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Research Article

A Framework for Intensional and Extensional Integration of Geographic Ontologies

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Abstract
This paper presents ongoing research in the field of extensional mappings between ontologies. Hitherto, the task of generating mappings between ontologies has focused on the intensional level of ontologies. The term intensional level herein, refers to the set of concepts that are included in an ontology. However, an ontology that has been created for a specific task or application needs to be populated with instances. These comprise the extensional level of an ontology. This particular level is generally neglected during the ontologies' integration procedure. Thus, although methodologies of geographic ontologies integration, ranging from alignment to true integration, have, in the course of years, presented a solid ground for information exchange, little has been done in exploring the relationships between the data. In this context, this research strives to set a framework for extensional mappings between ontologies using Information Flow Theory by presenting a case study of interoperability between the thematic content of maps.

1 Introduction

A well-formed domain ontology should be able to provide answers to two types of questions:

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- What is a *X*? Or what it means to be *X*? Or can you define *X*? and
- What is this? Or is this *X*?

The first type of question refers to processes called description, explanation, or definition, respectively. These result in the demarcation of the different concepts in the ontology, as well as their documentations. No reference is made at this point to how these concepts are included in the ontology in the first place. Furthermore, these processes help identify semantic relations from one part and semantic properties from the other part – as defined in Kokla and Kavouras (2002) and Tomai and Kavouras (2004) – which can generate the hierarchical structure of the ontology. The second type of questions refers to the process of categorization; namely the process of assigning members to a category. The process itself accounts for allocating the instances of each concept in the ontology. Therefore, a well-formed domain ontology should both include concepts that stand for some kinds of relationships among them, as well as instances of these concepts.

The aforementioned processes boil down to what linguistics, respectively, defines as:

- Intension; what you must know in order to determine the reference of an expression
- Extension; the class of objects that an expression refers to, in WordNet 2.0 (Cognitive Science Laboratory 2003)

Consequently, we can distinguish between the intensional level (the set of concepts) and extensional level (the concepts' instances) of an ontology.

The growing interest among geoscientists in ontologies, along with the plethora of data for the geographic domain, has revealed the need for consistent information and has set the path for ontologies integration. The issue, therefore, is how to integrate two or more geographic ontologies in order to produce a unified one, or at least how to generate mappings between different ontologies, so that users can switch between them, to achieve semantic interoperability. Bearing in mind that an ontology includes two distinct levels of elements (concepts and instances) that both provide ontological information, we present, herein, a methodology for utilizing both levels in order to advance integration.

The methodology applies tenets from Information Flow (IF) Theory in order to perform integration of ontologies at two levels: the intensional and the extensional. Thus far, the majority of approaches to geographic ontologies integration have explored only the possibilities of integration at the intensional level. The process of integration at this level aims at the analysis of definitions of the concepts, the extraction and statement of their semantic properties and relations and finally the revelation of heterogeneities that guide the establishment of the final/new schema. Herein, we explore the possibilities of adding the extensional level of the ontologies to the integration process. We apply tenets from the IF Theory to integrate the thematic contents of maps due to the lack of populated ontologies in the geospatial domain.

The remainder of the paper is organized as follows: we give a brief account of what has been achieved so far regarding ontologies' integration in section 2. The proposed framework for ontology integration at both the intensional and extensional level is presented in section 3. Section 4 presents the way this framework can be applied for the integration of the thematic contents of maps and we discuss its results. Finally, in section 5 we identify numerous future research questions concerning the intensional and extensional integration of ontologies.

2 Integrating Ontologies: The Way So Far

Several methodologies of ontology integration have been presented by scholars (Vckovski et al. 1999, Uitermark 2001, Wache et al. 2001). According to the framework presented by Kavouras (2005) we can identify four types of integration: alignment, partial compatibility, unification and true integration.

In the case of alignment, mappings are generated between the concepts of the two ontologies; no distortion is made to either of them. This is the simplest integration case for it can be seen as a "translation" mechanism between the two ontologies' concepts. For a methodology on generating mappings between geographic ontologies, refer to Cruz et al. (2004). On the other hand, partial compatibility refers to the unification of the common parts of the ontologies. The result is a single ontology but integration has just taken place for the common parts of the ontology with consequent distortion of the original ones. Unification is an extension of partial compatibility, which results in a single ontology, by unifying every branch of the two ontologies into one. The two initial ontologies are fully distorted.

True integration, on the other hand, refers to the procedure of producing a new ontology, which includes the initial ones without any alteration; however, it includes some new concepts that are needed to associate the ontologies. The initial ontologies can be reused independently from the integrated one. A methodology of true integration between geographic ontologies using Formal Concept Analysis has been introduced by Kokla and Kavouras (2000).

The abovementioned methodologies have dealt with the intensional level of ontologies; they do not treat integration at the extensional level. There has been one case where the integration process has been generated between geographic ontologies at the extensional level; Duckham and Worboys (2005) have proposed an algorithm of geographic ontologies integration depending on relationships between instances, which are able to infer taxonomic relations between the categories themselves. If prior knowledge of the taxonomies exists, it can be taken into account but it is not a prerequisite. The above-described methodology leaves a few open questions regarding the suitability of the assumption that extensional information can be used as an inference mechanism for the taxonomic structure of the intensional level. Two questions that should be addressed are:

- Do identical instances of two categories in the two ontologies refer to equivalent categories, or subsumed ones?
- How many instances to compare in order to achieve integration?

The first question reveals the problem of depending only on instances of ontologies to achieve integration. Two identical instances in two different ontologies may be members of two identical categories. However, this is not always the case; because these instances may belong to one category in the first ontology and to its subsumed category in the second ontology, given that the latter ontology is more detailed than the former. Therefore, inferring the taxonomic structure of the ontologies based only on instances is not adequate. On the other hand, integration at the intensional level has never tackled the issue of how many categories are included in the ontologies to give a result. Nevertheless, in the case of extensional information, there is an issue of sufficiency regarding the minimum number of instances that categories should have before the integration process can be pursued.

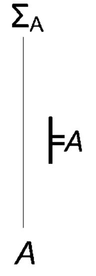

Figure 1 Classification ***A***

3 Integrating Ontologies: The Way Forward

In this section, we present a framework that can set the path for ontology integration at the intensional as well as the extensional level. The following paragraphs present the main notions of the proposed Framework.

3.1 Information Flow

As mentioned, the method utilizes IF Theory to provide the theoretical basis for the integration process. The basic idea behind it, as stated in Barwise and Seligman (1997) is the notion of containment, which translates as *the information an object contains about another*. IF is better understood within a distributed system. 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*" (as quoted from Bremer and Cohnitz 2004).

The sections that follow introduce the basic notions of IF Theory that are of use in the remainder of this paper.

3.1.1 Classification

The components of a distributed system are represented by a classification ***A*** (Devlin 2001), which is a triple, $<A, \Sigma_A, \models_A>$ 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 $\models_A$ to the types (Figure 1).

Each classification has a Local Logic that governs its types (Bremer and Cohnitz 2005). 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 in Worboys (2001), the sequent house $\vdash$ building indicates that houses are buildings.

3.1.2 Infomorphism

For relating two classifications, the notion of infomorphism (Devlin 2001) is introduced. Let ***A*** = $<A, \Sigma_A, \models_A>$ and ***B*** = $<B, \Sigma_B, \models_B>$ 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** (Figure 2).

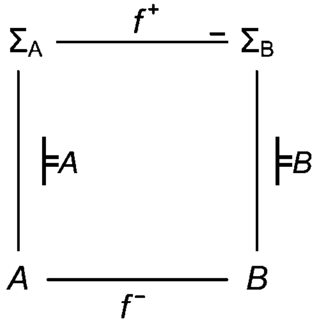

Figure 2 Infomorphism *f* from ***A*** to ***B***

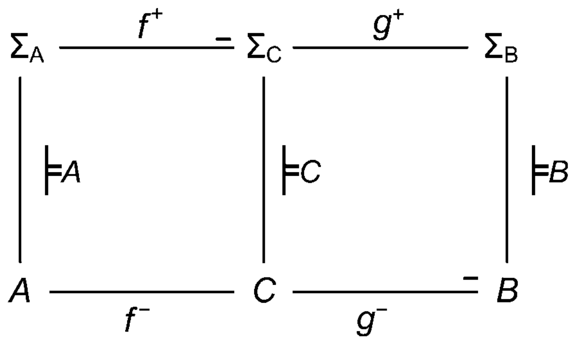

Figure 3 A channel *c* between classifications ***A*** and ***B***

3.1.3 Channel

We write $s1 \overset{c}{\mapsto} s2$ to denote *that a situation s1 delivers some of the information supported by a situation s2 with respect to channel c* as in Lalmas (1998). At this point it is important to mention that the notion of channel was first used to express relationships between situations in Situation Theory, as introduced by Barwise and Perry (1983), the presentation of the theory's basic tenets though, are out of the scope of this paper. The channel allows formalizing the context in which the flow of information takes place. In other words, a channel *c* is the medium of IF between two classifications ***A*** and ***B*** as those previously mentioned; it connects them through a core classification ***C*** via two infomorphisms *f* and *g* (Figure 3).

3.2 Semantic Interoperability

The IF Theory can be used to enable semantic interoperability between different communities that use their own classifications, by providing the necessary mappings across them. Approaches of generating mappings based on IF can be found in Kalfoglou and Schorlemmer (2003). In addition, Kent (2004) has developed the IF Framework for the standardization activity of Standard Upper Ontology, and proposed a methodology for ontology merging.

Interoperability in the context of IF takes place at both the type and the token level as it can be drawn from the above-presented notions of informorphism and channel. Therefore, when generating mappings between classifications, the instances of the classifications are compared as well.

4 An Example of Type/Token Level Mappings between Sources of Geographic Information: The Case of Thematic Maps

In this section, we explore the way IF 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, representing population density in a part of Europe at different times (years 1996, 1999 respectively) and taken from the "Regions: Statistical Yearbook" in 2002 (see http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-AF-02_001/EN/KS-AF-02-001-EN.PDF for additional details) and 2003 (see http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-AF-03_001/EN/KS-AF-03-001-EN.PDF for additional details) (Figures 5 and 6).

The usual elements of a thematic map are the background map, thematic content (expressed by symbols), title, legend, which explains the symbols used, and scale. In this case study we are interested to generate mappings between the thematic contents of the maps; thus, the elements that are of importance to us are the legend symbols that provide information about the thematic content and the regions on the maps that carry these symbols and present the spatial distribution of this content.

In this task, we regard maps as distributed systems with regularities whose components can be represented through the notion of classification which is characterized by local logics as discussed in section 3.1.1 and we attempt to provide mappings between these different systems (maps) to achieve semantic interoperability (Figure 4 shows this procedure).

The first map (Figure 5) – map_1 represents population density (pd) in 1996 using six classes. On the other hand, the second map (Figure 6) – map_2 – shows pd in 1999 using five classes. Following the discussion of section 3.1.1, in our example, map_1 and map_2 are the two classifications, the legend symbols are the types of each classification (classes of the ontology), while the regions on the maps bearing the symbols (which present the thematic content of the regions) are the tokens of the classification (instances of the classes).

As it stands, because of the different classifications, we are not able to reason whether population density of a region has increased or declined 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 changes in population density. However, to generate these mappings within the IF Theory, it is important to use a *channel* as described in the previous section. The channel in this example is a third map, taken from the 2003 Statistical Yearbook (Figure 7) – map_3, which shows total population change rates between the years 1996–2000, in the same European regions.

The idea of using IF Theory for generating mappings between different thematic maps was inspired by Worboys (2001) who applied it to formalize a representation system and gave the following example:

> ". . . let A be the classification of map elements and B be a set of real world objects and features. Then, the representations are the map objects, and map

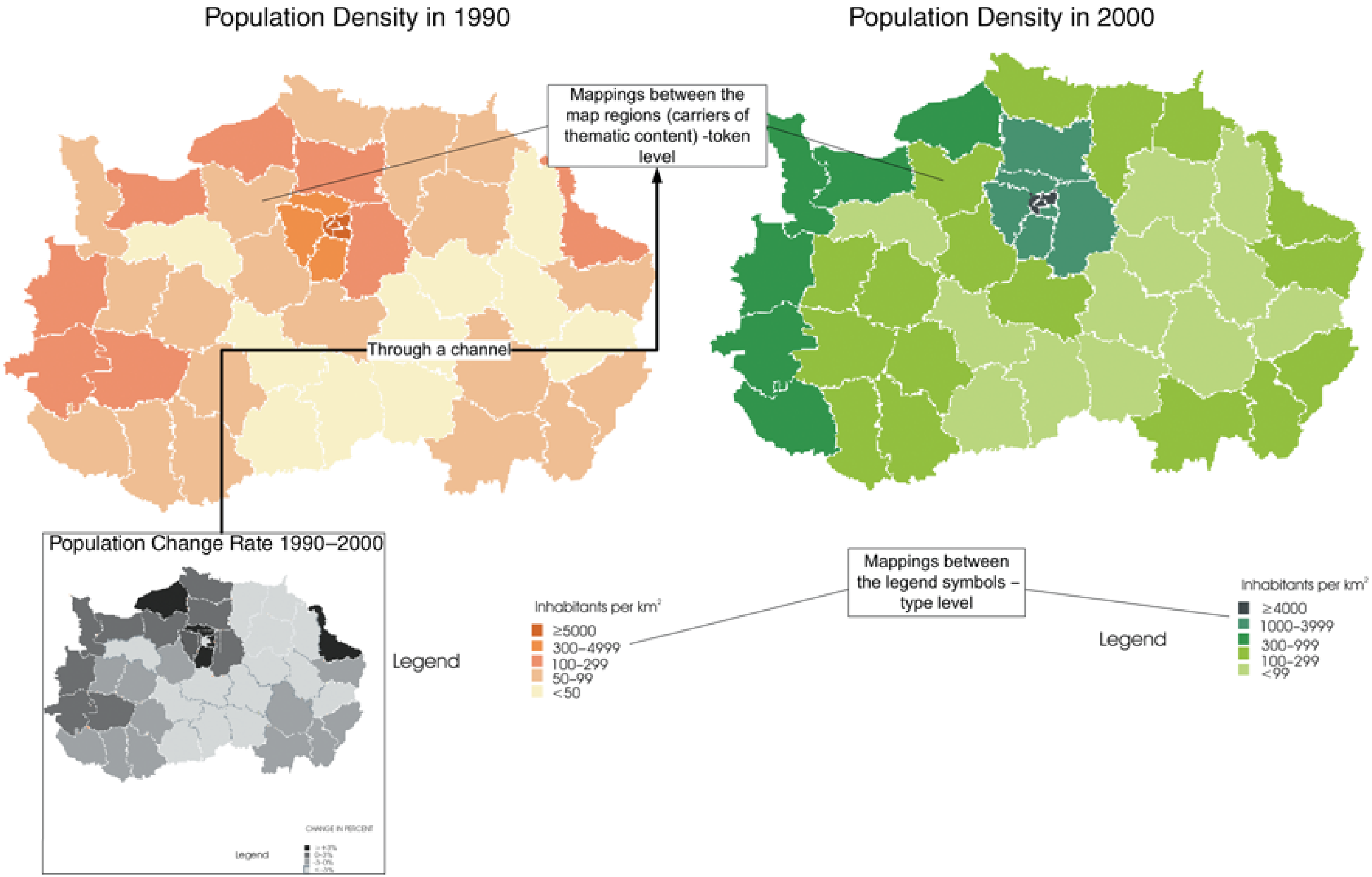

Figure 4 The interoperability aspect of information flow as applied to thematic maps

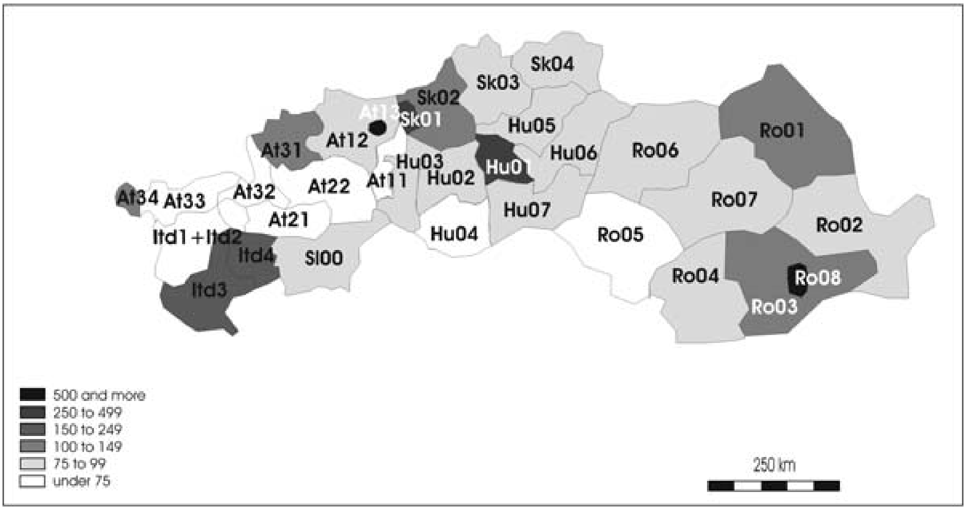

Figure 5 Population density (inhabitants per sq km) in European regions (NUTSII) in 1996 (map_1)

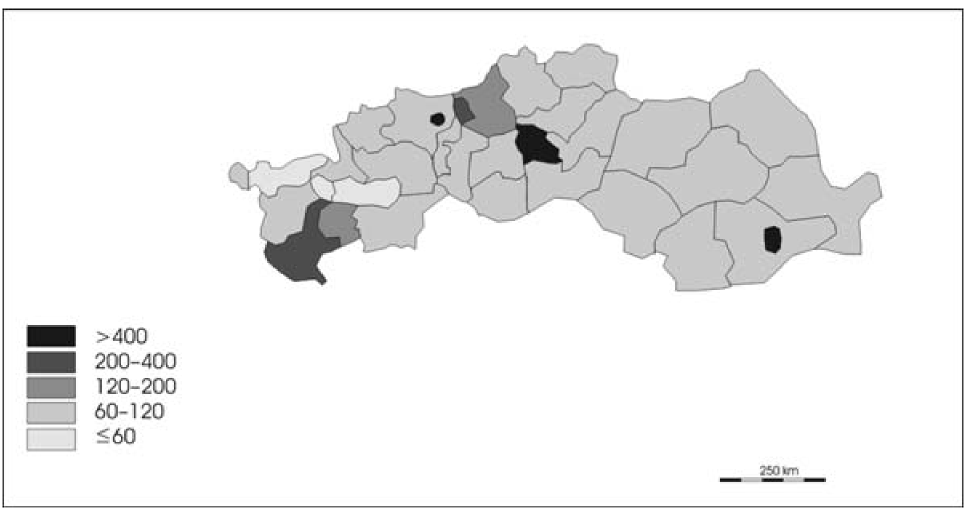

Figure 6 Population density (inhabitants per sq km) in European regions (NUTSII) in 1999 (map_2)

objects are representing real world objects. Let the core C be the cartographic process of surveying real world objects and associating them with map elements. The cartographic process might contain rules such as associating a red line on the map with a road on the ground. So a constraint in the local logic might be draw red line $\vdash$ surveyed road. In that case, red lines indicate roads."

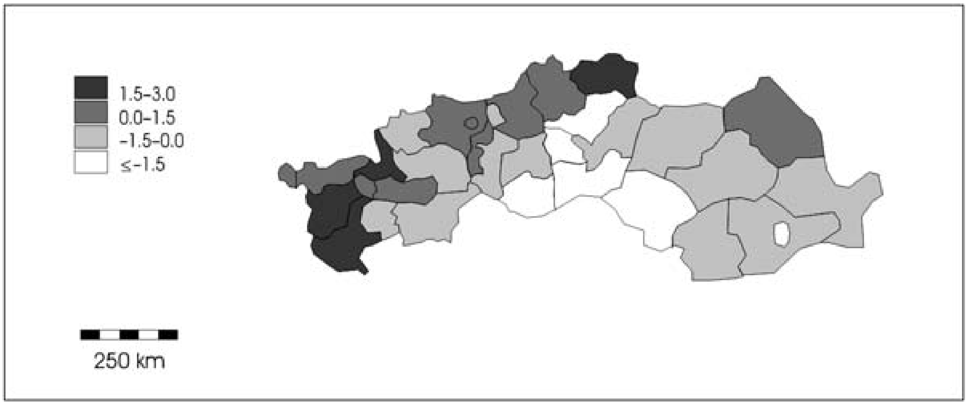

Figure 7 The channel map of total population change rate as a percentage for years 1996–2000 (map_3)

Several facts should be pointed out that ease the generation of mappings, in the example examined herein:

1. Each type (class) of the two classifications symbol sets has at least one region on the map (token) associated with it bearing the intended thematic content. Every map-literate reader knows that no symbol is included in the map legend, unless it provides real thematic data associated with a spatiotemporal entity that is visualized by the map.
2. The tokens of the classification (the regions on the maps) are finite, because they refer to a well-demarcated spatial area.
3. The tokens of the two classifications are equal in number because we used two maps for the same area, this practically means that all instances of one classification will be mapped onto all instances of the other, so these will be one-to-one mappings.

Taking a closer look at our test case, 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 8. 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. In addition, these mappings are one-to-many or many-to-one, which is not acceptable for the mappings at the token level since mappings of thematic contents of these kinds have no meaning; they should be one-to-one.

For that reason, we have 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 (Figure 7). Because of the 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 five years period*.

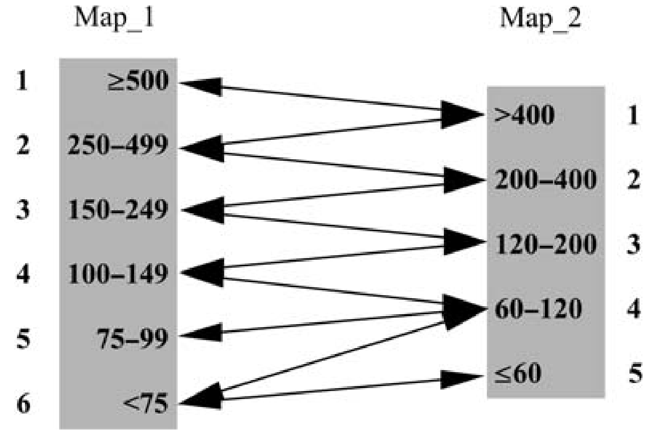

Figure 8 Mappings between classifications map_1 and map_2 at the type level

The steps that we follow are:

- With respect to map_3 and map_1 we calculate the pd in 1999 for the given regions (column 4 of Table 1);
- Then we compare these values to the pd deduced from map_2 (column 5 of Table 1), 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 2 of Table 3).

We think it is time to clarify several points and results. Column 4 of Table 1 shows the calculated pd for the year 1999 by combining information from map_1 and map_3. This procedure gives us a range of pd values. However, map_2 provides information of pd for this year also as a range of values (column 5 in Table 1). Therefore, column 2 of Table 2 shows the range of pd in 1999 values as deduced from the combination of the two aforementioned ranges of values, while column 3 of Table 2 shows the relation that holds between the true values' range of pd for the year 1999 and the pd classes of map_2.

The result of the pursued procedure is that 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 (Table 3).

The resulting relations between the true values' range of pd for the year 1999 and the pd classes of map_2 can be described in terms of inclusion, overlapping, extension, and refinement:

- Inclusion is met in cases where a token of the first classification has a true pd value range that can be properly included in a pd class of the second classification (i.e. AT12);
- The case of overlapping holds when a part of the first classification token's true pd value range can be included in a class of the second (i.e. RO05);
- Extension and refinement are special cases of inclusion because they involve a change of limits of the initial class. Extension holds when the first classification token's true pd value range can be included in a pd class of the second classification but involves expansion of the lower limit of the initial class (i.e. RO08), while

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) and as deduced from map_2 (column 5)

Regions (NUTS II nomenclature)	Population density (inhabitants/km^2), 1996 map_1	Total population change rate (1996–2000) map_3	Population density (inhabitants/km^2), 1999 (estimation map_1 & 3)	Population density (inhabitants/km^2), 1999 map_2
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

refinement involves the opposite procedure when the upper limit of the initial class is confined (i.e. AT33).

Recall at all times, however, that these relations hold among the tokens of the two classifications.

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)

Regions (NUTS II nomenclature)	Population denstity 1999	Relation
ITD3	200,0–255,0	Overlapping
ITD4	148,2–200,0	Overlapping
ITD1+ITD2	60,0–76,8	Overlapping
AT33	≤60,0	Refinement
AT34	120,0–150,8	Overlapping
AT21	≤60,0	Refinement
AT32	60,0–76,8	Overlapping
AT22	60,0–75,0	Overlapping
AT11	60,0–75,9	Overlapping
AT31	98,8–120	Overlapping
AT12	75,0–100,2	Inclusion
AT13	>400,0	Extension
SK02	120,0–150,8	Overlapping
SK03	75,0–100,2	Inclusion
SK04	75,9–101,4	Inclusion
SK01	200,0–247,0	Overlapping
SL00	74,1–99	Inclusion
HU03	74,1–99	Inclusion
HU02	74,1–99	Inclusion
HU04	60,0–74,1	Overlapping
HU07	74,1–97,8	Inclusion
HU01	>400,0	Overlapping
HU05	74,1–97,8	Inclusion
HU06	74,1–99,0	Inclusion
RO05	60,0–74,1	Overlapping
RO06	74,1–99,0	Inclusion
RO01	101,2–120,0	Overlapping
RO02	74,1–99,0	Inclusion
RO03	98,8–120,0	Overlapping
RO04	74,1–99,0	Inclusion
RO07	74,1–99,0	Inclusion
RO08	>400,0	Extension

5 Conclusions

Mappings in the context of IF can be easily generated in the case of thematic maps as the previous discussion has demonstrated. Future research comprises the application of IF concepts in the field of ontologies. This has not been fully addressed, herein, because

Table 3 Mappings at the instance (token) level

Regions (NUTS II nomenclature)	Class map1 to class map2
ITD3	4 to 4
ITD4	4 to 3
ITD1+ITD2	1 to 2
AT33	1 to 1
AT34	3 to 3
AT21	1 to 1
AT32	1 to 2
AT22	1 to 2
AT11	1 to 2
AT31	3 to 2
AT12	2 to 2
AT13	6 to 5
SK02	3 to 3
SK03	2 to 2
SK04	2 to 2
SK01	5 to 4
SL00	2 to 2
HU03	2 to 2
HU02	2 to 2
HU04	1 to 2
HU07	2 to 2
HU01	5 to 5
HU05	2 to 2
HU06	2 to 2
RO05	1 to 2
RO06	2 to 2
RO01	3 to 2
RO02	2 to 2
RO03	3 to 2
RO04	2 to 2
RO07	2 to 2
RO08	6 to 5

geographic ontologies are very hard to find, and even if this is the case, the majority of them is not populated with instances.

There is nevertheless a long way to go when trying to apply IF Theory to populated geographic ontologies. The problematic aspects of such an endeavour consist, among others, of several facts such as the following:

1. Ill-defined categories are more likely to include ill-defined instances.
2. Definition process produces less fuzzy results than categorization.
3. Relations among the tokens do not necessarily hold among the types and vice versa.

The first aspect boils down to the fact, that if integration at the intensional level has to tackle not properly defined categories or not clear-cut taxonomies then these issues are likely to be inherited at the extensional level as well. This practically means that instances of ill-defined categories are susceptible to the ambiguity of the categories they belong to.

The second point distinguishes between the notions of categorization and definition. According to cognitive scientists and psychologists, the process of assigning members to a category may result to overlapping categories or categories with blurred edges. While, on the other hand, defining a category may have shortcomings like partial or inadequate descriptions of a category, nonetheless, it results in a better demarcation among categories.

The third point can be easily clarified by the previous example. Figure 8 portrays the mappings at the intensional level, while the last column of Table 3 shows the mappings at the extensional level and illustrates the relations that hold between the instances. These relations, however, do not hold at the intensional level, for extensional level relations are one-to-one, while intensional level ones can also be one-to-many, or many-to-one.

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