Combined Topological and Directional Relations Based Motion Event Predictions

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Abstract. Spatial changes plays a fundamental role in modeling the spatio-temporal relations and spatio-temporal or motion event predictions. These predictions can be made through the conceptual neighborhood graph using the common sense continuity. This paper investigates that the extension in the temporal interval can effect the whole spatio-temporal relation and motion events. Spatio-temporal predicates form a unit of a motion event. We use the point temporal logic to extend the spatial predicates into the spatio-temporal or motion event predicates.

Keywords: Spatio-temporal relations, Spatial predicates, Spatio-temporal predictions, motion events.

1 Introduction

Spatio-temporal predictions are useful to initiate the new processus and to understand a physical phenomenon, fundamentally the spatio-temporal predictions are based on the predictions in the topological and directional relations [5,6,4]. In these methods, topological relations are computed by 9-intersection model [7] or alternatively by Region Connected Calculus $RCC8$[3] and directional relations are studied through method described in [10]. To fit the model in spatio-temporal context, an interval temporal logic[2] or point logic [9] are used. An hybrid method for defining the spatio-temporal predicates is developed in [8], this method consider only topological changes and spatio-temporal predicates are developed for moving objects.

Spatio-temporal motion event prediction is a process closely related to the spatio-temporal reasoning. The difference is, existing spatio-temporal reasoning provide us information that a topological or directional relation exists at time t_1, what is the possible topological or directional relation at time t_2. In this paper we define that if a spatio-temporal relation holds during an interval T, then how it will change spatio-temporal relation if an interval is extended and next time point is added to the interval.

The change in spatial scene is captured by the difference in topological, directional and distance spatial relations between the snapshot taken at point t_1 and

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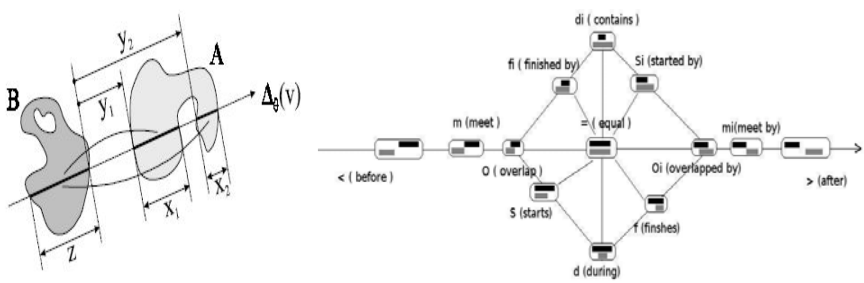
time point t_2. This change in relative position may result change in topological, metric or orientation structure of an image. This requirement needs analysis in topological, metric and orientation viewpoint at each step and comparison between two states, provided that both objects have a common lifetime.

Topological and directional relations are combined, method is argued in [13,14] and a complete Combined Topological and Directional relations (CTD) method is developed in [11]. Graph of CTD method represents all binary topological deformation in objects along with directional contents. In this graph, nodes represent the topological and directional position of object pair and edge represents the time. This neighborhood graph is used to predicate the spatio-temporal relations. Next section explains the CTD method and section 3 describes the spatio-temporal prediction some examples are considered in section 4 and section 5 concludes the paper.

2 CTD Method

1. **Oriented lines, segments and longitudinal sections** A and B be two spatial objects and $(v, \theta) \in \mathbb{R}$, $\Delta_\theta(v)$ is an oriented line at θ. $A \cap \Delta_\theta(v)$ is the intersection of object A and $\Delta_\theta(v)$, it is denoted by $A_\theta(v)$, called segment of object A and its length is x. Similarly length of $B_\theta(v)$ is z. y is the difference between minimum of $A \cap \Delta_\theta(v)$ and maximum of $B \cap \Delta_\theta(v)$. In case of polygonal object approximation (x, y, z) can be calculated from intersecting points of line and object's boundary, oriented lines are considered which pass through at least one vertex of two polygons. If there exist more than one segment, it is called longitudinal section as in case of $A_\theta(v)$ in figure 1(a).



(a) Object pair and oriented line

(b) Neighborhood graph of Allen relations

Fig. 1. Black (dark grey) represents reference and light gray argument object

2. **Allen temporal relations in spatial domain and fuzziness** Allen[1] introduced 13 jointly exhaustive and pairwise disjoint (JEPD) interval relations. These relations are arranged as $\mathcal{A} = \{<, m, o, s, f, d, eq, d_i, f_i, s_i, o_i, m_i, >\}$ with meanings *before, meet, overlap, start, finish, during, equal, during_ by, finish_ by, start_ by, overlap_ by, meet_ by, and after*. Allen relations in space

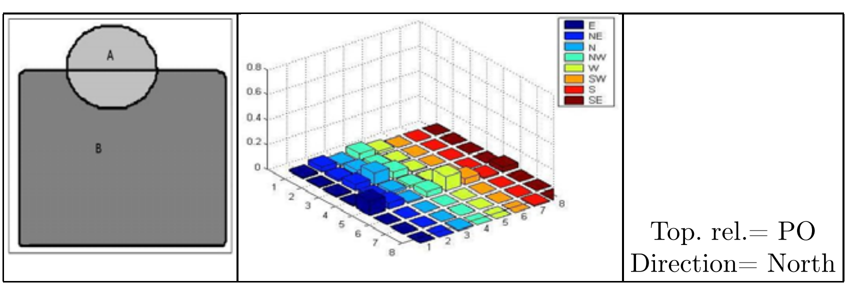
are conceptually illustrated in figure (1(b)). These relations represent eight topological relations in one-dimensional spatial domain.

Fuzzy Allen relations represent fuzziness at relation's level. Trapezoidal membership function is used for fuzzification due to flexibility in shape change. Let $r(I, J)$ be an Allen relation between segments I(argument object) and J(reference object), r' is the distance between $r(I, J)$ and it's conceptional neighborhood. We consider a fuzzy membership function $\mu : r' \longrightarrow [0, 1]$ and relations are defined as $f_<(I, J) = \mu_{(-\infty,-\infty,-b-3a/2,-b-a)}(y)$, and $f_>(I, J) = \mu_{(0,a/2,\infty,\infty)}(y)$ where $a = min(x, z), b = max(x, z)$ and x is length of(I), z is length of(J) and y is the difference between minimum value of $A_\theta(v)$ and maximum value of $B_\theta(v)$.

Most of relations are defined by one membership function but some of them are defined by conjunction of more than one membership functions like $d(during)$, $d_i(during\_by)$, f $(finish)$, f_i $(finished\_by)$, details are discussed in [12]. These relations have the properties: $f_<(\theta) = f_>(\theta+\pi)$, $f_m(\theta) = f_{mi}(\theta + \pi)$, $f_o(\theta) = f_{oi}(\theta + \pi)$, $f_s(\theta) = f_f(\theta + \pi)$,$f_{si}(\theta) = f_{fi}(\theta + \pi)$,$f_d(\theta) = f_d(\theta + \pi)$,$f_{di}(\theta) = f_{di}(\theta + \pi)$, $f_=(\theta) = f_=(\theta + \pi)$. The whole two-dimensional space can be explored with one-dimensional Allen relations using oriented lines varying from $[0, \pi]$.

3. **CTD method and topological relations** We extend these Allen relations for the $2D$ objects through the logical implication, where a areal object is decomposed into parallel segments of a $1D$ lines in a given direction and Allen relations between each pair of line segments are computed. The process of object decomposition is repeated for each direction varying from 0 to π, then $2D$ topological relations are defined as it provides us the information that how the objects are relatively distributed.

   These relations are not Jointly Exhaustive and Pairwise Disjoint (JEPD). To obtain JEPD set of topological and directional relations an algorithm for defuzzification of spatial relations was advocated in [11], it provides us the JEPD set of relations. Relations in this approach are called *Disjoint, Meet, Partial_ overlap, Tangent Proper Part, Non Tangent Proper Part, Tangent Proper Part Inverse, Non Tangent Proper Part Inverse, Equal.* In the following figure, an example for computation of topological and directional relations information of areal objects is given.



4. **Conceptual neighborhood graph in CTD method** A neighborhood graph for spatial relations in CTD method represents the possible transition in the topological and orientation perspective of spatial relations. Only one branch of translational-deformation is taken into account and possible transitions are presented into the graph.
In this figure 2, object can move to a circular path, *orientation neighborhood* and straightened path, a *topological neighborhood*, *diagonal path* a *topological and orientation neighborhood*. Neighborhood graph shows the allowable transitions among the relations, these transitions are possible when the objects move or change occurs in a spatial scene. In this figure 2, it is shown that every point of a neighborhood graph has eight possible direction nodes. Here relations are represented by a pair (α, β) where α represents topological and β represents the orientation relation.

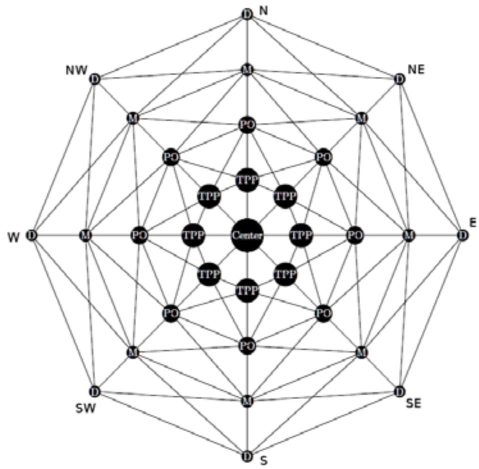


Fig. 2. Neighborhood graph in the system of combined topological and directional relations

3 Spatio-Temporal Predicates

The spatio-temporal predictions keep into account the history of spatio-temporal relation and they help us to estimate the spatio-temporal relations if the analysis interval is extended. For whole the clip, a relation exist if in each frame or at each partition, a separate relation exist in a particular sequence.

The relations depend upon topological changes, neighborhood graph depicts the physical transitions between spatial relations that can occur through the deformation of intervals. Spatio-temporal predictions about the moving objects are important and spatio-temporal change occurs when objects are continuously changing their position and temporal component is added to the interval and whole topological and directional relations change. At one end of the time space is closed and other end is an open end and different properties are used for example *holds, holds-at, occurs and occurs-at* and these properties are used to model the spatio-temporal predictions.

In this method, we combine the different information and a single method works in each situation and it provides us additional information. These spatio-temporal motion event predictions follow the mathematical relation. $STR_i = STR_{i-1} \cup SR_i$ or $STR_i = STR_{i-1} \cup SP_{i-1}, \forall\ i = 2, 3, ...$ where $STR(SR)$ stands for spatio-temporal relation (spatial relation), SP for spatial prediction which can predict only direction and topological relation and i denotes the time at which the relations are evaluated. These relations can be reformulated as $STP_i = STR_i \cup SP_i, \forall\ i = 2, 3, ...$ here $STP(SP)$ represents the spatio-temporal (spatial) prediction and spatio-temporal relation at i^{th} frame is the spatio-temporal prediction of $(i-1)^{th}$ frame.

4 Examples

Motion is a continuous phenomenon, of course, it can be analyzed at a discontinuous time pints and between these two points it can be directly interpolated. These time points can be chosen at a predefined time intervals or a specific video frame called snapshot. In modeling the spatio-temporal relations and motion events we need at least two snapshots, or two basic intervals where a stable spatial temporal relations hold. We start from two snapshots, at initial point, both spatio-temporal and spatial predictions represents the same semantics and possible predicates are given in table 1.

Table 1. Spatio-temporal predictions for two frames

SR	SP	STR
(D,N)	(D,NE)	Changing direction, getting closer or going away from N to NE
(D,N)	(D,N)	getting closer or going away in N
(D,N)	(D,NW)	getting closer or going away N to NW
(D,N)	(M,NE)	Snap from NE
(D,N)	(M,N)	Snap from N
(D,N)	(M,NW)	Snap from NW

When the interval is extended, a new snapshot or a basic interval where the spatio-temporal relation is not changed is added to the interval.

Spatial relations are represented in the neighborhood graph, every point has the eight possible spatial predictions. we discuss here the possible spatial predictions from (M,NE) and the existing spatio-temporal relation at this point is *Snap from NE* then the spatio-temporal predicates are depicted in table 2. These spatio-temporal predicates depend upon the current spatial predicates. Similarly, for other possibilities.

Table 2. STR predictions for third frames

STR_{i-1}	SP_{i-1}	STR_iorSTP_{i-1}
Snap from NE	D, E	Touching form NE
Snap from NE	M, E	Bypass
Snap from NE	PO, E	Graze, Enter, Into from E
Snap from NE	D, NE	Touch from NE
Snap from NE	PO, NE	Enter, Into from NE
Snap from NE	D, N	Touching from NE
Snap from NE	M, N	Bypass towards N
Snap from NE	PO, N	Graze, Enter, Into from N

5 Conclusion

Spatio-temporal prediction is a closely related to the spatial reasoning methods. In this paper, it is discussed that if the interval for which a spatio-temporal relation is analyzed is extended then it can effect the whole spatio-temporal relation and motion events. In modeling the spatio-temporal predictions, spatial predictions for topological and directional relations and neighborhood graphs are also important. Temporal domain is handled through the interval or point temporal logic. We used the topological and orientation information at the same time and CTD method is used for binary topological and directional relations between the object pair.

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