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PBAE: New UML Profile Based Formalism to Model Accessibility in E-Learning Systems*

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The integration of accessibility in e-learning platforms has become a necessity. Furthermore, the evolution of development technologies and assistive technologies impose constant change and improvements on online educational systems. The application of Model Driven Architecture (MDA) turns out to be the most appropriate method to use to follow this evolution. This paper presents a new formalism based on UML profiles called PBAE, which is used to apply MDA in the development process of accessible e-learning systems. Our goal is to use this formalism to specify all the accessibility requirements to define models of accessible e-learning systems. ArgoUML is used for implementing our formalism.

Keywords: e-learning; accessibility; WAI; MDA; UML profiles; ArgoUML

INTRODUCTION

E-LEARNING is one of the most inaccessible web-based technologies. Students with disabilities are frequently ruled out of virtual classrooms [10]. To remedy this exclusion, many countries have encouraged or compelled accessibility by law, such as in the US [16] and France [14], among others.

Despite these important measures, the currently developed e-learning platforms have paid little attention to accessibility.

In recent years, many research activities have focused on proposing approaches to handling accessibility to a web design process referred to as an engineering accessible web application [8].

Furthermore, both the evolution of the development and the assistive technologies impose constant change and improvements on these platforms. This allows developers to specify an accessible e-learning system on a more abstract and conceptual level instead of dealing with the technical details of low level coding. In this context, the application of the Model Driven Architecture (MDA) turns out to be the most appropriate.

However, MDA currently does not have sufficient semantic elements to completely define models and model transformations.

With this premise in mind, in this paper we present a new formalism called *Profile Based Accessible E-learning* (*PBAE*) in order to apply MDA to the development of accessible e-learning systems.

This paper is organised as follow: the next section reviews the state of the art related to accessible e-learning and the principal issues on web accessibility. This is followed by an outline of the main concepts of MDA. Our approach is then described and an applied illustration on ArgoUML presented [13]. The last section gives our conclusions.

BACKGROUND

E-learning and accessibility

The Learning Content Management System (LCMS) has become popular among web site hosts. It helps to create, reuse, locate, deliver, manage and improve learning content. Following this trend, Learning Management Systems (LMSs) are increasingly being used to construct distant learning environments. An LMS essentially focuses on competencies, learning activities, and the logistic of delivering learning activities [9].

The advantages of online learning have been widely described in the literature. However, most of the recently published literature in core distance-educational journals concerning the use of the Internet as an educational tool has only addressed the issue of accessibility for people with disabilities in using an online distance education environment [11].

Two main issues should be taken into consideration when designing a fully accessible e-learning environment: technological issues and methodological issues. A well designed learning content methodology, if not supported by a set of accessible tools, is not sufficient to allow disabled students to learn on the Net. Therefore, although adding a few enabling technologies is very impor-

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tant, it not enough because all types of disabilities are not taken into account. For instance, an LMS that has some accessible tools for specific learners might be unsatisfactory for other learners, such as visually impaired users. This issue becomes more critical if the learning methodology was designed for the sighted.

The main steps that must be followed to reach e-learning accessibility are:

- deciding accessibility goals for the education content;
- studying the disabilities of the targeted student; and
- designing the content to make sure it complies with the accessibility guidelines, assistive technologies and the appropriate pedagogical approaches [8].

People with disabilities

Disabilities can be grouped according to the type of impairment; generally there are four groups [1]:

1. mobility impairments (restricted movement or control of arms, hands and fingers);
2. visual impairments (blindness, partial sight and colour blindness);
3. hearing impairments (deafness and hearing loss);
4. cognitive impairments (including cognitive, language and learning disabilities such as attention deficit disorder, dyslexia, dementia, etc.).

Mobility impairments refer to physical disabilities that affect the ability to move, to manipulate objects, and to interact with the physical world [4]. People with physical disabilities may have difficulties in using pointing devices, in using keywords shortcuts (e.g. pressing two keys at the same time), or with programs that require a response in a restricted period of time.

Visual impairments include the range from low vision to full blindness, where the user cannot use the visual display at all. Although people with visual impairments have the greatest problem with information displayed on the screen (especially graphics and pictorial information), the use of a pointing device that requires eye–hand coordination (such as a mouse) may also pose an issue for them [1].

People with hearing impairments have difficulties detecting sounds or distinguishing auditory information from the background noise [6]. Deaf individuals cannot receive any auditory information at all. Many of them communicate through Sign Language, which differs significantly from the spoken language.

There are a wide range of cognitive impairments, including impairments of thinking, memory, language, learning and perception [1]. Most of them are partially related to difficulties in recognizing and retrieving information, comprehending, engaging, identifying, choosing and implementing solutions, or conceptualizing (such as problems in sequencing, generalizing previously learned information categorizing, cause and effect, abstract concepts, comprehension and skill development) [1].

Assistive technology

Assistive or enabling technology includes devices, tools, hardware, or software, which enable people with disabilities to use the computer. It presents an alternative way of accessing the content on screen, command the computer or processing data. Specific adjustment software or devices for manipulating the computer include [7]:

- screen reading software (speaks displayed text and allows simulating mouse actions with the keyboard);
- screen magnification software (for enlarging the content of the screen);
- Braille display (for displaying Braille characters);
- alternate input devices (e. g. screen keyboard) and special keyboard (to make data entry easier);
- keyboard enhancements and accelerators (such as StickKeys, Mousekeys, repeatKeys, SlowKeys, BounceKeys or ToggleKeys), mnemonics and shortcut keys;
- alternative pointing devices (e. g. foot operated mice, head mounted pointing device, or eye tracking systems);
- software mouse simulators (for moving the mouse pointer by pressing keys on the numerical keypad);
- speech recognition software (for text input or user interface control via speech);
- text to speech (makes the compute talk to user);
- predictive dictionary speeds up typing by suggesting words as the user types;
- comprehension software (allows dyslexic or learning disabled computer user to see and hear text as it is manipulated on the computer screen).

These technologies are designed to be used in the case of mobility, visual, hearing or cognitive impairments, depending on the type and severity of the disability. Screen magnification software may be suitable for low vision computer users because it enables them to read portions of the screen more easily by enlarging the screen's content. For the physically disabled, an alternative to a regular keyboard or mouse may be necessary in order to use the computer. Many users with mobility impairments use computers without assistive technologies, but navigate using the keyboard [4]. Others use hardware add-ons such as alternative pointing devices to aid their interactions.

Web accessibility initiative

The World Wide Web Consortium (W3C) realized that people with different kinds of disabilities often have difficulties in using the Web. These might be related to a combination of barriers in the

Web-pages presentation, and barriers in the user 'agents' (browsers, multimedia players or assistive technologies such as screen readers or voice recognition) [18].

The W3C Web Accessibility Initiative (WAI) has been established to raise awareness of universal access. WAI develops guidelines that can help to ensure that Web pages are widely accessible and, in particular, by users with disabilities and special needs.

The WAI gives a set of recommendations including:

- Web Content Accessibility Guidelines (WCAG),
- Authoring Tool Accessibility Guidelines (ATAG),
- User Agent Accessibility Guidelines (UAAG).

The WCAG is addressed to web authors, while the ATAG and UAAG are mainly set to software development communities [18].

The guidelines are mainly based on the following four principals:

- Perceivability—Information and user interface components must be presentable to users in ways they can perceive;
- Operability—User interface components and navigation must be operable;
- Understandability— Information and the operation of user interface must be understandable;
- Robustness— Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

In this paper, we are interested in WCAG. The WCAG discusses accessibility issues, provides accessible design solutions and contains many guidelines that are general principles of accessible design, not limited to certain browser or a particular technology.

The WCAG can be compared to a checklist, while the checkpoints are classified in three priority levels based on their impact on the accessibility of websites. The compliance of the priority levels result in three conformance levels (A', 'AA' and 'AAA'), which assess the conformance of each page [18].

Web Content Accessibility Guidelines (WCAG) 2.0 defines how to make Web content more accessible to people with disabilities.

A conformed web page to WCAG 2.0, should satisfy the following requirements:

- Level A: For Level A conformance (the minimum level of conformance), the Web page satisfies all the Level A Success Criteria, or a conforming alternate version is provided
- Level AA: For Level AA conformance, the Web page satisfies all the Level A and Level AA Success Criteria, or a Level AA conforming alternate version is provided
- Level AAA: For Level AAA conformance, the Web page satisfies all the Level A, Level AA and Level AAA Success Criteria, or a Level AAA conforming alternate version is provided.

MODEL DRIVEN ARCHITECTURE

MDA is an approach for application of specification and interoperability [6]. MDA is mainly based on the separation of concerns between domain knowledge and platform specificities. It relies on the use of MOF (Meta Object Facility) meta-models and UML (Unified Modelling Language) models for every step of the application life cycle.

This approach depends on the definitions of:

- a specification model called the Computational Independent Model or CIM;
- a conception model called the Platform Independent Model or PIM;
- an implementation model called the Platform Specific Model or PSM;
- a set of model transformations (also called mappings).

At the first level, systems requirements are modelled in a Computation Independent Model (CIM) that defines the system within an operating environment. At the next level, we find the Platform Independent Model (PIM). A PIM describes the system functionality, but without considering details about where and how the system is going to be implemented. The aim of the following step is to transform a PIM into a target Platform Specific Model (PSM). The most important advantage of this approach is that it allows software engineers to define automatic transformations from PIMs to PSMs [5].

To make MDA, in practice we can use a variety of language such as RDF or UML, which are available for this purpose. They vary greatly in their capabilities.

- UML (Unified Modeling Language) is the industry-standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems.
- RDF (Resource Description Framework) and RDF Schema (the Schema Language for RDF) are W3C Recommendations for describing metadata on the web.

In order to reach our goal, UML is the most appropriate language to use to define the different models of our global system at a very high level of abstraction. RDF will be used in the transformation of different obtained models in a web context.

The MDA architecture

CIM: The Computation Independent Model is the business model that describes the requirements of the application. The design of CIM is realised

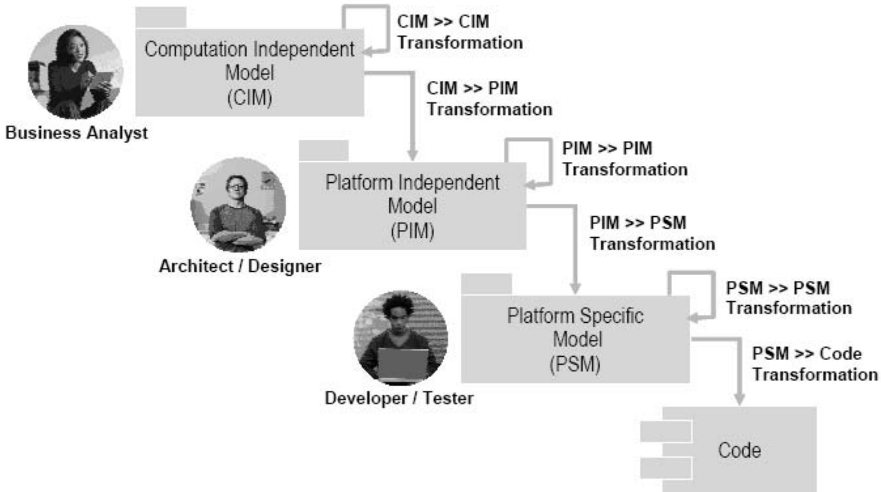

Fig. 1. Architecture of MDA models.

using UML use case diagrams. It is represented in Fig. 1 by *Business Analyst.*

PIM: The Platform Independent Model is the domain concept model. It is a model that describes all knowledge related to an application domain. The application components are specified without considering implementation techniques, but providing generic computing architecture. The PIM is generated from the CIM. The OMG encourages the use of UML at this level.

PSM: The Platform Specific Model is the data and processing model. It describes how a PIM is adapted to an existing platform, by integrating the implementation technical details, and provides the description of a deployable software system. Starting from a PIM, we can obtain one or more PSMs for different chosen platforms. A PSM is partially generated from a PIM. At this level it is possible to use the UML profiles to construct specific cartridges for disabled learners.

Model transformations: Model transformations are the heart of MDA. Transformation rules ensure the transfer from one model to another. The mappings can be considered as applications and are described by models.

The Object Management Group (OMG) encourages the use of the standard QVT (Query, View, and Transformation) that defines the metamodel for model mappings [15].

MDA (Model Driven Architecture) is a recent initiative from the OMG that supports the definition of models as first class elements for the design and implementation of systems.

According to the MDA approach, the most important activities are modelling the different aspects of a system and then defining transformations from one model to another in a way that allows automation. The main task of the system designer focuses on model definition, leaving implementation details until the end, which makes these models more portable, more adaptable to new technologies (i.e .NET, J2EE or Web Services) and more interoperable with other systems regardless of the technology they use [2, 3].

Model transformations are the heart of MDA because they enhance productivity. Transformation rules ensure the passage from one model to another. The mappings can be considered as applications and are described by models [3].

UML profiles and MDA

UML provides a set of extension mechanisms (stereotypes, tagged values and constraints) (Fig. 2) for specialising its elements, allowing customised extensions of UML for particular application domains [2, 15]. These customisations are sets of UML extensions grouped into UML profiles, which can play an important role in describing the platform model and transformation rules between models.

The profiles package included in UML 2.0 defines a set of UML artefacts that allows specification of a Meta Object Facility (MOF) model to deal with the specific concepts and notation required in particular application domains, such as real-time, e-learning and, among others, accessibility or implementation technologies (such as .NET, J2EE or CORBA)[2].

UML 2.0 outlines several reasons why a system designer and developer should customize his metamodel:

- to add semantics left unspecified in the metamodel;
- to add semantics that do not exist in the metamodel;
- to add constraints that restrict the way you can use the metamodel and its structure can be used;
- to add information that can be used when transforming one model to another model or to code.

Nowadays, there are OMG profiles such as the Enterprise Distributed Object Computing (EDOC) profile, the Common Object Request Broker

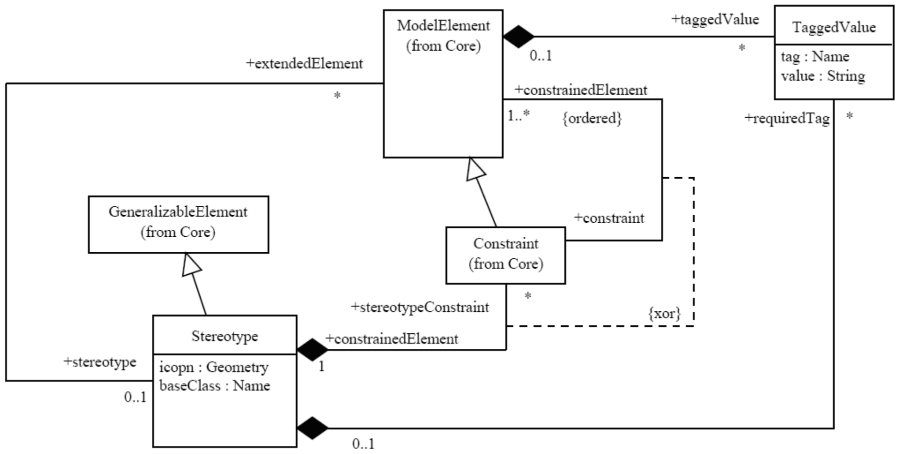

Fig. 2. Meta-model of UML profile.

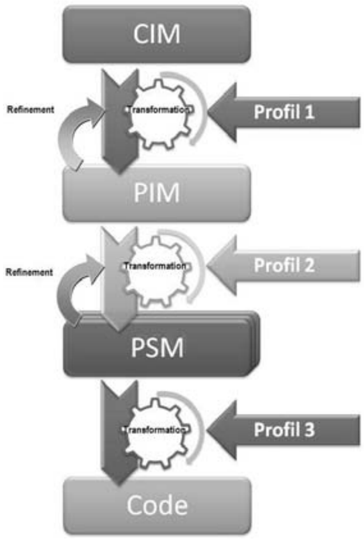

Fig. 3. Architecture of PBAEF.

Architecture (CORBA) profile and the Quality of Service (QoS) profile. Many other predefined profiles are defined, particularly in an educational context. The Cooperative Problem-based learning Metamodel (CPM) consists of a UML profile to design cooperative problem based learning situations at didactical level [12].

UML profiles can play a particularly important role in describing the computation model, the platform models and the transformation rules between models.

The mechanisms provided by UML profiles are very well suited to describing models for any implementation platform. The idea is to use the stereotypes of analysis and specification levels by offering general marks to a CIM and prepare the establishment of corresponding PIM. The same procedure is used with PIM and PSM.

A mark represents a concept in the PSM, and is applied to an element of the PIM to indicate how it must be transformed into the target PSM.

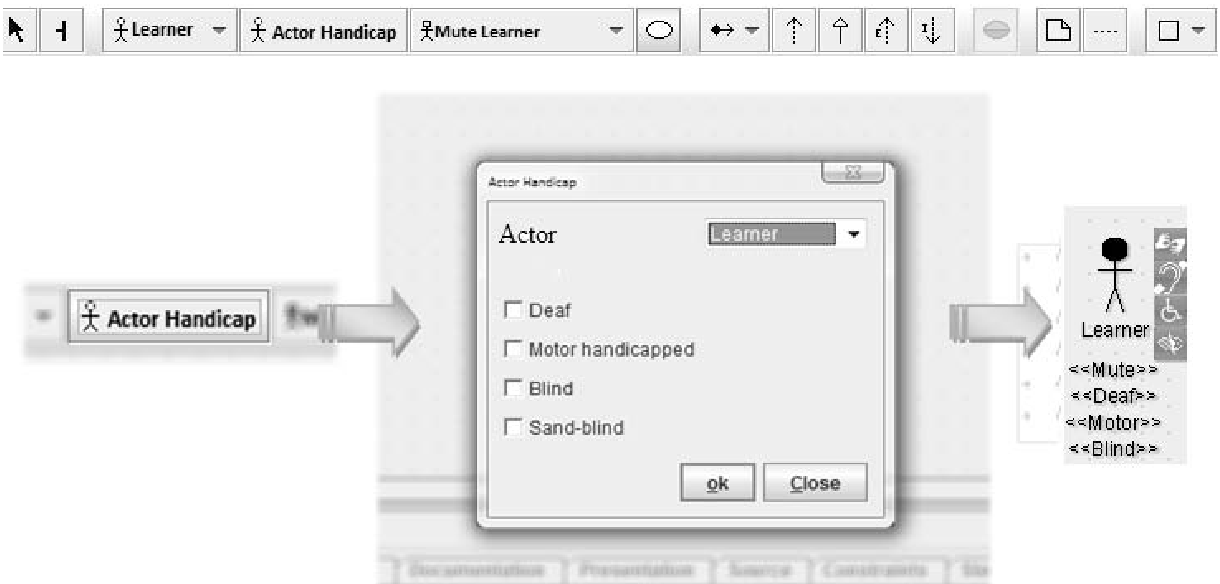

Fig. 4. Definition of disabled student in accessible e-learning systems.

OUR FORMALISM

In order to apply MDA in the development process of accessible e-learning systems, UML profiles is used to define a new formalism adapted to accessible e-learning systems.

Our formalism, called *PBAEF* (Profile Based Accessible E-learning Formalism), uses a UML profile at the three modeling level relative to the MDA approach about whom the two first models are detailed in this paper (Fig. 3).

The transfer from one model to another or the refinement of the same model is ensured by a set of transformation rules driven by UML profiles.

The definition of profiles is based on stereotypes, tagged values and constraints. Stereotypes are illustrated by pictograms whereas tagged values and constraints are described by text.

To implement our formalism, we used ArgoUML [13], which is one of the most efficient open sources Computer Aided Software Engineering (CASE) tools based on UML standards [17].

The CIM level

This model is defined by UML Use Case Diagrams. At this level, actors are profiled by using stereotypes in order to semantically enrich the model and to prepare it for eventual transformations. Every stereotype represents one or an aggregation of impairments corresponding to an actor, such as being blind or deaf (Fig. 4).

In an educational context, actors can be visually impaired students. For this reason a profile is composed to define the appropriate user profile (Fig. 5).

Having selected a type of actor, different actions are automatically assigned to it; for instance, course consultation using screen readers for blind students, or/and Braille printing or zoom functions for users with low vision (Fig. 6). As illustrated in

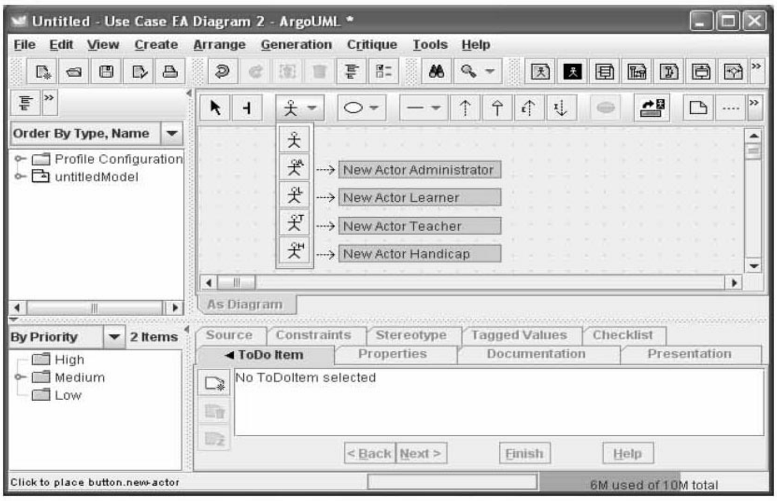

Fig. 5. List of stereotyped e-learning actors.

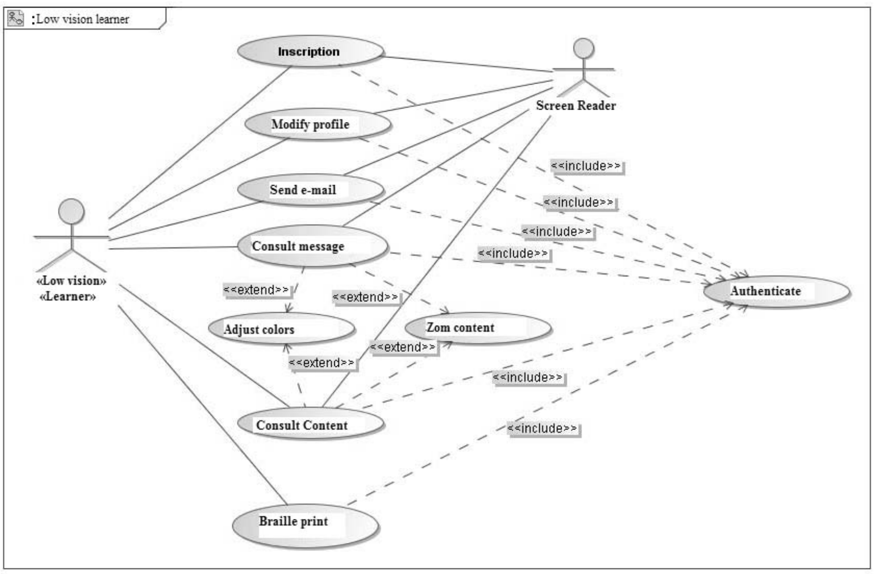

Fig. 6. Example of CIM for students with low vision.

Fig. 6, the screen reader is integrated in the Use Case Diagram and it is considered as an external actor.

The *MAR* (Metadata for Accessibility Repository) obtained at this level of transformation will be used at CIM to PIM transition.

The PIM level

PIM, which describes the systems functionality independently of any platform, is defined using UML class diagrams. This definition takes into account all the accessibility guidelines and all the e-learning standards such as LOM (Learning Object Metadata), SCORM (Sharable Content Object Reference Model) [14] (Fig. 7).

At this level, profiles are also used to improve the classes' semantic and at the same time to prepare PIM models for further transformation. Every profile is described by a simple or composed stereotype represented visually by pictograms (Fig. 7), tagged values and constraints. Tagged values give the model element more explanation with textual description and constraints are used to formally describe particular conditions on the model through the OCL (Object Constraint Language) language.

Figure 8 illustrates a histogram class represented by a picture symbol. The transformation of this class gives a new UML class diagram, which is a refinement of the same model.

For example, if a designer wants to model an image class such as histograms, it is automatically assisted through the image profiles corresponding to WCAG guidelines and derived from CIM mappings. The transformation of this element is based on ordinary UML concepts such as generalization and enhanced by accessible educational context.

All the accessibility proprieties are inherited. The histogram can be considered as an illustrative image. This image can be described by a short text limited by a certain number of characters fixed through constraints as expressed in the following example:

Context image
If alt < 60
Then longdesc –> isEmpty()
Else longdesc –> notEmpty()
Endif

This example means that when the length of textual alternative (*alt*) of one image is more than

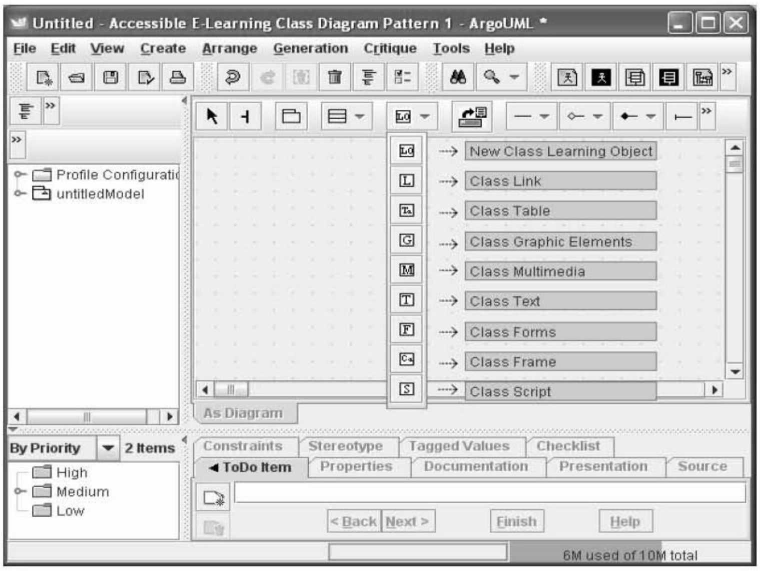

Fig. 7. Profiling learning object and e-learning standards.

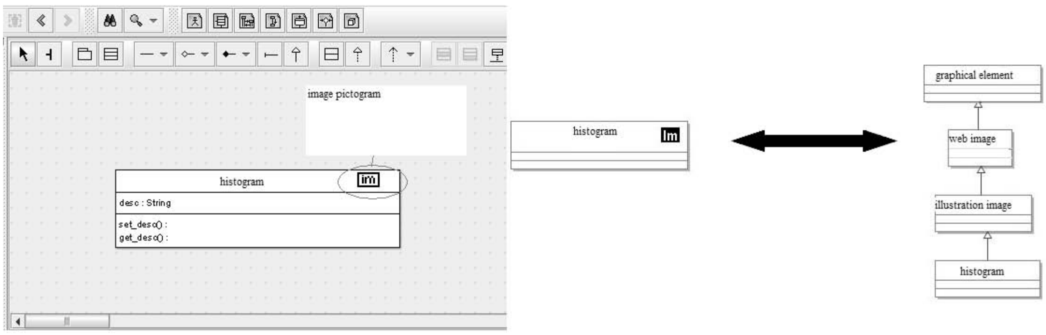

Fig. 8. Accessible image stereotype.

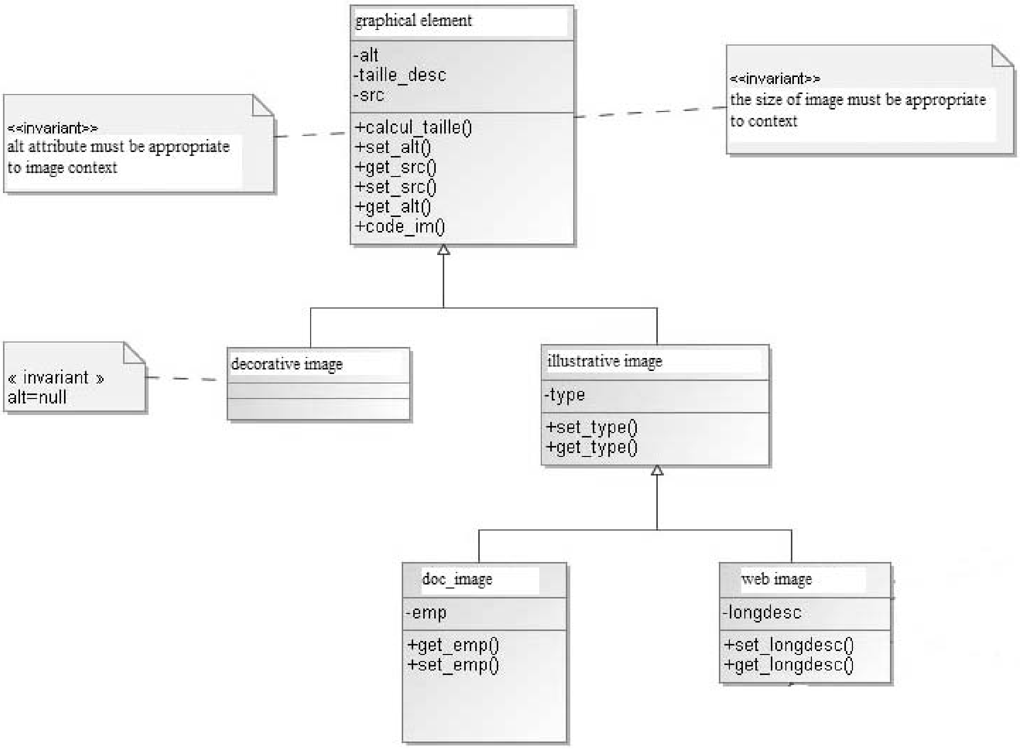

Fig. 9. Meta-model of accessible graphic Learning Object.

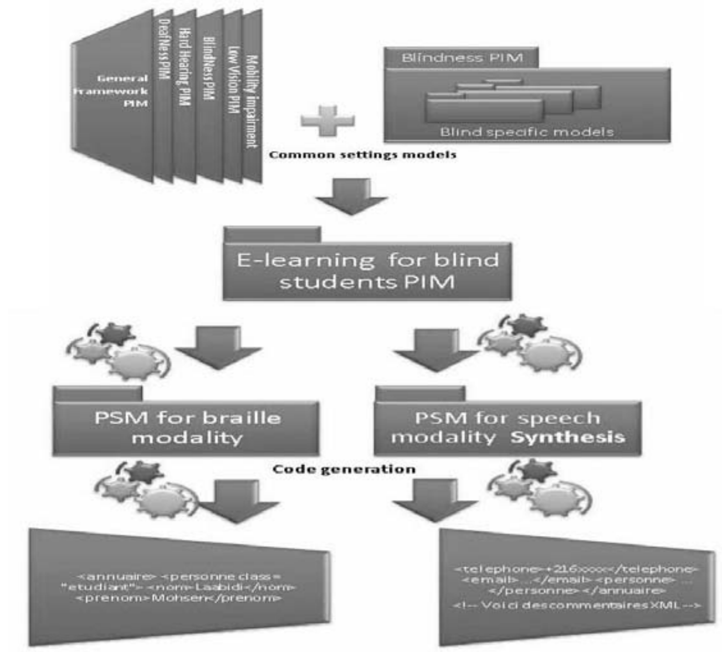

Fig. 10. Architecture of MDA based accessible e-learning system.

60 characters, the image must be described with more details using the *longdesc* attribute, which indicates the file containing this description.

For the same example, the tagged value can specify that *the content of the alt must be at least similar to the text subscribed on the image* (Fig. 9).

Finally, profiles defined at PIM level are also used to define automatic transformations from PIMs to PSM [15] (Fig. 10).

CONCLUSIONS

In this paper, we have introduced a new formalism that aims to make MDA applicable to the development of accessible e-learning systems. The *PBAE* is mainly based on the definition of UML profiles. E-learning standards and WCAG guidelines represent the core of each profile definition.

Our new formalism allows us to define clearly the different MDA models from the CIM to the PSM model and also to prepare model mapping using a formal description of both accessibility and e-learning and taking into consideration the semantic side of the web.

The application of *PBAE* was illustrated using ArgoUML, one of the most efficient open source Computer Aided Software Engineering tools. Extended by some adequate profiles, ArgoUML is now able to help us to create models of the target e-learning components conformably to the MDA approach.

The new formalism we developed is very promising. For instance, the entire defined stereotype, tagged values and constraints represent efficiency accessibility and e-learning standards. We propose in the near future to enrich our formalism by defining the transformation between different models. In this way, taking the semantic side of the web into consideration proves to be very interesting.

REFERENCES

1. A. Kavcic, Software accessibility: recommendations and guidelines, *Eurocon*, **2**, (2005), pp. 1024–1027.
2. A. Vallecillo-Moreno and L. Fuentes-Fernández, An introduction to UML profiles. European Journal for the Informatics Professional. Available at http://www.upgrade-cepis.org, **5**(2), (2004), pp. 6–13.
3. B. Selic, D. Starcevic and Z. Obrenovic, A model driven approach to content repurposing, *Multimedia*, IEEE, **11**(1), (2004), pp. 62–71.
4. C. Atkinson and T. Kühne, Model-driven development: a metamodeling foundation, *IEEE Software*, **20**(5), (2003), pp. 36–41.
5. N. Moreno and R. J. Romero, e-MDA Framework: model reuse in building e-learning systems, IADAT -e2005, *International Conference on Education*, Biarritz, France, July, (2005).
6. Mozilla Accessibility Project: Software accessibility–where are we today? Available at www.mozilla.org/access/today.
7. M. Arrigo, E-learning accessibility for blind students, *Recent Research Developments in Learning Technologies*, (2005).
8 P. Brusilovsky, Adaptive and intelligent technologies for web-based education, special issue of *Intelligent Systems and Tele-Teaching*, **4**, (1999), pp. 19–25.
9. R. Raghavan, *LCMS and LMS Taking Advantage of Tight Integration*, Click2learn, Inc., (2001).
10. S. Mirri, A multimedia broker for accessible learning objects transcoding, *Information and Communication Technologies*, **1**, (2006), pp. 641–646.
11. S. Kinash, S. Crichton and W. S Kim Rupnow, A review of 2000–2003 literature and the intersection of online learning and disability: Electronic curb-cuts, *American Journal of Distance Education*, **18**(1), (2004), pp. 5–19.
12. T. Nodenot and P. Laforcade. CPM: a UML profile to design cooperative PBL situations at didactical level, *Proceedings of the Sixth International Conference on Advanced Learning Technologies (ICALT'06)*, (2006) pp. 1113–1114.
13. http://argouml-downloads.tigris.org
14. http://www.accessiweb.org
15. http://www.omg.org/mda
16. http://www.section508.gov
17. http://www.uml.org
18. Web Accessibility Initiative, W3C. Available at http://www.w3.org/WAI, (2007).

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