Life and motion configurations: a basis for spatio-temporal generalized reasoning model

Pierre Hallot & Roland Billen

Geomatics Unit, University of Liege, 17 Allée du 6-Août,
B-4000 Liege, Belgium
{P.Hallot, rbillen}@ulg.ac.be

Abstract. Although intensive work has been devoted to spatio-temporal qualitative reasoning models, some issues such as management of complex objects life and motion remain. In this paper, we propose a model dealing with *existence* and *presence* of object concepts. First, we introduce *spatio-temporal states*, which express *existing spatio-temporal relationships between two objects at a given time*. Spatio-temporal states decision tree is presented. Based on this new representation, we construct a finite set of *life and motion configurations* which can be seen as a way to categorise *spatio-temporal histories.* Then, we present the model itself which is based on *25 generalized life and motion configurations.* Indeed, these generalized configurations are assimilated to *line-line topological relationships* obtained by projecting life and motion configurations in a *primitive space*. Finally, generalized life and motions configurations conceptual neighbourhood diagram and their interpretation in natural language are given.

Keywords: Spatio-temporal reasoning, spatio-temporal states, life and motion configuration, primitive space, spatio-temporal generalization, natural language interpretation.

1 Introduction

For years now, spatio-temporality has been key research issue in Geographic Information Science [1]. Indeed, temporality is closely related to spatiality for most geographical applications. Furthermore huge amount of spatio-temporal data is now available; spatio-temporal acquisition techniques such as the GNSS, RFID, Wi-Fi…are becoming casual. Researches in this area concern data acquisition techniques, information modelling, information management, visualization, analysis, ontologies, continuity [2]…. Potential applications are numerous; movement description, crime mapping, epidemiology, behaviour monitoring, robot navigation, way finding, battlefield information analysis system, logistics, fleet management, cultural heritage management... It is therefore crucial to develop efficient spatio-temporal analyses and reasoning processes to fully exploit these incredible information sources. Spatio-temporal modelling concerns spatio-temporal objects and also spatio-temporal relationships between these objects. Description of spatial relationships, spatial representation and spatial reasoning are typical *qualitative spatial reasoning* topics

[3]. This branch of AI has provided comprehensive spatial calculus such as RCC [4] and 9-intersection [5]. Integrating time in such models was a quite logical evolution [6, 7]. For instance, Gerevini and Nebel [8] have "temporalized" RCC with the temporal logic of Allen. They have proposed the Spatio-temporal Constraint Calculus (STCC) which is based on a combination of the 8 connection relationships (RCC-8) between two regions [9] and the 13 temporal intervals relationships proposed by Allen [10] and which describes spatial constraints during a valid time interval. Similarly, Wolter and Zakharyaschev [7, 11] have "temporalized" the RCC with the propositional temporal logic (PTL). There exists another way to develop spatio-temporal reasoning models. As mentioned in [6, 12], spatio-temporal reasoning is not just the addition of space with time; the world itself can be seen as composed of spatio-temporal entities. Thus, it is sensible to develop spatio-temporal reasoning based on spatio-temporal shapes [13]. Muller has proposed an integrated vision of spatio-temporal entities which is described in [14]. He considers space-time histories of objects as primitive entities and analyses directly spatio-temporal shapes or histories. He defines a specific space-time to characterise classes of spatial changes, which is the first full mereotopological theory based on space-time as a primitive. Recent models also use integrated qualitative description of space and time parameters such as distance, speed, acceleration to reason with and infer new knowledge. The analysed values are represented qualitatively in regard of their stability or not. For example, the qualitative trajectory calculus (QTC) [15] in its basic form describes in a qualitative way movement between two moving object assimilated to points. It assumes that two moving objects are disjoint most of the time. It is worth mentioning a work realized by Noyon et al [16] which introduces a relative representation of trajectories in space and time. Their objective was to represent space as it is perceived by a moving observer using basic primitives such as relative position and velocities. However, some spatio-temporal issues are not fully handled by these models and still have to be explored. We wish to point out three of them. First, most of trajectories descriptions models focus on collision detection and postulate that two moving objects share most of the time spatial disjoint relationships during their evolution. In many cases, it would be interesting to analyse what's happening when two objects share the same place during a certain period of time, e.g. in the field of crime mapping when a murderer meets his victim or in epidemiology when a carrier meet a healthy person during more than on instant Secondly, most of the models consider only coexisting objects. However, it could happen that an object "disappeared" for a while (e.g. an object leaves the analysed zone or information's cut occurs such as a GPS cycle-slip). Finally, using these reasoning models requires implementing new spatio-temporal operators (in STDMS or STIS). The model proposed in this paper attempts to answer these issues. Our aim is to develop a spatio-temporal reasoning model valid for coexisting and non coexisting moving objects, considering new vision of spatio-temporal relationships between them. At this stage of our research, we assimilate objects to points. This new representation of spatiality including life and existence properties is used to create a complete set of life and motion configurations. Theses spatio-temporal configurations represent all the possible interactions between two points from topological and temporal points of view. Having identified possible life and motion configurations, we wish to propose a spatio-temporal qualitative calculus that uses existing topological operators. The

selected operators are those of the 9-intersection established for line-line relations [5]. To apply such operators, we need to link spatio-temporal histories to life and motion configuration and project them in a primitive space [14], i.e. a space where spatial and temporal dimensions are not differentiated. This projection allows us to generalize life and motion configurations into a small finite set of primitive relations between two moving objects (corresponding to two lines) with enough remaining information to perform spatio-temporal analyses. Thus, in a preliminary step, we will be able to reason about spatio-temporal information using already implemented topological operators. The paper is structured as follow. First we present the concept of "spatio-temporal states" and their representation. Then, we construct life and motion configurations by combining theses "spatio-temporal states". After that, we present our reasoning model which is the projection of the life and motion configurations in a primitive space and some common sense explanation in natural language of the generalised spatio-temporal relationships. Finally, we conclude.

2 "States" model and spatio-temporal representation

2.1 Spatio-temporal states

Spatio-temporal evolution of objects can be rather complex; it is not limited to sharing or not sharing common place during a given time interval. Questions like existence, appearance, presence… occur: does a baby exist before his birth? Will this retired soccer player play again? Does this guy who is not working in a company exist for this company? Does a key is still present when in a pocket? In the preliminary step of our research, we have decided to reduce somehow the scope of spatio-temporal evolution by considering only moving points. We do not deal with other spatial representations such as regions or solids, and consequently we do not consider change of shapes. In terms of temporality, we wish to consider first continuous concepts such as existence and presence. By continuous we mean concept that last during a certain time interval. Then we will discuss instantaneous concepts, such as birth or death, appearance and disappearance. We are going to define different kinds of spatio-temporal states between two objects. By state we mean an *existing relationship between two objects at a given time*. We start with concept of *existence*. There is a time period where an object has not yet existed and one where it will not exist anymore. We also believe that an object which stopped to exist could not revive and that objects must have existed at least more than one instant to be considered. At a given time, four possibilities occur between points A and B: A does not exist and B does not exist $\{\nexists A \wedge \nexists B\}$, A exist and B does not exist $\{\exists A \wedge \nexists B\}$, A does not exist and B exist $\{\nexists A \wedge \exists B\}$ and finally, A and B exist $\{\exists A \wedge \exists B\}$. When existent, an object can be *present* or not. Examples of existing but non present objects could be a pedestrian who left a studied street, a thief who is in jail… In all theses cases, the object continue to exist but is not in the analysed space or it is not visible in this space. At a given time, four possibilities occur between points A and B: A is not present and B is not present {(A) ∧(B)}, A is present and B is not present {A ∧(B)}, A is not present and B is present {(A) ∧B}, A is present and B is present {A ∧B}. Note that the presence concept depends on the existence concept. It is crucial to consider these existence and presence concepts to fully encompass spatio-temporal complexity. Up to now, we have considered temporality only. When two objects are present (and therefore are existent), it becomes possible to consider spatial relationships between them at a given time. Topological relationships are by definition [5] associated to two spatial objects; a topological relationship can be identified between two objects if and only if they exist and are present. Possible topological relationships between points are “equal” or “disjoint”. In other words, at a given time, two possibilities occur between points A and B: A and B are equal {e} or A and B are disjoint {d}. Combining all these different possibilities regarding dependence relations between concepts, we obtain ten possible states between two objects and a decision tree (Fig. 1). The “*states*” compose a jointly exhaustive and pairwise disjoint set (JEPD).

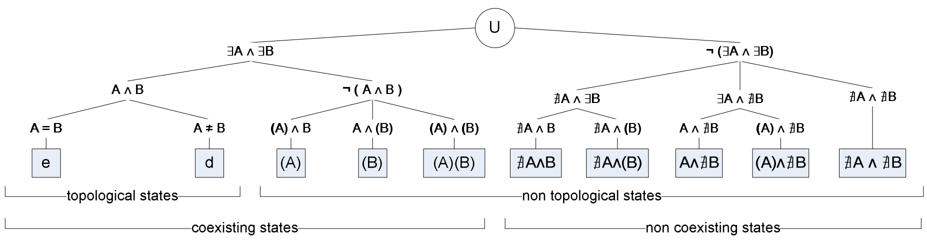


Fig.1. Decision tree of the ten possible “states”. (A) means that the object A is not present. States can be gathered into topological states and non topological states or coexisting states and non coexisting states.

The conceptual neighbourhood diagram of spatio-temporal states has been sketched, the dominance theory of Galton [17] has also been applied.

3 Life and motion configurations

Let us consider object’s *spatio-temporal history*. According to Hayes [18], (spatio-temporal) regions traced over time are termed spatio-temporal histories. In a n-D space, the spatio-temporal history is a n+1 dimensional volume. Remembering that we consider only points in this study, spatio-temporal history of an object is a line, continuous or not depending on object’s presence. Note that line’s extremities are not necessarily their birth or death as an object can exist without being present. The following figures represent a representation of spatio-temporal histories in the framework of spatio-temporal space [13].

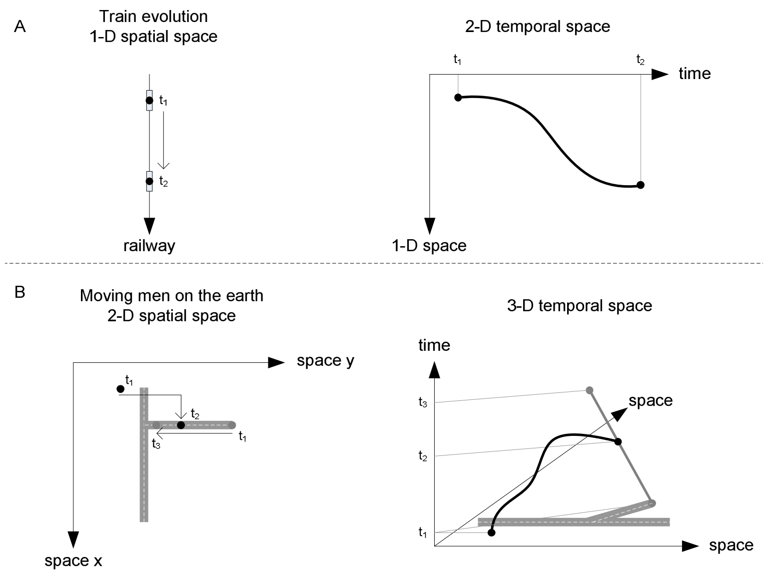


Fig.2. Representation of spatio-temporal situations with the concept of temporal space. Case A presents moving train on a railroad and its interpretation in 2-D temporal space. Case B presents two moving persons on roads and their representation in 3-D temporal space. First dies when meeting the second.

The figure 2A corresponds to a moving points in a 1D space (trains on railroads) with this interpretation in temporal space and the figure 2B represents two moving points in a 2D space (men moving at the surface of the Earth). In these cases, the starting point corresponds to the birth and the ending point corresponds to the death of the object. There is infinity of life and motion configurations when considering spatio-temporal histories in a spatio-temporal space (one axis being time and the others being related to the Euclidean space dimension where points move). However, it is possible to characterise spatio-temporal histories using spatio-temporal states as defined in the previous section. Indeed, spatio-temporal histories can be summarised into a set of successive states. Possible successions of states will define a finite number of spatial configurations. We have established the entire set of possible spatio-temporal configurations regarding spatio-temporal states. At this step of the research, we will present only the ones related states where objects have a continuous presence. A good life and motion configurations representation of spatio-temporal histories can be done adopting a degenerated notion of spatio-temporal space where the space axis is limited to the representation of three positions to have efficient visual expression of topological relationships disjunction and equality. Formal construction of life and motion configurations relying on states succession is presented in [19].

Spatio-temporal histories of points in a n-dimensional space can be fully described with a life and motion configuration represented in a 2-dimentional space, because their respective position in space, whatever space dimension, is reduced to two possible topological relationships.

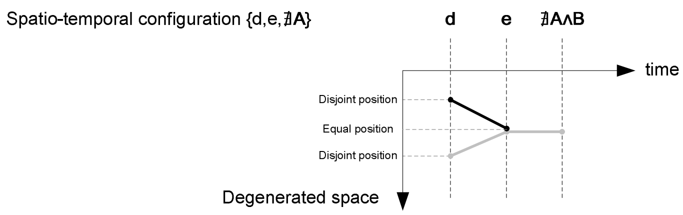


Fig.3. Representation of life and motion configuration {d,e, ∄A }represented in degenerated temporal space. Spatial dimension is limited to three possible positions for representing relationships (disjoint or equal).

Life and motion configurations are obtained by ordering the different states in time (fig. 3). The set ε of states is composed by (e_1, e_2, …, e_{10}), the ten possible state values. They are combined a finite number of time n which is what we call the level of the life and motion configuration. Life and motion configurations are denoted as {e_1,e_2,…,e_n}. It would not be possible to represent here the entire set of created spatio-temporal configuration. Some examples are represented in figure 4. In the following, we consider life and motion configurations created under two properties: objects could not revive and objects have a continuous presence, i.e. the spatio-temporal history is a continuous line. Based on these properties, there exist 4 spatio-temporal configurations at level 2, 88 at level 3, 778 at level 4… Note that this representation is compatible with the Allen's time interval relationships. In a more general way, it is also possible to describe life and motion configurations without using the property of continuous spatio-temporal history. In this case, an object can appear and disappear more than one time during the analysis, e.g. workers leave every night their monitored working building and come back every morning. In this case, the number of spatio-temporal configuration blows, e.g. for level 2 there is 100 configurations, 731 for level 3, 4435 for level 4, 24171 for level 5 and 127269 for level 6 … The exhaustive list of the life and motion configurations until level 6 is available at http://www.geo.ulg.ac.be/hallot. The figure 5 presents some extract of the life and motion configurations set. Dashed lines represent non present states.

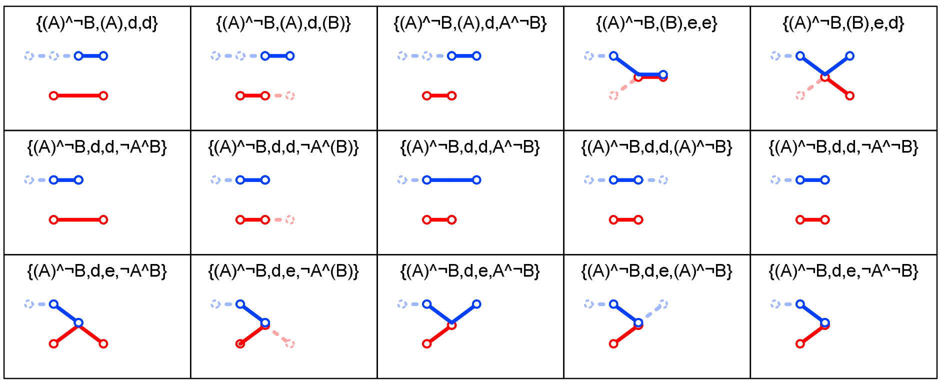


Fig.4. Extract of the life and motion configuration of level 3. The spatial axis of the temporal space is vertical and the temporal one horizontal.

4. Spatio-temporal generalised model

Although there are a finite number of life and motion configurations regarding spatio-temporal states, it is still huge and rather difficult to reason with. We propose to generalize life and motion configurations into line-line topological relationships by projecting them into a primitive space. A primitive space is a spatio-temporal space where the spatial and the temporal dimensions are not differentiated [14, 20]. Our aim is to associate spatio-temporal meaning to these generalised spatio-temporal relationships (i.e. the topological relationships between spatio-temporal histories in a primitive space) and take advantage of the existing calculus and operators already developed for such topological relationships. When the life and motion configurations are projected from the 2-dimensional degenerated temporal space into a primitive space, spatial and temporal dimensions become undifferentiated. Thus, it is possible to use a topological calculus on the spatio-temporal histories (through their corresponding life and motion configurations) to extract information from the life-lines. We switch from spatio-temporal analysis of a moving point to analysis of lines in a two dimensional space. The figure 5 presents the generalization processes from the formalization of spatio-temporal histories with life and motion configuration to their projection in a primitive space. Topological relationships are represented through their corresponding topological matrix intersection patterns [21].

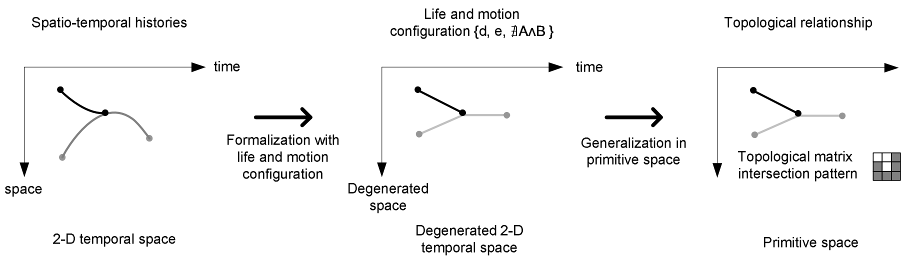


Fig.5. From left to right, formalization of ST histories into a life and motion configuration and generalization of life and motion configuration into topological relationships through a primitive space.

From [5], we know that there are 33 topological relationships between two lines in a 2-dimensional space. Here, 8 of them are impossible (see fig. 7) and lead us to 25 generalised spatio-temporal relationships. The level of generalisation is high. Obviously, part of spatio-temporal information is lost during the generalisation process. We assume that generalized spatio-temporal relationships contain enough meaning to perform efficient spatio-temporal analyses. The full description of the generalization process is out of the scope of this article. The 25 topological intersection matrixes obtained from the generalization are represented into the figure 7. Topological relationships are represented through their topological intersection matrix pattern and with a sample relationship.

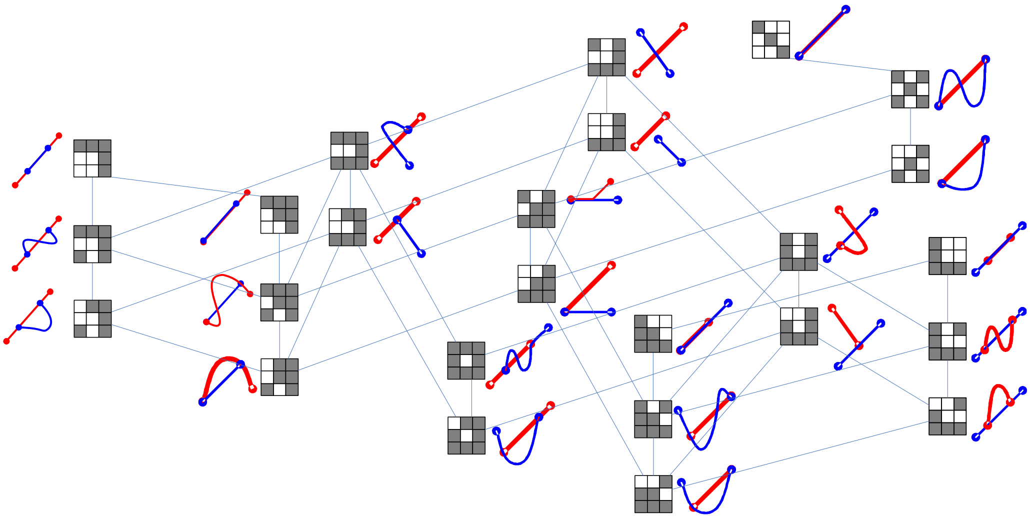


Fig.6. Conceptual neighbourhood diagram of the twenty-five generalised life and motions configurations (inspired from [21]).

Egenhofer and Herring [5] defined 15 conditions reducing the number of possible relationships between to lines to 33. We defined new condition which is necessary for representing generalized spatio-temporal relationships. This condition expresses that points can not move backward in time and that they can not instantaneously move in space. It reduces the number of possible generalized spatio-temporal relationships to 25 (see fig 7).

Condition: If A's boundaries not intersect B's exterior, then B's boundaries may not intersect A's interior and vice-versa.

$\mathbf{R_{\{\varnothing,\neg\varnothing\}}(A,B)\neq}$

A/B	A^0	∂A	A^-
B^0			
∂B	¬∅		
B^-		∅	

∨

A/B	A^0	∂A	A^-
B^0		¬∅	
∂B			∅
B^-			

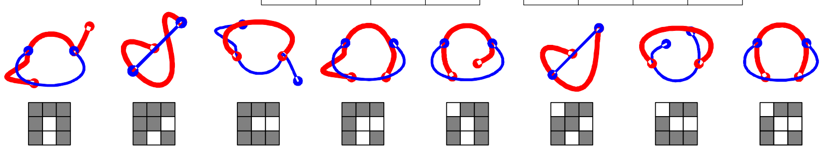
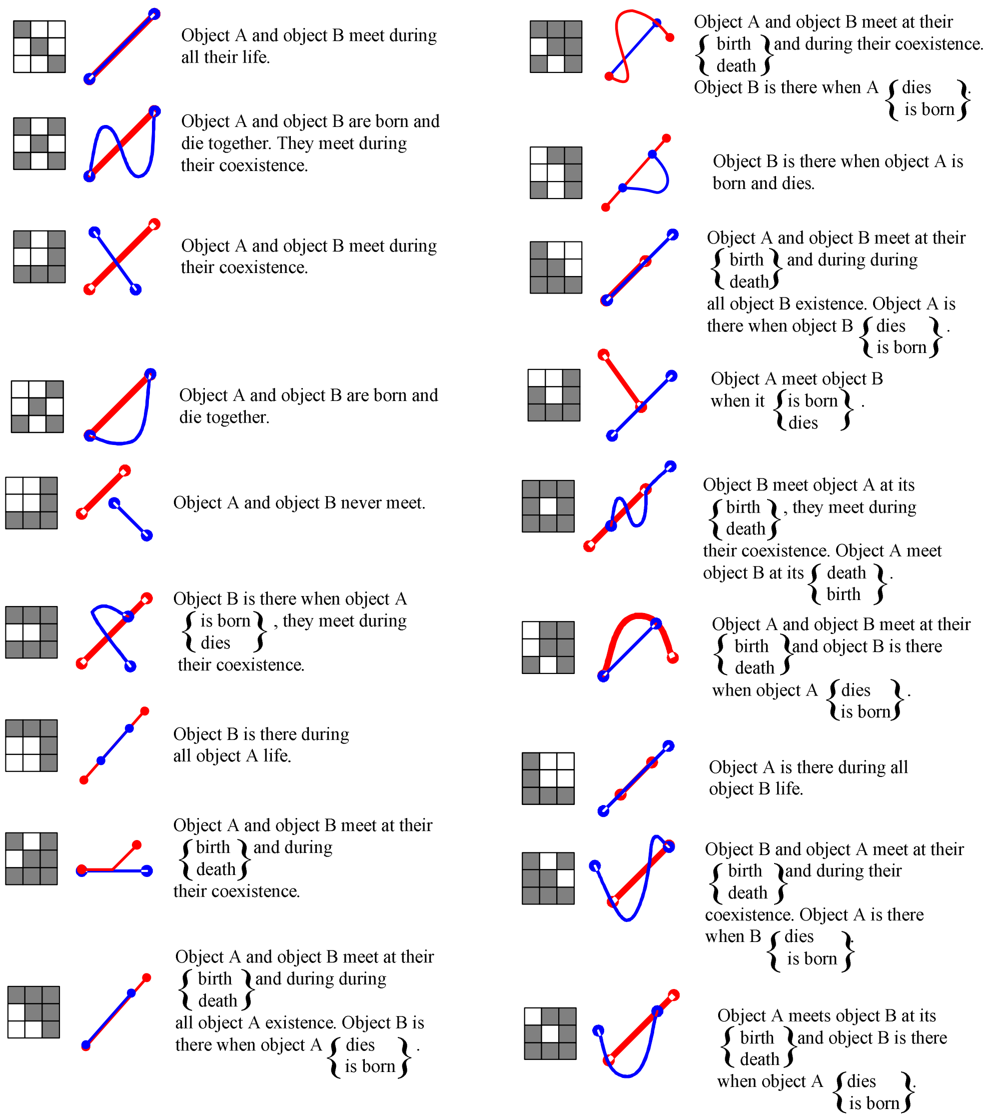


Fig.7. Eight impossible topological relationships between spatio-temporal histories projected in a primitive space.

Some recent works including [16, 22] has shown the importance of associating to configurations and relationships common sense interpretation in natural language. It is necessary to improve their understanding and facilitate their integration into intelligent systems. The next figure presents a natural language interpretation of the 25 generalised spatio-temporal relationships (represented by their topological intersection matrix pattern). Theses interpretation may also be retrieve by analysing the topological intersection matrices.



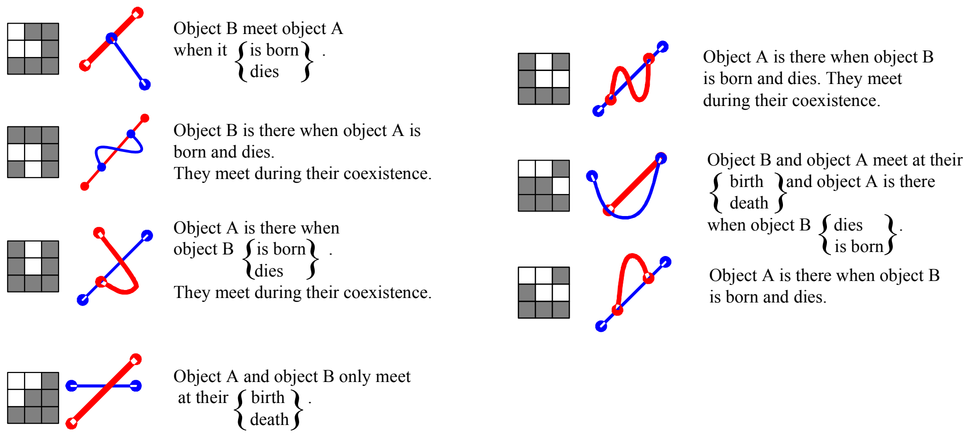


Fig.8. Commonsense interpretation in natural language of the twenty-five generalized of life and motion configurations.

Currently, generalized spatio-temporal relationships model is only available for objects with continuous presence, i.e. continuous spatio-temporal history. Next step of the research will be to propose a generalization including cases of discontinuity presence. Further challenges will be to develop transitions tables and to confront our model with real valid cases studies. We believe that this model could be useful for application such as crime mapping giving shortly information's such as: "Do theses persons meet?", "Did they share time together?", "Has a person ever left another?"…

5 Conclusion

Spatio-temporal reasoning models are needed to fully exploit increasing available spatio-temporal data. These models can be either combinations of spatial and temporal logic into a spatio-temporal logic or based on new mereotopology analysing spatio-temporal shapes. Among others, our model has been developed following the latter way. Some of them, dealing with qualitative trajectory analyses and movement description, are very efficient to describe movement between two disjoint coexisting objects. However, they imply new operators (e.g. in STDBMS or STIS) and cannot deal with not existing and not present objects. Our model aimed to overcome these limitations. First, we have proposed an extended temporal representation of existence and presence of objects. We have used this representation combined with topological concepts between objects to define spatio-temporal states, i.e. *particular spatio-temporal relationships between two objects at a given time*. We ended up with ten possible states which are a JEPD set. Based on this new representation, life and motion configurations, i.e. all the possible interaction between two points in a topological and temporal point of view, have been created to represent formally spatio-temporal histories. This exhaustive set was a strong basis to build our spatio-temporal generalized reasoning model. Indeed, the main idea of our research was to project life and motion configurations into a primitive space, i.e. where spatial and temporal dimensions are not differentiated, and to use topological calculus between lines to extract information. This operation gives us a set of 25 generalized spatio-temporal relationships. We have showed that out of the 33 spatial topological relationships between lines, 8 were impossible for representing spatio-temporal information. Finally, we have proposed a commonsense interpretation in natural language of the generalized spatio-temporal relationships. Future researches will be to check our model‘s validity with real dataset. Note that its implementation should be straightforward as topological operators between lines are implemented in every S(T)DBMS. Among other future developments, integration of other line-line calculi should be envisaged to manage more general cases where life-lines are not continuous.

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