Importance of spatial relationships for geographic ontologies

by Robert Laurini[1]

The goal of this paper is to present concepts concerning geographic ontologies and especially the use spatial relations. It is showed that spatial topological relations (Egenhofer) are not sufficient to model reality such as road and mountains. Finally, a primer list of adapted topological relations is given.

In this paper, the concept of ontology is presented and more exactly the concepts of geographic ontology. Those ontologies model not only conventional geographic features with their semantic relations, but also with spatial relations which exist between those features. The aim of this paper will be to identify those spatial relations, to show how to use them for modelling and manipulating geographic ontologies.

As an example, Fig. 1 gives a small ontology for natural disasters with only two relations, "is-a" and "implies" modelling causalities between some natural disasters.

Introduction

The word "ontology" come from Greek $o\nu\tau o\varsigma$ (being) and $\lambda o\gamma\iota\alpha$ (discourse), *i.e.* the discourse about existing objects. This word, usually written with a capital "O" is overall used in philosophy and theology (God = "I Am that I Am"). Now, in information technology, an ontology (with a low capital "o") refers to modeling things existing in the discourse which is a fundamental idea in data modelling: when something has no name, it is not existing in our brain, so not existing in our culture, so not existing in our

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world. It is told that Eskimos have 19 words to describe “snow” whereas some Equatorial tribes may have no word for this natural phenomenon; so the concerned ontology is different.

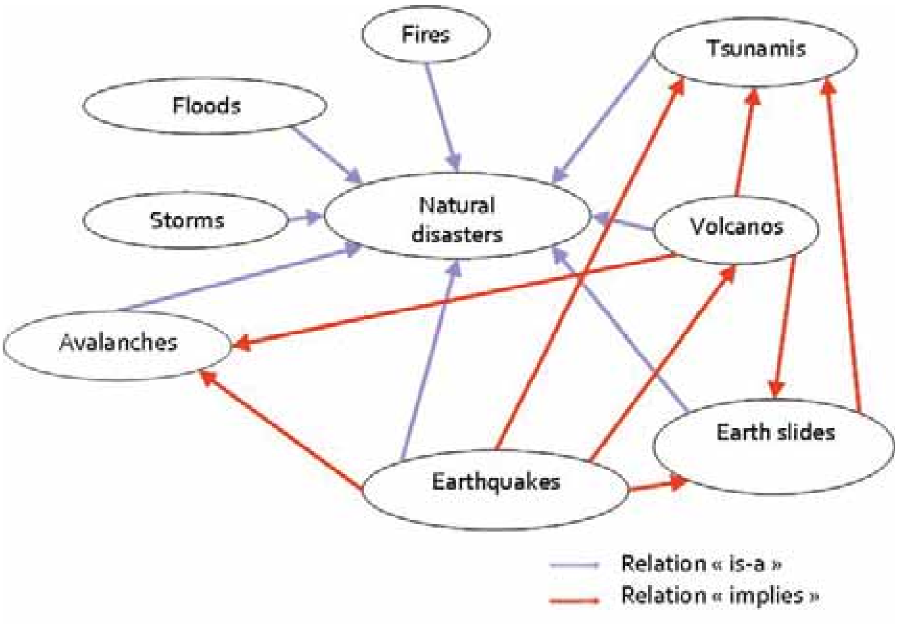


Fig. 1 – An example of ontology.

Aristotle defines ontology as «the theory of things and their relations», or as «the theory of entities, especially those existing in the language». In information technology (Gruber, 1993), the more used definition is «an ontology is a specification of a conceptualization», so on ontology is an artefact created to describe the meaning of a vocabulary. Indeed Guarino (1998) says that in artificial intelligence, an ontology represents an artefact made with a vocabulary for building reality, accompanied with a set of implicit assumptions concerning the meaning of words and of the vocabulary. So an ontology is neither a catalogue of objects nor a taxonomy, but an ontology not is reducible to a purely cognitive analysis, and represents the objective side of things.

Nothing prevents that different ontologies can be used to describe the same reality. Therefore two observers may have two different visions or two different understanding of the same reality, so giving two different classifications. For example, Kavouras, Kokla and Tomai (2005) gives three different classifications for water bodies coming from three various sources.

Ontology	Category_type
CORINE Land Cover	Peat bog
	Water course
	Water body
MEGRIN	Bog
	Canal
	Lake/ pond
	Salt marsh
	Salt pan
	Watercourse
WordNet	Body of water
	Bog
	Canal
	Lake
	Pond
	Salt pan
	Watercourse
	Watercourse

Fig. 2 – Example issued from Kavouras, Kokla and Tomai (2005).

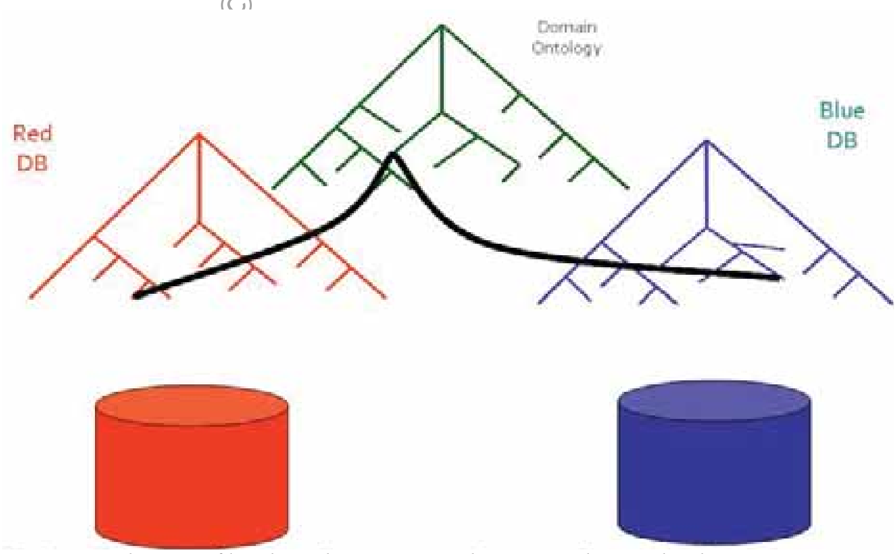


Fig. 3 – Mechanism of local ontologies using a domain ontology with relations.

Finally, an ontology can be considered as a conceptualization method; the main idea is to replace the domain of semantic interpretation (= conceptualization) by an ontology. Then, an immense description in intension must be built with few rules, integrating all possible and plausible facts organized in domains, contexts and applications. But the big question is «where to find all concepts?». As example, there is no authority to define a "seat"!

Originally in information technology, ontologies were created to solve interoperability problems between databases; in this context, each database must have its own ontology (usually a sort of re-writing its conceptual model) called local ontology; and to communicate a domain ontology (Fig. 3) must be used to link concepts. For each concept of the local ontology, one or more concepts of the domain ontology must exist. A special program called a mediator is in charge of this translation; in a sense (A ➔ B) it translates the query A into the B language using the domain ontology; then the query is made against B which gives a result. This result in the B language is again transformed by the mediator to deliver the answer in the A language.

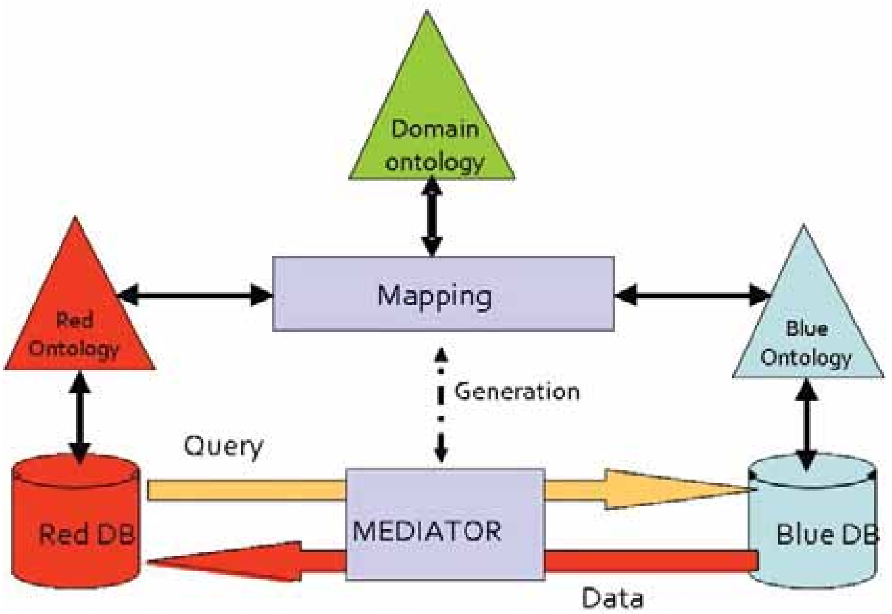


Fig. 4 – Translation and adaptation of the query and of the results by means of a mediator in charge of those transformations driven by a domain ontology.

In order to illustrate this process, an example will be taken. Suppose a British (say database A) is interested by the distance between Turin and Venice. The initial query will be:

```
Select    Distance
From      Distance_Table
Where     origin_city = "Turin"
          And destination_city = "Venice"
```

The mediator assisted by the domain ontology will transform this query into the following so to be accepted by B:

```
Select    Distanza
From      Tabella_Distanza
Where     citta_origine = "Torino"
          And citta_destinazione = "Venezia"
```

The B result will be 407 km. Then the lower part of the mediator will transform this result in miles, giving 253 miles.

To conclude this introduction, one can say that creating an ontology is an approach similar to conceptual data modelling. But in addition, it can include constraints, business rules, derived rules, etc.. There is no consideration of storage, but a distinction between concepts and terms must be made. Finally, from a mathematical point of view, an ontology is a graph of concepts, so a semantic network.

The Fig. 5 gives an excerpt of coastal geographic objects.

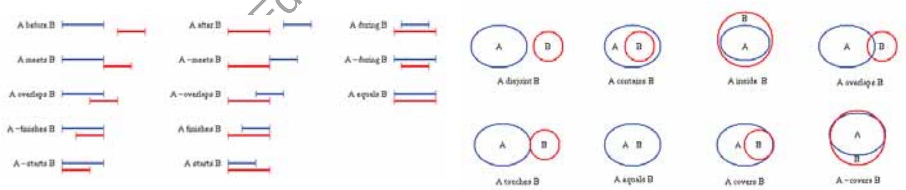
Obj. No.	Real World phenomena - Source Terminology	Object name	Object Description			
			Attributes			Implementation
			Source Terminology	User Defined Attributes	Object Identity	Point, Line, Area or Samples
34	Coastline Shore Shoreline Shoreline movement and configuration Mean low water Mean low water (springs) Median low water mark Low water mark Low water (mean) Low water (spring) Lower tidal limit	OBJECT-COAST (MLWs - MHWs)	Heritage Coast Coastline (managed) Coastline (unspoilt) Natural Coastline Coast (undeveloped) Coast (restored) Coastline (rural) Urban coasts	Heritage Coast Developed Undeveloped	PHYSICAL ENTITY : SPATIALLY HOMOGENEOUS	VECTOR (AREA) MULTI-ATTRIBUTE
35	Point Of Closure Base line	OBJECT-CLOSURE		Depth	COGNISED ENTITY : SPATIALLY HOMOGENEOUS	VECTOR (LINE) : SINGLE ATTRIBUTE
36	Areas of Responsibility Administrative Boundaries Admin. / County Boundaries Coastal Jurisdiction	OBJECT-ADMINISTRATION	Coastal cells (management) CZM unit Sea surface management areas Buffer zones Land ownership	Management Zone Land Ownership	GEOPOLITICAL ENTITY : SPATIALLY HOMOGENEOUS	RASTER : MULTI-ATTRIBUTE

Fig. 5 – Excerpt of a geographic ontology for coastline objects (Raper, 2002).

As an additional example, let us consider streets. Every three-year old child knows what a street is, especially when mother is saying «beware of streets!». So, if one wants to set a list of streets, one can ask to a street-cleaner, a postman and an employee of the electricity company. All of them will say «Yes, we have the street file!». But by examining those lists, one can observe that there are not identical: the street-cleaner passes only in public streets, the postman in all habited streets and the electricity employee only streets with electricity. This example shows that there are various categories in urban features: as the first guess is that those categories bearing the same names (streets) are the same, rapidly the second guess states that they are different.

Spatial and geographic relations

Spatial relations describe relations concerning mathematical objects in space (Laurini and Milleret-Raffort, 1989). As a first principle, let me say that spatial relations are hidden in coordinates. Topological relations such as at 1D, interval relations (Allen, 1983) and at 2D Egenhofer relations (Egenhofer, 1994) are well known (Fig. 6). But other relations exist such as projective (or cardinal such as North/South, East/West) relations and distance (near/far) relations (Fig. 7).



a) Allen relations (1D) b) Egenhofer relations (2D).

Fig. 6 – Topological relations. a) At 1D (Allen, 1983); b) At 2D (Egenhofer, 1994).

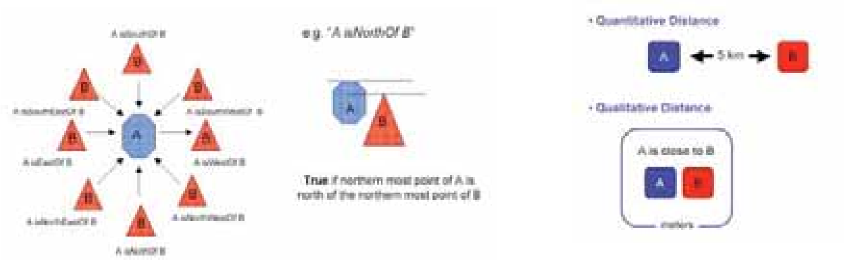


Fig. 7 – Projective and distance relations.

With such topological relations, it is easy to build a global ontology for water objects and continents (Fig. 8). But the Earth is spherical, and spatial relations must take the Earth roundness into account.

Characteristics of spherical spatial relations

As example, let us consider the relation “East_of” and transitivity.

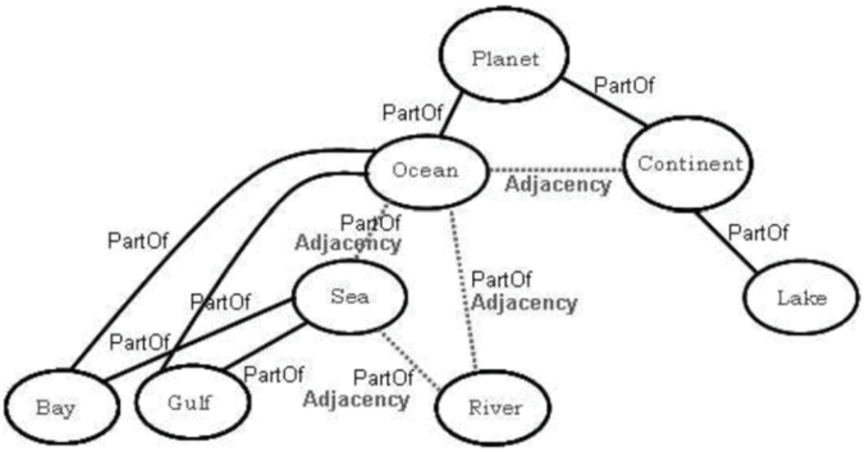


Fig. 8 – Example of ontology based on spatial relations.

$$\left.\begin{array}{l} East\_of\ (Belluno, Venice) \\ East\_of\ (Venice, Trieste) \end{array}\right\} \Rightarrow East\_of\ (Belluno, Trieste)\ [true]$$

But:

$$\left.\begin{array}{l} East\_of\ (Belluno, Beijing) \\ East\_of\ (Beijing, Washington) \end{array}\right\} \Rightarrow East\_of\ (Belluno, Washington)\ [false]$$

$$but{:}\ East\_of\ (Washington, Belluno)\ [true]$$

For the relation “North_of”, implications are different:

$$\left.\begin{array}{l} North\_of\ (Belluno, Zurich) \\ North\_of\ (Zurich, Berlino) \end{array}\right\} \Rightarrow North\_of\ (Belluno, Berlino)\ [true]$$

However, if one says «what is north of North Pole?». The answer is void; and moreover when one is at the North Pole, all directions are going south! But there is always an easternmost feature for any feature.

Finally, if we consider a planar space, there is no problems of transitivity; but on the globe, transitivity is partial, *i.e.* acceptable on “small territories” and not acceptable in “vast territories”.

Spatial relations in urban space

Considering a city and spatial relations between urban objects, we can make the assumption that the conventional 3D Cartesian is valid. Moreover considering again streets, some observations can be made.

- They are one-way streets and sometimes two-way streets can have several lanes.
- Some objects are positioned on the street (pedestrian zebras), some under such as sewerages, and some above such as traffic lights.
- Some concrete concepts such as sidewalks, medians, crossroads, T-junction, runabout, road signs, curves, engineering network can be defined with the "has_a" semantic relation, but their "topological semantics[2]" are stronger.
- Some objects such as engineering networks can be under streets or under sidewalks.
- For some actors, streets are defined by the lines with parcels whereas for others the streets are reduced to the asphalted part.

So those observations imply that Allen or Egenhofer relations are not sufficient to describe relationships between street objects. So, the question is «what could be the minimum set of useful relations?».

A – Binary topological relations

```
on (street, pedonal_zebra)
under (street, sewerage)
above (street, traffic_light)
along (sidewalk, street)
on (sewerage_grid, street)
```

B – Relations between urban features and places

```
host (barrack, army)
host (hospital, health_activity)
```

Representation of geographic features

A very important aspect when designing a geographic ontology deals with mathematical representations usually taken as attributes. For years,

[2] The concept of "topological semantics" has another meaning in Mathematics.

several models for instance for storing a simple polygon exist, but standardization has opted for one of them (OGC). For a street, several models exist depending from actor's vision. Fig. 10 illustrates four families of models totally different:

- the first model is based on graph with edge as street axes and nodes as crossroads;
- the second based on two polylines delimitating the private part and the public part (cadastre meaning);
- the third as an areal model for describing the section reserved for traffic;
- and finally a 3D model in order to integrate engineering networks.

The practical consequence is that topological relations for street objects can be defined differently according to the geometric model in use. And this figure does not take scales into account.

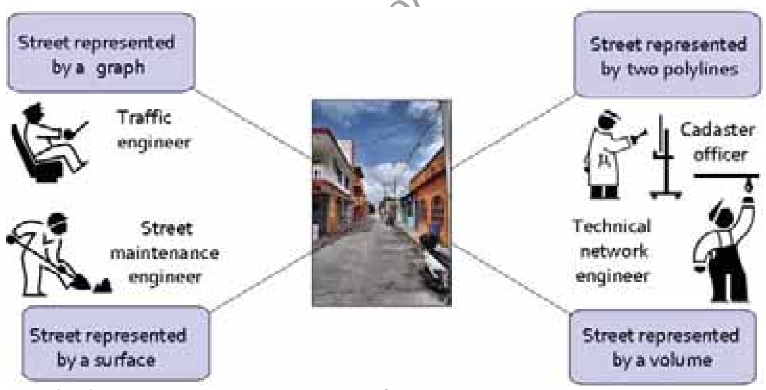


Fig. 9 – Multiple geometric representations of a street.

Fuzzy geographic features

Usually, two categories of features can be distinguished, crisp and fuzzy. Crisp objects must have well-defined boundaries such as administrative objects (countries, regions, provinces, natural parks, parcels, etc.) and anthropic objects such as streets, buildings.

Other objects, for instance some natural features can be defined as crisp objects, but there are difficulties. A river at some scales can be defined as a line whereas sometimes the expressions such as minor or major bed are used. Even some dry rivers can be without water. For seas, according to the tide levels, geometric shapes can be different. One of the more salient examples is "Mont Saint-Michel". Another example deals with mangrove which can be astride sea and jungle.

For those objects, fuzzy sets can be used in which some membership grades can be defined (Fig. 9). Between those fuzzy objects, topological relations can be defined. An interesting model (Cohn and Gotts, 1996) is the egg-yolk model with two parts, the core (the yellow part) and the extension, the white part of the egg.

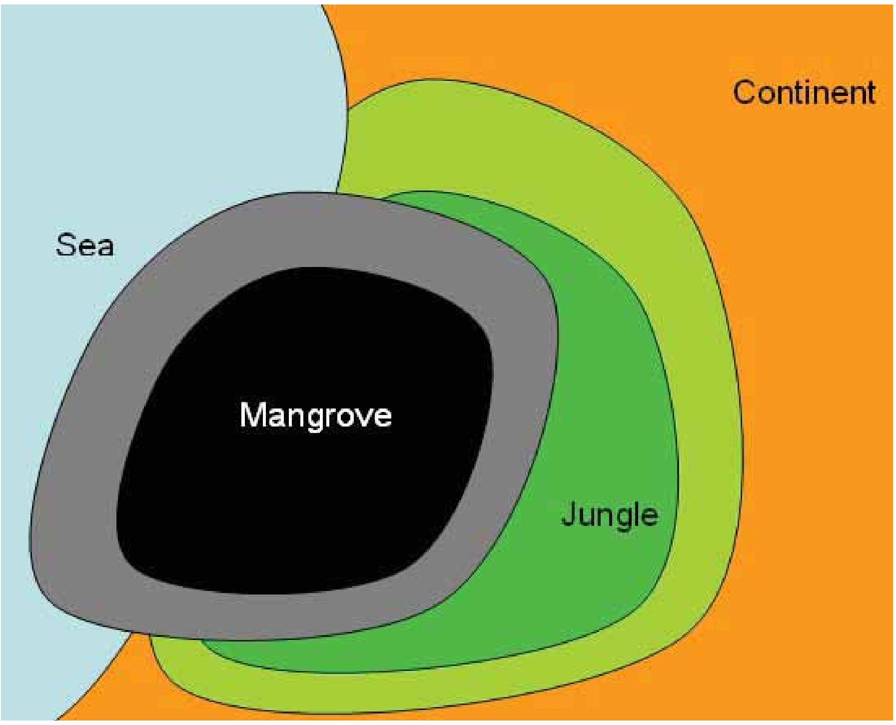


Fig. 10 – Fuzzy relations between geographic features.

Spatial relations for mountains

For mountains, one of the most important aspects is that vegetation varies with altitude. In this paper, only mountains in temperate climates will be dealt with. Fig. 11 gives a visual model for vegetation distribution in which two groups of rules must be defined. The first one describes southern and northern slopes, taking into account that category north or south is sometimes not appropriate. From a computational geometry point of view, those definitions depend on the used digital terrain model (Laurini and Thompson, 1992) in order to define practically altitude gradients.

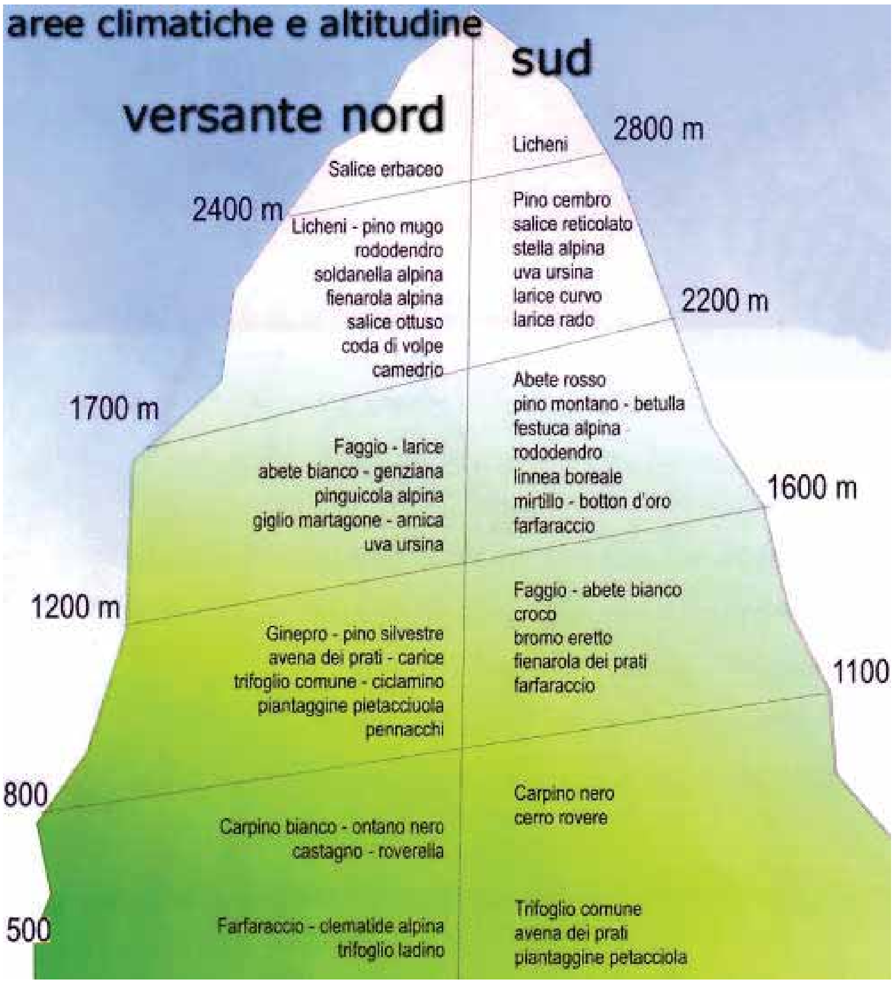


Fig. 11 – Relations between altitudes and vegetation[3].

`Shady_slope (place): if altitude gradient is facing towards South`
`Sunny_slope (place): if altitude gradient is facing towards North`

The second group is for describing vegetation in terms of knowledge chunks as exemplified in Fig. 11. For instance, in which `Zone28-35` and `Zone8-12` are fuzzy vertical zones:

[3] http://www.magicoveneto.it/natura/schede/AreeClimatiche-Altitudine.jpg.

```
Altitude_Climate (Shady_slope, Zone28-35, licheni)
Altitude_Climate (Sunny_slope, Zone8-12, ginepro)
```

This representation valid for vegetation can be easily extended to pastoral activities and socio-economic activities, for instance for skiing.

Conclusion

The goal of this paper was to give some research guidelines for defining and constructing geographic ontologies. Those ontologies not only give description of geographic features based on conventional semantic relations (*is-a* and *has-a*), but also on topological relations between objects. But the main problem is that neither Allen nor Egenhofer topological relations have the sufficient semantic power to describe links between geographic features.

With the description of some features such as street and mountain objects, a research direction is proposed. The first step will be to identify those relations and to express their geometric semantics, to test their efficiency. Then, a minimum set must be found.

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