The Domain Model of an Adaptive Learning System for Poor Comprehenders

by
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Abstract

Comprehension of stories involves the decoding of the text, the activation of prior knowledge and, ultimately, the construction of a coherent mental representation of what the story is about. Nowadays, more and more 8-10 year-old children turn out to be poor comprehenders: they demonstrate text comprehension difficulties, despite proficiency in decoding and well developed low-level cognitive skills, like vocabulary knowledge. A few adaptive learning systems promote reading interventions, but not for poor comprehenders. The TERENCE EU project aims at building a learning system that adapts its learning material to the specific needs of poor comprehenders.

For creating the conceptual model of the TERENCE system, we first need to understand (1) who the end users are, and (2) what the learning material is.

This thesis first analyses and specifies the user requirements of poor comprehenders, both hearing and deaf, thereby laying the groundwork for building the ontologies of the conceptual model of TERENCE.

The main learning material of TERENCE will consist in illustrated stories, and interactive games for reasoning about the stories. The domain sub-model of the TERENCE conceptual mode structures this learning material. It is thus composed of two main ontologies: one for stories, the other for reasoning games. The *main objective of this thesis* is to start building the domain ontologies of the TERENCE adaptive learning system. To the best of our knowledge, our domain ontologies are the first pertaining to stories (story ontology) and reading interventions (game ontology) specific for poor comprehenders.

Our engineering of the domain ontologies meant analysing the following material: (1) concept schemes and concepts pertaining to text difficulty, mainly for the story ontology, and (2) several taxonomies of reading comprehension and reading interventions, mainly for the game ontology. The material and the resulting ontologies were assessed under the guidance of the respective domain experts.

Specifying the context of use and the requirements of poor comprehenders also help us shape the student model of the TERENCE system. This model is again realised as an ontology. This thesis concludes presenting the purposes, the expected format and sources (ontologies and not) for the student model, as well as its relations with the domain ontologies and the user requirements specified in this thesis.

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I dedicate this work to my grandfather Mihai, whom kindness for people and passion for work influenced my whole personality but who unfortunately could not see the ending of my thesis.

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Chapter 1

Introduction

Some men see things as they are and ask why
I dream things that never were and ask why not.
-*George Bernard Shaw* -

1.1 Motivations

According to [KvWL07], comprehension involves the interpretation of the information in the text, the use of prior knowledge to interpret this information and, ultimately, the construction of a coherent mental representation of what the text is about.

Developing good written text comprehension skills for children not only ensures a continuous process of maturation but also a positive social integration. In some cases, their attempts to read results in such a degree of discouragement and frustration that reading subtracts rather than adds to their lives [Cai09]. This is why early an identification and prevention of reading difficulties is important.

In stories, in particular, comprehension depends on correlating the narrated events, which can be introduced in different parts of the stories, in order to construct a coherent representation of the story's meaning. Relations between a story's events can be of different types: in particular, causal, temporal, spatial or their mixture. Appropriately interspersed connectives in stories, such as because, while, and after, and pictorial representations facilitate the construction of conceptual relations between events in a novice comprehender's representation of a texts meaning.

However finding stories and educational material that are appropriate for children with comprehension problems is a challenge, and educators are left alone in their daily interaction with them. A few adaptive learning systems promote reading interventions, but they have high-school or university textbooks as reading material, instead of stories, and are developed for old children or adults. The TERENCE adaptive learning system (An AdapTivE LeaRning SystE for ReasoNing about Stories with Poor Comprehenders) is part of a homonymous project that aims at filling such a gap. Its main goal is building a learning system that adapts its learning material to the specific needs of its end users.

1.2 Research Goals of This Thesis

The so-called conceptual model of an adaptive learning system is made up of three main sub-models:

- the student model for the student's main features,
- the domain model that structures the learning material,
- and the adaptation model that, given the previous models, characterises the actual adaptive mechanism.

Thus, for creating the conceptual model of the TERENCE system, we first need to understand (1) who the end users are, and (2) what the learning material is.

The end users of the TERENCE system are poor comprehenders, and their educators. Poor comprehenders are children that demonstrate text comprehension difficulties, despite proficiency in word decoding and well developed low-level cognitive skills like vocabulary knowledge.

The main learning material of TERENCE will consist in illustrated stories, and interactive games centred around inference-making questions for reasoning about the stories. The domain model, that structures this learning material, is composed of two main ontologies: one for stories, the other for reasoning games.

The *main objective of this thesis* is building the domain ontologies of the TERENCE adaptive learning system. To the best of our knowledge, our domain ontologies are the first pertaining to the reading comprehension of stories (story ontology) of poor comprehenders, and reading interventions (game ontology) for poor comprehenders.

The main purposes and uses of the domain ontologies of the TERENCE conceptual model are as follows:

1. analyzing and classifying stories and text-comprehension games for directing the end users (poor comprehenders) towards the most adequate class of stories or games;
2. eventually, using automated reasoners for additional knowledge discovery (e.g., new relations between story concepts) for experts of the domain and teachers.

In order to build the domain ontologies, we first need to analyse and specify the main difficulties of poor comprehenders with respect to story reading. This means specifying the context of use and requirements of the users of TERENCE. Such specifications will also help us structure the student model of the TERENCE system, which will be again realised as an ontology.

For developing the domain ontologies and laying the groundwork for building the student ontology, this thesis tackles the technical research questions explained in Table 1.1.

1.3 Thesis Structure

Chapter 2 explains in detail what adaptive learning systems are. It overviews the architecture and concentrates on the so-called conceptual model of the architecture. The chapter then explains

Students:	What are the requirements of the system's main end users (poor comprehenders, hearing and deaf)?
	What is the purpose of an ontology representation?
	What sources can we reuse from the literature for creating our student ontology?
	What its formalisation level?
Domain:	What are the linguistic and cognitive features of stories and games that are relevant according to our users' requirements? What are their relations?
	What is the purpose of an ontology representation?
	What sources can we reuse from the literature for creating our domain ontologies?
	What shall we keep or refine or enrich in the literature, according to our experts of the domain?
	What is the formalisation level of our ontologies?

Table 1.1: Specific research questions

why the main sub-models of the conceptual model are nowadays realised as ontologies. It then overviews what ontology engineering means, in brief, outlining the so-called ontology life-cycle.

Chapters 3 and 4 lay the groundwork for building the ontologies of the conceptual model of TERENCE. They analyse and specify the context of use and the requirements of the users of the TERENCE system.

Chapter 5 gives the domain ontologies of the conceptual model. It outlines their engineering. Then it explains in details their life-cycle, e.g., the main sources used in building the ontologies, whether these are part of the literature or part of investigations with experts of the domain and, in the latter case, how the investigations are conducted. The chapter only presents the key concepts and relations of the domain ontologies. These are available for inspection by contacting the author of this thesis.

Chapter 6 presents on-going work concerning the student ontology, and its relations with the domain ontologies and the user requirements of this thesis.

Chapter 7 sums up the main results of this thesis and its achievements with respect to the state of the art of ontology engineering for adaptive learning systems.

Chapter 2

Adaptive Learning Systems and Ontologies

It is not the strongest of the species that survives,
nor the most intelligent. It is the one
that is the most adaptable to change.
-Charles Galton Darwin-

2.1 Introduction

The previous chapter provided us with motivations for creating an adaptive learning system, without giving a clear account of what such a system is.

This chapter first introduces adaptive learning systems in general, presenting the related state of the art in Section 2.2. Then Section 2.3 explains the general conceptual model and architecture of such a sytem. Therein, we explain in details the main sub-models of the conceptual model, with a focus on their semantic web representation with ontologies. Therefore Section 2.4 briefly overviews the field of ontology engineering in the Semantic Web, presenting the ontology life cycle.

The terminology and the presented conceptualisation of the ontology life cycle are later on applied to structure and explain our ontology life cycle in Chapter 5.

2.2 Background on Adaptive Learning Systems

An Adaptive Learning System (ALS) is usually a web-based application program that provides a personalized learning environment for each learner, by adapting both the presentation and the navigation through the learning content ([RP05]). Such a learning environment can dynamically reorganize learning resources to meet specific learning objectives based on an individual learners profile or learning portfolio ([Bru01]). More specifically, it offers the potential to uniquely address the specific learning goals, prior knowledge and context of a learner to improve that learners satisfaction with the course and motivation to complete that course ([DWC05]).

Poor comprehenders can have problems on different linguistic levels. It is necessary to work on the individual needs of each child if we want to help him develop skills for a better reading comprehension. Even on some type of skills the level of achievement can differ, therefore a personalized access to information is needed. Implementing ALSs focused on reading comprehension seams a viable approach to improving children's reading comprehension [BM07].

2.3 Conceptual Model of an ALS

The conceptual model of an ALS, presented in Figure 2.1, is usually made up of models describing the student relevant information (*student model*), the repository of the learning material (*domain model*), the description of the user hardware/software capabilities (*environment model*), the inferential rules that, given the previous models, provide the actual adaptation (*adaptation model*), engines that actually personalize the learning process (*adaptation engine*).

In the following, we present each of the components of the system in details.

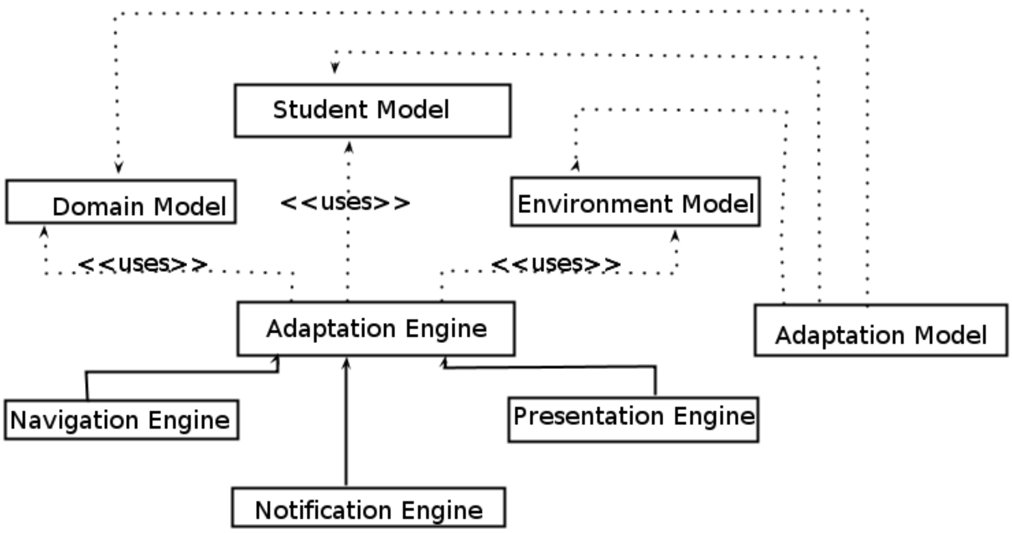


Figure 2.1: Adaptive system architecture. Source: [SAL+03].

2.3.1 Student Model

The range of features that are being considered to model the user for personalization is very wide. The main user features considered in the literature include the user's goals and tasks, knowledge, background and preferences, learning style, cultural facets, disabilities, background and experiences.

User individual traits, such as personality factors, cognitive factors and learning styles, started to gain attention in the research community[Bru01]. The modeling of this type of information depends on the system [SAL+03].

For example, IDEAL [SSsC01] is an intelligent agent-based environment for active learning. The system consists of a number of specialized agents with different expertise. Each student is assigned a unique Personal Agent that manages the student's personal profile (Student Model) including knowledge background, learning styles, interests, courses enrolled in, etc. The Course Agents manage course materials and course-specific teaching techniques for a course. At last, the Teacher Agent interacts with a student and serves as an intelligent tutor of a course. The basic components of a teaching agent are a domain expert module (it creates exercises and questions according to the student's background and learning status, provides solutions and explains the concepts and solutions to cope with student's misconceptions), a pedagogical module (it is a rule-based production system that uses the student model and pedagogical knowledge to determine the appropriate actions) and a student modeler (it provides a model of a student based on his/her learning style, knowledge background and interests).

There are various way to combine and represent features to create the user model. The basic format is a *vector of features* with the associated value (weight, 1–0 value, nominal value). In this category we can include the user background or the individual traits. A more complex representation is the *hierarchical representation* (tree or directed graph). This includes stereotyping (assign a stereotype to the user—included it in a classification class such as "beginner" or "expert") or domain structure (create an ontology of concepts and relations between the concepts). Other types of user modeling can include the usage data and knowledge derived from the usage data making use of logical reasoning or statistical models. For example in the AHA System [DADS02] the user profile consists of a set of records—with *key, value and firsttimeupdate* field.

The *firsttimeupdate* field is used to keep stable values after is set for the first time. The rule engines is an event-condition-action rules (described with a rule language in an XML format). This rules have associated some attributes which are trigger when they change.

Student Model with ontologies Recent research has focused on using Semantic web, mainly on personal definition of learning goals, synchronous and asynchronous communication and collaboration between learners and between professors [GDH+06]. Various systems and frameworks have been proposed in the literature [GDH+06]. We will be focusing on the ontological representation of the Student Model on the next paragraphs discussing USERML, GUMO, UserRDF, Grapple Statements.

1) UserML. UserML has been introduced in [Hec03] as user model exchange language. The idea of this approach is the division of user model dimensions into the three parts auxiliary, predicate and range as shown right below.

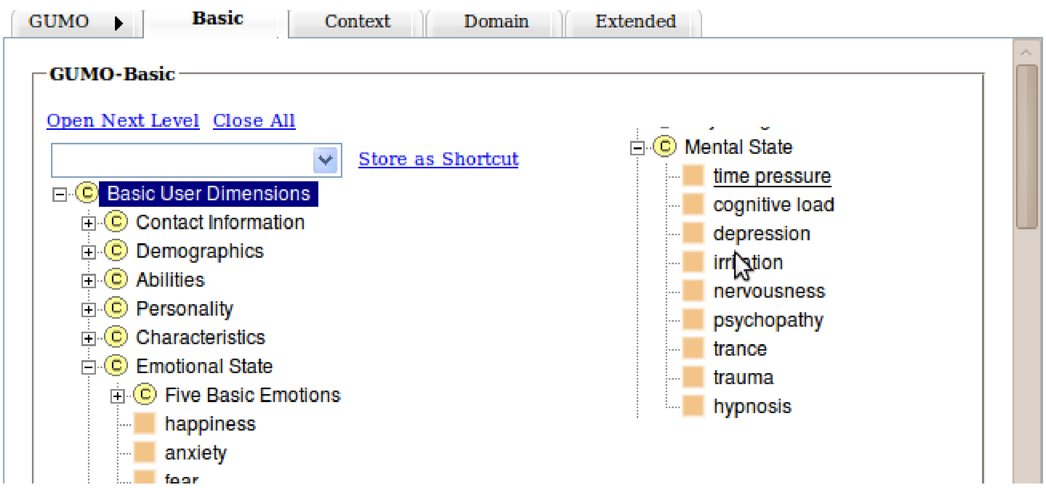
```
          subject UserModelDimension object
subject auxiliary, predicate, range object
```

For example, if one wants to say something about the user's interest in football, one could divide this so-called user model dimension into:

- the auxiliary part: has interest
- the predicate part: football
- the range part: low-medium-high

2) GUMO (General User Model Ontology). GUMO [HSB$^+$05] was designed according to the approach of dividing basic user model dimensions into triples (auxiliar, predicate, ranges). However, it turned out that actually everything can be a predicate for the auxiliary $hasInterest$ or $hasKnowledge$, what leads to a problem if one does not work modularized. The suggested solution is to identify basic user model dimensions on the one hand while leaving the more general world knowledge open for already existing other ontologies on the other hand, dividing GUMO in 4 parts (see Figure 2.2): GUMO-Basic contains user characteristics and personality traits, GUMO-Context models the environment around the user, GUMO-Domain with the general interest model and GUMO-Extended that contains the ranges, rating dimension and predicates that address other attribute such as Grapple Statements.

Figure 2.2: Screen-shot on $GUMOs$ user interface



In [HSBK05] presents the concept Physiological-State defined as owl:Class. It is defined as a subclass of $BasicUserDimensions$. A class defines a group of individuals that belong together because they share some properties. Classes can be organized in a specialization hierarchy using $rdfs : subClassOf$.

```
<owl:Class rdf:ID="PhysiologicalState.700016">
  <rdfs:label> Physiological State </rdfs:label>
  <rdfs:subClassOf rdf:resource="#BasicUserDimensions.700002" />
  <gumo:identifier> 700016 </gumo:identifier>
  <gumo:lexicon>state of body or bodily functions</gumo:lexicon>
  <gumo:privacy> high.640033 </gumo:privacy>
  <gumo:website rdf:resource="&GUMO;concept=700016" />
 </owl:Class>
```

Some short explanation of the elements of this class:

- rdf:ID - unique id for every concept
- gumo:privacy -default privacy for the class of user dimension

- gumo:expiry - qualitative time span of how long the statement is expected to be valid (e.g. emotional states hold normally no longer than 15 minutes, personality traits would not change within months). If we don't have new information we can work with old data.

3) Personal Reader: UserRDF. Personal Reader [HH04] uses UserRDF, an RDF-based language to model a user by statements, enriched with Metadata. The model is inspired by GUMO [HSB+05]. The properties besides the subject, predicate, object contain information such as the validity of the statement, the privacy of some statement, some further explanations (regarding the confidence and the trusting level) and as well administration properties (a statement can be replaced, declared or deleted - conceptually without physically deleting the statement) .

4) GrappleStatements[1]. GrappleStatements extend the statement idea mentioned in GUMO [HSB+05]. In the GRAPPLE User Modeling Framework (GUMF) a user profile consists of a set of statements, which are called Grapple Statements (or Grapple Statements or just statements). In a broad sense, Grapple statements can be considered as statements humans formulate in their everyday life. Examples of such statements in pure textual form are:

S1 := Mary likes chemistry
S2 := Mary does not like mathematics
S3 := Mary is color-blind
S4 := Peter is a good Java programmer (claimed by Mary)

The structure of a Grapple statement is presented bellow with elements that can be contained and some explanation taken from the deliverable D6.1a.

```
 <statement id=''081103-12A3B4243E''>
   <user> "POINTER to the ontology, denoting the learner" </user>
   <predicate> "POINTER to the ontology, denoting the attribute"</predicate>
   <object> "describing the value" </object>
   <level>"optional, a measurement for example in the knowledge can represent the level"</level>
   <creator> "who create the statement" </creator>
   <created> "when has the event been created </created>
   <what> optional, description of the type of event</what>
   <when> "optional, when is the statement valid" </when>
   <where> "optional, describes where the statement is valid" </where>
   <evidence> "optional, is there any evidence given" </evidence>
   <certainty> "optional, describes the uncertainty level of the statement"</certainty>
   <rating> "optional, if the statement has been rated by a community"</rating>
   <privacy> "optional, here possible privacy aspects can be stored" </privacy>
</statement>
```

We have discussed about modeling languages for the Student model. We will discuss now how we represent the transition from a novice student to an expert in some field - and how knowledge at the conceptual level could be represented.

[1]http://www.grapple-project.org/public-files/deliverables

Difference between Student and Expert. The Intelligent Tutoring Systems usually consist of a Student Model and an Expert Model. The Expert Model is used to provide explanation of the correct way to solve a problem[Van88]. Students should move from novice learners to expert learner, therefore the systems design them with the same knowledge representation language. The Student Model is represented as the expert model plus a collection of differences: misconception and missing conceptions. A misconception is an item that students have and experts don't have while the missing concepts is an item that experts have but students don't have.

The [Van88] distinguishes three types of representation of the difference between students and experts:

- Overlay Model: uses only the missing conceptions, the Student Model being a subset of Expert Model. Based on this idea [BG01] divides the Student Model in four layers:
  - Visited State - describes whether the user has already visited a unit;
  - Learner State - information on which exercises related to a particular unit the user has worked at and whether he/she successfully mastered them
  - Inferred State - layer describes whether a unit could be inferred as known via inference links from more advanced units the user already worked successfully
  - Known State, describes whether a unit has been marked by the learner as already known.
- Bug libraries: uses both misconceptions and missing conceptions. In addition the Student Model consist has a list of bugs that the Student may have. The way we obtain this bugs is done is by studying the specialized domain the students needs to become expert on and find the common errors.
- Bug part libraries: on this approach bugs are constructed during diagnosis rather than being predefined. Assuming we have conditions (conjunctions of predicates) and some actions trigged if the conditions are fulfilled . The predicates (assuming of cardinality P) and their actions come (of cardinality A) from predefined libraries. We can represent $A * 2^P$ distinct bugs.

This classification is necessary when we decide which of them suits best to the TERENCE model.

Some of the features of the user modeling. We will consider some of the features for the learning process.

- Knowledge. It is important to have a history of the familiarity of the user with some type of exercise (e.g. consistency checking of the story) in order to have a better understanding of what the student knows and what he might have lacks on.
- User goals and tasks. User goals and task are directly related with the skills we want to improve on some learner. They can be suggested by the system or by the teacher. Depending on the goal different exercise will be generated for the story.
- Background. This is mainly important for word recognition and for making inferences outside the text. For example when we read about a donkey we infer that it has four legs. Next chapter will focus on explaining the importance of background knowledge for reading comprehension.

2.3.2 Domain Model

The Domain Model is the repository for storing and structuring the learning contents and the overall knowledge on a particular domain: the concepts, relevant properties, requirements and goals.

2.3.3 Environment Model

The Environment Model includes a description of the capabilities of the hardware devices and software applications, used by the student in a particular learning session, useful for displaying the most appropriate for of resource to be delivered at each particular student equipment. This mean that the application should be adaptable on the device capabilities.

2.3.4 Adaptation Model

The Adaptation Model contains the specific inferential rules that define how the User Model, Domain Model, and Environment Model elements are combined to provide the actual adaptation.

2.3.5 Adaptation Engine

The Adaptation Engine is the software process that combines information from the Student, Domain and Environment models and the actual learner interaction with the system in order to personalize the learning process for appropriate learning experiences. It is guided by the rules described in the Adaptation Model. In essence, it is an inference engine, i.e. an automatic control mechanism that applies the axiomatic knowledge present in the knowledge base to arrive at some conclusion: the adequate learning contents to be delivered to the learner.

2.4 Ontology Engineering

Ontology engineering requires the definition and standardization of the ontology life cycle, ranging from requirements specification to maintenance, as well methodologies and techniques that drive an ontology's development. For the state of the art, we refer the reader to [Kee10], [CFGP03] and [CSFdC+08].

In particular, [KHSN08] sums up the methodologies for building ontologies around the three major stages of the ontology life cycle, i.e.,

1. building,
2. manipulating,
3. maintaining.

An example of how this methodology can be used is found in [LGPSS99].

2.4.1 Building Stage

In the building stage, four steps are needed: specification, conceptualization, formalization, and implementation.

1) Specification. This step is important and will direct the other activities, being the place where the main purposes should be defined. The following tasks are required at this stage:

- define the the objective of the ontologies (purpose) and the plan to get there (scope);
- define the types of users and the end users as well the type of uses;
- decide to reuse other ontologies and define the ontologies that will be used and the needed modification that match the purpose of the ontology; For example *Foundational ontologies* provide top level categorization can give a starting point in the development of the ontology by providing a basic structure. For types of ontologies that can be reused are explained in [Kee10];
- decide the architecture of the ontology (e.g., decide if the ontologies will be split into set of ontologies and how do they interact);
- decide the semantic reasoning: consistency checking, inference of new data, automatic classification, instances classification and subsumption reasoning;
- for further characteristics [MGGCGPS09] defines 32 features that characterize large-scale semantic applications. These features are connected with the design of the ontologies as well. For example the degree on which a part or the whole set of ontologies will constantly change during the application execution time or if they will not experiment any change during the execution time influences the way the architecture of ontologies will be constructed. Other features that influences ontology design depend on if the application will deal with contradictory data, uncertainty for reasoning, or will inter operate with other external applications.

2) Conceptualization. This step includes extracting terms and categorizing them in a intermediate representation. This step requires the use of different resources to collect these terms, for example, experts, books, handbooks, tables, other ontologies, text analysis, interviews, and so forth. Seed terms should be refined after extraction and conceptualized into groups.

This step requires the choice of one of the following three main approaches: bottom up approach, top down approach and middle out approach, see [UGUG96].

- A *bottom up approach* occurs when developers need to develop part of the ontology from sources different than ontologies, e.g., thesauri, lexicons, experts' verbal or non-verbal knowledge. Such an approach may produce ontologies with very high level of details. It can increase the effort and the risk of inconsistency.
- A *top down approach* means reusing existing ontologies, choosing and imposing arbitrary high level categories. This may increase stability.
- A *middle out approach* is a mixture of the above two approaches. It makes it easier to spot common terms, reach stable and agreed models, as well as keep the level of detail under control.

3) Formalization. Formalization reduces ambiguity. At the same time, informal specification may be preferred for human communication purposes. Depending of the already taken decisions (e.g., purpose of ontology) there are four levels of ontology formalization [KHSN08]:

- highly informal: expressed loosely in natural language or informal drawing, mind maps or UML;
- structured informal: expressed in a restricted and structured form of natural language;
- semiformal: expressed in an artificial formally defined language. The language can have a formal semantics, just like the "rigorously formal". It may happen that one does not use all of the language's expressiveness. For example, this is the case if one formalises a taxonomy in an OWL language, with which one can later on represent much more of the subject domain semantics;
- rigorously formal: meticulously defined terms with a formal semantics, theorems, and proofs of such properties as soundness and completeness.

4) Implementation. Ontology implementation means determining the technology that will be used to implement the ontology and integrate the new ontology with existing ones. Ontology implementation should provide systemic tools that meet the ontology's purposes. Users should be able to browse, search, and evaluate an ontology.

2.4.2 Manipulation Stage

In the manipulation stage, an ontology query language should be provided for browsing and searching, efficient lattice operation, and domain-specific operations.

2.4.3 Maintenance Stage

In the maintenance part, developers should be able to syntactically and lexically analyze the ontology by adding, removing, and modifying definitions, and also should be able to translate from one language to another. Ontologies should be built with different levels of generality. This means that different types of updating mechanisms should be provided. The rate of change in very abstract ontologies tends to be small.

Chapter 3

Context of Use

For me context is the key -
from that comes the understanding of everything.
-Kenneth Noland -

3.1 Introduction

Reading comprehension involves understanding the words on the page, computing the sense of each sentence, and even more. Deciding on what "even more" pertains to reading comprehension means choosing a model of reading in the literature of psycho-linguistics.

This chapter starts with an overview Section 3.2: this reports on the main models of reading comprehension as in Subsection 3.2.1, and continues with two taxonomies of reading comprehension for teachers as in Subsection 3.2.2.

Section 3.3 presents experimental methods studied by cognitive psychologists to investigate and detect poor comprehension.

Section 3.4 is a critical overview of existing strategies and interventions for improving the reading comprehension.

Section 3.5 concludes the chapter with readability metrics, factors and concepts relevant for measuring different levels of text difficulty, studied in the psycho-linguistics literature.

3.2 Reading Comprehension

In the following we will introduce what are the concepts involved in reading comprehension, by first presenting a simplified version of comprehension. We continue by presenting an inference centered model of reading comprehension and two taxonomies of reading comprehension for developing reading instructions.

3.2.1 Reading Comprehension in a Nutshell

The Simplified View of Reading Comprehension.

According to the so-called simple view of reading proposed in [PW86], reading comprehension consists of two related processes, namely, decoding and linguistic comprehension.

- *Decoding* is the ability of applying one's knowledge of letter-sound relations, including knowledge of letter patterns, in order to correctly pronounce and recognize written words. Decoding involves the integration of the following sub-skills:
  - orthography comprehension: the correct way of using a specific writing system (e.g. capitalization, punctuation, spelling, hyphenation),
  - phonology comprehension: the systematic use of sound to encode meaning in any spoken human language.
- *Linguistic comprehension* is defined as the capability of understanding the meaning of the entire text.

Both decoding and linguistic comprehension are necessary for achieving reading comprehension. However, according to several authors (e.g., see [OCP03a]), reading comprehension is more complex a phenomenon. It involves the construction of a coherent mental representation of the narrated events, which means being able to infer relations between the narrated events (e.g., causal, spatial, temporal) [Zwa99]. In the following, we present a more refined model of reading comprehension, focusing on inference making.

An Inference Centered Model of Reading Comprehension

The comprehension processes occur at multiple levels across units of language: word level (lexical processes), sentence level (syntactic processes), and text level (discourse processes). Across such levels, processes of word identification, parsing, and a variety of inference processes all contribute, interacting with the reader's conceptual knowledge, in order to produce a coherent mental model of the read text. [PLO05] presents a refined cognitive architecture of the processes of reading comprehension, centered around inference making. Figure 3.1 presents such an architecture in details. As we can notice the notion that involve the reading comprehension at the form level and meaning level are interconnected. The coexistence of this processes involves that it will be difficult to separate this processes. The decoding process will be followed by the identification of the word meaning, but this word meaning identification could change once we have identified other words, depending on the context.

In addition to that, in order to generate a successful reading comprehension, [MR92] adds that the reader makes inferences on the read text by stimulating two levels of coherence:

- *local coherence*, involves pieces of explicitly stated information that are close together in a text. These propositions of a text are in the working memory at the same time.
- *global coherence*, involves pieces of information that are so widely separated in the text that it is clear they could not be in short term memory at the same time (without retrieval from long term memory)

Because the two definition are very general and do not offer too much specific information regarding the metric for making the classification, we need to find some concrete concepts and metrics to represent these notions, as we will further develop.

Example 1 *In the following text S1 and S2 relations build a local coherence (the cause of prince's happiness), while S1 and Sn gives global coherence relation (*S1 *explains how in Sn the prince could fly).*

- *S1: The prince received a golden ring that gives him the ability to fly.*
- *S2: Therefore he was happy.*
- *...*
- *Sn: When lion wanted to attack him, the prince flu far away.*

3.2.2 Taxonomies of Reading Comprehension

A Coarse Taxonomy for Reading Comprehension

[DsP05] proposed six concepts related to reading comprehension, and accompanying questions. In the authors' intentions, such concepts and questions could be used by teachers for developing reading strategies and specific interventions. We outline them in the following and comment on them below.

- *Literal comprehension* amounts to the understanding of the literal meaning of the text, such explicitly stated dates and locations. Questions pertaining to literal comprehension can then be answered by a sort of pattern-matching process with the text. Such questions are usually used to see if the students understand the basic meaning of the text.

  Example 2 *If a text states "The accident occurred in January 1923" then a literal comprehension question may be "When did the accident occur?".*

- *Reorganization.* Students must use information from various parts of the text and combine them. Questions that address this type of comprehension are important because they teach students to examine the text in its entirety, helping them move from a sentence-by-sentence reading for achieving local coherence, to a more global reading for achieving global coherence. For example user might read at the beginning of a text that a king named John Kim was born in 1945 and then later at the end of the text that he died in 1990. In order to answer the question "How old was John Kim when he died?" the student has to put together two pieces of information that are from different parts of the text.

- *Event based Inferences* According to [MR92] inference is any piece of information that is not explicitly stated in text. We will see further a taxonomy of inferences that we will consider in defining our Domain Model. Usually questions pertaining to inferences on events relates to the temporal, clausal or spatial features of events or their relations.

- *Prediction* means determining what might happen in the future that should be consistent with present information.

- *Evaluation* requires that the learner gives a global or comprehensive judgment about some aspect of the text.
- *Personal response.* Readers needs to activate their personal knowledge. Answers are not found in the text; they come strictly from the readers.

Such a conceptualization has ambiguities and, matter of fact, no clear taxonomic structure. For example, *reorganization* should be related to *event based inferences*: for being able to coherently reorganize the read information, the reader needs to make inferences, like in our example above with temporal relations between events presented in the Reorganization concept. Moreover, there is no clear distinction between *prediction* and *evaluation*, or *inference* and *evaluation*.

A Fine-grained Taxonomy of Reading Comprehension Focusing on Inferences

Inferences involve generating links between parts of the texts that are not given explicitly and use our personal knowledge to fill the missing detail in order to construct an adequate, appropriate, and coherent representation of the text. To the best of our knowledge, the most fine-grained taxonomy of inference-making for reading comprehension is presented in [Chi92], built by refining existing taxonomies from the literature. In the author's intentions, teachers can asses the degree to which questions in the students reading material, accompanying manual or handbooks are distributed over each concept of the taxonomy.

In order to understand this, we first need to understand the proposed connection between questions and responses. There are three types of relations between questions and responses, explained as follows.

- *Textually explicit*: the responses are right there in the text.
- *Textually implicit*: both question and answer are present in the text but at least one step of logical inference is necessary to justify the answer.
- *Scriptural implicit*: the question is derived from the text but the answer is not. The user has to use his script or schema, combining information from the text and some background knowledge.

These 3 types of relation from the way they are presented by [Chi92] we consider that can be correlated with other concepts that we have already presented. For example the textually implicit relation requires the use of literal comprehension skills because no inferences in required in order to retrieve the answer of the question while for the other two relation the inference skills are required.

The three upper concepts of the taxonomy are then: lexical, propositional, and pragmatic or scriptural inferences.

1. *Lexical inferences* can be both textually implicit or scriptural implicit. The main sub-concepts are pronominal inferences and ambiguous words, explained as follows.
   (a) *Pronominal inferences (a.k.a., pronominal anaphoric resolution)*, that is, the reader is asked to infer (resolve) the referents of the pronouns.
   (b) *Ambiguous/unfamiliar word meaning*, that is, infer the meaning of unfamiliar lexical items. The reader should search in the surrounding environment for clues.

2. *Propositional inferences (a.k.a., logical inferences)* are derived from the semantic content of the text, and are textually implicit. The main components are as follows:

   (a) *Logic information inferences* ask the reader to determine the main features of an event, namely, actors, instruments, objects, time, place. In other words, inferring logical information means answering the questions "Who?", "What?", "Where?", "When?". Such a concept is further subdivided in:

      i. *referential inferences*, that is, the reader needs to specify the related antecedent of a given action, clarifying the role of objects and people of the action;

      ii. *spatio-temporal inferences*, that is, the reader is asked to locate events and actions in place and time.

   (b) *Logic explanatory inferences* means providing the intentions of the characters, as well as the causes and consequences of events, and conditions that enables the events to occur. Inferring explanatory information means answering questions of the form "Why?" and "How?". Such a concept is further subdivided as follows.

      i. *Motivational inferences* are performed when inferring the causes for a character's voluntary actions, thoughts and feelings. For instance, let us consider "Mutina arose early in the morning. After dressing, she had her breakfast and then went to the nearby market." A motivational question would be "Why did Mutina get up early?".

      ii. *Causative inferences* are like motivational inferences, except that they involve inferring the causes or consequences of events and states given in the text.

      iii. *Enablement inferences* involve inferring the conditions necessary for given events to take place.

3. *Pragmatic inferences* are concerned with information of what is outside of what is actually stated in the text, that is from the reader's store of prior knowledge, hence the related questions are considered to be scriptural implicit. There are three types of inferences that are considered to be pragmatics.

   (a) *Elaborative Informational*, splits as follows:

      i. *Referential*, like in "She is drawing a mouse" and "What instrument is she using?"; the possible answer is not in the text, albeit the reader can appeal to his background knowledge and infer that she can use a pencil, crayon or pen because she is drawing and not painting;

      ii. *Spatio-temporal* like in "John was skating" and "What season do you think it is?",

   (b) *Elaborative Explanatory*, splits as follows:

      i. *Motivational* like in "Carol watches cartoons" and "Why do you think that she is watching the cartoons?".

      ii. *Causative* like "A lot of plants start to disappear" and "Why do you think this happens?".

      iii. *Enablement* like in "He had only a piece of paper. He could not write" and "What else does he need in order to write?".

   (c) *Evaluative*, which amounts to assessing the significance, normality, morality and validity of events, characters, actions specified within the text. For instance, consider "He should have studied too much for the exam so he did not go to attend it" and the question "Do you think he has acted correctly by not presenting himself to the test?".

What makes the difference between logic and pragmatic inferences is the place where the information can be found: in the case of pragmatic inferences, the reader derives the answer from his/her knowledge (the response is not stated in text). In the above classification we have the logical and the pragmatic inferences to be different influenced by the background knowledge. But how this background knowledge should be controlled is still and open question. In the presented model it is controlled at the level of inferences but this sees difficult because of the complexity of the notion of background knowledge. Different type of knowledge can be fired while reading: linguistic knowledge or common knowledge of the world facts. Our ASL should somehow monitor the amount of common knowledge needed for drawing inferences concerning events of the story. Some other approach on storing the common knowledge it can be done at the level of of story genre e.g., fantasy stories are likely to require less common knowledge than historical stories. In the evaluation phase, users' previous topic/genre knowledge and background knowledge should be assessed.

Because the three inferential concept are not disjoint it makes this classification difficult to measure. For example in a sentence that require the fire of 3 different inferences it raises the question which will be considered more important, and what probability will be considered if the child does not give the right answer (the cause was the lack of which comprehension skill). A solution for this is training the system with equal probabilities and then to adjust this probabilities influenced by the further answer given by the child, or mistakes made by child [LMAC97]. Still we consider that is we further lower the inferential classes then the accuracy of the future classification will be higher. Therefore an approach to reading comprehension classification can be the the following: literal, bridging, and elaborative.

3.3 Experimental Methods for Detecting Poor Reading Comprehension

[OC07] presents the three methods studied in cognitive psychology to explore variables that are causally involved in poor comprehension. We explain them in the following.

- *Comprehension–age match (CAM) design.* This method require the presence of three groups of participants: (a) good comprehenders and (b) poor comprehenders, who are matched in age and single-word reading ability, and (c)an additional group of younger (CAM group), normally developing comprehenders. This younger group is selected so that their comprehension skill is at the same absolute level as that of the older poor comprehenders but is normal for their age. If the younger group performs better on some task known to differentiate between good and poor comprehenders (e.g., ability to draw inferences from text), this difference cannot be a product of the two groups comprehension levels, because the CAM group and the poor comprehenders are matched on absolute level of comprehension skill. This is why the difference is associated with the cause of the poor comprehenders delay. This is, of course, a strong test, because the CAM group is necessarily composed of younger children who have poorer word reading skills than the poor comprehenders.

- *Longitudinal Studies.* Authors state that "This studies measure sets of skills and abilities at different time points and then to assess whether some variables are better predictors of later comprehension skill than are others and particular (early) variables are better predictors of comprehension skill across time than (early) comprehension skill is a predictor of that variable. "

- *Training Studies.* If a group trained on some skill this is a candidate cause of good comprehension improves on a standardized measure of comprehension more than a control group not trained on that specific skill (but given some other training of a comparable duration), then it is assumed that the trained skill is causally implicated in the improvement in comprehension. For example, if training poor comprehenders to make inferences not only improved their inference making ability but also led to greater gains in their overall reading comprehension skill compared with a group of good comprehenders, one might assume that inference-making deficits were the cause of the poor comprehenders' reading comprehension problems.

The methods presented in the paper did not offer some metrics for their measurements or concrete examples. A further investigation is needed in case we want to explore and integrate this into our system. As well a further research needs to be done regarding which of this method is best for automatizing and TERENCE goal.

3.4 Strategies for Improving Reading Comprehension

Previous section has focused on defining the concepts/processed involved on reading comprehension to define a terminology. But having a successful reading comprehension for poor comprehenders requires training of the readers on different levels of the mentioned processes, sometimes having interconnections. For example readers may not generate deep-level inferences unless they have an appropriate comprehension goal [MO09].

This section will define and enumerate the reading strategies that the literature mention and try to define the relations and between this strategies. The section starts with defining what a reading comprehension strategy is. Then it overviews general reading comprehension strategies so far implemented in the cognitive and educational fields at a macro and micro-level of text analysis.

3.4.1 What a Reading Comprehension Strategy Is

A reading comprehension strategy is succession of cognitive or behavioral actions that is performed under particular contextual conditions, with the goal of improving some aspect of reading comprehension. Therefore it is important that we construct well designed reading comprehension interventions, crafted around well defined reading comprehension strategies.

[Gra07] represents strategies using Algorithm 3.1.

Algorithm 3.1 Format proposed by [Gra07] for representing reading comprehension strategies

```
if conditionStates then
  actionsSequences
end if
```

The production rule formalism helps researchers (and potentially teachers) keep track of the details of the strategies and develop suitable reading comprehension interventions.

Consider a very simple-minded intervention for purposes of illustration.

Example 3 *When a teacher asks the student to look for up a word in a dictionary when they encounter a rare word with which they are unfamiliar.*

- *The context: a word in the text that has low frequency or (more generally) is not in the reader's mental lexicon*
- *Strategic behavioral action: to hunt for a dictionary and to locate the word in the dictionary*
- *The strategic cognitive actions: to read the word's definition*

Algorithm 3.2 Dictionary Artifact Strategy

```
if word W is infrequent OR Reader does not know meaning of word W then
  reader gets dictionary
  reader looks up word W
  reader reads dictionary definition
  reader rereads sentence with W
  reader attempts to comprehend sentence as a whole
end if
```

According to [Gra07] there are two types of strategies defining the conditional states:

- objectively, e.g. the word is rare in the English language. These definitions are needed when building some computer technologies, as in the case of a computer tutor that asks the reader whether he or she knows the meaning of low-frequency words;
- subjectively, e.g. the reader has never encountered the word before. These definitions are needed when training students on self-regulating their application of meta-comprehension strategies.

Other examples of strategies found in [Gra07] are:

Algorithm 3.3 Contextual Word Definition Strategy

```
if word W is infrequent OR Reader does not know meaning of word W then
  reader rereads previous text for definitional clauses
  reader reads subsequent text for definitional clauses
  reader rereads sentence with W
  reader attempts to comprehend sentence as a whole
end if
```

Algorithm 3.4 Character Motive Strategy

```
if clause N states that character C performs action A then
  (1) reader retrieves from memory motives that explain A OR (2) reader rereads prior text for
  clauses with motives that explain A OR (3) reader constructs inferences from analogous prior
  experiences with motives that explain A
end if
```

We have not found in the literature a well defined distinction between intervention and strategy, some papers using the concept of reading comprehension strategy for the reading comprehension intervention concept and others the other way around. Some literature uses new concepts such as "big idea" and "objective" for strategy and intervention [BCIS07].

3.4.2 Overview of Effective Reading Comprehension Strategies

Reading strategies found in the literature are given as general advices without having a specific strategy for certain lack of comprehension or some schedule of applying some strategy before another. As well is unclear when the teacher should switch strategies or use them combined. This open question are very important if we want to teach children to activate automatically some strategies depending on the context and their reading goals.

A meta-analysis conducted by the US National Reading Panel (2000) over viewed more than 200 reading strategies for effectively improving reading comprehension, and clustered them as follows.

- *Decoding.* [LS74] analysis made clear that it was critical for children to develop fluency in word recognition. Fluent (i.e., automatic) word recognition consumes little cognitive capacity, freeing up the child's cognitive capacity for understanding what is read. The more effort required, the less consciousness left over for other cognitive operations, including comprehension of the words being sounded out.

  Thus, a first recommendation to educators who want to improve students comprehension skills is to teach them to decode well. Explicit instruction in sounding out words, which has been so well validated as helping many children to recognize words more certainly, is a start in developing good comprehenders- but it is just a start. Word-recognition skills must be developed to the point of fluency if comprehension benefits are to be maximized [Pre00].

- *Comprehension Monitoring.* [Cai09], [FLFB06], [McN04] mention self-monitoring techniques to assess understanding of text. Readers think what to do when they do not understand (their self questions could be: "Is this making sense?" "Should I slow down/ speed up?", "What does this word means?" "What text clues help me fill the missing information?"). If children have trouble understanding specific words, phrases, or longer passages, they use a wide range of problem-solving strategies including skipping ahead, rereading, asking questions, using a dictionary, and reading the passage aloud.

- *Synthesizing* in which students essentially attempt to activate background knowledge. Connecting children with their prior knowledge helps them personalize the information. It also helps them remember information easily when thy link it to their live. (e.g.: Is this subject familiar? Is this style or genre familiar? Does this remind you of other tells of other tells you have read?). In [rea10b] children choose a personality, write what they know about it and then learn new things about it. At the end they need to create a poster by incorporating their background knowledge with he new knowledge they have acquired, by choosing from a list of different characteristics of this personality.

- *Cooperative learning* means working with peers to support one another's understanding and use of strategies.

- *Visualizing* [rea10c] means forming a picture of the character, environment mentally and trying to describe it either by full text or just by presenting list of adjectives, nouns, verbs. Many children think visually, using shapes, spatial relationships, movement, and colors, and can benefit greatly from visualizing what is happening as they read. For children who may have lack of this skill, graphical aids and semantic organizers, like diagrams, may be of help to encourage the student to create his own image before representing one. In [rea10b], the authors propose that the window of the application to be divided in two parts. One with the written story and one with a board where children can drag and drop images to create the scene of what the reading passage is about. At the end children can visualize the movie of their writing. But regarding the automatic solving detecting if the child has understood correctly the story by using visualization is still more to go.

- *Story Structure*, that is, focusing in on the plot, characters and events in stories and main ideas in paragraphs.

- *Questioning* [rea10c], that is, posing and answering questions during reading to monitor comprehension of a text and integrate meaning. Children should be stimulated to create question when they feel something is not comprehensive or they are curious about something and as well they should write down the answer in case they get the clear image. Many children do not understand where to find the answers to the questions they are asked. They need to know that some questions can be answered by looking in one specific place within a book, while others are answered by taking information from several places often spread over several pages. Some questions require combining text information with personal knowledge and experience, while others rely on the personal knowledge of the reader. Children must be helped to decide on the type of question (for example detecting that some information cannot be inferred from the text) and where the answer can be found (for example children should select the paragraphs where the answer can be found and combined without giving the exact answer). Question should be asked or created before, during and after reading [rea10b]. Regarding the automatizing of this strategy [Gat08] presents how some NLP tools can be used to develop fact based WH-questions use in reading process with an acceptable generation achieving 81%. The same author concludes that the presence of the human input is still required to weed out ungrammatical questions and pragmatically poor questions.

  - *Inferential Questions* [McN04] good readers connect what they know with what they are reading, regarding actions, character's feelings, detecting inconsistencies. This mean that the strategies for reading comprehension would stimulate them to do so.(ex: What does that mean?, Why?).
  - *Prediction Questions* [rea10c], [McN04], [rea10a]. Ask question that will anticipate the content subsequent text, either by guessing what is coming next or by reminding themselves to watch out for some particular item that will aid comprehension. This strategy is usually used before reading some paragraph.

- *Vocabulary study*: explicit teaching of vocabulary development that facilitates student understanding of concepts, as opposed to surface level memorization. This can be done by presenting a word in different contexts having associated images and fragments of text.

- *Summarizing* [McN04]: identifying and integrating the most important points to create a coherent and succinct summary of a text. Summarizing clears up languages issues but as well detect inconsistencies between what children understand and what is the truth. In [rea10b] the child drags expression from a given text on some board. After selecting the main ideas the child has to express in his own words the story. On one side he will have the dragged ideas and on the other side a board where he can write. The dragged ideas can be easily automated by the machine but the summary should be verified by hand by the tutors because the NLP is not that developed to offer a good evaluation of the children's summary.

- *Paraphrasing* ([rea10c], [McN04]) essentially helps students remember the surface structure of the text by transforming it into more familiar ideas and challenge them for complete retention and as well to stimulate other strategies.

- *Grammar training*: use of morpho-syntax assessments as part of a protocol to identify children who might be at risk for later reading comprehension difficulties [Adl09].

- *Elaborations and Making Connection* [McN04], [rea10a]): associate the current sentence with their own related prior knowledge). In [rea10b] children have to choose what is more relevant sentence from a list of sentences that matches best to understand a text. From our point of view connections are sometimes tricky. For example the children need to associate that "Cinderella always wore rags, but one night she got to wear a ball gown" with " The caterpillar build a cocoon which opens a butterfly" because both Cinderella and butterfly transformed to something beautiful. This type of exercise can be made automatically on analyze but the generation of exercises requires a manual check and creation because it requires a deep analysis regarding the general knowledge of the children.
- *Evaluating* is used to see if children can make judgment regarding some text. [rea10b] ask children to choose some properties of some books and then they have to analyze some books and rate them based on their chosen criteria. This type of analysis of the exercises can be made automatically.
- *Combining Strategies*: [rea10b] suggests that children should be able to understand what strategy they used when they understood some part of the text.

A Reading Comprehension Questions Taxonomy

This section has focused on presenting general concepts of strategies without focusing on types of games or question that can enable readers improve these strategies. In the following we focus on a presenting a taxonomy of reading comprehension questions. In [LMAC97] a taxonomy of the types of question is given. This is composed into 2 main components.

1. *Micro-information*: questions can be answered by understanding or recognizing only specific sentences, phrases, or key words of the text. For this task the reader depends on his linguistic schemata (vocabulary and grammar). The reader must be able to group words together to form meaningful phrases and recognize syntactic relationships. The reader does not necessarily have to read or understand the entire text but must be able to identify those parts of the reading referred to in the questions. The authors suggest a bottom-up processing to be used. The questions included here are related with
   - Vocabulary-determine meaning from context
   - Determine referents (anaphora)
   - Select appropriate connector or usage of a given connector
   - Restate or paraphrase specific information
   - Answer factual questions
   - Recognize definitions
   - Recognize comparison-contrast relationships
   - Recognize classification
   - Recognize sequence (process and chronology)
   - Recognize cause-effect
   - Recognize fact-hypothesis
   - Recognize description
   - Identify function of a text

2. *Macro-information* the reader must read the entire text and integrate information found in different parts of the reading. In order to do this, he must draw upon his formal and content schemata. The authors suggest a top-down processing that include question to:

   - Analyze: the reader must examine and relate information which is explicitly present in different sections of the text
     - Organize sentences
     - Transcode information from text to graph or diagram
     - Verbalize from graph
     - Compare ideas in two texts
     - Recognize textual inconsistencies
     - Identify progression of text
     - Draw conclusion and/or deduction from explicit information
     - Predict from explicit information
   - Interpret: needs to interpret the information from the text
     - Recognize main idea or topic sentence
     - Recognize author's purpose
     - Choose appropriate title
     - Identify source and/or type of text
     - Identify intended audience
     - Recognize tone of author
     - Recognize opinion of author
     - Draw conclusions and/or inferences from implicit information
     - Infer what preceded
     - Predict what follows from implicit information
     - Make analogy between information in passage and new situation

After presenting the strategies and interventions the need of metrics for measuring the level of the reading toward some reading is required. Approaches for expressing these are presented for example in [LlCM10]. They introduce 4 Levels of Understanding and Associated Student Errors for Reading. At the lowest level of error of comprehension "making errors that reflect focus on decoding and retrieving facts or details that are not necessarily related to the text or item". We have observed that these levels are not completely disjoint. Still the idea of creating levels of misunderstanding can be used in the development of TERENCE. Next section will present more in detail the measurements of text comprehension.

3.5 Text Difficulty: Concepts and Metrics

In this section, we concentrate on ways of measuring the readability of texts devised by linguists and psychologists, in general.

Section 3.5.1 focuses on describing the factors that determine the difficulty of a text. Having determined these factors, we can present and comment on current readability formulas, as in Section 3.5.2. These are mathematical equations that take into account vocabulary difficulty and sentence complexity. In this manner, they can assign a grade level to a text.

In recent years, however, readability formulas were severely criticized. New approaches focusing on coherency were born. We present one the most general and recent, namely Coh-metrix, in Section 3.5.3.

3.5.1 Factors Influencing Text Difficulty and Accessibility

Factors that influence text difficulty and accessibility are summed up in [GG03]. They are divided into two groups.

In the first group there are six factors that are fairly easily defined, fairly easily identified, and largely inherent in the text itself. Of course, since reading is an interactive process that involves both the reader and the text, no text factors are fully independent of the reader.

In the second group are four factors that are less easily defined, less easily identified, and very definitely involve both the reader and the text.

Objective factors

1) Vocabulary. The authors sustain that vocabulary is an excellent predictor of difficulty because vocabulary reflects difficulty; a difficult or unfamiliar topic frequently needs to be conveyed using the difficult and unfamiliar vocabulary that is inherent to the topic. Because of this, simply replacing difficult words with easier ones may do little to simplify a text; in fact, it can even make a text more difficult. But wide reading in texts that include varied and novel words is the main route to vocabulary growth.

2) Sentence Structure. Very long, very complex, and certainly very convoluted sentences make texts more difficult to read. At the same time, texts that employ artificially short sentences, the sort sometimes written for beginning or remedial readers, do not have the sound of real language.

3) Length. Authors state that length can be an obstacle for students who do not read fluently. Additionally, it give references that shown that in some cases shorter texts summaries or much reduced versions of complete texts can actually produce better comprehension and memory than longer ones. However shorter is not always better. In making a point, giving verbal illustrations and examples is often useful. And, of course, giving illustrations and examples increases the length of a piece.

4) Elaboration refers to a certain sort of explanatory material. Elaboration makes information more meaningful and understandable, and information that is more understandable is more memorable. Authors give example of students who read the statements that are not elaborated. These students could answer almost no questions, while those who read the elaborated text could answer nearly all of them. However, as we noted above, shorter texts sometimes produce better comprehension and memory than longer ones. The matter of just when elaborations help and when they hinder is not yet resolved. It appears to be the case, though, that shorter texts may be more effective if the goal is simply to remember material, while elaborated texts may be more effective if one needs to thoroughly understand material for practice.

5) Coherence and Unity. Coherence refers to the integration of material, to how each topic and subtopic is defined and to how well the parts relate to each other. With young and inexperienced readers and with material that is unfamiliar to students, it is particularly important. Authors cite the following guidelines for creating coherent text: (a) making implicit referents explicit, (b) repeating a linking word from the previous sentence, (c) using the same terms for the same concepts, and (d) constructing sentences in keeping with the given-new format,(e) arranging text events in temporal order, (f) making implicit goals explicit, and (g) repairing coherence breaks caused by inadequate explanations, multiple causality, or distant causal relationships.

6) Text Structure. The majority of texts students encounter in school can be categorized as belonging to one of two broad categories, narratives or exposition, organized very differently. Typical narratives, more frequently used for children, reflect the temporal order of real life events in which motives, actions, results, and reactions occur in sequence, and episodes in the main character's life are integrated by goals and subgoals. Time thus provides a natural structure for remembering episodic information.

Exposition, seen as more difficult, is another matter. Expository text, even well written expository texts, can have a variety of organizations, and different authors have created different lists of the organizational patterns of expository writing authors frequently employed weak rhetorical patterns such as lists or simply presented material without any apparent pattern. Additionally, the texts employed few effective functional devices to aid the reader. One needs expository texts that are clearly organized and that make that organization apparent to the reader, and it appears that many of the expository texts used in schools fail to meet these criteria.

Subjective factors

7)Familiarity of Content and Background Knowledge. Reading a selection on a topic for which we have little familiarity is difficult. Of course, children read a great deal besides experience stories, but much of this material contains familiar content. These commonalities result in a good deal of familiar content in most short stories and novels. Not only must the reader have some familiarity with the contents of a selection, he or she must also have the background knowledge assumed by the author. In some cases, the general knowledge that one picks up from day-to-day living is sufficient. However, many humanities and social science texts also require extensive background knowledge for comprehension and thus pose problems for some students.

8) Audience Appropriateness. Obviously, the topic of a selection and the sophistication with which the topic is treated need to be appropriate for the students reading the selection. How can we determine if the poor comprehenders will appreciate it, relate to it, or be interested in it is an open question.

9) Quality and Verve of the Writing. In addition to the factors that have been presented thus far, one must consider the quality of the writing, the flair of the writing, the particular blend of topic, organization, and style that makes one piece of writing intriguing and memorable and another piece dull. The author recommend the modification of textbook passages by giving them "voice" which significantly can increase comprehension of the passages. Other recommendations include making text situations more dynamic, making the language more conversational, and highlight connections between the reader and the text and as well a clearly of writing.

10) Interestingness is likely to be the most subjective factor and the factor most dependent on the reader. Texts with material a child finds interesting as an integral part of their makeup are likely to facilitate comprehension, while texts in which the interesting material is an add on are likely to impede comprehension. This means to meet the children's interest.

3.5.2 Standard Readability Formulas

Previous chapter has mentioned the factors that influence comprehension but it did not offer any metrics of the level of difficulty, just some qualitative instances. This section offers quantitative factors of readability, mainly readability formulas. [Kla75] offers details on different readability indices[1]. These measurements help recommending a story to a child. Consider the following measures:

ASL = average sentence length (the number of words divided by the number of sentences);

ASW = average number of syllables per word (the number of syllables divided by the number of words);

PDW = Percentage of Difficult Words (PDW) (divide number words in text that are not in Spache Revised Word List / total number of words)*100;

DS = Dale Score, of words not on Dale-Chall list of 3,000 common words.

Given the above measures, we can define the following readability formulas.

1) Flesch Reading Ease (FRE) ([Fou77].) The output of this formula i a number from 0 to 100, higher score indicating an easier reading. The average document has a reading ease between 67-70. Scores between 90.0 and 100.0 are considered easily understandable by an average 5th grader while scores between 60.0 and 70.0 are considered easily understood by 8th and 9th grader.

$$FRE = 206.835 - 1.015ASL - 84.6ASW \tag{3.1}$$

Scores between 0.0 and 30.0 are considered easily understood by college graduates. If we were to draw a conclusion from the Flesch Reading Ease Formula, then the best text should contain shorter sentences and words. The score between 60 and 70 is largely considered acceptable. Table 3.1 is also helpful to assess the ease of readability in a document.

2) Flesch–Kincaid Grade Level (FKG). The more common Flesch–Kincaid Grade Level formula converts the Reading Ease Score to a U.S. grade-school level.

$$FKG = .39ASL + 11.8ASW - 15.59 \tag{3.2}$$

The result is a number that corresponds with a grade level. For example, a score of 8.2 would indicate that the text is expected to be understandable by an average student in 8th grade (usually around ages 13–14 in the United States of America).

The lowest grade level score in theory is -3.40, but there are few real passages where every sentence consists of a single one-syllable word.

[1] See also `http://rfptemplates.technologyevaluation.com/dale-chall-list-of-3000-simple-words.html`.

FRE score	Readability of the document
90-100	Very Easy
80-89	Easy
70-79	Fairly Easy
60-69	Standard
50-59	Fairly Difficult
30-49	Difficult
0-29	Very Confusing

Table 3.1: Interpretation of the Flesch Reading Ease score

3) Spache Readability Index/Grade Level. The Spache Formula ([Spa53]) considers unfamiliar words as words that 3rd grade and below do not recognize. The Spache Formula is best used to calculate the difficulty of text that falls at the 3rd grade level or below (for a higher level use the Dalle-Chall).

$$Spache = 0.141ASL + 0.086PDW + 0.839 \tag{3.3}$$

We mention in the following some guidelines to identify difficult words in Spache Readability Formula. Familiar words are considered words appearing on the Revised Spache Word List [2] and their variants that have regular verb form endings -ing, -ed, -es, plural and possessive endings of nouns. Difficult Words, i.e., the words not appearing on the Spache Word List are counted only once, even if they appear later with other endings. This counting includes words not appearing on the Revised Spache Word List and their variants that have irregular verb form endings or their variants that have adverbial, comparative, or superlative endings -ly, -er, -est.

4) New Dale-Chall Readability Formula. The formula for the Reading Grade Score (RGS) proposed for children above 4th grade ([DC48]) is:

$$RGS = (0.1579DS) + (0.0496ASL) + 3.6365 \tag{3.4}$$

Table show the conversion of the table in the level of education needed.

The main idea behind the Dale-Chall readability formula is that, a text written with familiar words is easier to read and, therefore, expressed ideas are easier to understand and remember.

Problems with readability formulas

- Surface characteristics: comprehension depends on the processing of the text base and situation model not just on the number of words, sentences ([MKSK96]).
- Reader's cognitive aptitudes: predicting reading has to take in consideration the readers's cognitive aptitudes regarding the theme ([MKSK96]).
- Cohesion and coherence. Readability formulas cannot capture the cohesion or coherence of a text. Research has clearly shown that readers have less difficulty reading cohesive texts ([MKSK96]).

[2] http://www.creativelearningdesigns.com/pdfs/SpacheList.pdf

Reading Grade Score	Reading Grade Level Education Level Age
4.9 and below	Grade 4 and Bellow
5.0 to 5.9	Grades 5-6
6.0 to 6.9	Grades 7-8
7.0 to 7.9	Grades 9-10
8.0 to 8.9	Grades 11-12
9.0 to 9.9	Grades 13-15 (College)
10 and Above	Grades 5-6 (College Graduate)

Table 3.2: Conversion table for the RGS formula

3.5.3 The Coh-Metrix Concepts and Metrics

Coh-Metrix [GMLC02] is a computational tool [3] that produces indices of the linguistic and discourse representations of a text. It has more than 60 readability metrics. Its metrics analyze the coherence of a text, and also the vocabulary, the sentence and text structure. The tool also also analyses non-numerics values such as title, genre, and source, without associating them with any metrics.

This said, the main concepts defining the readability metrics used in Coh-metrix are described as follows.

General word information and text information. This includes numeric metrics like number of words per text and sentence, number of sentences, number of paragraphs, syllables per words, frequency of content words (e.g., nouns, adverbs, adjectives, main verbs).

Coh-metrix distinguishes words into concrete and abstract. A word is classified as concrete using the MRC database [Col81]. The abstractness of a word is represented by the hypernym metric taken from Wordnet [4], that is, the the number of levels in a conceptual taxonomic hierarchy above (superordinate to) a word. For example, chair (as a seat) has 7 hypernym levels: seat → furniture → furnishings → instrumentality → artifact → object → entity.

Local/ Global Coherence. On the sentence level Coh-Metrics define local and global coherence through the adjacent sentences. Adjacent sentences are successive sentences in a span of text. For example, if a span of text has 4 sentences, then the adjacent sentences would be sentences 1-2, 2-3, and 3-4. A non-adjacent sentences are 1-3, 1-4, 2-4. Local coherence means integrating the meaning of usually of at most two adjacent sentences, while which means incorporating all the text knowledge with the reader's background knowledge on non-adjacent sentences. We will use this more concrete notion further in our ontology and inspired by this we will define new metrics.

Syntactic Formulas. Syntactic complexity is measured by number of modifiers. A modifier is an optional element that describes the property of a head of a phrase, For example, the noun-phrase

[3] http://cohmetrix.memphis.edu/
[4] http://wordnet.princeton.edu/

the lovely, little girl has three modifiers: the, lovely and little.

Regarding the syntactic indices Coh-Metrix introduces metrics regarding the connectives. Connectives are classified on two dimensions.

- On one dimension, the extension of the situation described by the text is determined. Positive connectives (e.g, and, after, because) extend events, whereas negative connectives (e.g., but, until, although) cease to extend the expected events.
- On another dimension, there are connectives associated with the type of cohesion, namely additive (also, moreover, however, but), temporal, logical, and causal.

The mean number of higher level constituents per sentence, controlling for number of words and the number of words that appear before the main verb of the main clause in the sentences of a text is other metric. Sentences that have many words before the main verb are taxing on working memory. Other metrics include the logical operators (e.g, and, or, if, then) because texts with a high density of these logical operators are difficult for most readers and as well the sentence syntax similarity indices which compare the syntactic tree structures of sentences meaning the proportion of nodes in the two tree structures that are intersecting nodes.

Referential and semantic indices. Referential cohesion occurs when a noun, pronoun, or noun phrase refers to another constituent in the text. For example, consider the sentence “When water is heated, it boils”. The word “it” refers to the word “water”.

In addition to referential indices, there are indices that assess the extent to which the content of sentences or paragraphs are similar semantically or conceptually. Coherence is predicted to increase as a function of similarity. One index of semantic similarity is content word overlap, which is the proportion of content words in two excerpts that share common content words.

Many aspects of a text can contribute to the situation model (or mental model), the referential content or microword of what a text is about. Causal/temporal/spatial/intentional cohesion reflects the extent to which sentences are related by causal/temporal/spatial/intentional cohesion relations relevant in the action plot and not relevant in texts that describe static scenes and texts that convey abstract logical arguments. They are measured using Wordnet characteristics, counting causal verbs, intentional verbs, spatial words. Temporal cohesion is measured by the repetition scores when analyzing the sequence of verbs that are classified in a particular tense and aspect.

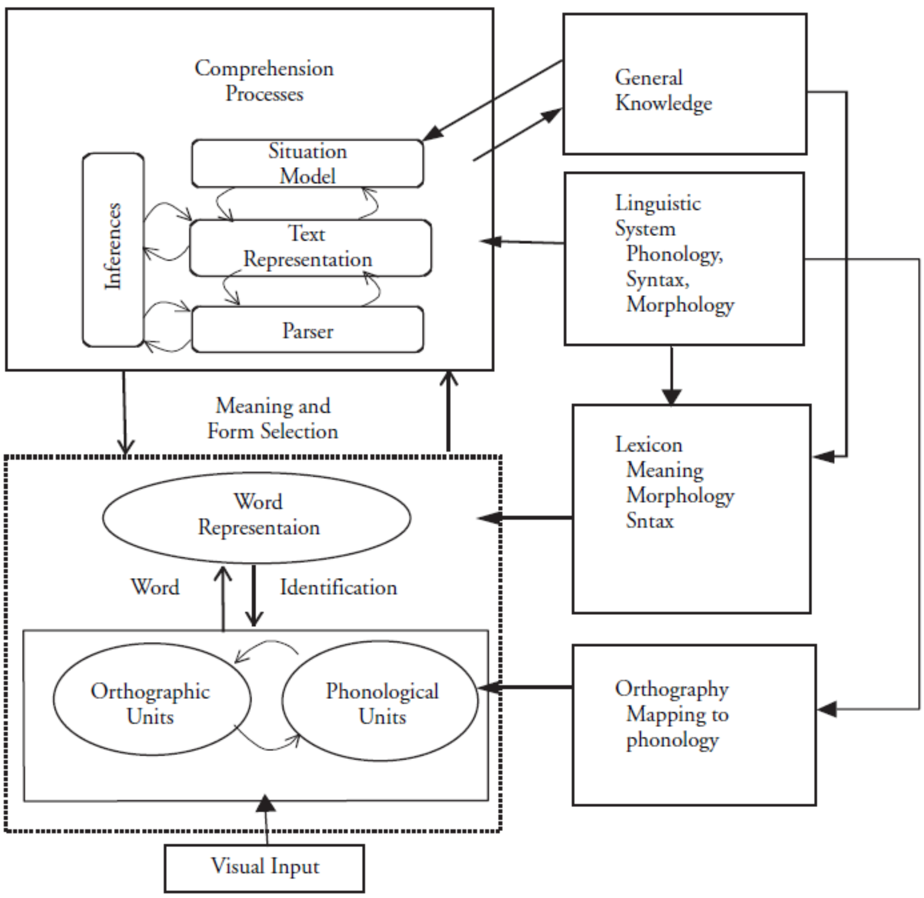


Figure 3.1: The components of reading comprehension from decoding words to comprehending texts, taken from [PLO05]. There are two major classes of processing events: (1) the identification of words, and (2) the engagement of language processing mechanisms that assemble these words into messages. Children must come to readily recognize words and encode their relevant meaning into the mental representation that they are constructing. Comprehension cannot be successful without the identification of words and the retrieval of their meanings.

Chapter 4

Preliminary User Requirement Analysis

Human requirements are the inspiration for art.
-Stephen Gardiner-

Following the user centred design [Cha04], we analyse, specify and include the user requirements right from the beginning into the whole ontology life cycle.

This chapter gives a preliminary user requirement analysis related to reading comprehension, divided into requirements of hearing poor comprehenders, and requirements of deaf poor comprehenders because the two classes of users have similar yet not identical requirements.

Section 4.1 explains who poor comprehenders are. Section 4.2 specify the user requirements of hearing poor comprehenders while Section 4.3 specify the user requirements of deaf poor comprehenders.

We conclude the chapter with presenting specific reading comprehension strategies for hearing and deaf comprehenders in Section 4.4.

4.1 Who Poor Comprehenders Are

There are different ways of assessing poor comprehension, as explained in Subsection 3.3. However, the difference between poor comprehenders and good comprehenders of the same age is at the reading comprehension level. Therefore, in this thesis, we adopt the following definition of poor comprehender.

Definition 1 ([CO07]) Poor comprehenders *are the group of children that have developed age-appropriate decoding skills but whose reading comprehension skills are not at the expected age level.*

In other words, although the child can decode the words, he or she has problems on making inferences [Cai09].

Such children often go unnoticed in the classroom because their difficulties are hidden behind their seemingly fluent reading, due to the fact that they have no decoding problems. As reported in [OS91], several experiments show that poor comprehenders without any handicap comprise up to 10% of 7-olds to 11-year-old in several countries. The estimate dramatically increases when the whole population of hearing-impaired children is considered. For instance, [Wau05] estimates that only 19% out of 504 hearing impaired 7-20 olds have reading comprehension scores above the third grade level.

The consequences of unremediated reading comprehension difficulties extend beyond literacy skills, and can have a negative impact, for instance, on motivations to reading, performances in science curricula and a child's self-esteem, e.g., [Cai09].

4.2 Hearing Poor Comprehenders Analysis

This section presents an overview of the range of word, sentence, and discourse levels skills that have been investigated in relation to poor comprehenders' reading comprehension difficulties. It analyzes the main components of the language and the existent experiments regarding the skills of poor comprehenders. At the end we discuss the relation to local coherence and global coherence, but as well the relation of such three levels of reading comprehension with the reading comprehension taxonomies of Subsection 3.2.2.

4.2.1 Word Level Skills

There is no strong evidence that the efficiency of word reading is impaired in all children with comprehension difficulties. For that reason, word level skills have not been a focus of training studies involving children with specific comprehension difficulties and there have been no studies investigating the efficiency of word-reading skills with a comprehension age match design[CO07].

However slow or inaccurate word reading may leave the reader with insufficient processing capacity to compute the relations between successive words, phrases, and sentences to construct a coherent and meaningful representation of the text [CO07].

Let us analyze the observation regarding different level of the word level skills.

Phonological Skills. Different experiments have proved that poor comprehenders do not have phonological difficulties which are typically associated with poor word reading [Adl09], [NCMD04] [NS98].

Vocabulary. In general, hearing and deaf poor comprehenders show relatively age-appropriate word recognition skills [Wau05].

Other observations regarding the vocabulary level follow.

- The difference between good and poor comprehenders is not influenced so much by the vocabulary [OLC04]. [OLC04] matches the two groups for knowledge of written and spoken word meanings. The group still differs on standardized measures of reading comprehension, and on experimental tests of specific comprehension skills such as inference making. However [Adl09] suggests that poor comprehenders' vocabulary deficit is considered both a cause and an effect of reading comprehension difficulties.

- Vocabulary knowledge influences reading comprehension indirectly, through its relation with memory. Knowledge of word meanings influences verbal memory, which plays an important role in supporting text representation and comprehension [NABCS99]. Some other researchers indicate that working memory difficulties in poor comprehenders may be unrelated to any vocabulary weaknesses [Cai06a].
- Children with poor reading comprehension have been not impaired in learning novel vocabulary taught through direct instruction, but children with both weak reading comprehension and vocabulary have been [OLC04].
- Poor comprehenders' short-term memory store appears to be intact. They are not impaired in their ability to store a series of words or digits when compared to good comprehenders with comparable word reading skills [Cai06b], [OLC04], [OYP86]. Other studies state that poor comprehenders are impaired on assessments of memory that require the simultaneous storage and processing of digits [YOP89] and words [NABCS99].
- Poor comprehenders have especial difficulty recognizing and expressing *abstract semantic relationships*, including making synonyms judgment involving abstract words [NS98] or association between words [LP07].
  - *Synonyms.* In [LP07]'s experiments children had to decide if some pairs are associatively and categorically related, e.g., red-green, hugs-kisses, sugar-spice, while in synonym judgment experiment from [NS98], the children must decide whether or not two spoken words have similar meanings. The synonyms are not only of abstracts words but as well concrete words (boat-ship; rug-mat, fast-quick; cry-sob). Poor comprehenders have been slower and less accurate at making synonym judgments, especially for low-image-ability items.
  - *Abstract words.* In [NS98] have compared short-term serial recall for lists of concrete words (e. g. , tooth, plate, fruit) and abstract words (e.g., luck, pride, wise). Although poor comprehenders and controls did not differ in memory span for concrete words, poor comprehenders have recalled fewer abstract words.

4.2.2 Sentence Level Skills

Once we recognize the words and retrieve their meanings, we need to establish the meaning of the entire sentence. Knowledge about syntactic structure can facilitate the comprehension of individual sentences [CO07] and some children with text comprehension difficulties have poor syntactic knowledge [NCMD04].

Syntactic awareness is assessed by tasks that involve the manipulation of sentences. Examples of task that assess this ability are as follows:

- *Grammatical correction error types*:
  - subject-copula verb agreement: e.g., "the baby are sick";
  - subject-verb agreement: e.g., "the girls climbs the tree";

  – tense agreement: e.g., “yesterday he plays”;

- *Word-order correction tasks* involve the storage and rearrangement of the jumbled words: e.g., “plays the boy in the yard”.

According to [Cai07] reading comprehension is more related to performance on the *word-order correction task*, and specifically to semantically reversible items because of a shared reliance on meaning-based processing strategies than the grammatically correction errors.

Poor comprehenders may have a deficit at the sentence comprehension level [CO06b]. Even if there have been used standardized assessment of grammar the results of experiments have been different. [CO07] states that not all children with poor comprehension have the same profile of skill strengths and weaknesses. However syntactic difficulties are sensitive predictors for future reading comprehension problems according to [Adl09].

Some examples of experiments regarding syntactic awareness in poor comprehenders and results regarding the weak skills of this group include the following:

- word ordering for active and passive voice of verbs with most errors in the passive voice [NS00];
- unscramble dative sentences e.g., “The donkey pushed the food to the cat ”[Adl09];
- regularization of irregular past tense verbs [NSC05];
- poor comprehender detect nonsense words but have difficulties on detecting syntactic errors (incorrect word order) and semantic error (anomalous sentences) [OHS05];

Poor comprehenders are impaired on assessments of memory that require the simultaneous storage of sentences [NABCS99].

4.2.3 Discourse-Level Skills and Processes

Research for poor comprehenders is mainly focused on the discourse-level skills and processes that help the construction of meaning-based, central to comprehension. In the following we analyze the skills involved in inference making and integration, use of cohesive devices and context, comprehension-monitoring, and knowledge about story structure.

1) Inference making and Integration. Inference and integration skills are essential for good comprehension and the inference-making skills of poor comprehenders have received much interest. It was proved that less-skilled comprehenders are poor at making inferences when reading or listening to text [CO07].

We will now analyze the two of the inferences described in Section 3.2.2. Generally it appears that poor comprehenders perform less well than control group on both types of relations [BCS05], although when the text was presented again to the children it has been noticed a greater improvement for the implicit relations than pragmatic relations [CO99], [Wau05].

- *Logical inferences*: poor comprehenders have problems with this type of inferences [Oak82], [Chi92]. To be noticed that in [Chi92] appear with the name Cohesive inferences. Sentence: “The dog was chasing the girl. The girl ran into the playground”. Task: “The dog ran into the playground”.

- *Pragmatic Inferences*: poor comprehenders have problems with pragmatic inferences even for simple inferences [CO07], [OY86], [YJ88], [Chi92].

Memory for the text itself does not appear to be a reason for poor comprehenders’ difficulties. They are able to recall literal detail from the texts [Oak82] and their inference-making difficulties are apparent even when the text is available to search through [CO07].

Poor comprehenders adopt a lower standard of coherence, that is, they have problems with *inconsistency checking* [Cai09], which are taken as an indication that they are not monitoring their comprehension. An example of inconsistency detection in short stories follows.

Example 4 *The following text, [CO06a], reveals two contradicting situations: the presence and the absence of moonlight:*

> *”Last night Jill walked home through the woods.*
> *There was no moonlight so Jill could hardly see her way.*
> *She walked along the path.*
> *The moon was so bright that it lit the way.*
> *Jill lives at the other side of the wood.”*

Poor comprehenders’ difficulties include *integrating text segments into coherent whole* [COE03], [LK06]. When children had to produce a story, the poor comprehenders stories had less recall of story content and inferred significantly fewer causal relationships in comparison with the control group.

Poor comprehenders’ writing contains poor causality related sequence of events. However they obtain better integrated stories when are required to narrate a sequence of pictures [OC96].

Background knowledge is not a dependent parameter for the inference making according to [OCBP01], [Oak82]. In the study from [Oak82] children have been taught a set of facts about an imaginary planet called Gan (e.g.,. “The flowers on Gan are hot like fire. The ponds on Gan are filled with orange juice”). They then listened to a multi-episode story followed by questions that assessed their ability to generate inferences. In order to draw each inference, children had to incorporate information from the knowledge base with a story premise. Memory for the knowledge base was assessed at the end of the story and only responses to the inference questions for which the knowledge base item was recalled have been included in the final analysis. Less-skilled comprehenders generated fewer inferences in comparison with the skilled comprehenders .

2) Cohesive Devices. We will be analyzing two types of cohesive devices, anaphoras and interclausal connectives.

- *Anaphora’s* are devices that maintain cohesion between sentences and phrases in a text. For example the anaphora she, referring to Jane in the preceding part of the text [Oak82]: “Jane speaks with Jimmy. She thinks Jimmy is very funny.”

- Poor comprehenders make more errors on questions that can only be answered if a pronoun has been correctly resolved relative to same-age peers [OY91], [OY86]. For example:"Chris lent his coat to Kate because she was cold". Who was cold, Chris or Kate?
- Poor comprehenders are also less likely to supply the appropriate anaphora in a cloze task [OY86]. [1] Regarding the process of pronoun in real time, [ME05] have created an on-line listening paradigm. The children having all 7 years old have listened to short texts. At the end of the second incomplete sentence, the question to choose between him or her was displayed on the computer. The time taken to read the probe indicated that the skilled comprehenders have been integrating the sentences during their reading, using information about the gender of the pronoun. The poor comprehenders haven't been sensitive to the information carried by pronouns. For example: "Louise had dinner with Malcolm in a restaurant. She chatted cheerfully with . . . "
- Poor comprehenders have lack of use of anaphoric strategies on writing, tending to be repetitive [AP08].

• *Interclausal connective*, such as "so", "because", "after", "but", used to indicate the relation between different propositions or sentences. Interclausal connective help the reader to integrate information between sentences in a text, being used for making the inferences correctly, having the explicit presence of links between parts of text. For example lets compare: "Nicola was late, so she took the bus" with "Nicola was late, because she took the bus". As we can observe the two sentence meaning is influenced by the interclausal connective.

Poor comprehenders are less likely to supply the correct connective (e.g. "because", "after", "but") to fill in a blank space in a sentence than are good comprehenders [CPA05]. In addition, when retelling aurally presented stories, poor comprehenders are less likely to include additional connectives than are good comprehenders [OY91].

3) Use of Context. When we read or listen to a text, we need to make use of contextual information to establish meaning, as well as to make local integrative links. The difficulties of the poor comprehenders presented in the literature regarding the context of use include the following observations.

• The use of sentence and story context facilitates understanding of words and phrases in text. A study made by [Oak83] and after by [OLC04] revealed that poor comprehenders make just few *instantiations*[2], showing that they do not use this more likely . The experiments made by them are the followings:
  - In [Oak83] reader infers a specific meaning of a common noun from the sentence context. For example inferring that fish is most likely a "shark" in the following sentence: "The fish frightened the swimmer".
  - In the experiment from [OLC04] two groups, poor comprehenders and control groups (9-10 years old) have participated. The children have received stories having a made-up word with a novel meaning (i.e., not a synonym of a known word). The meaning of the unknown word (e.g., wut) could be derived from information contained in one or two

[1] A cloze test is an exercise, test, or assessment consisting of a portion of text with certain words removed, where the participant is asked to replace the missing words

[2] Readers infers a specific meaning of a text

sentences that occurred either immediately after the unknown word (near condition) or after some additional filler sentences (far condition). The child had to guess the meaning of the word. Children with poor reading comprehension skills have been less able to infer the meanings of novel vocabulary items from context than the other children. In comparison with poor comprehenders, the skilled group has not not affected if the word was separated from the context by some text. Poor comprehenders have been influenced by this parameter. The same conclusion was derived in [NSC07].

- *Idioms* [3] Young children's and poor comprehenders' understanding of an unfamiliar idiom is influenced by the context in which it appears, whether the context supports a literal or a figurative interpretation of the phrase [LNC04]. Poor comprehenders understanding of the figurative sense of idioms is specially observed in opaque idioms, [4] such as "to be wet behind the ears" (to lack experience), where the words in the phrase provide little support for the figurative meaning [OCL05]. Poor comprehenders interpretations of these phrases are less likely to be based on the context of the story as a whole. They usually make just literal interpretation of the phrase itself.

4) Comprehension Monitoring. Comprehension monitoring is one of the metalinguistic skills that children acquire as their linguistic skills develop: the ability to reflect on the use of language. However, this ability tend to develop in tandem with the development of reading comprehension, rather than being a skill that is in place prior to beginning reading, and may even be a result of reading acquisition, meaning that is influenced by the age of the children. *Metacognition* knowledge about reading can include knowledge about the goals and processes of reading, and skill in applying such knowledge. It is causally related with reading comprehension failure. [Cai99] showed that poor comprehenders are less able than good comprehenders to adjust their reading style to meet different goals, e.g., reading to study for a later comprehension test versus skim reading to identify a particular piece of information. Poor comprehenders do have problems with comprehension monitoring [CO07].

5) Knowledge of Story Structure. [TN92] states that children's understanding and production of stories can be guided by their knowledge about story organization and goal-directed actions. [Per94] suggests that comprehension failure might arise through inadequate knowledge about how stories are structured.

Poor comprehenders are poor at selecting the main point of the story in two presentation conditions: either aurally or as a series of pictures [OY91]. After each story, children have been asked to select the main point of the story from a choice of four written statements: the correct main point, the main setting, the main event, and an incorrect main point.

Poor comprehenders have problems with elements that make a story well structured and integrated. Stories of the poor comprehenders are poorly organized in comparison with those of the good comprehenders.However they obtain better integrated stories when from titles that provided goals for the story. An example is "How the pirates lost their treasure", relative to simple titles such as "Pirates" [Cai03].

[3] Idioms are expressions such as "to spill the beans" (to divulge a secret) that take a figurative, rather than a literal, meaning.

[4] obscure relationship between literal and figurative meanings

Poor comprehenders have poor knowledge about the sorts of information provided by particular story features, such as story titles, story beginnings, and story endings. These textual features can be useful aids for reader, helping him or her to invoke relevant background information and schemas. [Cai96] presents the results of interviewing good and poor comprehenders about these features of stories. The majority of good comprehenders have been able to provide appropriate examples of the sort of information contained in a story title, such as "tells you what it's about and who's in it". In contrast, less than one-quarter of the poor comprehenders have been able to do so: some poor comprehenders have reported that titles does not give them any information.

The Role of Working Memory. Many of the skills involved in successful comprehension, such as integration and inference, anaphoric processing, use of context, comprehension monitoring, and structuring of stories, are dependent on the storage and coordination of information in memory [CO07]. For example, when encountering a pronoun, a reader who performs well on working memory tasks [5](and thus is presumed to have greater working memory capacity) is more likely to recall the noun referent, and hence better comprehends the passage. Skilled readers make more text-based inferences because the two sources of information are both available in working memory. Thus, an individual who has greater working memory capacity is able to hold in consciousness more information relevant to completing complex tasks such as reading, and shows better performance as a result [MO09]. Poor comprehenders' difficulties have been more pronounced when there was intervening text between the propositions of interest [CO07].

Although there is an evidence that memory impairments can arise through word-reading inefficiency, phonological processing difficulties or, perhaps, poor semantic skills, the working memory impairments of the poor comprehenders that we consider are clearly not due to such impairments. Furthermore, working memory appears to have a direct relationship with reading comprehension over and above short-term memory, word reading ability, and vocabulary knowledge [OCP03b].

[NCMD04] have asked poor comprehenders and controls (children with no comprehension problems) to repeat sentences (of increasing length and complexity) verbatim. Poor comprehenders have repeated fewer sentences correctly and the nature of the errors made by poor comprehenders differed from those made by control children. Poor comprehenders have been less likely to maintain the meaning of the target sentences. Authors suggest that a possible interpretation of this is that children simply haven't understood the sentences as well as control children have.

4.2.4 Recap Tables

We have observed that not all the poor comprehenders have the same deficit skills [CO07]. The results of studies on discourse-level processing skills are more consistent. In general, when word-reading ability and written vocabulary knowledge are controlled, poor comprehenders demonstrate deficits on many skills that are related to the construction of meaning. This means that a individual identification of the weakness of a skill is needed. [Cai09] states that the poor comprehenders difficulties can be encountered not only on the metacognition level but as well on the control processes that aid the construction of a mental representation of the text.

[CO07] states that younger readers' comprehension can be limited by word- and sentence-level skills in comparison with older readers. Poor reading comprehenders show phonological skills and

[5]Working memory span is generally computed on the basis of one of two ways: (1) the set size (i.e., 2, 3, 4, 5, or 6) for which all of the words were recalled for all of the trials, or (2) the sum of words recalled from trials in which all of the words were recalled (i.e., regardless of the set size).

nonverbal intelligence similar to those of typically achieving children, but their verbal IQ scores are lower [FLFB06] (page 52), thus being a factor for consideration. The studies in [Cai09] show that above the mentioned characteristics, poor comprehenders might have low self-esteem and motivation to reading. Our system should change these two characteristics by posting an appropriate stimulation text each time the child answers correctly and a good feedback when the answer is not the correct one. We assume that good stories (within the child's level of understanding and with images) will motivate children.

[CO07] state that children with weak narrative skills are more likely to experience later comprehension problems than children with weak vocabulary or syntactic skills. They also sustain that there exists a causal relation between narrative comprehension and reading comprehension. In general written narratives are of the same length for both poor and typical comprehenders [COE03], [LK06].

We will give the sum up of the studied research regarding the skills of poor comprehenders. Let GCET = Grammatical Correction Error Type and WOCT= Word Order Correction Tasks.

Poor comprehenders (PC) characteristics at WORD LEVEL			
		Yes	No
PC have age appropriate word recognition skills.		[Wau05]	
Phonology	This skill is not difficult for PC.	[Adl09] [NCMD04] [NS98]	
Vocabulary	Small vocabulary lowers the speed of learning of new words.	[OLC04]	
	PC have difficulties with abstract synonyms and associations between words.	[NS98] [LP07]	
	PC have difficulties with abstract words.	[NS98]	
Memory	There is a correlation between vocabulary and working memory.	[NABCS99]	[Cai06a]
	Have short term memory problems.	[YOP89] [NABCS99]	[Cai06b] [OLC04] [OYP86]

Table 4.1: Poor comprehenders and written word comprehension

Poor comprehenders (PC) characteristics at SENTENCE LEVEL		
	Yes	No
PC have deficit at sentence level comprehension.	[CO06b]	

Poor comprehenders (PC) characteristics at SENTENCE LEVEL			
		Yes	No
Syntactic awareness	There is correlation between syntactic awareness and comprehension.	[NCMD04] [Adl09] [CO07]	
1) GCEY	PC have problems with tenses.	[NSC05]	
2) WOCT	PC have difficulties with WOCT.	[Cai07] [NS00] [Adl09]	
Semantic level	PC have problems with checking consistency of information in sentences.	[OHS05]	
Working memory	PC have difficulties with accessing the memory that requires the simultaneous storage of sentences.	[NABCS99]	

Table 4.2: Poor comprehenders and written sentence comprehension.

Poor comprehenders (PC) characteristics at DISCOURSE LEVEL			
		Yes	No
The cause of difficulties on this level is not memory.		[Oak82]	[MO09] [CO07]
A) Inference Making	PC have difficulties with inference making.	[CO07] [BCS05]	
	BK is not a relevant parameter for inference making.	[OCBP01] [Oak82]	
	PC have difficulties with inference integration.	[COE03] [LK06]	
Inference Integration	Inference integration can be improved with visualization.	[OC96]	
	PC have problems with consistency checking.	[Cai09] [CO06a]	
	Logical inferences easier to improve than the pragmatic inferences.	[CO99]	
1)Logical Inferences	PC have difficulties with logical inferences.	[Oak82] [Chi92]	

Poor comprehenders (PC) characteristics at DISCOURSE LEVEL			
		Yes	No
2) Pragmatic Inferences	PC have difficulties with pragmatic inferences.	[CO07] [OY86] [YJ88] [Chi92]	
B) Cohesive Devices			
1) Anaphora	PC have difficulties with anaphora resolution.	[OY91] [OY86]	
	PC do not use it appropriately in writing.	[AP08]	
2) Interclausal connective	PC cannot supply the correct connectives.	[CPA05]	
	PC do not use it appropriately in writing.	[OY91]	
C) Use of Context			
1) Instantiations	PC make just few instantiations.	[Oak83] [OLC04] [NSC07]	
2) Idioms	PC have difficulties with opaque idioms.	[LNC04] [OCL05]	
D)Comprehension Monitoring	PC are less able to adjust their reading to meet different goals (e.g., to study/ skim).	[Cai99]	
	PC have difficulties with it.	[CO07]	
E)Knowledge about the story structure	Comprehension can be guided by this knowledge.	[TN92]	
	This knowledge influences comprehension.	[Per94]	
	PC have difficulties with grasping the main idea.	[OY91]	
	PC have difficulties on understanding the story features.	[Cai96]	
	Story's title influences the stimulation of story production.	[Cai03]	
D) Self esteem, narrative skills			

Poor comprehenders (PC) characteristics at DISCOURSE LEVEL			
		Yes	No
Self Esteem	PC tend do have lower self esteem.	[Cai09]	
Narrative skills	PC tend to have lack of this skill.	[COE03] [LK06]	

Table 4.3: Poor comprehenders characteristics at discourse level

4.3 Deaf Poor Comprehenders Analysis

Reading comprehension presents serious difficulties for many deaf readers across different languages and educational settings. In the following we will explain the characteristics of deaf children, then we continue to present the word, sentence and discourse level skills and characteristics of deaf poor comprehenders.

There are three types of hearing loss (HL): conductive, sensorineural and mixed.

- Conductive HL: i a blockage of the ear canal or dysfunction of the sound collecting apparatus [con10]. The auditory nerve is normal in this type of deafness, but the sound collecting apparatus has problem. [VSv+07] found that reading comprehension scores of children with implants have been significantly better than those of deaf children without implants, although the performance in implant users lagged substantially behind that in hearing children.
- Sensorineural HL: is irreversible type of HL that occurs when cochlear sensorineural elements or the cochlear nerve are damaged in some way [sen10]. It can progress to total deafness. Sensorineural HL can be treated with hearing aids or cochlear implants in most cases.
- Mixed HL: is the combination of the first two HLs.

There are different degrees of HL. HL's degree is determined by measuring, in decibels (dB), the hearing threshold. This is the amount of sound that is just barely heard. There are basically four degrees of HL:

- mild (26-45 dB) with little difficulty in hearing speech,
- moderate (at 46-65 dB),
- severe (at 66-85 dB),
- profound (over 85 dB).

It is at the severe level that the deaf term is first used. A child can be congenitally deaf or he/she can have lost hearing due to diseases such as meningitis. If a child becomes deaf before acquiring a language (eighteen months of age), he/she is said pre-lingually deaf whereas he/she is said per-lingually deaf if became deaf between eighteen and thirty-six months of age. Otherwise, he/she is said to be post-lingually deaf. The age factor is important because the age of first language acquisition has implications for the neural systems supporting the first language and for networks supporting language learned subsequently [MWB+08].

Studies from [WVBT06] measured the reading comprehension and word recognition of 464 deaf readers in the Netherlands. The average text comprehension score for the Dutch deaf readers was equivalent to the score for a hearing child six levels lower in school. Only 4% have demonstrated reading comprehension at the same level as hearing children of the same instructional age.

We will consider the same as we did in case of poor comprehenders, three levels of analysis of the text comprehension: word level, sentence level and discourse level.

4.3.1 Word Level Skills

Some studies have shown that low automatism in *recognizing words and parsing sentences* patterns is a significant source of difficulty for deaf children [Kel03], [KBC07], studies made for English language. These include problems with text decoding [Mus99] or poor phonological awareness [KH06], [PS00].

Other studies by contrary suggest that word reading identification scores of deaf children have been almost equivalent to the scores of hearing ones [Wau05], studies made for Dutch language.

Word recognition will be examined by focusing on two aspects of word form: one that seems to be a particular weakness of deaf readers, phonology, and one that may tap into one of their potential strengths, namely, orthography but as well on recognizing the meaning of the word.

- *Phonological knowledge*: deaf readers face severe obstacles in using English phonology, recognize and manipulate sounds, [KBC07], [PS00]. If the phonological knowledge of deaf readers is deficient, then they have trouble decoding novel words into a form that is understandable [KBC07]. Phonological knowledge is a factor in both deaf and hearing reading achievement [DMM+03].

- *Orthographic competence* allows a person to recognize words based on what their letters look like, that is, without resorting to sounding out the words intentionally and methodically. Orthography competence is a largely visual faculty, important for deaf readers because many rely on specialized attention to visual detail and on the identification of visual patterns during face-to-face conversations in sign language and during speech-reading [KBC07]. The focus of visual orthographic patterns can be affected by "single-letter positional frequency", meaning how often a certain letter tends to appear in a certain serial position within words, and "bigram frequency", meaning how often two particular letters tend to be adjacent to each other in English words. Studies have suggested that deaf subjects are as fast as the hearing subjects and they did not face obstacles on autograph patterns [DMM+03], and use it to compensate the lack of skills in phonological level.

- *Vocabulary.* Researchers claim that the deaf children's vocabulary is rather poor and characterized by lexical rigidity [Fur66]. This rigidity implies difficulties for deaf children on understanding written figurative language (metaphors, idioms, and proverbs) because they give a literal interpretation [OS89].

4.3.2 Sentence Level Skills

The text comprehension problems of deaf readers stem partly from their difficulties analyzing the syntactic relations among the words in various kinds of English sentences. This difficulties include:

- passive voice problems [KBC07]; For example in the sentence "The boy was hit by the girl"- many deaf readers would conclude that the boy was guilty of the violence.
- relative clause sentence [KBC07]; In the example "The boy who kissed the girl ran away, " many deaf readers would wrongly identify the girl as the one who took the flight.
- forming past tenses [MM02];
- drop of the constituents not explicitly realized in ASL (American Sign Language), such as determiners, prepositions, verb subjects and objects which are established discourse entities in focus, and the verb "to be", [MM02];
- the treatment of certain discourse entities as in ASL (e. g. , using "here" as if it were a pronoun) [MM02];
- putting plural markers on nouns [MM02];
- placing adjectives before the noun they modify [MM02];
- using conjunctions to concatenate clauses correctly [MM02];
- problems with subordinate clauses such as missing gaps [MM02];
- correct use of relative pronouns [MM02];
- delayed syntax acquisition [Bis83].

Some researchers try to find explanation for the lack of syntactic knowledge for English speakers:

- deaf signers encounter very limited opportunity to use and practice English syntax in face-to-face communication, for instance, the conventions of ASL; differ significantly from those of English. ASL has many syntactic features that English lacks: simultaneous signs, tense and number inflections on time words [KBC07] [MM02];
- many deaf readers face serious obstacles to represent a critical mass of words in their lexicons. Then it is enormously difficult for them to recognize and apply the conventional patterns for combining words in ways that are meaningful and grammatical. They simply do not have enough words to work with syntactically;
- more than 90% of students who are deaf or with hearing problems have hearing parents who do not share an effective mode of communication with their children and as a result are unable to read "aloud" to them or explicitly teach literacy skills [MH96].

4.3.3 Discourse Level Skills

Studies regarding the discourse level have revealed that poor deaf comprehenders focus on activities concerning the comprehension of isolated words or single sentences, reasoning on isolated concepts and losing the global view of the text [AP06], [BGF90], [Oli96], [YID92].

[HP90] premise that the contribution of discourse skill to reading comprehension is dependent on word-decoding competence, that is, automatic word recognition. Without word comprehension skills, discourse comprehension skills cannot help much. The studies have failed to investigate whether the strategic manipulations of the teachers have produced changes in the reader strategies that has been carried over to the comprehension of future passages read without the teacher's assistance.

It is considered by [KBC07] that deficient word recognition is responsible for difficulties applying discourse or strategic knowledge, ss for deaf children, a lack of the vocabulary and grammar knowledge used in texts affects discourse comprehension [GMM01].

Inferences seam to be difficult for deaf children: temporal, causal [AP06], anaphoric [AP08], [FVP98]

- implicitly relation (without connectives links) e.g.,"He does not find the frog. He is desperate. He looks everywhere in the room." Subordination or linguistic conjunctions like "then" are not necessary to express the causal-temporal link between "He is desperate" and "He looks everywhere in the room. "
- explicitly (with connectives links- e.g., "before") e.g., "He spoke before he went to play."

The difficulties with story comprehension are not limited to the understanding of deaf people's linguistic links (the conjunctions), but as well to the ability to construct the structure (either temporal, causal, spatial and anaphoric) of the story [AP06].

[BB96] states that inferences about predictable events are drawn in a similar manner by deaf and hearing readers and [GMM01] found that profoundly deaf children with good signing skills are often better readers than profoundly deaf children with poor sign language skills. Quantitative analysis of children responses to comprehension questions indicated that children could analyze, synthesize and evaluate narrative text and their ability to do so did not need to be supported by questions related to the story details [SW97]. Qualitative analysis indicated that children had difficulties with 7 reading tasks : locating pertinent information, applying relevant and accurate background knowledge, expressing themselves unambiguously, understanding the intent of the question, not relying too heavy or too little on the on background knowledge, considering consequential details and providing sufficient answers.

4.3.4 Recap Tables

We are now reviewing the studied literature regarding the deaf poor comprehenders. We will be using the same notations:

Deaf poor comprehenders (DPC) characteristics at WORD LEVEL		
	Yes	No

DPC have age appropriate word recognition skills.		[Wau05], [KBC07], [Mus99]	[Kel03]
Phonology	This skill is not particularly difficult for DPC.	[DMM+03]	[KBC07] [KH06] [PS00]
Vocabulary	DPC have a poor vocabulary.	[Fur66], [OS89]	
Orthography	DPC are relatively good on this.	[DMM+03]	

Table 4.4: Deaf poor comprehenders and written discourse comprehension.

Deaf Poor comprehenders (DPC) characteristics at SENTENCE LEVEL			
		Yes	No
Syntactic awareness			
GCET	DPC have problems with passive voice.	[KBC07]	
	DPC have relative clause sentence problems.	[KBC07]	
	DPC have problems with forming past tenses.	[MM02]	
	DPC tend to drop off determiners, prepositions verb subjects and objects.	[MM02]	
	DPC have problems putting plural markers on nouns.	[MM02]	
	DPC have problems placing adjectives before the noun they modify	[MM02]	
	DPC have problems problems with subordinates.	[MM02]	
	DPC have problems with relative pronouns.	[MM02]	
	DPC have problems with syntax acquisition.	[Bis83]	
Semantic level	DPC have difficulties.	[MW08]	
Working memory	DPC have difficulties.	[MW08]	

Table 4.5: Deaf poor comprehenders and written sentence comprehension.

Deaf Poor comprehenders (DPC) characteristics at DISCOURSE LEVEL			
		Yes	No
A) Inference Making and Inference Integration			

1) Consistency checking	DPC have problems with checking consistent and detecting inconsistent information.	[AP06]	
2) Logical Inferences	DPC have problems with propositional temporal and causal inferences.	[AP06]	
3) Pragmatic Inferences	DPC wrongly apply relevant background knowledge in pragmatic inferences.	[SW97]	
B) Cohesive Devices			
1) Anaphora	DPC have difficulties with anaphora resolution.	[AP08] [FVP98]	
2) Interclausal connectives	DPC no not always supply the correct connectives.	[MM02]	
C) Use of Context			
1) Instantiations			
2) Idioms			
D) Comprehension Monitoring	DPC tend to read a story sentence by sentence, not connecting the story events.	[AP06]	
	DPC tend to focus on activities concerning isolated reasoning or single sentences, words.	[Oli96] [YID92] [BGF90]	
E) Knowledge about the story structure	Problems on locating information.	[SW97]	
D) Self esteem, narrative skills	DPC tend to have low self esteem, and to express themselves ambiguously.	[SW97]	

Table 4.6: Deaf poor comprehenders and discourse comprehension

4.4 Specific Reading Comprehension Strategies for Hearing or Deaf Poor Comprehenders

4.4.1 Strategies for Hearing Poor Comprehenders

[LRL98] proves that improved syntactic awareness does not brings improvements in word-reading accuracy or reading comprehension for poor comprehenders comparable to good comprehenders. This experiment trained syntactic awareness in 8- to 10-year-old but with no influence on the reading comprehension for both groups.

Poor comprehenders have been taught successfully how to make inferences from clue words in texts. This type of lexical inference involves identifying and using key words: for example the words steam, splash, soap, and towel indicate a bathroom. A combination of training both lexical inference and question generation to test understanding leads to significant gains on standardized measures of reading comprehension [OY91]). Although poor comprehenders reliably demonstrate limited memory capacity, inference training is unlikely to lead to memory gains. Instead it might enable some poor comprehenders to compensate by using their memory resources more effectively [CO07].

4.4.2 Strategies for Deaf Poor Comprehenders

Strategies for developing word level skills on deaf poor comprehenders include:

- to associate a word as an intact unit with either the manual sign for the word or the finger-spelled version of the word.
- to use the cued speech which may be qualified as an intervention for helping children acquire representation of English phonological forms [LCL03], [KH06]) or lips reading [KH06]).

We will now analyze the strategies that can be applied for improving the sentence level skills for deaf children:

- Gains in comprehension of relative clause and passive-voice sentences when conventional workbook practice is combined with the entertainment appeal and unambiguous meaning of Keystone Kop silent films. There is also evidence, however, that the improved comprehension comes at the cost of slow, intentional analysis of target sentences[KSS00].
- Repeated Reading : students read texts multiple times to improve fluency. Repeated Reading may improve fluency because its practice can generate syntactic patterns. According to this line of thinking, repeated reading of the words in practice texts increases familiarity with them and frees processing resources ordinarily needed for word recognition, allowing investment of additional attention in the detection and practice of syntactic patterns[Kel03].

Chapter 5

The Domain Model

Keep your eye out for unexpected results.
It's almost more exciting than getting
the findings you predicted.
–Fred Gage

We will focus on the Domain Model, because as we will see that by defining a good Domain Model, the Student model, creation of the statements regarding one student (having taken as an approach the GRAPPLE model), will come automatically.

This chapter starts with introducing the ontology life cycle for our Domain Model, Section 5.1, followed by the presentation of the design patterns used in constructing our ontology, namely Section 5.2. The Chapter ends with a brief presentation of the concepts used in our Domain model by presenting concepts common to the Game Ontology and Story Ontology in Section 5.3.1, the Story ontology in Section 5.3.2, the Game ontology in Section 5.3.3 and the bridge ontology of the two ontologies, in Section 5.3.4.

5.1 The Domain Model Life Cycle in TERENCE

In this section we will explain the design choices while building the ontologies following the stages for ontology engineering, presented in Section 2.4. The presented Domain Model is currently in the building stage, therefore the section is focusing only on the design issues for the building stages mainly on the four steps: specification, conceptualization, formalization and implementation.

5.1.1 Specification

In developing our ontology, as in any project our first step was establishing the purposes of our ontology by posing and answering specific questions. The answers to such questions allowed us to specify the ontology requirements sketched in Figure 5.1.

Because we are not experts in cognitive science and linguistic we had to get knowledgable of the ontology domain to put together preliminary versions of the specifications themselves, let alone to build the domain ontologies. We simultaneously acquired and conceptualized more knowledge. We then discussed it over with the experts for examination, and iterated the specification and building process.

1) Purpose of the Ontology. First we enumerates the reasons for using ontologies in TERENCE. Then we present the purposes of our domain ontologies.

Arguments for Using Ontologies in TERENCE

- To share common understanding of the structure of information among people or software agents. This project contains researchers from different fields: Cognitive Science, User computer Interaction, Linguistics and Educators. Some definitions can be confusing for some people, therefore a common vocabulary is needed [Mus92]. Strategy, instruction, process events are all general concepts that might create misunderstandings. Having the common vocabulary the discussion will be more clear, with no room for ambiguity.
- To enable reuse of domain knowledge. Reading Comprehension ontology is very useful because it can be used in different e-learning systems. By constructing a good ontology this can be serialized and send among different web services, but as well there can be used parts of the definition to construct new ontologies.
- To make domain assumptions explicit. This would be very useful for new users who must learn what are the meanings of the terms in the domain. By stating all the assumptions they can be easily modified using ontologies. For example stating that some skill is dependent on some other skill. After a deep research it is possible that to be proved that this assumption was wrong. All we need to do is to modify the rules of the ontology.
- To separate domain knowledge from the operational knowledge. It is possible to add new types of skills and exercises in the hierarchical construction. Querying ontologies is made easily before and after this modification, because we don't need to know the whole structure of the sub concepts.
- To analyze domain knowledge. Formal analysis of terms is extremely valuable because we can reuse existing ontologies and extend them ([HM00]).
- Enrich the model with knowledge via collaboration from different teachers with strategies as it is done for the enterprise modeling in [GKL+09].
- According to [KG06] ontologies can represent various types of knowledge relevant for personalized adaptive learning and could be used by software agent to assist authors in the design of individualized learning or even to directly generate such experiences themselves.
- Sharing adaptation rules among other systems regarding for example the preferences of the users [KG06] can be applied to TERENCE as well.

Purpose of the Ontologies of the Domain Model. The main purposes of the ontologies are as follows:

1. analyzing and classifying stories and text-comprehension games for directing the end user towards the most adequate class of stories or games;

2. using automated reasoners for additional knowledge discovery (e.g., new relations between story concepts).

Specific purposes of the two ontologies are separately presented in the following.

- Purpose of the Story Ontology:
  - to develop a common terminology between the computer scientists, linguists and psychologists;
  - to ease the development of text difficulty concepts and metrics, which the psychologists can test and we can apply in the automatic analysis of texts;
  - to create a "concept scheme" for annotating stories to query stories and their features, as an "ontology for natural language processing" [Kee10].
- Purpose of the Game Ontology:
  - to develop a common terminology between the computer scientists, linguists and psychologists (which is based on the concepts studied in Chapter 3 and 4);
  - to ease the development of game difficulty concepts and metrics;
  - to create a "concept scheme" for annotating games to query games and their features like as an "ontology for natural language processing" [Kee10].

2) Reusing Taxonomies, Concept Schemes, Ontologies. Both the Game and Story Ontology are based on and refine concepts schemes or taxonomies presented in Sections 3.2.1, 3.2.2, 3.4. More precisely, we analysed and reused concepts concerning text difficulty or text analysis in general for the story ontology. We analaysed and reused concepts from taxonomoies concerning reading comprehension and interventions for the game ontology. Other concepts that we created were inspired by the Gold Ontology [gol10], and Cosmo Ontology.

Gold Ontology is a taxonomy of the linguistic concepts that we have been using in our construction (e.g., sentence, word, paragraph, written linguistic expression).

The Cosmo (COmmon Semantic MOde) ontology [cos10] is a public, open foundation ontology that is intended to include all the basic elements required to specify the meanings of any more specific concept in any domain. We have used the definitions of `Goal`, `Strategy`, `Practice` from this ontology. We have not completely reused this foundational ontology because the definition of some concepts does not correspond with ours. For example events in Cosmo have temporal bounds delineated by time intervals, mainly beginning and ending of Time Point while in our model we don't consider these properties as mandatory to define an event.

Regarding the time related concepts we have used the concepts from [HP04], an ontology related with TimeML [tim10].

3) Modularization of Ontologies. The architecture of the four ontologies is presented in Figure 5.2.

We want to create a clear separation between the story ontology and the game ontology because of the two separate purposes of TERENCE: recommend suitable story for a reader based on some feature and give suitable games for reader that could help him improve his reading comprehension.

Domain: TERENCE Domain Ontologies
Date: April 2010
Developed by: Rosella Gennari, Maria Keet, Oana Tifrea
Main purposes:

1. analyzing and classifying stories and text-comprehension games for directing the end user towards the most adequate class of stories or games
2. using automated reasoners for additional knowledge discovery (e.g., new relations between story concepts)

Other purposes:

- list all concepts that influence preferences of a story for a given reader (e.g. story genre, difficulty level)
- list all concepts that influence preference for a game for a given reader
- list all the relations between games' concepts and stories concepts

Level of formality: Seminformal
Type of Expert Users: the primary expert users are members of the consortium of the TERENCE project. This include cognitive scientists, computer scientists, psychologists. Later on, the ontologies should be refined so as to be assessed and used by the educators (teachers, parents) of poor comprehenders.
Source of knowledge:

- WHO: (a) linguists, (b) psychologists expert of deaf comprehenders (e.g., Barbara Arfé),(c) psychologists expert of poor comprehenders (e.g., Jane Oakill, Carretti), (d) experts of ontology engineering
- HOW:(a) structured and non-structured interviews (by face-to-face conversations),(b) questionnaires (via email), (c)focus-groups [VSS96] (two, one in l'Aquila in June with psychologists and engineers, one in Padova in July with psychologists),(d) literature review presented in Chapter 2, 3 and 4 guided by domain experts
- HOW-TO: (a) scientific literature,(b) foundational ontology, reference and domain ontologies, e.g, Gold [gol10]

Figure 5.1: Ontology requirements specification document for Domain Model

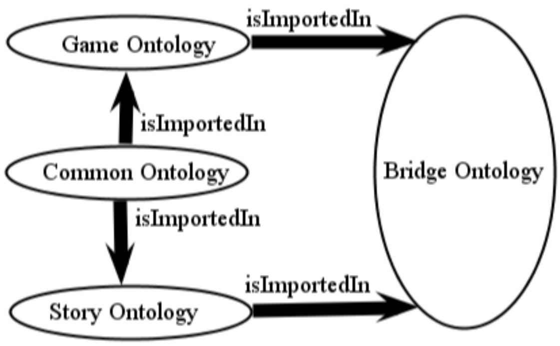


Figure 5.2: Modularisation of the Domain Model

Except these two ontologies we have created two more ontologies that are focused each of them on a specific design problem.

There are concepts that are being used in both ontologies, such as the `Language` concept. The solution was to create a Common Ontology that will be imported by both ontologies, Story and Game. In case of refactoring of the common concepts, the process becomes easier and as well a better understanding regarding the common concepts of the story and game ontologies.

The second ontology that we have created is the Bridge Ontology that includes the Story and Game ontology and concepts and properties that relates games with stories. Lets take for example the object property `hasFocusOnStoryFeature` that has as domain the `ReadingComprehensionGame` and as range `WrittenLinguisticExpression or StoryTitle or RelationType`, meaning that the the games can focus some specific sentence, word, paragraph, text, title, or relation between of the story or some relation (i.e., anaphoric relation, neighborhood relation). We can then state that "`Ex1 hasFocusOnStoryFeature` some`StoryTitle`" if the `Ex1` is requires to the reader to solve a question regarding the title of the story.

5.1.2 Conceptualization

We have been using (1) expert knowledge and (2) the literature review, under the guidance of experts of the respective fields as our source of knowledge to collect the concepts needed for our ontology and the relations between concepts.

We used the middle-out approach on creating the ontology which defines the basic concepts, then generalizes or specifies them (see Section 2.4).

We did not import a foundational ontology for creating our model because we did not want to overpopulate the ontology with concepts that are not necessary, given the fact that this ontology will be used by people with less experience with ontologies. Still as we have stated some concepts and relations that were taken from COSMO ontology.

A pure bottom-up method would have required definitions of a large number of detailed terms first, with the risk that many of them would not be important in the final ontology, while a mixture approach takes the advantage of both.

Another reason for choosing the middle-out approach is the nature of the terms found, some of them very general, others specific. Each source used required switching from bottom up to top down approach. For example the inference taxonomies from Section 3.2.1 and Section 3.2.2 have specific terms while the strategies taxonomy, presented in Section 3.4 has general terms mentioned.

5.1.3 Formalization

Currently, our ontologies are semiformal because we do not give a formal definition with all the axioms of each concept, but we use the annotations and just a minimum of relations between concepts for achieving our purpose. We have added primitive concepts and just few properties and constraints.

The reasoning service that characterizes our ontologies is, currently, limited to consistency checking. The intended reasoning service is to deduce knowledge that can help domain experts and educators construct a model of a set of stories and games that are suitable for a student given the current state of the student. For this, further work is needed.

5.1.4 Implementation

We chose OWL as our language of development for several reasons. Firstly, TERENCE will have a web-service based architecture. Moreover Grapple (see Section 2.3.1) uses OWL as well and using OWL for our Domain Model will make the integration smoother. One aspect that does with respect to the subject domain is to refine the represented knowledge so as to limit the possible models and adding more characteristics to the object properties, like that the is-part-of is not only transitive, but also reflexive [KA08] as we will further see for defining that a word is-part-of expression.

We named the ontology so that its contents can be identified appropriately on the Semantic Web (wwww.TERENCE.org the intended web site where the ontology will be published).

5.2 The List of Design Patterns used in constructing the Domain Model

This section first defines what an ontology design pattern is, and then enumerates and explains the design patterns used while developing the domain model.

5.2.1 Definition of Ontology Design Pattern

Before going to present the design patterns, we need to define the ontology design pattern concept.

Definition 2 (Ontology Design Pattern (OP)) *An OP is a modeling solution to solve a recurrent ontology design problem. It is an* `dul:InformationObject` *that* `dul:expresses a DesignPatternSchema` *(or skin). Such schema can only be satisfied by DesignSolutions. Design solutions provide the setting for* `oddata:OntologyElements` *that play some ElementRole(s) from the schema.*
dul: is for `http://www.loa-cnr.it/ontologies/DUL.owl#`
oddata: is for `http://www.loa-cnr.it/ontologies/OD/odData.owl#` *[GDdC+08]*

The design pattern are grouped in Figure 5.3. [BGGP+07] present a catalog of ontology design patterns organized in three different categories while [GDdC+08] extends this with other categories.

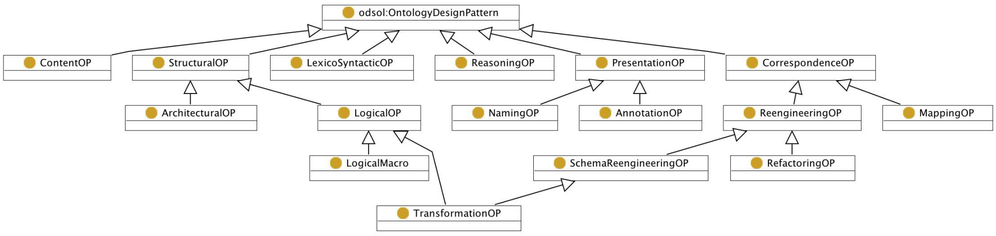


Figure 5.3: Design Pattern catalog according to [GDdC+08]

5.2.2 Structural OP

Logical OP. A logical design pattern is a formal expression, whose only parts are expressions from the logical vocabulary of OWL, that solves a problem of expressivity.

1)N-ary relation. The aim of this Logical OP is to solve the issue of modeling n-ary relations in an ontology expressed in OWL DL, which only natively supports the expressivity for binary relations. Figure 5.4 shows a diagram depicting the metamodel extension for the n-ary relation pattern. This Logical OP consists of defining a class that represents a relation with n arguments. Such a class is an instance of the metamodel class `NaryRelationClass`. Although applicable to relations with any arity, `NaryRelationClass` is typically instantiated for relations with three or more arguments. In our usage we want to express that relations between events have a type, with a distance in the text between events, and that a relation can be explicitly or implicitly presented. For this we have created the `RelationEvents` relation and the following object properties: `hasEvent1` , `hasEvent2`, `hasEventsDistance`, `hasRelationType`.

5.3 The Domain Ontologies

5.3.1 Common Ontology

We have defined a common ontology that has the classes and relations common to the story and game ontology presented below. The common ontology is imported in the other ontologies. This approach helps us save time for updating the common knowledge of the story and game ontologies.

In the common ontology we created the class `Language`, defined as a systematic means of communicating by the use of sounds or conventional symbols. The language concept will be used to distinguish between the stories based on the language and type of games based on the language. We want to evaluate the influence of a language to the story comprehension, that is, how the differences in the language may influence comprehension. Each student will have the preferred language and the system will give stories and games based on the language preferences. The individuals of Language are English and Italian, the main languages considered by TERENCE.

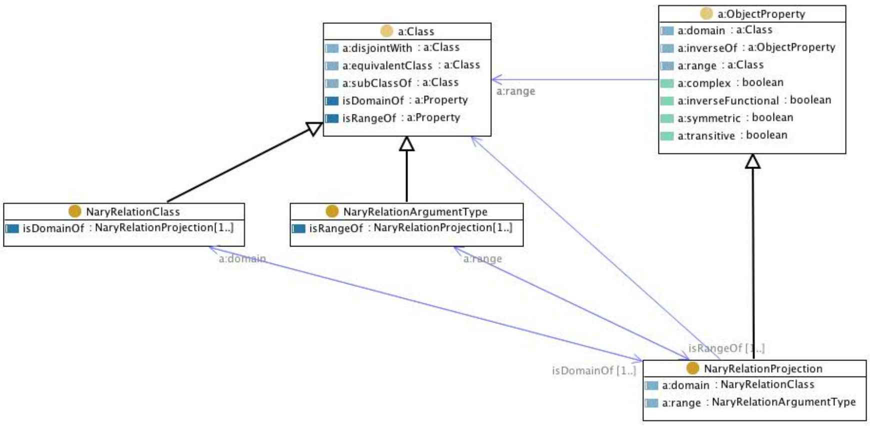


Figure 5.4: N-ary relation design pattern

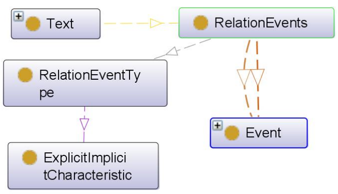


Figure 5.5: N-ary relation presentation

Thing
hasGenre some StoryGenreType
hasLanguage some Language
hasLengthType some StoryLengthType
hasTitle some StoryTitle
hasWorkingLoad some integer[> 100]
hasWrittenLinguisticExpression some WrittenLinguisticExpression

Figure 5.6: Story Superclasses

The object property hasLanguage will define the property of a concept of having a language. We have created the concept Background Knowledge that represents information known by the reader before starting to read a story or a game.

We have defined the subproperty Minimal Background Knowledge, representing the minimal amount of information required by reader. What is minimal background knowledge is still an open question for psychologists. It can be the understanding of the grammar rules (e.g., making inferences regarding two events by knowing the tense of the verb representing the two events). But our ontology will offer this freedom of expression by just adding extra information in the minimal background knowledge or deleting some other. The idea is that the psychologists need to determine the minimal background knowledge that it is common to the children and that requires to make inferences, experimentally.

NonMinimal Background Knowledge is the concept disjoint from Background Knowledge representing information that is not minimal. The object property requiresBK with the range Background Knowledge will be used to express what type of knowledge is required for a specific type of game or story.

5.3.2 Story Ontology

This section presents briefly some of the concepts that we used to create our story ontology, and the crucial design decisions we made in order to have the current version of the ontology.

The first version of the story ontology were built after a very preliminary analysis of the context of use and user requirements, conducted with interviews to cognitive scientists. The first version had then concepts taken from text difficulty resources, like Coh-metrix, (see Section sec:readabilitymetrics) and refined as in [Zwa99] or [tim10]. It was then discussed with the domain experts. In this manner, we could also refine and specify our user requirements in relation to story comprehension presented in Chapter 4. The ontology was refined and extended as an OWL ontology taking care of such requirements: we highlighted features of stories that are pivotal for the story comprehension of our users according to our user analysis (see Chapter 4). For a more detailed motivation of some concepts presented here the reader is invited to read Appendix A.1.

The central concept of our story ontology is the Story concept that represents a plot of narrative or dramatic art. The characteristics of the stories used in our ontology are given in Figure 5.6, mainly the genre, length, title, language, written linguistic expression.

Story syntactic and semantic structure. Story is characterized by syntactic concepts of story and semantic concepts of story. The syntactic concepts are represented by the

WrittenLinguisticExpression, composed by Word,Expression, Ilustrated Episode, Text and the relation between this concepts (see Appendix A.1 for details).
Each of WrittenLinguisticExpression concepts results from the Coh-metrix concept scheme briefly overviewed in Section 3.5.3, then refined through our user analysis in Chapter 4. Moreover, we introduced part-whole relations in OWL in order to properly correlate the above subconcepts, mainly that Text hasPart Illustrated Episode that hasPart Expression that hasPart Word.

The so-called semantic concepts are based on the Event concept and the concepts related with it, including relations between two Event concepts. The Event concept represents something that takes place in the story. Events can be divided in ActionEvent, that is related with Location, Time, Character concepts and State, that has no relations with Character.

Event Related Concept, with its there subconcepts (Location, Character, Time) gives us information regarding the the events of a story, and allows us to create relations between them. We created them starting from the event-indexing model of [Zwa99] and [tim10], which refer to a classical event calculus of AI [RN10].

The relation between Event and WrittenLinguisticExpression is made by hasPart object property, mainly Sentence hasPart some Event, meaning that an event is part of a sentence.

Coherence of a Story. Coherence represents the integration in a logical way of the information in text. We need this concept to distinguish between the levels (local, global) of coherence for establishing the difficulty of understanding of some events. The distinction is made by three types of concepts, Sentence,Paragraph, Event. The definition of Local Coherence Sentence Based was defined in Coh-metrix (Section 3.5.3). The other notions are born from the need to define better metrics to express the level of coherence of a text, needed to classify stories. The other reason for creating the notion of Local Coherence was because we need to understand if the children have in their working memory non adjacent paragraphs, or non adjacent events, as specified by our user requirements in Chapter 4.

Relation Related Concept. Differently than in the Coh-metrix concept scheme, and other readability formula described in Section 3.5.2, our ontology has events and relations between them as primitives that can be conveyed or not by connectives. This is in line with [tim10] and [HP04]. Of each relation, we need to be able to state its type, e.g., temporal, causal, both, so as to stir the pertinent question-game.

More precisely, differently than in 3.5.2 and [tim10], the user requirement analysis (see Section 4.2.3) tells us that text comprehension may be affected by whether relations are explicit or not in the text. That is why we created the Relation Related Concept concept and the following correlated concepts in our story ontology. Such a concept allows us to create concepts for two types of relations: relations between concepts pertaining to the Event; relations between concepts pertaining to the WrittenLinguisticExpression concept.

Relation Event Type. This concept is introduced to represent all types of relations that can exist between two events of Event Related Concept. The three sub concepts that we defined are Causal Relation, Spatial Relation and Temporal Relation.
For the Temporal Relations we have two main sub concepts.

- Sequential Temporal Relation occurs when an event precedes the other. The reason for introducing this concept is that at the age of 5 children are able to work with this type of relations [MM08].
- Non Sequential Temporal Relation occurs between two events when they overlap in time, that is, they can be represented with intervals with an intersection that is an interval along the real time-line. For these type of temporal relations events interval intersect. Non sequential relations can be expressed with connectives like "while", "when", "in the meanwhile". They are usually acquired later, around the age of 7-9, than sequential relations [GX02].

Such high level relations can be rendered with Allen temporal relations, and are most frequently found in English narratives, e.g., see [CS88].

Relation Type. Poor comprehenders have problems with making inference with different types of relations, not only event-based, e.g, anaphoric relations. See Table 4.3, row 13. The sub-concepts of this concept are the following two.

- Anaphoric Relation connects the word (sentence, phrase) and the word that replaces the word (sentence, phrase) in an anaphoric structure. This notion will be important when we want to inspect the distance in the text between the members of the anaphoric relation (in the number of words separating them).
- A Neighborhood Relation represent a binary relation between two concepts that refers how close are these concepts to each other using some metrics. This includes until now Relation Events, Relation Paragraphs and Relation Sentence.

The metrics presented in this paragraph are created by us for the need to express metrics that could express how difficult is to make inferences between two concepts found in text, based on the distance in text of the two concepts.

We defined as metrics for the difficulty of an Anaphoric Relation (i.e, making anaphora resolution) the number of words between the pronoun and the expression that this pronoun replaces.

We defined as metrics for the Neighborhood Relation of concept the distance between the two concepts in the text. Having these metrics we were able to classify the subconcepts of the Neighborhood Relation based on the adjacency.

A Relation Events between two events was constructed because poor comprehenders have problems making inferences between events as we mentioned in Section 4.6. For representing the relation between events there are two approaches, described as follows.

- Creating a class Relation Type in which we represents all types of relations and then create a class Relation that is defined as follows: hasEvent1 some Event, hasEvent1 some Event, **hasRelationType some RelationEventType**. In this kind of representation we cannot reason regarding for example the transitivity of some temporal relations. However, this type of representation allows us to correlate it to the implicit/explicit characteristic of relations, and to its subconcepts, and in case it is explicit it allows us specify the types of connectives and the connectives that render the relation.
- Create hierarchical properties of the relation and add information about them, e.g., transitivity, symmetry, antisymmetry, commutativity. This type of representation could be useful

for the reasoner because we can reason about temporal events. Still this representation does not offer us the possibility to see the exact connective that we are using and if the relation is explicit (or not) in the text. The second approach does not allow us to express the the explicit-implicit characteristic, which is an important concept according to our user requirement specifications.

The two subconcepts of the relation events are AdjacentEvents and NonAdjacentEvents, being disjoint. Except this intuitive meaning we added semantics to the ontology by creating a data property hasEventsDistance. We defined the AdjacentEvents as being those RelationEvents that hasEventsDistance < 2 and NonAdjacentEvents as being the opposite of adjacent events. The modality of calculating this distance needs further investigation. But this level of abstractness permits us to represent adjacency of events.

We introduced in the Text concept the property hasPart some RelationEvents, thus connecting the story with the events relations and not only with the events independently one from each other.

Relation Paragraphs represents the relation that exists between two paragraphs. We have Adjacent-Paragraphs and Non-AdjacentParagraphs as Relation Paragraphs' disjoint subconcepts. Distance between 2 paragraph is defined as follows: let p_m be the first paragraph, the p_n second paragraph in our paragraph relation, then the distance between p_m and p_n is $m - n$. To be noticed that we have an ordering of the paragraph which depends on the order it appears in the text. We need this relation to define the Local Global Coherence at Paragraph level.

Relation Sentences represents the relation that exists between two sentences. We have Adjacent Sentences and Non-Adjacent Sentences as Relation Sentences's disjoint subconcepts. Distance between 2 sentences is defined as follows: let s_m be the first sentence, the s_n second sentence in our sentence relation then the distance between s_m and s_n is $m-n$. To be noticed that we have an ordering of the sentences which depends on the order it appears in the text. We need this relation to define the Local Global Coherence at Sentence level.

To conclude, this section introduced the main concepts that form the story ontology and the design issues that we encountered in the development of this ontology. As already mentioned we constructed concepts that let us calculate the relevant (to our users) readability metrics (see Section sec:readabilitymetrics) for determining features of stories, and we also proposed new concepts and relations among them, such as neighborhood distance between events or paragraphs.

5.3.3 Game Ontology

This section presents some of the concepts that we used to create our preliminary version of the game ontology, and the crucial design decisions we took and leading to the current version of the game ontology.

After a preliminary analysis of the context of use and user requirements via interviews with the domain experts, we collected and analysed the taxonomies of Section 3.2.2. In particular, we focused on the last one, which is partly exploited in the YARC manual for classifying reading interventions. This was of mixed-up approach, reusing existing taxonomies, then refined according to the user requirements in Section 4.

This subsection presents first the Reading Comprehension Game, concept based on the taxonomies presented in Section 3.2.2, then a detailed explanation of how we extended this concept and added others to better simulate a game ontology.

Reading Comprehension Game concepts. The two subconcepts of the Reading Comprehension Game are Decoding Game and Linguistic Comprehension Game, concepts and Decoding Game's subconcepts (Orthography Game, with its subconcepts Capitalization Game, Hyphenation Game, Punctuation game, Spelling game, and Phonology game. Such games were introduced in Section 3.2.1.

Decoding Game is introduced due the fact that, according to our analysis of the context of use, educators are recommended to first help children decode well to be a good comprehenders (Section 3.4.2). This concept will be used as a control variable by the TERENCE system, meaning that children who do not successfully solve the decoding games either are not poor comprehenders or are cheating on testing.

Linguistic Comprehension Game is further subdivided into two main subconcepts: Semantic Comprehension Game and Grammar comprehension Game. These two concepts were created by us from the need to distinguish between games that focus on the meaning of a text and games that focus on the language structure of the text, both known to be difficult for poor comprehenders. Table 4.2 (rows 5,6,7) and Table 4.5 give the motivations of the Grammar Comprehension Game, Morphology Game and Syntax Game. During the focus group in Padova on July 2010, cognitive scientists stressed that grammar was shown to be only mildly or not correlated to comprehension in hearing poor comprehenders. Grammar can be both considered as a subject variable, relevant to the study, and as a text/experimental variable, if texts will vary for grammatical complexity.

In Section 3.2.2, we argued over the ambiguities of the presented taxonomies, also criticised by several psychologists because highly inapplicable in the classification of reading interventions, e.g., forcing a question concerning relations between events to be either temporal or causal. Based on such criticisms, our ontology has Semantic Comprehension Games, inspired by the research expounded in Subsection 3.2.1. The main subconcepts are as follows.

- Literal comprehension game: comprehension is due to literal reading of the text.
- Inference based comprehension game. For this game the reader should be able to derive logical conclusions from premises known or assumed to be true. It is a type of game that is known to be difficult for poor comprehenders, both hearing or deaf. See our user requirements specified as in Tables 4.6 and 4.3. This concept is further subdivided as follows.
  - Bridging game implies making connections between pars of the given text, that requiresBK some Minimal Background Knowledge. The subconcepts created by us were Lexical Inferences Comprehension Game, focusing on Vocabulary Comprehension Games and Cohesive device Comprehension Games, and Event-Based Comprehension games.

    Lexical Inferences Comprehension Game includes the games that require to determine the object or the subject of an event or to determine the referent entity for the cohesive devices (anaphora and atemporal and non spatial and non causative connectives between sentences). Regarding the object and subject of an action, a game that requires making inference regarding the meaning of a text will be found in the Lexical Inferences Comprehension Game, taking the information from the text.

    Event-Based Comprehension games pertains to and refines the comprehension skills analysed in Subsection 3.2.2, where referential inferences were moved to the Lexical Inferences Comprehension Game. The reason for this change is that the last taxonomy of Subsection 3.2.2 has an ambiguity regarding the difference between Referential inference, part of the Logical Inference, and Pronominal inference, part of the Lexical Inference. In our approach, we include in Event Based Comprehension Games questions/games regarding the relation between events (spatial, temporal, causal), thus making the understanding of the connections between the story ontology and game ontology easier.

– Elaborative Game requires making connections between pars of the text that requiresBK some NonMinimal Background Knowledge.

Example 5 *Let us look at the following example: "It was very smoky when John entered inside. He fainted." We know from our background knowledge that in smoky environment we could faint. Then we can derive that the cause of the faint was the smoke.*

We integrated Personal response Game and prediction Game in Elaborative Game because generating personal responses and prediction involves drawing inferences with BK. From our point of view evaluation and personal response are not two separate notions, and therefore we merged them together.

The Elaborative games can be further divided in Event Based BK Comprehension game with the subconcepts Causative Elaborative game, Spatial Elaborative game, Temporal Elaborative game) and Evaluative Game.

Reading Comprehension Properties. Figure 5.7 lists the properties that characterise the Reading Comprehension Game concept. In the following will explain briefly what they mean.

- hasTextAvailability represents whether during the specified game the text will be or not available. The property is given to check if the problem of the child is memory or not, or just simple he cannot make inferences even with the text present. A similar strategy is followed in the text comprehension tests by psychologists.
- hasConditionalState relates the game to the the student behaviour (part of the student model). For example, a game regarding a word that the user has searched previously in the dictionary is user dependent. User dependent games will have to have connections with the history of the operations made by the user and what operation applies.
- hasApplicability will state when a type of game can be applied. This means that applicability_of_practice contains all the features regarding when the game can be applied. Currently, we have only included the following ones.
  - application_of_practice_dependend_on_reading, with its subconcepts
    - aplicable_after_reading,
    - aplicable_before_reading,
    - aplicable_during_reading.

    For example let us take aplicable_during_reading and its subconcepts
    - aplicable_during_reading_paragraph,
    - aplicable_during_reading_text,
    - aplicable_during_reading_sentence.

    We can state that "ex1 hasApplicability aplicable_during_reading_paragraph". This further can be connected with the paragraph.
  - applicable_period this property states on which reading comprehension time interval intervention should be applied.

Figure 5.7: Reading Comprehension Description

- hasGameType will offer information regarding what type of game is the current game, with the solution checked automatically or not. The GameType subconcepts includes as well their own subconcepts. For example a ex1 hasGameType some Yes/No Question Type which is an Alternative Game Type, a Type Automatically checked.

An Overview of the General Idea of the Game Ontology. Figure 5.8 lists the main concepts of our game ontology, focusing on the following important concepts.

- Practice represents that act of doing something to acquire some Goal. There are two subconcepts of Practice, namely Generic Practice and Specific Practice. Generic Practice represent general activities that are not focused on a specific type of exercises. We have included Strategy as being a Generic Practice because the same the strategies and we have included all the general concepts regarding Reading comprehension strategies such as Comprehension Monitoring, Vizualizing, AnswerQuestions etc. Specific practices are specific activities, namely in our case a game to acquire a Specific Game.
- Goal is something that is achieved by Practice. This can include some metrics such as improve some type of game of strategy whose calculated results will be lower than a give threshold.

We introduced ReadingComprehesionLevel that will be level of comprehension that will characterize the student ontology. If a Goal is reached for a student than his process area of reading comprehension will be satisfied, and the level of reading comprehension will increase.

5.3.4 Bridge Ontology

The bridge ontology represents the concepts and properties that connects the story and game ontologies. For example hasFocuseOnStoryFeature has as Domain some Game and as range RelationType or StoryTitle or WrittenLinguisticExpression. This is used for example to express that DecodingGame hasFocusOnStoryFeature some Word.

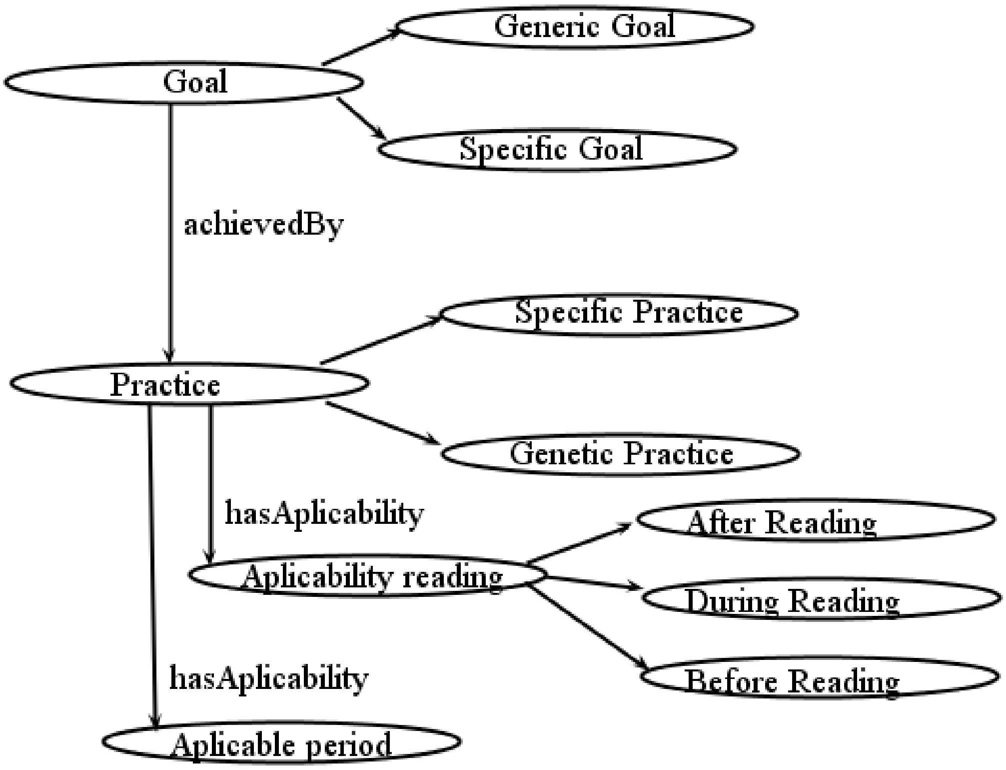


Figure 5.8: Concepts of the game ontology

Chapter 6

Work in Progress: The Student Model

As for the student model, different aspects of user modelling were studied independently from different angles. Aside from distribution, scalability and performance aspects [KF06] and context information [Jam01], the principal purposes 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 [HN99] and TRAILS projects [HLK$^+$07] based their modelling on (reasoning over) logged user actions. In the AHA! project [DSS06], on the other hand, user actions are typically not logged but immediately translated into higher-level user model information, and Brusilovsky and Millán [BM07] focus on Bayesian networks.

As Kay [Kay08] 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 [HSBK05] and GRAPPLE [DSv$^+$10] described in Chapter 2.

In this section, we outline preliminary work concerning the student model of TERENCE, represented as an ontology. We briefly outline its purposes, and then the main sources we plan to use in its design.

6.1 Purposes

The main purpose of the student ontology is to model the emotional and, mainly, cognitive characteristics of classes of poor comprehenders, hearing or deaf, and hence characterise individual students.

As for the cognitive part, the student model should specify the relevant cognitive features of poor comprehenders, like the lexicon knowledge and the capability of making specific inferences, that are related to concepts specified in the domain ontology, like the lexicon complexity and the different concepts of inference-making while reading.

6.2 Conceptualization

6.2.1 Reusable Sources: Ontologies and Taxonomies

In building the student ontology of TERENCE, we will start from GUMO-Basic, outlined in Chapter 2, following a mixed-up approach, see Chapter 2. GUMO-Basic defines generic user characteristics and personality traits by means of the so-called Characteristics and Personality classes. The TERENCE student model will need to refine them. For instance, it will have to specify whether the students are deaf or not; whether they are poor comprehnders or not. The integration with the domain ontologies will be pivotal. For instance, the game ontology foresees specific decoding games. These can be used to separate children that are poor comprehenders from those that (are not cheating and) have comprehension problems. More in general, the user requirements concerning reading comprehension outlined in Chapter 4 will direct the refinement of the GUMO-Basic ontology in TERENCE.

Besides this, the analysis of the context of use conducted in Chapter 3 will have to be extended and consider taxonomies that, in general, are concerned with the so-called learning styles of (generic) students. They are known in the psychology literature and their main concepts are listed as follows in [Mar91].

- The three senses:
  - auditory (listening): this children prefer to follow verbal instructions rather than written ones and find it comfortable to add spoken numbers mentally;
  - visual (seeing): this readers can read formulas and understand them and prefer maps to verbal directions when they are trying to find a place;
  - kinesthetics (moving, touching, writing and doing): this readers write things down, to clarify their thoughts. They have have to manipulate formulas in order to understand them. They like to draw pictures. and enjoy lab classes.
- Two reasoning types:
  - deductive: such children like to look at the big picture first, then get the details. When learning a new game, they like to know all the rules before playing;
  - inductive: such children like to see some examples when first learning a new subject, before developing an overview and prefer to learn the rules of a new game "as they go along".
- Two environments:
  - intra personal: when solving word problems, such children figure it out for themselves. They consider that doing school work with a group often is a waste of a lot of time;
  - interpersonal: before taking a decision, such children usually discuss it with their family or friends and they love group exercises.

6.2.2 Other Sources

What features of poor comprehenders we should consider in the student model needs to be further evaluated and refined with and for teachers. However, our interviews to the TERENCE pshychologists highlighted a series of critical factors that we have to keep under control in this respect.

For instance, teachers tend to confound grammar knowledge or even decoding skills with reading comprehension, and hence classify as features of poor comprehenders features of students that have other types of reading problems. Similarly, simply asking a teacher to evaluate the "inference abilities" of a student may not do. It is now open the question of what predictive factors for "inference abilities" could be considered in the student model for the TERENCE domain and that teachers may easily recognise.

Another type of approach to refining the student model is offered by the *user semantic profiling* of [EGP03]. Different techniques, machine learning based or not, have been applied to deliver personal solutions to users over the web. Therein, the authors explore the impact of ontologies on machine learning algorithms used for user profiling. The profiles of users are themselves stored in RDF. Using inductive logic programming techniques, the authors were able to discover meaningful and potentially reusable knowledge concerning users. Now, the learning data of TERENCE are stories and games, which will be structured by referring to the story and game ontologies of the domain model. For example, a story may be annotated with information like "This is a fantasy story. Its story length is short. It has an average number of events. It has an average number of sequential temporal relations. It has an average number of include relations." by using the related concepts of the story ontology. User profiling as in [EGP03] could then be used to deduce that "The student John likes fantasy stories that are short, with an average number of events, an average number of sequential relations, and an average number of include relations". In turn, such structured knowledge could be used for refining the student model.

Chapter 7

Conclusions

Finally, in conclusion, let me say just this.
-Peter Sellers-

The sub-models of the conceptual model of an ALS (e.g., student model, domain model, adaptation model) are nowadays realised as ontologies, as Chapter 2 explains.

There are few ontologies described in the literature for the student model and that we can reuse for creating the TERENCE student model, as explained in Chapter 6.

However, the domain model is highly domain dependent, as the word says. Differently put, there were no ready-available ontolgogies for the domain model that we could 'simply' refine to cater for our users. Thus, our engineering of the domain ontologies meant first of all:

(Step 1) analysing concept schemes and concepts pertaining to text difficulty, mainly for the story ontology;

(Step 2) analysing several taxonomies of reading comprehension and reading interventions, mainly for the game ontology.

The result of our analysis is in Chapters 3. It draws from two main sources: cognitive and educational psychology; computational linguistics. The material therein presented was collected and assessed under the guidance of the respective domain experts.

The subsequent main step of our ontology engineering was:

(Step 3) analysing the user requirements.

Such an analysis work was used for specifying the user requirements as in Chapter 4. The preliminary specifications of the users' requirements were also refined in collaboration with domain experts, via focus groups or interviews (structured and unstructured ones).

Our specifications allowed us to give a preliminary answer to the following research question of Table 1.1.

(Question 1) What are the requirements of the system's main end users (poor comprehenders, hearing and deaf)?

Thanks to this work, we could sensibly move to the fourth main step of our ontology engineering:

(Step 4) using the specifications for directing the refinement and enrichment of the aforementioned concept schemes/taxonomies with general and generic text-analysis ontologies.

Our ontology life-cycle is described in more details in Chapter 5, using terms introduced in Section 2.4. Our ontologies, so built, constitute a preliminary answer to the following questions posed in Table 1.1.

(Question 2) What are the features of stories and games that are relevant according to our users' requirements? What are their relations?

Tests to be conducted within the TERENCE project will further assess which of the concepts of our domain ontologies are experimentally critical for poor comprehenders.

In Chapter 5, besides explaining the key concepts of our domain ontologies, we explained their purposes, their sources, the formalisation level, the intended types of expert users, as summed up in Figure 5.1. In this manner, we could answer the following research questions of Table 1.1.

(Question 3) What is the purpose of our ontology representation?

(Question 4) What sources can we reuse from the literature for creating our domain ontologies?

(Question 5) What shall we keep or refine or enrich in the literature, according to our experts of the domain?

(Question 6) What is the formalisation level of our ontologies?

Finally, Chapter 6 presents on-going work concerning the student model and why this should be represented as an ontology. In particular, it already specifies the purposes of the ontology, and singles out the two main sources that we can use in its building: existing user ontologies (e.g., GRAPPLE) or taxonomies; other sources, like interviews with teachers. In this manner, we started tackling the following questions of Table 1.1.

(Question 7) What is the purpose of an ontology representation?

(Question 8) What sources can we reuse from the literature for creating our student ontology?

More precise answers to the above questions, and answering

(Question 9) what the formalisation level of the student ontology is

will require first analysing critical factors for building the student ontologies, some of which are already put forward in the end of Chapter 6.

Appendix A

Appendix

A.1 Some Story Concepts

Name of concept	WHAT	WHY
`Story Genre Type`	Characteristic of story	As we have seen in Section 3.5.1 it is important to give to children stories that interest them. This is the first reason for creating this concept. The second reason is that different genres of stories have different linguistic features (e.g., vocabulary) and world knowledge requirements, two things that can affect the story comprehension according to our user analysis. Story genre is closely related with purpose of the reading. For example, some goals for of reading narrative stories may be to understand the basic sequence of events described, be entertained, and extract some moral or point. On the other hand, the primary purpose of reading expository texts such as science or history texts is to learn or acquire new information about scientific or historical facts about natural/social events. In addition, these two types of texts differ in terms of the novelty of information contained in the text. Thus, the same reader may appear relatively strong or weak depending on the reading situations, which often involve different purposes that are largely associated with the text genres.
`Personal Narative` -subclassOf `Story Genre`	Are forms of writing in which the writer relates an event, incident, or experience in his or her own life	The events of a personal narrative are most often presented in chronological order, the order in which they actually occurred in time, using with a linear temporal flow. The personal narrative incorporates vivid descriptive details as well as the thoughts, feelings, and reactions of the writer. Usually a personal narrative is focused on one experience. This type of stories contain many sensory details and requires world knowledge that is encountered in the daily life, e.g., you should wear warm cloths on winter.
`Histocrical Naratives` -subclassOf `Story Genre`	Form of witting that contain true facts, place and people from past	For this type of story the readers use historical background knowledge, e.g., reader should know that in 18th century women could not vote. Sometime, in order to fully understand the story, the reader need to make inferences using such a type of background historical knowledge.

Fantasy Stories -subclassOf Story Genre	Form of writting that will involve magic, paranormal and unusual characters.	This stories are often used by psychologists in tests for such stories require a minimal background knowledge of the world. However, such stories have several descriptions concerning locations, time and the characters involved in an event, which may be inconsistent with the prior world knowledge of the reader. Such stories are likely to require games involving more logical inferences and knowledge of abstract words than, for example, personal narratives. As we already know from Table 4.3, rows 6–8, poor comprehenders have problems with abstract concepts and relations. We can use fantasy stories when we want to focus on improving strategies regarding abstract concepts, and inferences on various features of events.
Story Title	Word or expression or proposition that should be unique to the story	In Tables 4.3 and 4.6 we have observed that the story structure is a feature that influences comprehension. This is a Coh-metrix concept but presented without any analysis regarding what feature a title can provide us with, cfr. Section 3.5.3.
Story Length Type	Characteristic of story depending on the number of words it contains	As such, it is likely to affect the working load and hence the reading comprehension. We started dividing stories in Flash, Short and Long Stories.
Word -subclassOf WrittenLinguistic Expression	Represents a sound or a combination of sounds, or its representation in writing or printing, that symbolizes and communicates a meaning and may consist of a single morpheme or of a combination of morphemes.	(1) "word" appears in Chapter 4, when we analyze the word level reading comprehension, see Tables 4.4 and 4.1. According to row 6 of Table 4.1, poor comprehenders have difficulties both with abstract and ambiguous words, and we need a superconcept to include them both. Note that Coh-metrix has the word and abstract word concepts, as explained in Section 3.5.3, whereas it has no concept neither metrics for ambiguous words. (2) checking the decoding skills of the TERENCE users, and hence separating poor comprehenders from those with decoding difficulties, see Definition 1. (3) the number and type of words at different syntactic levels (sentence, paragraph, entire text) give us different readability metrics for stories for poor comprehenders. Thus the sub-concepts of Word in our ontology are: Abstract Word, Ambiguous Word and New Word. The New Word represent the word that will have provided explanation and possibles examples or visualizations, to extend the vocabulary of the children and facilitate their comprehension. This strategy helps the reader when he or she does not properly use his or her background knowledge, see Section 3.4. The introduced sub-concepts do not create a partition, meaning that we can query information regarding the word in general but as well specific words, e.g., abstract words.
Expression -subclassOf WrittenLinguistic Expression	An expression is a word or a combination of words representing a meaning as a whole; we consider a compound word as an expression.	The need for introducing expressions is motivated by the user requirements where we have stated that poor comprehenders might have problems with idioms (which are a type of expression) but as well in the anaphoric expressions, pronouns and inter-clausal connectives, see Table 4.3. An inter clausal connective is an expression because it can be formed by multiple words (e.g., moreover, by far, so far). We can annotate the expression and calculate the number of difficult ones (in the case of idioms) or the distance between the individual words and the expression meaning in the synsets. This is needed when the child reads for the first time a text. For example the child will start reading "being wet". The child's understanding draws an event episode related with water but then when he or she reads "behind ears" then the child changes this episode with the meaning of the expression "wet behind years". In this manner, we can assess the level of difficulty that expressions like idioms create for understanding a story.

`Sentence` -subclassOf `WrittenLinguistic Expression`	Sentences are defined as grammatical units consisting of one or more expressions, bearing minimal syntactic relation to the words that precede or follow it, often preceded and followed in speech by pauses, having one of a small number of characteristic intonation patterns, and typically expressing an independent statement, question, request, command.	According to 4.2, row 6, poor comprehenders tend to have difficulties with the right ordering of the words. An annotation at the sentence level will offer the possibility to count the number of events that are presented in one sentence. In p. of our Chapter 3 (context of use), we saw that not too long sentences simplify comprehension.
`Paragraph/ Illustrated episode` -subclassOf `WrittenLinguistic Expression`	Paragraph/illustrated episode represents the set of sentences that are illustrated in TERENCE	The notion comes from Section 3.4, according to which the literature recommends the use of visualization of specific reading portions of text. We can then calculate the number of illustrated episodes in the entire text, as well the distance between episodes. This will permit to investigate if the distance between illustrated episodes influences the reading comprehension and if the difficulty of a story can be influenced by the inferences made by events belonging to non-adjacent episodes. Paragraph/Illustrated episode has in it subdivision sentences.
`Text` -subclassOf `WrittenLinguistic Expression`	The Text concept represents the whole story.	Such a concept has a widespread use, e.g., for measuring the type and number of words in the entire text. The same is for events and relations.
`Location`	represents where a certain event takes place and represents the space of the action.	
`Character`	is an entity (person, object, fictional entity) that participates in some events	We have created a character because some entity can be both actor or object. `isActionActor` or `isActionAuthor`
`Time`	represent when a certain event takes place.	As for the end users, all our domain experts asserted that question-games addressing those features tend to be difficult for poor comprehenders, hearing and deaf.

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