Temporal reasoning on chronological annotation

Tiphaine Accary-Barbier and Sylvie Calabretto

LIRIS CNRS UMR 5205, INSA de Lyon, Bat. Blaise Pascal 7, avenue Jean Capelle, 69621 Villeurbanne cedex, France
`tiphaine.accary@liris.cnrs.fr`,
www: `http://liris.cnrs.fr/ taccary`

Abstract. Interval algebra of Allen [4] propose a set of relations which is particularly interesting on historical annotating tasks [1] . However, finding the feasible relations and consistent scenario has been shown to be NP-complete tasks for interval algebra networks [11, 10]. For point algebra networks and a restricted class of interval algebra networks, some works propose efficient algorithms to resolve it. Nevertheless, these sets of relations (made of basic relation disjunctions) are not intuitive for describing historical scenarios. In this paper we propose a set of concrete relations for the annotator, and we formalize it in terms of temporal algebras. We then describe how our model can be matched with other ones to merge calculation efficiency and information suitability.

1 Introduction

When a reader annotates temporal informations while reading documents, he builds his own implicit temporal model. This task is done thanks to the reader's reasoning capacities and to the integration of several documents (which can have many forms). Moreover human commentators can be satisfied by expressing partially the relations between events. Thus, when they note that an event e_1 takes place during another event e_2, and that e_2 occurs before e_3, the fact that e_1 also occurs before e_3 is implicit. Temporal informations issued from historical annotations are such as "Lyon's forum construction took place during the roman period". No quantitative information such as date or duration information is specified here. It only expresses the qualitative information that the interval of time associated with one event occurred during the interval of time of another event. Allen [4] first gives an Algebra for representing such temporal relations between pairs of intervals. This algebra is actually useful in many application areas as natural language processing [3], planning, knowledge representation and others [5, 6].

Meanwhile, besides some complexity problems, this type of representation involves some drawbacks when they are used to annotate historical events. First, the proposed relations are too simple and the expression of uncertainty require to practice relations disjunction which is not a natural process. Next, with this representation we can not express point-events. In order to join event network with temporal points, it would be useful to work with an intermediate model using point algebra [11].

The outline of this paper is the following. In section 2, we recall the main temporal algebras frameworks on incomplete qualitative informations (intervals and points). We then briefly show the principles of reasoning tasks which are feasible on these models. In section 3, we develop our new set of relations dedicated to temporal annotation. We show how our relations are translatable into end-point relations, and give exemples of use of such relations in different domains. Finally, in section 4, we will describe how our model can be matched with other ones to merge calculation efficiency and information suitability. We will conclude with a brief description of our actual research plans.

2 Representing temporal information

Representing and reasoning about incomplete and indefinite qualitative temporal information is an essential part of many artificial intelligence tasks [3, 5]. In this section, we first recall temporal algebra frameworks [4, 11] for representing such qualitative information. We then recall the reasoning tasks allowed on networks using these models.

2.1 Temporal algebras

Allen's framework The interval algebra IA [4] presents the thirteen basic relations that can hold between two intervals (Table 1).

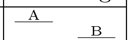
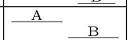
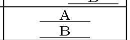
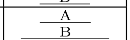
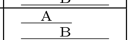
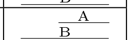
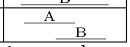
IA Relation	Notations	Meaning
before | after	$A\{b\}B \mid B\{bi\}A$	
meets | met by	$A\{m\}B \mid B\{mi\}A$	
equals	$A\{eq\}B$	
during | contains	$A\{d\}B \mid B\{di\}A$	
start | started by	$A\{s\}B \mid B\{si\}A$	
finish | finished by	$A\{f\}B \mid B\{fi\}A$	
overlaps | overlaped by	$A\{o\}B \mid B\{oi\}A$	

Table 1. Allen's basic relations between intervals.

To represent indefinite information, a relation between two intervals may be a disjunction of basic relations. To list disjunctions, we use subsets of $I = \{b, bi, m, mi, o, oi, d, di, s, si, f, fi, eq\}$ which is the one of all basic relations. Then, the relation $\{m, o, s\}$ between events A and B represents the disjunction: (A m B) $\vee$ (A o B) $\vee$ (A s B). On the representation network, vertices represent events and directed edges are labelled with sets of relations. Any edge without explicit knowledge is labeled with I.

Vilain and Kautz's framework The point algebra PA formalized by Vilain and Kautz's [11, 10] defines the three basic relations that can hold between two points $\{<, >, =\}$. In order to represent indefinite information, the relation between two points can be a basic disjunction of relations which are list in subsets of PA relations. As the possible disjonctions are very few, we can directly use disjonctive relations taken into $\{\emptyset, <, \leq, =, >, \geq, \neq, ?\}$ to express possible relations between two points. As an exemple, we can use $\leq$, instead of $\{<, =\}$.

Other algebras Vilain and Kautz [11] also show that there exists a restricted class of interval algebra, denoted SA networks, which can be translated into point algebra networks without losses of information. The SA set of relations is the IA subset which can be translated in terms of PA relations between intervals end-points. A description of this set can be found in [9, 7]. As an example, the relation: *roman period* $\{di, fi, si, eq\}$ *champdolian time* can be translated into the PA network shown on Figure 1 (where *roman period*$^-$ and *roman period*$^+$ are the end-points of interval *roman period*).

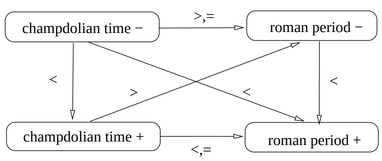


Fig. 1. Translation between SA and PA networks

Van Beek and Cohen [9] define a new point algebra and a new corresponding subset of the interval algebra. PA_c is the algebra with the same operators and underlying set as PA without $\neq$. The subscript 'c' indicates that the sets of tuples defining the relations in PA_c are convex. SA_c is the subset of SA that can be translated into relations between the end-points of intervals using only the relations in PA_c. An enumeration of the SA_c relations is shown in [9].

2.2 Reasoning tasks

Using interval or sub-classes of interval algebra networks for temporal annotation is particularly fit for many reasons. First, the proposed relations have a very plain semantic. Moreover, many works has been done on constraint inference. At least, finding feasible relations between all events is a useful mean to avoid hazardous human annotation. Automatically determining feasible relations between events on the network can be viewed as determinating the deductive consequences of temporal knowledge. Using some algorithms which saturate the constraint network, it is possible to derive and complete information on some edges labeled with I. These methods also permit both to refine ambiguous relations and to detect disjunction into annotations.

Path consistency. The idea behind the path consistency problem is the following: If we choose any three vertices i, j and k in the network, the labels on the edges (i,j) and (j,k) potentially constrain the label on the edge (i,k) that completes the triangle. For example, consider the three vertices *beuvreysian time (BT)*, *wabenian time (WT)* and *roman period (RP)* on the Figure 2:

$$(BT\{<\}WT) \wedge (WT\{mi\}RP) \rightarrow (BT\{<, o, m, d, s\}RP)$$

We can then change the label on the edge (*beuvreysian time*,*roman period*) from I to the set $\{<, o, m, d, s\}$ (see Figure 2). To perform this deduction, the path consistency algorithm [2, 8] uses the operations of set intersection ($\cap$) and composition ($\cdot$) of labels and checks whether $C_{ik} = C_{ik} \cap C_{ij} \cdot C_{jk}$, where C_{ik} is the label on edge (i,k). If C_{ik} is updated, it may further constrain other labels, so (i,k) is added to a list to be processed in turn, provided that the edge is not already on the list. The algorithm iterates until any changes are possible. As the inverse of a label is the inverse of each of its elements, a unary operation, "inverse", is also used to speed up the algorithm.

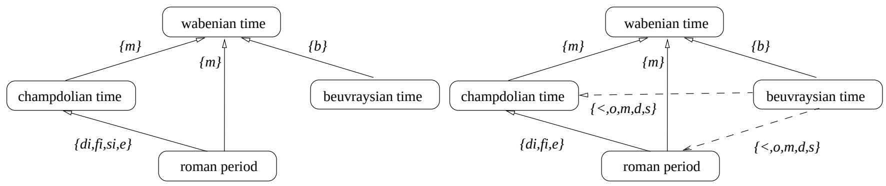


Fig. 2. Constraint propagation and adding of new relations.

Finding feasible relations. The labeled graph is stored in a $n \times n$ table C where entry C_{ij} is the label on edge (i, j). A relation $R_k \in C_{ij}$ is feasible with respect to a network if and only if there exists a consistent instantiation of the network where R_k is satisfied. The minimal label between two events (or points) in the network is the set consisting of *all and only* the $R_k \in C_{ij}$ that are feasible. The reasoning task is to determine the minimal labels of the network. As an example, on Figure 2, the relation between *roman period (RP)* and *champdolian time (CT)* is the disjunctive set $\{di, fi, eq\}$. So, there exists a consistent instanciation where $RP\{di\}CT$, an other where $RP\{fi\}CT$ and a last one where $RP\{eq\}CT$ (see Figure 3). Finding a consistent scenario and

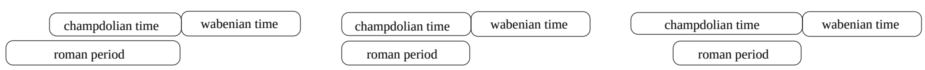


Fig. 3. Possible arrangements for *champdolian time*, *wabenian time* and *roman period*.

finding the feasible relations have been shown to be NP-complete for interval algebra networks [11, 10]. So we will work on restricted class of interval algebra networks and use Van Beek [8] algorithms.

3 A new model of relations for temporal annotation

It is unimaginable to leave human (expert or not) annotate documents only with basic interval relations. These are too much precise and it requires to use disjunctive notations which is an unusual practice. However, we want relations with precise semantics. We also need relations which will be connected with a well-known temporal algebra, in order to take advantage of efficient works already done on temporal constraint propagation.

3.1 Disjunctive relations proposed for annotation task

Finding useful relations in annotating tasks requires to parse what can be expressed or not with the existing relations. Allen's relations, presented in section 2.1, allow to describe some temporal scenarios. The relation *no_info*, which is the global disjunction is automatically used to specify that any information is known between events. If events end-points position are known, Allen's relations can then perfectly describe situations. However, when we have fuzzy knowledges to express, the use of disjunction of relations is necessary. To handle disjunction is not an intuitive phenomenon during an annotating stage: It is hardly to do very constricting for the commentator. A solution is then to propose a choice of pre-disjunctive or "fuzzy" relations[1] to the annotator. The choice of these relations have to be done in association with usual annotation tasks. In the chronology annotating framework, we have thus defined a restricted set of relations describing current scenarios. Consider the case of chronological annotation

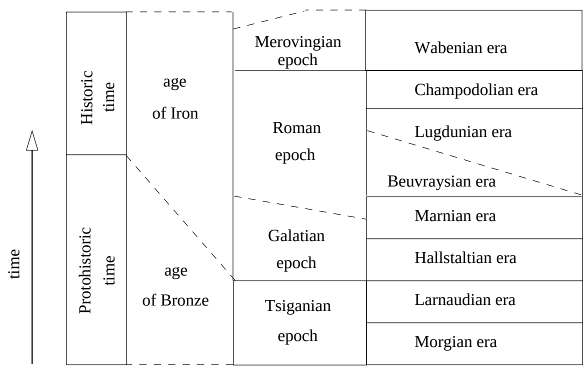


Fig. 4. Fuzzy prehistoric chronology.

[1] Our fuzzy relations are not Zadeh's ones [12]

in archaeology. Figure 4, which presents a prehistoric chronology, is a typical case of scenarios we need to express. On this representation, some end-points are fuzzy defined. For more legibility, we will call each event by his first letter (AI = Age of Iron).

To build this chronology, we can use Allen's basic relations. For example, we can express that *Halstaltian era meets Marnian era*. But a large part of these information are more fuzzy. Let us consider the *age of Iron* and the *Protohistoric time*. The only information which we can lay out there is that the start point of AI is during PT. We will annotate this scenario with AI *begin_in* PT. If you look at the relation between the *Galatian epoch* and the *Marnian era*, all we can say is that GE ends into MaE (GE *end_in* MaE). An other interesting scenario that can be noticed is the relation between the *Tsiganian epoch* and the *age of Bronze*. We know that TE is fully inserted into AB but without information on AB end-points positions. TE can be equal, during, starting or finishing AB: we will note this relation TE $fuzzy\_during$ AB. At least, the table shows us that there is an uncertainty about the existence of the Beuvraysian era. It implies than the *Marnian era* can have met the *Lugdunian era* or being before. We will express this situation with MaE $fuzzy\_before$ LE. These statements led us to

Annotation relation	end-point positions			
	A^-B^-	A^-B^+	A^+B^-	A^+B^+
fuzzy_before	$<$	$<$	$\leq$	$<$
fuzzy_during	$\geq$	$<$	$>$	$\leq$
common_begin	$=$	$<$	$>$	?
common_end	?	$<$	$>$	$=$
begin_in	$\geq$	$\leq$	$>$	?
end_in	?	$<$	$\geq$	$\leq$
begin_before	$<$	$<$	?	?
first_to_end	?	$<$	?	$\leq$
common_period	?	$\leq$	$\geq$	?

Table 2. Disjunctive relations proposed for events temporal ordering and corresponding end-points relations.

define a set of disjunctive relations corresponding to these temporal scenarios. Table 2 shows our set of nine "fuzzy" relations dedicated to historical annotation and their corresponding in terms of end-points relations.

An example of use : If our previous works leed us to develop this model for annotation of archaeological documents, these relations are not "dedicated" to this task. We can show an example of uses in others domains. Let us consider the exemple of events description shown on Figure 5. Temporal relations between events are not unambiguously given in the description. The first sentence only tells us that the time over which Fred reads the paper had a common part with the one over which he ates his breakfast. We can represent this sentence by

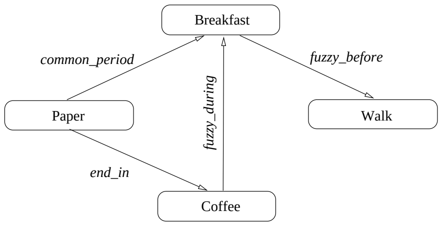


Fig. 5. Text description : *Fred was reading the paper while eating his breakfast. He put the paper down and drank the last of his coffee. After breakfast he went for a walk.*

Paper $common\_period$ *Breakfast*. This relation can afford a "wrong" possibility because it allows the m relation (telling that common period can be just on end-point) but such uncertainty does not penalize the system and the propagation will fastly compensates it. The second sentence gives the relationship between the end-points of the interval where Fred reads his paper and those where he drinks his coffee. The sentence is indefinite about other points. We can represent it as *Paper* end_in *Coffee*. If it does not appear in the text, we also know that drinking coffee is part of breakfast and occurs then during breakfast. Meanwhile, we can not know if Fred only takes a coffee as breakfast or if he drinks coffee at the beginning, at the end or during a part of his breakfast. We then represent it as *Coffee* $fuzzy\_during$ *Breakfast*. Finally, the third sentence tells us that Fred had a walk after breakfast. This walk can have been done immediately or a long time after. We then represent it as *Breakfast* $fuzzy\_before$ *Walk*. The resulting network is shown on Figure 5. The system can then convert the network into end-points relations and accomplishes constraint propagation.

3.2 Coding the network of fuzzy relations

As a convention, we will note interval of events I and relations R. The network of events i, j, and k will be represented as

$$I_i \overset{R_{i,j}}{\rightarrow} I_j \overset{R_{j,k}}{\rightarrow} I_k$$

To store a network of n events, we use a $n \times n$ table. Each table cell contains the matrix of end-points relation beetween I_i and I_j. The calculation of missing relations on the network is done by matrix product. The matrix $M_{i,k}$ is the result of $M_{i,j} \times M_{j,k}$. We can then use some efficient algorithms for PA networks (see section 2.2) to spread constraint and thus complete knowledge. Let $M_{i,k}$ be the matrix which symbols are the opposite of $M_{i,k}$ ones. $M_{k,i}$ is fastly obtained as the transposed matrix of $Mi_{i,k}$.

Consider the network issued from the temporal description example shown on Figure 5. Let $M_{C,W}$ denote the matrix of end-points between events *Coffee (C)* and *Walk (W)*. This network is stored in the matrix table shown on Table 3. $M_{C,W}$ is computed as the product of $M_{C,B}$ and $M_{B,W}$

$$M_{C,B} \times M_{B,W} \Longleftrightarrow \begin{pmatrix} \geq < \\ > \leq \end{pmatrix} \times \begin{pmatrix} < < \\ \leq < \end{pmatrix} \overset{results}{\rightarrow} \begin{pmatrix} < < \\ \leq < \end{pmatrix} \Longleftrightarrow M_{C,W}$$

This result can then be compared with the one already stored in the table. If the two relations are the same or if the new one can refine the other, it will replace it. Else, an inconsistency will be point out to the user. Finally, we can then translate back the resulting end-points matrix in terms of fuzzy relations. Here, $M_{C,W}$ will be translated into *Coffee* $fuzzy\_before$ *Walk*.

	B^-B^+	W^-W^+	P^-P^+	C^-C^+
B^-	$= <$	$< <$	$? \leq$	$\leq <$
B^+	$> =$	$\leq <$	$\geq ?$	$> \geq$
W^-	$> \geq$	$= <$	$\geq ?$	$> \geq$
W^+	$> >$	$> =$	$> ?$	$> >$
P^-	$? \leq$	$\leq <$	$= <$	$? <$
P^+	$\geq ?$	$? \ ?$	$> =$	$\geq \leq$
C^-	$\geq <$	$< <$	$? \leq$	$= <$
C^+	$> \leq$	$\leq <$	$> ?$	$> =$

Table 3. Storage of end-points relations matrix for the network of Figure 5. Cells in grey represents matrix issued from the translation of the given relations. Other matrix are issued from computation.

4 Knowledge reconstruction

It is relevant to discern computational knowledge which is expressed in terms of end-points (and is too fuzzy to be understood humanly), and knowledge contained at annotation level. Our system is really more interesting if the results of propagation process can be returned to the user in a comprehensible language. A return expressed in terms of events end-points relations is incomprehensible. What is pertinent, is to return an interval network labeled whith relations taken into our fuzzy set. For the sake of clarity, this set will be denoted as F.

We notice that F is a subset of the SA_c relations (see section 2.1). End-points matrix computed by the propagation use PA_c relations. All these matrix can then be translated in terms of SA_c relations but not necessarily in terms of F relations. To return to the annotator a network solely labeled with F relations, we have to pass cross a "simplification" stage in which each relation of $SA_c - (SA_c \cap F)$ must be akin to an F relation.

These classifications can lead to a punctual loss of precision on the information returned. However, just the result at t time can suffer these loss and the under layer network is not modified. Thus, information contained in the network still remain complete and the ones returned to the user are nevertheless meaningfull[2]. These "losses" can then be considered as an avdantage for user's relation perception.

[2] they can be understanding by users

Let us consider the matrix table issued from the description of Fred's breakfast (Table 3). We have previously seen that the computed matrix $M_{C,W}$ can be translated in terms of F relation without any loss of information. Now, it is different when we will compute $M_{P,W}$ which is the product of $M_{P,B}$ and $M_{B,W}$

$$M_{P,B} \times M_{B,W} \Longleftrightarrow \begin{pmatrix} ? & \leq \\ \geq & ? \end{pmatrix} \times \begin{pmatrix} < & < \\ \leq & < \end{pmatrix} \stackrel{results}{\rightarrow} \begin{pmatrix} \leq & < \\ ? & ? \end{pmatrix} \Longleftrightarrow M_{P,W}$$

This resulting matrix is not the end-points expression of one of our fuzzy relations. In terms of SA_c relation, it matches with the relation $I - \{bi, d, oi, mi, f\}$. When we project this relation in the F set, the corresponding relation is no_info. In this case we can lose a few informations about constraint on events end-points. Meanwhile, this loss is not very significant for two reasons. First, the missing end-points information could not have been represented in terms of temporal scenarios. Next, during the propagation, the matrix $M_{P,W}$ is also compute with the product of $M_{P,C}$ and $M_{C,W}$.

$$M_{P,C} \times M_{C,W} \Longleftrightarrow \begin{pmatrix} ? & < \\ \geq & \leq \end{pmatrix} \times \begin{pmatrix} < & < \\ \leq & < \end{pmatrix} \stackrel{results}{\rightarrow} \begin{pmatrix} < & < \\ \leq & < \end{pmatrix} \Longleftrightarrow M_{P,W}$$

This resulting matrix can be automatically translated into F relation: *Paper* $fuzzy\_before$ *Walk*. Now the network is fully informed (see Figure 6).

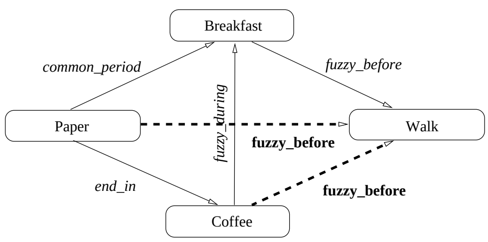


Fig. 6. Fully informed network for Fred's breakfast example after reconstruction stage.

5 Perspectives

In this paper we have presented a new model of temporal relations adapted to the description of chronology in Archaeology.

The prospects of our works are the following. First of all, we notice that the detection of inconsistencies is interesting only when it can be accompanied by a correction, or at least, by a support for correction. For the moment, when an edge is already labelled, the system is allowed to refine the already known relation if it is consistent or to provide an error if there is a conflict. In the case of refinement, two situations have to be considered. If the previous relation is the result of a calculation, the substitution is rightful. But if the "fuzzier" relation has been given by the user, it would be preferable to inform the user that a refinement was calculated and to let it decides of its implementation. This differenciation then requires the use of a flag system on relations to store their source. In the case of detection of inconsistency the error is provided but it will be useful to propose to the user both the "false" relation and the calculated solution with the list of human arcs which produce this result.

Another research area about this work is the study of possible consistent scenarios algorithms on our model of relations. It would be indeed very interesting to be able to propose possible chronological scenarios within the framework of temporal annotations.

In our future work, we also plan to compare possible visualization means for the results. We are indeed convinced that an adequate mode, in addition to facilitate the data processing, could lead the researcher to the construction of new assumptions.

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