2016 IEEE 24th International Requirements Engineering Conference

Towards Modelling and Analysis of Spatial and Temporal Requirements

Mounir Touzani
Université de Montpellier
Montpellier, France
email: touzani@lirmm.fr

Christophe Ponsard
CETIC Research Centre
Charleroi, Belgium
email: christophe.ponsard@cetic.be

***Abstract*—Requirements Engineering is a key step in any project aiming at evolving an information system. The temporal dimension of requirements is already supported by specific formalisms which enable the verification of the temporal behaviour of the system under construction. In contrast, space requirements have for long been reserved to Geographic Information Systems. Nowadays, systems are becoming ubiquitous due to generalisation of mobile technologies and the emergence of the Internet of Things and Cyber-Physical Systems. This increasing level of connection of the software with the real-world requires more systematic methods for capturing and reasoning about the system not only from the temporal but also from the spatial point of views. Here, we present our ongoing effort for systematically identifying, structuring and reasoning about spatial and temporal requirements. Our work lies at the cross-roads of goal-oriented requirements engineering and geomatics. We discuss our current progress on the design of a coherent set of notations borrowed from both fields to enrich domain and goal models with spatial and temporal properties. We also sketch how specific methodological support can be provided on top of them to achieve high quality requirements.**

I. Introduction

Requirements Engineering (RE) is a crucial step for the success of a project: many studies show that project failure usually find a root cause at the RE time [1]. Methods have been developed to ensure key properties of completeness, accuracy, non-ambiguity and testability. These methods can be very generic (classification requirements, checklists, goal refinement techniques) or very specific (formal modelling and verification). The former are lightweight but provide only limited warranties, while the latter are very precise but require specific expertise and are time-consuming. It is therefore interesting to consider intermediary classes of properties which could provide a good compromise between ease of application and ability to increase quality. Properties shared by many systems relates to the temporal nature of the intended behaviour but also to the spatial nature of the physical world elements which they monitor and/or control.

Temporal properties have been widely studied to analyse software intensive systems, including reactive and real-time systems [2]. Several variants of temporal logics have been defined to describe different aspects of the temporal behaviour of systems, e.g. discrete or continuous; instant-based or interval-based; bounded or unbounded; deterministic or not; linear or branching [3]. A large number of verification tools able to deal with system level design stage are also available: model-checker [4] [5] or proovers [6].

In contrast, spatial properties have mostly been used in the more restricted domain of Geographic Information (GI). According to [7], GI describes an object, phenomenon or a real-world action. It provides, for each object, information about the name, type, thematic features, shape, geographical location or even information about proximity relationships between objects. GI must go through several steps among which acquisition is crucial and relies on the use of sensors such as GPS, scanning, Internet protocols or Web Services. It has become the ground for a class of systems called "Geographic Information Systems" (GIS) [8].

Today's information systems are becoming increasingly connected with the real world thanks to the development of mobile Internet, the emergence of the Internet of Things and the definition of Cyber-Physical Systems. This leads to the development of new applications and systems having strong requirements about their perception of the real world, e.g. fleet management systems, travel companions, smart cities, factories of the future and soon connected cars. This requires the ability to capture and reason not only on the temporal dimension of the system but also on its spatial aspects. Moreover those properties can interact with each other.

Our current research focuses on the inclusion of the space-time (ST) requirements by borrowing and cross fertilising ideas from the RE and GIS fields. As underlying framework, we use goal-oriented requirements engineering (GORE) [9] which already explores a number of dimensions such as the "WHY / HOW" (goals and their refinement into requirements), the "WHAT" (functionalities) and "WHO" (agents and their responsibilities). The focus of this work is on the additional "WHEN" and "WHERE" dimensions.

The purpose of this paper is not to present final research results on this topic but to validate our research directions based on our current achievements. To reach this goal, we have formulated the following research questions and are seeking feedback both from the RE and GIS communities:

- **RQ1: Which notations can help the requirement engineer in easily capturing ST requirements ?** To answer this question, we need to consider existing notations from both fields, what is missing, how to best integrate them, how to extend them, which formalism and degree of

2332-6441/16 $31.00 © 2016 IEEE
DOI 10.1109/RE.2016.60

RE 2016, Beijing, China
RE@Next! Paper

precision to use (graphical, textual, mathematical), what about the tool support...

- **RQ2: Which methodological guidance can be provided based on those notations to produce better ST requirements ?** Methodological guidance can be considered at different stages: identifying ST requirements, reaching completeness/consistency/precision quality attributes, making the system robust in enforcing such requirements...
- **RQ3: Which interesting synergies can be identified between spatial and temporal requirements ?** One idea is that there can be some form of duality between those domains and that some techniques can thus be replicated across domains. Changing the nature of a requirement between temporal and spatial aspects can also be interesting to study.
- **RQ4: How useful/general is it ?** To answer this questions, there is a need to review practical use cases and to identify interesting classes of problems to investigate further.

This paper is organised as follows: in Section 2 we set the context of our research by presenting how the spatial and temporal dimensions are dealt with in GIS and RE domains, using the **KAOS** method used as reference framework. Section 3 sketches our current progress in addressing our research questions. Next, Section 4 identifies research directions and requests feedback from the RE community about them. A short running example related to a fire safety plan for a complex public infrastructure (e.g. a school) is used throughout the paper.

II. Background

In this section, we give a quick summary of several relevant approaches dealing with spatial and temporal requirements, mainly from the requirements engineering and geomatics communities. We present relevant modelling notations and specific properties. We also present a few mechanisms defined to identify, structure and reason about the requirements in terms of space and time.

A. The spatial and temporal approach in GIS

Space refers to the geographical location information and defines spatial relationships between objects. These relationships are as important as the entities themselves [10]–[12]. Many directions have been taken to define three classes depicted in Figure 1 : topological [13] (e.g. pharmacy is next to the laboratory), metric [14] (e.g. the city is located 5 km from the beach) or by projection [15] [16] (e.g. France is North of Spain).

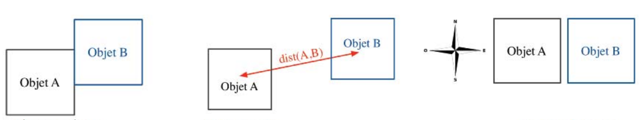

Fig. 1. Spatial relationships between two objects

The time dimension targets events occurring either at a moment or a period, or changes over a period [17] [18]. Classifications covering both the spatial and temporal dimensions have been developed to capture movement and transformation phenomena [19].

The perception of the relationships between objects in space and objects in time, shows a strong analogy. In [20], the author described three types of relationships: the adjacency (e.g. around 15 November 2015), inclusion (e.g. in the middle of the year) and distance (e.g. two weeks before the end of the year). Some common temporal relationships are illustrated in Figure 2.

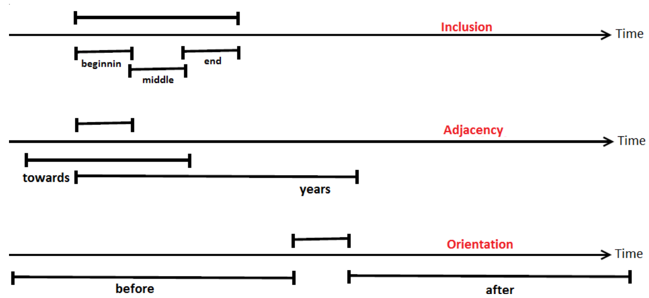

Fig. 2. Temporal relationships between two objects

In terms of modelling, the researchers' goal has always been to make the GI less complex [21], hence the need to formalise the spatial and temporal properties, and to ease the description of the geometry (size, position, shape and orientation) and temporality for better communication.

The representation of spatial objects requires modelling techniques adapted to the spatial and temporal phenomena. In this sense, the formalism of spatial and temporal representations through the use of spatial and temporal pictograms in models have been proposed and refined by Bédard. The latest evolution called PictograF [22] is depicted in Figure 3. They are classified according the dimensionality and nature, e.g. 0D temporal mean an event, 2D spatial is a surface. For the spatial nature, 2D and 3D abstractions can be considered (e.g. reasoning about surface on a 2D map). Other entity-relationship formalisms have also been proposed to ease the modelling of spatial information and associated temporal aspects and are reviewed in [23] and [24]. Some connexions with RE have also been investigated in [25].

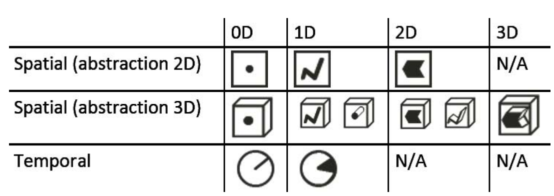

Fig. 3. Illustration of spatial and temporal pictograms (PictoraF)

B. Goal-Oriented Requirements Engineering

Goals capture, at different levels of abstraction, the various objectives the system under consideration should achieve. GORE is concerned with the use of goals for eliciting, elaborating, structuring, specifying, analysing, negotiating, documenting, and modifying requirements [9]. To support our research we focus on KAOS, a specific GORE method [26] but the same concepts and methods can be applied in other GORE variants like i* [27] and GRL [28].

The different abstraction levels to express goals can range from high-level strategic goals like "Maintain[Safe Operation of School]" down to operational goals such as "Maintain[All fire doors closed]" or "Achieve[Rapid Evacuation]". High-level goals can be progressively refined into more concrete and operational ones through relationships linking a parent goal to several sub-goals, with different fulfilment conditions using either "AND-refinement" (all sub-goals need to be satisfied) or "OR-refinement" (a single sub-goal is enough, i.e. possible alternatives). The "WHY" and "HOW" questions can be used to conveniently navigate to parent and sub-goals, respectively. This results in a goal tree structure as shown in Figure 4. The goal decomposition stops when reaching a goal controllable by an agent, i.e. answering the "WHO" question about responsibility assignment. These goals are either requirements on the software or expectations on the behaviour of agents in the environment. Domain properties can also be taken into account to justify a refinement. Such properties are intrinsically valid. An example is the following spatial and temporal property: "A physical object can only be in one place at a time"

The KAOS method is structured on the following four sub-models:

- The **goal model** structures functional and non-functional goals of the considered system. It also helps identify potential conflicts and obstacles related to goals and reason about their resolution. It is graphically represented as a goal tree.
- The **object model** defines and interrelates all concepts involved in goal specifications. Its representation is aligned with UML class diagrams and allows structuring entities, relations, events and agents.
- The **agent model** identifies the agents of both the system and the environment as well as their interface and responsibilities. They can be shown as part of goal trees or in more specific diagrams.
- The **operations model** describes how agents functionally cooperate to ensure the fulfilment of the requirements assigned to them and hence the system goals. Functional flow diagrams are used here.

RE methods usually only deal with the temporal dimension. For example, KAOS can capture the following aspects:

- Temporal properties can be expressed by using specific keywords such as "always" "eventually", "until"… over predicates referring to the object model. The property about evacuation could be state as "WHEN fire alarm is triggered THEN all occupants should evacuate WITHIN 10 min". A number of patterns were identified by [29]. On this basis, [30] proposed a lightweight specification system, based on a structured set of formulation patterns. This helps to state precise, coherent, non-ambiguous, expressive and easy to understand requirements.
- Temporal logic can be used to give precise mathematical semantics and to perform verification on models using tools such as model-checker or provers. E.g, the property about fire doors could be formalised as: $\forall fd : FireDoor \cdot \Box fd.isClosed()$
- Refinement patterns can be used for structuring goals. The best known is the "milestone" pattern which can break down a property into a chain of properties which must be successively achieved to "finally" reach the wished property. Another popular pattern is the "case base" decomposition, splitting a property into a set of complementary sub-properties based on some conditions. Such patterns are proven once and for all and can typically help discover some missing sub-goals. A comprehensive library of refinements was proposed by [31].

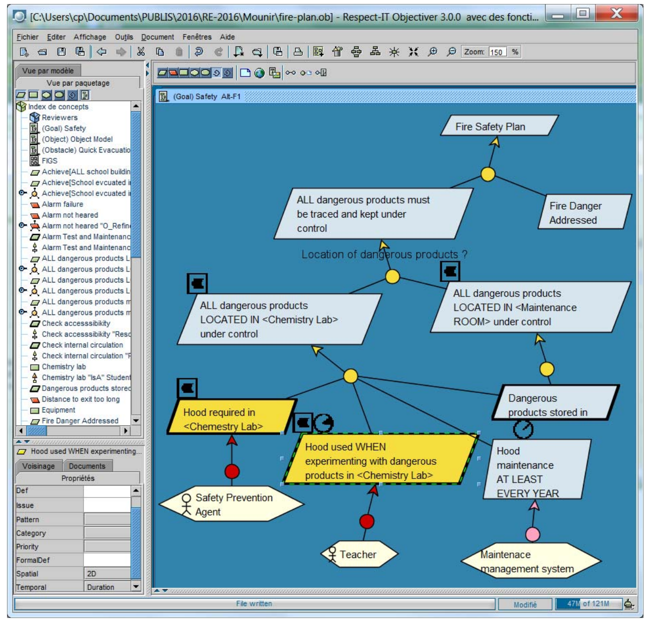

Fig. 4. High-level goals for the fire safety case shown in the extended tool

III. Current Progress

In this section, we present our current progress and provide some partial answers to our research questions.

A. RQ1: Which notations to support ST requirements?

Here, we present here our current experiments to RE notation extensions to support ST requirements. Up to now, we have focused only on the domain (aka object) and goal models which come first in the RE process. Our extensions were prototyped using a commercial RE tool for KAOS which supports plug-in both to extend the meta-model and to provide graphical additions inside diagrams [32]. The current prototype is illustrated in Figure 4 and is also available for download[1].

1) Extending the object model: In order to extend spatial and temporal notations in the Object model, we relied on the "PictograF" notation system [22]. These notations have been developed over the past 20 years and have thus reached a good maturity level, adoption and integration using UML stereotypes. This eases and systematises the capture of a number of domain properties which would otherwise be specified textually, generally only when needed by some refinement. The presence of such properties can help to refine goals and also to check for their consistency and completeness.

Figure 5 shows the use of those notations on our example. The right part of the diagram shows a spatial decomposition structure of the infrastructure into rooms of different types. Note that the aggregation relationship also takes a spatial sense when expressed over spatial entities. The left part of the diagram shows a number of equipments which can be required inside specific rooms for safety reasons. A spatial inclusion relationship "is in" is expressed between them.

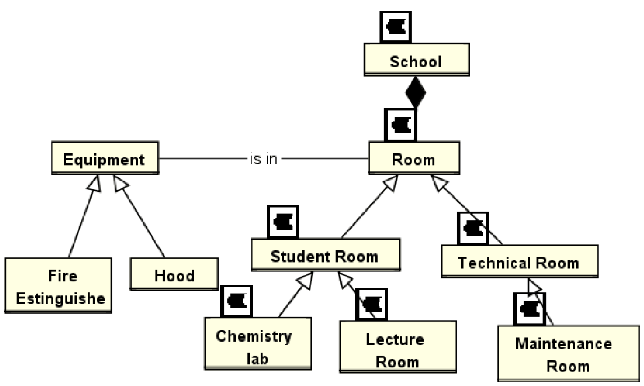

Fig. 5. Domain (object) model: a simple spatial decomposition

2) Extending the Goal Model: A central idea is to generalise some of the "PictograF" attributes (and related decorations) to goals. In this spirit, a goal could be marked as having a specific spatial or temporal dimension if:

- the goal is expressing specific temporal or spatial constraints on specific elements (independently of their nature, see next condition). For example, "All chemistry labs must be equipped with a hood" is of spatial nature.
- the goal is referencing elements already having such dimensions. This results in a consistency rule between annotations made in the object model. For example, a requirement whose scope is a building will have a spatial nature.

Figure 4 shows such a goal model. The decomposition structure expresses specific safety requirements such as the need for a hood in chemistry labs. The way they relate to higher level goals is detailed in the next section.

[1]The plug-in can be downloaded from : http://www.objectiver.com/packages/plugins/STPlugin.jar

B. RQ2: Which methodological guidance for ST requirements?

Extending RE model with ST notation results in more precise models. It also enables new ways to reason on those models in terms of completeness and to provide guidance in more systematically identifying requirements using more specialised goal refinement techniques. We highlight a few techniques of this kind identified so far to demonstrate some potential benefits.

1) Spatial Refinement Pattern: The expression of a property on a high level spatial entity such as a "School" can be propagated across the whole structure with different kinds of rules. A simple rule can be used to propagate the property as it is. For example, in order to ensure the building safety, all rooms should be safe. More specific conditions can be applied to specific rooms, based on their specificities. This means the safety conditions can be expressed in more specific cases, for example a chemistry lab should be equipped with a hood. This can also be seen as a way to perform case-based decomposition (e.g. some "special rooms" and other "normal rooms"). This pattern will result in a goal decomposition tree whose structure is quite similar to the spatial decomposition.

More complex propagation constraints can also be expressed on the spatial structure. For example, the capacity of a structure can be (recursively) expressed in terms of the sum of the capacities of all spatial sub-entities. Other operators like maximum capacity for hosting some events can also be applied.

2) Transforming between spatial and temporal requirements: A frequent constraint is related to time to travel. For example, the evacuation of a building will defined as the maximum time to achieve it. Reasoning on it will however require to consider the distance people have to travel from different locations as well as potential physical obstacles which can slow them down (e.g. stairs). This also applies to other forms of travel, e.g. on a transportation network (train with waiting times, roads with traffic jam).

3) Obstacle analysis driven by ST criteria: Goals are often over-idealistic. In order to produce robust requirements, they must be tested against adverse conditions that can prevent their achievement (i.e. risk analysis). RE techniques have been defined to generate obstacles to goals starting from monolithic obstacles and refining them into possible root causes which can then be controlled [33].

Amongst obstacles generation techniques, heuristics are the most interesting for practical use. They rely on the alteration of specific constraints expressed by some requirement in order to generate the corresponding obstacles. The presence of ST constraints can thus be a good generator of obstacles from which one can derive a specification that will be able to enforce those ST constraints in a much robust way.

Figure 6 illustrates this on the evacuation time for our fire safety case. First, the requirement is propagated to all buildings. Then, obstacles are generated against meeting the 5 minutes deadline. Among the obstacles, time can be transformed into distance using a previously stated refinement

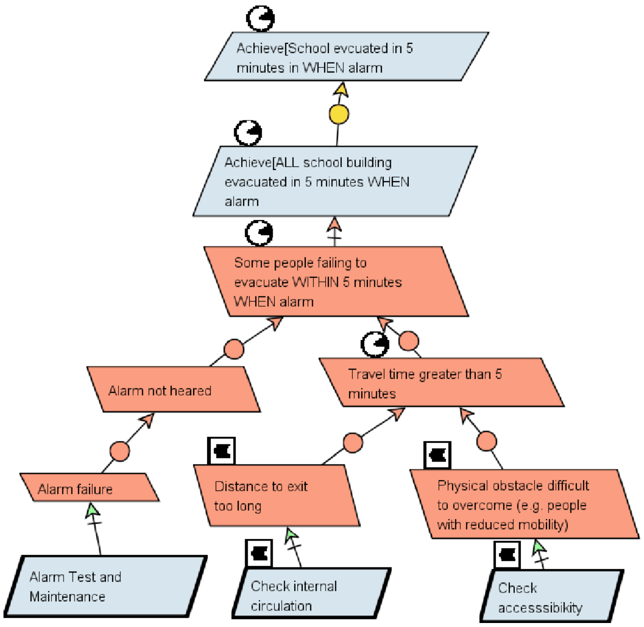

Fig. 6. ST obstacle analysis

technique. This problem can then be mitigated by checking and improving the internal navigation structure of the building. Another spatial problem could be related to physical obstacles to progress that cannot be managed by specific people, e.g. people with reduced mobility. Such an analysis is fully detailed in [34].

C. RQ3: Which synergies between ST requirements?

The previous sections have already highlighted some similarities between spatial and temporal dimensions. Dualities can be more systematically explored as sketched in Table I.

TABLE I
DUALITY BETWEEN SPATIAL AND TEMPORAL RE DIMENSIONS

	Spatial domain	Temporal domain
Dimension	1	0, 1, 2 or 3
Existential quantification	Once (past/future)	Somewhere (in a given dimensions/direction/interval)
Universal quantifier	Always (past/future/in interval)	Everywhere (in a given direction/dimension/volume)
Absolute measure	"Universal/Logic" time	"GPS" coordinate
Relative measure	w.r.t. reference event	distance, surface, volume w.r.t. reference object
Qualitative reasoning	Relative position of events, intervals	relative positions of objects (topology)
Quantitative reasoning	Event counts in a specific time interval	Spatial capacity of a given space according to specific business rule

D. RQ4: How useful/general is it?

This question is still difficult to answer at the present state of our work. In addition to the small running example used here, we conducted some case studies in the following application domains:

- organisational change: the case of the merger of two universities in the city of Montpellier [35].
- logistics domain: the capture of spatial and temporal constraints for complex optimisation of vehicles routing, including the presence of temporal variability (predicable traffic jam) and spatial restrictions (roadworks) [36].
- assessment of the accessibility of public places for disabled people [34]

So far, the approach proved useful to help in the discovery and structuring phase. An element which was less anticipated is that it also seems to help in increasing the understandability of the model and thus ease the validation phase.

IV. Discussion and Expectations from RE-Next

Starting from a collection of available notations and modelling techniques from the RE and GIS fields, we have sketched a first and still quite rough version of what could be an integrated support for spatial and temporal requirements. We have prototyped and applied it on a few cases of different sizes, complexities and application domains.

So far, the results are quite encouraging but are also raising a number of interesting new questions open for debate:

- **Extension of graphical notation**. Some temporal aspects of the domain, like periodic events, cannot be captured using the currently investigated notations. ST notations could also be applied on attributes of the modelled entities as proposed by [37]. This would increase the granularity and precision levels but the danger is also to start encoding requirements inside the object model. In the same spirit, the semantics of the annotations should be made more precise.
- **Relation between domain and goal models**. As we have shown in our example, using the domain structure can help to derive refinements. Beyond this simple example, other kind of ST relationships (e.g. containment, overlaps) can be used to drive the model decomposition or to make sure it is complete and consistent.
- **Formulation patterns for ST requirements**. In our example, we used some keywords for expressing temporal requirements (e.g ALWAYS, WHEN, WITHIN, EVERY...) but also for spatial requirements (e.g. ALL, LOCATED...). Building a library of formulation patterns would help in stating more precise requirements. To our knowledge, there is no such work for spatial requirements so the research focus should be there.
- **Reasoning on ST requirements**. Formulation patterns provide a good level of structuring which could then lead to more formal logics, i.e. extending temporal logics with extra predicates for spatial properties and using existing spatial or mixed ST algebras to reason on them [38] [19].
- **Enhanced obstacle analysis**. Heuristics can be gathered for driving obstacle analysis using ST requirements. More semantic aspects can be included, e.g. capturing agents capabilities w.r.t. space and time dimensions could be used both for the generation step but also to propose realisable resolutions.

- **Operationalisation of ST requirements using Business Rules**. A maintainable way to implement ST requirements in an Information system is through a Business Rules Management System (BRMS). The mapping or formalisation of ST requirements into existing BRMS languages could be interesting an piece of work.

At this stage, we plan to analyse more deeply the above issues, relying on more case studies and on the feedback gathered both from the RE and SIG communities. Based on this, we will be able to validate the best decisions to make regarding the mentioned open issues and possible new research directions that will be identified. We will then consolidate our work in one or several of the following directions: increase the notation support, identify more methodological guidance (patterns, heuristics, formulation templates), cover the responsibility and operation models.

In order to give more chance to experts from both fields to experiment with our approach, we plan to widen the tool support to other GORE variants. We are currently considering Open Source tools like StarUML2 [39] and jUCMNAV [40] which already propose some extensions for RE and GIS.

ACKNOWLEDGEMENT

This work was partly funded by the Walloon Technological Innovation Partnership project (nr. 7481). We thanks Pr. Libourel, Pr. Laurent and Pr. Quinqueton for their feedback and support for the on-going case study conducted at LIRMM (attached to Montpellier Universities and CNRS) and Espace-Dev (UM, UAG, UR, IRD). Thanks also to Respect-IT for giving us access to the Objectiver SDK.

REFERENCES

[1] D. L. Hughes, Y. K. Dwivedi, A. C. Simintiras, and N. P. Rana, *Success and Failure of IS/IT Projects: A State of the Art Analysis and Future Directions*. Springer Int. Publishing, 2015.

[2] Z. Manna and A. Pnueli, *The Temporal Logic of Reactive and Concurrent Systems*. New York, NY, USA: Springer-Verlag Inc., 1992.

[3] V. Goranko and A. Galton, "Temporal Logic," Stanford Encyclopedia of Philosophy http://plato.stanford.edu/entries/logic-temporal/#TemReaAntModDay, 1999.

[4] A. Cimatti, E. Clarke, E. Giunchiglia, F. Giunchiglia, M. Pistore, M. Roveri, R. Sebastiani, and A. Tacchella, "Nusmv 2: An opensource tool for symbolic model checking." Springer, 2002, pp. 359–364.

[5] K. G. Larsen, P. Pettersson, and W. Yi, "Uppaal in a nutshell," *Int. Journal on Software Tools for Technology Transfer*, vol. 1, pp. 134–152, 1997.

[6] J.-R. Abrial, M. Butler, S. Hallerstede, T. S. Hoang, F. Mehta, and L. Voisin, "Rodin: an open toolset for modelling and reasoning in Event-B," *STTT*, vol. 12, no. 6, pp. 447–466, 2010.

[7] R. Becker and al, "Network visualization," *4th International Symposium on Spatial Data Handling, Zurich, Switzerland*, 23-27 juillet 1990.

[8] R. Laurini and D. Thompson, *Fundamentals of Geographic Information Systems.* Academic Press Limited. 0-12-438380-7, 1992.

[9] A. van Lamsweerde, "Goal-oriented requirements engineering: a guided tour," in *Requirements Engineering, 2001. Proceedings. Fifth IEEE International Symposium on*, 2001, pp. 249–262.

[10] D. Papadias and M. Kavouras, "Acquiring, representing and processing spatial relations," in *Presented at Sixth International Symposium on Spatial Data Handling*. Taylor Francis, 1994.

[11] E. Clementini, "A Conceptual Framework for Modelling Spatial Relations," Thse de Doctorat en Informatique, INSA Lyon, 2009.

[12] M. J. Egenhofer and R. D. Franzosa, "Point-set topological spatial relations," *International Journal of Geographical Information Systems*, vol. 5, no. 2, pp. 161–174, 1991.

[13] D. Randell, Z. Cui, and A. Cohn, "A spatial logic based on regions and connection," in *Proc. 3rd Int. Conf. on Knowledge Representation and Reasoning*. San Mateo: Morgan Kaufmann, 1992, pp. 165–176.

[14] D. Pullar and M. Egenhofer, "Toward formal definitions of topological relations among spatial objects," in *Proc. of the 3rd Int. Symposium on Spatial Data Handling*, Sydney, Australia, 1988, pp. 165–176.

[15] K. Zimmermann and C. Freksa, "Qualitative spatial reasoning using orientation, distance, and path knowledge," *Applied Intelligence*, vol. 6, pp. 49–58, 1996.

[16] G. Ligozat, "Reasoning about cardinal directions," *Journal of Visual Languages and Computing*, vol. 9, no. 1, pp. 23 – 44, 1998.

[17] A. Allen and S. Yabushita, "On galaxy interactions during violent relaxation of clusters," *The Astrophysical Journal*, vol. 278, pp. 468–468, 1984.

[18] A. U. Frank, "Qualitative temporal reasoning in GIS - ordered time scales." *In Waugh, T. C. et (eds.), R. C. H., diteurs : Proc. of the 6th Int. Symposium on Spatial Data Handling.*, 1994.

[19] C. Claramunt and B. Jiang, "An integrated representation of spatial and temporal relationships between evolving regions," *Journal of Geogr. Syst.*, vol. 3, no. 4, 2001.

[20] A. Le Parc-Lacayrelle and Al, *Entreposage de documents et donnes semistructures.* Hermes, Lavoisier., 2007.

[21] A. Zoghlami, *Modélisation et conception de systèmes d'information géographique gérant l'imprécision*, 2013.

[22] Bédard, Y., E., Bernier, S., Larrivée,, "PictograF," http://pictograf.scg.ulaval.ca, 2012.

[23] A. Miralles, F. Pinet, and Y. Bdard, "Describing spatio-temporal phenomena for environmental system development: An overview of today's needs and solutions." *IJAEIS*, vol. 1, no. 2, pp. 68–84, 2010.

[24] F. Pinet, "Entity-relationship and object-oriented formalisms for modeling spatial environmental data," *Environ. Model. Softw.*, vol. 33, pp. 80–91, Jul. 2012.

[25] M. Touzani, L. Anne, T. Libourel, and J. Quinqueton, "Towards Geographic Requirements Engineering," in *KMIKS'2015*, Hammamet, Tunisia, Apr. 2015.

[26] A. van Lamsweerde, *Requirements Engineering - From System Goals to UML Models to Software Specifications*. Wiley, 2009.

[27] E. S. K. Yu and J. Mylopoulos, "Enterprise modelling for business redesign: The i* framework," *SIGGROUP Bull.*, vol. 18, no. 1, pp. 59–63, Apr. 1997.

[28] International Telecommunication Union, "Recommendation Z.151 (10/12), User Requirements Notation (URN) Language Def." 2012.

[29] M. B. Dwyer, G. S. Avrunin, and J. C. Corbett, "Patterns in property specifications for finite-state verification," in *Proc. of the 21st Int. Conf. on Software Engineering*. New York, NY, USA: ACM, 1999.

[30] M. Mahaux, "Vers une Spécification Allégée pour l'Analyse des Besoins Orientée-Objectifs," Master thesis, University of Louvain, 2004.

[31] R. Darimont and A. van Lamsweerde, "Formal refinement patterns for goal-driven requirements elaboration," in *Proc. of the 4th ACM SIGSOFT Symposium on Foundations of Software Engineering*. New York, NY, USA: ACM, 1996.

[32] Respect-IT, "The Objectiver Requirements Engineering Tool," http://www.respect-it.com, 2005.

[33] A. van Lamsweerde and E. Letier, "Handling obstacles in goal-oriented requirements engineering," *IEEE Trans. Softw. Eng.*, vol. 26, no. 10, pp. 978–1005, Oct. 2000.

[34] C. Ponsard and V. Snoeck, "Objective accessibility assessment of public infrastructures," in *Computers Helping People with Special Needs, 10th Int. Conf. Linz, Austria*, July 2006, pp. 314–321.

[35] M. Touzani, C. Ponsard, A. Laurent, T. Libourel, and J. Quinqueton, "Vers une modélisation et une analyse des exigences spatio-temporelles," in *Actes du 34e Congrès INFORSID, Grenoble, France*, June 2016.

[36] R. D. Landtsheer and C. Ponsard, "Verifying Geostatistical Travel Time Properties on Routing Networks," in *Int. Conf. on Operations Research and Enterprise Systems (ICORES16)*, February 2016.

[37] Y. Bédard and S. Larrive, "Modeling with pictogrammic languages," *Shekar S, Xiong, H. (eds), Encyclopedia of Geographic Information Sciences*, pp. 716–725, 2008.

[38] D. V. Pullar and M. J. Egenhofer, "Towards the defaction and use of topological relations among spatial objects." *In Proc. of the 3rd International Symposium on Spatial Data Handling*, p. 225242, 1988.

[39] StarUML2, "A sophisticated software modeler," http://staruml.io, 2014.

[40] University of Ottawa, "jUCMNav: Juice up your modelling," http://jucmnav.softwareengineering.ca/twiki/bin/view/ProjetSEG, 2001.