On the Use of Automated Reasoning Systems in Ontology Integration*

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Abstract. Ontology Integration is a challenge in the field of Knowledge Engineering, whose solution is indispensable for the envisioned Semantic Web. Some approximations suffer from logical confidence, and others are hard to mechanize. In this paper a method – assisted by Automated Reasoning Systems – to solve a subproblem, the merging of ontologies, is presented. A case study of application is drawn from the field of Qualitative Spatial Reasoning.

Key words: Ontology merging, lattice categorical theory, formal ontology building

1 Introduction

Ontology building has been an aim of the Knowledge Representation (KR) community during the last decades and, with special emphasis, in the last years, with the project of Semantic Web (SW). Such a project aims to enrich the Web by machine processable information [5]. Ontologies help to assign metadata to information by means of the formal description of the elements which belong to the discourse universe. This point of view restricts the attention to projects more feasible than ontologies for commonsense reasoning, which need the representation of a huge portion of human experience, encompassing knowledge about spatial, physical, social, temporal, and psychological aspects [19].

Nevertheless, ontology building is not sufficent. Knowledge Engineering practice shows that the representation is not static. Ontologies must be maintained as any other component of information systems. Knowledge Reuse requires ontologies are extended, refined or integrated [28].

The acceptance of ontology representation languages as OWL[1] has facilitated the proliferation of ontologies. Thus, the necessity of relating ontologies arises in order to take advantage of the knowledge jointly contributed by different ontologies. Basically, there exist three kinds of reconciliation of the knowledge represented by ontologies: merging, alineation and integration.

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[1] http://www.w3.org/TR/owl-features/

The aim of this paper is to propose a formal definition of ontology merging, following ideas from [9]. The definition we propose is inspired in methods for cleaning Knowledge Databases referenced by ontologies [3, 11]. Likewise, a merging method assisted by Automated Reasoning Systems (ARS) is described. This method is based on the formal framework of ontological extensions presented in [9, 10].

For the sake of clarity, the method is illustrated by merging two spatial ontologies designed for Qualitative Spatial Reasoning (QSR). Two spatial ontologies will be merged. The first one is the Region Connection Calculus (RCC) [12]. The second one is a micro-ontology about the relative size of spatial entities, SIZE. The interest of this merging arises from human perception. For example, it is known that some topological relationships (i.e. *A is properly contained in B*) only are possible if the involved objects possess relatively suitable size. Thus, it is interesting the joint management of both ontologies. In this case, merging is advisable. Currently, we use RCC as meta-ontology in order to spatially interpret concepts associated to ontologies [8]. Spatial metaphora is a powerfull technique for user's understanding of ontology-based information systems (see [15, 23]). In general, the mereology is a natural source for supporting metaproperties on concepts and relations in Ontological Engineering [18, 20].

The structure of the paper is as follows. Next section addresses the problem of ontological evolution, using as example the case of Qualitative Spatial Reasoning. Ontologies RCC and SIZE are described in section 3. In section 4, the notion of *lattice categorical ontology* is presented and practical features of this notion are justified. Next, section 5 contains the logical ground for the formalization of the ontology merging method and the running example is computed. The article ends with some notes on related work and future aims.

2 Evolution of ontologies: Extending or revising?

The revision of an ontology may be considered, to some extent, from two points of view. On one hand, the task is similar to knowledge revision, thus the problem can be analysed by means of classic methods (see e.g. chapter 6 in [25]). On the other hand, ontology evolution should preserve some sort of backward compatibility, while possible. Therefore, the advantage of extension on revision is the feasibility of preserving ontological features of source theory. This option is only possible if the theory is *robust* [6]. A formalization of robustness given in [2] is presented in [9], and it will be described in section 4. A discussion of these aspects can be found in [10].

Nevertheless, an ontological insertion is not interesting if it is not supported by a good theory about its relationship with the source theory, as well as a sound expansion of a representative class of models of the source theory to models of the new one (such class have to contain the *intended* models). For example, in the case of mereotopological reasoning, it can be necessary to show an intuitive topological interpretation of the new elements (and a re-interpretation of the older ones compatible with basic original principles), which should be formalized.

This requirement is mandatory if one wishes to expand models of theory source to models of the new theory [11].

Therefore, one could consider ontology evolution as a sequence of extensions and revisions. As we have already commented, both methods are intimately tied. Likewise, above discussion is appliable for merging formal ontologies. Therefore, two ways for merging two ontologies O_1 and O_2 based on these ideas can be considered. A first one consists in repeatedly extending O_1 by defining the terms of O_2 (using the language of O_1) producing this way a conservative extension of O_1. Such definitions cannot exist in many cases, so it is necessary to consider a second method, based on the *ontological insertion* of the terms of O_2 in O_1 (possibly in parallel). For obtaining sound extensions, it is necessary to design axioms relating terms of both ontologies, for preserving basic features [9].

3 Two examples of formal ontologies

We succintly present the main features of the ontologies used in the example.

3.1 RCC ontology

The *Region Connection Calculus* is a well-known topological approach to qualitative spatial representation and reasoning. For RCC, the *spatial entities* are non-empty regular sets (NERC)[2] (A deep introduction to the theory can be found in [12], and the set of axioms appears in figure 1). The topological models of RCC have been investigated by N.M. Gotts in [16], where the author shows that every regular connected nontrivial topological space is a model of the theory (choosing as elements the NERCs); although it is also possible to study the models by means of a complete algebraic description [29]. Spatio-temporal reasoning has been studied in several papers [31, 27, 17].

$DC(x,y) \leftrightarrow \neg C(x,y)$	(x disconnected from y)
$P(x,y) \leftrightarrow \forall z[C(z,x) \rightarrow C(z,y)]$	(x part of y)
$PP(x,y) \leftrightarrow P(x,y) \wedge \neg P(y,x)$	(x proper part of y)
$EQ(x,y) \leftrightarrow P(x,y) \wedge P(y,x)$	(x identical with y)
$O(x,y) \leftrightarrow \exists z[P(z,x) \wedge P(z,y)]$	(x overlaps y)
$DR(x,y) \leftrightarrow \neg O(x,y)$	(x discrete from y)
$PO(x,y) \leftrightarrow O(x,y) \wedge \neg P(x,y) \wedge \neg P(y,x)$	(x partially overlaps y)
$EC(x,y) \leftrightarrow C(x,y) \wedge \neg O(x,y)$	(x externally connected to y)
$TPP(x,y) \leftrightarrow PP(x,y) \wedge \exists z[EC(z,x) \wedge EC(z,y)]$	(x tangential prop. part of y)
$NTPP(x,y) \leftrightarrow PP(x,y) \wedge \neg\exists z[EC(z,x) \wedge EC(z,y)]$	(x non-tang. prop. part of y)

Fig. 1. Axioms of RCC

[2] A set x of a topological space is regular if it agrees with the interior of its closure.

Fig. 2 illustrates the set of eight jointly exhaustive and pairwise disjoint (JEPD) relations called RCC8. If one considers RCC8 as a calculus, all possible unions of the basic relations are also considered.

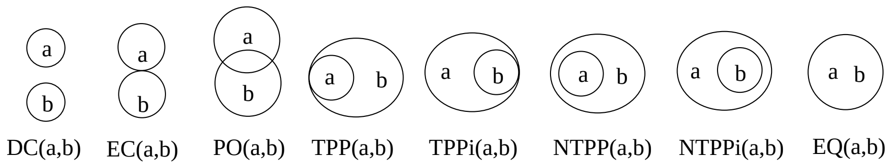


Fig. 2. Spatial relations of RCC8

The set RCC relations enjoys the structure of lattice whose Hasse diagram is shown in figure 3, that coincides with their intended meanings. This structure is provable by RCC [11].

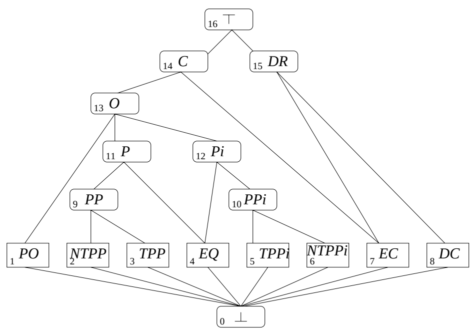


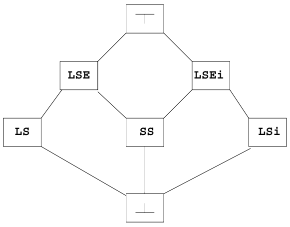
Fig. 3. The lattice of spatial relations of RCC

3.2 SIZE ontology

The ontology RCC is insufficient for reasoning with many spatial features. Therefore there appears the need of enriching RCC to reason with other features. The second ontology dealed in this paper is SIZE, the natural ontology about the relative size of spatial entities. Such an ontology has already been used jointly with RCC in [14], where the authors extend the study of constraint satisfaction problems on RCC8 done in [27].

The SIZE relationships are: $LS(x, y)$ (*x have less size than y*) and its inverse, $LSi(x, y)$; the relation LSE (*x have less or equal size than y*) and its inverse $LSEi(x, y)$; and $SS(x, y)$ (*x and y have the same size*).

Some axioms of SIZE are shown in figure 4 (rigth). The SIZE ontology suffices to prove that the relations form the lattice depicted in figure 4 (left).



$\forall x, y(LS(x,y) \vee LSi(x,y) \vee SS(x,y))$
$\forall x, y(LS(x,y) \rightarrow \neg(LSi(x,y) \vee SS(x,y))$
$\forall x, y(LSE(x,y) \leftrightarrow LS(x,y) \vee SS(x,y))$
$\forall x, y(SS(x,y) \leftrightarrow SS(y,x))$
$\forall x, y(LS(x,y) \leftrightarrow LSi(y,x))$

Fig. 4. Some axioms of SIZE and the associated lattice

Note that SIZE does not deal with the qualitative size of regions. In this case, adjectifs (unary predicates) have to be used [21].

3.3 Articulation of RCC and SIZE

The articulation of two ontologies describes the existent relationship between terms of both ontologies (see [4] for a formalization of such notion). The articulation of RCC and SIZE is depicted in figure 5. Note that the articulation is

$$E' := \begin{cases} TPP \sqsubseteq LS & EQ \sqsubseteq SS \\ NTPP \sqsubseteq LS & SS \sqsubseteq DC \sqcup EC \sqcup PO \sqcup EQ \\ TPPi \sqsubseteq LSi & LSi \sqsubseteq DC \sqcup EC \sqcup PO \sqcup TPPi \sqcup NTPPi \\ NTPP \sqsubseteq LSi & LS \sqsubseteq DC \sqcup EC \sqcup PO \sqcup TPP \sqcup NTPP \end{cases}$$

Fig. 5. Relationship between RCC and SIZE

simple; in fact, it can be considered as a sublattice of that of RCC (see fig. 6).

In this work the merging of RCC and SIZE as running example is computed, preserving articulation and satisfying a minimality condition (the size of concept lattice) more feasible to achieve than categorical minimality [4]. Lastly, note that SIZE is independent from space dimension. Thus it is also valid for working with temporal intervals, then one might think of combining SIZE with Allen's ontology about temporal intervals [1].

4 Extension of lattice-categorical theories

In this section we remember formal definitions and properties, formalizing two notions: robustness (*lattice categoricity*) and extension (*lattice categorical extension*). Our thesis states that one can change *logical completeness* by *lattice categoricity* to make easier the design of feasible methods for extending a theory. A formalization of these ideas can be found in [9, 10].

Consider a first order language, let $\mathcal{R} = \{R_1, \ldots, R_n\}$ be a (finite) set of concept symbols (or relations symbols with the same arity n) and let T be a theory[3]. Given $M \models T$, we consider the structure $L(M, \mathcal{R})$, in the language

[3] In the general case, one can consider definable concepts/relations in T.

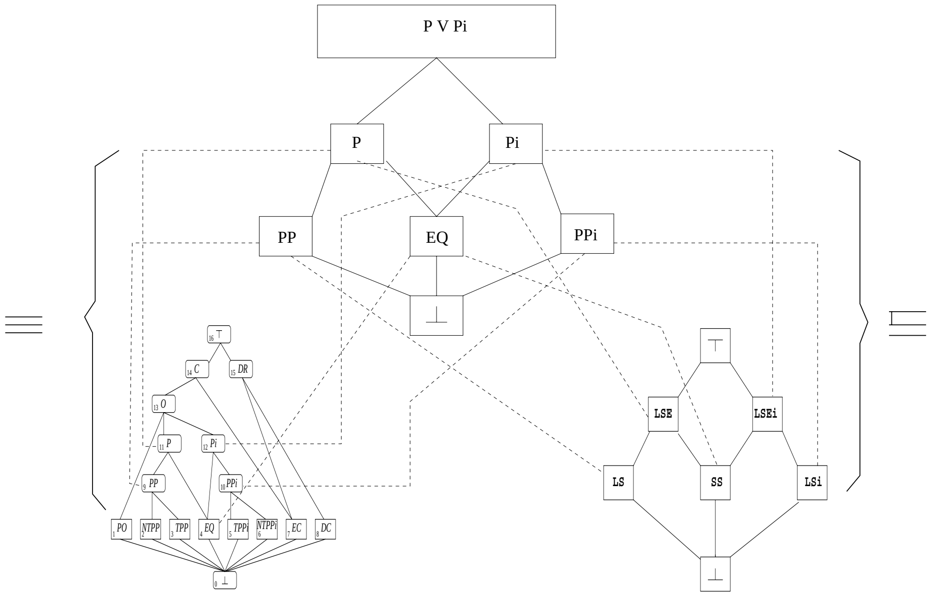


Fig. 6. Articulation of RCC and SIZE

$L_{\mathcal{R}} = \{\top, \bot, \leq\} + \{r_1, \ldots, r_n\}$, whose universe is the interpretations in M of the relations (interpreting r_i as R_i^M), $\top$ is M^n, $\bot$ is $\emptyset$ and $\leq$ is the subset relation. Notice that, in general, $L(M, \mathcal{R})$ does not have lattice structure. Nevertheless, this requisite is assumed in the remainder of the paper. The *Formal Concept Analysis* FCA [13], produce such structures. In any case, it is easy to satisfy it by extending by definitions of new relations.

From the logic point of view, a finite lattice L on a set $A = \{a_1, \ldots a_n\}$ can be categorically axiomatized by the set of axioms composed by:

1. A set $\Theta_{\mathcal{R}}$ of formulas that contains the axioms of lattice theory
2. The domain closure axiom (*d.c.a.*),
3. Unique names axiom (*u.n.a.*),

And additionally, a set of (dis)equations $E_{\mathcal{R}}$ which characterizes the Hasse diagram of the lattice.

When $L(M, \mathcal{R})$ is a lattice, the relationship with the self model M is based on two facts. The first one is that the lattice L can be characterized by a finite set of equations E_L, plus $\Theta_{\mathcal{R}}$. The second observation is that there exists a natural translation Π of such equations into formulas in the First Order Logic language in such way that if E is a set of lattice equations characterizing $L(M, \mathcal{R})$ (so $L(M, \mathcal{R}) \models E$), it holds that $M \models \Pi(E)$. Note that $\Pi(E)$ is consistent with T.

Definition 1. *Let E be a $L_{\mathcal{R}}$-theory. We say that E is a* lattice skeleton *for a theory T if the following conditions hold:*

1. *There exists* $M \models T$ *such that* $L(M, \mathcal{R}) \models E + \Theta_{\mathcal{R}}$.
2. $E + \Theta_{\mathcal{R}}$ *has only one model (modulo isomorphism).*

Proposition 1. *Suppose that* E *is a set of equations in the language* $L_{\mathcal{R}}$ *such that* $E + \Theta_{\mathcal{R}}$ *has an only model. The following conditions are equivalent:*

1. E *is a lattice skeleton of* T.
2. $T + \Pi(E)$ *is consistent.*

Corollary 1. *Every consistent theory has a lattice skeleton.*

The theory that we preserve throughout is the translation of RCC8 language of E_{RCC} (In figure 7 it is described using Propositional Description Logic notation)[4]. Note that such theory has a limited syntactic complexity; one can say that this theory has *exogenous* character, as countepart to the endogenous character of their definitions in RCC. That is, it is a theory on relations without explicit reference to their definitions with respect to elements of the universe of the model.

$$
\begin{array}{rl}
\top \equiv & C \sqcup D \\
DR \equiv & EC \sqcup DC \\
C \equiv & O \sqcup EC \\
O \equiv & PO \sqcup P \sqcup Pi \\
Pi \equiv & EQ \sqcup PPi \\
P \equiv & EQ \sqcup PP \\
PPi \equiv & TPPi \sqcup NTPPi \\
PP \equiv & TPP \sqcup NTPP
\end{array}
\qquad
\begin{array}{rl}
PO \sqsubseteq & \neg P \sqcap \neg Pi \sqcap \neg DR \\
NTPP \sqsubseteq & \neg TPP \sqcap \neg Pi \sqcap \neg DR \\
TPP \sqsubseteq & \neg Pi \sqcap \neg DR \\
EQ \sqsubseteq & \neg PPi \sqcap \neg DR \\
TPPi \sqsubseteq & \neg NTPPi \sqcap \neg DR \\
NTPPi \sqsubseteq & \neg DR \\
EC \sqsubseteq & \neg DC
\end{array}
$$

Fig. 7. *Exogenous* representation of E_{RCC} in Propositional Description Logic.

Definition 2. T *is called a* lattice categorical (l.c.) theory *if any two lattice skeletons of* T *are equivalent modulo* $\Theta_{\mathcal{R}}$.

In other words, if one assumes that the only relations are in $\mathcal{R}$, then T can prove the intended lattice structure induced by $\mathcal{R}$.

Proposition 2. *The following conditions are equivalent:*

1. T *is l.c.*
2. *If* E *is any lattice skeleton for* T, *then* $T \vdash \Pi(E)$.

That is, T is a l.c. if $E_0 + \Theta_{\mathcal{R}} \equiv E_1 + \Theta_{\mathcal{R}}$ for all E_0, E_1 lattice skeletons of T. Since a l.c. theory T has an only nonisomorphic lattice associated to $\mathcal{R}$, we denote this lattice by $L(T, \mathcal{R})$, to emphasize the lattice categoricity[5]. As it will shown in the next section, RCC is l.c.

[4] The last two formulas are ommited because their translations are tautologies.

[5] T is a l.c. theory if $E_T + \Theta_{\mathcal{R}}$ is a *strictly categorical theory* (that is, given any two models of $E_T + \Theta_{\mathcal{R}}$, there exists one only isomorphism between them).

Theorem 1. *Let T be a consistent theory. There exists T' an extension of T which is lattice categorical.*

A pair (T, E) where T is lattice categorical and E is a lattice skeleton for T, called *lattice categorical core* (l.c.c.). Thus, (T, E) is a l.c.c. if $T + \Pi(E)$ is a l.c. theory. The pair (RCC, E_{RCC}) that it will describe in next section is a l.c.c.

To simplify the discourse, in the remainder of the paper a l.c.c. will be simply called *ontology*.

Definition 3. *Given two ontologies $O_1 = (T_1, E_1)$ and $O_2 = (T_2, E_2)$ with respect to sets of concepts/relations $\mathcal{R}_1$ and $\mathcal{R}_2$ respectively, we will say that O_2 is a* lattice categorical extension *of O_1 (denoted by $O_1 \rightarrow_{lc} O_2$) if $\mathcal{R}_1 \subseteq \mathcal{R}_2$ and $E_2 \models E_1$.*

5 Merging Lattice categorical ontologies

In this section a proposal of ontology merging is presented. To simplify, suppose O_1 and O_2 are two ontologies with disjoint signatures. We assume that E' is a set of formulas relating concepts of both ontologies.

Definition 4. *An l.c. ontology $O = (T, E)$ is a* lattice categorical merging *of O_1 and O_2 with respect to E' if $O_1 \rightarrow_{lc} O$, $O_2 \rightarrow_{lc} O$, $L(T, \mathcal{R}) \models E'$, and it is the lattice of minimum size with that property. In the case that articulation O_a exists, then the following diagram is conmutative, the interpretation of O_a in O does not depend on the intermediate ontology:*

$$\begin{array}{ccccc} & & O_1 & & \\ & \nearrow_{lc} & & \overset{lc}{\searrow} & \\ O_a & & & & O \\ & \overset{lc}{\searrow} & & \nearrow_{lc} & \\ & & O_2 & & \end{array}$$

The following method for l.c. merging is based on the one for lattice categorical extensions introduced in [9]:

1. **First stage:** Joint skeletons E_1 and E_2 with E'; let $E_0 := E_1 \cup E_2 \cup E'$
2. Find, with MACE4, the lattices that models E_0.
   If such lattices do not exist, ontologies are not compatible with respect to E_0, then there is not merging (E_0 is not satisfiable). If MACE4 outputs some model, follow in (3).
3. **Second stage: User analysis of a lattice of minimum size**. If any of the relationships of the lattice is not accepted by the user, refine E_0 by adding new (dis)equations, to discard such lattice. Turn to the apply MACE4 to the refinement.
   This stage is repeatedly applied until a model L (of minimum size k) is accepted by the user. On this way a skeleton S_0 is obtained.

4. **Third stage: achieving lattice categoricity**. Refine S_0 (by the addition of (dis)equations) until that the only model of size k is L. Let S be the resulting set of equations.
5. **Fourth stage: Certification**. Certify (with an automated reasoning system, OTTER, if it is necessary) that L is the only model of S of size k. This way it is accurated that $O = (T_1 \cup T_2 \cup S, S)$ is a l.c. merging.

Theorem 2. *The method described above outputs a l.c. merging of O_1 and O_2.*

5.1 Merging RCC and SIZE

Suppose that it is intended to use SIZE on connected regions. Intuition says that it is unknown (a priori) the size relation between disconnected regions. Notice that this implies an ontological re-interpretation of SIZE relations. For example, $LS(x, y)$ has to be understood as *region x is connected with a region y of bigger size*. That reinterpretation is compatible with articulation depicted in figure 6.

Starting with the SIZE skeleton:

$$E_2 = \begin{cases} \top \equiv LS \sqcup LSi \sqcup SS & LSE \equiv SS \sqcup LS \\ LSi \sqsubseteq LSE \sqcap \neg SS & LSi \sqsubseteq \neg SS \\ \neg SS \equiv LS \sqcup LSi & LSEi \equiv SS \sqcup LSi \end{cases}$$

The set E_0 is compounded by E' (fig. 5) jointly with:

$$\begin{cases} EC \not\sqsubseteq LSE & EC \not\sqsubseteq LSEi & SS \not\sqsubseteq \neg EC \\ DC \not\sqsubseteq LSE & DC \not\sqsubseteq LSEi & SS \not\sqsubseteq \neg DC \end{cases}$$

The execution trace of the method is described by the following table:

Refinement	Minimum size of a model	Number of models
without refinements	23	8
$LS \not\sqsubseteq O, LS \not\subseteq O$	24	1
$SS \not\sqsubseteq O$	24	1
$LS \sqcap PO \not\equiv \bot$	27	1
$LSi \sqcap PO \not\equiv \bot$	31	1
$SS \sqcap PO \not\equiv \bot$	31	1

It accepts the final lattice depicted in figure 8. It is important to note that the user may need to interpret some of the new nodes. For example, node 22 represents the relation *distinct sizes* (that is, ¬SS), and node 23 represents the relation *x partially overlaps with a region y of distinct size*. However, the use of new nodes can be unnecessary in practice; some nodes only represent algebraic operations on basic nodes (to satisfy lattice structure). Therefore, this lattice can be pruned in order to obtain a ontological simpler structure.

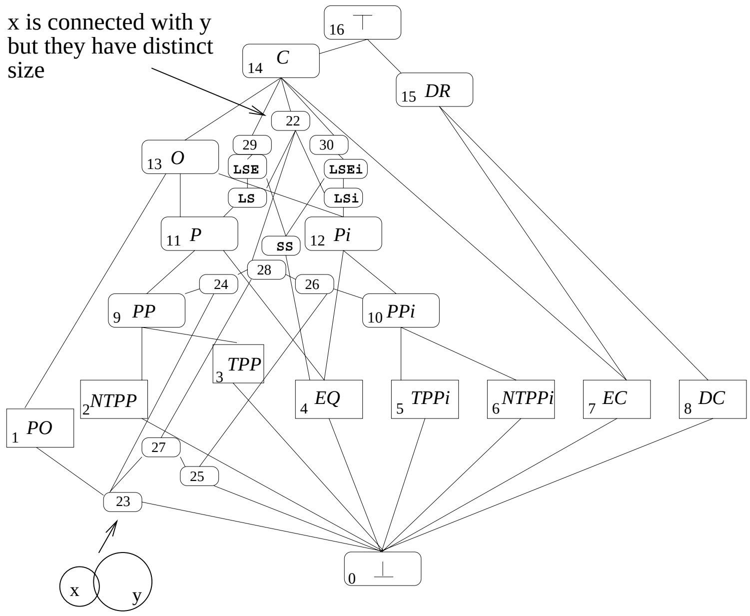


Fig. 8. Merging of RCC and SIZE on connected regions

6 Final Remarks and Related Work

In this paper a method for merging formal ontologies is presented. The method is concept-driven (the basic requirement is the categoricity of concept lattice), and logic-based. There are several approachs to solve the problem, but, in general, they do not make use of automated model finders to find an alternative merging. Therefore it is hard to compare these (not logic-based) methods with the method of this paper. For example, Prompt [26] facilitates the necessary tasks for merging two classes in a new class, locating possible equivalences. In our method, limited to concepts, the ARS induces the possible algebraic operations with the classes, while Prompt asks the user. Hcone [22] is, in general terms, a similar approach. However, it is based on the use of Wordnet to determine relations between concepts. In our case, the process starts with known relations and the remainder is induced by the method, always asking user's approval. A similar situation occurs with ONION [24] which also uses linguistic features to compute the articulation.

The essential feature of the method of this paper, designed for formal ontologies, is that it builds an ontology with certifiable categoric features. Additionally, since alternative models are offered, the user is enforced to refine the knowledge for discarding some ones, obtaining in this way more information about the merging.

In [4], ontology merging by means of algebraic specifications is formalized. The merging is a colimit, when the ontologies are compatible. In our approach, the resulting common lattice categorical extension(s), of minimun size, can be considered as a practical variant of colimit notion, and the compatibility is determined by the existence of models. The feasibility of the method depends on the reasoning on finite structures, in constras to the abstract notion of colimit.

A pertinent question to ask is: what are the limits of applicability of the method? At first sight it seems that depends on the model finder. However, the formal method is designed for concrete domains. In such situations, users can recognize the soundness of ontologies depicted from MACE4's results. In the case of merging a little ontology with a big size one , it could be interesting to design *contextualized merging* in order to simplify the merging process. In fact we have contextualized SIZE on connected regions. Finally, when one must select the best merging ontology from data (*data-driven*), the problem is different. In this case the user can not recognize new concepts. To solve this limitation it can be interesting to use *cognitive entropy* [10] to select the lattice in each step of the model. The ontological insertion of new data-driven concepts has been studied in [7].

References

1. Allen, J.F.: Maintaining Knowledge about Temporal Intervals, *Communications of ACM*, 26(11):832–843 (1983).
2. Alonso-Jiménez, J.A., Borrego-Díaz, J., Chávez-González, A.M., Martín-Mateos, F.J.: Foundational challenges in Automated and Ontology Cleaning in the Semantic Web. *IEEE Intelligent Systems* 21(1):42-52 (2006).
3. Alonso-Jiménez, J.A., Borrego-Díaz, J., Chávez-González, A.M.: Ontology Cleaning by Mereotopological Reasoning, *Proc. DEXA Workshop on Web Semantics (WebS'04)*, IEEE Press, 137-137 (2004).
4. Bench-Capon, T., Malcolm, G.: Formalising Ontologies and Their Relations, *Proc. of Database and Expert Systems Applications (DEXA 99)*, LNCS 1677, Springer, pp. 250-259 (1999).
5. Berners-Lee, T., Hendler, J., Lassila, O.: The Semantic Web, *Scientific American* 284(15):34-43 (2001).
6. J. Borrego-Díaz and A. M. Chávez-González: Using Cognitive Entropy to Manage Uncertain Concepts in Formal Ontologies. P.C.G. da Costa et al. (eds.): URSW 2005-2007, LNAI , vol. 5327, pp. 315-329. Srpinger, Heidelberg (2008).
7. Borrego-Díaz, J., Chávez-González, A.M.: Data-Driven Automated Management of Defficent Information in the Semantic Web. R. Moreno Díaz et al. (eds.): EUROCAST 2007, LNCS, vol. 4739, pp. 305-312. Springer, Heidelberg (2007).
8. Borrego-Díaz, J., Chávez-González, A.M.: Visual Ontology Cleaning. Cognitive Principles and Applicability. *Proc. 2006 European Semantic Web Congress*, LNCS 4011, Springer, pp. 317-331 (2006).
9. Borrego-Díaz, J., Chávez-González, A.M.: Extension of Ontologies Assisted by Automated Reasoning Systems, *Proc. 10th Int. Conf. on Computer Aided Systems Theory (EUROCAST 2005)*, LNCS 3643, pp. 247-253, Springer (2005a).
10. Borrego-Díaz, J., Chávez-González, A.M.: Controlling Ontology Extension by Uncertain Concepts through Cognitive Entropy. *Proc. ISWC'05 Workshop on Uncertainty Reasoning for the Semantic Web*, 56-66 (2005b), `http:// sunsite. informatik. rwth-aachen.de/Publications/CEUR-WS/Vol-173/ paper6.pdf`

11. Chávez-González A.M.: *Razonamiento Mereotopológico Automatizado para la Depuración de Ontologías*, Ph. D. Thesis, University of Seville (2005).
12. Cohn, A.G., Bennett, B., Gooday, J.M., Gotts, N.M.: Representing and Reasoning with Qualitative Spatial Relations about Regions (1997). chap. 4 in [30].
13. Ganter, B., Wille, R.: *Formal Concept Analysis. Mathematical Foundations*, Springer (1999).
14. Gerevini, A., Renz, J.: Combining Topological and Size Information for Spatial Reasoning, *Artificial Intelligence* 137:1-42 (2002).
15. Gerimenko, V., Chen, C.: *Visualizing the Semantic Web. XML-based Internet and Information Visualization*, Springer, London (2003).
16. Gotts, N.M.: *An Axiomatic Approach to Topology for Spatial Information Systems*, Report 96.25, School of Computer Studies, Univ. of Leeds (1996).
17. Grigni, M., Papadias, D., Papadimitriou, C.: Topological inference, *Proc. 14th Int. Joint Conf. on AI (IJCAI'95)* 1:901-906, Morgan Kaufmann (1995).
18. Guarino, N., Welty, C. Towards a Methodology for Ontology Based Model Engineering, *Proc. Int. Workshop on Model Engineering ECOOP 2000* (2000).
19. Liu, H., Singh, P.: ConceptNet. A Practical Commonsense Reasoning Tool-Kit *BT Technology Journal* 22(4): 211-226 (2005).
20. Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A.: *WonderWeb Deliverable D18 Ontology Library*, IST Project 2001-33052 WonderWeb (2001). `http://wonderweb.semanticweb.org/deliverables/documents/D18.pdf`
21. Hernández, D., *Qualitative Representation of Spatial Knowledge*, LNAI vol. 804, Springer (1994).
22. Kotis, K., Vouros, G.A.: The Hcone approach to Ontology Merging, *Proc. European Semantic Web Symposium (ESWS 2004)*, LNCS vol. 3053, pp. 137-151, Springer (2004).
23. Lamping, J., Rao, R., Pirolli, P.: A Focus + Context Technique Based on Hyperbolic Geometry for Visualizing Large Hierarchies (1995). *Proc. ACM Conference on Human Factors in Computing Systems CHI'95.*
24. Mitra, P., Wiederhold, G., Kersten, M.L.: A Graph-Oriented Model for Articulation of Ontology Interdependencies, *Proc. 7th Int. Conf. Extending Database Tech. (EDBT 2000)*, LNCS 1777, pp. 86-100, Springer (2000).
25. Nebel, B.: *Reasoning and Revision in Hybrid Representation Systems*, LNAI vol. 422, Springer, Berlin (1990).
26. Noy, N.F., Musen, M.A.: The PROMPT suite: Interactive tools for ontology merging and mapping. *Int. J. of Human-Computer Studies*, 59(6):983-1024 (2003).
27. Renz, J.: *Qualitative Spatial Reasoning with Topological Information*, LNAI vol. 2293, Springer (2002).
28. Staab, S., Studer, R. (eds.) *Handbook of Ontologies in Information Systems*, Springer (2004).
29. Stell, J.G.: Boolean Connection Algebras: A New Approach to the Region-Connection Calculus, *Artificial Intelligence* 122:111-136 (2000).
30. Stock, O. (ed.) *Spatial and Temporal Reasoning*, Kluwer, Dordrecth (1997).
31. Wolter, F., Zakharyaschev, M.: Qualitative Spatio-Temporal Representation and Reasoning: a Computational Perspective, Lakemeyer, G., Nebel, B. (eds.) *Exploring AI in the New Millenium*, Morgan Kaufmann, 273-381 (2002).