MAPPINGS BETWEEN MAPS – ASSOCATION OF DIFFERENT THEMATIC CONTENTS USING SITUATION THEORY

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Abstract.
The notion of an object bearing information is central to the traditional situation semantics framework. Herein, this notion is extended to the realm of thematic maps as a vehicle for the formalization of their thematic content. Maps are the most acknowledged graphic representations of spatial phenomena. In the light of Situation Theory, we apply its evolution theory; Information Flow, to examine how information between different thematic maps can flow through channels that allow the generation of mappings. This approach views maps as distributed systems with regularities. These distributed systems can be further regarded as classifications in need for semantic interoperability. We therefore, explore the framework of Information Flow Theory, in order to provide a general framework for formalizing the thematic content of maps.

1 Introduction

This paper provides a framework for formalizing the information content of thematic maps. Maps are the most acknowledged graphic representations of spatial phenomena and are widely used due to their expressive power and convenience of conveying geographic information. To be more specific, thematic maps display information of a phenomenon (theme), revealing its spatial and temporal reference. Usual components of a thematic map are: the background map, the thematic content (expressed by symbols), the title, the legend, which explains the symbols used, and the scale.

The need to formalize the thematic content of maps is underlined by the fact that maps are sources of spatial information of different type; in addition, they are widely used by agents for varied purposes. Accordingly, once we formally express the information transmitted through maps, we have a better understanding of how maps represent the world. The more we explore spatial phenomena, the more complex our maps become, and that should be done without sacrificing their expressiveness and ability to convey information (and sometimes meaning) to the map-reader. This research compares the information content of two different thematic maps representing the same phenomenon, by generating mappings between the two maps. The objective of such a comparison, adopting the map-reader's point of view, is having a consistent overall view of the displayed phenomenon.

For demonstrating the aspects of this research, let us consider a map that represents population density of a certain part of Europe (l) at time t, and another one that also represents population density of another part of Europe (l') at the same time t. Due to the difference in population density classes, and to different symbols (areas of different color intensities), it is complicated for the map user to have a complete view of the phenomenon for the two regions at time t.

In order to map between these two different graphic representations, we adopt the formal theory of Information Flow (evolution of Situation Theory) introduced by Barwise and Selingman (1997). We view maps as distributed systems (having separate parts that constitute a whole) with regularities. In this context, we define these distributed systems as classifications, and we attempt to provide mappings between these different systems (maps) to achieve semantic interoperability. To make it more explicit to the novice reader, and paraphrasing Sowa's definition (Sowa 2005), a mapping of concepts and relations between two classifications A and B preserves the partial ordering by subtypes in both A and B. If a concept or relation *x* in classification A is mapped to a concept or relation *y* in classification B, then *x* and *y* are said to be *equivalent*. The mapping may be partial: there could be concepts in A or B that have no equivalents in the other classification. No other changes to either A or B are made during this process. The mapping process does not depend on the choice of names in either classification. Figure 1 illustrates the notion of mapping between two classifications. Figure 2 portrays the procedure adopted in the paper to formalize the content of thematic maps and to generate mappings between them.

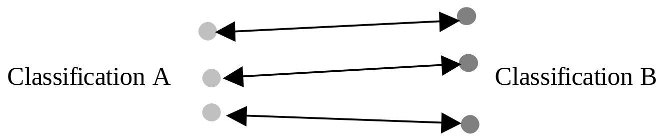


Figure 1. Mappings between two classifications

In the remainder of the paper, we touch upon the value of maps as information bearers and outline the basic elements of thematic maps in section 2. An account of the proposed framework for formalizing the thematic content of maps in terms of the basic notions of Situation Theory and Information Flow is presented in section 3. Section 4 provides a case of how we can apply the Information Flow framework to thematic maps. Finally, in section 5 we discuss the computational aspect of the approach as a future research question.

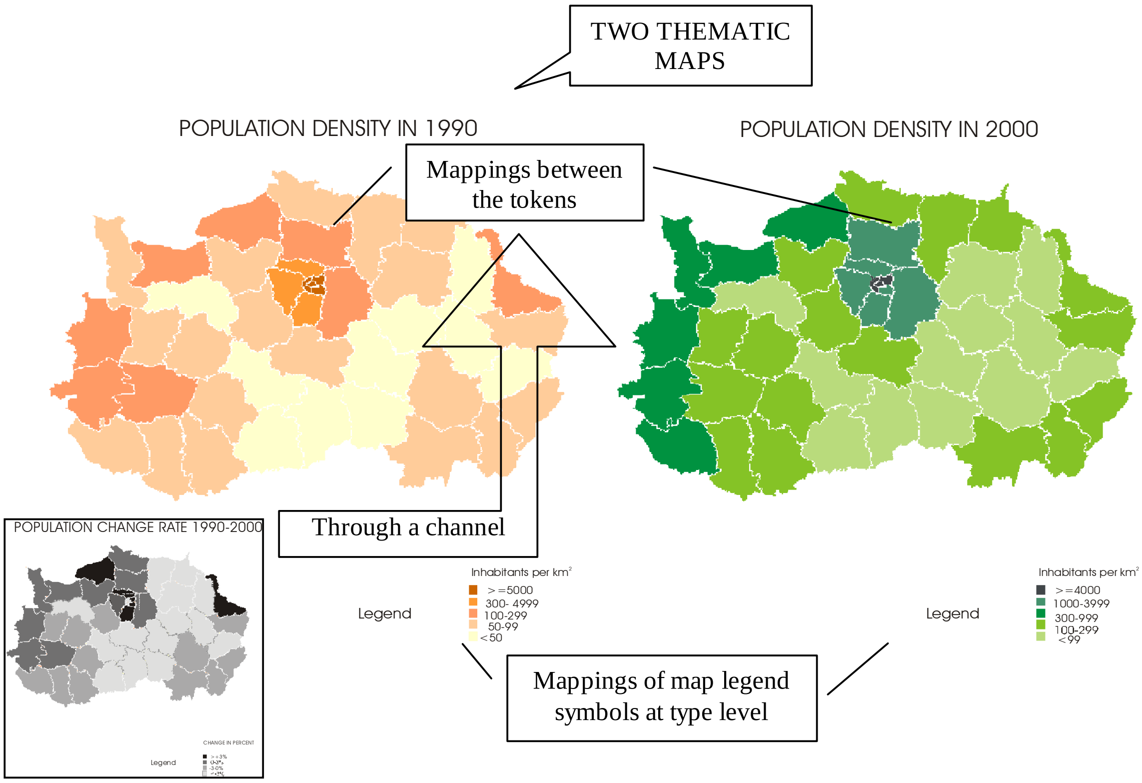


Figure 2. The formalization of a thematic map content and the interoperability aspect of information flow as applied to thematic maps

2 THE VALUE OF MAPS

Maps are the most acknowledged graphic representations of spatial phenomena and are widely used due to their expressive power and feasibility of conveying geographic information. Important questions can be asked:

- How maps represent the world (at least a portion of it).
- How do they get the information conveyed?
- Can there be a model to formally account for the way maps represent the world?

An answer to these questions can be found in MacEachren (1995), where a semiotic perspective is followed to explain certain aspects of map representations. While Ingram (1999) examines how representation in maps resembles Natural Language literal and non-literal meaning.

2.1 Bearing Information

Map-making includes a wide range of maps from topographic to cartograms, analog to digital, static to interactive, each of which bears information. For instance, topographic maps provide information about location, distances between point features, sizes, shapes, and orientations of linear and surface features. Moreover, maps contain classificatory information of real spatial features since they can represent a church as a point, a road as a line and a country as a polygon. What is more, maps can represent point/linear/surface features through different point/linear/surface symbols, which classify spatial features other than by their spatial extent; a very important cognitive process. Maps provide a means for reasoning about space, about time and about attributes in space and time (MacEachren 1995); however it is not always the case that information a map sign carries is identical to its meaning. Herein, we explore the expressive power of thematic maps in the way they encode and convey, indirect spatial information, and attempt to provide a formalization framework for modeling their information content.

2.2 Thematic maps in context

A topographic map shows spatial features at their accurate location (given a coordinate system of the surveying process and a map projection). On the other hand, a thematic map seeks to visualize the distribution of some kind of phenomena with accurate characteristics. Usual elements of a thematic map are: the background map, the thematic content (expressed by symbols), the title, the legend, which explains the symbols used, and the scale.

Usually, in thematic maps, the background map is not detailed (unless the scale is large enough to allow extensive representation of features); that is why in this paper, we will not tackle issues of distortions due to map projection, or accuracy of the background elements.

The thematic content is of special importance to a thematic map because it guides the map-designing process. The thematic content must stand out from the background map so there is no figure/ground ambiguity as discussed by Pratt (1993). The separation of the visual field into figure and ground is done automatically since it reflects a fundamental characteristic of visual perception (Robinson et al. 1995). The content of thematic maps is represented by symbols that make use of visual variables (i.e., shape, pattern, direction, hue, size, and intensity) to distinguish between different phenomena. Symbolization is the most crucial step of the map-making process because the right selection of symbols for representing phenomena ensures the final product in terms of clarity, balance, visual contrast/ hierarchy etc (ibid.).

3 INFORMATION FLOW AS THE PROPOSED FORMALIZATION FRAMEWORK

The basic idea behind the Information Flow (Barkwise and Seligman 1997) is the notion of *containment*, which translates as the information an object contains about another. Information Flow is better understood within a *distributed system* (ibid). Distributed systems are regarded as wholes with interrelated parts. Regularities within these systems ensure the flow of information between the parts. Consequently, the more random a system is the less information can flow (Bremer and Cohnitz 2004).

Parts of a distributed system are considered as particulars; they are of some type. Different types are connected by *constraints*. A constraint is the link between situations, or types of situations, and it is used to model the regularities of the distributed system (Devlin 2001a). We write C=<<involves, S, S’, 1>> to mean that situations *S* and *S’* are involved by constraint *C*. Additional to these, there are *background conditions* as a third parameter to the previous relation, which now becomes C=<<involves, S, S’, B, 1>>. Background conditions were introduced by Barwise (Surav and Akman 1995), to account for conditionals and circumstantial information and furthermore, to formalize context.

3.1 Classification

The components of a distributed system are represented by a classification A (Devlin 2001b), which is a triple, <A, Σ_A, ⊨ A >, where A the set of objects of A to be classified, called tokens of A, Σ_A the types of A, used to classify the tokens, while the tokens stand in relation ⊨A to the types (Fig.3).

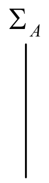


Figure 3. Classification *A*

Each classification has a Local Logic that governs its types (Bremer and Cohnitz 2004). This logic allows inferences to be drawn at the type level of the classification. The sequent $\alpha \vdash \beta$, for types α, β indicates that the inference from α to β holds. For instance, the sequent house $\vdash$ building indicates that houses are buildings (Worboys 2001).

3.2 Infomorphism

For relating two classifications, the notion of infomorphism (Devlin 2001b) is introduced. Let A =<A, Σ_A, $\models$ A > and B =<B, Σ_B, $\models$ B > be two classifications. An infomorphism f between them consists of two functions; f + from types of A to types of B, and f - from tokens of B to tokens of A (Fig.4).

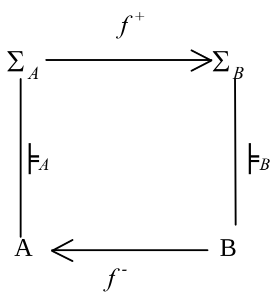


Figure 4. Infomorphism *f* from *A* to *B*

3.3 Channel

The notion of channel is used to express relationships between situations (Devlin 2001b). We write $s_1 \overset{c}{\mapsto} s_2$ to denote that a situation s_1 delivers some of the information supported by a situation s_2 with respect to channel c (Lalmas 1998). The channel allows formalizing the context in which the flow of information takes place. In other words, a channel c is the medium for the flow of information between two classifications A and B as those previously mentioned; it connects them through a core classification C via two infomorphisms f and g (Fig. 5).

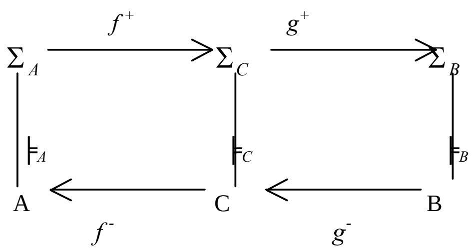
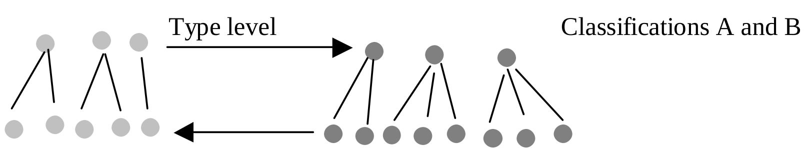


Figure 5. A channel *c* between classifications *A* and *B*

Figure 6 illustrates how the concept of Information Flow works. Herein, we examine how the principles of the flow of information can be applied between different thematic maps to draw inferences about their thematic content; that is the information they carry.



Token level Instances

Figure 6. Applying the Information Flow framework to generate semantic interoperability between communities that use different classifications

4 THEMATIC MAPS AND THE FLOW OF INFORMATION

In this section, we explore the way Information Flow Theory can be incorporated with the reading of thematic maps. We examine this by giving an example of IF-mappings between two symbol-sets of thematic maps, taken from Regions: Statistical Yearbook, (2002) and (2003), representing population density in a part of Europe at different times (years 1996, 1999) (Figures 7 & 8). In this task, we regard maps as classifications that are characterized by local logics as discussed in section 3.1. In the context of Information Flow, we consider classifications to be populated, which means instances of the categories must be included in the classification.

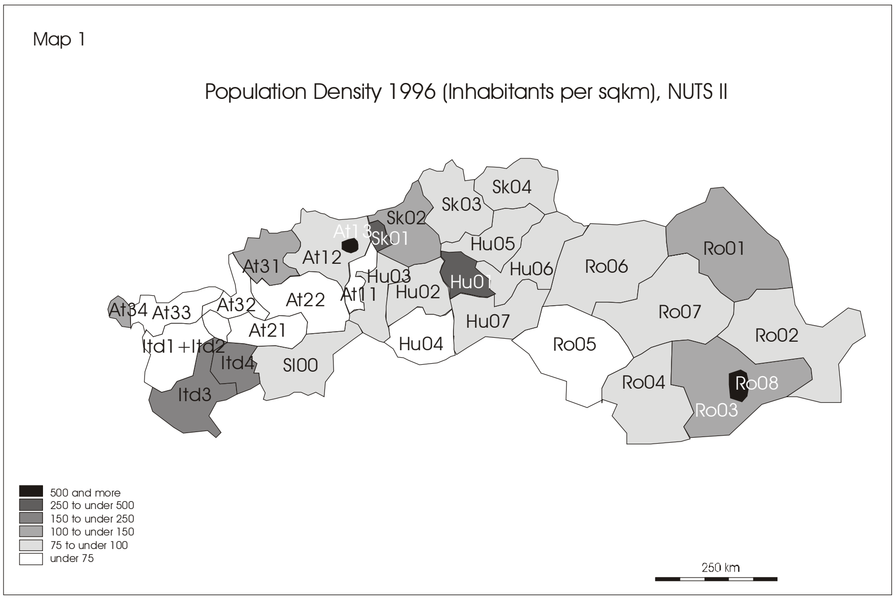


Figure 7. Population density in European regions (NUTSII) in 1996 (map_1)

Note: Several alterations have been made to the original maps so that figures 7- 9, and would be adequately portrayed in black and white. In addition, in figure 7, we added labels for the regions (not present in the original map) according to NUTS II Nomenclature.

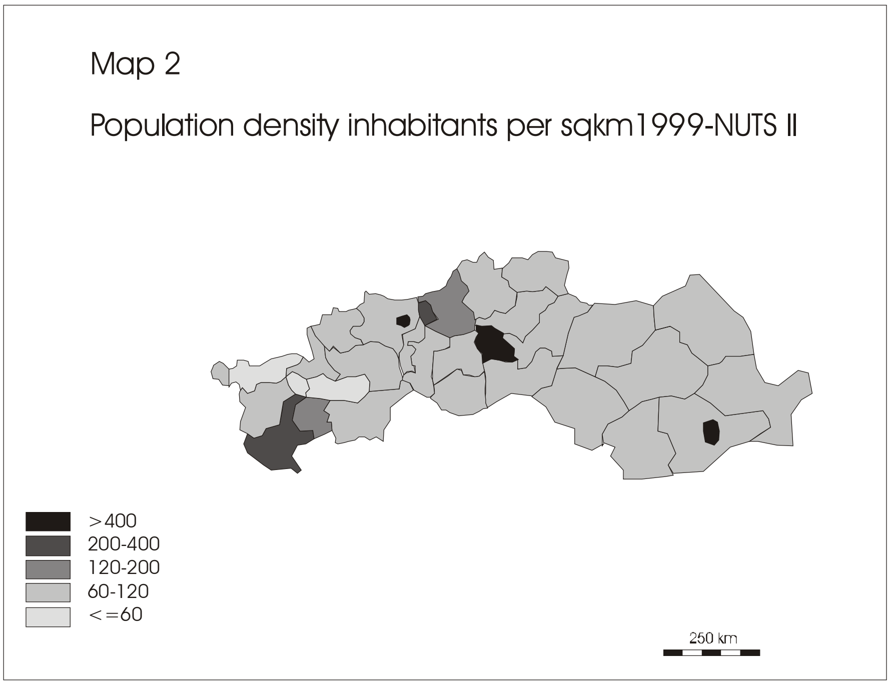


Figure 8. Population density in European regions (NUTSII) in 1999 (map_2)

The first map (Fig. 7) – map_1 represents population density (pd) in 1996 using six classes of pd. On the other hand, the second map (Fig. 8) – map_2 - represents the thematic concept of population density in 1999 (pd) using five classes of pd. As it stands, because of the different classifications, we are not able to reason whether population density of a region has increased or reduced over the three years time. Therefore, the goal is to produce mappings between these two different classifications to be able to draw secure inferences about the *phenomenon*. To generate these mappings in the framework of Information Flow, it is important to use a *channel* as described in the previous section.

Map_1 and map_2 are the two classifications; the legend symbols are the types of each classification, while the regions on the maps bearing the symbols are the tokens of the classification. The channel in this example is a third map, map_3, taken from Regions: Statistical Yearbook, (2003) (Fig. 9), which shows total population change rates between 1996 and 2000, in the same European regions.

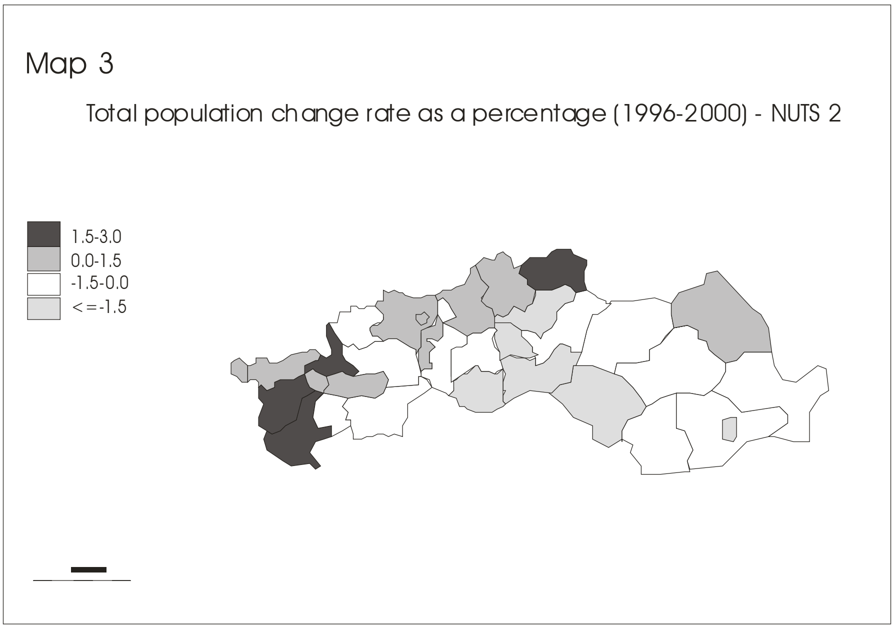


Figure 9. The channel: map of total population change rate as a percentage for years 1996-2000 (map_3)

In our example, we have: different classifications of population density for different times for the same regions. In order to be able to compare these situations, we need a mapping from one classification to another in terms of types and tokens. The obvious relations for the classifications of map_1 and map_2 are shown in figure 10. Although these mappings at the type level are very easily generated, they do not hold at the token level because the values of population density are examined, herein, at different times.

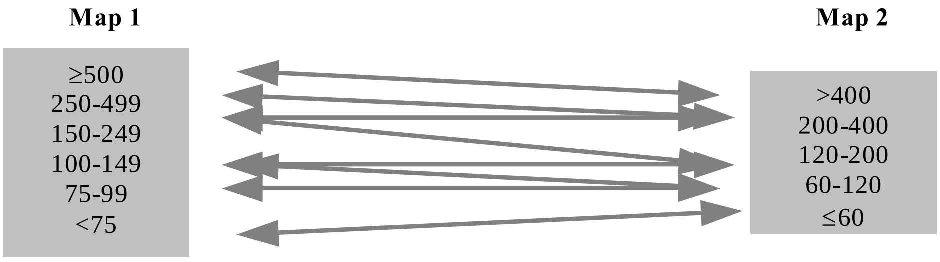


Figure 10. Mappings between classifications map_1 and map_2 at type level

For that reason, we need to find a way to compare these classifications at the token level as well. To do this, we need a source of information that is able to account for changes in population density across time that will serve as the channel within which the information between the two classifications can flow. As already mentioned, the channel in this case is map_3 showing population change rates between 1996 and 2000 for the study region (Fig. 9). Because of lack of other resources for this kind of information, we use map_3 as a channel assuming that *change rate of population is equally distributed within the four years period (A)*, assumption *A* falls in the case of background conditions discussed in section 3.

The steps that we follow are:

- With respect to map_3 and map_1 we calculate the population density in 1999 for the given regions (column 4 of table1)
- Then we compare these to the population density deduced from map_2 (column 5 of table1), and we end up with its true value for every region for the year 1999 (column 2 of table 2).
- Finally, we establish mappings between the two classifications (column 4 of table 2).

REGIONS (NUTS II NOMENCLATURE)	POPULATION DENSITY (INHABITANTS/ KM2), 1996 MAP1	TOTAL POPULATION CHANGE RATE (1996- 2000) MAP3	POPULATION DENSITY (INHABITANTS/ KM2), 1999 (ESTIMATION MAP1 & 3)	POPULATION DENSITY (INHABITANTS/ KM2), 1999 MAP2
ITD3	150-249	1,5-3	151,8-255,0	200-400
ITD4	150-249	-1,5-0	148,2-249,0	120-200
ITD1+ITD2	<75	1,5-3	<76,8	60-120
AT33	<75	0-1,5	<75,9	<=60
AT34	100-149	0-1,5	100,0-150,8	120-200
AT21	<75	0-1,5	<75,9	<=60
AT32	<75	1,5-3	<76,8	60-120
AT22	<75	-1,5-0	<75,0	60-120
AT11	<75	0-1,5	<75,9	60-120
AT31	100-149	-1,5-0	98,8-149,0	60-120
AT12	75-99	0-1,5	75-100,2	60-120
AT13	>=500	0-1,5	>=506,0	>400
SK02	100-149	0-1,5	100,0-150,8	120-200
SK03	75-99	0-1,5	75,0-100,2	60-120
SK04	75-99	1,5-3	75,9-101,4	60-120
SK01	250-499	-1,5-0	247,0-499,0	200-400
SL00	75-99	-1,5-0	74,1-99,0	60-120
HU03	75-99	-1,5-0	74,1-99,0	60-120
HU02	75-99	-1,5-0	74,1-99,0	60-120
HU04	<75	<=-1,5	<74,1	60-120
HU07	75-99	<=-1,5	74,1-97,8	60-120
HU01	250-499	<=-1,5	247,0-493,0	>400
HU05	75-99	<=-1,5	74,1-97,8	60-120
HU06	75-99	-1,5-0	74,1-99,0	60-120
RO05	<75	<=-1,5	<74,1	60-120
RO06	75-99	-1,5-0	74,1-99,0	60-120
RO01	100-149	1,5-3	101,2-152,6	60-120
RO02	75-99	-1,5-0	74,1-99,0	60-120
RO03	100-149	-1,5-0	98,8-149,0	60-120
RO04	75-99	-1,5-0	74,1-99,0	60-120
RO07	75-99	-1,5-0	74,1-99,0	60-120
RO08	>=500	<=-1,5	>=494,0	>400

Table 1. Population density for each region of the study area, as deduced from map_1(column 2), as estimated from map_1 and map_3 (column 4), as deduced from map_2 (column 5).

REGIONS (NUTS II NOMENCLATURE)	POPULATION DENSTITY 1999	RELATION	CLASS MAP1 TO CLASS MAP 2
ITD3	200,0-255,0	Overlapping	4 TO 4
ITD4	148,2-200,0	Overlapping	4 TO 3
ITD1+ITD2	60,0-76,8	Overlapping	1 TO 2
AT33	<=60,0	Refinement	1 TO 1
AT34	120,0-150,8	Overlapping	3 TO 3
AT21	<=60,o	Refinement	1 TO 1
AT32	60,0-76,8	Overlapping	1 TO 2
AT22	60,0-75,0	Overlapping	1 TO 2
AT11	60,0-75,9	Overlapping	1 TO 2
AT31	98,8-120	Overlapping	3 TO 2
AT12	75,0-100,2	Inclusion	2 TO 2
AT13	>400,0	Extension	6 TO 5
SK02	120,0-150,8	Overlapping	3 TO 3
SK03	75,0-100,2	Inclusion	2 TO 2
SK04	75,9-101,4	Inclusion	2 TO 2
SK01	200,0-247,0	Overlapping	5 TO 4
SL00	74,1-99	Inclusion	2 TO 2

HU03	74,1-99	Inclusion	2 TO 2
HU02	74,1-99	Inclusion	2 TO 2
HU04	60,0-74,1	Overlapping	1 TO 2
HU07	74,1-97,8	Inclusion	2 TO 2
HU01	>400,0	Overlapping	5 TO 5
HU05	74,1-97,8	Inclusion	2 TO 2
HU06	74,1-99,0	Inclusion	2 TO 2
RO05	60,0-74,1	Overlapping	1 TO 2
RO06	74,1-99,0	Inclusion	2 TO 2
RO01	101,2-120,0	Overlapping	3 TO 2
RO02	74,1-99,0	Inclusion	2 TO 2
RO03	98,8-120,0	Overlapping	3 TO 2
RO04	74,1-99,0	Inclusion	2 TO 2
RO07	74,1-99,0	Inclusion	2 TO 2
RO08	>400,0	Extension	6 TO 5

Table 2. Population density for each region of the study area for the year 1999, as deduced from map_1 and map_2 and the channel map_3. The third column shows the relation that holds between map_1 and map_2 regarding the classifications' instances/ regions (token level). The fourth column shows the mappings at the instance (token) level

The result of the pursued procedure is that we transformed the classification of population density classes of map_1 into the classification of map_2. Consequently, we ended up with a classification of legend symbols of five (5) classes for map_1 identical to those of map_2 (Table 2). Furthermore, we established relations (Table 2) between the thematic contents of map_1 and map_2; namely, we provided mappings at the token level of the two classifications.

The resulting relations between the tokens of the two classifications can be described in terms of inclusion, overlapping, extension, and refinement. Inclusion is met in cases where a population density class of the first classification can be properly included in a population density class of the second (i.e., AT12 in Tables 1, 2). The case of overlapping holds when a part of a class of the first classification can be included in a class of the second (i.e., RO05). Extension regards expansion of the limits of the initial class (i.e., RO08), while refinement involves the opposite procedure when the limits of the initial class are confined (i.e., AT33). Recall at all times, however, that these relations hold among the tokens of the two classifications.

5 FURTHER WORK

This paper applied the framework of Information Flow using central notions of Situation Theory, to formalize the content of thematic maps. When we use the theory of Information Flow to generate mappings between different maps with different thematic contents the procedure is quite complicated and maps are regarded as distributed systems in which parts stand in relations to each other. An example of Information Flow mappings between two maps has been examined herein. In the future, we aim to expand the methodology to other types of maps such as topographic ones. A major concern of mapmaking in the era of communication and information is the formalization of symbols used by different cartographic traditions, a task that could be facilitated within the Information Flow framework.

Nevertheless, work is needed on the computational aspect of the proposed framework so that it can be used in knowledge representation. Several proposals on tools (Tin and Akman 1995) for computing with situations are still under development. The field of Information Flow has proved to be attractive to information scientists as in Kalfoglou and Schorlemmer (2003) or Kent (2004), with fruitful results so far. In addition, channel theory has been proposed as a methodology for information retrieval (Lalmas 1998) and that may also work in the case of the information carried by maps.

6 ACKNOWLEDGEMENTS

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Selected Publications:

Eleni Tomai, Marinos Kavouras, "From "Onto-GeoNoesis" to "Onto-Genesis" The Design of Geographic Ontologies", accepted for publication in Geoinformatica.
Eleni Tomai, Marinos Kavouras, "Qualitative Linguistic Terms and Geographic Concepts- Quantifiers in Definitions", accepted for publication in Transactions in GIS.
Marinos Kavouras, Margarita Kokla, Eleni Tomai, "Comparing Categories among Geographic Ontologies" accepted for publication in Computers and Geosciences.
Eleni Tomai, Marinos Kavouras, "Where the city sits? Revealing Geospatial Semantics in Text Descriptions", 7th AGILE Conference on Geographic Information Science, Crete, Greece, 28 April - 1 May, ESRI Best Paper Award
Athanassia Darra, Marinos Kavouras, Eleni Tomai, "Representing Semantic Similarity of Socioeconomic Units with Cartographic Spatialization Metaphors", Accepted for publication in International Journal of Pure and Applied Mathematics