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KRDB Research Centre Technical Report:

A Short Travel through Time for Novice Readers: Representation, Reasoning and Visualisation

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Keywords	artificial intelligence in education architectures (web-based), knowledge modelling and representation, qualitative temporal reasoning, CP, intelligent interfaces, HCI, storytelling tool
Number	KRDB09-4
Date	11-May-2009
URL	http://www.inf.unibz.it/krdb/
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Abstract

We are working on a story-telling web tool for novice readers, in particular, deaf children. The tool aims at stimulating children to reason on the qualitative temporal relations between events of stories. In this paper, we review the major theories and tools for qualitative temporal reasoning, studying the three facets of time, relevant for such a tool: representation, reasoning, and visualisation.

Contents

Chapter 1

Introduction

Text comprehension enables a broad access to information and knowledge. In narratives, text comprehension depends on the readers' detection and deduction of logical dependencies, and on the construction of a global mental representation of causal-temporal relations between the narrated events [Bamberg87, TB85].

In particular, temporal dimension is a concept that children learn indirectly through narration. At the age of 5, normally developing children become able to make deductions with temporal relations, reasoning on sequences of events with before and after [MM08]. This ability seems to develop further from the age of 7 to that of 9, when children become novice readers, as far as text comprehension is concerned, and start mastering the while relation, as far as temporal reasoning is concerned, e.g., see [GX02]. Such relations (before, while and after) are qualitative temporal relations.

The essence of qualitative temporal reasoning is to find ways for representing continuous properties of time by discrete systems of symbols [CH01]. It has received much attention in the AI literature and, more recently, in the semantic web via TimeML, a temporal markup language.

We are working on a story-telling web tool for temporal reasoning, focussing on contemporary stories for children, in particular, deaf children. The tool will adopt the qualitative temporal relations between events of stories that 7–9 olds should be able to master, that is, before, while and after. The tool should stimulate children to reason on the time dimension of stories, so as to enable the construction of a global mental representation of temporal relations between the narrated events.

In this report, we review the major theories and tools for qualitative temporal reasoning in AI, and assess whether they are suited for creating such a web tool.

Chapter 2

The Many Facets of Time

Temporal reasoning is a branch of AI that lies at the intersection of various fields: discourse analysis, natural language processing and understanding, knowledge representation, constraint satisfaction and programming, planning, etc. Traditionally in AI, temporal reasoning consists of "formalising the notion of time and providing means to represent and reason about the temporal aspects of knowledge" [Vila94]. In other words, it means choosing:

representation: a time granularity and structure, and a formal language for them;

reasoning: a reasoning system, amenable to automation, with specific reasoning tasks that, ideally, are computationally tractable.

A third facet of time is often neglected in AI, and confined to HCI:

visualisation: the visualisation of temporal information.

However, this is also a crucial facet in the development of an educational tool for temporal reasoning in children stories, given that graphics seem to be a relevant support for humans in semantics oriented tasks [DS97, Paivo91].

In this paper, we consider the three aforementioned aspects of temporal reasoning all together. The following excerpt of the "The Ugly Duckling" story, by H.C. Andersen, gives an instance of a (qualitative) temporal reasoning problem:

> Mummy duck is sitting on some eggs: she has five eggs, four are small, and one is big. All of a sudden, while she is still sitting on eggs, the small eggshells crack and four little yellow ducklings peep out. Mummy duck watches the big egg but sees no signs of cracking So she decides to keep on sitting on it. After some days, while she is sitting on it, the big eggshell also cracks and an ugly gray duckling peeps out...

Answering a question such as "do the small eggshells crack before or immediately before the big eggshell cracks?" means solving a temporal reasoning problem.

In the following three chapters, we use the problem in order to illustrate various issues pertaining to the three aforementioned facets of time, and related to the creation of a web tool for novice readers.

Chapter 3

Time Representation for Children Stories

There are different temporal structures, for instance, linear, cyclic, or branching [Vila94]. Linear time corresponds to our natural perception of time (in Western culture) as being ordered collections of temporal primitives, e.g., time has a direction, and proceeds from the past to the future [Hajnicz96]. Contemporary stories for children (in Western literature) seem to be usually based on a linear time structure [Nikolajeva00]. Temporal events of a story can thus be assimilated to either time points or time intervals. A time point can be considered as an instantaneous event. A time interval is a continuous event with a start and a different end.

Exhaustive, mutually exclusive qualitative relations are possible among time points and among time intervals of a linear structure, see Figure 3.1 for the latter case—note tha such relations can be extended to non-linear structures, see [Hajnicz96]. Other relations are possible between a time point and a time interval [Meiri95]: before and its inverse, starts and its inverse, during.

A qualitative approach to time is embedded in TimeML. TimeML is a temporal markup language [TimeML] that aims at capturing the richness of time information in written documents, and

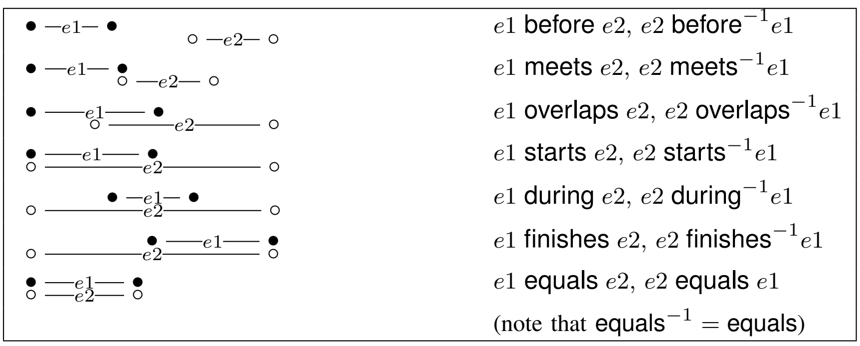

Figure 3.1: Relations between intervals.

```
relType ::= 'BEFORE' | 'AFTER' | 'INCLUDES' | 'IS_INCLUDED'
            | 'DURING' | 'DURING_INV' | 'SIMULTANEOUS'
            | 'IAFTER' | 'IBEFORE' | 'IDENTITY' | 'BEGINS'
            | 'ENDS' | 'BEGUN_BY' | 'ENDED_BY'
```

Figure 3.2: The syntax of the TLINK relations.

as such it must be considered in the creation of a web tool for temporal reasoning in stories for children. As for temporal relations, TimeML defines a TLINK tag that links tagged events to other events or times; see Figure 3.2 for their BNF representation. The TLINK relations are based on the atomic Allen relations, according to [Mani et al. 07]. We introduce the Allen relations below, and then compare their expressive power with that of TLINK.

In his seminal paper [Allen83], Allen motivated his time representation as follows: "This representation is designed explicitly to deal with the problem that much of our temporal knowledge is relative, and hence cannot be described by a date (or even a fuzzy date)". In the Allen representation, intervals are primitive entities. Each interval is uniquely associated with an event. Between any two pairs of events, there is precisely one atomic Allen relation, namely, a relation at of the form before, meets, during, overlaps, starts, during, finishes, equals or its inverse at-1; see Figure 3.1 for their interval representation. For instance, the sentence states that the relation during holds between the event "small eggshells cracks" and the event "Mammy duck broods".

As Allen arguments, his representation of time allows for "significant imprecision"—it is often the case that temporal knowledge is relative without relations to absolute dates. Indefinite information can be represented by means of disjunctions (unions) of the Allen atomic relations. Then the Allen relation rel is the disjunction of atomic relations. The set of Allen relations forms the Allen Interval Algebra (IA) with conjunction (intersection), inverse and composition, e.g., see [Ladkin93].

Note that overlaps (and its inverse) and disjunctions of TLINKS relations are instead forbidden in TimeML, see Figure 3.2. This can be rather restrictive when annotating stories for children, due to inherent imprecision of data (e.g., "at sunrise, the Ugly Duckling ran away from the farmyard") or different text interpretations by the annotators (e.g., knowledge dependent information). Therefore, in this setting, one may need a more expressive language than TLINKS. One could use the relations of a subalgebra of the Allen one, say, the continuous-endpoint subalgebra (CA), that is computationally tractable—we will specify what we mean by a tractable subalgebra in Chapter 4 below, after introducing the necessary details. This is a widely investigated subalgebra, already used in several NLP tasks [vanBeek92], that allows for expressing vague information such as before or meets and before or meets or overlaps.

Alternatively, one could adopt one of the Freska representations [Freska91], based on the notion of conceptual neighbourhood: relations between semi-intervals are used instead of relations between intervals. However, relations such as before or meets seem to be missing in such calculi, and we found such relations in stories for children for expressing information such as "at some point before" no further specified in text.

This said, the expressive power of such a language should be balanced by tractable reasoning tasks that, possibly, can exploit existing automated reasoning tools. We review some of them in the next chapter.

Chapter 4

Temporal Automated Reasoning Tasks and Tools for Allen-like Relations

The constraint literature has a number of studies on subalgebras of IA, and algorithms for different reasoning tasks. In the remainder of this chapter, we introduce some of such subalgebras, which seem relevant for story telling, and the related reasoning tasks with their computational complexity, primarily, the so-called consistency checking and deduction tasks [Gennari98]. For the entire list of all the maximal tractable subalgebras of IA, we refer the reader to [Krokhin et al. 05]. First of all, what do we mean by a tractable subalgebra? This notion is best explained by introducing (binary) constraint problems for A, where A is any subalgebra of IA (other constraint-based models are possible, e.g., see [Apt03]). In essence, an A constraint problem is given by a finite sequence of variables, $e1, e2, \ldots, en$, each representing an event and ranging over a finite collection Di of intervals of reals, and one (binary) constraint $C(i, j) \in A$ for each pair of variables (ei, ej) with $0 \leq i < j \leq n$. A tuple of intervals $(I1, \ldots, In)$ of $D1 \times \cdots \times Dn$ is a solution to the constraint problem if Ii $C(i, j)Ij\, Ij$ holds, for each $C(i, j)$ of P.

An A problem P is satisfiable or consistent if it has a solution. We will say that $rel \in A$ for (ei, ej) is deduced if $relIiIj$ holds, for all solutions $(I1, \ldots, In)$ to P. Let $DCij$ the set of deduced relations for (ei, ej). The deductive closure of P is the set of all such $DCij$, for $0 \leq i < j \leq n$. If there is a PTIME algorithm that can decide on the satisfiability of any A problem, then we say that A is a tractable subalgebra. In case the tractable subalgebra A contains all the atomic relations, the deductive closure of any A problem can be computed in PTIME by resorting to the algorithm for A satisfiability [Nebel95].

For instance, let us consider the CA subalgebra of IA. This is tractable. More specifically, checking its consistency can be done in quadratic time in the number of events by means of the algorithm for the point algebra (PA) developed in [vanBeek92].

PA relations are conjunctions of relations between end-points of intervals of the form: (1) $x = y$, (2) $x \leq y$, and (3) $x \neq y$. CA relations can be represented as PA relations of the form (1) and (2). Therefore, one can use the PA consistency algorithm in order to check the consistency of a

CA problem. Computing the deductive closure of a CA problem can be done in cubic time in the number of events, with the path consistency algorithm.

In turn, this algorithm can be used to decide on the consistency of the maximal tractable subalgebra that contains CA, namely, the ORD-Horn subalgebra [Nebel95]. Computing the deductive closure of the ORD-Horn subalgebra can be done in time $O(n5)$ by resorting to the path consistency algorithm, with n equal to the number of events.

However, neither the ORD-Horn subalgebra and, hence, nor CA allow for expressing disjointness, as in "before or after". Notice that Sp and Ep are the only maximal tractable subalgebras that allow for it [Krokhin et al. 05]: Sp can viewed as the set of relations obtained by replacing each of the basic relations meets, overlaps, during, finishes and their inverses with their disjunction with before; Ep can viewed as the set of relations obtained by replacing each of the basic relations meets, overlaps, during, starts and their inverses with their disjunction with before.

In a temporal reasoning tool for novice readers, consistency checking and deductions are relevant tasks:

- consistency checking: given a temporal constraint problem from a story, decide on its consistency and, in case the problem is consistent, return a solution;
- deduction: given a pair of events of a story, deduce the relations between them. This task is related to question answering.

What about automated reasoning tools for Allen-like relations?

TANGO is an annotation tool for TLINKS of TimeML [TimeML]. Since TimeML forbids disjunctions in TLINKS, the deductive-closure algorithm of TANGO is not complete for the composition operation as specified in IA—a weaker form of composition for IA is studied in [RL05]. For instance, the algorithm cannot compute the Allen composition of before and its inverse, since the result is the disjunction of all the Allen atomic relations.

Alternatively, one can encode the temporal problem into an IA constraint problem, and then use state-of-the-art constraint systems for consistency checking as well as for computing the deductive closure, e.g., see [GM07] for an application in a story telling tool. If only relations of a specific subalgebra matter, one can use a dedicated reasoner, e.g., Timegraph [GS93]. This was developed in the context of story comprehension, and as such employed within EPILOG, a computational system for Episodic Logic, a very expressive NL-like logic. TimeGraph handles the PA relations, and hence accepts the CA relations as input. It allows for consistency checking and computing deductions as well. Other tools, such as [Alspaugh05], were proposed in the literature for qualitative reasoning with Allen relations; their development seem to be discontinued.

Chapter 5

Visualisation of Events and Allen-like Relations

Time itself has many theoretical and practical aspects [Aigner et al.07]. In particular, the visualisation of time involves representational and perceptual issues as well, and it must be intuitive for the intended end users. Therefore the visualisation of temporal information in stories for children, which is the focus of this chapter, is not an easy business. In the following subsections, we describe different visualisations of Allen-like relations, which are usually developed in the HCI literature. We divide tools and visualisation techniques in two classes, according to their possible employment:

1. for the visualisation of a single pair of temporal events and their relations;
2. for the visualisation of temporal events and their relations in a whole story, with more than two events.

5.1 Visualisation of a pair of events and their relations

The classical visualisation between pairs of time intervals is the one displayed in Figure 3.1, e.g., see [Hajnicz96]. However, this visualisation is at loss when disjunctions of relations must be considered for expressing indefinite information, e.g., "before or immediately before".

[HR97] proposes an interesting solution: the first interval, say A, is represented by a gray bar; the second interval, say B, is represented by a segment bounded by two circles, a white circle for the left end and a dark circle for the right hand. Then interval B can terminate in different positions with respect to the termination of interval A, and this allows for the representation of CA relations or, more generally, PA relations. Figure 5.1 is an example taken from [CC01].

[CC01] surveys other approaches by considering different aspects in visualising temporal information, such as, the time granularity (points versus intervals), and the capability of expressing disjunctive relations between a pair of intervals or points. According to their survey, time points are usually associated to some graphical objects, such as circles, boxes, or ad-hoc icons; objects

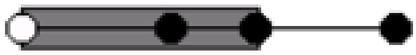

Figure 5.1: The [HR97] visualisation of a disjunctive relation.

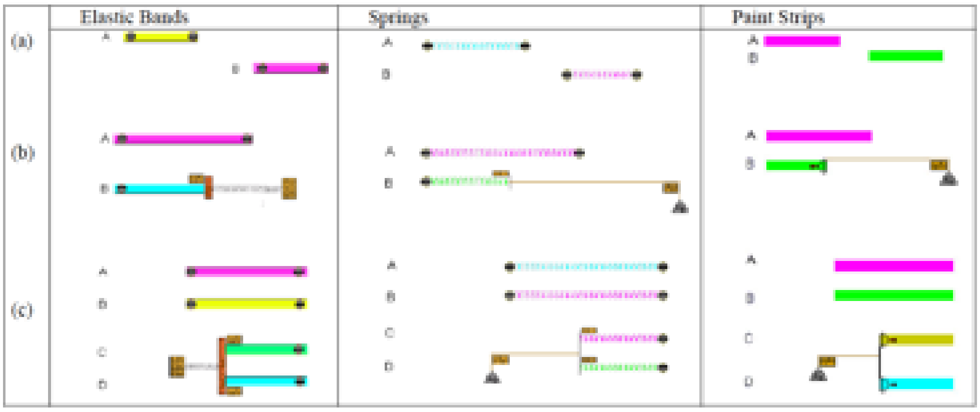

Figure 5.2: Examples of the three visualisations of Allen relations proposed in [CC01].

are located with reference to a time axis, which is usually represented as a horizontal line. The usual graphical elements for intervals are boxes or lines; temporal location and extent of intervals are displayed with reference to a (possibly implicit) time axis, as for time points.

Then [CC01] proposes three alternative visual metaphors for the representation of intervals and their relations, which can scale up to the visualisation of relations in a network with more than two intervals. Their metaphors are based on concrete objects and phenomena from the physical word: elastic bands, springs and paint strips, see Figure 5.2.

According to [CC01], the (a) cells represent an atomic Allen relation, namely, before, whereas the (b) cells visualise indefinite information, namely, the disjunction of the atomic relations starts-1, equals, starts.

5.2 Visualisation of a network of a number of events and their relations

The three visual metaphors proposed in [CC01] can also render networks of more than two events, and their relations, see the (c) cases of Figure 5.2 with four events (A, B, C, D). However, such a visualisation does not seem to scale up well to a network with a number of events, as it is the case for the events and relations found in stories.

The most famous tool for temporally annotating texts with TLINKS relations, namely TANGO (see Chapter 4), uses Graphviz (www.graphviz.org/) in order to visualise temporal relations among events. See Figure 5.3(a).

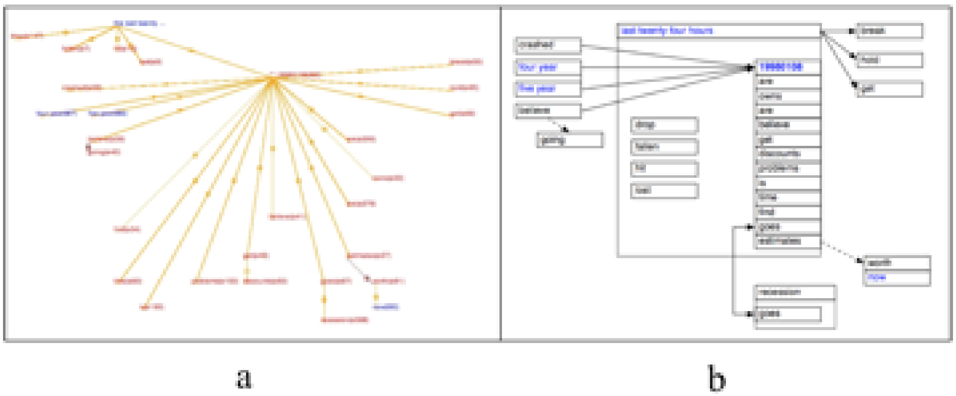

Figure 5.3: The Graphviz (a) and the T-BOX (b) visualisations.

Figure 5.4: The Pattern visualisation.

Nick Chubrich [Verhagen05], who proposed many ways for improving over the TANGO visualisation, introduced a mechanism that allows annotators to select a whole group of events, and use only one link to state that every event in this group stands in a particular temporal relation to another even. T-BOX [TimeML] derives in a crooked way from this. See Figure 5.3(b).

In the PatternFinder tool [Fails et al. 06], used in the medical context, temporal annotations are visualised using rows; Figure 5.4 represents an example of the Pattern visualisation, where each row is a single pattern match for a patient.

Chapter 6

Conclusions

As explained in the introductory chapter, 7–9 old children should be able to master qualitative relations of the form before, while and after. This was recently further sustained in [Arf et al. 09]. The web temporal reasoning tool for novice readers, at which we aim, can then include such relations.

In this paper, we studied three facets of time, relevant for such a tool: representation, in Chapter 3; reasoning, in Chapter 4; visualisation, in Chapter 5. As explained in Chapter 3, TimeML is the de facto mark-up language for web documents, albeit its expressive power seems too narrow for precisely rendering the kind of indefinite information that we find in stories for children, see, e.g., [GM07]. In Chapters 3 and 4 we survey more expressive representations, and the related (tractable) reasoning tasks and tools. To the best of our knowledge, none of the surveyed tools supports consistency checking with explanation—if the story is inconsistent, an explanation for its inconsistency should be provided. Before committing to a specific time representation or reasoning tool, we will analyse the frequency of temporal relations in (contemporary) stories written for or by novice readers.

In Chapter 5, we analysed several visualisation metaphors and tools for Allen-like relations. The temporal visualisation in a tool should be evaluated in relation to the tasks of the tool, and considering the users of the tool. Given this, the visualisations of temporal relations as in Graphviz, T-BOX or PatternFinder do not seem to be suited to a story-telling web tool for novice readers [Tominski06]. For instance, when the users are children, educators and cognitive psychologists visualise temporal events using images. The use of time-varying data visualisation [JR05] inspired by the illustration literature (e.g., speedlines approach, flow ribbons approach) could be a viable solution.

According to the review in this report, the visualisation of time emerges as the hardest and least explored of the three facets of time for the design of a web tool for novice readers.

Acknowledgements

The first author of this report was supported by a CARITRO grant.

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