Extending the Cardinal Direction Calculus to a Temporal Dimension

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Abstract

Qualitative techniques for spatial reasoning are important in artificial intelligence. We present an extended cardinal direction calculus (XCDC) for spatio-temporal event representation and reasoning. The methods presented in this paper can be used in systems based on natural language processing which are also discussed in this paper.

Introduction: Events as 3D entities

A graph in a system of coordinates is a classical way of graphical representation of spatio-temporal relations. Similarly we consider an event as a combination of both a temporal span (time interval) and a spatial extension (space region). Although the time-space requires four dimensions to describe any possible object or event, we concentrate on events as spatio-temporal entities in a 3D space. This is because we analyse real-world situations as being located in flat open areas and we make abstraction from the actual altitude of these objects. The representation consists of two dimensions for space and one additional time dimension. The horizontal axes represent spatial aspects of an event. As it is necessary to choose directional orientation in CDC (see next section) these axes are denoted by N and W, meaning *north* and *west* respectively. The third axis denoted by T represents time.

XCDC: Representation and Reasoning

With a 3D representation we can describe situations using three main projections: on the N-W plane, on the T-N plane and on the T-W plane. For each projection, the spatio-temporal relation between two events is represented by a pair of direction-relation matrices from the Cardinal Direction Constraints (CDC) technique originally proposed in [2]. The key idea of that formalism is based on dividing the plane around the reference object (i.e. the object from which the direction relation is determined) into nine regions named after the geographical directions: *NW*, *N*, *NE*, *W*, *O* (central region meaning the same location), *E*, *SW*, *S* and *SE*. This areas, called direction tiles, are closed, unbounded (except for O), their interiors are pairwise disjoint and their union is the whole plane. Directions between the reference object A and target object B are represented in a 3 x 3 matrix denoted by dir(A,B) and defined as follows:

$$dir(A,B)=\begin{bmatrix} f(NW(A)\cap B) & f(N(A)\cap B) & f(NE(A)\cap B) \\ f(W(A)\cap B) & f(O(A)\cap B) & f(E(A)\cap B) \\ f(SW(A)\cap B) & f(S(A)\cap B) & f(SE(A)\cap B) \end{bmatrix},$$

$$where\ \ f(X)=\begin{cases} 1, if\ \ X\neq\varnothing \\ 0, if\ \ X=\varnothing \end{cases}.$$

Now we can define the spatio-temporal relation between two events A and B as follows:

$$TS(A,B)=[dir_{N-W}(A,B), dir_{N-W}(B,A), dir_{T-N}(A,B), dir_{T-N}(B,A), dir_{T-W}(A,B), dir_{T-W}(B,A)],$$

where $dir_{X\text{-}Y}$(A,B) denotes a direction-relation matrix for the projection on the X-Y plane.

Now we compare the efficiency of the proposed solution

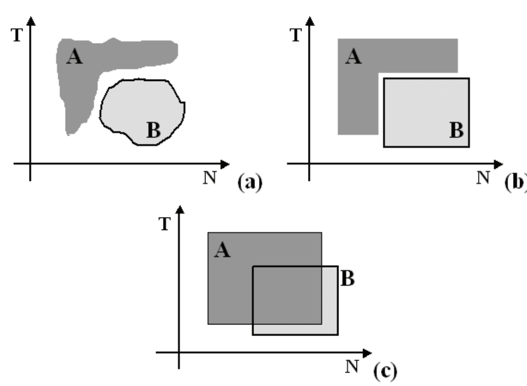

Figure 1: (a) Real-world situation, (b) knowledge collected using XCDC formalism and (c) the rectangle calculus.

with the rectangle calculus (originally presented in [1]). Fig. 1a shows a real-world situation which can be described with the following two sentences: *Fire (event A) is spreading across the area. A group of tourists (denoted as B) was successfully evacuated before the fire reached the place where they had been staying*. As we can see the

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spreading of an event can be illustrated by the size of a figure (in space) growing in time (along the time dimension axis). Fig. 1b shows an illustration of how information about the event is described in a system which uses an XCDC technique. In that solution some knowledge about the shapes of the objects can be lost, however all the information about relations between the events is retained. Fig. 1c presents the same task realized with the rectangle calculus. This time a false information can be generated. In particular we can make the conclusion that some tourists were trapped in the burning area and that a rescue team needs to be sent. It is not so hard to imagine dangerous mistakes can be made.
Using XCDC techniques the partition of the plane into nine regions is induced by the four lines bordering a reference object at the top, bottom, left and right side. It follows that in a computer representation any event is approximated by the rectangular area called "minimum bounding box". That allows us to build a knowledge representation without

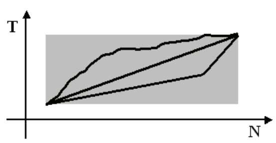

Figure 2: Different possible trajectories of an object in the T-N projection depending on the change of velocity.

possessing information about the exact trajectory of an object (Fig. 2). It is enough to define the first and the last point of a movement to represent the rectangle of all possible (in time-space projections) or the most probable (in the N-W projection) routes. The solution described seems very useful especially in a system analysing real-world situations, where the observers can lose eye contact with an object for some time or a transmission from an vehicle can be interrupted.
Let us consider the following example which presents a possible use of the XCDC formalism for reasoning about

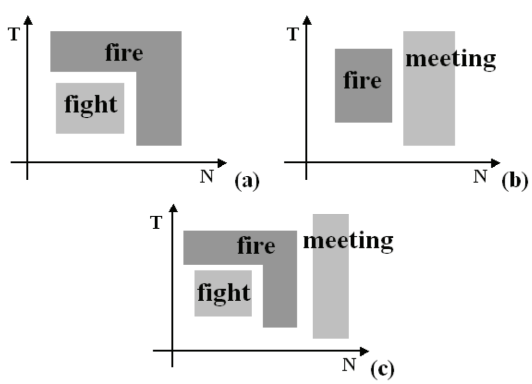

Figure 3: XCDC representation of the messages received by a security system.

real-world events. There are two text messages (written in natural language) sent by two different informers to the security system. Message 1: *There was a fire to the north of the place of the fight. The fire and the fight started at the same time. After the fight finished, the fire enveloped also that area*. Message 2: *The fire lasted during the meeting of Mr White with Mr Smith and was to the south of the site of the meeting*. Fig. 3a and Fig. 3b show the XCDC representation of these two messages (for simplicity we discuss the example only in the projection on the T-N plane). Fig. 3c shows the total knowledge collected by the security system, which is now ready to answer any question about qualitative spatio-temporal relations between the three events described by the users. Moreover, the analysis of both space and time allows the system to draw further conclusions. For example, we know that Mr White did not take part in the fight, as nobody can be in two different places at the same time. This can narrow the future search for people involved in the fight (or responsible for the outbreak of the fire).
Sometimes we are not sure about the exact location of an object. The sentence *The red box was placed to the left of the blue one* gives no information e.g. about the size of both objects. In fact if one of them is much bigger it can occupy more than one direction tile (Fig. 4). In the case of

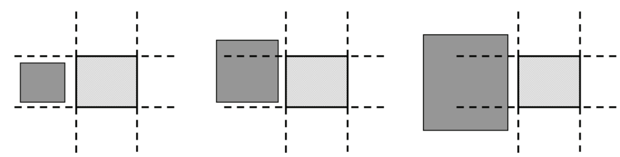

Figure 4: Examples of different size of a target object.

missing information we always assume all possible situations (see some analogy to quantum mechanics) so in that example the relations between the boxes would be described as a set of four possible matrices:
dir(blue,red)=$\{W, W \cup NW, W \cup SW, SW \cup W \cup NW\}$.
Of course the information could become more precise if some new facts were added to the system.

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