Comparing Representations of Geographic Knowledge Expressed as Conceptual Graphs*

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Abstract. Conceptual Graphs are a very powerful knowledge and meaning representation formalism grounded on deep philosophical, linguistic and object oriented principles [1], [2]. Concerning geographic knowledge representation and matching, the study and analysis of geographic concept definitions plays an important role in deriving systematic knowledge about concepts and comparing geographic categories in order to identify similarities and heterogeneities [4]. Based on the proposed algorithm for the representation of geographic knowledge using conceptual graphs, we also present a method that takes into consideration the special structure of conceptual graphs and produces an output that shows how much similar two geographic concepts are and hence which concept is semantically closer to another. For producing the conceptual graph representation of any geographic concept definition we follow two steps, tagging and parsing, while for measuring the similarity between two geographic ontologies we apply proper modifications to the Dice coefficient that is mainly used for comparing binary structures.

1 Introduction

Conceptual Graphs are a powerful knowledge and meaning representation formalism grounded on deep philosophical, linguistic and object-oriented principles [1], [2]. They provide extensible means of capturing and representing real-world knowledge. Fundamental studies about Conceptual Graphs and some of their applications in the field of Knowledge Representation are found among others in [3].

Concerning geographic knowledge representation, the study and analysis of geographic concept definitions plays an important role in the attempt to derive systematic knowledge about concepts and compare geographic categories in order to identify semantic similarities and heterogeneities [4]. Therefore, the exploitation of effective methods for the representation of geographic definitions forms the basis of the research for analyzing geographic concepts in order to structure their meaning and extract semantic information.

The purpose of the present research is to develop an algorithm for the representation of geographic knowledge using conceptual graphs and then, based on the

* This work extends the use of conceptual graphs in geographic knowledge representation as first introduced in [18]. It also addresses the issue of comparison.

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proposed methodology and the special features and structures of conceptual graphs, to describe a well-defined process for comparing two geographic concept definitions in order to quantitatively measure their semantic similarity. The comparison process takes into consideration the structure of the corresponding conceptual graphs and produces an output that shows how much similar two geographic concepts are and hence which concept is semantically closer to another.

By introducing an algorithm that takes a geographic concept definition as input and produces the corresponding conceptual graph representation, we achieve to break many limitations and obstacles in the extraction of semantic information from definitions of geographic concepts. Furthermore, we provide alternative deterministic means of facilitating semantic interoperability since the similarity between geographic ontologies depends on specific results of the introduced method for comparing geographic ontologies.

2 Related Work

During the last years, research has been done in order to represent and extract information about geographic concepts. Approaches on geographic knowledge representation include methodologies that are based on analyzing geographic concept definitions and finding effective representations. These can be found among others in [5] and [6].

Conceptual Graphs are a diagrammatic and expressive way of knowledge representation that was firstly introduced for the representation of contents of natural language texts. According to the conceptual graph theory [7], a conceptual graph is a network of concept nodes and relation nodes. The concept nodes represent entities, attributes, or events (actions) while the relation nodes identify the kind of relationship between two concept nodes.

Conceptual Graphs are formally defined by an abstract syntax that is independent of any notation, but the formalism can be represented in either graphical or character-based notations. In the graphical notation, concepts are represented by rectangles, conceptual relations by circles and the arcs that link the relations to the concepts are represented by arrows. The linear form is more compact than the graphical and it uses square brackets instead of boxes and parentheses instead of circles.

Research into establishing comparison methods for similarity measurement between two conceptual graphs is included in [8] and [9]. The main goal of the proposed approaches is to determine whether a query graph is completely contained in any given conceptual graph.

On the other hand, in many text-oriented applications, comparison methods for text representations are proposed and implemented. For instance, in [10] different types of coefficients are introduced for similarity measurement of various data structures and representations. Among them, the Jaccard coefficient, the Cosine coefficient and the Dice coefficient are mainly used for comparing binary structures not only because their results are widely accepted, but also because they are very simple.

Our algorithm for similarity measurement is based on the Dice coefficient, which is calculated using the following formula:

$$S_{D1, D2} = 2\ C\ (D_{1, 2}) / (C\ (D_1) + C\ (D_2)) \quad (1)$$

C ($D_{1, 2}$) is the number of terms that the two representations (D_1 and D_2) have in common and C (D_1), C (D_2) is the total number of terms in D_1, D_2 respectively. Its simplicity and normalization are the main reasons for taking it as the basis for our proposed algorithm.

After adopting proper modifications to the above formula due to the special structure and content of conceptual graphs representing geographic concept definitions, we propose a comparison methodology that measures similarity quantitatively and can be used as a matching criterion for similarity measurement between two geographic ontologies.

3 Unfolding Concept Definitions

Every geographic concept definition is usually given by a few sentences that contain two types of information: the *genus* and the *differentia*. The *genus*, or hypernym, specifies the class in which the concept is subsumed and contains information that is frequently used for concept taxonomy construction. On the other hand, the *differentia* specifies how different that concept is from the other concepts in the same class. It is a set of attributive adjectives and prepositional phrases that differentiates words with the same genus. It can also provide the purpose, the location, the look and many other aspects of general knowledge through the existence of one or more sub-clauses, each one giving a different kind of general information.

For example, Table 1 shows the genus and the differentia of the definition: *A Canal is a long and narrow strip of water made for boats and irrigation.* This definition of the concept *Canal* appears in the lexical database WordNet [11].

Table 1. Genus and Differentia of the geographic concept *Canal*

Genus	*Strip*
Differentia	*Long, narrow* (attributive adjectives) *Of water* (prepositional phrase) *Made for boats and irrigation* (sub-clause)

Moreover, we consider that every definition of a geographic concept consists of two parts: the *main* and the *secondary* part. The *main* part of the definition is the clause that contains the genus, its attributive adjectives and the prepositional phrases describing the genus, while the *secondary* part contains the given sub-clauses, which further describe the geographic concept.

The main part consists of the *determinant* section, which follows the general form [{article}+{concept name}+{is}], and the *attributes* section. The *attributes* section is the descriptive clause of the *main* part that contains the genus, the attributive adjectives and the prepositional phrases. The *attributes* section has the general form: [{attributive adjective}*+{genus}+{prepositional phrase}*], where the asterisk declares one-or-many. Table 2 shows the above parts in the definitions of the concept *Canal*.

Table 2. *Canal* Definition' s main and secondary parts

Main part	Determinant section	Attributes section
	A Canal is	*A long and narrow strip of water*
Secondary part	*Made for boats and irrigation* (sub-clause)	

The *secondary* part of a definition contains one or more clauses that provide a particular kind of information (purpose, location, etc.). Each sentence in the secondary part contains a reserved phrase (for example: used for, located at, made for etc.) that indicates the semantic relation of the provided information [4]. In the above example, the *secondary* part contains only one sentence ('*made for boats and irrigation'*) in which the deserved phrase '*made for*' declares that the sentence describes the purpose of the described concept.

4 Representation Algorithm

The proposed methodology transforms the definition of a geographic concept into the corresponding conceptual graph without losing any of the information contained in the definition. The representation algorithm consists of two main steps: *tagging* and *parsing*. In the first step, we follow appropriate rules to tag every word of the concept definition. In the second step, we apply a deterministic algorithm in order to parse the tagged definition and create the corresponding conceptual graph.

Alshawi [13] was the first who developed the idea of using a hierarchy of phrasal patterns to identify formulas in concept definitions. Later on, other researchers [14], [15] proposed the method of parsing the definition first, and then doing a search to locate defining formulas and use some heuristics to find the words involved in the relations. This paper is based on the last approach. We parse a geographic definition sentence before we transform it into a conceptual graph and then perform further steps at the graph level.

We separately tag and parse the *main* and the *secondary* part of a geographic concept definition. In that way, we produce two conceptual graphs, one corresponding to the *main* part of the definition and the other to the *secondary* one. By joining them, we result in the complete conceptual graph representation of the geographic concept.

4.1 Tagging

Every definition is made of tokens. Table 3 summarizes the chosen parts of speech (tags) that we associate with the words of the *main* and the *secondary* part of the geographic concept definition. The difference between 'vb' and 'v' tags is that 'vb' always belongs to the *determinant* section of the *main* part and represents the special verb that introduces the definition of the geographic concept.

Concerning the *determinant* section, which always consists of an {article}, the {concept name} and the verb {is} (for example: 'A Canal is'), it is tagged using the abbreviations 'art', 'n' and 'vb'. Therefore, the tagging step for the *determinant* section of *Canal* produces the output: '{A (art) Canal (n)} {is (vb)}'.

Table 3. Tags used in the first step of the algorithm

Article	Noun	Verb "be"	Verb	Adjective	Preposition	Conjunction	Reserved Phrase
Art	n	vb	v	adj	prep	conj	rp

As regards the *attributes* section, which contains the genus, the attributive adjectives and one or more prepositional phrases, it is classified into the general form [{attributive adjective}*+{genus}+{prepositional phrase}*]. Consequently, it is tagged using the abbreviations 'adj' for all attributive adjectives, 'n' for the genus and 'prep', 'n' for the prepositional phrases. Thence, the tagging process on the *attributes* section of '*Canal*' produces: '{a (art) long (adj)} {and (conj)} {narrow (adj)} {strip (n)} {of (prep)} {water (n)}'.

Finally, for the *secondary* part of a concept description, which contains one or more sentences, we apply the tagging process in each one of them. The abbreviation for the reserved phrase is 'rp' (made for, used for, located at, etc.) while the rest words of the *secondary* part are usually tagged with the abbreviations 'n', 'adj' and 'conj'.

The *tagging* step for the given definition of *Canal* results in: '{A Canal (n)} {is (vb)} {a long (adj)} {and (conj)} {narrow (adj)} {strip (n)} {of (prep)} {water (n)} {made for (rp)} {boats (n)} {and (conj)} {irrigation (n)}.

4.2 Parsing

The *parsing* process in the introduced methodology is an algorithmic procedure consisting of three phases. In the first phase, we *parse* the tagged *determinant* and *attributes* sections of the *main* part of the definition in order to create the corresponding conceptual graph. Next, we apply *parsing* rules in all clauses that belong to the tagged *secondary* part of the definition ending in the creation of the corresponding conceptual graph for each clause. Finally, we combine the previously created conceptual graphs in a single one that represents the entire geographic concept definition.

Parsing *Determinant* and A*ttributes* Sections (*Main* Part)

The conceptual graph of the tagged *determinant* section (*{article (art) concept name (n)}{is (vb)}*) always follows the general form of Figure 1. The concept type *{genus}* refers to the genus contained in the *attributes* section of the tagged *main* part. Figure 2 shows the conceptual graph for the representation of the *determinant* in the phrase *'A Canal is a …strip…'*.

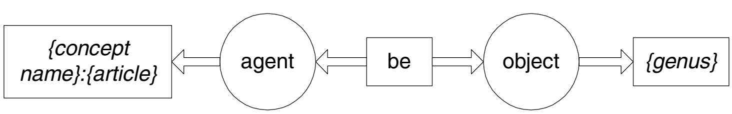

Fig. 1. Conceptual graph representing the *determinant* section

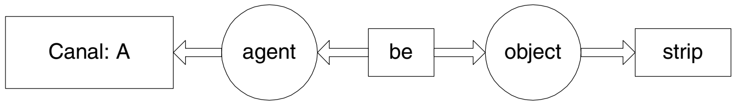

Fig. 2. Conceptual graph for *Canal*'s *determinant*

Concerning the attributive adjectives (tagged with '*adj'*) in the *attributes* section, we define one concept type for each one of them, which is connected to the genus concept type via a concept relation of type '*atr'* (Figure 3).

Moreover, for every tagged prepositional phrase, we introduce a conceptual relation of type '*preposition'* which is also connected to the genus of the definition and to the graph that corresponds to the remaining terms of the prepositional phrase. In general, a tagged prepositional phrase consists of one preposition (tagged with *'prep'*), one or more attributive adjectives (tagged with '*adj'*) and nouns ('*n'*): *{preposition}{attributive adjectives}*{noun}**. The attributive adjectives (if exist) characterize the noun (for example: 'a strip of water' or 'a strip of cold water'). Figure 4 contains the general form of the conceptual graph corresponding to the prepositional phrase of type *{preposition}{attributive adjective}{noun}*.

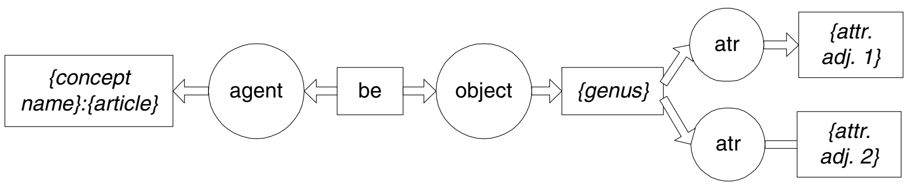

Fig. 3. Conceptual graph general form for attributive adjectives

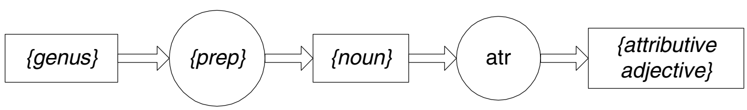

Fig. 4. Conceptual graph general form for every prepositional phrase

Therefore, for the given definition of *'Canal'*, the *main* part is represented as follows.

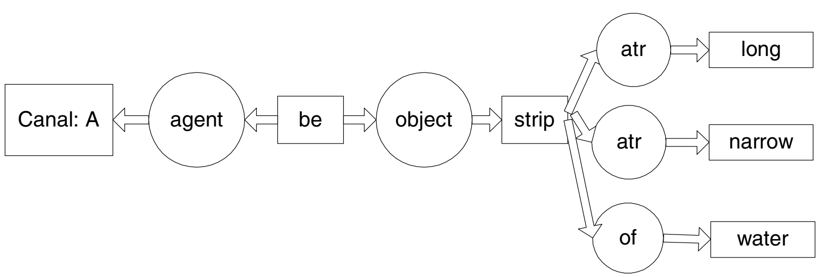

Fig. 5. *Canal*'s *main* part conceptual graph

Parsing *Secondary* Part

Every sentence in the *secondary* part, as resulted from the tagging process, consists of a reserved phrase that reveals the sentence's semantic relation type and the remaining part providing the information itself or value of the relation (for example 'made for boats and irrigation'). In the parsing procedure, the tagged reserved phrase is transformed into the corresponding concept type (for example *'made for'*). This concept is related to the genus concept via a concept relation of type *'agent'* and to the concept types that correspond to other structural elements of the sentence via a concept relation of type *'object'*.

Figure 6 shows the general conceptual graph representation form of a definition's *secondary* part. We consider that the general type of every sentence in the *secondary* part is: *{reserved phrase}({attributive adjectives}{information})**, where the *'information'* is represented with the concepts *'info 1'*, *'info 2'*.

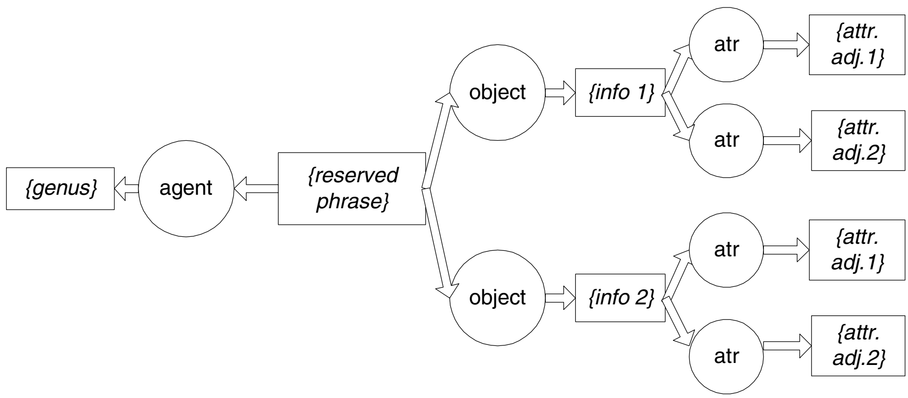

Fig. 6. Conceptual graph general form for the *secondary* part

Figure 7 shows the representation of the *secondary* part of the 'C*anal'* definition.

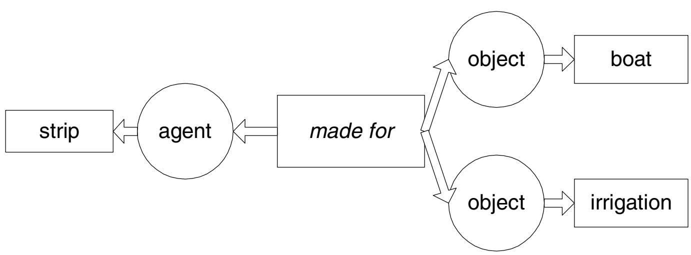

Fig. 7. Conceptual graph representation for *Canal*'s *secondary* part

The above step draws from the methodology for analyzing definitions and extracting information in the form of semantic relations which was introduced by [15] and further pursued by [16] and [17]. This approach consists in the syntactic analysis of definitions and in the application of rules, which examine the existence of certain syntactic and lexical patterns. Patterns take advantage of specific elements of definitions, in order to identify a set of semantic relations and their values based on the syntactic analysis.

Combination

The combination of the conceptual graphs corresponding to the *main* and *secondary* parts of a geographic concept definition produces the integrated representation of the definition. It is the simplest step in the overall procedure since both of the two graphs contain the common concept '*genus*'.

Figure 8 represents the conceptual graph corresponding to the output of the parsing method for the *main* and the *secondary* parts of the definition: *'A Canal is a long and narrow strip of water made for boats and irrigation'*.

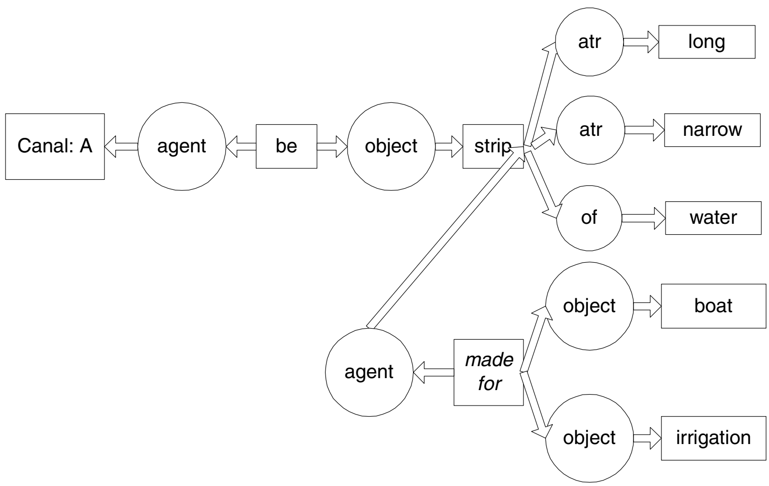

Fig. 8. Conceptual graph representing *Canal'* s concept definition

5 Comparison Algorithm

Analyzing geographic concept definitions constitutes an effective way for revealing and capturing geographic knowledge. Based on the proposed algorithm for representing geographic knowledge using conceptual graphs, we introduce a straightforward methodology for the semantic comparison of two geographic concepts.

The procedure takes as input two geographic concept definitions and follows the next steps:

1. Builds the corresponding representations of the given definitions (CG1 and CG2).
2. Determines the 1…n intersections of CG1 and CG2 (I1, I2, … In).
3. Applies a well-defined formula in each intersection that relatively measures how similar the two conceptual graphs are, in order to produce a real number between 0 and 1 that shows the value of similarity between the two geographic concepts according to our algorithm.
4. Summarizes the outputs of the previous step in order to produce the overall similarity value.

In the next paragraphs, we describe the proposed comparison methodology along with an illustrative example that semantically compares concepts *Sea* and *Lake*. The definitions of these concepts, as they appear in the lexical database WordNet are:

- *Sea*: A large body of salt water partially enclosed by land.
- *Lake*: A body of fresh water surrounded by land.

5.1 Building Conceptual Graph Representations CG1 and CG2

For transforming the definitions of the two geographic concepts into the corresponding conceptual graphs, we follow the introduced representation algorithm. Applying the two steps, tagging and parsing, in every part of the given definitions, we construct the conceptual graphs CG1 and CG2 shown in Figures 9 and 10.

In this step, it is necessary to find synonyms and hypernyms for category terms and concepts. Reference ontologies, dictionaries or thesauri may provide this information, however human intervention may also be necessary at this phase.

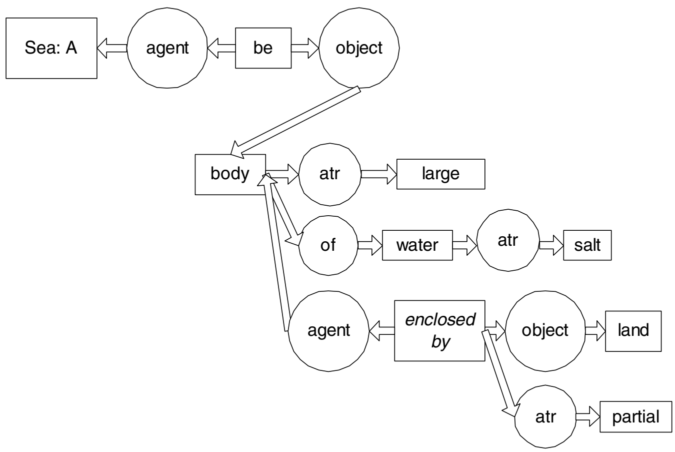

Fig. 9. Conceptual graph representation CG1 of '*Sea'* definition

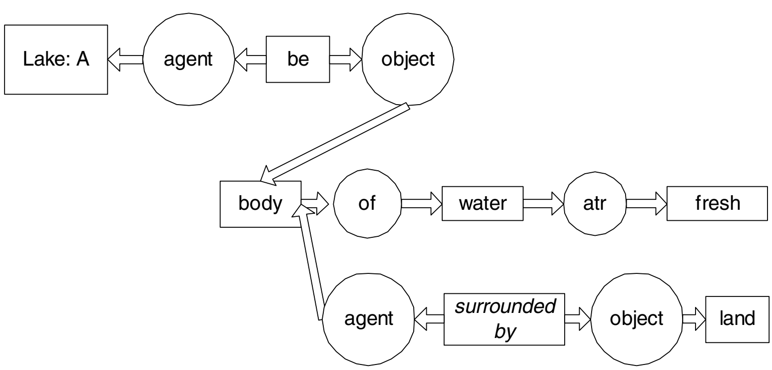

Fig. 10. Conceptual graph representation CG2 of '*Lake'* definition

For the purpose of our running example, we used WordNet and Merriam-Webster online. For example, concepts "enclosed by" and "surrounded by" are synonymous and therefore they represent the same concept.

Exploring the two definitions and analyzing their corresponding representations (CG1 and CG2), we conclude that they have the same genus or hypernym (‘*body*’), which means that they subsume in the same class. But, concerning their *differentia*, which specifies how different a concept is from another concept in the same class, we notice that the concept ‘*Sea*’ is characterized by the attributive adjective ‘*large*’, the prepositional phrase ‘*of water*’ and a single sub-clause (‘*enclosed by land*’) which describes further the concept, while ‘*Lake*’ is characterized by the prepositional phrase ‘*of water*’ and the sub-clause ‘*surrounded by land*’. The attributive adjective ‘*fresh*’ refers to the noun ‘*water*’.

The next table summarizes the differences in every part of the given definitions.

Table 4. Genus and differentia for ‘*Sea*’ and ‘*Lake*’

	Definition: *Sea*	Definition: *Lake*
Genus	Body	Body
Main part	Large, of water	Of fresh water
Secondary part	Enclosed by land	Surrounded by land

5.2 Determining Intersections I1, I2, …In of CG1 and CG2

After comparing CG1 and CG2, we determine their intersections depending on their structure, concept nodes and relation nodes. We name the corresponding conceptual graphs I1, I2, … In.

Every intersection I consists of all concept types that appear both in CG1 and CG2 and all relations that relate these concepts and appear in both CG1 and CG2. When an intersection consists of a single concept node, then there are not any relation nodes.

Therefore, comparing the conceptual graph representations of definitions ‘*Sea*’ and ‘*Lake*’, we build the intersections I1 and I2.

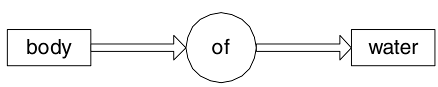

Fig. 11. Intersection I1 of CG1 and CG2

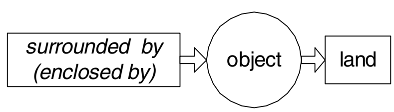

Fig. 12. Intersection I2 of CG1 and CG2

It is important to mention that we never consider the intersection of Figure 13 because it is common to all conceptual graphs that represent geographic concept definitions according to the introduced methodology.

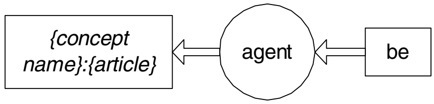

Fig. 13. Common intersection

5.3 Applying the Proposed Similarity Formula in I1, I2…In

To determine how similar CG1 and CG2 are, based on each of their intersections, we apply a deterministic formula that produces a number between 0 and 1. 1 indicates that CG1 and CG2 are semantically equivalent, while 0 indicates that they are completely different.

Moreover, because the similarity between two geographic concepts represented using conceptual graphs depends on both the concept types that they have in common and their position in CG1 and CG2, it is essential to construct a similarity measure that depends on both of these characteristics.

In the comparison algorithm, we adopt and properly reform the Dice coefficient in order to measure the similarity between CG1 and CG2 (where CG1 and CG2 represent geographic concepts). The proposed coefficient is analogous to the Dice coefficient but it also depends on what kind of concepts the two graphs have in common. For example, two geographic definitions that share the same genus are more similar than two entities that have in common only one or more attributive adjectives.

Therefore, if CG1 and CG2 are conceptual graphs that represent the definitions of two geographic concepts, I is any of their intersection and:

- C_{CG1} and C_{CG2} represent the number of concept nodes in CG1 and CG2.
- $C_{I\text{-}GENUS} = 1$ when I contains the common genus of CG1 and CG2 (if exists) and 0 otherwise.
- $C_{I\text{-}MAIN}$ is the number of concept nodes of I that also belong to the main part of CG1 and CG2.
- $C_{I\text{-}SEC}$ is the number of concept nodes of I that also belong to the secondary parts of CG1 and CG2.

Then the conceptual similarity measure S_C of CG1 and CG2 based on their intersection I is calculated as follows:

$$S_C = 2(W_{GENUS}*C_{I\text{-}GENUS} + W_{MAIN}*C_{I\text{-}MAIN} + W_{SEC}*C_{I\text{-}SEC})\ (C_{I\text{-}GENUS} + C_{I\text{-}MAIN} + C_{I\text{-}SEC}) / (C_{CG1}+C_{CG2}) \quad (2)$$

Where:

- $W_{GENUS} = 0.5$, is the weight of the common genus in CG1 and CG2 (if exists).
- $W_{MAIN} = 0.3$ / (total number of concept nodes of CG1 and CG2 belonging to their main part), is the weight of every concept node in I that belongs to both main parts of CG1 and CG2.

- W_{SEC} = 0.2 / (total number of concept nodes belonging to the secondary parts of CG1 and CG2), is the weight of every concept node in I that belongs to both secondary parts of CG1 and CG2.

Assigning different weights to concepts of I, depending on their position in CG1 and CG2, we achieve to relate the value of S_C not only with the total number of concepts that the two conceptual graphs have in common in intersection I, but also with the exact position of every concept in I in both definition representations. This means that the proposed similarity measure is higher for two definitions that have a number of common concepts belonging to their main parts than two definitions that share the same number of common concepts but in their secondary parts.

The selected values ensure that the weight of the common genus (if exists) is always bigger than the weight of any other concept the two graphs have in common and that the weight of any common concept belonging to both main parts of CG1 and CG2 is always bigger than the weight of any common concept belonging to both secondary parts of the two graphs. In case that CG1 and CG2 are exactly the same (i.e. they have the same genus and the same main and secondary parts), the similarity measure equals 1.

Therefore, applying the above formula for the calculation of S_C for I1 and I2, we are able to measure the semantic similarity between the geographic concepts '*Sea*' and '*Lake*' based on their intersections:

$S_{C(I1)} = 2\ (0.5 * 1 + (0.3/5)*1 + (0.2/5)*0)\ (1 + 1 + 0) / (7 + 5) = 0.186.$

$S_{C(I2)} = 2\ (0.5 * 0 + (0.3/5)*0 + (0.2/5)*2)\ (0 + 0 + 2) / (7 + 5) = 0.026.$

5.4 Estimating the Similarity Measure from $S_{C(I1)}, S_{C(I2)}, \ldots S_{C(In)}$

The exact value of the proposed similarity measure for two geographic concepts expressed by conceptual graphs is the sum of $S_{C(I1)}$, $S_{C(I2)}$… $S_{C(In)}$.

Consequently, the corresponding value for concepts '*Sea*' and '*Lake*' is: 0.186 + 0.006 = 0.212. From this result, it is obvious that CG1 and CG2 are semantically similar and that they do have concepts in common. In case there were a greater number of common concepts (especially if they belonged to the main parts of the two graphs), this value would be higher.

6 Conclusions and Further Work

The present research focuses on the representation of geographic concept definitions using conceptual graphs and the development of a comparison methodology that is based on the proposed representation method.

Developing a straightforward and easy-to-implement process for transforming a structured geographic concept definition into the corresponding conceptual graph representation breaks many limitations and obstacles in the extraction of semantic information from definitions of geographic concepts and facilitates the implementation of an interoperable geographic environment.

Moreover, the comparison algorithm, based on the structure and content of the graphs expressing geographic concepts, produces as output a similarity value between 0 and 1, which shows how much two concepts are semantically close to each other.

The present work is the first step towards establishing methodologies for identifying and representing similarities between concepts in geographic ontologies. The next step involves the extension of the introduced algorithm in order to allow measuring the similarity between two geographic concept definitions according not only to the conceptual similarity of their representations, but also to their relational similarity. This is very important because of the bipartite nature of conceptual graph representations (concepts and relations).

Furthermore, we are going to incorporate characteristics which ensure that the semantic similarity is measured not only quantitatively but also qualitatively and that the similarity algorithm also takes into account the heterogeneities between two conceptual graphs that represent geographic concept definitions.

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