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Knowledge Rep. - Temporal Reasoning and Planning.

DATE: 28/2/93

In a world without change we would have no reason to think about the guide to relating change - time. Allen & Hayes [87] specify properties of time in an attempt to capture the 'common sense knowledge about time' which people use everyday interacting with the world. Our aims for creating theories of reasoning about time is 'a general theory of time' (Allen,1984). Allen [83] implements an algorithm for reasoning about time within a temporal network using the interval algebra specified. [A & H] formalised this theory in 1987 which 'subsumed' that of Allen's in 1983. We desire to examine the algorithm to see if it captures the theories of intervals, points and moments. This is achieved by studying the axioms that formalise the theory and relating them to the algorithm. We do not know but must assume that these axioms are themselves complete. Any possible incompleteness will be detailed. In any situations where the algorithm is seen to lapse in the face of the theory we propose possible solutions to the problems generated.

The properties of time that are not explicitly implemented in the temporal reasoning algorithm are given as follows. Note that at this stage their mention does not mean the algorithm does not inherently possess these properties. In action it may do just that.

The endless nature of time given in axiom M3 is not captured with the algorithm for reasoning in a network. Ordering and non-circularity axioms (M2, ML2) are not captured at various stages of operation within a temporal hierarchy. The temporal reasoning procedure does capture certain aspects. Given two completely separate relations the algorithm cannot generate any intermediary relations expressing the ordering of meeting places. Because this interval algebra is a relative notion such cannot be expected anyway. Within the temporal network however as long as intermediary relations exist then two meets cannot occur at the same time without the intervals themselves meeting and this is a property of the transitivity table.

If we have two relations such as i:j [: - meets] and i:k the insertion of another such as l:j will generate the relation l meets k from the transitivity table as the only option. The algorithm works well for this property of unique meets (M1) where relations exist between the intervals. Axiom M4 concerns intervals being periodic over time intervals is certainly not explicitly a feature of the temporal reasoning algorithm. Obviously most temporal actions can be grouped together into a larger event. Temporal reasoning does allow this but it is not strictly incorporated. Axiom M5 is also captured by calculation in the transitivity table where there is only one time period between two meeting places.

The nature of the algorithm is such that it can only propose relations from the data that it possesses. Any temporal properties which rely on the existence of a certain relation or interval being generated may only be captured by the algorithm innately, i.e. there will be no explicit constraint satisfaction leading to insertion or deletion. The non - existence of an interval may be implemented by its non-occurrence in the database. The internal constraint function will just return union of all possible relations for two relations. It depends on the algorithm outside of this to capture many of the properties of time.

Points are not mentioned in the paper introducing the algorithm. As Allen states, 'The formal notion of a time point, which would not be decomposable, is not useful.' Indeed the 1987 paper does not introduce points in their own right. Points in any capacity are not dealt with in the confines of a temporal reasoning network yet the algorithm should capture their behaviour internally as they are defined in [A & H,87] despite their explicit non-implementation.

Moments are not implemented whatsoever in any temporal network reasoning network. The algorithm rigidly capture a single time line theory yet within a network of a related set of intervals meetings within branches are captured.

SECTION 2: Are the properties of time 'in' the algorithm?

We wish to see if all of the temporal properties not implemented are captured by the algorithm in an internal implicit fashion or by its determinism (behaviour in operation). Properties that are not implemented may be included easily with some constraints or checks at a meta-level or even pre-processing stage and this idea is examined in a number of cases. The usefulness of including time points explicitly and optional time/date arguments (as outlined in the conclusion of Allen [83]) are also proposed at stages as 'property catching solutions.'

Endless time can be said to be handled implicitly within any temporal network in two ways. Firstly, the network will always remain open as more relations can be entered *ad infinitum*. Secondly, for the intervals which are on the outer edges of the network we can always add relations which meet these to capture the unbounded nature of time. No information other than a meets with an endless interval will be generated however so its efficacy may be questioned.

Axiom M2 on the ordering of time may or may not be seen depending on what the relations are that we have in the network. There may be incompleteness from the first relation inserted into the network. There is nothing to prevent this being a:a in the algorithm. Once we have such an inconsistency all manner of relations can be generated and inserted. In this way the algorithm is incomplete. In a consistent network where we have for example the relation c:d and we wish to insert d:c the constraints function still calculates relations but a null intersection (with d:d) prevents these inconsistent relations being entered into the network. This is one way in which the algorithm prevents circularity . If we have the relation e:f and we wish to insert the relation g:h and there are no intervals relating these meets then obviously the ordering of time is not captured. The algorithm can obviously recover from such a state if a relating interval is later inserted. In this way the temporal hierarchy may hover between one which does and one which does not capture temporal ordering. It may also be said that if there are no intermediary relations we do have two temporal networks inside which temporal ordering is most definitely preserved.

A sequence of intervals constitutes a longer interval (Axiom M4). The algorithm does not capture this nor in many senses does it need to. A grouping function could take any two intervals e.g. h:g and refer to them as one interval b. Specific relations which apply to h and g can be calculated using a new transitivity table for any new relations to b. The same relations may not apply if h and g do not share the same relations with other intervals in the network. For example, h overlaps k and k is overlapped by g. The relation with b (h:g) is k during b. With a process for generating larger intervals M4 can be installed. It may be of real use in a situation where we have date/time information for our reasoning principles and desire to obtain information on a large scale. In standard operation within a network, the generation of such 'front end' intervals would require an exponential number of comparisons.

Points are introduced by [A & H] as solely being the end points of intervals. [Allen,83] refers to this briefly and states that it is the same as reasoning about intervals themselves. Time points cannot be further sub-divided. [A & H,87] define these points as occupying no time. The algorithm can capture endpoints implicitly from reasoning within the transitivity table. It would not be able to deal with points explicitly but in the confines of Allen & Hayes interval algebra it is not required to. Villain [82] introduces points as explicit units of time and presents the possible comparisons that can occur between points and intervals but such is not relevant for Allen & Hayes definitions. If points were represented explicitly two relation sets for each begin and endpoint would be required but the overall result would be the same and a restricted transitivity table would be needed (for point/point and point/intervals computations.)

Again axioms are introduced which capture the notion of endpoints. PBE3 provides the relation between meeting of intervals and point ordering. This states that an interval exists between any two points. The reasoning mechanisms do not violate this but the algorithm cannot explicitly generate an intermediary interval. To demonstrate, if we have two relations, i is overlapped by j and j overlaps k, the algorithm cannot generate an interval between the ending of i and the beginning of k. This displays a major incompleteness of the algorithm. Though the intervals may or may not meet no information is gleamed and PBE3 cannot be truly captured. Again to solve this problem the reasoning process may be expanded to insert intervals between any two points that satisfy all of the other relations of the temporal network, if we have enough information which may not be the case.

Points are of zero duration and are not 'in' the intervals of which they border. This means they can only be referred to indirectly being in other intervals. With relation to the example of [A&H,87] a ball is thrown in the air. According to [A&H,87] if when it reaches its peak there is a point this is of zero duration. Presumably there are intervals on either side where the ball is of near zero velocity. The indirect nature of referral to points leads us to state that the ball reaches its peak within a larger interval. The algorithm has no capability to do this. In this area a weakness in the theory of points in time as [A&H,87 define them is not out of the question. The algorithm can state where intervals start, meet or end. Any more details not available.

Moments are not in the reasoning process at all. "A moment is an interval with no internal structure." There are no points inside a moment. Axiom MO2 introduces five possible relation moments can have. Moments can have the same five relations with intervals. Obviously intervals can have more relations with moments. The reasoning process could be expanded by introducing certain tests to see which type of relation we are inserting and/or comparing in the network. Clearly, moment restrictions need to be propagated throughout the network. One of these is the overlap problem. For example the relation of an interval overlapping a moment needs to be prevented by the algorithm as there is no place for it in the temporal theory.

To reason about moments inherently requires an automatic mechanism to detect that the time period is non-decomposable. This could be in the form of testing for an internal structure or such. If the temporal theory possesses an AXIOM OF HOMOGENEITY then every interval possesses a subinterval. Moments are defined as having no subintervals. They are therefore not intervals according to this theory. The validity of the hypothesis of moments in relation to a minimal duration is not questioned here.

As we have seen here the algorithm for reasoning about such an interval algebra does not capture much of the theory of time as stated by [A&H,87]. We must also ask if the algorithm for temporal reasoning was created to portray these properties. What it does, reasoning about the insertion of intervals into a temporal network, it does well. With the addition of some restrictions on initial network creation/insertion it would work very well. As Shoham says, "The interval theory of Allen has no clear semantics." The theory of points causes problems not in the definition of themselves as the endpoints of intervals but due to the fact that they can only be referred to indirectly in the theory of [A & H,87]. There is no real place for this in Allen's algorithm. The interval algebra is antithetical to modal logic which is point based and of more long-term use in temporal reasoning.