A scalable solution for the integration of qualitative models

HQQGIS: Hybrid Quantitative - Qualitative Geographic Information System

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1 Introduction

Since ancient times, men had the necessity to catch somehow the concept of "information", to model it in a certain way and even to find out methods to store it. Information is a term with many meanings depending on context, but is, as a rule, closely related to such concepts as meaning, knowledge, instruction, communication, representation, and mental stimulus. Of course an important part of the information field is the one concerned with geographical and spatial matters. In general, geographic (or geospatial) information is created through the manipulation of geographic (or spatial) data. Nowadays, geospatial information can be stored, transformed and queried within special informatics systems named GIS (Geographic Information System).

1.1 Geographic Information Systems

In the strictest sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. In a more generic sense, GIS applications are tools that allow users to create interactive queries (user created searches), analyze spatial information, edit data, maps, and present the results of all these operations. But what exactly does a GIS do? GIS is a part of your life everyday and you may not even be aware of it. The roads you drive on are designed using GIS to analyze traffic volumes and other pertinent data to determine the best locations, materials, and maintenance schedules. The forests you drive by everyday are managed using GIS to analyze health issues, harvesting capabilities, reforestation opportunities, fire dangers, and more. Most utility companies rely on GIS to develop the infrastructure that allows their companies to function; water, electrical, phone and oil and gas lines are mapped , monitored, and analyzed all using GIS. Law enforcement is using GIS to plot and track crimes and correlate crime statistics helping to monitor and even predict the probability of a crime occurring. As stated in [2], the spatial components of GISs provide a mean to process and communicate information mainly regarding the location of spatio-temporal entities. However, locational information covers only one aspect of the entire spatio-temporal informative set. Within standard GISs, there are two methods widely used to store data: Raster and Vector. Both of them provide a geometric representation of space, which is unable to provide an extrinsic description of all those relations and features which are contained in the spatial domain. Indeed, although geometric models are based on a really sound theory and permit to accomplish a big range of spatial analysis, it takes quite some effort to query a GIS by some qualitative requirements.

1.2 Qualitative Models

An alternative to geometric models are qualitative models: special kind of models that are successful in representing the reality by its qualitative nature. A qualitative model describes in a formal way a certain aspect of the reality; it specifies features, properties and relationships for the entities of the modeled domain, as well as rules and constraints such entities are constrained by. A particular subset of qualitative models consists of all that models that deal with spatial or spatio-temporal aspects. Such models aim to get a representation of space based on qualitative features and relations subsisting for and among spatial entities. Especially, according to Clementini and Di Felice [4], the qualitative spatial relations between objects can be either:

- Topological relations;
- Projective relations;
- Metric relations.

One qualitative model, usually, focus on representing one specific fundamental spatial feature/relation, i.e. direction and orientation [10, 11], relative position [17], topology [8, 5] etc. Some qualitative models, however, deal with features that could be defined as target-oriented, that is, certain spatial properties whose analysis is useful to achieve a certain purpose. Up to today, a lot of sound qualitative models have been developed in order to deal with some specific qualitative aspects. Basing on such models it is possible to represent space by qualitative relations subsisting among objects rather then by their own geometry. Although qualitative spatial representations have not the same metric precision of geometric ones, they provide a different way to reason about space, really useful when dealing with qualitative spatial analysis. Iwasaki [14] describes the goal of qualitative approaches as follows: "*Broadly speaking, qualitative-reasoning research aims to develop representation and reasoning techniques that will enable a program to reason about the behavior of physical systems, without the kind of precise quantitative information needed by conventional analysis techniques such as numerical simulators. . . . Observing pouring* *rain and a river's steadily rising water level is sufficient to make a prudent person take measures against possible flooding - without knowing the exact water level, the rate of change, or the time the river might flood.*"

In another way I would say that qualitative reasoning emulates human reasoning making use of the power of logic and symbols. Especially, qualitative models allow to represent space in a more human-like way and human being to perform spatial analysis in a more natural way.

2 Motivation

People often use qualitative spatial thinking and reasoning in everyday life [15, 18], nevertheless current commercial GISs mainly support quantitative/location-based spatial queries providing a very strong mean for spatial analysis, however they provide really weak means to allow users to make qualitative spatial queries. For example, point to point distance in metric units or direction in degrees does not necessarily conform to people's usage of terms and concepts, due to the fact that people's spatial concepts are often more qualitative in nature. A qualitative GIS would complement the existing models. The incorporation of qualitative spatial relations will give GIS users a greater choice in formulating queries, depending on the task being performed. Furthermore, by better accommodating the human requirements, qualitative models will also contribute toward the greater utilization of GIS technology.

Nowadays if one wants to operate a qualitative spatial analysis through a GIS, one will run into several problems. First, one need to find a mapping from the qualitative requirements to some geometric constraints. Later on, one will have somehow to implement such requirements. Lastly, when querying the GIS, due to the fact that qualitative information will have to be computed from quantitative one, the interrogation and retrieval time will increase. If a GIS would explicitly include the storage of qualitative relations, it would provide a powerful instrument for operations and searches based on them, highly improving time performances. Furthermore, an ad-hoc data structure - oriented to qualitative information storage, retrieval and reasoning - will firstly reduce efforts that today are needed to translate from qualitative representations (typically human) to mathematic/geometric representations (standard GIS). Again, the direct storage of qualitative information will give a new face to GISs: they will natively provide the possibility to carry out qualitative queries and qualitative spatial analysis. The users would be furnished with a high-power system, able to satisfy human-like requests as much as qualitative models present within the GIS will be closer to human mental representations. Suppose a GIS perfectly mirrors the totality of the humans mental representations, then it will be perfectly tuned in to its users, completely nullifying human-machine communication efforts. The users can query the GIS in the same way they exchange information with another human being. Thus, the more the system will employ qualitative models and the more such models will trend to human mental representations, the more the system would become user-friendly leading to a range of novel kinds of spatial analyses that are impossible to imagine nowadays. It is impossible to well determine the kind and the range of new possible requirements that will be possible to satisfy.

The intrinsic properties of such a system would also lead to the possibility to directly collect and store qualitative data avoiding a specific geometric description. Nevertheless it would be possible to reconstruct a geometric approximation directly from qualitative relations if sufficient qualitative information is available in the system.

3 Problem Statement

Although qualitative reasoning methods are rapidly emerging and developing in several areas, they are still relatively unused in the Geographic Information field. Up to now only the topological aspect has been taken into consideration and integrated in the major part of GISs. Indeed the OpenGIS Consortium [13] recognized as a standard feature the implementation of the 9-intersection calculus [8]. However, GISs are not optimized to answer to topological queries as processing the query will always go down to the geometric level. It is evident how such querying method would be highly overcome in performances if it would be possible to directly query on requested relations. Moreover, other qualitative relations are completely unconsidered within nowadays GISs.

4 Research target

Prompted by an analysis on nowadays GIS functionalities and limitations as discussed previously, and by results and abilities of cognitive science and qualitative models and reasoning, I imagined a hybrid GIS system where capabilities of both quantitative and qualitative models are available together. The main idea is to empower a standard quantitative GIS by a qualitative relations storage layer and a qualitative reasoner, able together to easily manage qualitative spatial analysis. The qualitative aspect will be separated by the purely geometric one that still will be available within the quantitative layer (standard GIS). Nevertheless the two layers have to be linked with each other and spatial data has to be mirrored within both, obviously using different kind of representations. The qualitative layer indeed will directly store information as qualitative relations among spatial entities. In the following sections I will give a logical overview of the Hybrid Quantitative-Qualitative GIS as I imagine it. Later I will describe in more details, analyzing concepts and structures the system will need. Lastly I will explain the approach that, in my opinion, is the best one to move towards the realization of this kind of system, also describing the topics I am interested in and those I will not take care of during my investigation.

4.1 Hybrid Quantitative-Qualitative GIS: logical overview

At a conceptual level such a system has the shape of a multi-tier database for (geo)spatial data, having at a first level the quantitative/geometric representation of the space stored in a standard GIS. Above it lie several Qualitative Storage Units (QSU) related in a network/graph scheme that will take care to store qualitative relations subsisting among geometric objects. The standard GIS layer will deal with quantitative/geometric information, while the Qualitative Storage Network, composed by the whole set of QSUs, will manage the qualitative aspects of spatial or spatio-temporal relations. A manager engine will take care of the whole structure; it will contain a querying engine as well as a UID (Update Insert Delete) engine that will deal respectively with the data retrieval and update, insertion and delete tasks. A rough sketch of the logic framework is depicted in Fig. 1 (pag. 5). Edges between QSUs represent conceptual connections for the stored spatial facts: a link among two different QSUs exists in the case information carry on from them together represents a more complex qualitative spatial relation or part of it.

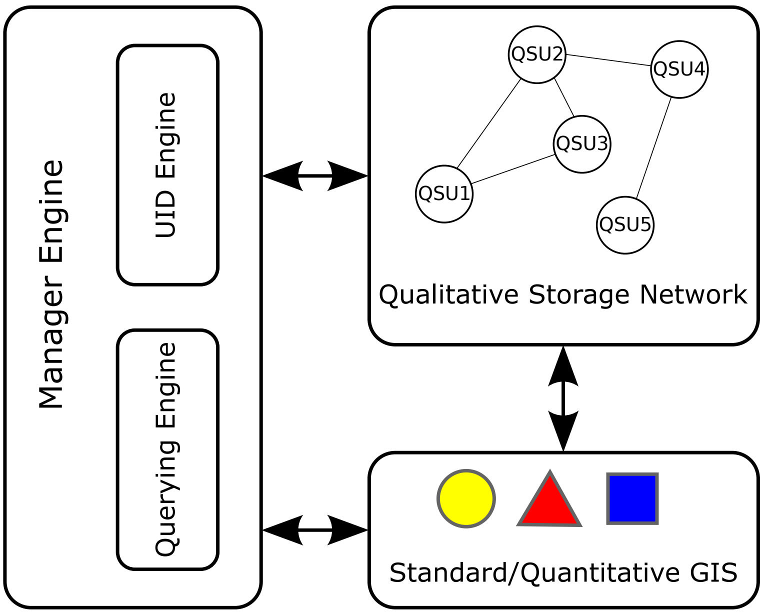
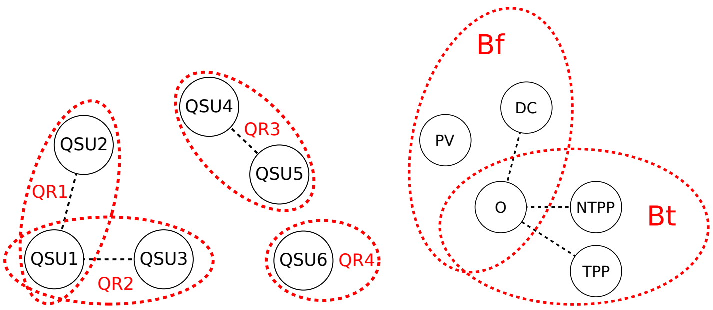


Figure 1: HQQGIS - rough logic framework.

4.2 The Qualitative Storage Network

Logically, the qualitative layer will be grounded on set of qualitative spatial relations, thus qualitative models (QM), extensible at wish. Let enumerate such models as $QM_1, QM_2, ..., QM_n$ and the qualitative relations introduced by the totality of the n qualitative models as $QR_1, QR_2, ..., QR_m$. The idea is to recursively describe every qualitative relation in terms of more elementary relations in order to obtain atomic spatial information pieces. Every Qualitative Storage Units $QSU_1, QSU_2, ...QSU_k$, will store either such qualitative atomic information or complete qualitative relation, referencing objects involved in the specific relation by unique object identifiers. This means that, in the case two different qualitative relations QR_j and QR_k share a piece of common information, such commonality could be stored in a common node in the network i.e. QSU_i. Thus, as shown in Fig. 2(a) (pag. 6) information carried on by one qualitative relation could be split within several Qualitative Storage Units, in which case dotted lines represent connection paths between QSUs that together describe a single relation. In the case a non-atomic relation is given it is important to decide whether it has to be stored as a unique block in one single QSU rather than split in its atomic components and thus stored in several connected QSUs. By the description of all the models trough the same formalism, it will be possible to identify and abstract in common Qualitative Storage Units the common factors among models, this will reduce data redundancy within the system and will also provide the basic principle for retrieval and reasoning operations.



(a) QSN logic framework (b) Partial example of a QSN

Figure 2: Qualitative Storage Network (QSN)

4.2.1 A Storage Example

As an example let now suppose the qualitative layer is empty and the system only encompasses the following qualitative models:

- RCC-8 [5]
- 5-Intersection [3]
- Visibility model [21, 9]

RCC-8 is a well known qualitative model that deals with topological relations between two regions differentiating 8 qualitative relations (cf. Fig. 3(c) on page 8):

- $Disconnected = DC$
- $ExternallyConnected = EC$
- $PartialOverlap = PO$
- $Equal = EQ$
- $TangentalProperPart = TPP$
- $TangentalProperPartinverse = TPP_i$
- $NonTangentalProperPart = NTPP$
- $NonTangentalProperPartinverse = NTPP_i$

The 5-Intersection model (cf. Fig. 3(a) on page 8) defines ternary relations among regions in a plane. Using internal and external tangents between a pair of (reference) objects to build a frame of reference (FoR) it differentiates 5 basic relations depending on which acceptance zone the third (primary) object lies in:

- $After = Af$
- $Between = Bt$
- $Before = Bf$
- $LeftSide = Ls$
- $RightSide = Rs$

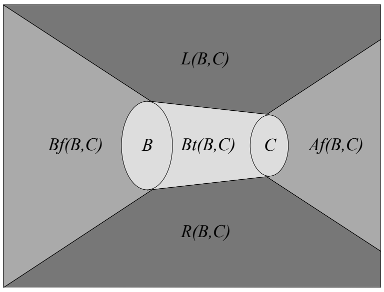
Furthermore, the version we use in our example also includes 2 extra relations that are only able to hold when the reference objects overlap:

- $In = In$
- $Out = Out$

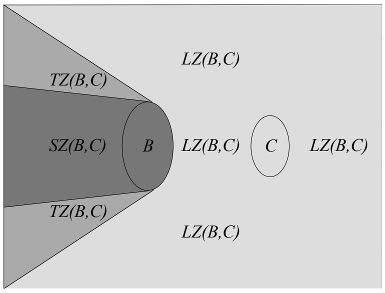
If the primary object is a region it could happen that it overlaps multiple acceptance zones; in this case multiple basic relations hold simultaneously as an AND-composed relation.

Lastly, the Visibility model (cf. Fig. 3(b) on page 8) splits the plane into three acceptance zones using a procedure really similar to the 5-Intersection one, defining three basic visibility relations:

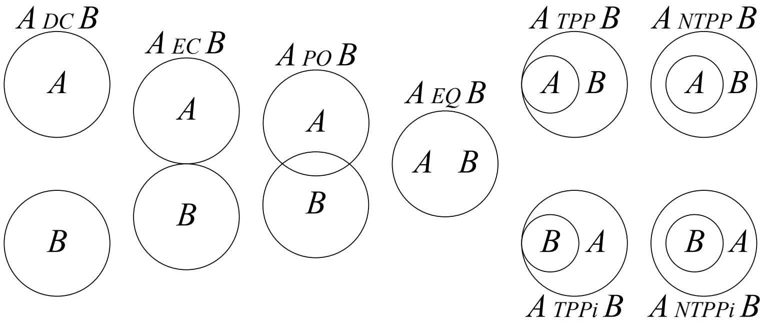
- $Visible = V$
- $PartiallyVisible = PV$
- $Occluded = O$



(a) 5-Intersection Model



(b) Visibility Model



(c) RCC-8

Figure 3: Frames of reference

Also in this case the primary object can lie in more than one zone giving rise to AND-composed relations.

Part of the corresponding QSN is depicted in Fig. 2(b) on page 6. Such QSN can be easily understand comparing the frameworks exposed in Fig. 4,5 and 6. For example, the Before (Bf) relation can be also obtained from the combination of more different relations, i.e. a Partially Visible relation, holding when the primary object overlap the Twilight acceptance Zone (cf. Fig. 6 TZ(B,C)) or from the combination of an Occluded relation and a Disconnected one:

$$PV(\mathtt{A},\mathtt{B},\mathtt{C}) \implies Bf(\mathtt{A},\mathtt{B},\mathtt{C})$$
$$O(\mathtt{A},\mathtt{B},\mathtt{C}) \wedge \mathtt{A}\, DC\, \mathtt{B} \implies Bf(\mathtt{A},\mathtt{B},\mathtt{C})$$

Similar observations can be made for the Between (Bt) relation:

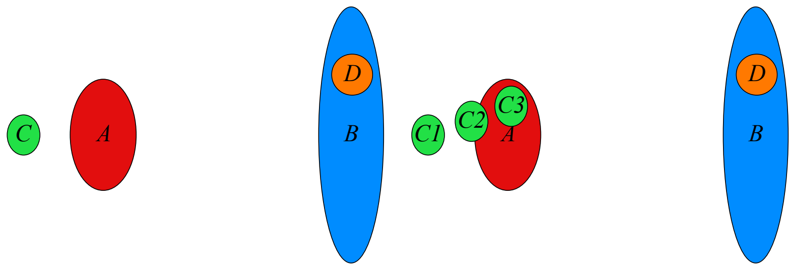
$$O(\mathtt{A},\mathtt{B},\mathtt{C}) \wedge \mathtt{A}\, NTPP\, \mathtt{B} \implies Bf(\mathtt{A},\mathtt{B},\mathtt{C})$$
$$O(\mathtt{A},\mathtt{B},\mathtt{C}) \wedge \mathtt{A}\, TPP\, \mathtt{B} \implies Bf(\mathtt{A},\mathtt{B},\mathtt{C})$$

Suppose now having an object configuration as shown in Fig. 4(a) on page 9. Analyzing such a configuration in terms of the three models described above, we can draw a table containing every holding spatial fact (see Fig. 5 on page 10).

Suppose again that a human operator gives a qualitative description of such a configuration in his own natural language and that from the interpretation of it the following relations are derived (underlined in the table of facts)[1]:

1. $O(\mathtt{C}, \mathtt{A}, \mathtt{B})$
2. $Bt, Ls, Rs(\mathtt{A}, \mathtt{B}, \mathtt{C})$
3. $\mathtt{A}\, DC\, \mathtt{B}$
4. $\mathtt{A}\, DC\, \mathtt{C}$
5. $\mathtt{D}\, NTPP\, \mathtt{B}$

Using the normal reasoning tables of the models only a subset of the whole table of facts could be inferred.



(a) Object configuration (b) Reasoning on object C

Figure 4: A simple example

Nevertheless, applying a combined reasoning that takes into account all the three models simultaneously, it is possible to infer the whole list of facts. As an example suppose we want to know which is the 5-Intersection relation holding for the triple $(\mathtt{C}, \mathtt{A}, \mathtt{B})$. The 5-Intersection permutation tables are not useful in the sense that they give rise to an OR series of possible solutions. Here is where the combined reasoning enter the game. It grounds on the same principles of the QSN, so for example from the given relation $O(\mathtt{C}, \mathtt{A}, \mathtt{B})$ we know that C lies in a certain area according to the Visibility model, but such an area corresponds to a set of possible areas in the 5-Intersection one. Particularly the object C can lie in one of the three positions depicted in Fig. 4(a) on page 9 that respectively correspond to the relations $Bf(\mathtt{C}_1, \mathtt{A}, \mathtt{B}), Bf, Bt(\mathtt{C}_2, \mathtt{A}, \mathtt{B}), Bt(\mathtt{C}_3, \mathtt{A}, \mathtt{B})$. From the given relation $\mathtt{A}\, DC\, \mathtt{C}$, we also know that A is not connected with C, thus the only possible solution is that the $Bf(\mathtt{C}, \mathtt{A}, \mathtt{B})$ relation hold. Using similar reasoning procedures it is possible to infer all the facts in the table depicted in Fig. 5 on page 10. The example above should only demonstrate the principles underlying my proposal and thus represent a simplified vision of the problem proposed. The relations given to describe the spatial scene have not been proved to be the

[1] The given qualitative description is not demonstrated to be minimal.

minimal set necessary to infer all the other facts. This leads to two important research questions:

1. Does a minimal set of relations exist that allow us to infer all the facts of a certain object configuration? Whether this set exists, is it unique? How can it / one be computed?
2. In the case a non atomic relation is given, has it to be stored as it is or decomposed in atomic relations?

Visibility	V(A,B,C)	O(A,B,D)	V(A,C,B)	V(A,C,D)	P(A,D,B)	V(A,D,C)
	O(B,A,C)	V(B,A,D)	V(B,C,A)	V(B,C,D)	VPO(B,D,A)	VPO(B,D,C)
	V(D,A,B)	O(D,A,C)	O(D,B,A)	O(D,B,C)	V(D,C,A)	V(D,C,B)
	(1) O(C,A,B)	O(C,A,D)	V(C,B,A)	O(C,B,D)	V(C,D,A)	P(C,D,B)
5-Intersection	BtLR(A,B,C)	Out(A,B,D)	(2) BtLR(A,C,B)	BtLR(A,C,D)	Out(A,D,B)	BtLR(A,D,C)
	Bf(B,A,C)	BtAfLR(B,A,D)	Af(B,C,A)	BtAfLR(B,C,D)	BfBtLR(B,D,A)	BfBtLR(B,D,C)
	Bt(D,A,B)	Bf(D,A,C)	Bt(D,B,A)	Bt(D,B,C)	Af(D,C,A)	Bt(D,C,B)
	Bf(C,A,B)	Bf(C,A,D)	Af(C,B,A)	Out(C,B,D)	Af(C,D,A)	Out(C,D,B)
RCC-8	(3) A DC B	(4) A DC C	A DC D	B DC A	B DC C	B NTPPi D
	D DC A	(5) D NTPP B	D DC C	C DC A	C DC B	C DC D

Figure 5: Table of facts referring to Fig. 4(a) on page 9

4.3 Qualitative Spatial *Meta-Model*

As shown in the example above, my main aim is to integrate several aspects of qualitative representation and reasoning in order to obtain a better and finer model of the spatial reality. I want to focus my research on the development of a formal methodology to merge together different qualitative models that deal with different aspects of the spatial domain. I want to investigate whether it is possible to develop a kind of *meta-model* that, given two qualitative models with their respective reasoning tables, is able to merge them obtaining a combined model with combined reasoning tables. This *meta-model* will be grounded on the same principles governing the Qualitative Storage Network: the atomic relations (see above) will represent primitives for the *meta-model*. The underlying idea is that of re-defining the starting models in terms of such primitives. In this way, the model definitions will work as a common factor on which the meta-reasoner can reason on in order to combine the starting models. Similar models have already been developed in the past even if only concerning certain specific spatial relations.

As an example, let us consider the $\mathcal{OPRA}_m$ calculus [19]. The Oriented Point Relation Algebra is a directional calculus whose granularity is scalable through a parameter m. The basic entity is what they named oriented point (O-point): a point in the plane provided with an orientation. The calculus aims to provide directional information of a point with respect to another. The frame of reference (FoR) is composed by m lines passing through the O-points, giving rise to an alternation of linear and half-planar sectors. Between every pair of linear sectors there is an angular gap of $\frac{2\pi}{2m}$. This calculus presents an integration schema where data represented in different granularities can be mixed and also allows to transform data from a granularity to another. Furthermore, as demonstrated in [6], the $\mathcal{OPRA}_m$ calculus is expressive enough to encode relations from other directional calculi providing thus the equivalent *meta-model* I described above even if only working with a specific spatial aspect, namely, directional information.

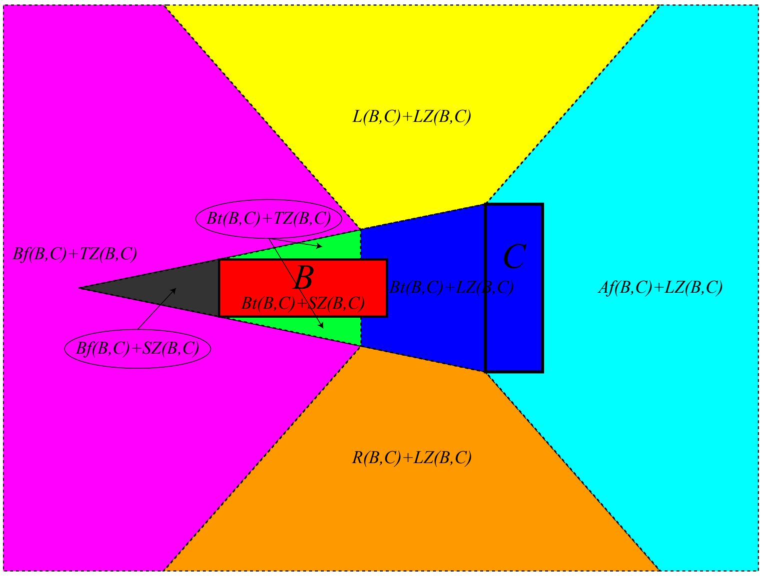


Figure 6: A mixed frame of reference: Visibility + 5-Intersection

Another approach to the integration of several qualitative calculi is provided in [12]. In chapter 8 Galton copes with qualitative continuity developing a full theory based on what he names Topological Mode (TM) spaces. The treatment of TM spaces are beyond the aim of this document, nevertheless, although Galton deployed such a theory to cope with spatial changes, an interesting result from our point of view is the demonstration that given two qualitative models, representing two different TM spaces, it is possible to form a larger TM space by taking their Cartesian product. Using as a base his theory he could cope with completely different qualitative models, like for example RCC [5] and Allen's intervals [1], reaching the same results than original treatments. Galton

R1 = (Bf , LZ)	*R9 = (Af , SZ)*
R2 = (Bf , TZ)	***R10 = (L , LZ)***
R3 = (Bf , SZ)	*R11 = (L , TZ)*
R4 = (Bt , LZ)	*R12 = (L , SZ)*
R5 = (Bt , TZ)	***R13 = (R , LZ)***
R6 = (Bt , SZ)	*R14 = (R , TZ)*
R7 = (Af , LZ)	*R15 = (R , SZ)*
R8 = (Af , TZ)	

Table 1: permutation pairs $(R_{5-Intersection}, R_{Visibility})$; only bold relations are realizable.

also claimed that the hardest part is to demonstrate that the calculus under analysis represents a model for a TM space. Even if the TM space theory is oriented to the study of spatial changes, it shows that it is not impossible to provide a universal mean able to cope with completely different aspects of the spatial domain.

To give an example, lets now consider the models described above. First of all it will be shown how to merge models basing on similar FoR or basing on FoR grounded on the same primitives i.e. the visibility and the 5-Intersection models. For both of them the FoR is built by the usage of internal and external tangents. The overlap of the two FoR is depicted in Fig. 6 on page 11. Now it is possible to identify a finer subdivision of the plane, basing on the pair $(R_{5-Intersection}, R_{Visibility})$ of the relations holding for the 5-Intersection and for the Visibility models. Actually, the 5-Intersection allows for 5 different relations and the Visibility for 3, that means that all possible permutations of the pair (R5-Int,Rvis) would be 15 (see table 1 on page 12), nevertheless, some of them cannot occur because of the definition of the acceptance zones. Indeed, every acceptance zone is a subset of the whole plane $\Re^2$ according to a system of geometric/mathematic constraints. In this case, only 8 combinations are possible (bolded in the table). The new acceptance zones will be enumerated, obtaining in this case 8 different areas standing for 8 possible (pairs of) relations. This reduction from 15 to only 8 possible relations is induced by the fact that the two models carry on a common baggage of information, thus, them relations are not completely unrelated. For the same reason, them reasoning tables can be merged together obtaining a more accurate reasoner. The resulting merged model will be expressive enough to encode both the models. My objective thus is defining which are the atomic universal atomic relations that, considered together in one comprehensive model will be able to encode all models of the spatial domain.

A more complex combination would be between models grounded on different criteria. Considering again the same example as above, RCC-8 and 5-Intersection. In this case it is also necessary to cope with the calculus arity, indeed, RCC-8 is a binary calculus, while 5-Intersection is ternary one. To cope with the first problem, we have to re-define the models using the same primitives. I would say that the most suitable way is that of using acceptance areas. In this case we can redefine the RCC-8 using as acceptance areas boundaries, interiors and exteriors of the spatial objects, this will yield to a formulation that is a mixture of the RCC-8 [5] and the 9-Intersection [8] models. Also Egenhofer with the 9-Intersection calculus copes with topological spatial relations among regions on a plane, obtaining a set of 9 different relations, one of those only occurring when considering regions with holes. In our example thus, basing on the same procedure of Egenhofer, but only considering simple regions, we will obtain a different definition of the RCC-8 model. To cope with the arity problem is a minor problem, in the sense that should be sufficient to consider all the possible permutation of three objects, exactly as the table of facts of the previous example (cf. Fig. 5 on page 10) shows. Again, the examples I gave are only a simplification of the proposed problem. Obviously, the aim of my research is to generalize the concepts expressed above, particularly, trying to answer the following research questions:

1. Is such a universal *meta-model* realizable? under which assumptions?
2. Whether it is, which are the primitives able to encode every qualitative spatial model?
3. Which is the computational complexity of its reasoning system?

Whether the *meta-model* would be realizable and computationally satisfactory, it would allow the HQQ GIS to be extensible at wish with any number of qualitative models, furthermore, if every model is expressed in terms of the primitives, the physical representation of the QSN should not explode in branching terms.

4.4 Querying Engine

The querying engine will lie on the *meta-model* described in the previous section and must be able to process hybrid quantitative-qualitative as well as purely qualitative queries. In the remainder of this section I will present an example to let understand how the querying engine should work out basing on the following assumptions:

- The system is only formed by three qualitative models
  - RCC-8 calculus [5] for the topological aspect
  - 5-Interseciton calculus [3] for directional/positional information
  - Visibility model [21] for treatment of visual issues
- The system is realized and working on a server, accessible via web.
- The client interface to the system is available for mobile phones and includes a natural language interpreter.

Imagine a man is driving on a certain road looking for the house of an old friend where he has been only once several years ago. The scene is depicted in Fig. 7 on page 14: the squares represent houses and the arrows within them indicate their intrinsic orientation: the entrance door. The man knows the house is on the road but cannot remember the address, nevertheless he remembers that from his friend's house it is possible to see a lake and also that there is a forest on the other side of the road. Suppose the user is provided with a mobile phone equipped with a GPS antenna and an internet connection, so he can use the HQQ GIS client interface. He can ask to retrieve:

"*all the houses that*

border the road

AND lie on the other side of the road with respect to the forest

AND see the lake"

The query will return the result outlined by a red circle. In Fig. 8 on page 15 is depicted a rough description of the querying engine that can be used to follow the querying operation row from the formulation to the retrieval of information.

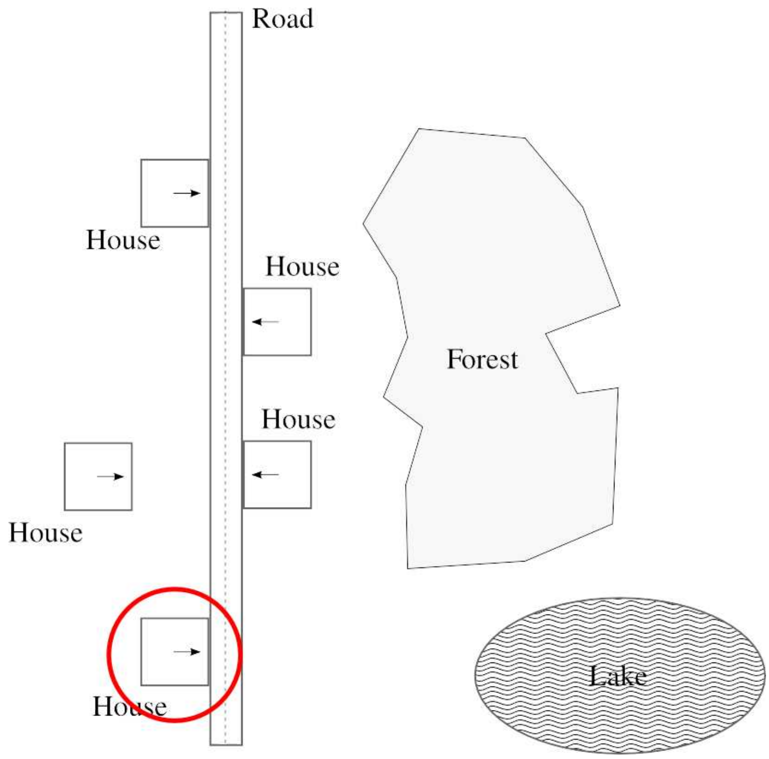


Figure 7: Query example dataset

The query is expressed in natural language, however, the interpretation of natural language does not fall within the scope of this work and therefore we assume that it comes to the system already translated in a formal qualitative query language. The querying engine, analyzes the query to find out the quantitative and the qualitative requirements that will be addressed towards the standard GIS and towards the QSN respectively. The qualitative part will be semantically interpreted to obtain the qualitative relations required. Lastly, the logic interpreter basing on the principles described for the QSN and for the *meta-model*, will decide to interrogate different areas of the QSN to obtain the required information. Such information will be recomposed from the logic interpreter and raised up to the semantic interpreter that will correlate them with the appropriate request in the original qualitative requirements. Lastly the analyzer will take the qualitative and quantitative information to merge them together according to the user query. A query like the one in the example would require big efforts to be processed on a standard GIS, because it does not regard geometric features, but refers to purely qualitative concepts. The query would need to be preprocessed to find out the corresponding geometric meaning and then turned into purely geometric queries.

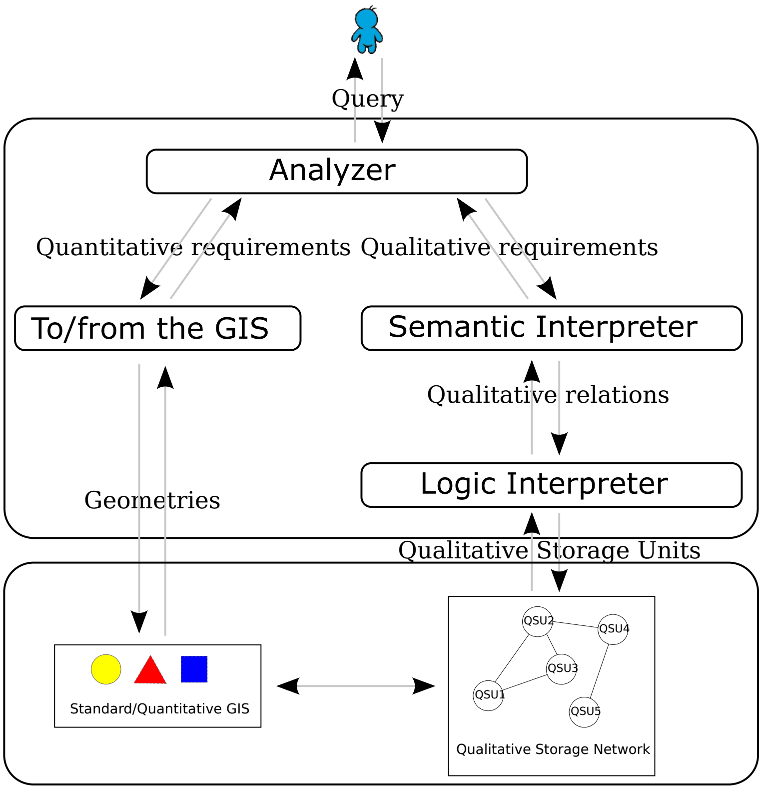


Figure 8: Logical overview of the querying engine

4.5 Personal focus

I want to focus my research on qualitative spatial representation and reasoning, particularly I want to investigate on the possibility and eventual methods to realize the Qualitative Storage Network and the *meta-model* as I described them in the previous sections in order to move towards the realization of a Hybrid Quantitative-Qualitative Geospatial Information System. Mainly I will concentrate my efforts towards the realization of the QSN and the querying engine.

4.5.1 Concrete approach

In the early stages of my research, I will study qualitative spatial models in order to select a minimal group of them so that together they are able to describe at a satisfactory level the most salient aspects of a spatial environment. The most stable and successful models will have to be chosen and, whether several models will be available for a certain aspect of the spatial domain, those which are demonstrated to be more similar to human mental models must be preferred. This will allow to obtain a system as user-friendly as possible. My objective is to achieve a comprehensive data network where the common factors are raised to a shared common level, to optimize the system performances and to avoid redundancies in data storage. Once obtained the fundamental qualitative spatial model set I will use it to operate a methodological top-down analysis in order to determine the atomic relations through it which should be possible to define other qualitative models. Using such atomic relations as a base case, I will develop the *meta-model*. It will have to be general enough to allow for the mixing of the most possible number of qualitative models. Models re-definition will be done through the means of the atomic relations, but the meta-reasoning that will be able to find relations between relations or, in other words, to determine the common information carry on by different relations, will have to take into account semantics. I will build on the ideas underlying the Semantic Web [16] and the Semantic Geospatial Web [7] and on ontological principles in general [20] [1]. Indeed, if different relations among spatial entities carry on the same piece of information, it means that they constitute a semantic net, being them connected by such common information pieces. In other words, we can say that such relations semantically overlap. Thus, it is quite clear that an ontological approach could be useful in the ongoing work, nevertheless, focusing not my research on ontologies development, I will look for a spatial ontology suitable to adapt to the goal of my research in order to obtain a taxonomy of the qualitative spatial atomic relations that will provide a formalism to identify semantic connections among different qualitative relations. Now it will be possible to enter the realization phase. I will have to choose the most efficient data structures for data storage. A deep search on algorithms and data structures will be necessary: such structures will have to provide powerful, robust and easily extensible storing means that will make the Qualitative Storage Network concrete. Such structures have also to be efficient for the operations will be necessary to satisfy. Later the querying engine can be drawn and developed. It will have to be able to analyze a query in order to find out the best pattern within the whole structure to retrieve information required.

4.5.2 Topics Excluded from the Investigation

I will not take care of the natural language interpretation, indeed such a matter, even if really interesting and closely related to my topic, is a very huge and hard field and quite out of my first intentions. Moreover, I will not care about the link between the quantitative and qualitative layers, I will only deal with this as much as it is necessary to furnish a correlation between them, but I will not cover this matter in details. Equally, I will not care about inconsistency problem within data, either within the quantitative side, as well in the qualitative network or between the two layers. Also I will not deal with integration of different data sources on the quantitative tier as well as communication among different GISs. Lastly I will not analyze the geometric approximation from qualitative relations.

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