The Design of An Intelligent Adaptive Learning System for Poor Comprehenders

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Abstract

Developing the capabilities of children to comprehend written texts is key to their development as young adults. Text comprehension skills develop enormously from the age of 7-8 until the age of 11. Nowadays, several young children (5̃% – 10% of novice readers) turn out to be poor (text) comprehenders: they demonstrate text comprehension difficulties, related to inference-making skills, despite proficiency in low-level cognitive skills like word decoding.

Though there are several pencil-and-paper reading interventions for improving inference-making skills on text, and addressed to poor comprehenders, the design and evaluation of Adaptive Learning Systems (ALSs) are lagging behind.

The use of more intelligent ALSs to custom-tailor such interventions in the form of games for poor comprehenders has tremendous potential. Our system embodies that potential.

This paper presents the design of our ALS by focusing on its intelligent adaptive engine and the related conceptual models, and by presenting the visual interfaces for story telling and gaming.

Introduction

Developing the capabilities of children to comprehend written texts is key to their development as young adults. Text comprehension skills and strategies develop enormously from the age of 7-8 until the age of 11, when children develop as independent readers. Henceforth, we refer to 7-8 to 11 olds as *novice* (text) *comprehenders*. Nowadays, more and more novice comprehenders turn out to be *poor* (text) *comprehenders*: they demonstrate difficulties in deep text comprehension, despite well developed low-level cognitive skills like vocabulary knowledge, e.g., see (Cain et al. 2001) for hearing poor comprehenders, and (Marschark et al. In Press) for deaf poor comprehenders.

The following subsection briefly outlines the characteristics of poor comprehenders in relation to text comprehension, according to current findings in cognitive psychology, thereby providing the motivations and rationale for the design of our adaptive system for poor comprehenders.

Poor Comprehenders

In the United Kingdom, poor comprehenders are estimated to be 5% to 10% of novice comprehenders (Lyon, Fletcher, and Barnes 2003). Similar numbers were identified in Italy (Cornoldi, De Beni, and Pazzaglia 1996), as well as in other countries (Ehrlich and Rémond 1997; Nation and Snowling 1998; Paris et al. 2005). The estimate dramatically increases when the whole population of hearing-impaired children is considered. For instance, in (van Bon, Wauters, and Tellings 2006) the authors estimate that only 19% out of 504 hearing impaired 7-20 olds have reading comprehension scores above the third grade level.

Several studies experimentally demonstrate that poor comprehenders fail to master the following reasoning skills in processing written texts, e.g., see (Cain et al. 2001):

(s1) coherent use of cohesive markers such as connectives ('because', 'before', 'after') that signal relations in text,

(s2) inference-making from different or distant parts of a text, integrating them coherently,

(s3) detection of inconsistencies in texts.

Nowadays, there is clear evidence that such reasoning skills (s1, s2, and s3) are very likely to be causally implicated in the development of deep text comprehension. In particular, experiments show that inference-making questions centered around (s1, s2, and s3) together with adequate visual aids are pedagogically effective in fostering deep text comprehension, e.g., see (National Reading Panel 2000).

Rationale of Our Work

The successful comprehension of stories steps through the construction of a coherent mental representation of the narrated events, which means of being able to find relations between the narrated events, eventually introduced in different parts of the stories (Zwaan 1999). Relations between a story's events can be of different types: causal, temporal, spatial, etc.. Contrary to classical readability formulas, the presence of appropriately interspersed connectives in stories, such as 'because', 'while', and 'where', accompanied by pictorial representations can facilitate the construction of conceptual relations between events in a novice comprehender's mental representation of a text's meaning, e.g., see

(Cain In Press), p. 40, and (Duran et al. 2006) for temporal connectives in particular.

However, finding stories and educational material that are appropriate for poor comprehenders is a challenge, and hence educators are left alone in their daily interaction with poor comprehenders. Most reading material for novice comprehenders is paper based, and is not easily customisable to the specific needs of poor comprehenders, e.g., in the type or number of cohesive temporal connectives. Few ALSs promote general reading interventions, but they have high-school or university textbooks as reading material, instead of stories, and are developed for old children or adults, and not specifically for poor comprehenders, hearing and deaf.

Our ALS will help fill such a gap: its reading material (in English and in Italian languages) will be stories adapted to poor comprehenders, and its reading interventions will be interactive question-games centred around reasoning skills, like (s1), (s2), and (s3) above, that foster the development of deep text comprehension, both accompanied by adequate visual aids.

Background on ALSs

The conceptual model of an ALS is usually made up of (see (Santos et al. 2003)): the student model that describes the student's main features, the domain model that structures the learning material, the environment model for the hardware/software capabilities, and the adaptation model that, given the previous models, characterises the actual adaptive mechanism and adaptation engine. In order for ALSs to be pedagogically effective, the adaptation components usually require more specialised AI-techniques, tailored to the specific needs of their users (Brusilovsky 2000; Paramythis and Loidl-Reisinger 2004; Shute and Zapata-Rivera 2007), than those of a classical intelligent tutoring system. Both the planner approach of the MIGRAINE system (Buchanan et al. 1995) and the progress-based guidance mechanism of QuizGuide (Brusilovsky, Sosnovsky, and Shcherbinina 2004) are particularly relevant to the adaptation engine of our ALS. The MIGRAINE system uses a knowledge base and a text to generate questions to patients that are trying to comprehend a medical report on their condition, an approach that leads to a better understanding and a greater satisfaction. QuizGuide, instead, proposes quizzes to students. Quizzes are grouped in sets, according to their topics. QuizGuide attempts to guide students to the most relevant self-assessment quiz sets, by tracing correct and incorrect answers for the quizzes, calculating mastery levels for each quiz. These levels are propagated to the topic level, forming the mastery view of the whole topic. The evaluation of progress-based navigation support in QuizGuide demonstrated that this technology has succeeded in guiding towards the most appropriate quiz sets.

As for the student model, different aspects of user modelling were studied independently from different angles. Aside from distribution, scalability and performance aspects (Kobsa and Fink 2006) and context information (Jameson 2001), the principal motivations for the development of user models are (i) to characterise an individual user and (ii) have a generic representation of types of users. The former has received most attention research and proof-of-concept implementations. For instance, the KBS-Hyperbook (Henze and Nejdl 1999) and TRAILS projects (Heller et al. 2007) based their modelling on (reasoning over) logged user actions. In the AHA! project (De Bra, Smits, and Stash 2006), on the other hand, user actions are typically not logged but immediately translated into higher-level user model information, and Brusilovsky and Millán (Brusilovsky and Millán 2007) focus on Bayesian networks. As Kay (Kay 2008) already points out, with maturing ALSs, long-term usage, and interoperability issues among extant systems, the second option becomes more important. There are, however, few ontologies described in the literature, primarily being the generic user models of GUMO (Heckmann et al. 2005) and GRAPPLE (De Bra et al. 2010).

The fact that they are generic allows us to reuse them and make them more specific for the domain and students of our ALS. To the best of our knowledge, there are no user or domain models that, nowadays, cover adequately our specific subject domain of poor comprehenders, and deep text comprehension skills.

The Conceptual Model of our ALS

The preliminary analysis of the context of use and the user requirements already allows us to characterise both the learning material and goals of our ALS, and hence draft the conceptual model, as outlined in the following subsections.

The Learning Material

The main learning material of our ALS consists in illustrated stories, and interactive games centred around inference-making questions for reasoning about the stories.

Stories. Even if finding stories for novice comprehenders is not difficult, finding stories that are adequate to poor comprehenders can be a challenge. For instance, the comprehension of causal-temporal relations in text is problematic for poor comprehenders. However, the use of more causal-temporal connectives in stories seem to facilitate the comprehension of the text for poor comprehenders. The appeal and adequacy of the resulting stories will be evaluated with different types of poor comprehenders, e.g., with different ages, grammar skills and, in case of deaf children, different first-language. Especially with deaf children, we may have to significantly modify texts, e.g., by simplifying vocabulary and grammar, two factors that may also affect text comprehension, e.g., see (Goldin-Meadow, S., and Mayberry, R 2001) and (Musselman 2000).

Reasoning games. The reasoning games are based on a story's explanatory events. Preliminary prototypes of the games are being designed by following assessed interventions for stimulating the reasoning skills on texts outlined in the motivations. For instance, according to our analysis, poor comprehender seem to be in need of games that pose and solicit questions about specific features of events in the stories, monitoring the students' comprehension of the story

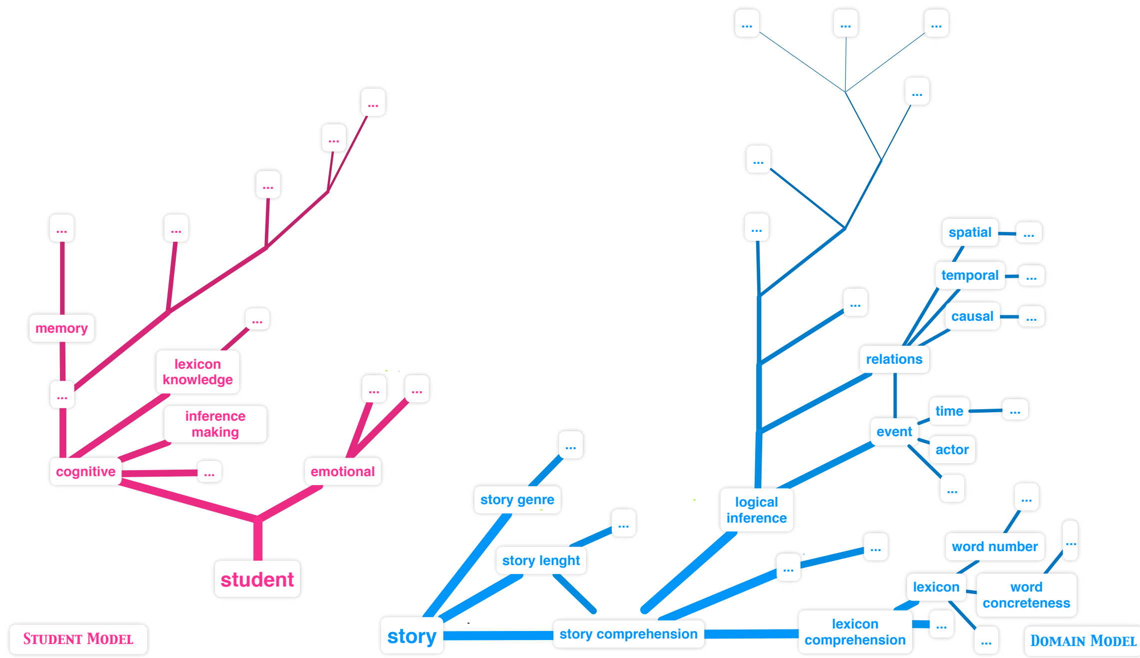

Figure 1: A snapshot of the student and domain models

flow. Let us make two concrete examples of such question-games, starting from the following excerpt of a famous children's story.

> *Mummy Duck watches the big egg but sees no signs of cracking. So she decides to keep sitting on it. After some days, while she is sitting on it, an ugly gray duckling cracks the big eggshell...*

The games of our ALS will feature who-questions like

Who *cracks the big eggshell?* (1)

or more complex ones like

Does the big eggshell crack before *Mummy Duck watches it?* (2)

for reasoning about implicit causal-temporal information in the story. Such questions will be accompanied by adequate visual aids that help children foster their deep comprehension of the related information, in line with the results of (Arfé, Gennari, and Mich 2009).

The Main Components of the Conceptual Model

The conceptual model of our ALS is specified as follows:

1. the learning material described above becomes part of the domain model, which is composed of two main sub-models: one for story-comprehension, the other for reasoning games;
2. the student model for the characteristics of poor comprehenders, split into emotional ones and cognitive ones;
3. the adaptation model for the teaching process, specifying the rules correlating concepts of the domain model and concepts of the student model;
4. an environment model for the capabilities of the hardware devices and software applications used by the learner in a specific learning session.

In particular, Fig. 1 offers a snapshot of the preliminary student model and story sub-model (of the domain model) of our ALS. The models are being developed as OWL ontologies starting from existing ones. More precisely, as for the student model, we are starting from the generic user model of GRAPPLE (De Bra et al. 2010), and refining its cognitive part.

The student model specifies the relevant (according to psychologists) cognitive skills of poor comprehenders, like the lexicon knowledge and the capability of making specific inferences, that are related to concepts specified in the story-comprehension submodel, like the lexicon complexity and the different concepts of inference-making while reading. As for the story-comprehension sub-model, we are refining the taxonomies of text comprehension overviewed in (Chikalanga 1992).

The Architecture of our ALS

The current logical architecture of our ALS is divided into three layers, namely: the data layer, the application layer, and the interaction layer. See also Figure 2. The data layer stores the stories, smart games, and (causal-)temporal knowledge (according to the domain model), the information specific to each learner (according to the student model), and the information about the supported clients (according to the environment model). The application layer implements the adaptation engine, and the intelligent backbone responsible for the automated feedback on games (e.g., correct or incorrect answers to games). Finally, the interaction layer contains the users' interfaces.

The following two subsections detail the intelligent backbone of the application layer of the system, and the role of web services in it. Then a prototype of the interaction layer for students is briefly outlined.

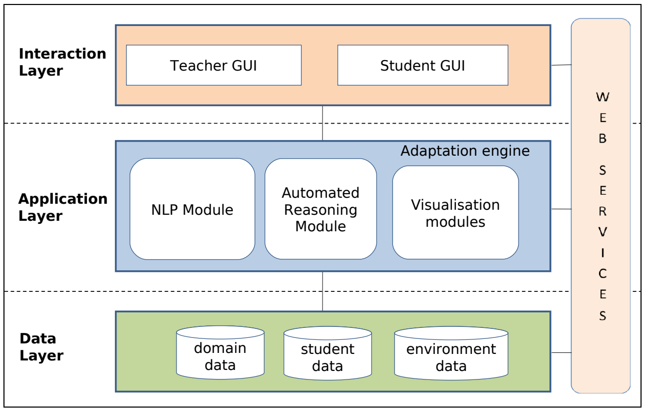

Figure 2: Architecture and adaptation engine.

The Intelligent Backbone of the Adaptive Engine

The main modules of the adaptation engine of our ALS are a constraint-based automated reasoner and a natural language processing (NLP) module, consisting of a processor for English stories and one for Italian stories, that lay at the core of the engine and constitute its intelligent backbone, so to speak. A similar idea was proposed in the LODE web e-tool for deaf children for the first time in (Gennari and Mich 2007). The NLP component of LODE serves to annotate Italian stories with events and relations of the TimeML language, and the automated reasoner automatically answers temporal reasoning games starting from such annotations.

However, the work conducted within LODE highlighted several limitations of TimeML and annotation tools for annotating stories, e.g., see (Di Mascio et al. 2010). For instance, according to the on-going cognitive analysis, we already know that the extension should allow for the annotation of the actor of an event. The refined annotations for stories will thus allow the NLP module of our ALS to generate and answer simple questions of the reasoning games, such as who-questions, e.g., see question (1). Other questions that require to deduce implicit information from the annotations of stories, like question (2), will be answered with the help of the automated reasoning module embedding a constraint-based reasoner.

The way in which the adaptive engine assesses the performance of a student on games can be manifold. In particular, the approaches of MIGRAINE (Buchanan et al. 1995) and QuizGuide (Brusilovsky, Sosnovsky, and Shcherbinina 2004) seem the most relevant for our adaptive engine in that they use questions for assessing the users' understanding of a specific domain. Similarly, the adaptive engine of our ALS should be able to assess (correct and incorrect) answers to games by also making use of the IRT theory (Baker 2001) for assessing when students guess. According to the assessment of the students' performance on a class of games, our ALS will attempt to guide the students to the most pertinent new game class, following the game sub-model of the domain model.

The Role of Web Services

Adaptive hypermedia techniques have proven their ability to support an improved user learning experience, albeit with some exceptions. Nevertheless, there has been no widespread adoption of these techniques so far (Brusilovsky and Henze 2007). One of the reasons is that ALSs are usually monolithic, and they lack of re-usability and interoperability. Our ALS will advance on this by virtue of its architecture based on ontologies and web services, as well as by using automated annotation and reasoning tools. In the specific context of our ALS, tasks will be implemented through web services and their composition. For instance, let us refer to the generation of a temporal question-game like question (2). The composition will go as follows:

1. firstly, a NLP web service operation, that takes the story as input and returns the annotations in the novel annotation language, is invoked;
2. secondly, these annotations are taken as input, and an operation of the Automated Reasoner service deduces further causal-temporal annotations as output;
3. finally, these latter annotations are taken as input and a further operation of the NLP web service generates as output the example question-game.

A first clear advantage of such an approach is that it allows for the reuse of our architecture in other languages, by implementing the appropriate NLP services. Furthermore, since web services are accessible through HTTP calls, they can be invoked directly in their respective organisations. Finally, the high-level operations might also be implemented with a programming-in-the-large paradigm, e.g. BPEL (Weerawarana et al. 2005), thus allowing for an easy deploy of further operations, that become web services, and therefore re-usable to build up more complex tasks.

The Interaction Layer for Students

The graphical user interface (GUI) for students has stories and games. The GUI that we are currently experimenting with is dynamic and implemented in Adobe Flash^{TM}.

Fig. 3 is a screenshot of the GUI in story-reading modality (default choice). The story (written in Italian in the figure) is about a grandmother having a pic-nic with her grandchildren. The GUI is divided into two panels. In the left panel, the text of the story is linearly visualised. The right panel of the GUI features the dynamic story illustrations, and three upper boxes for navigating the interface. The "Leggi" upper box ("Read") is the default choice and shows the interface in story-reading modality, the "Parole" box ("Words") enables a function of our ALS that shows the meaning of the words, and the "Gioca" box ("Play") shows the interface in game modality.

Figure 3: A screenshot of the student GUI prototype

Conclusions

In this paper we motivated the need of an ALS for poor comprehenders, with a first analysis of their requirements. Then the paper outlined the current conceptual model of our ALS, focusing on its adaptation engine. The intelligent backbone of this mainly consists of an NLP module and a constraint-based automated reasoner for generating question-games for reasoning about stories, and providing an automated feedback to the games.

Currently, we are working on a finer-grained analysis of the user requirements, to be reviewed through evaluations. Such evaluations, more in general, will serve to assess the usability of our ALS, and in particular: (1) the appeal and adequacy of its learning material, (2) the pedagogical effectiveness of our ALS in improving the text comprehension of poor comprehenders.

Acknowledgements

Figures 3 refers to a prototype of the student GUI developed in collaboration with Semion Lapin and Michela Carlini; Lapin is also the story illustrator. The preliminary requirement analysis that ended in the motivations and rationale originate from a joint work with B. Arfé and J. Oakhill. We also thank the GRAPPLE members of L3S. Our thanks are also due P. van den Broek for pointing out the Coh-metrix tool to us.

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