Towards Children-Oriented Visual Representations for Temporal Relations

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Abstract. Developing the capabilities to read and comprehend text is fundamental for the development of children. Traditionally, the comprehension process is stimulated by educational interventions carried out by primary school educators, who aim, e.g., at retracing temporal relations among main events of a story. While a dual-coding approach pairing verbal and pictorial information proves to be successful, existing proposals for the visualization of a story's events and their relationships seems dedicated mostly to computational linguists or information engineers rather than children and educators. The FP7 European project TERENCE faced this issue creating the first adaptive learning system for text comprehension for primary school children. The paper, after a review on the state-of-art of visual representation of temporal relations, discusses the TERENCE choices for achieving a children-oriented approach.

Keywords: Technology Enhanced Learning, temporal relations, visual interface.

1 Introduction

Reasoning coherently with time concepts (e.g., before and after) is a cognitive ability that children have to possess in order to be proficient with text comprehension [16]. This ability starts to develop after the age of 5 and continue to develop from the age of 7 to that of 9, when children are able to master the while connective, and futher to the age of 11, when children become independent readers [13]. More and more children in that age range turn out to be poor (text) comprehenders, demonstrating difficulties in, among others, coherent use of connectives (because, after, before) and inference-making from different parts of the text [6].

Text comprenhension may be improved by educational interventions aimed at reasoning about stories specifically designed so to include appropriately interspersed temporal connectives through which children construct relations about story's events (e.g., [5], [19]). It has to be observed that according to the dual-coding theory [18] both verbal information and visual imagery – processed differently and separately along distinct channels in the human mind – can be integrated to represent information so that they re-inforce each other in the learning process.

It is worth noting that the adequacy of a visual representation of time strongly depends on its final users and their tasks [1]. The issue of selecting/designing adequate

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time representations has be faced within the context of Learning Management Systems, offering functionalities to deliver, track, report on and manage learning content, learners' progresses and learners' interactions, and of the more specifical class of Adaptive Learning Systems (ALS's), able to tailor their behavior to the individual learner [4].

One such case is the TERENCE system, an ALS designed within the framework of an FP7 EU multidisciplinary project (www.terenceproject.eu), to support 7-11 years old poor text comprehenders in their learning activities and educators in the design and realization of learning material. The system presents to children adequate stories, organised into difficulty categories and collected into books, along with instructional smart games for reasoning about stories. The presentation of the learning material is actually organised as a cognitive stimulation plan designed by the neuro-psychologists involved in the project. While a comprehensive description of the "TERENCE solution" (psycho-pedagogical approach, internal and external models of stories and games, and system architecture) can be found in [11], here we focus on the requirements of children-oriented visual representrations of temporal information specifically designed for the task of story comprehension. To this aim, in Section 2 we review existing proposals for the representation of temporal connectives and assess them with reference to children-oriented design. In Section 3 we present the main features of the "read and play" visual interaction enviroment of TERENCE, and finally, in Section 4 a brief discussion on the evaluation of our proposal is given and conclusions are drawn.

2 Visual Representation of Temporal Connectives

Defining suitable visual representations for temporal structures of stories needs the integration of theoretical and methodological work both from traditional areas devoted to temporal representation (logic, reasoning, and databases) and from information visualization research field [1].

2.1 Existing Proposals for Representation of Temporal Structures

Broadly speaking, it is necessary to address issues referring to two cases: (1) single pairs of temporal events and their relations, and (2) temporal events and their relations within a whole story with more than two events.

With reference to case (1), first proposals for visualization techniques, based on seminal Allen's work on temporal logic [2], came from [14,15] (see Figure 1). Stemming from their results, other researchers proposed visual metaphors and tools surveyed e.g., in [1], [7], [9]. More specifically, [7] presented results classified according to four design dimensions: temporal structure, order, representation, and history; [9] classified literature proposals according to time granularity and capability of expressing disjunctive relations between pairs of intervals or points, while [1] uses time, data and representation dimensions.

Moving from the single pair of events of case (1) to the complexity of case (2) means moving from linear representations to graph and network representations. A proposal bridging cases (1) and (2) is in [9], who introduces three alternative visual metaphors that can scale up to the relation visualization in a network with more than two intervals. These metaphors, based on concrete objects and phenomena (elastic bands, springs and paint strips in Figure 2), can also render networks of more than two events, and their relations (case (c) in Figure 2).

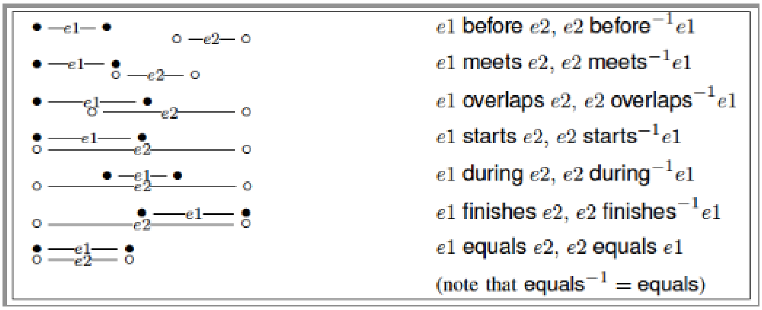


Fig. 1. Relation between intervals by [15]

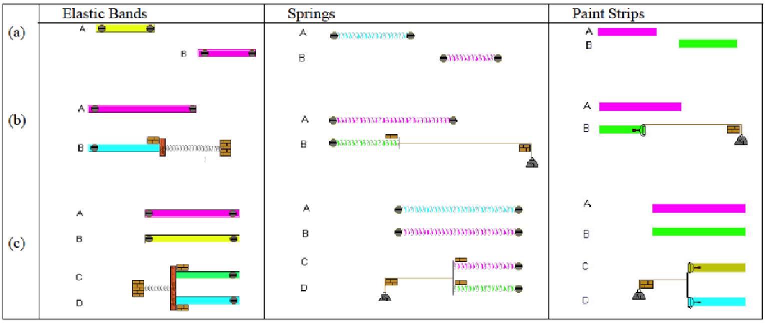


Fig. 2. The metaphorical representations proposed by [9]

As to case (2) it has to be observed that *temporal annotation* of stories is a complex task posing specific challenges deriving, among others, from high density of temporal relations and distances within the text of involved objects (e.g., events) [21]. Several tools have been proposed to deal with the complexity of temporal annotation and the consequent low markup speed, hard-to-avoid inconsistencies, and low inter-annotator agreement: in PatternFinder tool [12], temporal annotations are visualized using rows; BAT[1] describes annotations as graphs with edges and labeled nodes that are displayed according to the pivot table format; a number of proposals are based on Graphviz[2], an open source graph visualization software, among which TANGO[3] and tools derived from it, namely T-BOX [21] and TARSQI[4], and TATOT [10], which, differently from

[1] http://www.timeml.org/site/bat/
[2] www.graphviz.org/
[3] http://www.timeml.org/site/tango/
[4] http://www.timeml.org/site/tarsqi/toolkit/

the other tools, allows users to find a node in the graph (along with all its relations) clicking on the event annotated in the text.

2.2 Towards Children-Oriented Representations

While adequate for computational linguists or information engineers, existing visual representations fail to directly support the requirements of educators and, above all, young learners for a number of drawbacks:

- *High degree of abstraction.* Almost all proposals are based on abstract elements, and even metaphors based on real objects, such as paint strips, turns out to be not realistic enough, while recent studies prove that children appreciate realistic illustrations [8].
- *Fine granularity.* Based on Allen's work on temporal logic, all proposals aim at clearly differentiate among distinct configurations of non overlapping intervals (the first two cases in Figure 1, i.e., relations *before* and *meets*), or overlapping intervals (the other cases in Figure 1, i.e., relations *overlaps*, *starts*, *during*, *finishes*, *equals*), arriving to a level of detail that turns out to be excessive and counterproductive for children novice in the mastering of the general meaning of 'before', 'after' and 'while' [16].
- *Lack of global vision.* None of existing proposal aims at relating events to the global context of a narration, while stories are a first class tool of a psychopedagogical stimulation plan [20].
- *Groundness on a pre-existing model.* Visual representation of temporal data and temporal connectives are generally based on (crowded) timelines and visualization of intervals. Anyhow, it has to be underlined the crucial difference between adult-oriented time representation and child-oriented time representation aimed at supporting text comprehension: in the first case we build on a pre-existent mental model of time and temporal connectives, while in the latter we have to induce the construction of a mental model of time and temporal connectives. Relying on his/her mental model, an adult can grab temporal information from the exploration (and possibly the filtering) of timelines (often characterized by huge quantity of data) that would on the contrary overwhelm a child who is trying to acquire common sense time concepts. Furthermore this would be inconsistent with consolidated pedagogical approaches built on question-based games [11][20].

A final observation, more general and related to the design of any interactive application, refers to the *lack of juiciness*, and in general to the different approaches of adult and children with respect to interactions: in adult-oriented systems the focus is on productivity, with a consequent requirement of minimality of the interface in order not to distract users from their tasks, while in children-oriented application the focus is on playfulness, with a requirement of juiciness of the interface, and the achievement of the task is a side-effect of the activities carried on by the child.

For all these reasons, in TERENCE individual visualizations of events and of their temporal relations are associated to smart games and playing activities, within a visual interaction environment where children read stories and play games designed so to force the acquisition of temporal reasoning.

3 The TERENCE Proposal

The main idea behind TERENCE is that the stimulation by the system integrates with the traditional stimulation by teachers. According to the advice of the experts involved in the project, the psycho-pedagogical stimulation plan in TERENCE, based on the constructivist pedagogical approach [17], is inspired by a traditional teaching strategy including reading the story and analyzing the text via inference-making question answering. Learning sessions mirrors a warm-up, peak, and relaxing phases structure, specifically: (1) reading a story, silently – warm-up, (2) resolving related smart games for analyzing the story – peak, and (3) playing with other games able to relax the learners according to a their performances in the previous step – relaxing.

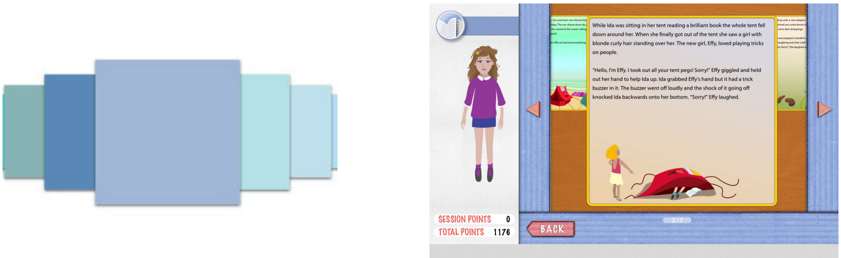
Learning material includes stories and associated smart games, along with accessory material: *stories*, organized in books, are ordered and actually written into four different versions with increased cognitive difficulty [3]; instructional *smart games* are factual (e.g., “guess who did something”), temporal (e.g., “what happened before/after this event?”), and causal (e.g., “what caused this?”, or “which is the effect of this?”); *accessory material* includes elements designed in order to make the learning experience appealing, such as avatars available for the children, cards illustrating the characters of the books, relaxing games that can be played by children after the stimulation for entertainment and relaxing purposes.

Table 1. The story grammar proposed by [20]

Story Grammar based on Stein and Glenn (1979)		
Element	**Definition**	**Example**
Setting	Introduction	*Once upon a time there were three bears, the momma bear, the popa bear, and the baby bear. They all lived in a tiny house in a great big forest.*
Initiating Episode	An episode that sets up a problem or dilemma for the story	*One day a little girl named Goldilocks came by.*
Change episode	The turning episode	*She was surprised to see the house and noticed it was empty.*
Resolving episode	An action or plan of the protagonist to solve the problem	*She went inside to find the three bears gone and ate the baby bear's soup, broke the baby bear's chair, and fell asleep in the baby bear's bed.*
Final episode		*Seeing the three bears, Goldilocks ran away.*

As to story structures, the most common strategies for stimulating reading comprehension by educators are based on analysis of stories structured according to the so-called “story grammar” reported in [20] and summarized in Table 1. One may notice some key structural characteristics (SC): (SC1) Stories are relatively “light”, i.e., with a limited number of episodes, events, and participating characters; (SC2) episodes are temporally ordered, and (SC3) episodes are short.

Accordingly, in TERENCE stories are structured as interactive sequences of illustrated episodes visualized according to a *carousel pattern* (Figure 3-(a)), a focus+context interactive pattern that proves to be efficient for exploring small sets (coherently with SC1). In the case of story episodes it allows the child to focus on single episodes (coherently with SC3) while maintaining a global vision on the whole story and on the order of episodes, by providing a direct visual representation of the relative time of occurrence of episodes (coherently with SC2), as illustrated in Figure 3-(b).



(a) (b)

Fig. 3. Browsing through story episodes

As to the individual representation of events and their temporal relations, as said before, TERENCE associates them to smart games. More specifically, *time games* can be classified into:

- *before*, *after*, and *before-after* games, where the child has to reason about purely sequential events, and
- *before-while*, *while-after*, and *before-while-after,* where the child has to reason about both sequentiality and contemporaneity.

In all cases the child has to select the correct answer in a set of three. For all games the visula interface is based on the same general pattern (see examples in Figure 4). A main content area (on the right) is divided into three portions: a lower bar displays three cards corresponding to the possible choices, a middle area displays the question to be answered, and an upper part depends on the specific games.

As to the mechanisms designed so that children build their mental model of temporal relationships, we observe that, though events have a duration, and in principle might hence be associated to time intervals, the level of granularity and the degree of indeterminacy of temporal information in learner-oriented stories make interval-based visualizations (such as techniques based on Allen's relations) not adequate. In TERENCE we adopted a simple dual-coded card-based representation for the events, including an illustration and a verbal sentence. Figure 4 shows examples of a *before-after* game and a *before-while* game, based on intuitive visual metaphors for representing event sequentiality, event contemporaneity, correct answer and wrong answer. In particular, as to before/after connectives, we maintain the sequentiality of Allen's relationship while ignoring the distinction between 'before and 'meets' cases (see Figure 4(a) and Figure 4(b)); as to while connectives, we maintain Allen's suggestion to use parallelisms while ignoring the distinction among different cases of partial and complete overlapping (see Figure 4(c) and Figure 4(d)).

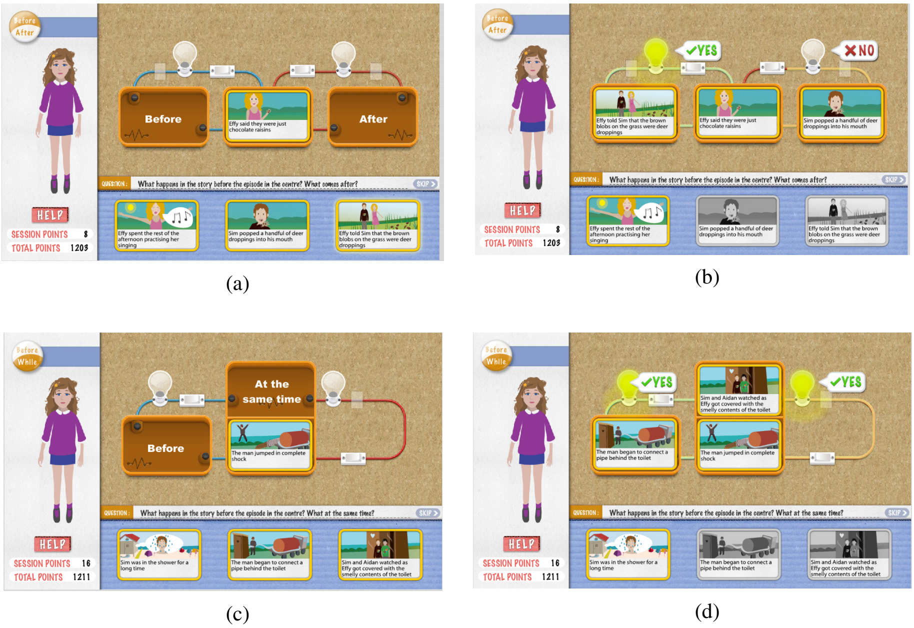


Fig. 4. Examples of before-after and before-while games

4 Discussion and Conclusions

In this paper we focused on one of the most important aspect for the TERENCE scientific impact: the visual representation of temporal relations. The value of this aspect was considered within the evaluations of the project. It is worth noting that TERENCE is designed and developed in an iterative manner, based on the user-centred design approach, in which four evaluations were performed: two expert-based evaluations and two user based evaluations. The complexity of the evaluation is due to the fact that, in a Technology Enhanced Learning system like TERENCE the evaluation deals with two main facets: the usability of the system and the psycho-pedagogical intervention, which investigates the learning outcomes. Table 2 provides a synoptic view of the evaluations: the first column specifies the characteristics of the evaluation (expert-based/user-based, formative/summative, qualitative/quantitative), the second and third column specify the issues and the release under evaluation, respectively, and finally the last column indicates the number of users involved.

In particular, the aspect the paper deals with is validated by considering the educational value that the TERENCE system produced; in fact, the analysis of data, gathered in a pre-post test involving two groups of users (experimental and control groups) during the summative evaluation (last column of Table 2) showed that (1) the stimulation plan significantly improved comprehension in the experimental group, (2) TERENCE improved reading comprehension also in comparison with a control group, and (3) TERENCE improved comprehension both in poor and good comprehenders, demonstrating, de facto, that the choices implemented in the visual interface in terms of visual representations for temporal relations are appropriated for a children-oriented system (for details on psycho-pedagogical aspects we refer to [11], while for the main usability aspects we refer to [8]).

Table 2. The TERENCE project evaluation

Evaluation Characteristics	Issues	Release (Month)	Involved Users
1st expert-based Formative Qualitative	Usability Curricular material (e.g., stories)	Prototypes (March 2012)	about 10 domain experts of text comprehension and interaction design
1st user-based Formative Qualitative	Usability Learning outcomes	1st release (June 2012)	about 170 learners (deaf and hearing)
2nd expert-based Formative Qualitative	Smart Games revision and production	2nd release (Sept 2012)	about10 domain expert of pedagogy
2nd user-based Summative Quantitative &Quantitative	Usability Learning outcomes	3rd release (March 2013)	About 830 learners (deaf and hearing)

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