Towards an Ontology of Spatial Relations and Relational Constraints

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1 The Need for Constraints and Spatial Relations Ontology

Research in automated generalisation has suffered from the lack of availability of tools developed for past projects, preventing researchers from reusing what their colleagues have already done and concentrating on novel aspects (Edwardes et al 2003). A solution was proposed and developed in Zurich, using Web services technology to share processes between distant platforms (Neun and Burghart 2005), (Foerster et al 2008). This paves the way for much more complex and powerful systems to be designed. This has been demonstrated at the Cogit laboratory, when Touya et al (2010) showed how a full map could be generalised using different processes used in different geographic contexts (urban, rural, mountainous etc). While this was done with all the processes available on the same system, the Web services allow us to do this with processes available on different platforms. The interoperability of systems has been identified as an important component of an on-demand generalisation system (Regnauld 2007, Gould and Chaudhry 2012), but the interoperability of the knowledge used by generalisation systems is also an issue (Balley and Regnauld 2011). In particular, we want to propose a common way of describing and representing spatial relationships between geographic features. This would make it much easier to link the map requirements based on such relationships, with generalisation knowledge relying on them, and tools to compute them.

Moreover, Stoter et al (2010) showed that defining generalisation constraints was a very challenging task for users with no expertise in the generalisation process, even for cartographers. Helping non-expert users to express their specifications as constraints is, thus, an urgent need to develop the use of automatic processes. An ontology containing classical generalisation constraints, among which relational constraints i.e. constraints on spatial relations (Duchêne 2003), would be the starting point for developing tools to help non-expert users.

In this paper, we try to make a step towards an ontology of spatial relations and relational constraints between geographic features in the context of generalisation.

The next part deals with the modelling and the classification of spatial relations to enable the creation of a spatial relations ontology. The third part briefly describes a proposition to model generalisation constraints as an ontology. Finally, the fourth part proposes methods to use the ontology in automatic processes.

2 Modelling Spatial Relations

2.1 Spatial Relation Types: Quantitative vs Binary Relations

We distinguish two ways of describing a relation between a pair of objects. The first way consists in characterising the relation by means of a quantitative measure, *e.g.* the proximity between two buildings is characterised by a distance, a relation of relative orientation is characterised by an angle. This way is valid for relations classified as "metric relations" by Egenhofer and Franzosa (1991). The second way consists of associating the relation to a predicate like *is parallel to*, *is included in*, *goes along*, etc. In this case, the status of the pair of objects with respect to the predicate is binary: it meets the predicate or not. In some cases, a family of predicates can be defined so that a given pair of objects only meets one predicate of the family, *e.g.* for topological relations, the predicates of the 4-intersection model (4IM) (*included, includes, covered by, covers, overlaps, equals, meets, disjoint*) or of the 9-intersection model (9IM) (Egenhofer and Franzosa 1991). Sometimes, this family of predicates covers all possible situations (like in 9IM), *i.e.* the family of predicates is an enumeration. Otherwise, only a few particular configurations are identified and described by a predicate while the other ones are just not covered (*e.g. is parallel to* and *is orthogonal to* are two predicates that describe particular relative orientations).

Whether we consider one relation (*e.g.* relative orientation) and associated predicates (*parallel*, *orthogonal*), or several relations (*parallelism*, *orthogonality*) is an arbitrary choice. We choose the second, therefore we distinguish between *quantitative relations* (relations described by a quantitative measure) and *binary relations* (relations described by a predicate, which are present or not between a pair of objects); some of the binary relations form families or enumerations.

Now, a particular situation with respect to binary relations is the situation where the relation is not completely present, but almost (*e.g.* the building is not strictly parallel to the road but almost, it is not clear if it is parallel to the road or not, cf. (Duchêne et al. 2012)). This situation is remarkable in the context of generalisation, which seeks to avoid the fuzziness and replace it with a sharp relation through caricature. Therefore, for each sharp binary relation we propose to add an associated fuzzy relation in our ontology corresponding to the case where the sharp relation is almost present, *e.g. near parallelism*. A particular case is when a family of sharp relations exists, like the topological relations corresponding to the predicates of the 4IM or the standard 9IM. In such a case, the fuzzy relations are not linked to one sharp relation, but at least two: a fuzzy relation can be added on each edge of the conceptual neighbourhood graph linking the sharp relations, as illustrated in Figure 1. The same applies to 9IM.

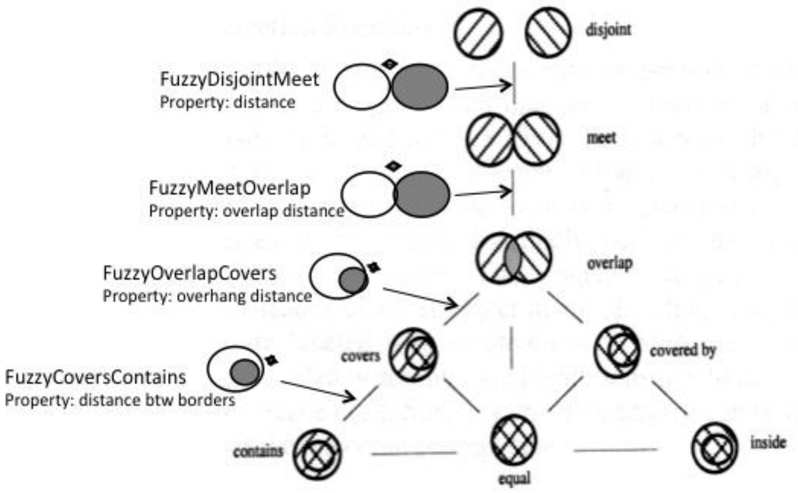

Figure 1. A fuzzy topological predicate is added on every edge of the neighbourhood graph of the 4-intersections model by (Egenhofer and Al-Taha 1992)

Fuzzy topological relationships have been studied by Winter (2000) and Bejaoui et al (2009) in the context of object with fuzzy limits. Here, in the context of cartographic generalisation, the fuzziness is a 'perceived fuziness' due to the perception limits.

To summarize, we distinguish between *quantitative* and *binary* relations, and among binary relations, we further distinguish between *sharp* and *fuzzy* relations.

2.2 Spatial Relations Model

To enable interoperability between the components of a generalisation system specifying, extracting and exploiting spatial relations and associated constraints, we propose to formalise these relations in the form of an ontology (Figure 2). This section describes how we propose to model the highest level of this ontology. The proposed model is made of several facets that should be considered when extending a spatial relation from the ontology. Each facet is not equally relevant for binary, quantitative and fuzzy relations distinguished in section 3.1.

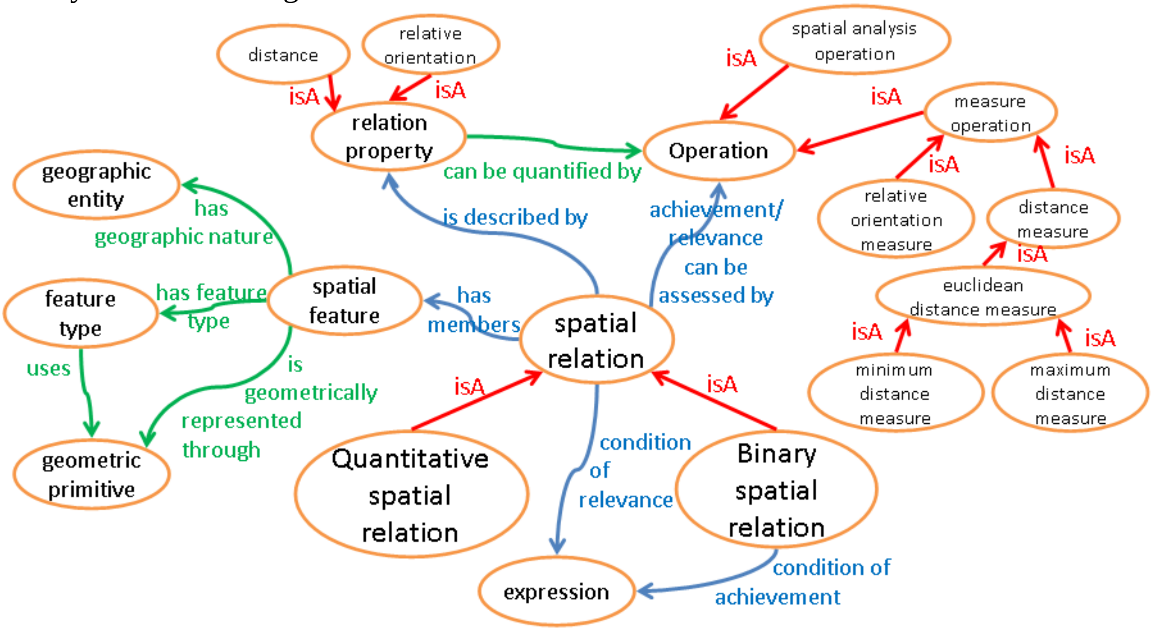

Figure 2. OWL model for spatial relations.

A spatial relation links some spatial features which can be described through different facets: the concepts they reflect in the real world, the types of geometric primitive representing them digitally, and more precisely their feature types in a dataset.

Relations are seen as predicates that hold or not between spatial features. Quantitative relations always result in a value (or measure) and therefore it can be considered they always hold (even if it might be irrelevant to consider them), while binary relations do not.

Any relation (quantitative or binary, sharp or fuzzy) can be relevant or not to consider between a given pair of objects (e.g. if two buildings are separated by a river, it can be relevant or not to consider their proximity relation, it can be relevant or not to consider their parallelism provided it holds). The relevance depends in particular on the generalisation specifications.

Assessing the achievement of a binary relation means assessing if it holds. Assessing the relevance of any relation means assessing if it is relevant to consider it Assessing a relation may require a condition to be specified. This condition ("expression" on Figure 2) may refer to a threshold (*e.g.* two features are *near* if their relative distance is less than 10m), to other relations (e.g. two features are *aligned* if they are *near* and *parallel*) or to other elements like an intersection matrix template.

Relation properties enable to better describe relations after they have been assessed. They may be quantitative measures (*e.g.* a relative distance characterising an occurrence of the relation *near*) or other information. Quantifying a relation means calculating the values of its properties.

Operations may be provided to guide assessment or quantification. For instance, the type of distance measure to use (minimum, maximum or average distance) depends on the geographic nature and on the geometric primitive associated with the features. Operation types can also refer to complex spatial analysis operations. As described in section 4, operation types are currently used to help identifying the right tool at processing time. However, ongoing research is looking at alternative ways to match the operations and tools (Gould, 2012).

2.3 Spatial Relations Taxonomy

The proposed spatial relations ontology model includes a taxonomy derived from previous spatial relations classifications (Egenhofer and Franzosa 1991, Steiniger and Weibel 2007, Bucher et al, 2012). It is composed of eight relation types while each relation may also be fuzzy, like the almost parallelism relation that is a fuzzy orientation relation (Figure 3).

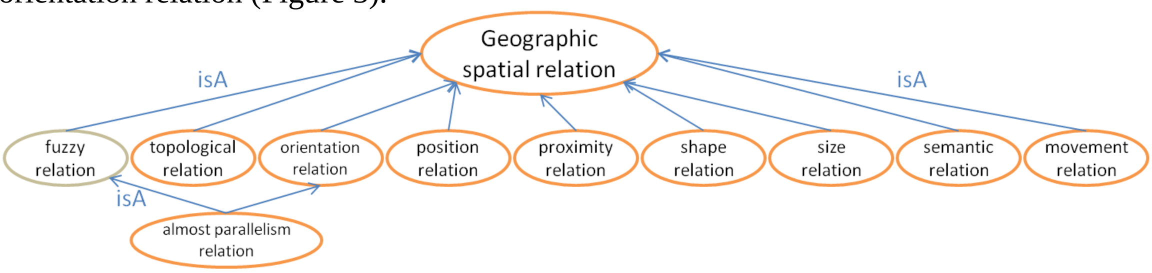

Figure 3. Proposed taxonomy for spatial relations between two geographic entities. Fuzzy relations are also one of the other types (*e.g.* orientation relation).

Topological relations contain the classical 9-intersection primitives (Egenhofer and Franzosa 1991) like *meet* (Figure 4a) as well as fuzzy topological relations (Winter 2000) like *fuzzy covered by* (Figure 4b, the distance between the building and the forest limit makes it a fuzzy relation between *touches* and *covered by*). Orientation relations can be binary like *relative orthogonality* (Figure 4c) or fuzzy like *almost parallelism*

(Figure 4d). The position relations gather the *relative position* relations (Figure 4e and f) and proximity relations represent features close to each other (Figure 4g).

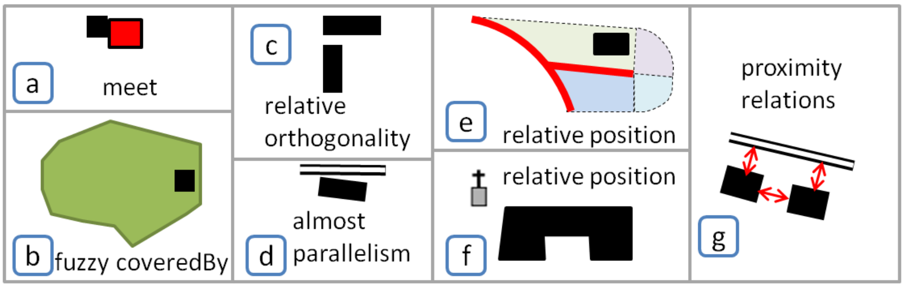

Figure 4. Examples of spatial relations.

Figure 5a and Figure 5b show classical examples of shape and size relations between buildings. The semantic/logical relation type is illustrated by the *is access to* relation (Figure 5c) and the *is flat* relation between a lake and relief (Figure 5d). Finally, movement relations gather relations that can be expressed by a movement verb (Mathet 2000) like "the river *circles* the building" (Figure 5e) or "the path *passes all across* the forest" (Figure 5f).

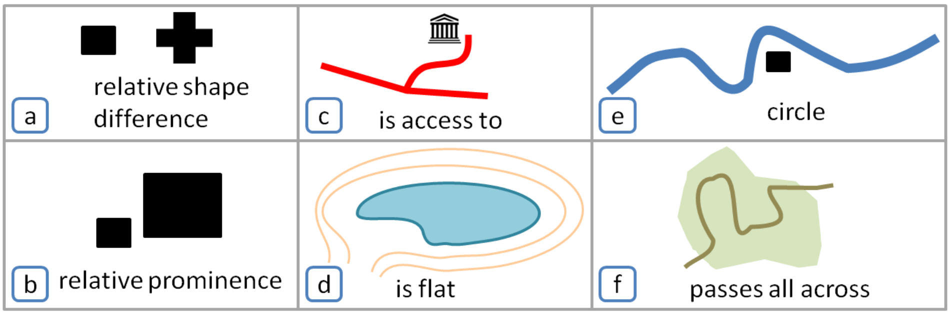

Figure 5. Other examples of spatial relations.

Moreover, some features may be related to some part of a feature and not to the complete feature itself. For instance, the limit of the forest locally *circles* the building in Figure 6f, or the building *is on* a summit in Figure 6a which is a characteristic part of the relief. Evenly, features may be related to implicit structures of a feature, like the skeleton of a polygon, that *follows* a river (Figure 6e), or the thalweg in which the river *flows* (Figure 6c). However, we believe that such spatial relations require an extension of our model presented in the previous section, and thus need further investigation.

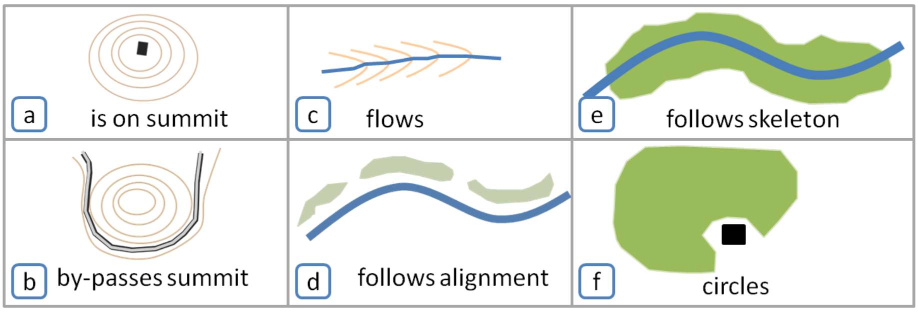

Figure 6. spatial relations between a feature and a part (or an implicit structure) of a feature.

2.4 Use Cases of relations modelling

2.4.1 Modelling the *follow* Relation for on-demand mapping involving user's data

Let us consider an on-demand mapping use case where cycle routes captured by a user must be integrated into reference data featuring roads and cycle tracks. Before conflation (Figure 7), it is expected that cycle routes *follow* roads and cycle tracks, i.e. they are almost parallel and close to the referential sections. This spatial relation enables to express on-demand map specifications:

- Only main roads must appear on the map, plus minor roads *followed by* a cycle route.
- Cycle routes *following* a road must share its geometry in the final map.
- Cycle tracks must not appear on the final map, but cycle routes *following* a cycle track must be symbolised as "cycle friendly".

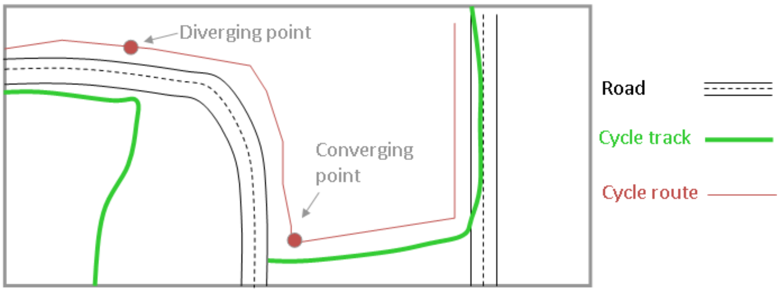

Figure 7. Situation before conflation: (driving direction from left to right) The cycle route follows roads and cycle tracks. The first and last portions of the cycle route are cycle friendly.

Modelling the follow relation using our ontology enables to have it assessed and exploited by the third part tools performing the filtering of roads, the conflation and the symbolisation of cycle routes.

The relation between cycle routes and roads can be described as shown in Figure 8. Both members are supposed to be network sections. A tolerated maximum distance between sections is provided as a condition of achievement. This tolerance has to be decided by the user or automatically evaluated using the advertised accuracy of data sources. The relation can typically be assessed via a network matching operation.

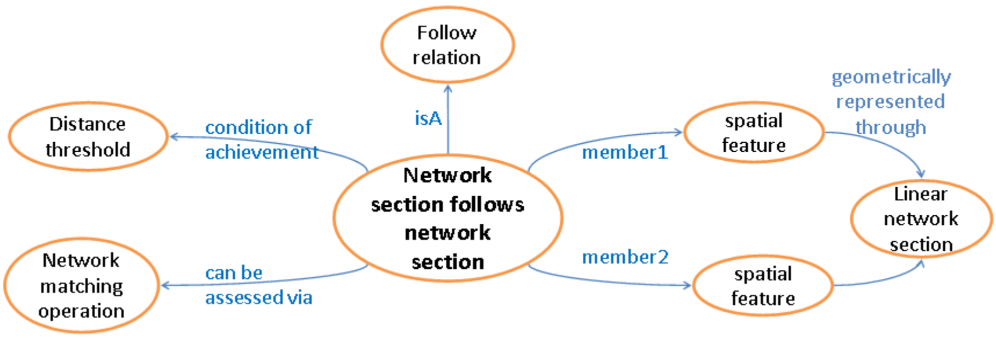

Figure 8. Modelling of the *follow* relation adapted to cycle routes and roads.

Cycle tracks are not a network and do not necessarily share geometry with roads (notably because they may have been produced by another provider). The cycle route/cycle track relation is slightly different from the cycle route/road one. It can be modelled as shown in Figure 9. Member 2 is not supposed to be a network section. As cycle route sections can be partly cycle-friendly (Figure 7), they may have to be split prior to symbolisation. Consequently, convergence and divergence nodes are stored as a property relation. A local matching operation could assess the relation and calculate its properties.

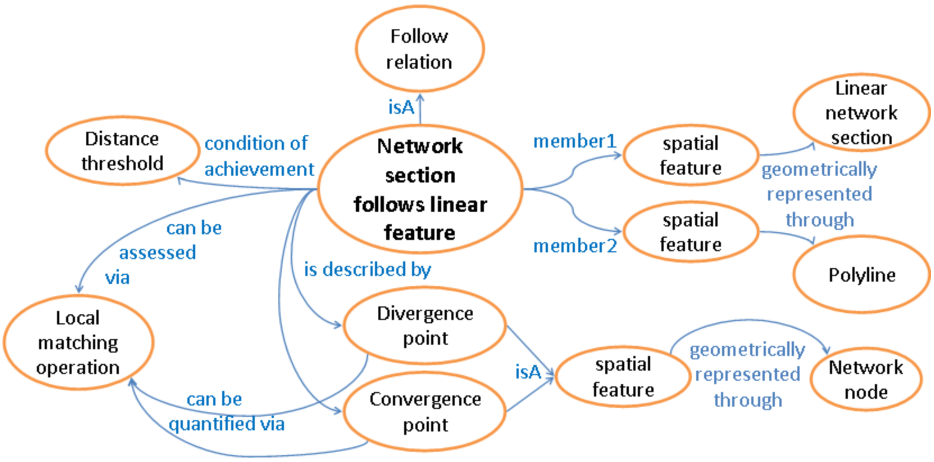

Figure 9. Modelling of the *follow* relation adapted to cycle routes and cycle tracks. Divergence and convergence points are properties of the relations.

2.4.2 Modelling relations between user data and reference data

Let us consider the case where user comes with his own thematic data, referenced for the localisation using some topographic data, and wants to make a map by overlapping them on another topographic data. A typical example is fire brigades referencing fire hydrants on a road network and they want to make a map using an updated version of their road network. Relations between user data and topographic data have a special importance compared to the relations among topographic data, therefore they should be preserved during data processing (e.g. migration of thematic data or the generalisation of topographic data). For instance, fire brigades want that the fire hydrant stays at the same side of the road, and also want to get the same relative position of fire hydrants among the surrounding buildings

(Jaara et al 2012) propose a model for referencing the thematic data by storing relations, and the model can also be used to constraint data processing based on relations. According to this model, relations are either between thematic and topographic objects, or between thematic and characteristic objects. *Characteristic objects* are defined as additional objects that are extracted from the initial topographic data. As examples of characteristic objects, we have river-road intersections, top of bend of a road segment. So the spatial feature of the ontology in this case can be thematic (e.g. hydrants), topographic (e.g. roads and buildings) or characteristic (e.g. top of bend). In the model, every relation has two members (or spatial features): the first is a thematic object and the second is topographic or characteristic object.

For example, a car accident located at the top of a bends has two relations: "near" and "on road", the modelling of the two relations is described in Figure 10.

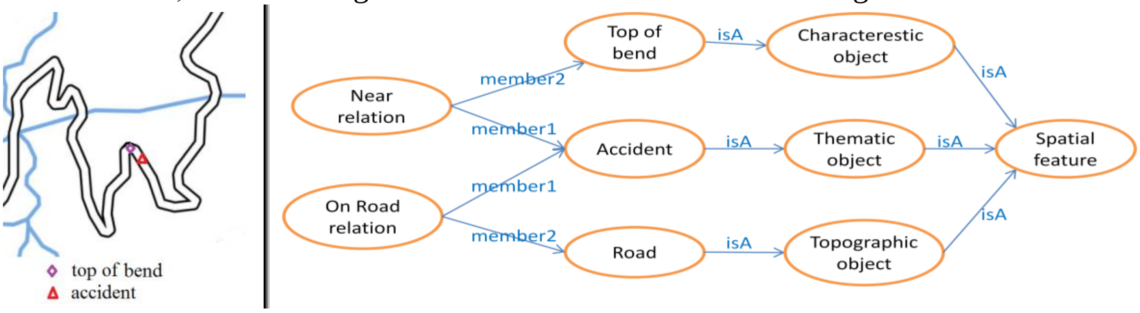

Figure 10. Modelling "near" and "on road" relations of an accident

3 Proposed hierarchical model for a Constraints Ontology

In order to fulfil the previous needs, our proposal is to build a generalisation constraints ontology to be integrated into what Balley and Regnauld (2011b) called the *semantic referential* (Kuhn, 2003), and to be completed incrementally. There is a large literature on constraint modelling for generalisation (Beard 1991, Louwsma et al 2006, Burghardt et al 2007). The model of the ontology relies on the constraints modelling of Touya et al (2010) that synthesise this literature: a constraint is defined on the character (*e.g.* area) of an entity (*e.g.* building) and has an expression type (*e.g.* threshold type, character < threshold) (Figure 11).

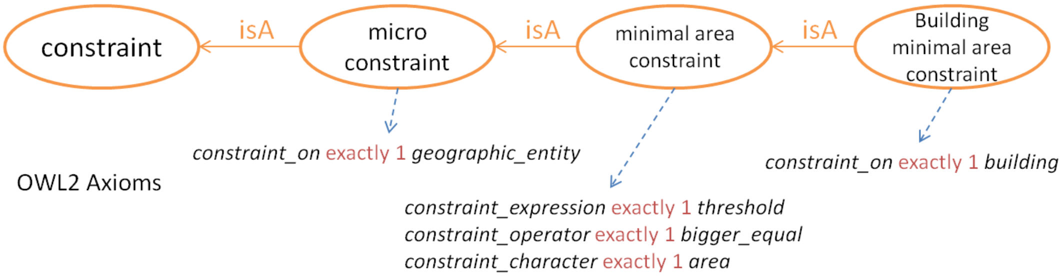

Figure 11. Principles of the hierarchical constraints model in OWL2: the axioms restrict the variables for a user to define his constraints.

As suggested by Regnauld (2007), such constraint ontology is based on geographic entity ontology that contains characters or properties defined on entities (*e.g.* a building has the character "area"). The paper deals with the spatial relations and relational constraints that could be added in this generalization constraints ontology. Four types of relational constraints have been identified (Figure 12): the classical relational preservation constraints that monitor the preservation of salient relations during generalisation (*e.g.* preserve river *circles* building relations); the relation caricature constraints that monitor only fuzzy relations to make them sharp (*e.g.* caricature *almost parallelism* relations into *parallelism* relations); the relation transformation constraints that change a relation into another during generalisation (*e.g.* transform road/building *parallelism* relations into *adjacency* relations); finally, non-creation constraints that prevent non-existing relations from being created by generalisation transformations (e.g. no *relative prominence* relation between buildings can be created by building enlargement algorithms).

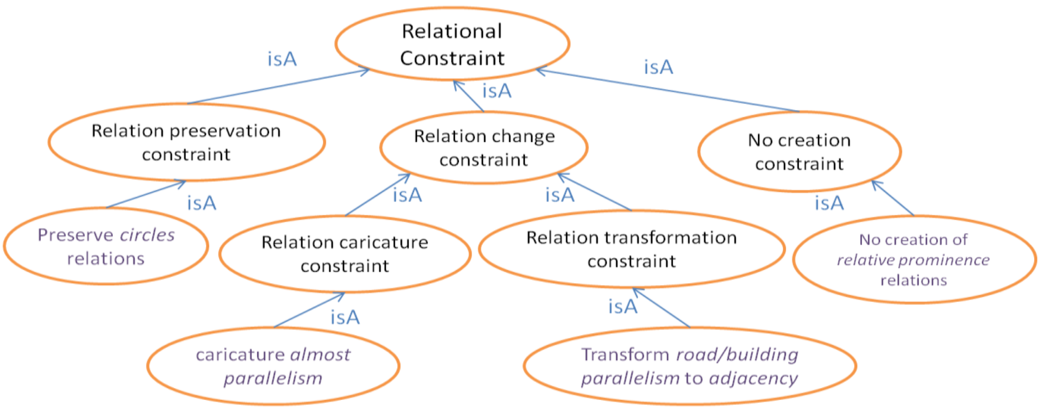

Figure 12. Four types of relational constraint in the proposed ontology illustrated by existing generalisation constraints.

4 How to link relations and constraints with measure algorithms to assess them

One of the goals of the spatial relations ontology is to enable the automatic selection of algorithms in a process of generalisation or on-demand mapping.

A first proposal to link relations and constraints to the measure algorithms enabling to assess and quantify them is to annotate the algorithms with the spatial relations ontology concepts (Lemmens 2008). Touya et al (2010) proposed to use a registration mapping, *i.e.* a file that matches algorithms to ontology concepts, here algorithms being Java classes.

The "operation" proposed in the relation model allows more flexibility: depending on the map specifications and available data sources, a spatial relation may be best assessed via different, more specific operations. In the proposal of Balley and Regnauld (2011b), operations are defined in an ontology and determining the most suitable one is the duty of rules and task templates. If available tools have been annotated with operations, they can be selected by semantic matching. This approach is currently under implementation (Balley et al 2012).

Gould (2012) proposes an even more flexible matching. His assumptions are, it is unlikely to have available tools annotated through our operation ontology, and such annotations wouldn't be sufficient to make a choice between several implementations of the same operation. He therefore proposes to develop an additional "algorithm ontology" refining the link between operations and tools.

5 Conclusion

To conclude, an ontology of spatial relations and relational constraints is a valuable tool to improve map generalisation automation and on-demand mapping. This paper proposes a first model towards such an ontology, as well as a first taxonomy of spatial relations to fill the ontology model. A constraint ontology, related to the relations one is also proposed. Now, it needs to be completed and improved, and to be tested in automatic processes by the research community, in order to converge to a standard and shared generalisation knowledge.

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