# Spatial Semantic Definition to Generate a Semantic Description for Spatial Data

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**Abstract.** In this paper, we present a discussion about what semantics is, in order to propose the spatial semantics definition, which is used to generate a semantic description for spatial data. Thus, we have analyzed that it is not possible to catch the entire semantics from a map, because the semantics is annotated by the problem context. Therefore, we propose to obtain a partial semantics, according to a specific context. At the same time, our approach generates the semantic content of geographic objects involved in a cartographic vector map. Moreover, we have proposed an ontology to embed the relations, properties and characteristics that compose the vector maps. Additionally, in the ontology definition the terms of non-terminal and terminal concepts and the set of relations have been introduced in this approach. These terms are used to link raw data from vector maps to an abstract environment in order to construct a semantic description. Also, we present a case study to point out the way to generate a semantic map description by using the ontology that has been proposed.

## 1 Introduction

Nowadays, the semantic interoperability in Geographic Information System (GIS) is approached by using the spatial semantic representation. This interoperability is based on the integration of spatial schemas, query languages and sets of semantic rules, which can provide data knowledge and geographic representation interfaces [1] and [2].

Several works related to semantic interoperability have been published. In particular, [3] presents an approach to semantic similarity assessment combining two different strategies: feature-matching process and semantic distance computation.

In [4] and [5] an ontology-driven GIS, as a system integrator has been proposed. In these works, a special model to conceptualize the geographical information and to solve problems related to the integration and interoperability in GIS of different types at different levels of detail has been described.

In [6], the Naive Geography is introduced, as a body of knowledge that captures the way people of reason about geographic space and time. Probably, future generations of GIS will incorporate formal models of naive geography.

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Other works relate the semantic approach to the spatial data processing based on the concept of geographic entities. [7] enables the seamless integration of several types of information through the use of flexible spatial object classes. These classes are composed of combination of other classes that represent the richness of the geographic world.

In this paper, we attempt to define the *spatial semantics*. Our definition is composed of properties of spatial data in the same context. In addition, we consider that it is important to make evaluations to know the *semantic contents* from different perspectives. This process to compare several contexts (*subject domains*) is focused on catching the *semantics* and evaluating similar meanings (*contents*), so that these *semantic contents* can be quantified according to similitude degrees.

For instance, the purpose of map generalization process is oriented to preserve the semantics [8] representing the most important properties that characterize the subject domain. In this sense, the generalized representation in a particular scale should keep the same *semantic content* than the original map, because the properties are the same only the context is changed (see Fig. 1).

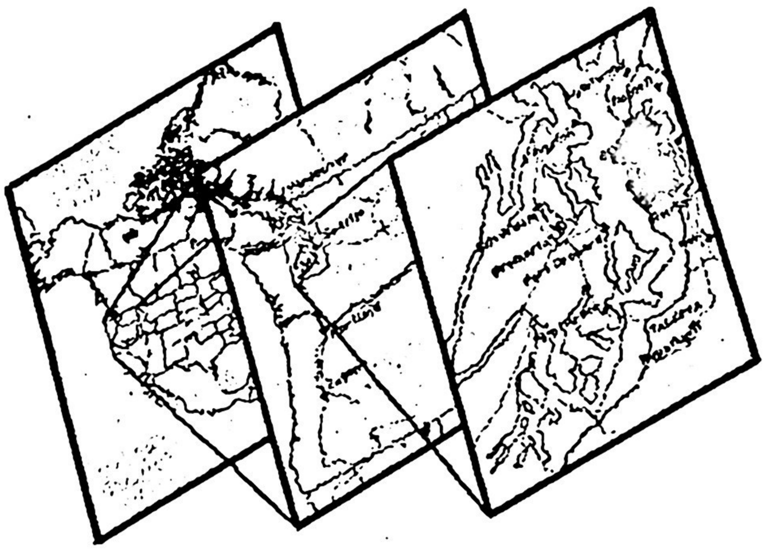

**Fig. 1.** Different contexts to map generalization

In our subject domain, a map provides information about the spatial layout of the reality, e.g. accurate topographic maps go to a definite picture of the distances and directions between points, and sizes, shapes and orientations of linear and areal features. A map also provides classified information about the spatial reality. For instance, a point may be classed as a capital city, a line as a river, or region as a desert. Statements in a natural language may likewise give information either of a classified kind, or of a precise spatial kind.

On the other hand, maps are interesting because their production is governed by detailed, conventional techniques of projection and generalization, yet they are understood in a direct and natural way. Furthermore, maps make a good area of study both for those who wish to assimilate cases of linguistic meaning to cases of natural meaning and for those who wish to investigate the differences among the two types of meaning.

Our discussion initiates with several definitions related to semantics, according to the state-of-the-art. Moreover, we propose a spatial semantic definition, which is oriented to relate the concepts without depending on the subject domain[1].

The rest of the paper is organized as follows. In Section 2 we present an overview related to semantics definition according to the state-of-the-art. Also, we describe the meaning of context and subject domain, which are the basis to formalize spatial semantics. Section 3 sketches out the spatial semantic definition and description. A case study to generate a semantic description, by means of a proposed ontology is shown in Section 4. Our conclusions and future works are outlined in Section 5.

## 2 From semantics to spatial semantics

S*emantics*[2] can be defined as the study of the meaning in some sense of that term. In this case, it can be considered as an abstraction process, which is used to appropriately express the essence of any context. Other definitions related to semantics are described as follows.

*Semantics* is a subfield of linguistics that is traditionally defined as the study of meaning of (parts of) words, phrases, sentences, and texts. Semantics can be approached from a theoretical as well as an empirical (e.g. psycholinguistic) point of view [9].

The decompositional perspective towards meaning holds that the meaning of words can be analyzed by defining meaning atoms or primitives, which establish a language of thought. An area of study is the meaning of compounds; another is the study of relations among different linguistic expressions (homonymy, synonymy, antonymy, etc.).

Semantics includes the study of thematic roles, argument structure, and its linking to the syntax. It deals with sense and reference, truth conditions and discourse analysis.

Many of the formal approaches to semantics applied in linguistics, mathematical logic and computer science originated in techniques for the semantics of logic, most influentially being Alfred Tarski's ideas [10] in model theory and his semantic theory of truth. Also, inferential role semantics has its roots in the work of Gerhard Gentzen on proof theory and proof-theoretic semantics [11].

Other definitions consider that semantics is the part of the structure of language, along with phonology, morphology, syntax, and pragmatics, which involves understanding the meaning of words, sentences, and texts. In this case, the semantics is preserved over the contexts, which are related to the specified theme. Moreover, semantics can be considered as a resolution knowledge model, because it encapsulates all the understood terms by the human mind[3].

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[1] It is defined as a set of "names" that describes the spatial context (domain). Thus, it consists of starting with *a priori* knowledge about the geographic objects that involve a partition (map).

[2] From the Greek *semantikos*, or "significant meaning," derived from *sema*, "sign".

[3] Cognitive essence produces *semantics*, which is represented by means of *mind maps*.

On the other hand, semantics is not only the area in which linguistic ideas are useful in the analysis of maps. In the 1970s, communication theory was perhaps the dominant paradigm for understanding how maps convey information [12]. This sort of framework derives from the study of information transmission and noise reduction in engineering. It typically consists of a source (producer of the map) linked to a recipient (the map user) via a channel (the map itself), with sometimes an "encoder" between source and the channel, and a "decoder" between the channel and the recipient.

Additionally, according to these assumptions, we consider that it is possible to make an analogy between the language and the maps, because both components contain defined structures, and our work is oriented to formalize cartographic representations. This is a complex problem, because maps are defined in different contexts. In essence, the contexts can be the map purpose, intended audience, scale, properties and relations among geographic objects, cartographic representation methods and so on.

When we look at how various sign systems inherent in maps provide an explicit meaning to specific sign relations, several key issues are presented by themselves. Perhaps the most important is to recognize that maps are powerful tools, because they provide a mean to melt three fundamentally different categories of meaning. These categories are meanings about space, time and attributes in space-time. Beyond this basic taxonomy of meaning, there are questions about the specificity of sign relations, directness of reference and associated literality of interpretants, differences in the concreteness of referents given meaning through signs, and the etymology of specific signs or groups of sign relations [13].

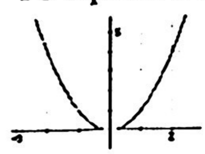
To provide a definition of spatial semantics, it is necessary to appropriately define the subject domain to know what the map requirements are. Prior definition is the following: it is the information that a map can provide us; furthermore, *map semantics* depends on *context*. Nevertheless, this asseveration breaks with the intuitive idea that semantics (of any object) is unique. For instance, *"John Smith"* is *"John Smith"* although he changes his sex or becomes a lawyer. Maps preserve the same essence, without considering the interpretation, whereby they have been made. We can say that it is true, but we also believe that it is not possible to obtain this essence, at least not completely, because if it is obtained, it means that we have a way to represent it[4]. According to this point of view, we express spatial semantics as follows:

*Map semantics* exists, but it can never be fully obtained, since it is abstract. We only have approximated representations about that. Moreover, the representations contain a part of the *entire semantics*; therefore these representations are *partial semantics*.

For instance, see the parabola case. We can obtain different representations:

a) To multiply a number by itself.

b) To square a number.

c) 

[4] This representation depends on the problem.

d) $f(x)=x^2$

The semantics is the same: *"parabola"*, for all the representation cases. However, every representation contains different information quantity, according to the expression level.

For example, a person who has a high school level could assert that *a* and *b* are the representation of the same thing, but probably he could not say anything regarding *c* and *d* representations. Then, which is the relation that exists between semantics and information quantity? What can be obtained about the study object? According to these questions, both cases are equivalent, only the representation contains the semantics in a *partial form*.

Considering the parabola example, the information quantity depends on the *a priori* knowledge that we have about the study object. Therefore, the semantics will depend on two factors: the richness of the semantic representation and the knowledge about the specific representation. It can be expressed as follows (see Eqn. 1).

$$S = S_r + S_c + S_d \Rightarrow S_r + S_c \rightarrow S, \tag{1}$$

where:
$S$ is the semantics.
$S_r$ is the semantic representation[5].
$S_c$ is the given semantics by the *a priori* knowledge.
$S_d$ is the unknown semantics[6].

At this point, we say that semantics can help us to make changes in the representation. Some examples are: to change from geographic objects representation to a conceptual representation [14], to modify the scale by means of map generalization process [8], to construct from a raster representation to more compact representation[7] [15]. Such semantics can aim to make the representation changes. The results produced by the representation changes are semantically equivalent to the original representation. In fact, semantics is a guide to make representation changes.

On the other hand, the *objective* is a parameter, which serves to select the semantic information quantity required to solve the problem. It depends on the map user, cartographic representation methods, scale, involved thematics and the information quantity. The *objective* is defined by the *context* and the *context* is defined by the *problems* to be solved.

In this case, the context selects the semantics, which is required from a map. For instance, if the context is the *"hydrology"*, then the semantics of a *"topographic map"* is restricted by the *context*. Since we know that a *topographic map* has more information than a *hydrologic map*. That is, a river and a water body maps provide the *same information* than a topographic map, if both maps have been processed in the same context.

Therefore, the context of a problem selects the semantics that is required by a study object to solve the problem. We propose some definitions related to semantics:

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[5] It is the information quantity that is provided by the representation.
[6] It is the semantics that involves the study object, but we do not know the meaning about it.
[7] Digital elevation models (DEMs).

*Problem or objective (P)*. It has initial and final states. That is, a study object ($O_i$), a result object ($O_f$) and a set of constraints ($K$) that involve the problem or objective (see Eqn. 2).

$$P = \{O_i, O_f, K\} \tag{2}$$

*Context ($\Psi$)*. It is denoted by the problems that can be defined into it (see Eqn. 3).

$$\Psi = \bigcup_i P_i \tag{3}$$

Therefore, semantics is always defined by a specific context and it is given by a collection of geographic objects (*a map*).

## 3 Spatial semantic definition and description

We have analyzed different proposals about the semantic characteristics for different geographical objects that compose the maps. However, to define spatial semantics it is indispensable to know the context or subject domain that involves the spatial data.

In the last section, we presented some semantic definitions in a different sense and we finalized that the analogy of the maps can be defined by means of structures oriented to formalize a cartographic description, according to their intrinsic characteristics. This assumption depends on the context, likewise it is important to consider the subject domain of the spatial structures [14].

Our approach proposes to define a *general context* for vector maps to obtain the spatial semantics of the spatial data, by means of an ontology that involves all the characteristics or essential properties related to geographic objects.

In those terms, we define a map as a spatial partition $\Omega$ inside a universe of geographic objects $\alpha_i$, which consists of a set of primitives of representation. $\Omega$ is the set of partitions of the primitives, which can exist into that partition $\Omega$ and these are represented in the same partition [14] (see Eqn. 4).

$$\Omega = \alpha_i \cup \{Rp_l, Rp_p, Rp_a\}; \quad i = 1,\ldots,n, \tag{4}$$

where:
$Rp_l$ is the primitive of representation "linear".
$Rp_p$ is the primitive of representation "punctual".
$Rp_a$ is the primitive of representation "areal".
$i$ represents the thematic number that involves the spatial partition.

According to map definition, it has a *unique semantics* related to the context dependency. Therefore, the union of all the information (geographic objects, relations and symbol sets) contained in the map, represents the semantics. In this case, regarding the interpretation, we can obtain different *approximations*.

For instance, people who have more knowledge in a certain field can obtain more information about a map, than people who do not have cartographic knowledge.

Nevertheless, the information that can be obtained about the map, depends on the knowledge to handle and interpret the data. However, in some circumstances, it is possible that the information quantity obtained by prepared people is the same than people without preparation. This implies that the *map semantics* is simple and a unexpectedly ambiguous[8].

On the other hand, we have talked about not only the information, which is obtained by a map, but also about the information quantity that can be obtained depending on the knowledge about the map. However, certain aspects should be considered, e.g. map purpose, map use, etc. According to these aspects, it is indispensable to count on *a priori* knowledge about the map, in order to solve the peculiarities that can appear in the interpretation and analysis stages [8], [14].

Furthermore, to obtain the spatial semantics, it is important to know the subject domain that involves the geographic objects, because the semantics depends on the context.

We propose a *subject domain* definition, which can be used as an alternative component to describe the characteristics that involve a map. It is defined as a set of "names" that describe the characteristics that compose the primitives of spatial representation. Thus, we can start with *a priori* knowledge about the geographic objects that appear, e.g. in the map legend. For instance, "blue" lines are united under the concept (name) "river" and "black" lines are united under the concept "fracture", etc. In reverse, the different concepts are united under the same description of the spatial representation that is *"line"* [14].

As we have already mentioned, we are not able to describe the *entire semantics* of a map $M$. Then, we define a *partial semantics* $S'$ to be a subset of the semantics $S$. See Eqn. 5.

$$S'(M) \subset S(M) \tag{5}$$

Moreover, we define the *partial semantics* in terms of a map description based on concepts and relations as shown in Eqn. 6.

$$S'(M) = D_M(C, R), \tag{6}$$

where:

$D_M$ is the description of the map $M$.

$C$ is the set of concepts.

$R$ is the set of relations that exist within the map.

We propose to define two types of concepts: *terminal* ($C_T$) and *non-terminal* ($C_N$) *concepts*. The first ones are concepts that do not use other concepts for defining their meaning (they are defined by simple values). The *non-terminal concepts* define their meaning based on other concepts (terminal or non-terminal as well). See Eqn. 7.

$$C = C_N \bigcup C_T \tag{7}$$

Each concept has a set of attributes. From this point of view, all attributes of a *terminal concept* are simple, e.g. the type of all attributes belongs to the set of primitive types ($T_P$), as shown in Eqn. 8.

[8] For example, a map to arrive from home to school.

$$T_P = \{number, character, string, enumeration, struct\},$$
$$A = \{a_i \mid type(a_i) \in T_P\}, \quad (8)$$

where:
$T_P$ is the set of primitive types.
$A$ is the set of attributes.

Then, the set of *terminal concepts* is defined by Eqn. 9.

$$C_T = \{c(a_1, a_2, ..., a_n) \ni a_i \in A, \ i = 1,..,n\} \quad (9)$$

In the same way, the *non-terminal concepts* have at least one attribute that does not belong to $T_P$ set. It is denoted by Eqn. 10.

$$C_N = \{c(a_1, a_2, ..., a_n) \ni \exists a_i \notin A\} \quad (10)$$

Finally, the set of relations $R$ is defined by the set of pairs that are related to $\Gamma$ and $\Phi$, where $\Gamma$ and $\Phi$ are non-reflexive, non-symmetric and transitive relations (see Eqn. 11).

$$R = R_\Gamma \cup R_\Phi = \{(a,b) \mid a\Gamma b, \ a \in C_N, \ b \in C\} \cup \{(a,b) \mid a\Phi b, \ a \in C_N, \ b \in C\} \quad (11)$$

Fig. 2 shows the proposed ontology to extract the *map semantics* to generate a semantic description, which represents the relations among the characteristics that involve the maps.

As we have denoted, the ontology consists of two types of concepts: *non-terminal* and *terminal* and a set of relations. The relations that provide the ontology are the following: "*has*" ($\Gamma$) and "*is-a*" ($\Phi$).

As we can see in Fig. 2, we use three relations in the ontology, but they are used to denote a symbology. The "*has-a*" relation is a particular case of the "*has*" relation (the cardinality of the relation is exactly one)[9].

In addition, Fig. 2 shows only some set of concepts because of showing everything is difficult due to space limitations. These concepts are represented by "boxes with three points". For instance, in the case of concepts, they are punctual, also there are two concepts (*town* and *village*), but it is possible that many others can exist such as: archeological sites, monuments, wells, buildings, etc.

[9] The cardinality of *is-a* relation is always 1.

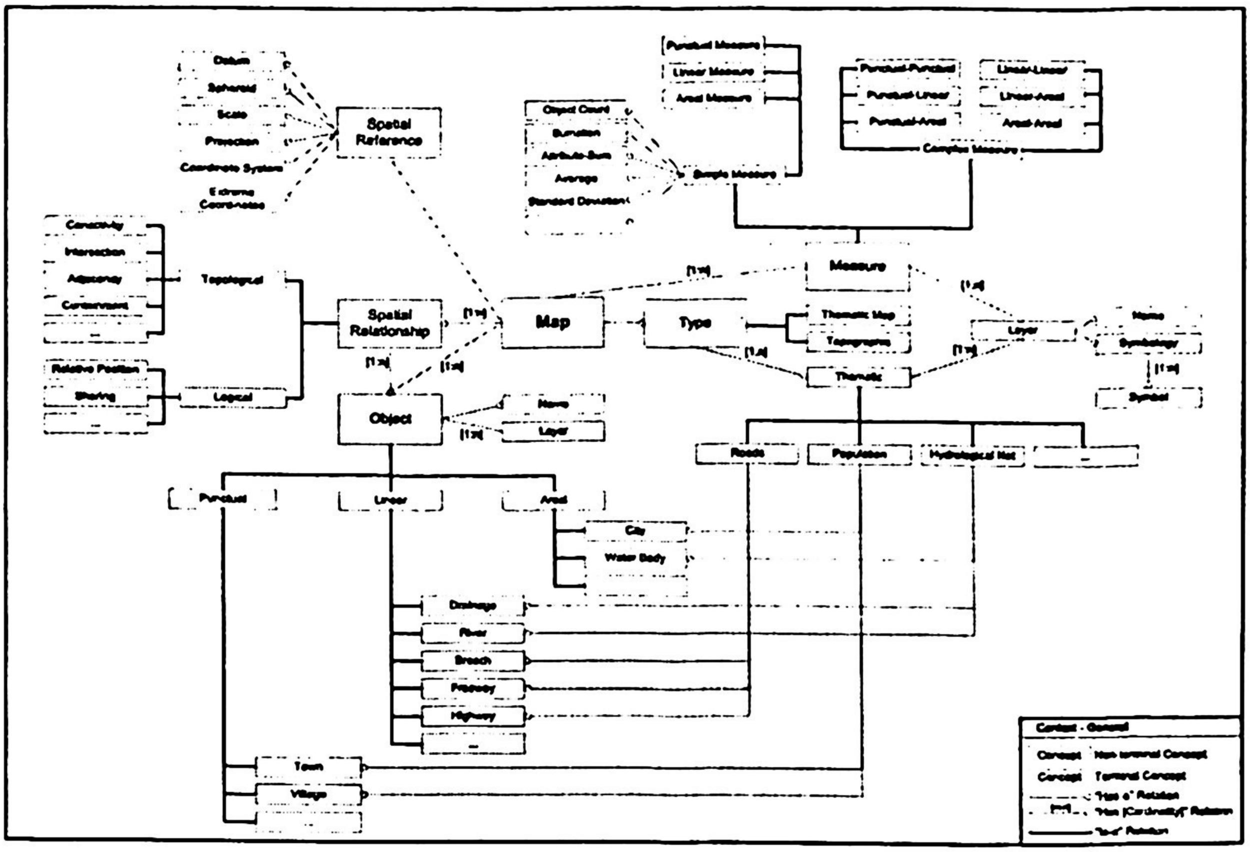


**Fig. 2.** Ontology to extract map semantics

As we had mentioned the information quantity that can be obtained from a map, is restricted by the context. Then from this point of view, the context is a *subset* of the ontology, since the defined ontology is general.

In other words, the context $\Psi$ is a type of map description that does not have specific values (see Eqn. 12).

$$\Psi(M) \subset D_M(C,R) \tag{12}$$

In Fig 3, we depict the context for hydrologic maps, it is possible to appreciate that hydrologic maps is a subset of the ontology as shown in Fig. 2.

Also, Fig. 3 describes the context of maps with hydrologic thematic of a linear type. As we appreciated in Fig. 3, there are concepts related to neither linear nor areal objects[10]. However, the relations are preserved regarding the general ontology.

[10] Note that there are neither measurements nor spatial relations that involve the type of objects.

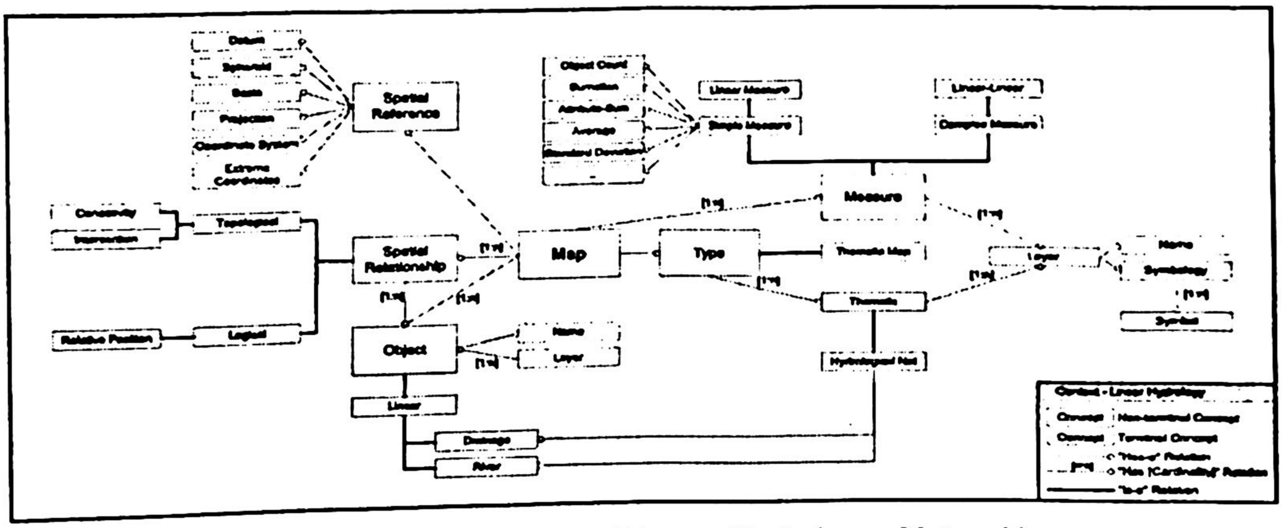


**Fig. 3.** Example of context (Linear – Hydrology - Network)

# 4 Case study

In this section, we present a case study to show the use of the proposed ontology to describe the spatial semantics for a thematic map.

The map described in Fig. 4, depicts different thematics, which are composed of different layers, where each layer contains objects of a type of a spatial representation primitive.

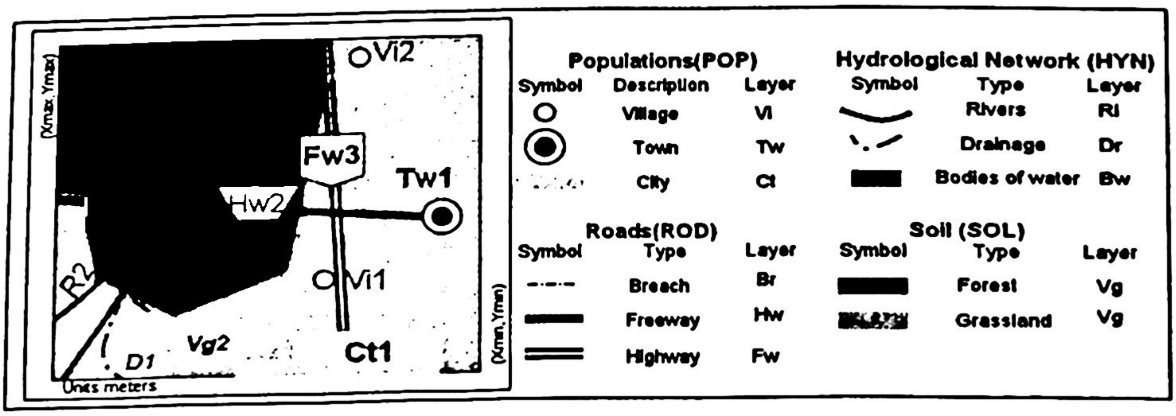


**Fig. 4.** Thematic map used for the case study

Moreover in Fig. 4, we can appreciate that the map contains *Populations* (POP), *Hydrologic Network* (HYN), *Roads* (ROD) and *Soils* (SOL). In addition, each thematic and its layers are presented in the legend, and they are described by specific symbols. In this case, the map is composed of 3 punctual objects, 6 linear objects and 5 areal objects.

This map shows situations that are frequently presented in real maps, because there are diverse relations, properties and symbols for every geographic object represented in the partition.

Thereinafter, we use the ontology to describe the map. Fig. 5 depicts the semantic description. It is possible to appreciate in Fig. 5 that the description is initialized in the *non-terminal concept* called "*Map*". Also, the *non-terminal concepts* are denoted by means of *rectangles* and the values of the *terminal concepts* are represented by *ellipses*.

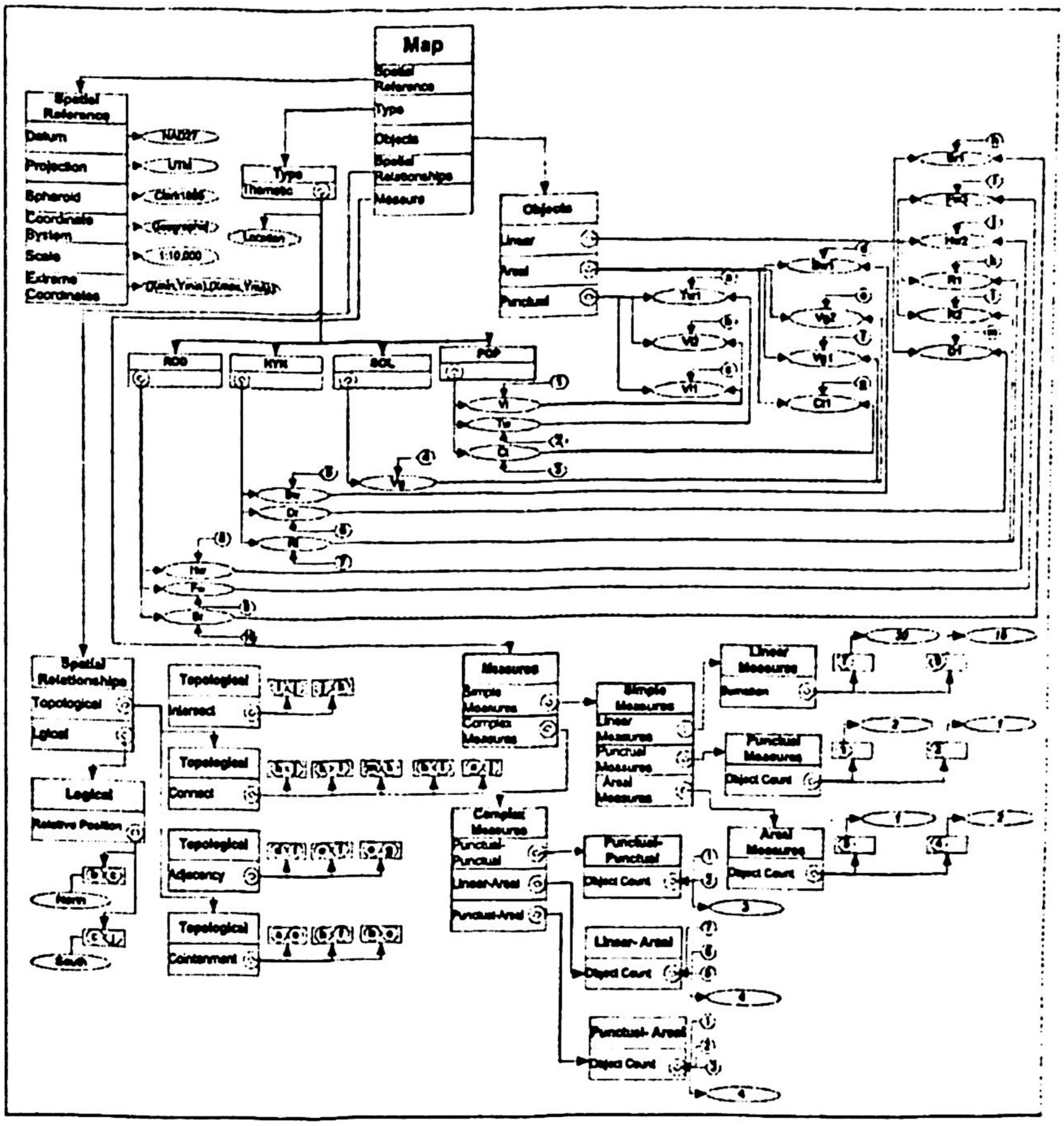


**Fig. 5.** Semantic description of thematic map shown in Fig. 4

According to the attribute that contains each non-terminal node, we establish a relation, which defines another non-terminal or terminal concept (depending on the case or objective) providing the total description of the geographic objects that compose the partition (see Fig. 4).

On the other hand, the properties (*attributes*) that belong to each terminal node contain quantitative values. Additionally, the ontology encapsulates all the topological and logical relations, symbol sets, and measurements about the map content.

In this approach, it is important to previously characterize[11] the topological relations in order not to consider all of them in the semantic process, because in real cases, they could be a lot. This situation will generate some mistakes due to a larger set. Additionally, the semantic description directly depends on the context; therefore it is not possible to count on general context, since some semantic ambiguities can be presented in the spatial description.

This approach is focused on describing, in a general orientation the *semantic content of a map*. However, this description depends on the number of spatial relations, properties and cartographic *measurements*[12], whereby it is possible to increase the semantic resolution in the description[13]. Also, the thematic map semantically described, preserves its content in another more general context.

The semantic description can be made by using *tuple* of *non-terminal* and *terminal concepts* related among themselves (they are denoted by *Concept* ***relation*** *Concept*).

For instance, Fig. 4 is composed of several spatial objects. The layer presents the relation "**is-a**" (*HWY* **is-a** *Linear Object*). Moreover, the topological relation ***"Intersect"*** is presented between *Hw2* and *Fw3*, which both are linear objects. In the same Figure, we appreciate that ***"Intersect"*** relation is a *topological relation* and at the same time, it is a *spatial relation*, whereby this relation is congruent with the description *Fw3* ***Intersect*** *Hw2*. In Table 1 all the spatial relations are presented, according to the description of Fig. 5.

**Table 1.** Spatial relations among geographic objects

| Objects | Vi2 | Vg2 | Vg1 | Ct1 | Fw 3 | Hw2 | R1 | R2 |
|---|---|---|---|---|---|---|---|---|
| Tw1 | | ♠ | | | | ♦ | | |
| Vi2 | | ♠ | | | ♦ | | | |
| Vi1 | ↑ | | | | | ↓ | | |
| Bw1 | | | ♥ | | | | | |
| Vg2 | | | ♥ | ♥ | | | | |
| Vg1 | | ♥ | | | | | | |
| Br1 | | | ♠ | | | ♦ | | |
| Fw3 | | | | | | ♣ | | |
| Hw2 | | | | | | | ♣ | |
| R1 | | | | | | | | ♦ |
| D1 | | | | | | | ♦ | |

♣=Intersect, ♦=Connect, ♥=Adjacency, ♠=Containment, ↑=North, ↓=South

[11] *Characterize* means identify, refers to the relations by means of names to avoid ambiguities.

[12] A measure is a procedure for computing measurements, which are the basis for evaluating characteristics of cartographic phenomena.

[13] This assumption is just considered for the case study, because the semantic map description contains all the relations of the map.

## 5 Conclusions and future works

In the present work, we describe the general aspects for the semantic processing of spatial data. We initiate our discussion with several definitions about semantics, in order to achieve a definition related to spatial semantics in a particular sense.

Moreover, we propose a general approach based on extracting the properties of geographic objects to obtain an approximation of their spatial semantics, according to a specific context.

We have mentioned that map semantics can not be obtained in either a *general* or a *entire* form. Therefore, it is necessary to define a *partial semantics*, which is annotated by the context of the map.

We propose that partial semantics associated to a map is given by a map description, which consists of a set of concepts and relations among them. Additionally, we propose an ontology to represent the context (in a general form). Thus, the ontology is used to construct the mechanism to perform the semantic description (*partial semantics*) of the map.

On the other hand, in ontology definition, we introduce two fundamental components: *non-terminal* and *terminal concepts*. Due to these types of concepts, it is possible to link raw data from a geographic database to an abstract environment such as the semantic description.

In addition, the ontology contains two types of basic relations (*has* and *is-a*). They are used to join many concepts, which exist into the geographic context. At the same time, they allow us to express new relations such as being particularly spatial interactions.

Also, we present an ontology that partially represents the general context of vector maps. The case study has been used to depict how a specific context is defined to make the semantic description.

This representation allows us to make well structured descriptions, since it is used as a well-known structure (e.g. UML uses the same structure). Moreover, with this structure, the step to well structured descriptions are simplified, such as GML, XML or other specifications, which enable to represent the spatial semantics.

In our future work we will attempt to define a *grammar* in order to perform formal definitions. Nowadays, we are starting to develop a research related to generate a detailed ontology in automatic process (for example, to consider raster maps).

Other directions are oriented to develop automatic descriptions of maps, and these directions can be applied to handle the automatic cartographic generalization process.

The most important future work is related to define the comparison process of semantic information (*contents*), that is, the process to obtain similitude measurements among semantic descriptions, according to the contents that have been obtained in different contexts (*context comparisons*). Furthermore, we will attempt to provide approaches to measure the *ambiguities* and *inconsistencies*, which can be presented into the contents. Also, we will propose to provide mechanisms to minimize the confusion degrees in these contents.

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