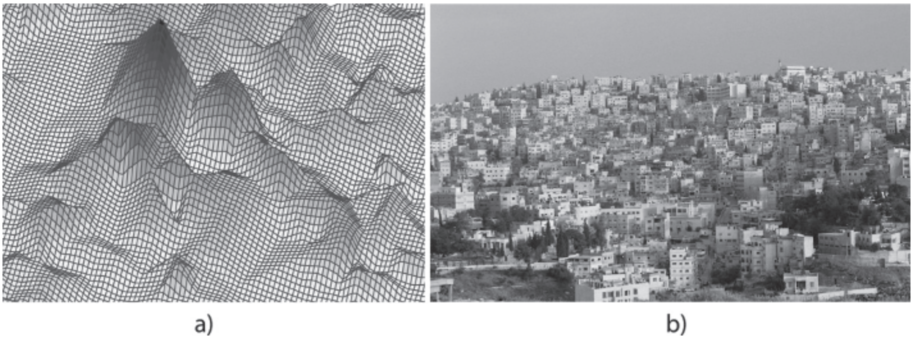


Figure 1.2. *The morphological city: a peak in the density surface or an aggregation/composition of buildings. For a color version of the figure, see www.iste.co.uk/mathian/spatiotemporal.zip*

In practice, the first morphological delimitations in France have been made on the basis of aerial photos (field source), and the discontinuity of built area is detected through a proximity criterion based on a spacing threshold of 200 m. This criterion implies that the city incorporates, starting from the center, all the built-up area, as long as there is no discontinuity of more than 200 m between two buildings. The value of the threshold (200 m) resulting from institutional recommendations, makes reference to people's space practices. This threshold can obviously be questioned and takes a different meaning depending on the context. Nowadays, the approach can integrate new sources. They may be of the object type, such as the topographic data base of national institutes that include the localization of buildings, or of the field type (or rather of the "categorical coverage" type to use Plewe's terminology [PLE 98]) such as the coverages of land use produced by interpretation of a satellite image. For each new source, the questions of the choice of relationship measurement (distance, adjacency...) and of the value of the threshold associated with the discontinuity concept have to be raised. Thus, the city object is the result of a modeling process, either of composition of lower level objects (buildings), or of extraction of the "built" category of the land use coverage. Figure 1.3 illustrates this approach: the construction of such a *fiat* and *composite* object is made from conceptual reflection (conceptual domain) by operationalizing them through the implementation of a generic process (model domain) mobilizing observable data (empirical domain). Depending on the type of selected source, it will be necessary to assess the capacity of the source to "meet" the model requirements in terms of data. For example, if the choice to build the city-object is focusing on the extraction of built patches [GUE 12], it will be necessary to ensure that the resolution of this source is compatible with the level of resolution associated with discontinuity as it is defined in the model, namely 200 m. If there is a unique representation of the object in the concept domain and in the model domain, this representation is no longer unique in the empirical domain, because it depends on the sources and associated parameters.

If we continue with the example of the city, this time considering a functional point of view, namely that of an urban employment center attracting the labour force of a residential area, then other questions will come up. This design introduces the concepts of "center" and "area" and the fact that the relationship between these entities should be measured by the flow of individuals resident in the *area* and working in the *center.* The model becomes more complex, introducing new objects and new observables, which multiply the possible ambiguities (definition of a center, of an area being attracted) and the number of possible choices when passing to the empirical domain: which indicator to adopt to identify "attracted" entities and what threshold to associate with it? This is more often specified by coming and going between the model domain and empirical domain. The separation between these two domains ensures the possibility to verify the adequacy between the conceptual object and empirical object. However, it is not without ambiguity. For example, in the case of the morphological city, the threshold of 200 m, which relates at the origin to an empirical knowledge, is used in the model domain almost as a standard, given the generality of the use of this threshold in a variety of countries. In the case of the functional city, the indicator most often used to measure the intensity of the attraction is the share of the labour force living in a place and working at the center. The most used threshold for this share in the literature concerning the definition of European urban areas is 10%. This threshold, unlike the former, has no generic character to the extent that it depends on the mesh in which the information on commuters is captured. Therefore, this threshold appears in the form of parameter in the model domain, and its possible values are studied in the empirical domain. The objects constructed following this approach are of the *fiat* type. The specifications of the whole process that leads from story to measurement must be explicit in order to verify its consistency.

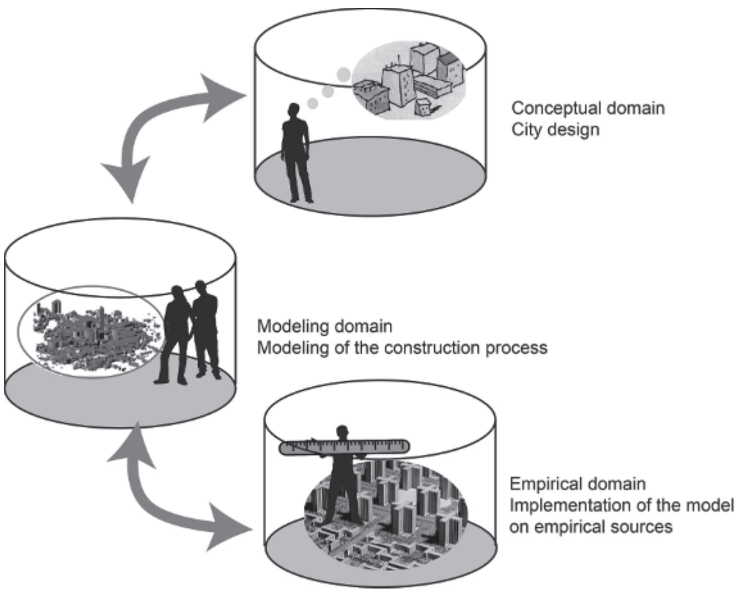


Figure 1.3. *From the conceptual object to its measurement: three steps*

1.2. Locating spatial objects in time

The basic concepts to apprehend the spatial objects of interest being defined, the question is about situating these objects in time. The challenge is to consider them in their full spatio-temporal dimension, by focusing on their evolution as well as on the processes leading to their transformation. In a parallel way to the approach adopted in the first part of this chapter, we will proceed in two stages, first examining the point of view of the philosophers, and then that of the geomaticians, in order to benefit from the additional insight of these two approaches.

1.2.1. *Objects' formalization in time: "endurant" and "perdurant" entities of philosophers*

The dichotomy that the philosophers introduce between the "endurantist" and "perdurantist" conceptions constitutes an enlightening starting point. It consists of two ways of apprehending the world, following the way entities' relationship to time is conceptualized. These two designs are sometimes regarded as opposed in philosophy, giving rise to debates (for example [LEW 88, MAC 02]), but they can also be interpreted as complementary. From a thematic point of view, when there is a need to understand the dynamics of the geographical space, it is indeed the complementarity of these designs that is relevant. In such a spirit, Grenon and Smith [GRE 04] proposed to distinguish between the following two types of entities[9] (Figure 1.4):

– The entities called *snap (*also called "continuant" or "endurant" by philosophers) are entities that have the capacity to persist in time (hence, the term "endure") and that we can observe at any moment of their existence[10]. Therefore, they exist in their entirety at each moment, maintaining their identity. They have an extent in space (in other words, they have "spatial parts") and make up a whole, observable at each moment. However, they do not have "temporal parts" [HAW 04]. Individuals, trees, rivers, cities and administrative units are entities of this type. An individual being does not have "temporal parts", and if he/she evolves over time, it retains his/her identity (Wilson the child and Wilson the pensioner refer to a single person) [LIV 09]. The same happens for a city: Lyon retains its identity even if the city of the middle ages has little to do with the city of today. It exists and can be observed, characterized, at any date of its existence, from Roman antiquity to nowadays. Properties (such as age, surface area and density) are also considered as "endurant" entities. These entities depend on the objects they are associated with (the age of an individual, the length of a river, the number of inhabitants of an administrative unit and the density of a city) and do not have an existence outside of them in the case of an object approach. In a field approach, a cluster of points verifying the same property, defines a spatial extent associated with this property (for example, the set of points having the same altitude that allows identifying the equilibrium line of glacier and following the evolution of a glacier in time).

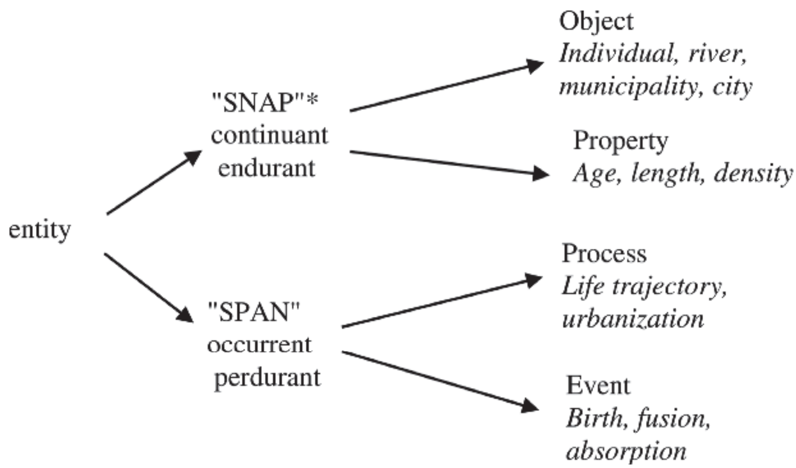
9 Within the meaning of the definition given in section 1.1.1, i.e. the objects, properties, relationships, events and processes identified to describe and represent an area of interest.

10 The categorization introduced in the first part about *bona fide* versus *fiat* entities, also makes sense in this context. When reference is made to the ability of a *bona fide* entity to persist in time, its existence refers to its physical presence whereas for a *fiat* object (i.e. a built object), its existence concerns the time of the convention (for example, Yugoslavia) or of the conception.

– The entities called *"span*[11]" (also named "occurrent" or "perdurant") refer for their part to events and processes. It concerns entities that have an extent in time. In fact, processes do exist only because of the succession in time of their temporal parts [GRE 04, LIV 09]: they are characterized by a beginning and an end, and a succession of time intervals, each corresponding to a change. If such a *perdurant* entity is observed at a given time t, its entirety cannot be accessed. As a matter of fact, what would aging, growth or acceleration in a time snapshot mean? An entity, such as a process, *is built in* time, it *rolls out* in some way, "it IS its history" [LEN 09]. However, the events correspond to a phenomenon that can be regarded as punctual. While event and process are often distinguished by differences in duration, Galton and Mizoguchi [GAL 09] instead insist on a difference of temporal delimitation, the process spreading over time (outflow of water in a river and spreading of the built area) while the event is dated (for example, fusion of two communes or avalanche). Let us notice that the difference between an event and a process is a matter of perspective and choice in the granularity of the observation. Therefore, the avalanche is an event at the spatial and temporal scale of the lives of the inhabitants, but a process at the scale of the monitoring of the snow along the slope during the seconds or minutes that it lasts. Finally, in some cases, the event marks the beginning or end of a process (for example, starting a new construction).

From the point of view of the domain expert who is interested in the evolution of a spatial phenomenon, who is in other words adopting a dynamic perspective, the two approaches are complementary, each offering a vision on the phenomenon of interest. An individual is a "snap" entity, his/her life trajectory is a "span" entity: this trajectory is composed of different phases of youth, maturity and old age of the individual. A city is also a "snap" entity, it exists at each step of time (of its existence) maintaining its identity. Its "growth" process, as it can be measured by the evolution of its population, of its economic activity or of the extent of its spatial insertion, for example, is a "span" entity. For mobile objects, the "span" conception of certain entities is required from the outset: such is the case of a crossing (for example, maritime), a ride or a pedestrian walking, whereas the objects associated with them, the vessel that crosses the sea and the individual who walks on the street, are "snap" entities. A double temporality must sometimes be envisaged, for example, for a vessel, the one associated with its aging process and the other corresponding to the crossing from one port to another.

11 In English, "SNAP" has the meaning of photo, snapshot, whereas the term "SPAN" refers to the duration, to the scope. This play on words puts the emphasis on two complementary sides of temporality [LIV 10].



According to [SMI 94, GRE 04]
*: the totality of the terms used in the literature is included in this diagram as synonyms, but it should be noticed that for some philosophers there are nuances.

Figure 1.4. *Categories of entities from the ontological point of view (in italics, some examples related to a variety of objects (human beings and spatial units)*

As highlighted by Bittner *et al.* [BIT 04] in an article proposing to develop an ontological theory encompassing both the spatio-temporal process and the *endurant* entities that are involved in it, the two entities are formally linked: a slice of the *perdurant* entity corresponds to a state (in terms of existence and property) of the endurant entity associated. Figure 1.5 illustrates the two points of view to characterize the phenomenon of urban sprawl for a city in space and time. Galton and Mizoguchi [GAL 09] advocate a related position, stressing the mutual interdependence between matter and objects, on the one side, and events and processes, on the other side, (that is to say, roughly, the two sets of entities represented in Figure 1.4). Indeed, aging would not make sense without an object undergoing this process. Table 1.2 proposes for a few thematic examples, couples of *endurant*/*perdurant* entities that make sense together. On the one hand, the objects with their properties, and on the other hand, the trajectories that these objects describe in time under the action of processes and events. Vessels, such as endurant entities, are thus associated with the crossings that they perform, which are perdurant entities. Lakes and their saline property, endurant entities, are for their part associated with the process of salinization, perdurant entity that implies an increase in the salinity rate over time.

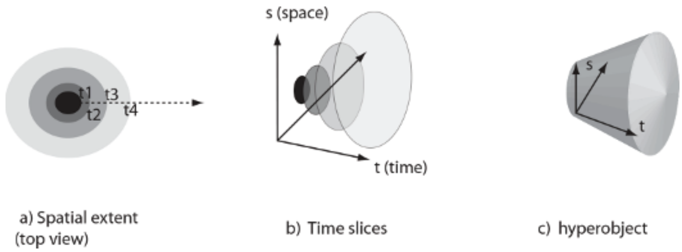


Figure 1.5. *Three representations of the urban sprawl of a city*

Terminology Entity types	Endurant Continuant "snap"	Perdurant Occurent "span"
Ontological point of view	Objects (fixed or mobile) Properties	Trajectories Processes and events
Thematic point of view	– Individuals (human beings), ships, herds; – Cities; – Countries; – Forests, lakes; – Roads.	– Rides, crossings, journeys; – Urbanization, congestion, growth; – Creation, recomposition (former Yugoslavia), disappearance; – Bushland expansion, salinization; – Traffic.

Table 1.2. *Entities' various relationships with time: ontological and thematic points of view*

Galton [GAL 04] relates these *endurant* and *perdurant* entity conceptualizations to the way of conceptualizing time, space and space-time. Therefore, he extends to time the dichotomy made between field and object approaches mobilized above for space. Thus, he presents a parallel between the spatial concept of field and the temporal concept of duration, on the one side, and between the spatial concept of object and the temporal concept of event, on the other side. This approach results in two conceptions to take into account simultaneously space and time. The first can be qualified of space-time and corresponds to a conception often noted "3D + 1": the objects are considered with their coordinates (*x*, *y* and *z*), referring to their position in space, and then time is added. In this conception, objects can be followed in time as well as in their transformations. This approach corresponds to the case where time-space is designed as existing *a priori*. Objects, events and processes are then positioned inside. It is an *endurantist* vision. The second refers to a conception denoted “4D” in which objects, events and processes define together hyperobjects. This conception is compatible with a *perdurantist* vision. The consequence is that there is no *variation* in time or space, it is integrated in the hyperobject (see Figure 1.5).

1.2.2. *From change to objects’ life*

Research in the area of integration and formalization of time in information systems are not new, and the 1990s mark the beginning of specific formalisms with respect to the introduction of time into geographical information systems. If these last 20 years have seen a good number of conceptual and operational formalization developments, a true gap was observed between these advances in the field of research and their integrations into geographical information systems [OSU 05]. These systems have been strongly modeled by the cartographic culture consisting of presenting territories’ states, the most up-to-date, and they still leave today to the responsibility of users the care to generate evolution and change. This is done most of the time by multiplying static layers for each date.

In recent years, these attempts were enhanced by reflections on the ontological categories previously presented. Without making a detailed review of all the formalizations developed, nor of the computer developments, for which readers are referred to specialized analyzes [ABR 99, YUA 01, WOR 05, PLU 11], we propose here to walk through the different stages of these developments. Indeed, they raise interesting questions, some of them still remaining unanswered.

The model corresponding to cartographic use, consisting of giving an updated status of a map, is the snapshot model. Change can then only be identified by comparing two successive states of the map. That is often still the used model. However, the first foundations of the issues associated with the introduction of time in order to identify change have been posed since 1988 by Langran and Chrisman [LAN 88]. They already pointed to the fact that a representation of the dynamics by simple superposition of dated layers (“stamped”) represents only an accumulation of states where time only exists through the interpretation of the user. They proposed a “Space-Time composite” model based on the differentiation between the status of the map and those of the objects (versions). That way they introduced a differentiation between the changes at the object level (mutation) and the result of these changes at the map level (event) (Figure 1.6). The data model that they propose is change-based in the case of a field-oriented approach. If the field’s elements are pixels, each pixel is described by the sequence of its states. In the case of a non-regular partition of space for example, polygons of land use, these are decomposed into elementary polygons according to a principle of uniqueness of history. The elements constructed that way have stable geometries in time. Figure 1.7 illustrates these elements in the case of a city's morphological extension. The different states of the city in time will be described by a series of polygons of built-area: the historical center by t0, the center and the first periphery by t1 and so on for the different urbanized peripheries. However, the elements formed (called "amendment vectors") have no meaning *a priori*: they are simply associated with a story.

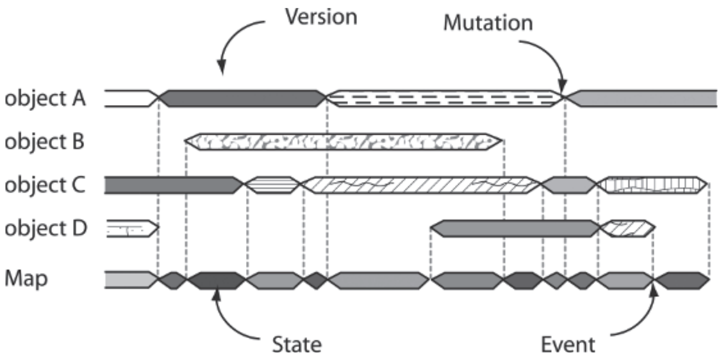


Figure 1.6. *The relationships between map states and object versions (according to [LAN 88])*

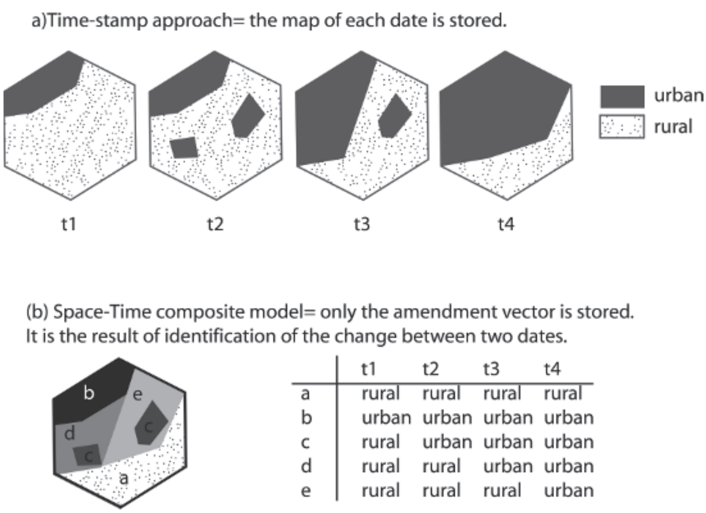


Figure 1.7. *The space-time composite data model (according to [LAN 88])*

In this model, the focus is, therefore, above all spatial: changes are only envisaged relatively to the geometry (shape), and the temporal dimension is regarded as a dimension that allows identifying/controlling the definition of the entities. Furthermore, the model is not adapted to an “object” approach.

From this pioneering attempt, a number of works have succeeded, some constituting conceptual formalizations, others leading to operational developments. We retrace the major steps because they constitute a set of interesting elements of reflection. Each development indeed, allowed experimenting with a point of view and going further into the conceptual and computer representation of a spatio-temporal phenomenon. The developments have focused simultaneously on the formalization of change and that of the temporal dimension of a phenomenon, and this in a formal framework incorporating the duality of “object” and “field” representation [PEU 88]. Thus in 1994, Peuquet proposed to extend the formal dual framework associating the “location-based” and “object-based” to the “time-based” temporal dimension. This framework places the triad framework at the forefront enabling the identification of *what, where and when* [PEU 94]. Furthermore, this framework formalizes the fact that our knowledge about phenomena is built through the prism of three subcognitive systems that operate in different ways, but cannot operate independently of each other. By allowing the positioning of a phenomenon according to the spatial and temporal dimensions, this framework allows in particular introducing the notion of event and representing it relatively to these dimensions. Conceived that way, a system must be able to record all types of changes. This framework has constituted a base for contemporary developments and the following ones. Time is introduced in it with the same status as space. A phenomenon can be conceptualized according to these 3Ds that find a simple correspondence in the empirical domain and guide the structuring of the information according to the three components: theme/time/space (Figure 1.8) [PEU 94, YUA 99, MEN 00].

Other developments have committed themselves to express change, to define primitives relatively to each of the three components. Therefore, change may refer to the existence of the object (appearance/disappearance), to its spatial properties (localization/form) or to its thematic properties (qualitative or quantitative). These last two changes are often linked: the type of culture of a plot can change without modifying its shape, but a change of shape usually causes a change in the quantity produced, for example.

This is, for example, the case of the model proposed by Cheylan [CHE 95]: the object is defined by its identity, its spatial extension and its thematic attributes. The monitoring of its evolution needs, therefore, to integrate the change relative to each of these three aspects: the movement for the spatial part (the movement is here referred to in the sense of change in shape and/or localization), the genealogy for the identity part and life for the thematic part. Figure 1.9 illustrates these three aspects of change according to the interrelations that exist or not between the entities: – interrelations in space (case of the partition where an entity's change of geometry implies that of one or several others); – interrelations in time (case of the genealogy where a given entity is depending on the entities it is generated from).

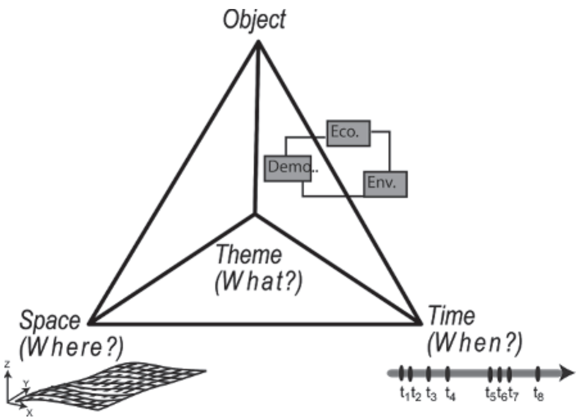


Figure 1.8. *The triad framework*

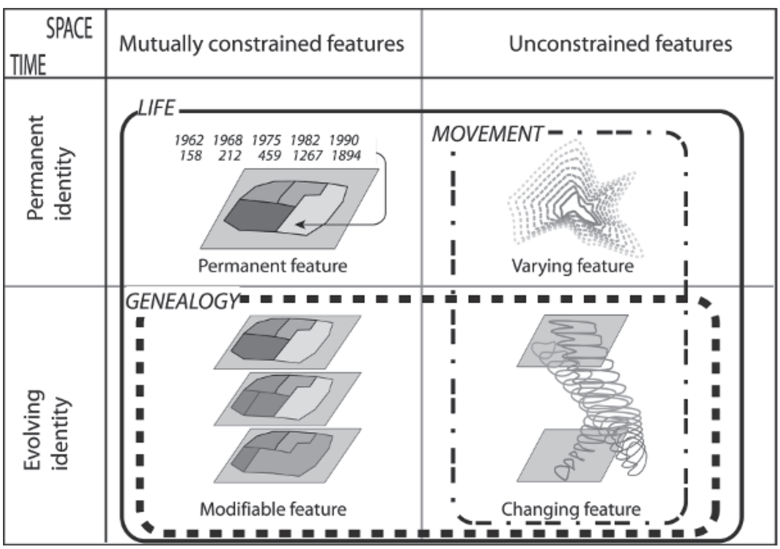


Figure 1.9. *Types of change and categories of objects (from [CHE 93, CHE 00]). For a color version of the figure, see www.iste.co.uk/mathian/spatiotemporal.zip*

Therefore, among the various questions about the representation of change in data models, that of taking into account the interrelations between objects in the description of change appears to be paramount. To the triad "what?, where? and when?" is added the opportunity to question the "how?" [CLA 95]. Claramunt and Thériault propose a typology of what they call "the spatio-temporal processes" into three groups (Figure 1.10). To the first group that concerns the evolution of an object, they add two groups identifying the changes related to the relationships between objects: – a group concerning the relationships that are associated with genealogy and spatial diffusion; and – a group identifying the changes affecting the structure of a set of objects. The geographical object is here considered from a systemic perspective, any change affecting it is likely to have repercussions on other objects (for example, deformation of a border).

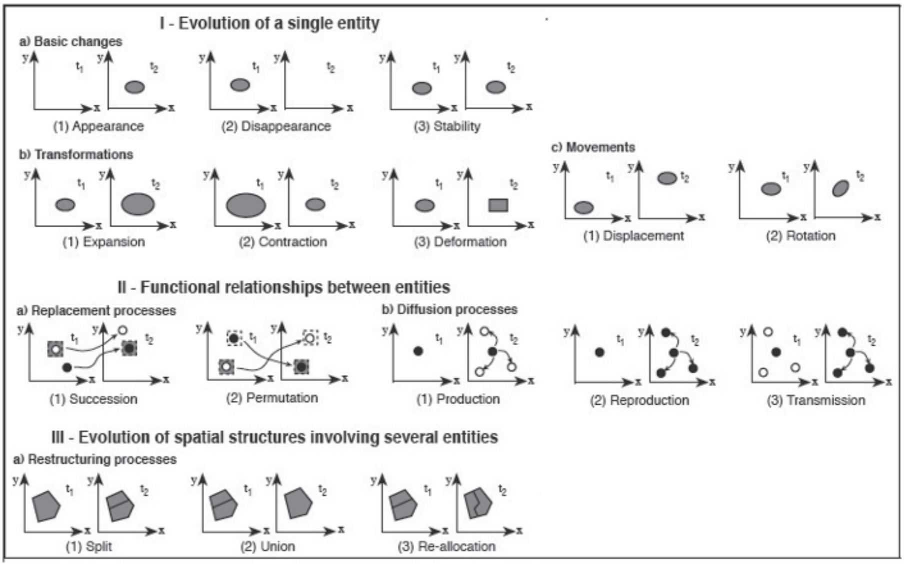


Figure 1.10. *Typology of spatio-temporal processes according to Claramunt and Thériault 1995 [CLA 95]*

This enhancement proposed by Claramunt and Thériault is fundamental to the extent that it clarifies, through the categorization, the relationships that objects maintain with other objects: here, this only concerns relationships of genealogy (successions) and topology, but all types of relationships between objects can be concerned, as well spatial relationships (proximity) as belonging relationships (to an upper level geographical entity) and as functional relationships (influence, exchange...).

From an operational point of view, multiple computing formalizations have been created. Usually developed for a specific question, they have mobilized “object” or “field” formalisms of space. Developed approaches are based either on the identification of objects’ change or on events definition and identification of associated spatial and temporal componants [YUA 99, YUA 01, PLU 11]. Consequently, the “Spatio-temporal Object Model” proposed by Worboys [WOR 94] describes the change of an object on the basis of spatio-temporal atoms: the aggregation of these atoms forms the object in 3Ds (two dimension (2D) for space and one dimension (1D) for time). This model is suitable for an object-oriented approach. In parallel, Peuquet and Duan proposed in 1995 a field-oriented model, “Event-based Spatio-Temporal Data Model”, which models change through the events associated with sets of localizations (pixels) (ESTDM) [PEU 95]. We can also mention the model developed by Raper and Livingstone [RAP 95], the “Object Oriented geomorphologic model” proposing an object-oriented system based on points integrating geomorphological events. The spatio-temporal data model (STDM) model proposed by Wachowicz [WAC 99] can also be quoted, object-oriented and inspired by the developments of “Time Geography”[12]. It proposes a very original framework of objects’ representation: by merging the spatial and temporal dimensions, the objects are represented according to a spatio-temporal trajectory in which states, events and changes succeed to each other.

The totality of these developments leads to approach the concept of identity with precision, and to refer to the objects in their *endurant* characteristic. Some developments have focused more specifically on the question of the object’s identity, reaching beyond the single notion of identification and giving it a more philosophical meaning, just like the case of the ship of Theseus[13]. This question essentially concerns the object-oriented approach. When do the alterations on each of its components affect the object itself, namely its identity? The change may affect only the characteristics of the object, or the object itself: the change of culture of a land plot changes its status without changing its identity. What happens if the plot changed ownership? If the single point of view of the plot is considered, then the owner may only be a qualitative attribute of the plot. But from the owner’s point of view, ownership will be a determining factor in the definition of the plot’s identity, and this change can then be regarded as a creation, after the destruction of the previous one. The notion of identity then becomes central. Several works have been

12 The “time-geography” paradigm, introduced by Hägerstrand in the 1970s in Sweden, will be illustrated in Chapter 2, section 2.4.3 and discussed again in Chapter 4.

13 The metaphor of Theseus’s ship has been used by philosophers since the antiquity for questioning the identity and change from an ontological point of view [LEN 09]. The story is told by Plutarch: the ship of Theseus would have remained docked in Athens, the rotted planks being changed gradually. Once all the planks have been replaced, is it still the same boat? And what if the worn planks had been kept aside and then used to reconstruct the boat, “which would be the true ship of Theseus?” [LEN 09].

developed around these issues of identity [REN 96, HOR 98]. Renolen proposed formalizing these changes with graphs illustrating the genealogy of objects ("history graph") and introduced more complex changes as the division or union of objects. Are the 13 states composing "European Union" the same object as the European Union composed of 27 states? What happens to Germany's identity when it was divided into two states in 1949? And at the reunification in 1990, do we find the same object as before 1949? Or still, how can we handle the identity of a forest fire that moves, changes shape and divides itself into several centers? These questions go beyond mere computer management of identity and refer to the intrinsic nature of the object. Hornsby and Egenhofer [HOR 98] introduced the concept of identity states (existing, that never have existed and having already existed) and proposed a visual language to represent the states and the transitions between these different states. The objects may appear (birth or sometimes reincarnation) or disappear; it is a question of grasping their "presence". Germany could be modeled as a "having already existed" identity state from t = 1990. The changing ownership plot could be modeled as a new object created from another destroyed one.

The following positions raise once more the question of what it means to "integrate time" in geographical information systems. While the first attempts of developing "temporal GIS" drew upon the developments made in the area of databases [ABR 99], some authors agree, however, to say that the representation and reasoning about geographical dynamics require more than the simple introduction of time through the notion of change. Indeed, such approach fits in an *endurantist* perspective (vision called 3D+1, 3D for space and 1 for time) while it should be necessary to reflect on the formalization of *perdurant* objects (4D) [YUA 01, REN 00, GAL 04, WOR 05]. Galton demonstrated that such a perspective would allow reconciling "object" and "field" approaches from the spatial point of view, as well as from the temporal point of view. The object approach enters into time through events, whereas the fields approach enters through processes. The challenge is then to make several points of view coexist: a cyclone could, according to the observer, be represented in the form of an event or of a process, in the form of a spatial object or defined by the values of a space field.

The first developments associated with time have introduced the need to work on change, and then on the events and processes, in a "data management" kind of vision based on the background history record and the reconstitution of evolution. These different experiences rooted in the formal development of databases lead then to the need to return to a conception of events and processes envisaged under the thematic perspective, by linking them to the identification of the causes of space's transformations.

1.3. Conclusion

The insights provided by the developments covered in this chapter are fundamental in the way that they guide a conceptual reflection upon the objects, their properties and their relationships and the way that this reflection should be connected to the question being asked. These concepts will be running through the following chapters. The computer environments, in which the various formalisms that have been discussed here are then implemented, do not have neutral roles. The same is true for the formalisms associated with the methods that will then be used to describe and analyze change. The conceptualization of objects in a dynamic context constitutes, in our opinion, the necessary basis to allow using the rich potential of methods and technical environments, without distorting the essence of objects as well as questionings that are dealt with.

Many categories have been introduced in this first chapter. The first concerned *what* is changing, the following *how* change occurs. Some categories are conceptual (*bona fide*/*fiat* objects, *endurant*/*perdurant* entities), others are methodological (field/object approaches, simple/composite entities). Facing a thematic question, reference to these categories facilitates the identification of the entities at stake and the evaluation of the different possible manners to represent them. Reflecting on categories helps to evaluate the consequences of different points of view and different methodological choices in front of a given question. Therefore, such reflection at an early stage of the research is useful to ensure consistency between thematic questioning, concepts and data.