Kong, S.C., Ogata, H., Arnseth, H.C., Chan, C.K.K., Hirashima, T., Klett, F., Lee, J.H.M., Liu, C.C., Looi, C.K., Milrad, M., Mitrovic, A., Nakabayashi, K., Wong, S.L., Yang, S.J.H. (eds.) (2009). Proceedings of the 17th International Conference on Computers in Education [CDROM]. Hong Kong: Asia-Pacific Society for Computers in Education.

Time Representation and Reasoning for a Story-telling Web Tool—the State of the Art

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Abstract: We are working on a story-telling web tool for primary-school classes. The tool should allow teachers to create or modify short stories, and elaborate temporal reasoning games that stimulate children to reason on the time dimension of stories. In this paper, we review the major theories and tools for qualitative temporal reasoning, studying two facets of time, relevant for such a tool: representation and reasoning.

Keywords: artificial intelligence in education architectures (web-based), interaction design, knowledge modelling and representation.

1. Introduction

Developing the cognitive capabilities of children to comprehend written texts is key to their development as young adults. In written stories, comprehension depends on the construction of a coherent mental representation of relations between the narrated events, e.g., see (Bamberg, 1987) and (Trabasso & van den Broek, 1985). Relations between events can be causal or temporal. Automated temporal reasoning is well studied in ICT, and off-the-shelf automated tools are available for it. We intend to exploit this body of knowledge, and develop it further by studying children's causal-temporal and temporal reasoning on stories, in collaboration with psychologists and experts of usability. In this paper, we concentrate on temporal reasoning.

According to child developmental studies, 8 olds are sensitive to the role of temporal relations in texts (such as *before*, *while* and *after*), and start using them in order to draw context-based deductions, e.g., see (McColgan & McCormack, 2008) and (Ge & Xuehong, 2002). Such reasoning capabilities develop further until the age of 11, when the concrete operational stage ends. 8 to 11 year old children are novice text comprehenders (*novice comprehenders*, henceforth). However, nowadays more and more novice comprehenders show problems in making global deductions on texts, as it seems to be the case of deaf children (Oakhill & Cain, 2000). Most educational material for novice comprehenders is mainly paper based, and educators cannot easily adapt it to the different types of novice comprehenders with text comprehension problems. The available electronic tools (*e-tools*, in brief) tend to concentrate on spelling, grammar, or highlighting passages of texts. Even when such e-tools tackle higher-level cognitive functions, they do not fully exploit artificial intelligence (AI) techniques or technologies.

We are working on a story-telling web tool for primary-school classes, focussing on contemporary stories for children. The tool originates from LODE, a logic-based web system for deaf readers (Gennari & Mich, 2007), recently become a project (http://lode.fbk.eu). Our tool aims at being an AI system for novice comprehenders, focusing on those with problems in making global deductions on texts, and their educators. It will offer them: (1) hypertextual stories (*h-stories*, in brief); (2) smart temporal reasoning games; (3) visual interactions with the h-stories and games.

The tool will adopt the qualitative temporal relations between events of stories that novice comprehenders should be able to master. In this paper, we review the major theories and tools for qualitative temporal representation and reasoning, in AI and HCI combined. As such, this paper paves the way for the design of the web tool.

2. The Many Facets of Time

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" (Vila, 1994). In other words, it means choosing: *(1- representation)* a time granularity and structure, and a formal language for them; *(2 - 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: *(3- visualisation)* the visualisation of temporal information. However, this is also a crucial facet for an educational tool like ours. We refer to (Di Mascio & Gennari, 2009) for a survey of visualisations of temporal events and their relations, whereas this paper concentrates on their representation and reasoning.

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 the 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 remainder, we use the problem in order to illustrate various issues pertaining to the two aforementioned facets of time in a story-telling web tool.

3. Time Representation of Qualitative Relations

There are different temporal structures, for instance, linear, cyclic, or branching (Vila, 1994). 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 (Hajnicz, 1996). Contemporary stories for children (in Western literature) seem to be usually based on a linear time structure (Nikolajeva, 2000). 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.

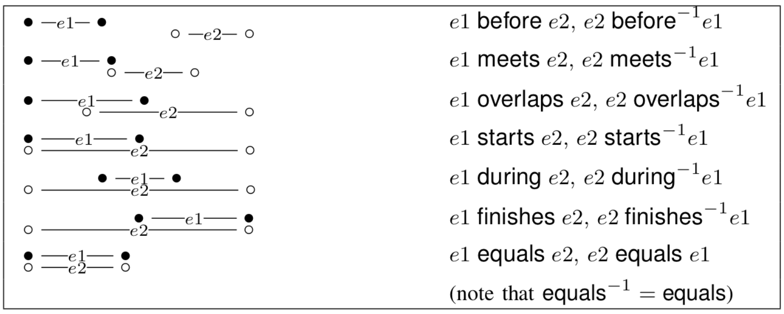

Figure 1. Relations between time intervals.

Exhaustive, mutually exclusive qualitative relations are possible among time points and among time intervals of a linear structure, see Figure 1 for the latter case—note that such relations can be extended to non-linear structures, see (Hajnicz, 1996). Other relations are possible between a time point and a time interval (Meiri, 1995).

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

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documents, and 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 time instants. See Figure 2 for their BNF representation. The TLINK relations are based on the atomic Allen relations, according to (Mani, Wellner, Verhagen, & Pustejovsky, 2007). We introduce the Allen relations below, and then compare their expressive power with that of TLINK.

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

Figure 2. The syntax of the TLINK relations.

In his seminal paper (Allen, 1983), 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 an *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 1 for their interval representation. Such relations are mutually exclusive. For instance, the above excerpt of "The Ugly Ducking" 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". Indefinite information can be represented by means of disjunctions (unions) of the Allen atomic relations. Then an *Allen relation rel* is an atomic relation or a disjunction of atomic relations. The set of the Allen relations forms the *Allen Interval Algebra* (IA) with conjunction (intersection), inverse and composition, e.g., see (Ladkin & Maddux, 1994).

Note that *overlaps* and disjunctions of TLINKS relations are instead forbidden in TimeML, see Figure 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 that is computationally tractable—we will specify what we mean by a tractable subalgebra in Section 4 below, after introducing the necessary details.

4. **Temporal Automated Reasoning Tasks and Tools with Qualitative Relations**

The constraint literature has a number of studies on subalgebras of IA, and algorithms for different reasoning tasks. In the remainder of this section, we introduce some of such subalgebras, which seem relevant for story analysis, and the related reasoning tasks with their computational complexity, primarily, the so-called consistency checking and deduction tasks (Gennari, 1998). For the entire list of all the maximal tractable subalgebras of IA, we refer the reader to (Krokhin, Jeavons, & Jonsson, 2005).

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 (Apt, 2003)). In essence, an *A constraint problem* is given by a finite sequence of variables, $e_1, e_2, \ldots, e_n$, each representing an event and ranging over a finite collection D_i of intervals of reals, and one (binary) constraint $C_{ij} \in A$ for each pair of variables (e_i, e_j) with $0 \le i < j \le n$. A tuple of intervals $(I_1, I_2, \ldots, I_n)$ of $D_1 \times \ldots \times D_n$ is a *solution* to the constraint problem if $I_i\, C_{ij}\, I_j$ holds, for each C_{ij} of P.

An *A* problem P is *satisfiable* or *consistent* if it has a solution. We will say that $rel \in A$ for (e_i,e_i) is *deduced* if I_i *rel* I_j holds, for all solutions $(I_1, I_2,\ldots,I_n)$ to P. Let DC_{ij} the set of deduced relations for (e_i, e_i). The *deductive closure* of P is the set of all such DC_{ij}, for $0 \le i < j \le n$. 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 (Nebel & Bürckert, 1994).
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 (van Beek, 1992).
PA relations are conjunctions of relations between end-points of intervals of the form: (1) $x = y$, (2) $x \le y$, and (3) $x \ne y$. 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 (Nebel & Bürckert, 1994). Computing the deductive closure of the ORD-Horn subalgebra can be done in time $O(n^5)$ 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 S_p and E_p are the only maximal tractable subalgebras that allow for it (Krokhin, Jeavons, & Jonsson, 2005): S_p 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*; E_p 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 primary classes, consistency checking and deductions are relevant tasks:

(1) consistency checking: given a temporal constraint problem from a story, decide on its consistency and, in case the problem is consistent, return a solution;
(2) 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 (Renz & Ligozat, 2005). 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., as in (Gennari & Mich, 2007). If only relations of a specific subalgebra matter, one can use a dedicated reasoner, e.g., Timegraph (Gerevini & Schubert, 1993). 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.
However, none of the surveyed tools seem to tackle another relevant task in a e-tool like ours, namely, (3) consistency checking with explanation of inconsistencies, that is, explaining incoherent answers to smart temporal reasoning games.

5. Conclusions

As explained in the introductory section, 7–9 old children should be able to reason with qualitative relations of the form *before*, *while* and *after*. This was recently further sustained in (Arfé, Gennari, & Mich, 2009). The web temporal reasoning tool for novice comprehenders and their educators, at which we aim, will include such relations. In this paper, we overviewed two facets of time, relevant for such a tool: representation, in Section 3; and reasoning, in Section 4. (Di Mascio & Gennari, 2009) presents the state of the art on the third facet, visualisation, and (Di Mascio, Gennari & Arfé, 2009) is a preliminary study of the visualisation of temporal relations by first and second graders.

Acknowledgements

The work of the first author was carried on within the LODE project (http://lode.fbk.eu), supported by a CARITRO grant.

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