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A General Framework Supporting User-Adaptive Learning for Highly Interactive Content in Virtual Learning Environments

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Proyecto de Fin de Máster en Sistemas Inteligentes

Un Marco de Referencia para la Integración de Aprendizaje Personalizado Basado en Contenido Altamente Interactivo en Entornos Virtuales de Enseñanza

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Máster en Investigación en Informática
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Resumen

El campo del e-Learning ha evolucionado y madurado durante las últimas décadas. Poco queda ya de aquellos antiguos repositorios de contenido estático que recibieron un sonoro fracaso en los 90. Los actuales Sistemas de Administración del Aprendizaje (SAA) son ricas aplicaciones Web que apoyan los procesos de aprendizaje para múltiples roles y estrategias pedagógicas. Además, los SAA combinan muchas de las herramientas más comunes que se encuentran disponibles en la Web (por ejemplo foros, chats, wikis, etc.), revisadas y adaptadas para aumentar su potencial educativo. Como consecuencia, los SAA se han convertido en una tendencia muy popular en el campo del aprendizaje asistido por ordenador.

Sin embargo, los SAA siguen teniendo tareas pendientes. Una de las más importantes concierne a la falta de soporte para el aprendizaje adaptativo de estas plataformas. Aunque la idea de personalizar la experiencia de aprendizaje a las necesidades de cada alumno ha estado presente en el campo durante décadas, pocos de los conceptos propuestos han llegado a los SAA. Muchas han sido las causas a las que se ha atribuido esto, a las que nosotros ahora queremos añadir una más: la ausencia de contenido flexible y altamente interactivo en este tipo de entornos. Este tipo de contenido permitiría por una parte, adaptar de forma más sencilla el contenido educativo, y por otra, facilitaría que el sistema pudiera llegar a "conocer" al alumno para personalizar su aprendizaje. Según nuestra opinión, muchos de los sistemas adaptativos que han triunfado en otros campos (por ejemplo *Amazon*™) lo han hecho en parte por guardar multitud de información sobre la interacción del usuario para así personalizar los servicios que le ofrecen. Si algún día los SAA tienen que dar soporte al aprendizaje adaptativo, esto debería tenerse en consideración.

Dentro de este enfoque, proponemos la introducción de contenido altamente interactivo en SAA, y concretamente de video juegos educativos. El potencial del aprendizaje basado en juegos está ya prácticamente fuera de discusión; además su potencial adaptativo está todavía por descubrir. Sin embargo, existe un problema relacionado con la accesibilidad de los juegos, un tema que debe solucionarse dada la importancia de involucrar a todos los alumnos en su educación.

Por ello en este trabajo proponemos un marco de trabajo genérico y flexible que tenga en cuenta estos requisitos:

- Que facilite la integración de juegos en SAA.
- Que permita establecer un canal de comunicación entre distintos SAA y juegos para dotar al SAA de más información sobre la interacción con el usuario.
- Que considere accesibilidad desde el momento de su concepción como algo fundamental.

Abstract

The field of e-Learning has evolved and matured during the last decades. From the old static repositories of content that achieved a thunderous failure in the 90's very little is left. Modern Learning Management Systems (LMS) are now powerful Web-oriented environments that support the learning processes for multiple roles and pedagogical strategies. Moreover, LMS brings together most of the common features that are available on the Web (e.g. chats, forums, wikis, etc.), but reviewed and adapted to enhance their educational potential. As a consequence, LMS are probably the most popular trend in computer-supported learning not only within the academia but also in the industry.

Nevertheless, LMS still have some pending tasks. One of the most important is the lack of explicit support for adaptive learning that these systems usually present. While the idea of computer-supported adaptive learning has been around for decades, populating the research field with multiple approaches and pilots, LMS have not incorporated any of those ideas in order to tailor the learning experience for the needs of each student. Many are the reasons that have been related to this issue; nonetheless we would like to point out one more: the absence of highly interactive and flexible content that could be easily adapted on the one hand, and which could provide LMS with valuable information about the user interaction on the other. In our opinion, most of the adaptive systems that have achieved success in other fields (e.g. *Amazon*™) are known to store all the data that the system can get from the user in order to personalize their services. If adaptive learning is to be supported by LMS, this should be considered as a mandatory point.

Within this perspective we propose the introduction of highly interactive content in current LMS, and more specifically the introduction of educational adaptive video games. During the last years the educational potential of video games has been broadly accepted in the academic community, and their adaptive potential is to be unveiled yet for educational purposes. However there is a problem in educational gaming that has not been addressed yet: the lack of "accessibility", which should be addressed given the importance of involving all the students in learning.

Therefore in this work we present a general and flexible framework that deals with these issues:

- It facilitates the integration of video games in Learning Management Systems.
- It establishes a communication channel between different LMS and games to provide the LMS with information about the user's interaction.
- It considers accessibility as a mandatory requirement since its conception.

Table of Contents

Index of Tables

Index of Figures

Chapter I

Introduction

1. e-Learning: the digital age meets education

The evolution and rapid development that technology has experienced in the last decades has changed our lives dramatically. Especially the rise and extension of the Web and the Internet has modified the way we interact with the world and what we expect from it, giving origin to what has been called the *digital revolution*. And this sudden revolution has not only affected the business sector; the fact is that all the fields have been forced to follow a process of self-reinvention in order to accommodate to this new digital age (*adapt or die*).

The educational field would not be the one to escape from this trend. During the last decades the interest in how to exploit the new possibilities presented by technology in order to provide students with better learning experiences has increased exponentially, originating a research field known as Technology-Enhanced Learning (TEL). Numerous approaches are covered within this field, including, for instance, the use of intelligent tutors, mobile devices, videogames or even educational robots, achieving different rates of adoption in each case (P. Brusilovsky, 1998; Sharples et al., 2005). One of the trends that have really achieved general adoption is related to the use of Web-based systems, the so called *e-Learning*. The term comes from the early 90's, when the rise of the Internet provoked that the market were suddenly populated with loads of systems containing primarily hypermedia and hypertext learning materials. The "big idea" was that students would be able to access such content from the comfort of their own homes, learning at their own pace and exactly when they wanted. That is the well known motto of "learning everywhere and at every place", which originated a trend that was given the name of *e-Learning*. Nevertheless these early and naïve e-Learning systems were mainly a spectacular failure, as their simplicity made them unattractive to students, what added to the disconnection between instructor and student resulted in systems with a very low access rate, high dropout rates, and which produced very poor learning outcomes (Fernández-Manjón et al., 2007; Fernández-Manjón et al., 2009).

But the e-Learning field learnt from its mistakes, and with the explosion of rich web applications e-Learning reinvented itself. Thus e-Learning systems are not any more passive repositories of content which students are supposed to access at their own risk, but rich applications that support the learning processes in multiple manners and for all the roles involved in them (that is not only students but also instructors, content authors or even course administrators).E-Learning systems are not any more naïve repositories of static content but live environments that provide students and instructors with tools supporting the whole learning process. These are the so called *Learning Management Systems (LMS)*, also known as Virtual Learning Environments (VLE). If these terms were to be defined with total accuracy differences between them will arise; however for the scope of this work all will considered the same as they present a common set of features.

The use of these systems has growth so much in the last years that now most of the educational institutions in the developed countries offer these systems as a support tool. For instance, most of the universities in Spain have their own Virtual Campus, which is usually a web platform based on a LMS. Best known examples of these tools could be *Moodle*™, *Sakai*™, *.LRN*™ or *WebCT™-Blackboard*™.

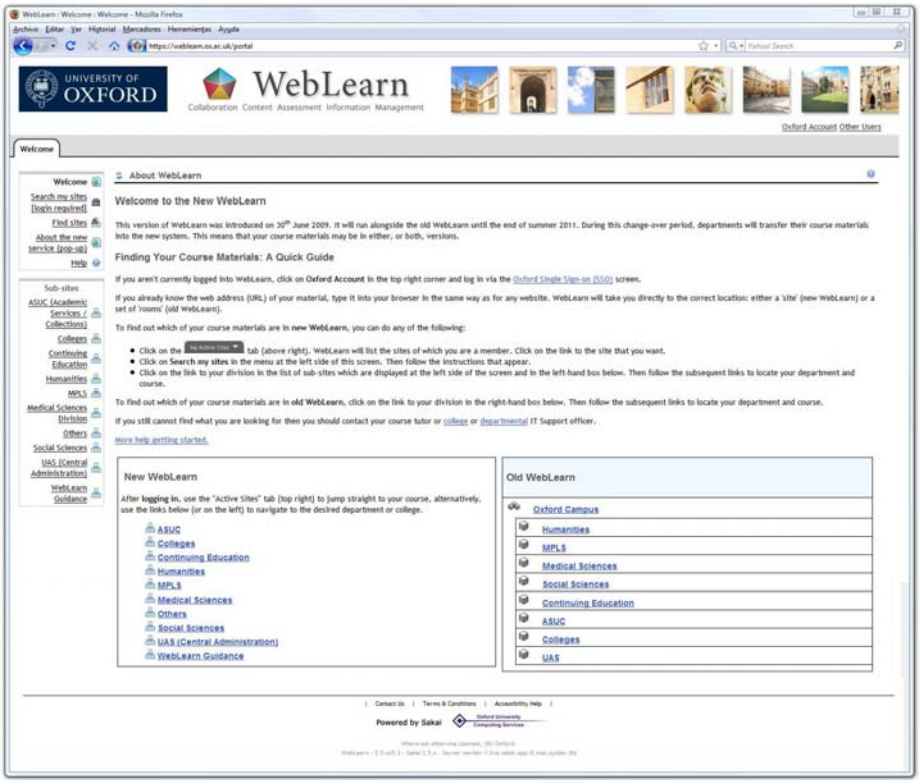

Figure 1. Screenshot of the Virtual Campus used in Oxford University, which is based on the Sakai™ Learning Management System.

2. The need of personalization in e-Learning

So now the discussion is not any more about the effectiveness of e-Learning environments, but about how to move towards new challenges. Between the multiple active research areas that might lay the basis for next-generation e-Learning systems, we can find authors advocating for the integration of the Semantic Web (Koper, 2004), social software (Cho et al., 2007; Naeve et al., 2006), informal learning (Eraut, 2004; Folkestad, 2006), computer supported collaborative learning (Cho et al., 2007), mobile learning (Sharples et al., 2005), etc.

In this mare magnum of research, there is a strong trend that advocates for the personalization of the learning experience for each individual. Multiple researchers have put forward that students abilities, attitudes and conditions towards learning may vary so widely that what might make a student learn might not work at all for a different student (Gagné et al., 1992). Moreover, it has also been said that the lack of personalization in learning may be one of the foremost causes of scholastic failures and drop outs. While instructors can deal with this issue in the classroom, at least partially, it is much more difficult to do so in online courses. That is a strong argument to support the need of e-Learning systems that incorporate personalization as a mandatory feature.

This idea is not new. The concept of personalized learning has been around almost since computers were born. Authors quickly started to argue that computers could support the development of "intelligent systems" that would be able to guide students during the learning process, providing in this manner personalized, student-meaningful learning experiences. Following this basic idea multiple systems rapidly started to populate the market. Some of the most popular were Adaptive Hypermedia Systems (AHS) (P. Brusilovsky, 1998; P. Brusilovsky et al., 2007) or Intelligent Tutors

(Murray, 1999).

In spite of these efforts, adaptive learning systems have not achieved a real success in terms of general adoption. As a proof of that, we could say that there are few LMS integrating ideas from adaptive learning environments or providing any kind of explicit support for adaptive learning. This might be attributed to several factors. To begin with this field of research is currently being developed, and little evidence about the effectiveness of the approaches presented to the academic community has been provided. Secondly, developers of e-Learning platforms may see that the relation between development cost and effectiveness of adaptive systems is still unbalanced, what makes the investment very risky (Hauger et al., 2007). Nonetheless, this lack of success of adaptive learning systems is probably related on the one hand, to the kind of content they are usually intended for and, on the other hand, to a lack of real data about the user.

About the first issue, these systems are usually oriented to Web and multimedia materials which are not very flexible and therefore it is difficult to personalize them if we try to go beyond a simple personalization of the interface. The second issue is as well related to the type of content. This kind of content is not really interactive and as a consequence system cannot really track the interaction with the student and thus it is much more difficult for the system to infer knowledge about the student. Since most of the adaptive learning models proposed include an explicit or implicit model of the student as a base, this is a major issue. The conclusion is that the introduction of new types of content, much more interactive and flexible, may provide, or at least outline, new perspectives that could lead to the general adoption of adaptive learning systems.

3. Video games: the future of adaptive e-Learning systems?

Video games are one of the types of content that meet the requirements above described in terms of flexibility and interactivity. In fact, video games have been pointed out as a good educational approach due to the numerous enhancements of the educational processes they can provide, if properly used (Aldrich, 2005; J. Gee, 2007; J. P. Gee, 2003; T. W. Malone et al., 1987). Between the most frequently cited advantages related to educational gaming are their power to keep students focused and motivated (T. Malone, 1981), their ability to immerse students in the in-game world (Squire, 2003), their short feedback cycles (de Freitas et al., 2006), perception of progress or their relation to constructivist theories and support of scaffolded learning (Prensky, 2001).

Moreover, some authors indicate that video games are an ideal medium for personalize learning experiences (Leutner, 1993). Digital games are rich pieces of interactive software that can gather a lot of information about the students. Furthermore adaptation is innate in digital games as game designers try to adjust the learning experience to enhance the engagement of the game for each user. It is true that most of the adaptation techniques implemented in video games are naive, like rough profiles of difficulty (e.g. novice, intermediate and advanced) where the user should choose the one that better fits him/her. Nonetheless there are video games which implement much more advanced adaptation models, like Dynamic Difficulty Adjustment techniques (R. Hunicke, 2005). As a consequence, educational games could not only provide real game-based adaptive learning experiences, as digital games can be adapted on-the-fly, but to provide a very interesting source of interaction that could be used to enhance the amount and value of information about the user, improving thereby the performance of the overall adaptive system.

But in spite of the potential of adaptive educational gaming, there are still few educational games implementing adaptive behaviour. The scarceness of adaptive educational games may be directly influenced by the extra development cost it involves. Moreover, market pressure makes that game companies keep their advances in the matter very secret, what impedes reuse and prevents the academic community could from profiting on the advancements of the industry.

4. Accessibility in e-Learning and games: a specific case of adaptation

Accessibility is an issue that has a great impact in technology-enhanced learning settings. After all education is a universal right and therefore when it is not taken into account students with special rights may be deprived of such right. According to the 2007 US Census Bureau[1], 18% of the US population and 11% of children from 6 to 14 have some level of disability, with 12% of the total population having a severe disability. That is a lot of students that need special support from educational technologies, affecting both e-Learning environments and educational games.

Thus there has risen an initiatives aiming to guarantee the universal accessibility of e-Learning environments and educational games, such as the *IMS AccessForAll (IMS Global Consortium, 2004a)* specification or the *International Game Developers Association (IGDA)* special interest group in accessibility, which provide guidelines to produce accessible content (M. H. Bierre, T Martin, M McIntosh, T Snider, 2004). These guidelines usually recommend that all the information, even the small details must be transmitted through alternative channels at the same time in order to make the content accessible to people with visual or hearing disabilities. That is usually carried out, for example, by combining subtitles and sound/voices so the lack of a sense does not imply that any kind of information is lost.

It is interesting to see the relation that exists between accessibility and adaptation in the terms above defined. For instance, consider an "ideal" adaptive learning environment and a specific situation where a learner is located at an extremely noisy place. If an activity of the course that the learner is accessing contains information that is transmitted through sound, the student will not be able to receive it. Thus the system should be able to adapt the learning experience and provide the information using text or other channels available at that time. In this case there is little between a person that is deaf and a student that can hear perfectly under normal conditions.

Therefore accessibility could be seen as a specific case of user-adaptation. Moreover, ideally adaptive learning environments should compulsory deal with accessibility issues. However both fields are still analyzed separately.

5. Summary and conclusions of the chapter. Identification of goals

In this chapter the e-Learning field has been described, giving a high-level perspective, trying to explain where it comes from and how it has evolved and become a mature technology. However there are still unresolved issues, like the lack of explicit support for adaptation in e-Learning systems. While the concept of computer-supported adaptive learning has been around in the field even before e-Learning was born, it has not found its way to reach the most popular platforms nowadays: the Learning Management Systems. Between the causes, the lack of scalability of typical

[1] http://www.census.gov

adaptive learning environments, like AHS and IT, and the deficiencies of the content which is typically used within these systems in terms of flexibility and interactivity, which impedes the systems of getting the amount of information needed to get real knowledge about the user.

After that educational gaming has been introduced as a very promising field, with lots of advocators (and also some detractors) arguing about the potential of games for learning in terms of motivation, immersion and short feedback cycles, and after a long list, for supporting adaptive learning. Nonetheless several pending issues need attention in this field, such as how to integrate the games in the classroom. Furthermore, it is not clear how to design or implement adaptive games, neither from an educational nor an entertainment-driven perspective, which is a major challenge.

Finally issues about accessibility in e-Learning and games have been presented. While the importance of making technology accessible to all people with independence of their specific needs is broadly accepted there is no general agreement in how to translate this to video games. And if video games are to be integrated in our schools this is an issue that cannot be left aside.

The heterogeneous nature of this chapter may surprise the reader since, apparently, there is not a clear connection between the fields presented. But, in my opinion such connection not only exists but also can help to solve the numerous challenges discussed so far if it is developed carefully; actually most of those challenges are unlikely to get solved if each field is considered separately.

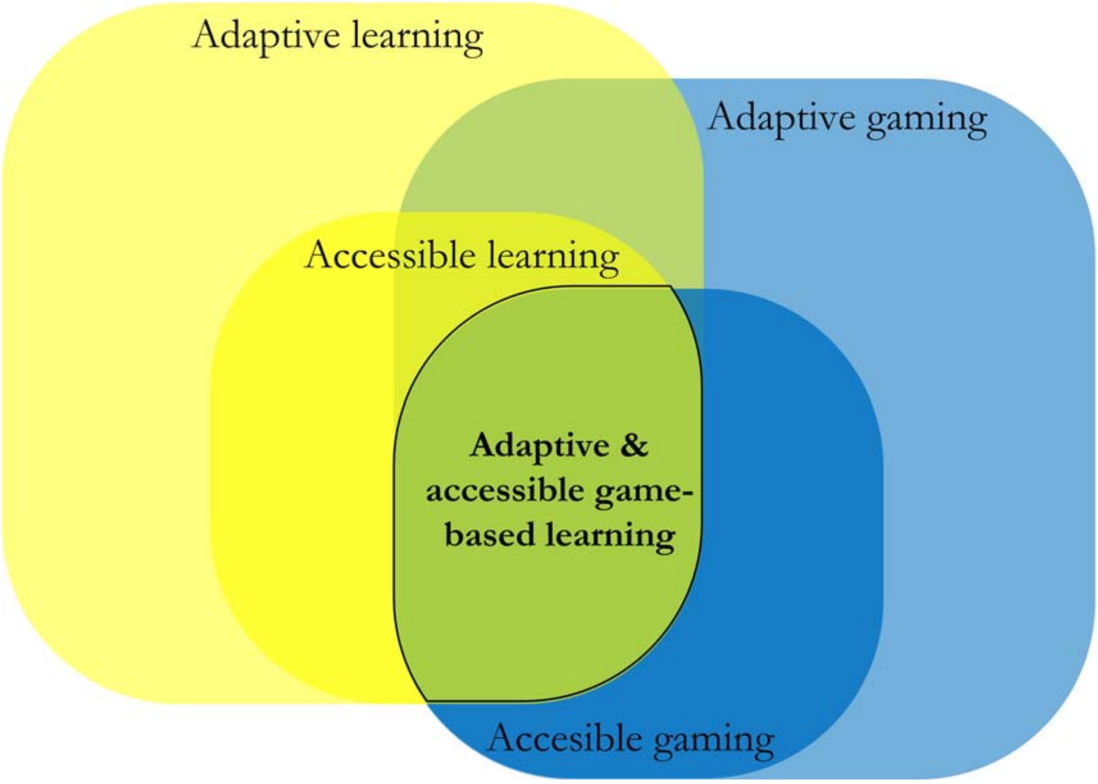

Figure 2. Venn diagram representing the relation between adaptation and accessibility in learning and gaming.

In this manner, e-Learning environments can profit from games as they are highly interactive pieces of software that can provide loads of valuable information about the user, how he/she learns and plays. Moreover video games are, as opposite to Web and typical multimedia content, extremely flexible and could be adapted in many different ways to cater for the needs of a broad audience. In return e-Learning can be an ideal medium to introduce games in the classroom given its general adoption.

On the other hand, accessibility can be considered just a special case of adaptation. Actually “accessibility” can be defined as the intent to attend the special requirements of people with disabilities and impairments, a definition that fits very well in the concept of adaptive gaming and adaptive learning (cater for the needs of each individual). Moreover, addressing the needs of impaired people from a more general point of view can achieve a level of enhancement of the game and learning experiences that could not be achieved otherwise.

As a conclusion, we oversee that all these issues can converge in one solid approach, which constitutes the ambitious motivation of this work. The final goal could be summarized as the development of adaptive game-based learning experiences that could be integrated into current e-Learning systems to promote its general use and which consider accessibility as a special case of adaptation.

In addition we should clarify a bit the scope of this work and the approach followed. It is almost impossible to address the problem presented from all the different perspectives (that is, e-Learning environments, adaptive learning, adaptive gaming, accessible gaming, etc.). Besides, each field itself is still mutable and attracting a lot of research from different areas. Thus the scope of this work is limited to make a general study of all the fields and aspects, trying to find points were they could converge, and propose a general framework where research within the areas involved could coexist. Therefore it is not the purpose of this work to develop a full model of adaptation where detailing all the aspects, but to generate the base for a future and ambitious line of research. However, this work is promoted within the *FLEXO*[2] project (Spanish Ministry of Industry, Tourism & Trade, “Avanza” Program I+D: TSI-020301-2008-19), which aims to develop a generic model of adaptive and accessible learning in open-source systems. Within this project the *<e-UCM>*[3] research group, where this work has been developed, is focused on the development of adaptive and accessible games that can be integrated in e-Learning systems. That constraint motivated that the approach followed in this work is much more closed to the “gaming” point of view than to any other. Finally, we also include as an appendix the result of this work, the paper entitled *“Implementing Accessibility in Educational Videogames with <e-Adventure>”*, which is to appear in the proceedings of the 1st International Workshop on Multimedia Technologies for Distance Learning (MTDL 2009). Further details about the workshop and the full citation can be found on appendix A.

Considering all these premises we define the following goals:

- *To develop a general framework that integrates adaptive gaming in Learning Management Systems, with the double motivation of enhancing students' experience in terms of engagement and learning outcomes and provide sources of user-related information for the LMS in order to maximize the adaptation capabilities of the system. Besides the framework should consider additional requirements that may arise as a consequence of considering accessibility as a particular case of adaptation.*
- *To particularize the framework for the <e-Adventure> platform as a requirement of the FLEXO project, with the objective of facilitating the development of adaptive and accessible video games that could be integrated in standards-compliant Learning Management Systems.*

[2] http://www.ines.org.es/flexo/

[3] http://www.e-ucm.es/

Chapter II

State of the Art

1. Introduction

In this section the state of the art that supports the motivation of this work is presented and discussed. As this work aims to achieve the convergence of e-Learning, adaptive educational gaming and accessibility as a particular case of adaptation into a solid approach that would address some of the challenges that these areas are facing separately, the state of the art of each field has to be analyzed separately. However, a detailed description of all the fields is out of the scope of this work. Therefore these areas are analyzed from the perspective of what each one can contribute to the global junction, describing the most representative approaches and ideas that could be reused for this work.

Therefore this chapter is structured in five sections, six if this introduction is counted. Firstly, in section 2 the current state of the art of adaptive learning environments and e-Learning systems is analyzed. Then in section 3 issues about adaptation in video games are discussed, both considering educational and entertainment-driven uses. After that, in section 4, the most important initiatives that are being carried out to guarantee the universal accessibility in e-Learning systems are briefly presented. The last discussion, section 5, describes the special nature of accessibility in digital games, as the particularities of this type of content demand special attention. Finally section 6 provides the conclusions that we have extracted from the analysis of all these fields, and which lay the basis of our motivation to approach this work.

2. Adaptive Learning Environments and Learning Management Systems

According to some scholars, the observation of the Computer Assisted Instruction (CAI) field depicts a clear dichotomy, with Adaptive Learning Environments (ALEs) on one side, and Learning Management Systems on the other (Hauger et al., 2007; Paramythis et al., 2004). While the first have rarely escaped the research field, the second are the most popular tools in the market of learning technologies. While ALEs implement innovative and complex techniques for user-modelling, content adaptation, etc., LMS integrate concepts that have succeeded in the world of Web technologies and apply them to the support of learning from a practical point of view. In this section we briefly describe both trends from a critical point of view, trying to identify successful elements that could be applied the framework we aim to develop.

2.1. Adaptive Learning Environments

The idea of developing software tools to support students along their educational process almost dates back to the day computers were born. Very quickly the concept evolved and the idea of providing personalized tutoring using computers arose. Actually Adaptive Learning Environments (ALE) are one of the pioneer systems targeting user-personalization, applying techniques that have been generalized to other fields, like online associative shopping systems (e.g. *Amazon™*[4]) or music players (e.g. *LastFM™*[5]). However, between the numerous systems which could be labelled as Adaptive Learning Environments, only few have achieved real success, and they were never left the boundaries of the research field. This section provides a brief

[4] http://www.amazon.com

[5] http://www.lastfm.es/

analysis of the most popular trends in ALEs, the so called Intelligent Tutors (IT) and Adaptive Hypermedia Systems (AHS). Thus in section 2.1.1 the common techniques used in ITs and AHSs are discussed. After that, in section 2.1.2 common approaches to the representation of user and domain information (user and domain modelling) are presented, as those are relevant for our work. Finally section 2.1.3 aims to provide the reader with a critical view of ALEs, identifying potential causes of their failure. It is not the purpose of this work to give concrete examples of ALE systems, which can be consulted in one of the reviews on ALEs that are available in the literature: (P. Brusilovsky, 1996; Graf et al., 2005; Hauger et al., 2007; Kareal et al., 2006; Paramythis et al., 2004; Shute et al., 2003).

2.1.1. Intelligent tutors and Adaptive Hypermedia Systems.

One of the first trends that could fall in the category of Adaptive Learning Environments is the related to the development of Intelligent Tutors or Intelligent Tutoring Systems (IT). As an informal description, an IT is an expert system that provides customized instruction and feedback to the student. Usually ITs are considered as Artificial Intelligence programs that simulate the behaviour of a real instructor. In this manner, first pilots of ITs were mainly shell-based conversational systems where students could ask questions and receive feedback (Murray, 1999), although modern ITs include GUI-based interaction. The main goal of ITs were to detect wrong mental patterns of the student, correct them by providing the adequate information, or guide the student to the acquisition of the right mental pattern. Thus ITs are clearly oriented to the personalization of the learning experience according to the *knowledge* the student has (or has not). In addition, some ITs provide adaptation according to the preferences of the student.

Other trend that has been focusing on the personalization of the learning experience for each student is the related to Hypertext and Hypermedia Systems. Hypertext could be defined as collections of text (nodes) containing links to other chunks of text (other nodes) (McKnight et al., 1991). With the generalization of multimedia the term “hypermedia” was coined as a generalization of hypertext, considering not only text but other kinds of information such as images, sound, etc. (Gygi, 1990; Seaman, 1993). Hypermedia Systems rapidly attracted researchers trying to implement adaptation techniques over HS that could personalize the information that each user receives depending on his/her specific characteristics, originating the so called *Adaptive Hypermedia Systems (AHS)* (P. Brusilovsky, 1996; Peter Brusilovsky et al., 2001; De Bra et al., 2003).

In AHS adaptation is usually carried out at two levels (Beaumont et al., 1995): at the *content level* and on the *link (or navigational) level*. Adaptation at the content level is usually related to the presentation of that content. Thereby, no adaptation over the content itself is carried out. Typical examples of adaptation at the presentation level would be replacing a graphic by another one. However, few times the own content is adapted, as this is a significant challenge. Regarding the approaches followed in AHS for “content adaptation”, (Hauger et al., 2007) classifies them in 5 categories (adapted from (Hauger et al., 2007)):

- *Additional explanations.* The system tailors the content that is delivered to the user, displaying only the parts of the document that match the student’s knowledge or learning goal. The idea of adapting the learning content according to the learning goals is quite frequent in AHS. For instance, Brusilovsky (1996) identifies that students usually have different goals and expectations when approaching to learning in diverse contexts or situations.
- *Prerequisite explanations.* If a prerequisite (a concept that the student

needs to have to be able to understand others) for a concept is not sufficiently known, that information is inserted by the system so the student can really understand the concept.

- *Comparative explanations*. The system links the knowledge that the student is trying to acquire to those that already has, facilitating learning for students who prefer meaningful learning (Ausubel, 1963).
- *Explanation variants*. When this kind of adaptation is carried out, the system chooses from a list of knowledge fragments which is the one that better suits the learner's requirements.
- *Sorting*. The system orders the pieces of information according to the student's requirements and learning tastes. This facilitates learning for students with different learning styles (Vermunt, 1996).

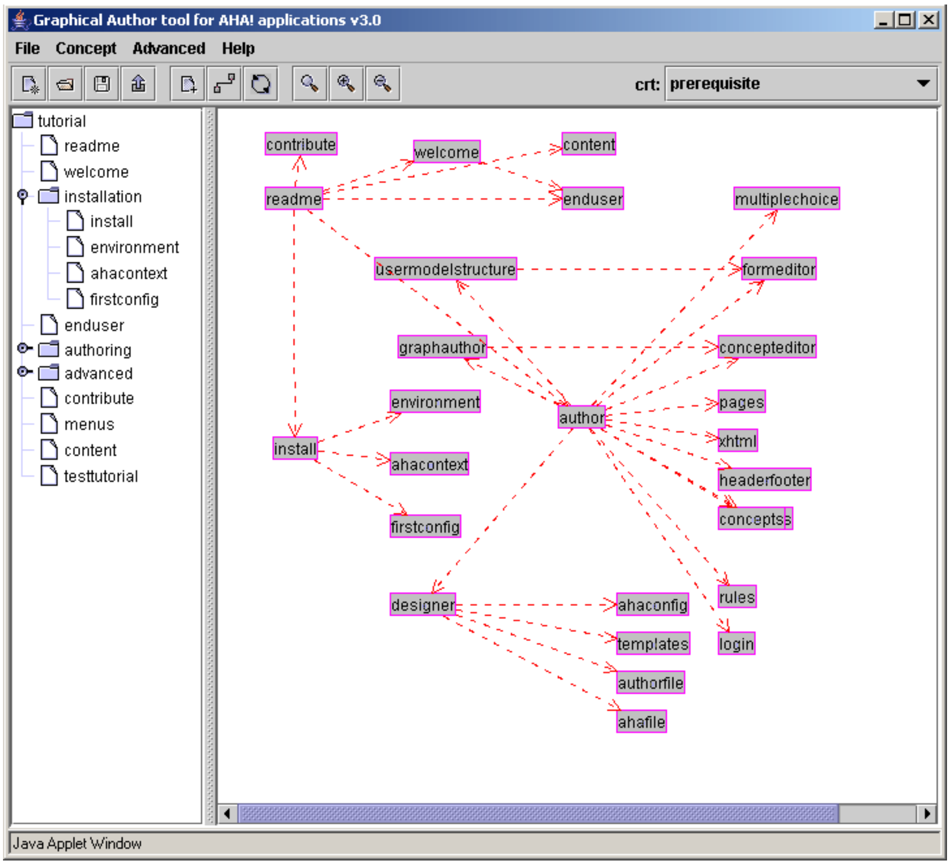

Figure 3. Graphical author tool for the AHA!© Adaptive Hypermedia System. The editor allows instructors to define prerequisites between nodes, fixing the possible navigation itineraries. Adapted from the AHA! Online tutorial[6]

Adaptation at the link level is, on the other hand, oriented to guide the user in the discovery of the knowledge that the system presents. For instance, following this approach it could be possible to prevent the user from accessing an advanced piece of content before other, more basic concepts, are acquired. Moreover, instructors could apply different instructional strategies over the navigational space by defining

[6] http://aha.win.tue.nl:18080/aha/tutorial/

alternative routes over the navigational space for users with different requirements. Navigational adaptation approaches can be classified as follows:

- *Direct guidance.* The user has not the control over the learning process, as the system decides in each step what is the next portion of knowledge that the student has to be acquired. This is usually performed in a manner that the user is not aware of this process. For instance, an approach in this regard is to display the same "next link" button for all users but adapting the content that is displayed next for each user.
- *Adaptive sorting.* The system proposes the order in which the student has to visit all the pieces of information, but the user decides where to go next. This is usually done by sorting the list of links.
- *Adaptive hiding.* Depending on the characteristics of the user and the knowledge he/she possesses, the system hides or disables links that lead to concepts that are irrelevant or distracting.
- *Link, map and graphics annotation.* Links, graphics or other content are annotated by text, colouring, an icon, etc., to give some extra information to the learner that could help him/her during the process of knowledge discovery.

2.1.2. Student and domain models

As discussed so far, there are a lot of different approaches and adaptation techniques within the field of Adaptive Learning Environments. Most of them rely on implicit or explicit models, like the adaptation or instructional models. However, the most common models in these systems are the information that the system keeps about the user, which is usually known as the *student model*, and the *domain model*, used to represent the knowledge that the student must acquire. While the first is always present, implicitly or explicitly, the second can be present or not depending on the type of ALE. According to Aroyo (2006), some adaptive systems use a specific domain model (*"concept-based")*, but others are not bound to a specific concept and do not require a domain model. ALEs of the second type try to be applicable for teaching multiple domains. However, concept-based systems are much more frequent. The next paragraphs give more details and general considerations about how ALEs treat the student and the domain models.

Kareal (2006) states that the presented information should adapt to the learners' prior knowledge and skills, learning capabilities, learning preferences or styles, performance level and knowledge state, interests, personal circumstances (location, tempo, etc.) and motivation.

- *Student model.* Also called learner model. This is a general model containing information about the user, but including data about his/her approach to learning. This may include the idea of learning styles. While instructors usually have the intuition that learning styles exist, there is no evidence that confirm this hypothesis. Actually, the approach of learning styles has been criticised sometimes by claiming that the same person will necessarily use different learning styles for different goals and domains. Regarding how student models are updated, this could be done either at interaction time, keeping the trace of the student, or using the assessment of the learning experiences in order to determine what knowledge did or did not acquire. Besides, student models may include information about the knowledge the student has, does not have, and even what he/she thinks to have (wrong assumptions). When such issues are considered, the definition of a domain model is also required (P. Brusilovsky et al., 2007).

- *Domain model*. As discussed in section 2.1.1, most of current ALEs are focused on the adaptation of how the content is presented to the student. Therefore the domain is usually a representation of the course being offered. Nonetheless, in the cases where more general learning activities are supported the domain model may additionally contain information about workflows, instructional approach, participants and their roles, etc. (P. Brusilovsky, 1996).

2.1.3. Current limitations of ALEs

As analyzed so far, ALEs have been on the debate for long. Most of them propose interesting features and approaches to guide the student through the learning process, or to personalize the "chunks" of content that are presented to them. Then the question is why these systems have not succeeded beyond the research field. Some authors have depicted possible causes of this lack of success. According to (Conlan et al., 2002) the level of reuse in ALEs is very low, as most of the times these are tightened to a certain domain. Other authors point out that the lack of standardization in the field is one of the main causes of this lack of reusability (Paramythis et al., 2004). This is a major issue, as to enable full interoperability between platforms there should be "standard" models for user and domain. While the first issue could be addressed, the second is almost impossible.

In our opinion, this is lack of generalized adoption is also linked to the type of content these systems consider. The adaptation of documents is a very complex issue given that documents are rigid pieces of content. While there are techniques for adapting and building text automatically (these are usually investigated within the natural language processing field), they are costly and not mature enough to be applied in real scenarios. On the other hand, these approaches present limitations that come from the nature of the content they present, not from the implementation or design of the systems. While the system is able to track the interaction of the user *within the system* (e.g. links that are pressed), it is not able to track the interaction with the content as documents are not interactive. This is a clear constraint that limits the source of information that the system can use to infer the user model. Thus ALEs make their assumptions about the user by measuring time stamps of the navigation events (e.g. when a link is followed), the results of online tests or the sequence of nodes visited. But how can the system determine, for instance, if the user is stuck? Just determining if the student is really reading the text, skimming it or has gone for a coffee is something hard. This is a major issue that should be addressed as adaptive systems that have succeed, as *Amazon*™ or *LastFM*™ rely on huge amounts of data about the user and his/her interaction within the system.

2.2. Learning Management Systems

By the term of *Learning Management System*, informally speaking, we identify environments that are usually Web-oriented, and which support the learning process with multiple tools like synchronous and asynchronous communication facilities, course management features, in-built assessment tools, etc. Moreover, LMS include mechanisms to involve people with different roles (e.g. instructors, students, course administrators, etc.), facilitating the interaction between all of them. In addition, their use is getting more and more generalized in diverse contexts (undergraduate education, professional training, etc.), not only as an alternative to face-to-face learning, but also as a complement to traditional models. This approach has been dubbed b-Learning (Garrison et al., 2004; Osguthorpe et al., 2003).

In this section we provide an overview of these environments, analyzing two aspects that are especially relevant for the scope of this work: the standards and specifications that have been developed to guarantee content interoperability within these systems, and the support for adaptive learning that modern LMS implement.

2.2.1. Standards and specifications to promote interoperability and reuse

The rapid generalization of the use of Learning Management Systems has promoted that the market had been populated with a broad range of competing platforms, each one trying to get their own business quota. Additionally, the e-Learning field is mature enough to admit that we cannot rely on delivering any kind of content at the students and expect them to learn. There is a need for high quality content, built with solid educational principles. This means that the authoring and maintenance costs for this content are becoming huge, and the variety of competing platforms may put the investment at risk if that expensive content is not interoperable between environments such as LMS, content repositories, etc.

That is the motivation for the trend of developing standards and specifications for educational content that is revolving e-Learning and therefore, Learning Management Systems. That is the case of the *Learning Objects Model* (Balatsoukas et al., 2008; Polsani, 2003) which addresses these issues by proposing a development strategy of learning content based on self-contained pieces of content that can then be assembled into courses and a standardized interchange format to simplify the interoperability of contents among systems and avoid vendor lock-in. The LOM model has been developed therefore in a very flexible manner, as a Learning Object can be, in fact, whatever kind of educational content, going from a simple HTML document to a huge, complex course. However, this may be seen as a drawback that limits the level of goal accomplishment that the model can get, as the lack of an underlying instructional model and a delimitation of the LO structure makes the model too complex to be manageable by instructors and therefore reusability may be unfeasible.

Taking LOM as a base, there are standards trying to regulate the encapsulation of content. That is the case of the IMS Content Packaging specification (IMS Global Consortium, 2004b) promoted by the IMS Global Consortium. The specification establishes a standardized format for the packaging and distribution of LO which is mainly a compressed file containing all the learning contents along with a manifest file which provides information that mainly describes the structure of the learning contents. Most of the more popular LMS have facilities to import and export IMS CP contents, such as *Moodle*™ (Dougiamas et al., 2003) or *WebCT*™/*BlackBoard*™ (Goldberg et al., 1997). This widespread adoption suggests that IMS CP can be taken as a preferred standard when it comes to packaging content.

In addition, the IMS CP specification is flexible and can be customized to specific scenarios through the so-called Application Profiles. One such profile is the Shareable Content Object Reference Model (SCORM) Content Aggregation Model (ADL, 2006), created in the context of the Advanced Distributed Learning (ADL) initiative.

ADL SCORM not only covers the packaging of learning objects, but also provides a communication protocol between an LMS and the learning objects that enables the exchange of data between the LMS and the content itself. This allows the LMS to gather tracking and assessment information generated within the LO. Moreover this connection can be used by the LMS to drive some kind of adaptation of the content (Ghali et al., 2008). In addition, the latest version of the ADL SCORM (Academic ADL Co-Lab, 2004) reference model introduces the concepts of Sequencing and Navigation (SCORM SN). SCORM SN allows content developers to create activity sequences and to define the interaction mechanisms to navigate through them. Thereby the interaction between the student and an LO can affect the sequencing process through the aforementioned communication mechanism (Anido-Rifón et al., 2002; Gonzalez-Barbone et al., 2008), which can also have valuable meaning from adaptation point of view. In this case the idea would be to alter pre-defined sequences of activities according to the outcomes of previous activities.

SCORM SN has a homologous alternative in the IMS Simple Sequencing specification. Another specification that is competing with SCORM is IMS Learning Design (IMS Global Consortium, 2003). In IMS LD, the LOs are part of the environments provided to the student during the exposition of activities and their outcomes can affect future branching decisions during the learning experience.

2.2.2. Current support for adaptive learning in LMS

Current specifications such as SCORM or IMS-LD include mechanisms for establishing a communication channel between LMS and content. Besides, they include specifications that allow instructors to define sequences of activities with branches. In this manner the outcomes of some activities can affect the decisions of the system and change what is the next activity to be delivered to the student. While this outlines a potential for adaptation, it is not an "in-built" adaptation feature. Actually, as some studies reveal, the support for adaptation in LMS is scarce.

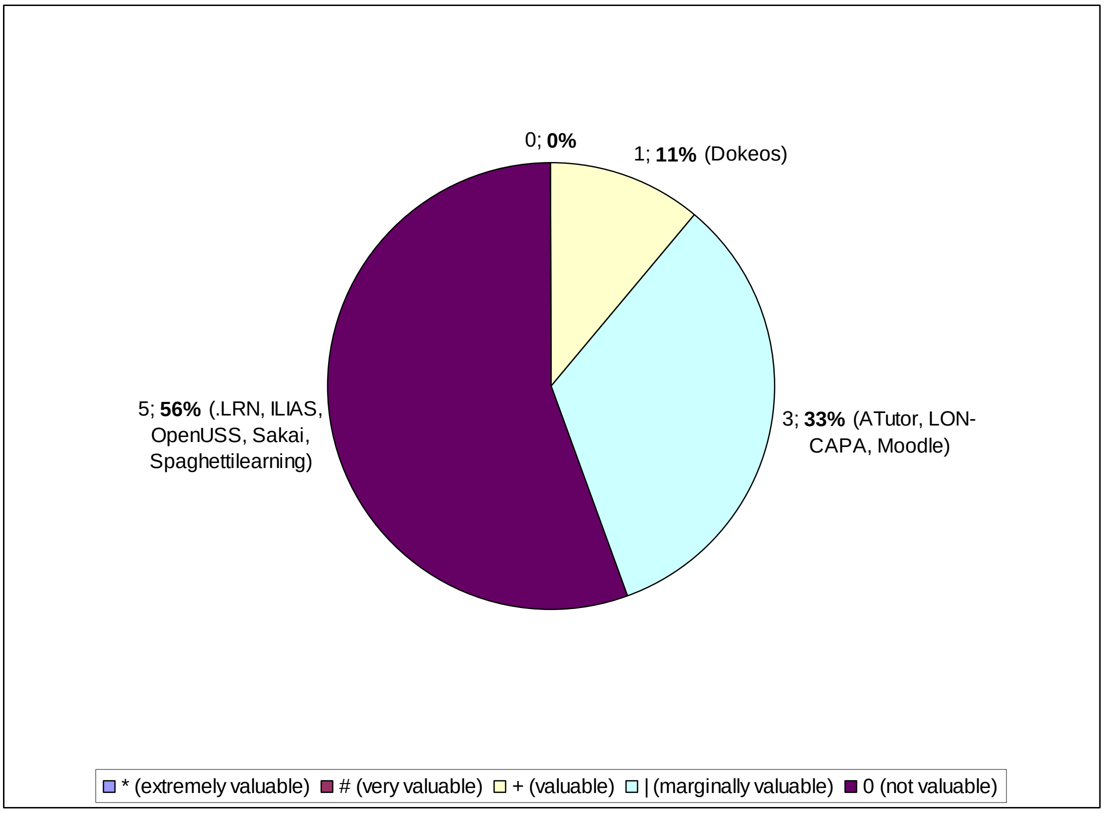

Figure 4. Results of the evaluation of adaptation in LMS carried out by Graf & List.

For example, in 2005, Graf & List (2005) carried out an evaluation of open source e-Learning platforms, including most of the more popular LMS, analyzing the quality of the support for several functionalities (e.g. forums, tests, etc.) provided by these environments, with special interest on the support for "adaptivity". In this work "adaptivity" is defined as "*all kinds of automatic adaptation to the individual user's needs (e.g. personal annotations of learning objects or automatically adapted content)*". The study evaluated 9 different platforms, including *Moodle*™, *.LRN*™, *ILIAS*™ and *Sakai*™, 4 well-known LMS, which met minimum criteria about its usage: to have an active community, a stable development status, and a good documentation of the platform. In this study adaptivity was evaluated according to the *Qualitative Weight and Sum (QWS)* approach (Scriven, 1991), giving each platform a level of quality within these 5 possibilities: *, #, +, | or 0, where * means extremely valuable and 0 means not valuable. The results of the evaluation are summarized in Figure 4.

As the graphic depicts, support for adaptivity in most of the platforms was evaluated as not valuable (56%) or marginally valuable (33%). Only 1 was evaluated as valuable (*Dokeos*™).

Multiple causes can be attributed to this lack of support for adaptation. Between the most frequently cited we find the scepticism of e-Learning developers towards the efficacy of Adaptive Learning Environments or the risk that involves investing in such technologies due to their high development costs.

3. Adaptive video games

The field of adaptive gaming is very wide and complex, including lot of research from the AI and Machine Learning fields. It is not the intention of this work to focus on such aspects, but on general trends and issues that could be applicable to general adaptive educational game development. Details about the concrete techniques applied in each case can be gathered from the references included along this section.

Thus this section starts with a discussion about the motivations for developing adaptive games and the relation that exists between those motivations and their potential to maximize the effectiveness of learning. After that, in section 3.2, we discuss the most common approaches for including in-game adaptation in games. As this section describes, most of the approaches deal with the concept of "challenge", trying to adapt the difficulty of the game for each player's abilities. In section 3.3 we provide an analysis of how adaptive video games generate information about the user in order to provide personalized gaming experiences. Finally, in section 3.4 some high-level approaches that are relevant for this work are described, including architectures, learning models and methodologies that deal specifically with adaptive gaming for educational purposes.

3.1. About the motivation of adaptive gaming and its relation to learning

There are multiple motivations that justify the need of user-adaptation in video games. Different authors have analyzed from the business perspective the economic profit that adaptable gaming experiences bring to the gaming industry, as adaptable gaming would attract more players into the market, one the one hand. For instance, Beal (2002) argues that gender-based adaptation may bring more female players, based on the relation between genders and approaches to problem solving, as girls usually prefer reasoned strategies where the solution is the logic conclusion of a thorough analysis of pros and cons. According to this supposition, a female player will undoubtedly need more time than a male player to react, for example, to the attack of an enemy. On the other, adaptive gaming will increase the overall satisfaction of the player as a costumer and therefore the "replay-ability" of the game will increase; that is, the probability that the player will play the game again, or future issues of the saga (Beal et al., 2002).

However, the most interesting from the educational point of view comes from the relation between learning and playing video games. Actually one of the reasons used to support the need of adaptation in video games is that the ability of the players increases as they learn how to play the game. This notion is considered by all game developers, although not all of them are conscious about it. The most traditional approach is to assume that the player will learn to play gradually as long as he or she progresses in the game, and use this "scalar acquisition of knowledge" to balance the difficulty of the games. That is what Charles (2004) calls the "learning curve", which can be smoothed applying adaptation techniques. Linking this to an educational process could make students (in this case players of an educational game) improve their learning outcomes.

This idea has been linked to the theory of flow proposed by (Csikszentmihalyi, 1990) (Chen, 2007). Based on the definition of Csikszentmihalyi of flow, which could be summarized as an extremely engaging experience, authors like (Chen, 2007; Salen et al., 2003) state that games have thus proven to be an ideal medium to achieve optimal flow experiences. As stated by (Shernoff et al., 2003) this is one of the most difficult characteristics of engaging learning activities. However, flow is still a notion in videogames, with scholars trying to model the aspects of the relation game-player that cause optimal flow (Cowley et al., 2008).

Another feature of video games that is remarkaby aligned to learning & education is that games provide immediate feedback to the player (Chen, 2007).

3.2. General approaches to the management of challenge in games: from difficulty profiles to DDA

Along with the development of adaptive gaming, different approaches have been proposed. For instance, a game could uses changes of camera and sudden turns in character's view in order to provide in-game guidance, and how this may be used for educational purposes. Following a similar idea, some authors have identified the potential for education of NPC-guidance (Non-Player Character). In this manner, the game will use a NPC to provide some aid to the player without breaking the game atmosphere, for instance, when the player is stuck. One good example of this approach is *The* Prime *Club/Climb*™ game (Stern et al., 2005). Other approaches would be to provide simple hints, like illuminating a specific area of the scene, or adapting the behaviour of NPCs or even the own player's abilities. Other interesting approaches are those trying to provide adaptive game narratives, which is something challenging from a technical perspective but full of potential, as the *Façade*™ game depicts (Conati, 2002). However, the most common approach is to deal with the concept of challenge and try to adapt the game to make it enough challenging to be engaging but not frustrating, according to the player's abilities (that is again, the theory of flow). In this section we analyze most common approaches for dealing with difficulty adjustment in games: difficulty profiles and gaming 'mods' on the one hand, and Dynamic Difficulty Adjustment on the other.

3.2.1. Difficulty profile settings & gaming modification tools

The idea of personalizing the challenge of games for the abilities of each individual is not new, although the most common approaches to achieve this can be considered quite straightforward. However, "straightforward" in the last sentence should not be given a negative meaning. Sometimes simple solutions work better for complex problems than more advanced solutions. That will depend on the requisites of each application.

In this line two approaches are the most used by far: *difficulty profiles* and *gaming modification tools*. The first one is related to the typical screens where players select the difficulty of the game from a very limited range of options (typically novice, medium and advanced). In this manner the game is configured, before play starts, with a set of pre-defined parameters, such as the number of opponents per room, the speed of vehicles or the damage that each shot will produce in enemies, that are completely static (that is, they will never be changed online in the game). During the game-play the challenge that the player faces will increase linearly as a function of the levels or game tasks completed, assuming that the ability of the player increase linearly as well, or not vary at all. This behaviour is quite easy to implement for game developers, as once the parameters that will be adjusted in each case are identified the exact values for each difficulty profile can be determined during the testing phase. In other kind of games, such as adventure games, the difficulty profiles can be implemented completely "ad-hoc", allowing novice users to progress in the game without completing complex tasks. It deserves to be noted, nonetheless, that there are neither standards for defining difficulty profiles in games nor to define how to measure the difficulty of a game: each developer chooses their own classification.

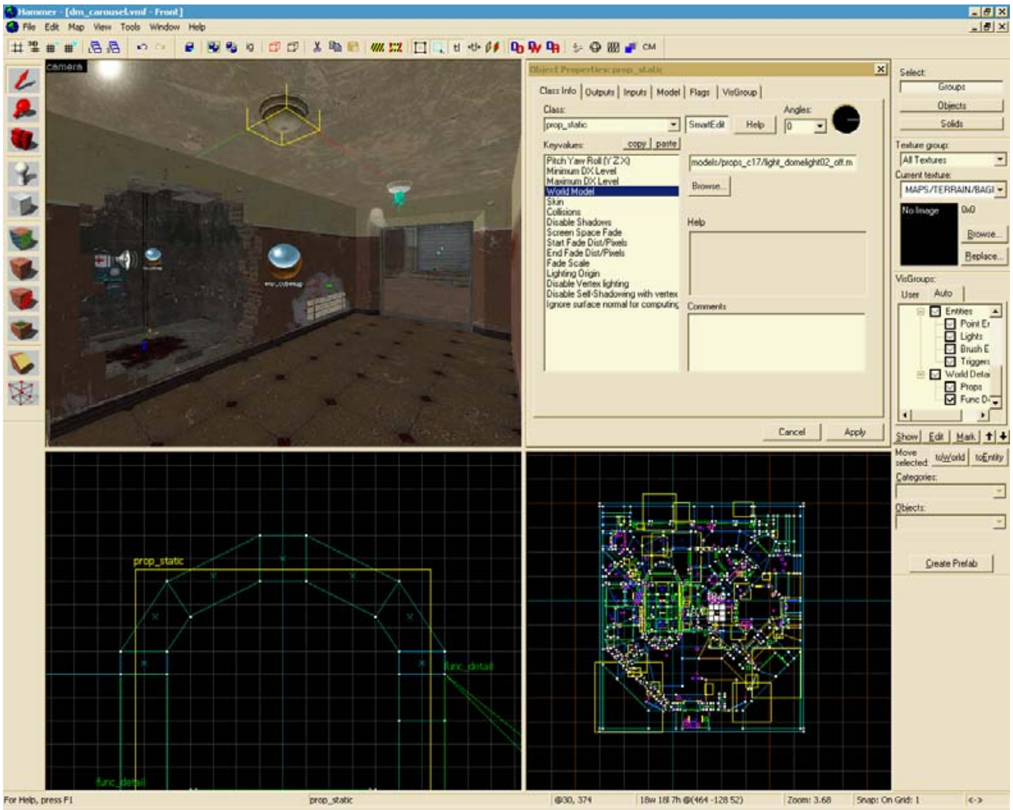

Figure 5. Screenshot of the *Hammer*© editor, developed by *Valve Software*™[7]. This is the map modification tool for the popular game *Half Life 2*™.

The second approach, game modification tools ('mods' in colloquial language), is very popular as well, but it is more tightly linked to certain game genres, like Role-Playing Games, First-Person Shooters or strategy games. These tools typically allow users to customize their own game-play experience by defining their own maps, levels, and characters. The challenge of the game can be adjusted thereby by modification these elements. This makes the life time of the games much longer as when players are not challenged by the original game any more they can produce their own new levels. That is why these modification tools are sometimes developed and distributed by the own company that created the game. That is the case of *id*

[7] http://www.valvesoftware.com/

Software©[8] or *Firaxis©*[9].

3.2.2. Dynamic Difficulty Adjustment

The high-level approach that is most frequently cited is, probably, the technique known as *Dynamic Difficulty Adjustment (DDA)*, also called *Automatic Dynamic Difficulty*. This technique could be defined as the process of automatically adapting the game experience with the objective of keeping the player in the flow channel all the time, which is performed in real time, transparently to the user and based on the player's performance.

The idea actually tightly related to the concept of *flow*, as the motto of DDA is to detect in-game situations where (1) the challenge that the player is facing is excessive for his/her skills, making the game *frustrating*, and the opposite, (2) situations where the challenge is insufficient to match player's capabilities and thus the game becomes *boring*. To achieve this goal, the game is expected to be continually monitoring the performance of the player and estimate somehow the level of challenge. Typically this will be carried out using heuristics over certain parameters such as the times the player has been killed in the last minutes or the rate of increase/decrease of health. When the value returned by the heuristic is less than a minimum reference value the game will assume that the game is too easy (thereby boring) and will increase the challenge, for instance, by increasing the number of enemies. In the opposite situation, where the heuristic exceeds a maximum reference value the challenge will be decreased.

Figure 6. Screenshot of MaxPayne™. Copyright by 3D Realms™[10].

There are lots of specific architectures proposed under the term of DDA (Robin Hunicke et al., 2004; Robin, 2005) including multiple techniques taking from the Artificial Intelligence (AI) in general, and Machine Learning in particular, like neuronal networks or fuzzy logic. Actually this field has attracted a lot of research,

[8] http://www.idsoftware.com/

[9] http://www.firaxis.com/

[10] http://www.3drealms.com/

becoming a good test bed for applying state-of-the-art advances in AI. For instance, in (Spronck et al., 2006) the authors present a novel approach called "Dynamic scripting" for in-game adaptation. Nevertheless, very few of these initiatives have finally moved from the stage of "innovation" to the stage of "product", and when this happens few details about the implementation are made public. The best example is *Max Payne*™, which is for many the "prime" example of DDA games. *Max Payne*™, released in 2001, is a third-person action game (shooter) where the player controls a member of the New York police department. The only issue that we know about DDA in *Max Payne*™ is a rough description of the parameters being used: average health, kills made per level, number of deaths per level.

Other action games including some kind of DDA that have been published recently are *FarCry*©[11] and *Left4Dead*©[12]. This last one is supposed, according to its developers, to include a revolutionary adaptation and AI engine called *The Director*™[13]. This adaptation engine features a dynamic system for game dramatics, pacing and difficulty. This game engine is supposed to be able to adapt elements such as the in-game music to enhance immersion. Moreover, its sequel (*The Director2*™) is even able to adapt the maps of the game online. Nonetheless the game still includes difficulty profiles so the interest of the player is also taken into account in this process.

As a summary, DDA could be seen as the antithesis of difficulty levels. Defenders of DDA argue that players should never be allowed to select the level of challenge; instead of that the game should adjust the difficulty for them. The next words of Scott Miller from *3D Realms*™, project leader of *Max Payne*™, which is the "prime" example of DDA games, could summarize the opinion of DDA supporters:

"As developers, it should be 'our job' to properly play balance the game, not the player's choice. In other words, skill levels are an easy way out for developers too lazy or incompetent to properly play balance their own games."

(Scott Miller, project leader of *Max Payne*™, *3D Realms*™.)[14]

As these words depict, DDA is controversial. In fact, arguments advocating for and opposing to DDA can be counted in the same numbers. For instance, removing all the selectable difficulty profiles will leave the player completely unprotected against a possible flaw in the design of DDA. Besides the effectiveness of DDA depends on a completely noiseless execution, as if the player is aware of the automatic changes that are happening in the game he/she would be able to cheat the system and immersion could get damaged (Charles et al., 2005). This is typical of karting games such as *Crash Bandicoot*™[15] or *Mario Kart*™[16]. For instance, in *Mario Kart*™ players who are in the last positions when the race comes to the final laps receive special power-ups and bonus in order to leverage the opportunities of winning. When players become aware of this behaviour they lessen their performance when the end of the race is approaching in order to get the bonus that will allow them to win. Additionally

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[11] http://es.wikipedia.org/wiki/Far_Cry

[12] http://www.l4d.com/

[13] http://left4dead.wikia.com/wiki/Director

[14] Extracted from http://dukenukem.typepad.com/game_matters/2004/01/autoadjusting_g.html

[15] http://village.crashbandicoot.com/splash/

[16] http://www.mariokart.com/wii/launch/

this arises the problems of privacy, and other people argue that users should be given option to choose so they still in control of the experience.

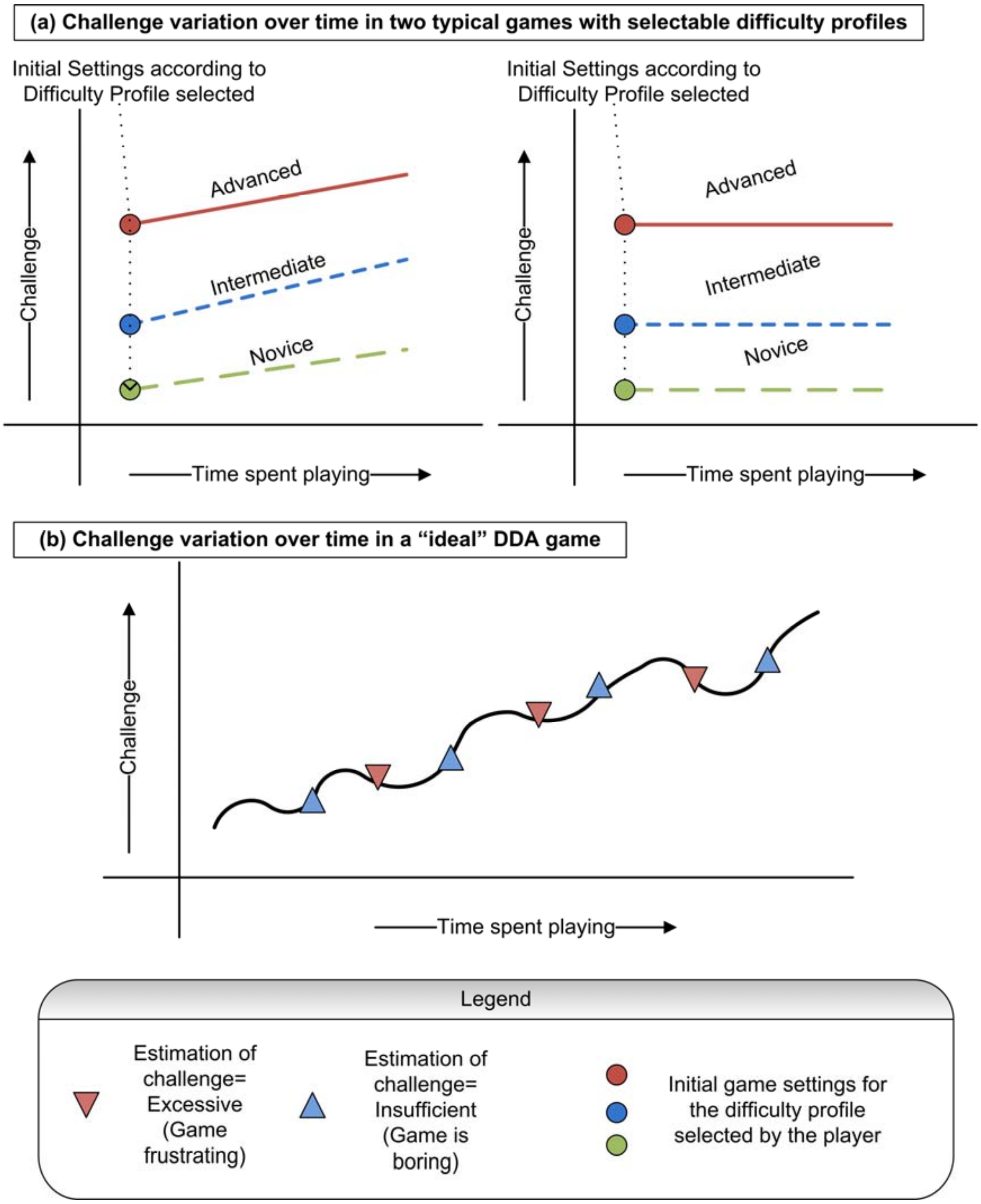

Figure 7. Typical curves of challenge variation in games following the approach of "difficulty profiles" (a) and DDA (b)

3.3. Acquisition of knowledge about the player

All the adaptive systems share the need to acquire knowledge, somehow, about the user. The more the system knows a user, or the specific features of the user that are relevant to the system, the more accurate adaptation could be provided. When it comes to adaptive video games, we could identify two different approaches. On the one hand, there are studies that have been conducted in order to analyze how different groups of people (usually demographic groups) play games, what elements of games find more attractive, and how their motivations for playing video games vary between groups. Those are "offline" approaches, as the adaptation that the games execute depends on pre-defined settings that are balanced to match the requirements of the average individual that belongs to that group: there is no online learning about the user. On the other hand there are approaches which try to do the opposite, acquiring knowledge from the in-game interaction. Those are "online" approaches. In the next two sections both are briefly presented separately. However, the "ideal" adaptive game may need to combine them into one, solid approach, using "offline" knowledge to provide gross-grained adaptation for groups and "online" information to particularize the adaptation for the individuals (fine-grained).

3.3.1. Offline: player types

The notion that not all the players adopt the same approach to play video games, following diverse strategies and with different motivations for the use of video games, have been around for a while. For instance, the informal classification of players between *hardcore* and *casual* is quite popular within the gaming field, where hardcore players can be intuitively defined as players that spend longer playing video games and that are especially loyal to specific games and genres. Casual gamers are usually given an opposite definition: players that typically play games sporadically, preferring easy games, and which tend to quit games more quickly when they become boring or frustrating. However the definition of these terms is still under discussion (Fritsch et al., 2006; Kuittinen et al., 2007). Nonetheless, the importance that video games have gained in the last decades have attracted scholars from heterogeneous fields such as economics, psychology, sociology or human behaviour who have tried to analyze how different people approach to video games (Zaphiris et al., 2007). While these studies were mostly devised for the achievement of other goals, they provide valuable information for the design of adaptive games that suit the broadest possible audience (Griffiths et al., 2004).

Probably the most recurrent research in this line is the study of the difference between females and males, as traditionally females have felt less attracted to the gaming market than males. For instance, Hartmann (2006) describes 2 studies about the dislikes of German females with regard of video games. The first study indicates that lack of meaningful social interaction, followed by violent content and sexual gender role stereotyping of game characters, were the most important reasons why females disliked fictional video games. The second study revealed that female respondents were less attracted to competitive elements in video games, suggesting an explanation for gender-specific game preferences. Beal (2002) identifies the differences in problem-solving between males and females as another contributing factor for girls' dislike of some types of games. However, Beal argues that many of these issues could be solved by adjusting some simple parameters of the games. For instance, girls, who usually prefer to solve problems using reasoning, will need more time to face conflicts in games where action is predominant.

About the motivations that players have to play different games, the genre of *MMOGs (Massively Multiplayer Online Games[17])* is one of the most studied. The interest in these games dates back to Bartle, who analyzed the aspects of *MUDs* (*Multi-User Dungeon* games[18], prequel genre of MMOGs) that people typically enjoyed the most in 1996 (Bartle, 1996). These are achievement within the game context (Players give themselves game-related goals, and vigorously set out to achieve

[17] http://en.wikipedia.org/wiki/Massively_multiplayer_online_game

[18] http://en.wikipedia.org/wiki/MUD

them); Exploration of the game (Players try to find out as much as they can about the virtual world); Socialising with others (Players use the game's communicative facilities, and apply the role-playing that these engender, as a context in which to converse (and otherwise interact) with their fellow players); and Imposition upon others (Players use the tools provided by the game to cause distress to (or, in rare circumstances, to help) other players). From there Bartle proposed taxonomy of four styles of players according to the element they enjoy the most: achievers, explorers, socialisers and killers respectively. The work of Bartle is being used in game design to balance and adapt MMOGs. Taking the work of Bartle as a start point, other authors have developed other taxonomies like the one proposed in (Yee, 2006), who also broke those motivational factors in subcomponents. Other classification of player types that is quite popular is the one proposed by Robin D. Laws (2001), which classifies gamers into six categories (*butt-kickers, power gamers, tacticians, specialists, method actors and storytellers*). Another interesting taxonomy of players is the one developed by (Bateman et al., 2006) which includes different types of games.

3.3.2. Online: Player models

According to Charles, the approaches described in the previous section provide a rough categorization of players rather than catering for individual players (Charles et al., 2004). This thought could summarize the motivation of applying online learning techniques to the infer knowledge about the player abilities during the game, as following this approach the information that is obtained belongs directly to the user that is playing the game without taking into account stereotypes.

Within this scope, most of the scholars handle the concept of *player model*, either explicitly or implicitly. The idea is tightly related to the concept of student models exposed in section II.2.1.2, adopting ideas from adaptive learning environments. Given the technical complexity of this field it will not be my intention to analyze the concept from an in-depth, rigorous point of view, but to make and overall description of this trend.

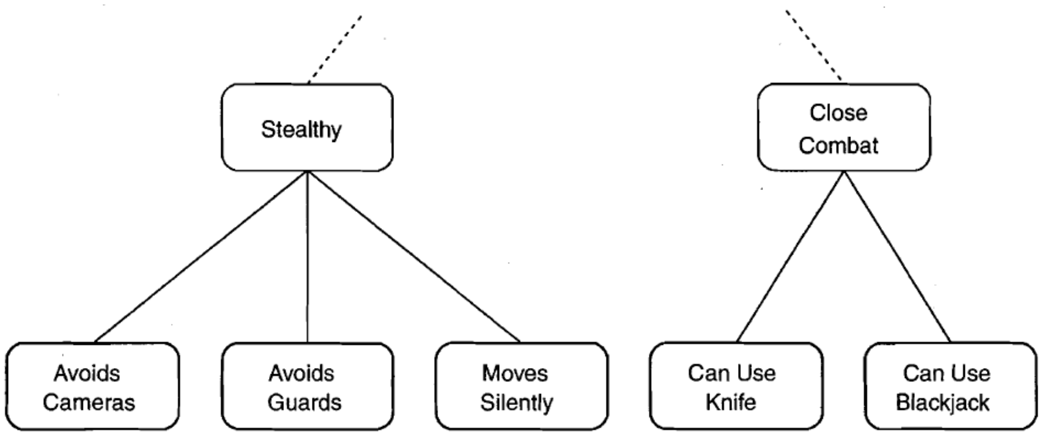

Figure 8. Example of a hierarchical player model for Shot'em up games. Adapted from (Houlette, 2004)

The simplest approaches in adaptive gaming that consider the idea of a player model see it as a statistical representation of the player based on the frequency of repeated actions or average values and parameters. However, this approach seemed to naïve so rapidly other authors started to propose more advance player models. For instance in (Charles et al., 2005) the author proposes the definition of multiple overlapping models focused on different aspects of game-play and the user as a player. Similarly, (Houlette, 2004) proposes hierarchical player models built as trees. Low level traits are leaves in the tree. These traits are abstracted by other traits of higher levels (nodes), computed by a function over their children. Finally in multiplayer games the model should contain social attributes and behaviours. (Chiou et al., 2008) is an example of applying Neuro-Lingüistics Programming Techniques for the generation of user models. (Yannakakis et al., 2005) describes a system that uses Bayesian networks to infer a player model for the PacMan game considering that the player will adopt a gaming strategy from three.

Some authors have pointed out the potential of player modelling in video games, especially if they could be reused. Between the ideas that have been around, player models may bring a new age of game-play experiences if a user could have something like a "pluggable player model" that could take with him/her and use it in any kind of game to get a game experience that would be completely customized. The potential for educational applications goes beyond imagination if this could be merged effectively with a student model. Nonetheless, given the current state of the art the idea is not more than science fiction.

However, multiple questions arise around the idea of player modelling. No one player model will work for all games, genre, setting, level of realism, etc., which reduces the scalability of approaches to in-game adaptation that heavily rely on player modelling. Additionally there is an important issue about its cost. Player models have to be updated constantly in the game, which involves to be permanently observing the in-game world trying to infer knowledge about the player. The AI techniques needed to produce a really valuable acquisition of knowledge that is truthful about the player may be more costly to implement than the AI of the game and more time-consuming to execute. Another issue that is often discussed is how to initialize the player model. While authors state that the player model could be initialized by the user, others argue that user-entered data cannot be trusted, proposing advanced methods such as the monitoring of pulse rates or face expressions which at the same time has its own disadvantages.

3.4. Learning models, methodologies and architectures for educational adaptive gaming

There are other initiatives, more theoretical, that try to abstract general ideas and concepts from the approaches above described so they could be reused and scaled. Those approaches share an underlying motivation: to facilitate the development of adaptive games. However, to make a thorough description of all these approaches is out of the scope of this work. Thus in this section we describe some approaches that are especially relevant because they explicitly consider adaptive gaming for educational purposes.

The first approach has been proposed in our own research group (Moreno-Ger et al., 2007a; J. Torrente et al., 2008b). It is a general adaptation model, analyzed from a high-level perspective, for educational gaming. The novelty of the approach is that it introduces a LMS in the process as the entity that must control the adaptation process. The argumentation that supports this idea is built upon the knowledge that the LMS has about the instructional approach, the learner (even if the LMS does not have a user model it will contain his or her profile), etc. In this manner the LMS would carry out a first adaptation phase, called *gross-grained* where general decisions are taken. For instance, the LMS would decide what activity must complete the student, or what kind of content should be delivered. This is important as not all the students may profit from using a video game (e.g. students requiring further guidance). After that, if a game-based activity is planned for the student, the LMS initializes the game with the appropriate settings and launches it. From that moment the game takes the control over the game-based learning experience, developing a much more *fine-grained* online adaptation (second phase).

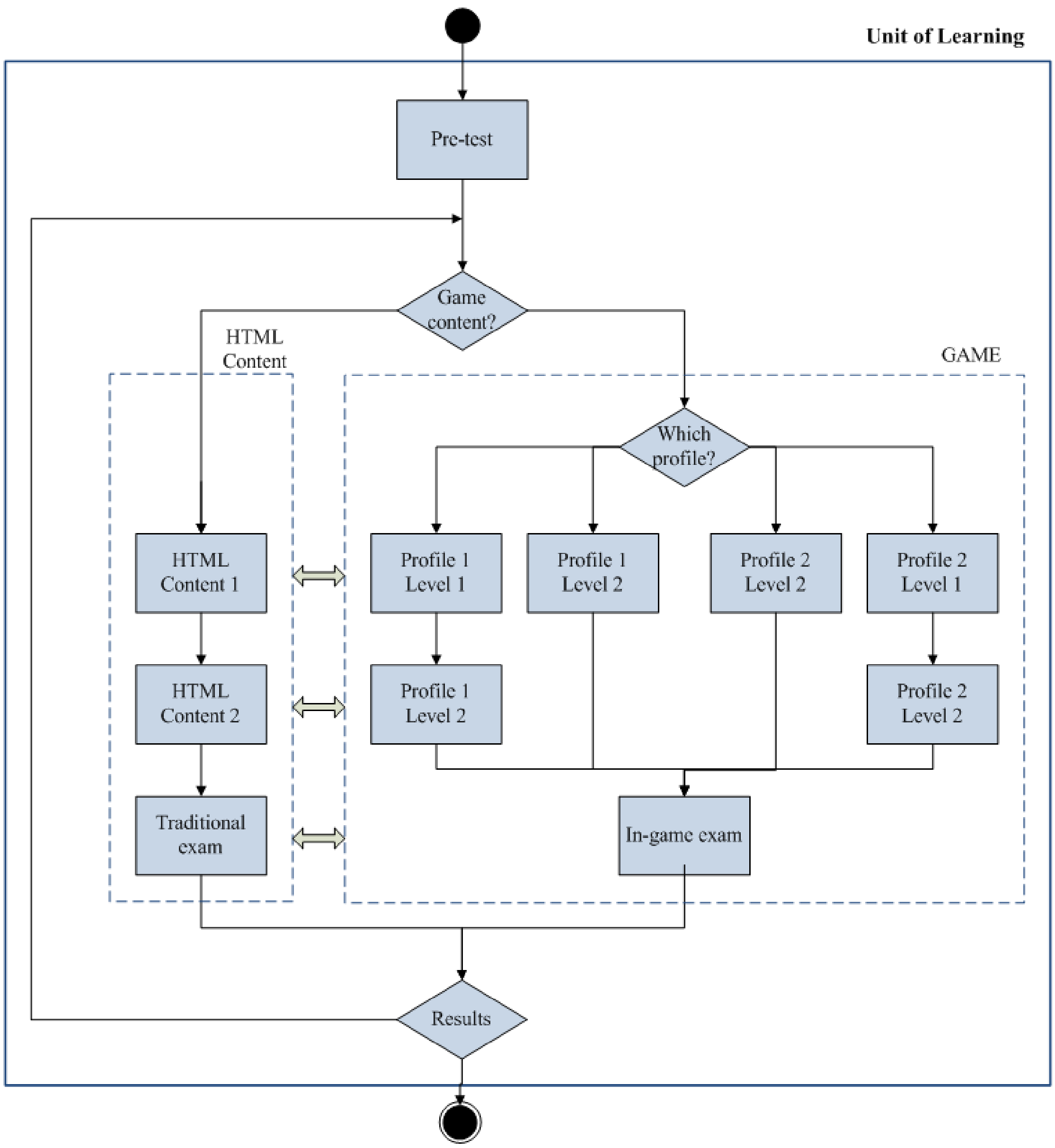

Figure 9. Adaptation model considering adaptation in two phases (gross-grained Vs fine-grained), as described in (J. Torrente et al., 2008b). In this model two itineraries are considered as an example, one is game-based and the other HTML-based. Within the game several student profiles are considered for adaptation. Copyright Springer-Verlag©.

Another interesting work is the one described in (Carro et al., 2002). In this work the authors present a methodology for describing adaptive educational game-based environments and a model that supports the design of the adaptive environment where the game is integrated. The main novelty of this approach is that it considers the whole learning environment, considered as a set of activities that the student must accomplish in order to achieve the learning goals, and how to use games as one of these tasks. The methodology proposed considers an engaging story that should connect all the activities and would be personalized for each kind of user. The types of users should be decided in advanced. Besides it considers the design of in-game feedback as a very important issue from an educational point of view.

Finally, the work presented in (Peirce et al., 2008) is also of special interest for this project. In this paper the authors present an architecture for the development of adaptive educational games. The architecture integrates some ideas that are interesting, as the need of carry out the adaptation in a manner that it does not affect the immersion. Besides it considers a separation between the process of detecting in-game situations that require some kind of adaptation (*Inference*), and the process of performing the adjustment of the game (*Realization)*. The possible adaptation mechanisms that the game will support, according to the principles implemented in this architecture, are defined as *Adaptive Elements*, which are annotated with meta-data in order to describe the scenarios where they could be executed and the outcomes expected for the adaptation process. The architecture is configured with a set of adaptation rules that examine the learner model, which is considered explicitly and determine the desired adaptation outcome. Figure 10 shows the general structure of the architecture proposed by (Peirce et al., 2008).

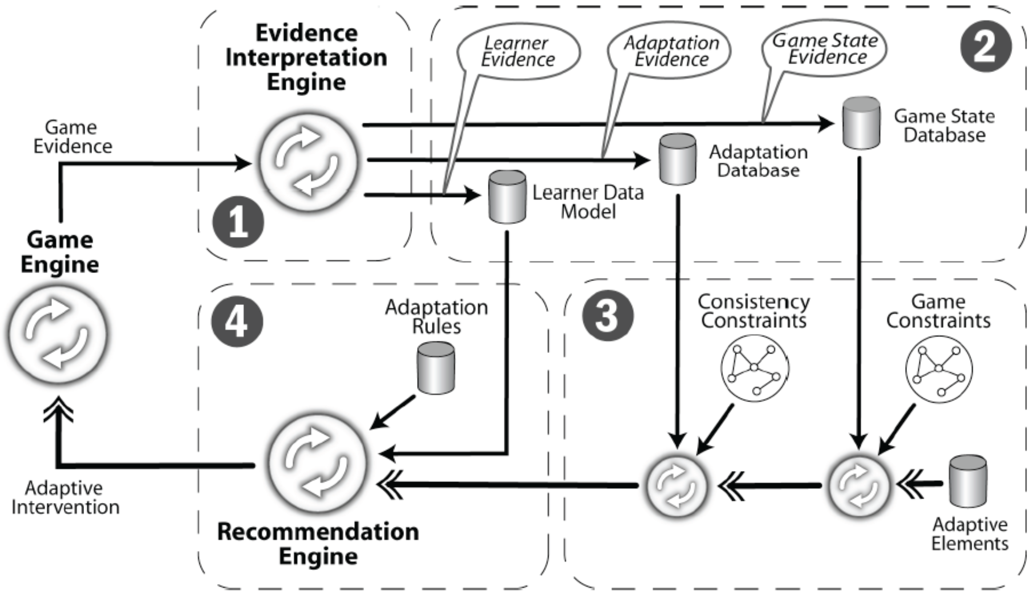

Figure 10. Diagram of the educational gaming architecture described in (Peirce et al., 2008)

4. Assistive technology & accessibility in e-Learning

The boom of the digital age brought the challenge of universal accessibility. While the rapid development of technology caught us completely unaware of the importance of guaranteeing its universal access, nowadays our society is concerned about the requirements of people with special needs and the source of discrimination technology can be when those needs are not met.

As a consequence, we have seen how different technologies have been developed in order to guarantee the access of people with special needs to the information society. In this section the overall state of the art of universally accessible technology is presented from the perspective of their use and impact in learning. Thus the initiatives here presented are grouped in three categories, going from the most general to the most "e-Learning" specific. The first one analyzes the most representative families of products that have been devised for the general use of computers. The second section describes some initiatives that are specially oriented to guarantee the universal access of the Web. Finally the third section describes initiatives that are directly oriented to promote the general accessibility of e-Learning platforms.

4.1. Assistive technology for computer-based use

4.1.1. Special and adapted hardware

Most of the initiatives trying to generalize the access of computers with independence of the characteristics of the user have lead to the development of special hardware. One of the most typical problems that people with special needs face when using computers is the difficulty of handling standard input devices. For instance, people with reduced mobility in hands may find painful, or even impossible, the use of QWERTY keyboards and mice. Visually impaired people may use standard input interfaces, but the lack of vision makes typing more challenging. The problem gets much worse when it comes to the usage of a computer mouse, as this kind of hardware relies on the sense of vision to point and click on the screen.

To tackle these issues and others of the same nature there have been design quite a lot of special input devices. The variety of these devices is wide, going from adapted standard hardware, like oversized keyboards with larger keys for people with limited mobility or high contrast keyboards for people with low vision, to specific devices like mouth joysticks or eye trackers for people who cannot use hands or Braille keyboards for blind people.

Figure 11. This specialized joystick mouse, called *JAWS 2™*, enables people who cannot use hand-input devices to control a computer with their mouth, chin and cheeks.

The second typical problem is the reception of output signals from the computer, which is special relevant for visually impaired people. The most common approach to solve this problem is the development of screen magnifiers, hardware that works as a magnifying glass for the monitor.

4.1.2. Accessible software

In the field of accessible technology there are also software-oriented initiatives. The best known approaches rely on complex pieces of software. That is the case, for example, of the screen reader tools that visually impaired people use. This kind of software apply text-to-speech techniques to convert text into audio so visually impaired people can have access to the information on the computer. Software-based screen magnifiers are also a good example. These tools usually augment the area of the screen around the mouse pointer. Another example is screen keyboards, intended for people with low hand mobility. Using screen keyboards people that cannot use a standard keyboard but that can use a mouse or a trackball (it only requires one finger) is able to type text into the computer. Modern operative systems include tools like those in their standard releases.

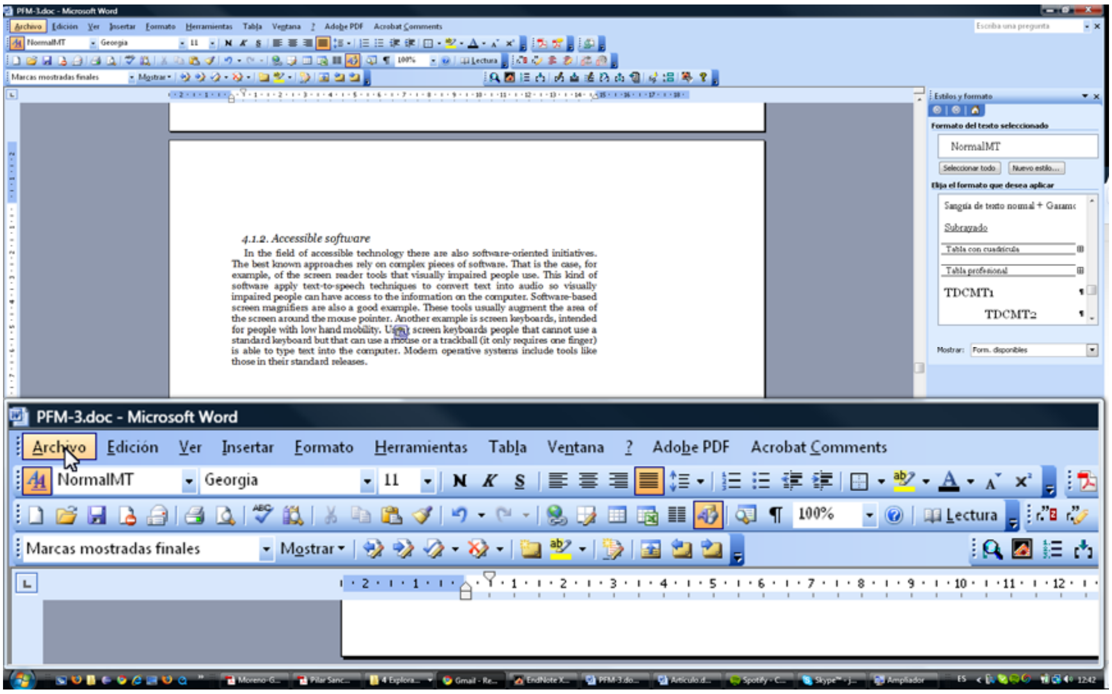

Figure 12. Out-of-the-box screen magnifier included with Microsoft's Windows Vista©

However, in many occasions there is no need to use specific software in order to guarantee the accessibility of computers. Just to make slight modifications of some parameters can turn an application that is completely unbeatable for a person with special needs into something affordable. For example, software that is designed with accessibility in mind usually includes interfaces for adjusting the response times of the system.

4.2. Initiatives towards the universal accessibility of the Web

Given the actual importance of the Internet, the lack of accessibility of the former World Wide Web meant a real discrimination for people with special needs. This has provoked the raise of a special concern towards the accessibility on the web during the last years. Due to the clear web-orientation of e-Learning environments, the initiatives aiming to facilitate the access to the web for people with special needs are of special interest for the e-Learning field.

Thus during the last decades have risen diverse initiatives aiming to guarantee the WWW accessibility, promoted both by public and private institutions. One of the best known in this concern is the *Web Accessibility Initiative (WAI)* promoted by the World Wide Web Consortium (W3C)[19], a highly influential organization that develops interoperable technologies, such as specifications and guidelines for Web applications. WAI includes guidelines & techniques for the development of multiple types of applications related to the Web, such as Rich Internet Applications or authoring tools for web applications, and for different technologies such as CSS or HTML. It also defines a set of guidelines (WCAG 2.0) for the development of the content in Web systems, addressing text, images, multimedia content, the navigation between contents, etc. Additionally WAI defines how to evaluate the level of accessibility of a Web application, including three level of success (A, AA and AAA).

Other initiatives have a direct legal motivation. For instance, *"Section 508"*[20], is a law promoted by the federal government of the United States. This law specifies a set of standards that information applications of federal agencies must comply with, including concrete requirements about the type of alternative interactions that must be provided for different users. The interest that governments are taking in the development of regulations that guarantee the access to the Web demonstrates the importance of this issue.

4.3. Special initiatives about accessibility in e-Learning

Education is a universal right. Thus when technology is applied to support learning accessibility becomes even more important than for other purposes.

As a consequence there are initiatives that specifically deal with the development of accessible digital contents for educational web environments. A very thorough approach was undertaken by the *IMS Global Consortium*[21] in their *IMS AccessForAll* set of specifications[22], which provides specifications for the design and personalization of learning resources to meet the needs of all kind of users/learners. As IMS focuses their efforts in the generation of specifications that guarantee content interoperability between platforms, their view of accessibility in learning is centred on the embedment of meta-data that describe accessibility in such specifications.

A similar approach is the *ISO/IEC 24751-1:2008*[23] standard developed by the *International Organization for Standardization (ISO)*. This standard aims to provide a framework to describe learner needs and preferences and how to use them to describe digital learning resources so students can be given the appropriate resources that better meet their needs.

CAST (Center for Applied Special Technology)[24] is a non-profit research and development organization that works to expand learning opportunities for people with special needs through Universal Design for Learning (UDL), a framework for

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[19] http://www.w3.org/

20 http://www.section508.gov

21 www.imsglobal.org/

[22] http://www.imsglobal.org/accessibility/index.html

[23] http://www.iso.org/iso/catalogue_detail.htm?csnumber=41521

[24] http://www.cast.org/

designing curricula that enable all individuals to gain knowledge, skills, and enthusiasm for learning. Thus UDL is mainly centred on the design of the courses from a pedagogical point of view, aiming to provide teachers with guidelines for creating flexible goals, methods materials and assessments for students with all kind of needs.

As this section describes, there is a real interest in the e-Learning community to guarantee the universal access of digital learning resources. Unfortunately, these initiatives are principally focused on the accessibility of most common types of e-Learning educational content (including many forms of multimedia content), but do not adequately cover highly interactive content such as educational games or immersive learning simulations. Besides, most of them are centred on common physical impairments (visual, hearing, speech or mobility problems), but few attention is given to the special needs of students with cognitive and learning impairments.

5. Accessibility in digital games

5.1. Input Device Adaptation for Video games

One of the most common approaches to increase the accessibility of video games is to seek their compatibility with assistive technologies (Kearney, 2005), like those described in section 4. That includes compatibility with adapted and special hardware, but also with software. For instance, there are games that can be combined with screen-reading tools, mouse emulators or virtual keyboards.

However, digital games have their own specific devices: gamepads and joysticks. Thus we can find also special devices that can be used to substitute or adapt gamepads provided by game consoles (e.g. voice-controlled joysticks or tongue sensors that allow users to play games with movements of the tongue), especially for people with reduced mobility in hands.

Figure 13. Dream-Gamer Cap™: adapted controller for Sony's Play Station™. Games are controlled by means of movements of the head.

We can find a lot of different adapted game controllers in the market nowadays, even for the most recent consoles such as *Nintendo*™ *Wii*™ or *Sony Play Station 3*™. One example is *Dream-Gamer*, an adapted controller for the *Sony*™ *Play Station*™ family that allows players to control the games with movements of their heads. The controller is commercialized by *Excitim Limited (Dream-Racer Technology)*™[25] .

In this line, the work presented in (Sjostrom, 1999) shows the use of the *PHANToM*™ device as an example of how hand-controlled devices (which provide human-computer interaction based on body movements and the sense of touch) can increase accessibility of video games. *PHANToM*™, created by *SensAble*[26] *Technologies Inc.*, allows controlling games and other software by introducing just one finger in a thimble and pivoting at the wrist. This approach does not only facilitates access to the games for a wide range of people with impaired hand mobility of diverse degrees (videogames are controlled with easy movements of one finger), but also for visually impaired people as the device allows them to perceive the shape and texture of some 3D objects by the force-feedback produced by the device itself.

There are also software-based approaches in the development of accessible games. Most of these approaches are intended for visually impaired people. In this line we find *auditory games*, (also known as "audio - games") (Friberg, 2004) which are specially designed for people with visual impairments, where the information from the game is transmitted through audio (Röber, 2005). In some of those games the indications are given with abstract sounds, but the games with major acceptance are those which give users voice descriptions reproduced through text-to-speech synthesizers.

Another way to provide audible information is with descriptive sounds. Specific sounds, which are used intensively throughout the game, are given special meanings so it is easy for disabled players to remember the association between sounds and meanings. Other games receive input through voice or by means of other specific devices (Targett, 2003).

5.2. Methodologies, Tools and Design Patterns for Accessible Videogames

Other works, such as (Gärdenfors, 2002), have focused on providing design guidelines of several aspects of video games (e.g. interfaces) or methodologies aiming to guarantee the achievement of good levels of accessibility in video game development (Friberg, 2004; D. Grammenos, A. Savidis, & C. Stephanidis, 2007). There are also design patterns and web initiatives providing indications on how to create accessible video games, although they have not been translated into broadly accepted standards or specifications yet.

The *International Game Developers Association* (IGDA) has a *Special Interest Group* that focuses on accessibility issues[27] and published a white paper which provides an analysis of the field (K. Bierre, J. Chetwynd, B. Ellis, D. M. Hinn, S. Ludi, T. Westin, 2005; M. H. Bierre, T Martin, M McIntosh, T Snider, 2004). This document provides a general overview, covering what accessibility in video games means, why it is necessary, and the kind of disabilities can be addressed at the design stage. That work also gives indications about how to adapt an already created game to improve its accessibility through adding subtitles and customizing text fonts, or how

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[25] http://www.dream-racer.com

[26] http://www.sensable.com/

[27] http://www.igda.org/accessibility/

the textual information and subtitles should be produced, either by recording or synthesizes. Along with these ideas, they encourage the use of other approaches to gather user input such as use voice recognition or other specific devices. Although the report does not propose any concrete pattern or methodology to create accessible games, it includes a summary of possible approaches to provide accessibility in games from a game designer point of view, which deserves special attention as it covers most of the state-of-the-art techniques that are being used now. The next table summarizes these approaches and identifies the "functional limitations" that each can address.

Table 1. Summary of approaches proposed in (M. H. Bierre, T Martin, M McIntosh, T Snider, 2004)for addressing accessibility in games

In-game Actions	Functional limitations
Subtitles. All information presented by sound (dialogs & cut-scenes) should be provided by text alternatively.	Deafness, low hearing
Alternative sound files. Sound files that use bass vibration from the subwoofer may give important feedback to deaf gamers.	Deafness, low hearing
Optional simplified interface mode. Just the basic controls are displayed but the full features are still available. Interface will require less movement to navigate.	Limited hand mobility
Customizable controls. Allow users to remap controls.	Limited hand mobility
Customizable fonts: at least size, type, colour.	Low vision
Self-voicing capability. Use text-to-speech tools to automatically get in-game text read.	Blindness, low vision
Colour schemes selection. Providing an alternate set of colour schemes could allow those who are colour blind to select the art that appears the best for their particular vision.	Colour blindness
High contrast mode. Using black & white cartoon style as rendering option will help to see scenes.	Low vision
Configuration of colour for characters & objects. This will help to recognize important elements of the game, like enemies.	Low vision
Sonar to inform about distance to objects & characters currently facing. More info could be available pressing a key.	Blindness, low vision
Global Position System to determine position of nearby elements via voice.	Blindness, low vision
Sound compass using 3D sounds to represent directions.	Blindness, low vision
Direct Orientation. By using the numeric keyboard a blind gamer could orient the avatar directly in 8 directions.	Blindness, low vision
Standard text presentation to allow **compatibility with OS screen readers** or special contextual dictionaries (e.g. for gamers with dyslexia).	Cognitive impairments, low vision, blindness
Keyboard navigation for all controls + with visual and spoken feedback. Allow all commands to be entered via the keyboard and provide both a visual and auditory message to indicate what has been done.	Low vision, blindness, deafness, low hearing, limited mobility
In-game tutorials / user feedback / automatic help. This feature would be helpful to almost all gamers. Guiding them through a game and providing extra feedback would be	Cognitive impairments (specially

helpful, since they would pick up many of the main points of the game easily.	learning impairments)
Improve hardware support for miscellaneous special devices.	Vision impairments, limited mobility
Finer Control on Degrees of Difficulty. Allow the modification of degrees of difficulty to a further extent than usual in games. For example, customization of movement speed settings.	Cognitive impairments, (specially learning impairments)

A unique approach from a technological point of view is proposed by *FORTH* (Foundation for Research and Technology - Hellas) (D. Grammenos, A. Savidis, & C. Stephanidis, 2007), and is based on the *Unified User Interface Design* (UUID) (Savidis, 2004). UUID proposes a design pattern that tries to address, mainly, the problems that related to interaction with the game. This work identifies that games which design is too closed to a specific interaction method (e.g. the use of the mouse) will rarely be accessible. To solve this, UUID considers the game tasks in an abstract device-independent way. In later design phases, the interaction for each game task is designed and mapped to one or multiple input/output devices, depending on the targeted disabilities. Several video games have been developed following these guidelines, achieving accessibility for people with a wide range of special needs. These are the universally accessible games (*UA-Games*). An example is *Access Invaders* (D. Grammenos, A. Savidis , Y. Georgalis & C. Stephanidis, 2006), which supports different game settings depending on the potential disabilities of each player, such as blindness (in which case the game will be loaded with the appropriate characteristics of the Audio-Games), damaged vision, cognitive disabilities or motor disabilities.

As far as development tools are concerned, the market is populated with many authoring environments for the development of video games. There are development frameworks for game programming (such as *Microsoft XNA™*[28]), game development environments which allow people without technical knowledge to develop their own videogames (like *Game Maker*™[29] or *Unity3D*™[30]) and even simple editors oriented to specific game genres like *The FPS Creator*[31] or *Adventure Game Studio*[32]. However, none of these initiatives includes pre-configured features targeting game accessibility. This means that accessibility has to be implemented from scratch for every individual game, which involves an extra development cost that is considerable.

5.3. Accessibility in Entertainment-driven video games

There are some entertainment-driven video games, both commercial and open source, that implement features to enhance accessibility or that have been modified after being published for this purpose. One of the best known commercial AAA games because took accessibility issues into account is *Half Life 2*™. *Half Life 2*™ is one of the first games that is known to provide all the necessary information that is provided by sound with subtitles (also called captions). The development team of *Half Life 2*™

[28] http://www.xna.com/

[29] http://www.yoyogames.com/make

[30] http://unity3d.com/

[31] http://www.fpscreator.com/

[32] http://www.adventuregamestudio.co.uk/

decided to introduce accessibility for people with hearing impairments since the design stage after they received complaints concerning the first issue of the saga. The reason is that in *Half Life*™ certain information that was essential to complete the game was transmitted across cut-scenes (videos) without subtitles, making it impossible for people with hearing impairments to reach the end of the game (K. Bierre, J. Chetwynd, B. Ellis, D. M. Hinn, S. Ludi, T. Westin, 2005).

Figure 14. Valve's *Half Life 2*™.

Terraformers™ is another example of product that was directly designed with accessibility features from the beginning. *Terraformers*™ is an adventure action game that includes a normal mode in which visual graphics are reproduced as usual in first-person 3D games, but it also has an accessible mode. In that mode, a 3D sonar is activated to tell players what is in front of them and the contrast of the graphics is increased for vision-impaired people (Westin, 2004); this mode also allows the player to select objects from the inventory using voice commands.

Figure 15. Terraformers game: left image shows normal mode, and right image

shows the same scene with high contrast.

In spite of these initiatives, accessibility is still scarce in digital games. In 2004 the *International Game Developers Association (IGDA)*, which is an influential organization in the world of video games, carried out a survey between game studios trying to determine the current state of accessibility within the game industry (M. H. Bierre, T Martin, M McIntosh, T Snider, 2004). In this survey game studios were urged to report about games that were being developed at that time considering accessibility issues. The survey contained questions about the category the game belonged to (action, fighting, racing shooter, simulation, strategy, role-playing, family entertainment, edutainment, sports, others), the distribution method (CD/DVD, Web Browser, Downloadable), and types of disabilities addressed, between others. The next graph describes the results of the survey in terms of categories (some games fell under multiple categories).

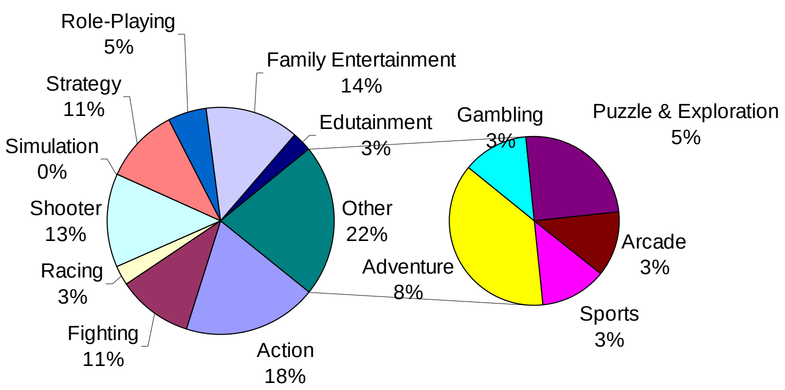

Figure 16. Results of the survey carried out by the IGDA in 2004 in terms of game categories.

As a summary of the results of the survey, "action" was the most popular game genre for accessibility. Regarding the methods used by the survey responders to distribute their games CD/DVD was being used in 36.37% of the cases, Web-based games in 21.21% of the times and the Internet (downloadable games) in 42.42% of the times. Regarding the types of disabilities addressed, vision-related problems were the most popular ones, as the next figure shows. However, the most relevant data of the survey is that only 20 replies were received: that gives the idea of the current level of awareness of accessibility of the gaming industry.

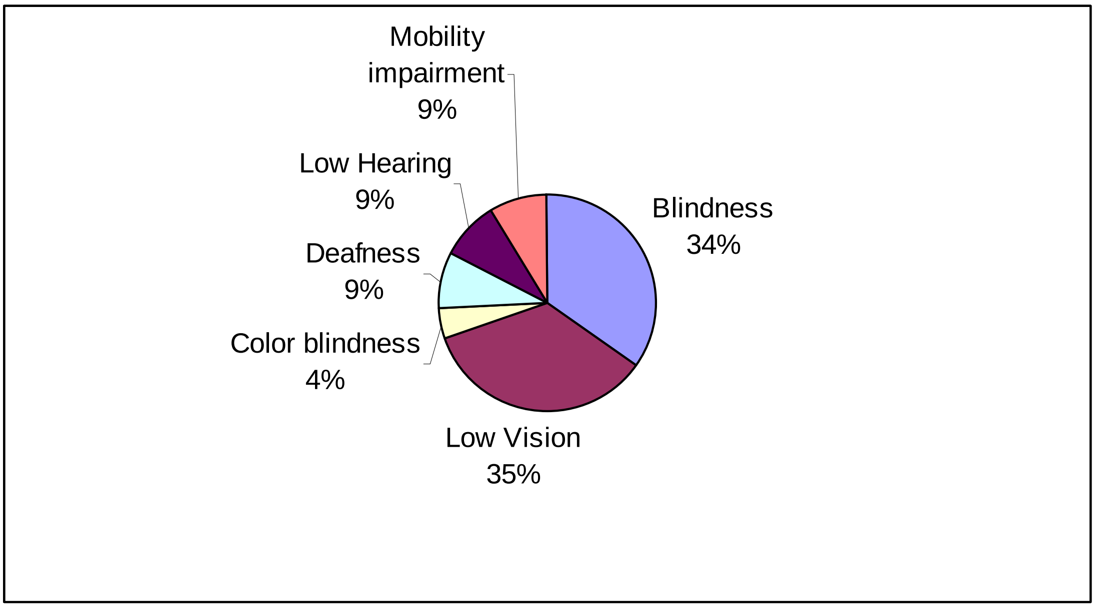

Figure 17. Results of the survey carried out by the IGDA in 2004 in terms of impairments addressed.

6. Summary and conclusions of the chapter

As we have discussed, instructional systems that aim to adapt the learning experience for the needs of each student as an individual are much older than e-Learning itself, dating back to the first days of Intelligent Tutors and Adaptive Hypermedia Systems. However, few of these concepts have been integrated in modern e-Learning systems. The lack of total success that ITs and AHS have achieved (outside the academia), favours that the scepticism about its real effectiveness has spread out around the Technology-Enhanced Learning community. However, we should not reject all these approaches as some adaptation techniques used in ALEs may be applicable to adaptive games.

On the side of adaptive gaming, the shortest conclusion we could extract is that this is still a mutable field were little agreement has been achieved between scholars and game developers. On the one hand, most of the games are still relying on the straightforward mechanism of difficulty profiles, which has got some criticism (but is still profitable). On the other hand, there is little evidence, from a commercial point of view, of the effectiveness of the most advanced techniques such as DDA. Besides, the field of research in adaptive gaming is populated with complex approaches that have never been put in practice in real products. Furthermore, from the approaches that have achieved more success, like MaxPayne™, we are still knowing few details, since game developers keep those very secret, protecting the investment realized. Other drawback of the most complex techniques in adaptive gaming, such as DDA, is that the possibilities of scaling the approaches proposed to other genres different from than action/shooter games, are at least under discussion. What parameters will you use for adjustment a point-and-click adventure game, for instance, where there are no health levels? In short, we could say that there is little evidence supporting huge investments in this technology. Other simple but less costly approaches, like providing hints or in-game guidance, may be considered.

Another interesting conclusion about adaptive video games is that, although there are clear alignments between games and learning, there is no evidence about how to properly model these elements and use them for educational purposes: research is still ongoing in this field. Finally, other issues that are still under discussion are how to evaluate in-game adaptation without compromising the performance of the AI algorithms, the problem of personal privacy (a lot of data is being gathered from you without letting you know) or how to palliate the negative effects of adaptation when this is carried out with complete transparency (e.g. players that become aware of this behaviour become frustrated, players cannot compete as there is no objectivity to compare results, etc.).

Regarding accessibility, we have seen how this issue has been addressed in computers in general, and in the Web in particular. The multiple approaches here have been motivated by the need of making people with special needs part of the Information Society, which in our opinion has clearly influenced their orientation. As a consequence, the common pattern within the initiatives that promote accessibility in the Web is their aim to guarantee that the user can get to the information. After that is done, it does not really matter what happens with the content that the user got (it makes sense, after all the term "accessibility" comes from "access"). And video games are being addressed in the same way. Although the approach may be valid for the Web, just making games "accessible" for users with special needs may not be enough. The reason is quite simple: the motivation that users have to utilize the Web and video games are different, as while users mainly tend to use the Web for gathering information (the new concepts of Web 2.0 put this assumption in doubt anyway), they use video games for getting outstanding engaging, immersive and finally, satisfactory experiences. Typical actions that have been proposed to address adaptation in games (e.g. duplicate the channels where information is transmitted in the game) may damage the immersion in the game and therefore they may not meet all the needs of that user, but just a part. When it comes to educational gaming this would mean that the effect of adjusting the game to make it accessible might destroy one of the main reasons of integrating games in learning (engagement and motivation), turning the overall approach pointless.

Thus we advocate for a more general perspective to cater for people with special needs. Considering "accessibility" as a specific case of adaptation would be a feasible solution as the principles adaptive games are built around meet all these requirements. Nonetheless, special requirements that arise from dealing with special needs, which are mainly concerning the need for special hardware support, should be considered (e.g. special input devices).

Chapter III

The Framework Proposed

1. Introduction

As it has been discussed so far, the main goal for this work is to develop a general framework that facilitates the development of adaptive educational games in e-Learning, with some additional requisites: the games should be able to integrate in standards-compliant Learning Management Systems and accessibility should be considered explicitly in the framework, but as a special case of adaptation. In addition, given that this work involves several areas that are still mutable and changing, with a lot of research currently being developed to address the challenges each are facing separately, the framework must be as flexible as possible. In this manner it is important to point out that the framework does not define a concrete adaptation or instructional model, but gives the tools that will support others implementing diverse adaptation and strategies, including multiple elements observed in the state-of-the-art that could be helpful for adaptive game-based learning.

Thus, the chapter starts by providing a general description of the main characteristics and ideas that the framework implements. That is, namely, how we see the problem according to the study of the state-of-the-art and our own experience. The next section describes the different models that the system may need to use. After that, a general software architecture that implements those ideas is given. The main idea behind the architecture is to allow reusability and interoperability between multiple research approaches for detecting and executing adaptation, in-game activity monitoring, model maintenance, etc. Finally, the last section describes briefly how would the framework need to be configured from an authoring point of view; that is, the roles of people that this task may involve and a description of the process. This will facilitate the development of authoring tools for the production of games following the theories and ideas exposed in the framework.

2. General description of the framework

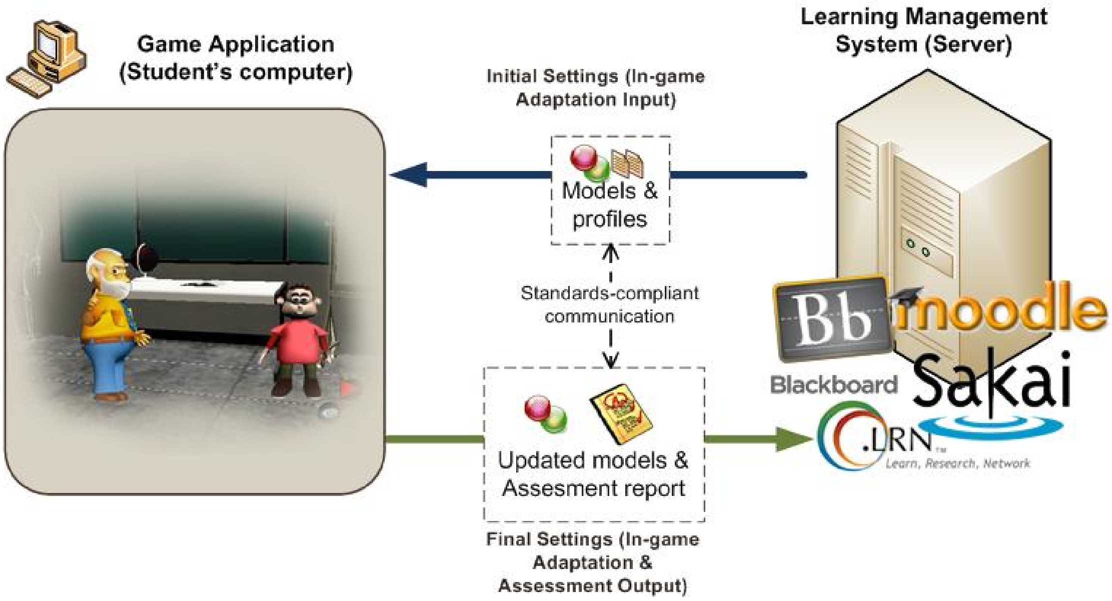

Figure 18. Top-level view of the framework, including entities involved and information exchange

To describe the framework, we will start by giving a high level view of the entities involved and how these communicate: the Learning Management System (LMS), and the game. Following the adaptation model described in section II.3.4, in the framework we propose the LMS is responsible of controlling the learning experience. The LMS has a "global perspective" that the game will never have, as the LMS may "know" valuable information as the course (sequence of activities, next materials to be delivered, educational goals) where the game is being used (the same game could be reused for different purposes, courses and learning goals) or the instructional approach defined by the teacher. Actually all the roles involved in the learning process (students, instructors, etc.) have access to the LMS, which facilitates some issues like the gathering of information about the student or displaying the results of the learning experience, both for the student (i.e. feedback) and the teacher (assessment). Therefore in our framework the LMS is the "main leader", taking decisions that may affect not only this concrete game-based learning experience but the "overall" learning experience of the student. This is what we call the "gross-grained" adaptation phase.

Therefore, the main responsibilities of the LMS could be summarized as follows:

- To generate the initial settings for the configuration of the game, and launch the game with such configuration.
- To initialize, maintain and store long-life models. For example, the student model and the domain model.
- To drive a first adaptation phase (gross-grained), where the type of content to be delivered to the student is decided, along with the initial configuration of the game. Actually in this phase the LMS must decide if a game is a suitable type of content for that user.
- To deliver the game to the student's computer.

On the other side, the game will be responsible to carry out the next actions:

- To monitor the player's performance in the game.
- To update and maintain short-term models and, above all, the player model.
- To drive the fine-grained adaptation phase where the in-game details are configured.
- To produce an assessment of the learning experience, according to the configuration of the game.

Regarding the configuration of the framework, adaptation and assessment behaviours are authored from a top-level view by defining profiles with a set of rules in each case matching the structure Condition->Effect. Where the condition the condition will refer to states of the models involved in the framework, in order to determine situations that require adaptation or assessment because they are important from a pedagogical point of view, the effect will be different for both adaptation and assessment. In the first case, that effect will be related to the changes that must be executed in the game. In the second, the effect will be related to the assessment that the game must produce in those situations.

Figure 19 describes the general adaptation model that is behind this approach, given the activities that both LMS and game should carry out.

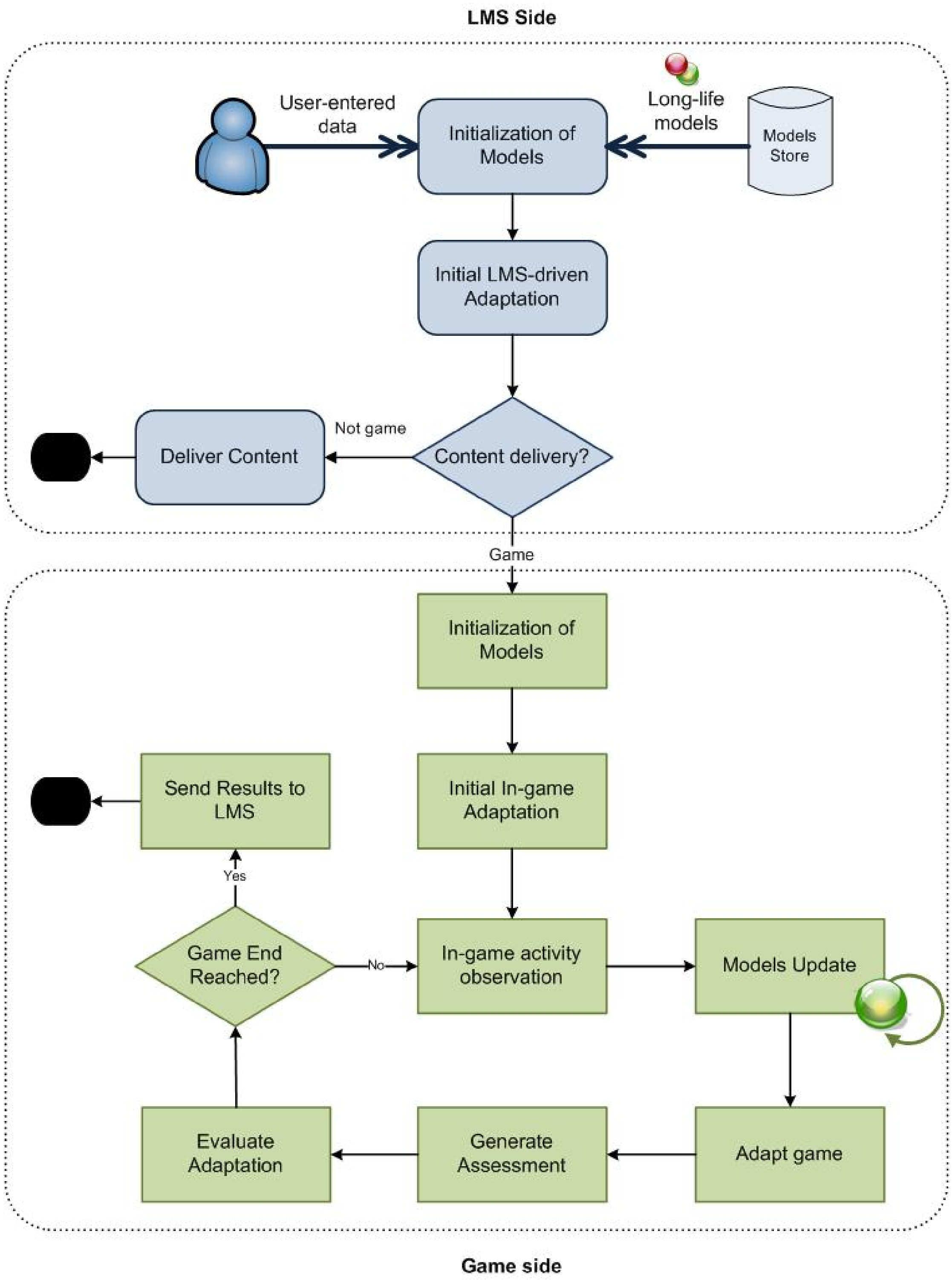

Figure 19. Adaptation model, including sequence of activities divided by entity responsible (LMS in blue, game in green).

3. Models

The framework considers that the adaptation could be performed taking as input one or more of the models that have been discussed in the state-of-the-art analysis. That includes not models originated both in the "gaming" and "adaptive learning" fields. In general, the models that are taken into account in the framework are the following: user model, domain model, context model and game progress model. It is important to highlight that this does not mean that the system has to use all of these models mandatorily. That would be a burden more than something helpful. For each instantiation of the framework the designers of the systems should decide what models are needed. However, for the scope of this framework it is important to have all of them into account as they may be important for adapting the game in diverse situations. In addition, the models needed by the system may not need to be always explicitly represented. In many cases the designers of the systems would only need implicit representations of the models.

2.1. User model (UM)

All adaptive systems that we could find in the market, like the ones described in section II.2.1, use some kind of user model. It is the most important model in the framework and hardly any instance of it could avoid using a particularized version of the user model. In this case, the user model will contain information about the user that will play the educational game. The complexity of this model demands a hierarchical structure, where the user is analyzed from different perspectives. Hence the conception of user model used in this framework includes different sub-models that may overlap depending on the specific instantiation being used. Those are: the *General Model (GM)*, the *Student Model (SM)*, the *Player Model (PM)* and *Special Needs Model (SNM)*.

- *General Model (GM)*. First of all, the user model should consider general data about the student, including demographic data such as the gender, cultural background, and age or raze. As it has been discussed in section II.3.3.1 this might be important depending on the case. For instance, a game should be adapted to meet the different in-game problem solving strategies that males and females usually adopt. Moreover, the system, directed by the instructional approach being followed, may decide to deliver a different type of game for each student depending on the gender, or simply decide to deliver other type of content. Other example where the general model would be useful is to provide adaptation for avoiding situations of language misunderstanding (for instance, a game that is developed in Spanish intended for users from Spain and South America, where the same word may have a different meaning).
- *Student Model (SM)*. Secondly, the system will need information about the user as a *student*. This is essential and will be typically used during the first, general adaptation phase (gross-grained) carried out by the LMS. The student model will provide the adaptive engine with information such as his/her learning style (e.g. exploratory or guided), learning preferences (e.g. prefers learning with games or multimedia content), etc. In addition, the student model may contain information about the knowledge of the student, although as discussed in II.2.1.2 modelling knowledge is not straightforward. The SM should be particularized both for the current domain that is being taught, and even for a global domain that represents the whole knowledge of the student. That adds the drawback that they approach may not be scalable. The information about the knowledge of the student may include what he/she knows and even what he/she does not know or what he/she thinks that know (i.e. wrong assumptions).
- *Player Model (PM)*. Thirdly, the system will need to analyze the user as a *player*. The abilities of the user when playing diverse sorts of games, his/her preferences about game genres, etc. will need to be considered for online adaptation of the game. Thus the user model may need to include a player model. The player model may also need to follow a hierarchical structure, given

the complexity of the problem. For instance, it may include a long-life sub-model storing all the information that would be reusable for later executions of the game or even of different games, and a short-life sub-model of the user during game play. While an example for the first sub-model would be the strategy that the player usually follows in action games, an example of the second sub-model would be the emotional state. As Gilleade (2005) argues, this is important as emotions conditions how users play. Therefore, it may be interesting to detect when the user feels satisfied, frustrated or bored in order to determine the causes of negative emotions and plan actions to remediate them, and the causes of positive emotions to reinforce the elements that are generating them. To generate such short-term model typical information about the in-game interaction (e.g. scenarios visited, logs about interaction with other objects and characters, etc.), but also low-level information taken from the input devices (Kelly et al., 2006). Actually there are studies conducted that use special hardware like eye cameras or heart rate measuring devices to monitor players' vital constants like pupil dilatation, or heart beat rate, and use it to determine emotional states of the player.

- *Special Needs Model (SNM)*. And last, but not least, the user model will need to store information about the special needs of the user. This is essential if accessibility is considered as a particular case of adaptation. Typically the information stored will include but not limited to, visual impairments (e.g. none, low, blind), hearing impairments (e.g. none, low or severe), mobility impairments (e.g. none, can only make slow and short movements,), speaking impairments (e.g. none, low, severe) and even cognitive impairments. Please note that modelling special needs of the user is a complex task, especially when it comes to cognitive impairments. There are hundreds of types of disabilities, differing very slightly sometimes about what people that suffer them can and cannot do. Regarding the initialization of the special needs, these could be inserted manually when the student enrols the course, for instance, as information about disabilities is not expected to change very frequently.

2.2. Domain, Context and Game States models

Other models that the system may need are the domain, context or even game states model. However, these models are not so important in our opinion and therefore will only me required for certain cases of adaptation.

- *Domain model (DM)*. Adaptive systems that have been applied to learning usually include, somehow, a model of the domain that is being taught, as discussed in section II.2.1. Moreover, if the user model includes information about the knowledge of the student, some kind of domain model is required to represent such information about users' knowledge. This is closely related to the pedagogical approach that is being taken by the instructor. However, this idea is rarely used in adaptive educational games. Besides, the domain model may be important also for defining the assessment criteria. For instance, the author of the adaptation may decide that reaching certain game states is something important from a pedagogical point of view. That is, when those game states are reached it has a meaning for the teacher in terms of evaluation. While the instructor may decide just to assign a score to the student, more sophisticated pedagogical design may require the identification of accomplishment of learning goals or the acquisition of a certain skill.

- *Context model (CM)*. In many cases where and how the game-based learning experience is taking place will be indispensable to maximize its effectiveness. This assumption implies that information about the *context* may be required. Typical information stored in this model will include special constraints imposed by the environment. For example, in a noisy room the game should avoid providing crucial information through sound. Subtitles should be used instead. Or the use of voice commands will result impossible if the student does not have a microphone in that moment. Contextual adaptation will be especially relevant for mobile game-based learning experiences. Actually, most applications that are devised for mobile devices include adaptation to the specific features of the device as a strong point. This will include, for instance, representing information about the device itself, like the screen dimension. It is important to highlight the relation between the context model and the special needs model. While the first represent permanent actions the user will not be able to do, the second is related to temporary actions the user cannot do. The adaptation engine of the game would need to consider both models to generate the actual list of *limiting factors* of the user. We could define limiting factors as the special requirements that the user has in the moment of executing the game, with independence of what was the cause (either a permanent disability or a restriction imposed by the context). In some cases the game could not need these models as inputs to determine the limiting factors, but to infer them from the observation of the in-game interaction. For instance, consider a student with severe osteoarthritis in fingers. This kind of impairment could be classified as a severe mobility impairment if the student hardly can move the mouse or hit a mouse button and the game does not support other input devices. If the adaptation engine monitors the interaction in the game, measuring response gaps, it would be able to determine that situation by "listening" to the input devices. Finally, the context model could be long-life or short life, depending on whiter the LMS can determine pre-fixed places where educational games will be played or not. For instance,

- *Game States Model (GSM).* Many kinds of adaptation will need to be defined depending to what has happened in the game so far. As discussed about the domain model, it may be interesting to link somehow "game states" with learning achievements. To get this it would be essential to have some knowledge about the progress of the student in the game. We could assume that all the video games are designed around a conflict that serves as a goal for the player. Typically, to accomplish the final goal the player would need to achieve intermediate objectives by performing certain tasks. In this manner the game could be represented somehow as a Finite State Machine (FSM) where states are the intermediate goals and transitions between states are the completion of the in-game tasks proposed, or the failure to do so. While this approach may not be valid for all games as it is a rough simplification, it will work for most of the cases. The initial and final states could be unique or multiple depending on the design of the game (e.g. Will all the students start at the same position? Will be the choices of the player influence how the game ends?). Moreover if the game could not be represented using such representation of a FSM the framework would still be valid; just avoid using the game model to define the adaptation.

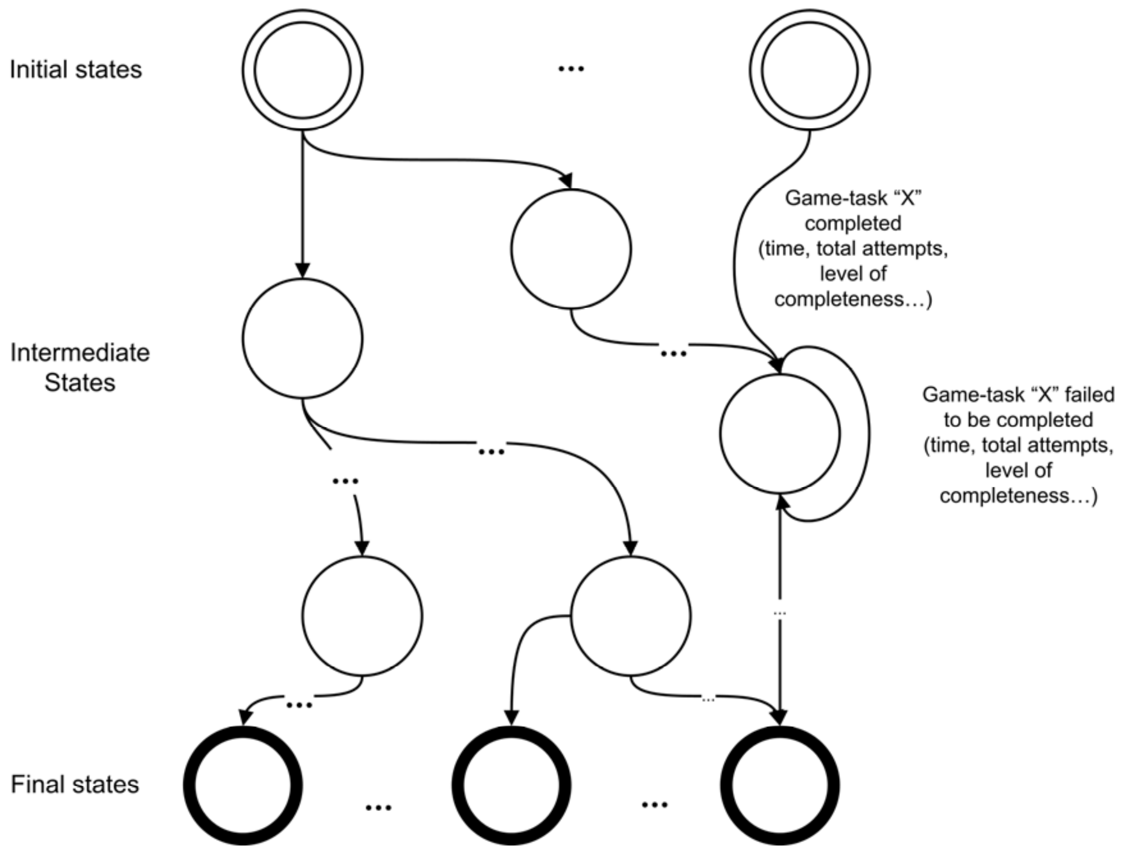

Figure 20. Game states model.

Over this FSM more details may be required for consideration. The game adaptation engine will not only need to know if a certain task is completed, but also information about *how* it was completed. That will provide the system with very valuable information about the student and his/her game habits and skills. Typical parameters that will be considered are the time and/or attempts needed to complete the task, the level of completion of the tasks or even the accuracy. The concrete parameters used will depend mainly on the genre of the game (e.g. the level of completion of a task may not make sense for adventure games where the player usually achieves or does not achieve something, but no intermediate options are allowed).

4. Reference architecture

Once the general principles of this framework have been described, we propose a reference architecture to implement adaptive educational games based on the framework. The architecture has been designed modularly to meet the requirements of flexibility imposed in the definition of goals. Figure 21 provides an overview of the modules this architecture is composed of, and the data that each module exchanges with the others.

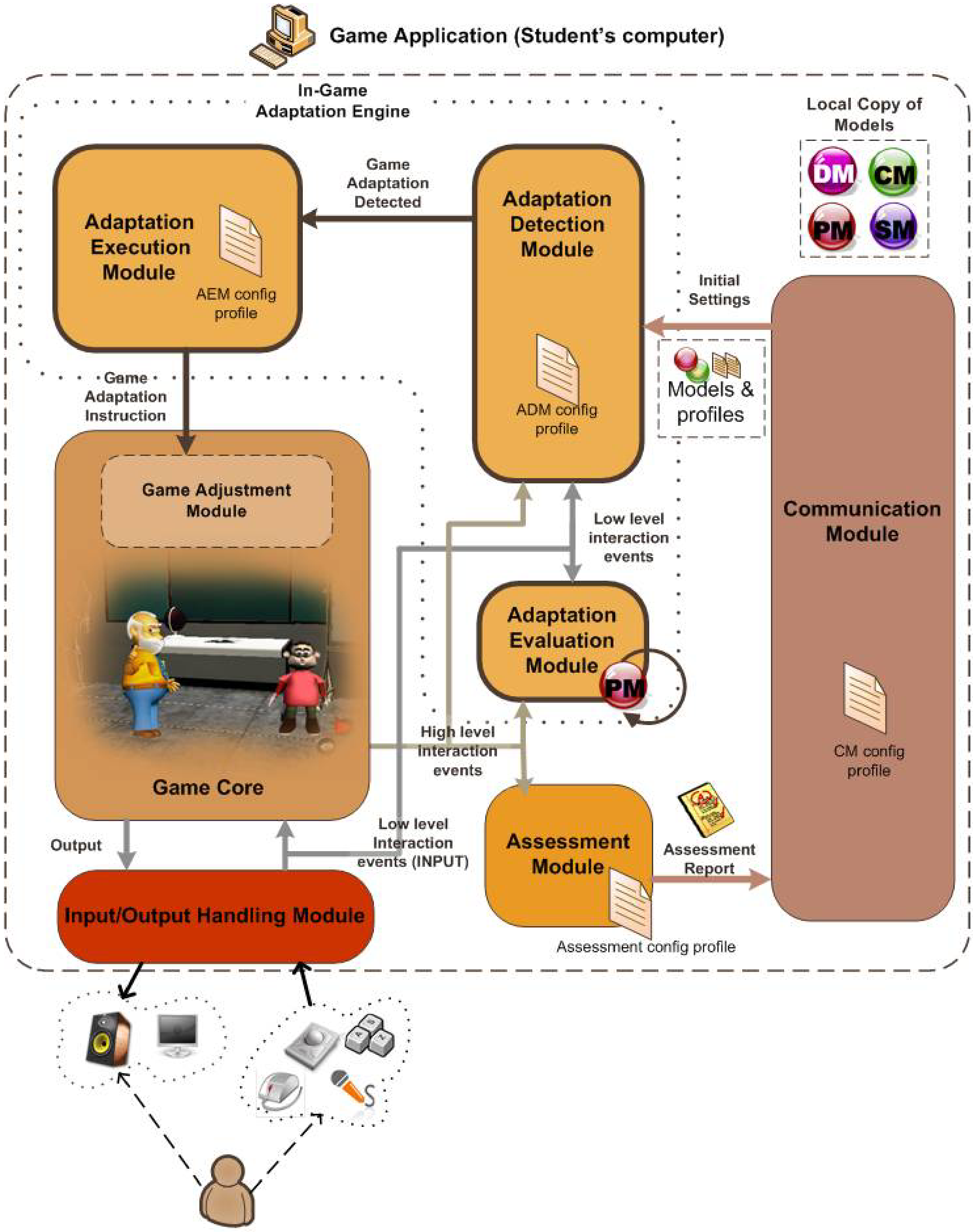

Figure 21. Modular architecture proposed for developing adaptive games

- *Input/Output Handling Module*. This module has to be flexible to configure and support as many input and output devices as possible, as adaptation in terms of special needs may require multiple input/output channels enabled at the same time. Moreover, the Input/Output Handling Module will be responsible of providing the rest of the modules with information about the low-level interaction events that occur in the system. These events, such as mouse clicks or keys pressed could be useful to detect adaptation situations.
- *Adaptation Detection Module*. The Adaptation Detection Module (ADM) is

the responsible of detecting in-game situations that will require some kind of adaptation. As the framework is designed to be flexible so multiple approaches could be applied, the behaviour of this module will not be limited to identification of patterns, but might include also online learning. The behaviour of this module is determined by the ADM configuration profile, which will be mainly a set of “Condition-Effect” rules, as introduced in section 2. In this manner the work of the ADM is to monitor the activity in the game, listening to the events (low level and high level) that the I/O Handling module and the game core are responsible to produce (respectively), and use them to identify when the conditions of the rules are met. Therefore the ADM will also need to access the local copy of the models that are available to all the modules. When the ADM detects a situation that requires adaptation, it notifies the Adaptation Execution Module of the situation that has been detected. The AEM will use the configuration files to determine what actions must be carried out. In addition, the ADM must assign priorities to the rules. For instance, in the same loop the ADM may determine that two adaptations must be carried out. Those adaptations may be contradictory, so the ADM should determine which one must be executed. These priorities could be defined by the author of the adaptation behaviour in the ADM configuration profile.

- *Adaptation Execution Module*. The Adaptation Execution Module (AEM) is the responsible of executing the specific modifications in the game when a situation that demands adaptation is identified. Nonetheless, this module is expected to work in high level terms. For instance, it could tell the game core to increment or decrement the difficulty of a game, but in a manner that the definition of adaptation is reusable. That is, it will never tell the game core to increment specific variable values, as this will make the design of adaptation completely implementation-dependant. Instead of that, the behaviour of the game is defined in the AEM configuration profile that will determine how to map abstract adaptation into the specific game.

- *Game Adjustment Module*. This module is completely dependant of the implementation of the game. It will receive high-level adaptation orders from the AEM and implement them on the actual technology being used. For instance, if the AEM determines that difficulty should be incremented in the game, the GAM will know what parameters within the game must be adjusted.

- *Adaptation Evaluation Module*. One of the problems that adaptive games may have is that they completely trust on the adaptation process sometimes. That is, to assume that all the adaptations that are executed in the game are 100% appropriate for the user. As adaptation is a very complex issue the system should not assume that all its decisions are always perfect, but that mistakes and imperfections might occur. As a consequence the system may need to measure the effectiveness of the adaptation process. That is the purpose of the Adaptation Evaluation Module (AEM). This can be done in multiple ways, but probably the most intuitive is to rely on the update of the player model as a way to evaluate the adaptation. If the player model is properly maintained and adaptation is carefully designed it is likely that wrong adaptations will trigger, after that, other kinds of adaptation as a response to changes observed in the game.

- *Assessment Module*. The assessment module also monitors the interaction in the game by listening to the high level events produced by the game core.

In this manner the instructor can define how to evaluate the game-based learning experience, which is something that most of the educational video games usually lack, mostly because of the difficulty of getting instructors involved in the development of the games and other technical issues. Please note that assessment has a clear LMS orientation. It may lead to an update in the student module, as a consequence to the acquisition of a certain portion of knowledge, but on the LMS side. The configuration of the assessment module is done also using a set of Condition-Effect rules, as discussed in section 2. Conditions are defined over the high-level interaction events that the assessment module receives (e.g. the player has visited a new scene, etc.) and relevant game states.

- *Communication Module*. The communication module is the responsible of establishing the connection with the Learning Management System to receive the input data (e.g. user model) and to send output data (e.g. the assessment report). The communication between game and LMS could be implemented in multiple ways. Perhaps the most simple is to develop ad-hoc versions for specific LMS. Besides some LMS are implementing plug-in architectures in the latest versions (e.g. *Moodle*™) that could be used to establish the communication with the LMS. However this solution is still platform dependant, which compromises the reusability of the platform and the investment in the development of adaptive educational games using the framework may be risky. Thus we advocate for the use of current specifications of the e-Learning field to exchange information with the LMS, as for example, ADL SCORM. This approach adds platform interoperability, so “ideally” any game could be used in cooperation with any LMS that complies with these specifications. (A. Del Blanco et al., 2009; A. del Blanco, Torrente, J., Moreno-Ger, P., Fernández-Manjón, B., 2009).

5. Summary and conclusions of the chapter

In this paper we have proposed a general and flexible framework that meets the requirements stated by goal 1, as defined in section I.5. It relies on a general adaptation model that is based on the one described in (J. Torrente et al., 2008b). In addition it separates the detection, execution and evaluation of the adaptation in order to guarantee modularity and ease the introduction of AI techniques that can be really complex. Besides, the definition of the Communication Module allows the game to interoperate with any standard-compliant LMS in order to exchange data. Finally the framework also considers assessment not only due to its pedagogical value, but also as an effective manner to close the adaptation cycle by the redefinition (i.e. update) of the student model.

However, in spite of the work done this framework also present some flaws. On the one hand, how the communication between modules is performed is not defined. It will be very important to define interfaces for the exchange of data between modules, especially for those modules that communicate directly with the game core. Nonetheless, to achieve this we need to develop a general adaptation model that identifies types of adaptation that are relevant from a pedagogical point of view.

Chapter IV

Particularization of the Framework for <e-Adventure>

1. Introduction

The second goal of this work, as stated in section I.5, was to integrate the framework into a game authoring tool with the double purpose of 1) fulfil one of the main goals of the FLEXO project (to produce an authoring tool for the development of adaptive and accessible educational games); and 2) test its effectiveness in a real scenario. In this chapter we describe the approach followed to tailor the general framework proposed in chapter III to meet two specific types of adaptation, as a proof of concept: 1) adaptation to meet special needs (gross-grained adaptation); and 2) adaptation to avoid in-game frustration (fine-grained adaptation), enhancing the immersion and focus of the student. This is implemented in the <e-Adventure> educational game authoring tool.

1.1. About <e-Adventure>

<e-Adventure>[33] (Moreno-Ger et al., 2008b) is the result of the research carried out in the <e-UCM> group on educational gaming. To be more specific, the <e-Adventure> family of authoring tools (Lavín-Mera et al., 2009; J. Torrente et al., 2008a; J. Torrente et al., 2009) implements the research outcomes of Moreno-Ger PhD. Thesis (Moreno-Ger, 2007). The more relevant features of <e-Adventure> are summarized in these main points:

- *Low-cost orientation*. One of the problems that are preventing the introduction of video games in the classroom, according to (Moreno-Ger, 2007) is their high development costs. Thus <e-Adventure> focuses on low-cost games that could be rapidly developed without requiring high investments, but keeping a high educational value (Moreno-Ger et al., 2008a; Moreno-Ger et al., 2008c; Moreno-Ger et al., 2007b). This is achieved by narrowing the types of games that can be produced with the tool to *point-and-click* adventures. These games provide a good balance between development costs and educational value (Dickey, 2006).
- *Education-specific purpose*. <e-Adventure> aims to guarantee a high educational value of the games. This is achieved by supporting the integration of the games with e-Learning environments and the support for authoring adaptation and assessment behaviour in the games (A. Del Blanco et al., 2009; Moreno-Ger et al., 2007a; J. Torrente, Moreno-Ger, P., Martínez-Ortiz, I., Fernández-Manjón, B., 2009b).
- *Instructor-oriented*. The platform is composed of two applications: a game authoring editor (used to create the educational games) and a game engine (used to execute the games). The idea is that instructors could develop their own educational video games, or at least contribute directly in the development process, as it does not require any technical background or programming skills (J. Torrente et al., 2008c).
- *Mature technology and several cases of use*. <e-Adventure> is now becoming a stable product instead of a research prototype, and its effectiveness has been tested in the development of several educational video games and game-like simulations (Moreno-Ger et al., 2008a; J. Torrente, Moreno-Ger, P., Fernández-Manjón, B. & del Blanco, A., 2009a).

These four characteristics, as above described, were our motivation for using <e-

[33] http://e-adventure.e-ucm.es

<e-Adventure> as a test-bed for our framework. Besides the simplicity of the *point-and-click* adventure game genre facilitated the implementation, and the inherent importance that narration has in these games, instead of other game elements (3D graphics, complex AI, etc.), minimized the risk of loosing engagement and immersion when the game is tailored for students with special needs.

2. General particularities of the framework

As introduced in section 1, the particularization of the framework for the <e-Adventure> platform is a proof of concept to address two simple types of adaptation. Thus several simplifications have been made in order to facilitate the implementation. On the one hand, no communication is established between the game and the LMS. Thus the user model is generated by the game before game-play starts. On the other hand, all the configuration profiles are packaged along with the game. Finally, no assessment is considered.

Figure 22. Example of the in-game tool "screen magnifier" in the 1492 <e-Adventure> game (J. Torrente, Lavín Mera, P., Moreno-Ger, P., Fernández-Manjón, B., 2008).

In the next paragraphs we provide a general description of how both adaptations are designed.

- *Adaptation in terms of special needs.* Students are encouraged to fill a form where they select special requirements when the game is launched. According to that information, the game can perform two actions: enable some specific *input/output modules*, or *in-game tools*. For instance, if the student is blind the system will activate a voice interface module that allows users to interact with the game using voice commands. In-game tools are an in-game screen magnifier and an in-game audio-text tutorial, and are targeted for non-severe disabilities. For example, if the student has low vision the system will put the in-game magnifier in his inventory, and when it is used it will allow the user to augment areas of the screen. As the magnifier is completely integrated in the game it does not break immersion. The tutorial explain users with special needs how to interact with the game depending on the IO modules that are enabled.

- *Adaptation to avoid frustration caused by "stuck situations"*. This is especially relevant for *point-and-click* adventure games, as players usually have to complete a specific set of actions by combining objects and interacting with NPCs which order is completely fixed. As a consequence it is quite common that a player gets stuck at some point when has no idea about the next task that must accomplish. In our implementation of the framework for <e-Adventure> we detect these situations by matching the current interaction trace with a permanent record of past in-game situations where the player did not know how to continue. If the diagnosis is positive, the system will place a NPC in the game that provides guidance. When the NPC enters the scene he/she establishes a conversation with the player in order to offer help. Then, following the typical conversational flow in *point-and-click* adventure games the NPC guide gives the player three options. One is to accept the help. In case this chosen the NPC will give a clue that is chosen from a list. Another option is to reject the help. Finally, the third option allows the user to notify the system that he/she knows how to carry on in the game. This information is used in the adaptation evaluation phase in order to detect false positives.

Figure 23. In-game conversation between the player and the NPC guide when the system detects a situation where the student is "stuck".

Adaptation in terms of special needs is carried out mainly in the initial phase of adaptation. The actions that the system executes are the configuration of the input and output handling modules that the user will need, along with the in-game tools.

Besides, in the initial adaptation phase both models used for this example, the Special Needs Model (SNM) and the Player Model (PM) are initialized (see section 3) using user-entered data. Figure 24 describes the whole adaptation process in comparison with the general one proposed in section III.4.

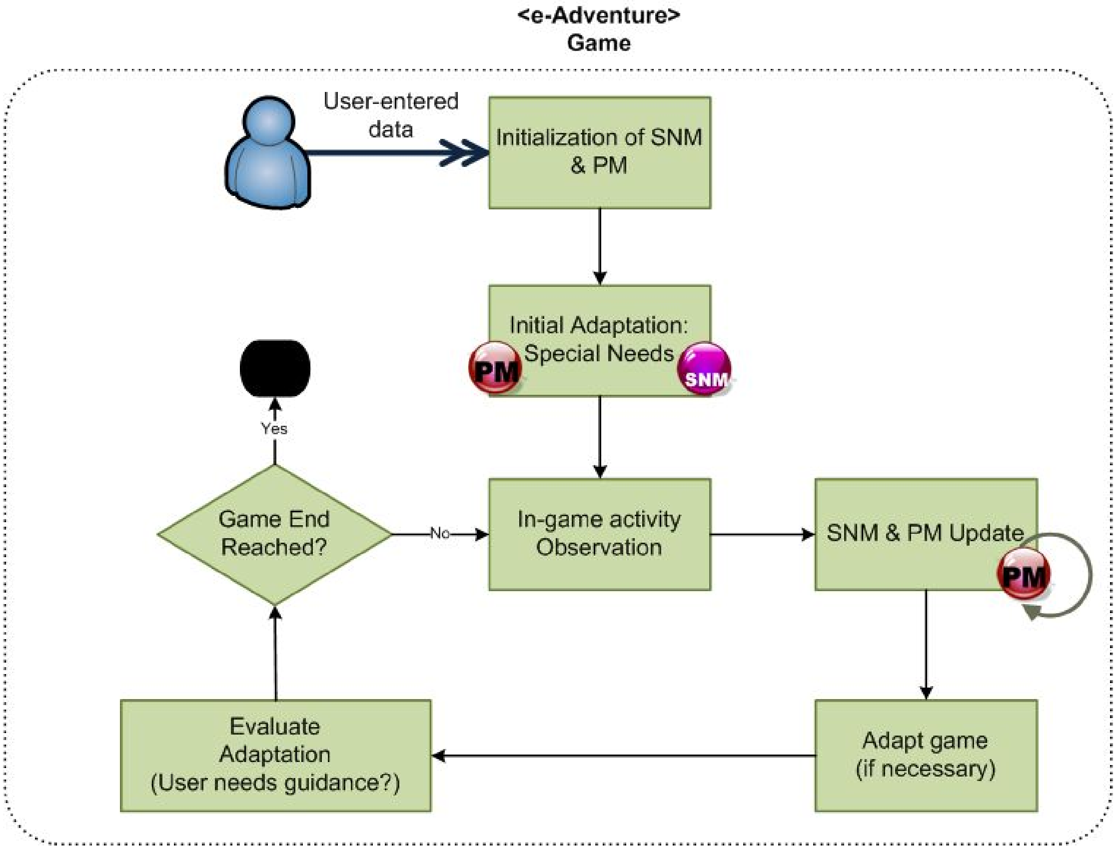

Figure 24. Particularization of the two phase adaptation model proposed in section III.4

3. Particularization of the models

As discussed in section 2, for <e-Adventure> we have contemplated two different adaptation mechanisms. The first one, adaptation to cater for special needs, required the particularization of the Special Needs Model (SNM) (sub-model contained in the User Model as described in section III.3.2.1). The second one, in-game adaptation to prevent "*stuck situations*" required the particularization of the Player Model (which is also a sub-model of the UM). No other models are considered in this example. In this section we describe how that particularization has been carried out.

- *Special Needs Model*. Most of the information about special needs that the SNM should contain can be classified in four categories according to the group of impairments of a particular student in a particular context. Those are visual, hearing, mobility and cognitive impairments. Table 2 contains the attributes used to represent special needs of the user, including not only disabilities but also preferences, as this could help students with minor impairments to maximize their satisfaction when playing <e-Adventure> games. To simplify the implementation, no cognitive impairments are considered yet in <e-Adventure>, as the table depicts.

Table 2. Attributes of the Special Needs Model for <e-Adventure>

Group	Attribute	Accepted values
Visual impairments	Vision level	*Low-vision* (unable to read normal text but who would be able to read it with some aids); *Complete impairment* (unable see anything on the screen).

Visual preferences	Preferred colour combination	Preferred text and background colours for the student.
	Forbidden colour combination	Text and background colours that would impede or make the student's access to the game the difficult.
Hearing impairments	Hearing level	*Low hearing* (able to hear background sounds, requires subtitles for conversations); *Complete Impairment* (requires full subtitles for every event)
Hearing preferences	Preferred sound level	0-100
Mobility impairments	Hand-arm mobility level	Difficulties using mouse; Difficulties using keyboard; Cannot move hands

Regarding the initialization and maintenance of the SNM, ideally the LMS should carry them out. However, to simplify this proof of concept, each user introduces them manually when the game starts.

- *User model: Player Model (Local).*To deal with the second adaptation mechanism, in <e-Adventure> we defined a simple player model that has only two attributes: *Player Frustrated* and *Detection Attempts*, which be assigned the values *true* or *false* or a number within the range 0-MAX_ATTEMPTS respectively. While the first attribute will store if a situation of frustration has been detected, the second one will store the number of detection attempts that have been carried out. Although *Detection Attempts* does not refer to a property of the player, it is considered here because it is essential for evaluating adaptation, as if the system repeatedly identifies a false situation of frustration, the system would be annoying the player all the time. This model, which is short-life (it is initialized when the game starts and destroyed when it is quit), is initialized with the values <*false, 0*>. When the system detects an in-game situation that may imply a high level of frustration in the player's emotional state, the model is updated with values <*true, Detection Attempts+1*>. The system will execute the necessary in-game adjustments, and after that it will evaluate if frustration has disappeared. In that case the model will store values <*false, 0*> again. If *Detection Attempts* exceed the maximum value, this adaptation is deactivated.

4. Particularization of the architecture

As it has been introduced in section 2, the communication link between the LMS and the game is not established in this example. Therefore the Communication Module described in section III.4 is not being used for this example. This section depicts the implementation details of all the other modules that are considered for this example: *the Input/Output Module, the Adaptation Detection Module, the Adaptation Execution Module, the Game Adjustment Module and the Adaptation Evaluation Module.* Besides, Figure 25 depicts the particularization of the architecture presented in section III.4 for this example.

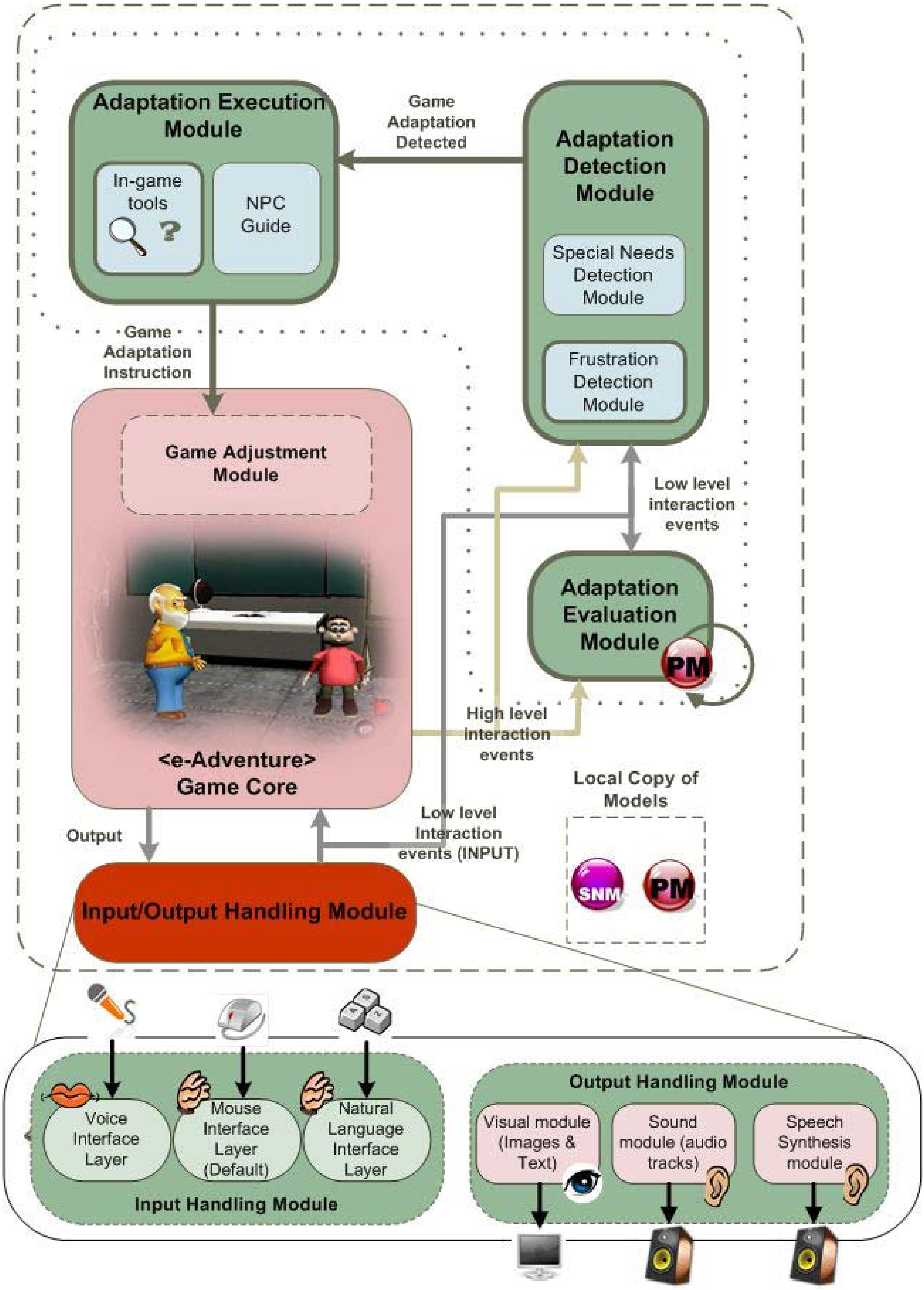

Figure 25. Particularization of the architecture proposed in section III.4 for <e-Adventure>.

Input/Output Handling Module (IOM).

The Input/Output Handling Module includes several pre-configured input/output modules, which are designed to support multiple interaction mechanism so students with special needs can play the game. The input modules implemented in the IOM for

<e-Adventure>: the Mouse Interface module (MI), the Voice Interface module (VI) and the Natural Language Interface module (NLI).

The MI is the classical interaction mechanism in *point-and-click* adventure games, where students usually need to point the mouse over NPCs (Non-Player Characters) and objects they find on their way in order to trigger any kind of in-game interaction. Therefore students need to be able to move the mouse and to see the elements on the screen in order to play the games, which may make them inaccessible to students with visual or mobility impairments. The VI is controlled by speech so students only need to be able to speak to control the games. Using a microphone, students can directly "give orders" to trigger any interaction in the game (e.g. "go to the library" or "grab the notebook"). The VI does not depend on the student's voice to work so students do not need to train the system, which is always an excruciating task. Besides, the VI accepts diverse synonymous orders for the same action (e.g. examine the scene or describe the scene) so students do not really need to learn how to use the VI, which is a typical problem in voice recognition.

Table 3. Some example of voice commands supported by the Voice Input Module in <e-Adventure>

Order	Description
Examine the table	The game will provide a description of the object "table", if it exists in the scene.
Go to the left	The student's avatar in the game will move in that direction, discovering new items that were still hidden.
Grab the pencil	The game will take out the object "pencil" from the scene and put it in the student's inventory[34].
Name items in the scene	The game will tell the student which items have already been discovered so he or she can interact with them.

The NLI accepts the same orders as the VI, but uses the keyboard as the input device. Thus students can interact with the game using text in natural language, which is helpful if students have speech and visual impairments or they are not allowed to speak due to environment circumstances (e.g. at a library).

Table 4 summarizes all the input modules according to the special requirements they can cover.

Table 4. Principal input and output modules

Input/output module	Senses Required	Used by …
Mouse Interface		Students with no disabilities. Hearing impaired
Voice Interface		Visually and/or mobility impaired
Natural Language Interface		Visually, speech impaired

Likewise, in <e-Adventure> we have included three output modules: the visual module, the sound module and the speech synthesis module. The visual module is not

[34]The inventory is an element that is usually present in point-and-click adventure games. Players use the inventory to store objects they find on their way and keep them for a later use.

only used to print images on the screen (the background image for the scene, for the characters and objects, etc.) but also text. Text is a key element in *point-and-click* adventure games, as most of the information is provided through conversations with other characters which are usually textually represented on the screen. Accessibility could be added to conversations by recording all the dialogues by using the sound module (which can play audio tracks in mp3 format), but it would significantly increase the cost of the games, which is a problem when the budget is very limited (as is usually the case for many educational projects). This is why the speech synthesis module is helpful, as it allows visually impaired students to play the game without compromising the cost. Nonetheless higher-budget projects can use the standard sound module (which plays mp3 files) for increased sound quality.

Finally, as it was described in section III.4, the IOM provides the Adaptation Detection Module and the Adaptation Evaluation Module with low-level interaction data generated with the events that input devices provide. In this case low-level interaction data are mouse events, keyboard events and speech inputs.

Adaptation Detection Module

For this proof of concept the Adaptation Detection Module has two play two roles. Each role is “played” by a specialized module, as Figure 25 depicts. One of the modules deals with special needs, which is performed during the initial adaptation phase. This is action is straightforward as the module only needs to check the SNM model generated through user-entered data in order to detect the special requirements. When detection is positive the ADM notifies the AEM using a data structure that contains the list of input/output devices and in-game tools that have to be enabled.

The other module detects potential situations of frustration using a CBR (Case-Based Reasoning) system. Each ‘case’ is an entry on a database containing a representation of a game situation and if it was evaluated as a situation of frustration or not. In each loop the ADM checks the current situation with the Case Base using heuristics in order to determine if frustration is taking place. If the heuristic returns a positive identification of frustration, the ADM notifies the AEM by sending a simple signal of *frustrationDetected*.

As it would be impossible to store the whole interaction trace in a case base, the CBR system stores simplified versions of the high-level interaction events produced within the system. The Frustration Detection Module uses the high-level input data that the game provides to make a simplification of the interaction trace broke down in time intervals. Those events are related to the number of scenarios visited, number of objects/characters interacted with, number of books accessed, number of options browsed in the menu, average time spent on each scenario, etc. The time intervals considered are 1) the last minute, 2) the last 5 minutes and 3) the last 15 minutes, given that <e-Adventure> games do not usually last more than 25 minutes.

Adaptation Execution Module, Game Adjustment Module and Game Evaluation Module (AEM, GAM, AVM)

The AEM receives the outputs of the ADM. Therefore it also has two modules, one related to special needs, which mainly sets the Input/Output Handling Module according to the IO devices that must be activated and configures in-game tools, and a second module that executes the game adjustment for frustration detection: halts the game, makes the NPC guide appear in the scene and launches the conversation between guide and player. To simplify implementation, this module is integrated with the GAM. Besides, the AEM is connected to the Adaptation Evaluation Module so it knows that in the next loop it will have to check whether that potential situation of frustration was a false positive or not. Therefore the Adaptation Evaluation Module will analyze the option chosen by the player and determine if it was a false positive or not. As a consequence it updates the Case Base used by the ADM and the Player model, as described in section 3.

5. Summary and conclusions of the chapter

In this chapter we have described a proof of concept carried out to check the design of framework presented in chapter III. This proof of concept has consisted of a particular instantiation of the framework for a specific game genre (*point-and-click* adventure games) and two particular cases of adaptation, one carried out during the initial in-game adaptation phase, and the other during the online adaptation phase. The environment chosen to integrate this particular instance of the framework was the <e-Adventure> platform in order to satisfy the second goal proposed in section I.5.

This example highlights how development of adaptive educational games can be performed by instantiating the framework, with the particularities required in each case. For instance, in this example we have not used the Communication Module, several Modules have been combined to facilitate the implementation and configuration profiles for each module are embedded in the package that contains the game.

However, there are limitations in the current implementation status of this framework in <e-Adventure>. Firstly, it has only been implemented in the game engine, developing in this manner an experimental version that is now under testing. Thus we have to integrate these ideas in the game editor so the modules can be configured without requiring direct access to the code. Secondly, the use of a CBR system has some disadvantages. As it heavily relies on past experiences in order to detect frustration, a huge amount of data that could be a burden for the <e-Adventure> engine. In addition, the CBR would need much more training than the one we could carry out. Thus we are analyzing other possible technologies for detecting in-game frustration. Finally, the interfaces that each module uses and provides to enable the communication with other modules should be clarified, extracting conclusions that would be used to refine the general framework proposed in chapter III.

Chapter V

Conclusions & Future Work

1. Summary

This work started with the ambition of exploring the e-Learning, adaptive gaming and accessible gaming fields from a new perspective. It was our opinion that the mutual collaboration between these areas could address, at the same time, some of the challenges that these research areas are facing nowadays. The main challenges we have identified are:

- *Lack of support of adaptive learning in Learning Management Systems.* In spite of all the research done in the field of computer-supported adaptive learning for decades, the support for adaptation in modern Learning Management Systems is still a pending task. This fact has raised multiple discussions within the research community, which is trying to determine what the causes of this "failure" are, given that the potential of adaptive learning is broadly accepted. According to several authors, the lack of support for adaptation in LMS could be associated to a lack of scalability of adaptive systems (e.g. Adaptive Hypermedia Systems), which are too tightly related to the domain and instructional approach; the scepticism of e-Learning developers, who rise doubts about the ability of Adaptive Learning Environments to return on the investment required for their development; the absence of standards in Adaptive Learning Environments that guarantee interoperability between platforms; and finally the lack of evidence in regard of the effectiveness of adaptive systems, as only few commercial approaches have achieved success (e.g. LastFM™, Pandora™ or Amazon™) (Ghali et al., 2008; Graf et al., 2005; Paramythis et al., 2004; Shute et al., 2003). In this work we have also discussed one more aspect, the nature of the content that Adaptive Learning Environments usually store, which lack in flexibility and interactivity. While the first hinders the adaptation of the content beyond the presentation and navigation, the second prevents the LMS of getting valuable tracking data in the amount required to infer real knowledge about the user. The conclusion is that new forms of content meeting these requirements of flexibility and interactivity should be introduced in LMS. And video games meet both.
- *Need of intensive research in the adaptive gaming field.* While the gaming industry is starting to realize that the more video games can cater for the requirements and tastes of different users the more profitable they become ("replayability" increases, the demographic spectrum of target audience gets wider, etc.), the perfect formula for the development of adaptive games is to be discovered yet. From the perspective of the industry, the high development costs of designing and implementing in-game adaptive behaviour is a clear barrier in an industry where risk is predominant. In addition, the approaches followed in the titles that have achieved more success amongst gamers are, on the one hand, very closed to the game genre (usually *Shot'em up* games), and on the other, the complete details are never published due to the high competence suffered in the sector. From the point of view of the research field, adaptive gaming has become a popular test bed for scholars researching in the field of Artificial Intelligence, but few of the approaches proposed have become real technology. Moreover there is still an ongoing discussion, with scholars advocating for old or new approaches frequently, which puts in risky any investment for a specific technology. Moreover, even when the intuition about the potential benefits of applying adaptive gaming to support learning are quite clear, there is very little knowledge about how to design

adaptive game-based learning experiences that guarantee a high educational value. All the pilots developed so far are still ad-hoc research projects that unable the extraction of solid design principles that could be applied in other developments. The conclusion is that adaptive gaming is still confusing and mutable, and there is a need of mechanisms that promote intensive research and collaboration between scholars and industry that could reuse the work done by other people, which will facilitate a more rapid development of adaptive game technologies.

- *Lack of awareness in the gaming community about the need of attending the requirements of people with special needs. Need of a customized approach to deal with special needs in games going beyond the application of techniques that come from web-accessibility*. The gaming industry has been completely unaware about the need of making games that are playable by people with special needs. Thanks to initiatives of different condition (e.g. legal initiatives, communities of disabled gamers such as *AbleGamers.com*, associations of developers such as the *IGDA*, etc.) the awareness of this problem is increasing. Nonetheless, in our opinion the approaches proposed for developing "accessible" games are missing important details due to the excessive influence that web-accessibility have on them. When accessibility is related to software, the goals vary depending on what the software is intended for. In short, the different motivations that users have to utilize software conditions the goals accessibility should pursue. In this regard there are clear differences between web-oriented content and games, while users approach to the web in order to get information (although this is changing with the new panorama of Web 2.0), games are expected to provide enjoyable, immersive, engaging and finally, satisfactory experiences that have little relation with information access. Thus when discussing accessibility in games the goal should not be to guarantee that games are playable for all, but that the immersion, engagement, enjoyment and satisfaction are guaranteed for all. Obviously this is major issue, and could only be approached since a more general perspective: accessibility should be addressed from the point of view of adaptation in video games, taking in consideration the additional functional requirements accessibility involves, which are mainly related to a flexible design of the interface and channels of interaction, supporting multiple input and output devices.

As a result of identifying those challenges, we have tried to consider the areas involved as a total, trying to get a wider scope. This led us to propose a general framework that targeted the challenges of 1) the lack of adaptation support in LMS, 2) the need of intensive research in adaptive gaming and 3) the special consideration that accessibility deserves in games. The main requirements of the framework, as established in section I.5, are these:

- Integration of the games in LMS with active communication channels for the exchange data about the users.
- Flexible design so diverse approaches and techniques for adaptive gaming developed by one or multiple parties could interoperate and be tested separately and in conjunction.
- Explicit consideration for accessibility issues in games, considered as a special case of adaptation.

In addition other important requirements were added to address the issues discussed:

- Use of e-Learning standards to guarantee interoperability and reuse between diverse games and LMS:

- Support for multiple input/output devices.

2. Contributions

This work has been directed by the abovementioned premises, producing some interesting outcomes that can be applied in real contexts thanks to the integration with the <e- Adventure> authoring tool, which will facilitate future research that seems, at least, promising. In summary, the main contributions of this work would be the following:

- To have reviewed and analyzed three active research topics: adaptation support in e-Learning environments, adaptation in games and accessibility in games, from a broad and critic perspective, identifying challenges and possible common points where the fields involved could profit from mutual cooperation.
- To have proposed how that cooperation could be established linking the three areas: 1) Learning Management Systems and adaptive gaming are integrated through the need of highly interactive and flexible contents in LMS; 2) adaptive gaming and accessible gaming by considering this last a special case of the first one and identifying additional requirements.
- To have developed a general and flexible framework that integrates concepts from Adaptive Learning Environments and adaptive gaming. The framework is built upon the ideas aforementioned, including an implicit model of adaptation that considers two phases where the LMS drives the first, gross-grained one and the game drives a fine-grained adaptation that rises from the permanent in-game observation of the student's performance. The observation of the in-game activity also produces an assessment report that is sent to the LMS using a standards-compliant channel (e.g. SCORM) for processing. The framework is designed modularly, encapsulating the functionalities for detecting, executing and evaluating the adaptation in different modules, which facilitates that multiple parties could work together in a project that considers adaptive gaming. Besides the framework is configured using profiles that are authored without needing programming skills, allowing that instructors could contribute in the definition of adaptive behaviour as it is an important educational aspect. As a last remark, the design of the framework is not tied to any specific instructional nor adaptation model so each instructor could define those according to the instructional strategy selected for the course.
- To have particularized the framework for a specific scenario as a proof of concept, considering gross-grained adaptation to deal with special requirements and in-game fine-grained adaptation to detect situations of frustration and provide guidance to avoid rapid quits of anxious students.
- To have implemented the particularized version of the framework in the <e-Adventure> educational gaming authoring tool, as part of the objectives of the FLEXO research project where the <e-UCM> research group is involved, allowing the development of adaptive and accessible educational video games.
- To have embedded explicit support for accessible design in <e-Adventure>. Dealing with special games is costly as it requires investing in expensive technologies such as text-to-speech or voice recognition. Thus to have an

authoring tool that embed this features out-of-the-box may help in reducing such high development costs.

- The last remarkable contribution are the results of this investigation: a research paper that will be published in an international workshop, which describes how the <e-Adventure> supports the development of educational games that cater for the special needs of students with visual, hearing, mobility and cognitive impairments, without adding an extra development cost.

3. Future work

In spite of all the work done, this is just the beginning of an ambitious line of research that we expect to generate positive results within the next few years. This work has been useful to understand the complexity of the fields involved and to develop strategies for approaching the next steps of this research. Therefore these are the next issues we are planning to address in the near future:

- To revise and refine the concepts of our framework by developing several adaptive and accessible video games and test its efficacy in real learning scenarios. We are planning to carry out this within two different lines. On the one hand we have signed an agreement with an educational organization that is specialized in professional training to produce an educational adventure game with the next goal: to improve the development of creativity and innovative thinking for directors and team leaders. This will allow us to test the efficacy of our approach in the field of professional training, which demands immediate benefits. Moreover the particularities of the specific learning context we will face and the broad nature of the target audience the game is intended for will allow us to observe how different people approach to solving the in-game problems. This will facilitate us the acquirement of knowledge about users taken directly from the experimentation. We could use that knowledge to validate our framework and redefine concepts. On the other hand we have applied for an AECID project in cooperation with the UDG University (Universitat de Girona) to develop games to help children with learning problems from unstructured families in Colombia. If the project is granted, we will have the opportunity to develop a methodology for the production of educational video games that cater for special needs without limiting to typical "accessibility" approaches. We will try to design the games in a manner where education and enjoyment is always guaranteed, and use the results of the experience to validate and redefine again our framework.
- To define software interfaces for the modules of our framework in order to start building reusable pieces that will compound, at the end, a set of open source libraries including out-of-the-box functionalities for detecting, executing and evaluating adaptation. The idea is to involve other parties in this concern so we can also get valuable feedback from scholars and other professionals of different background.
- To develop a general adaptation model for educational applications. This model will include how to design and implement adaptive educational games for improving the learning outcomes of diverse students according to their specific needs. To achieve this we will first have to identify specific instances of the user model presented in section III.2.1 and analyze the adaptation techniques that maximize the learning outcomes for each one.

As a last remark, we would like to emphasize that this is just the beginning of a promising research line that we expect will deliver us adaptable, accessible and enjoyable game-based learning experiences.

Chapter VI

Appendices

Appendix A. *“Implementing Accessibility in Educational Videogames with <e-Adventure>”*

Complete Citation:

Javier Torrente, Ángel del Blanco, Pablo Moreno-Ger, Iván Martínez-Ortiz y Baltasar Fernández-Manjón. (2009). *Implementing Accessibility in Educational Videogames with <e-Adventure>.* ACM International Workshop on Multimedia Technologies for Distance Learning (MTDL 2009), In Conjunction with the ACM International Conference on Multimedia (In press). Beijing, China, ACM Press.

Abstract:

Web-based distance education (often identified as e-learning) is being reinvented to include richer content, with multimedia and interactive experiences that engage the students, thus increasing their motivation. However, the richer the content, the more difficult it becomes to maintain accessibility for people with special needs. Multimedia contents in general and educational games in particular present accessibility challenges that must be addressed to maintain e-learning inclusivity. Usually the accessibility of multimedia content in courses is addressed with the definition of simpler but more accessible content that diminishes the benefits of the richer content. Hence we need new, accessible multimedia technologies that guarantee that the learning experience is motivating and engaging to all students. We will focus our work on educational games, trying to leverage their engaging narratives to produce educational experiences that are attractive to all students, including people with special needs. Nonetheless the development of accessible games is a major challenge, due mostly to the additional development cost it involves. In this paper we present how the <e-Adventure> game platform facilitates the development of educational videogames for e-learning, simplifying the introduction of accessibility from the design stage of the game development process.

About the ACM International Workshop on *Multimedia Technologies for Distance Learning (MTDL 2009)* and the *ACM International Conference on Multimedia (ACMM 2009)*:

This paper has been accepted for publication in the proceedings of the 1st ACM International Workshop on *Multimedia Technologies for Distance Learning (MTDL 2009[35]). MTDL* 2009 aims to discuss problems, current studies, and solutions in how to use multimedia and communication technologies to improve e-learning, and will be held in Beijing, China, on the next October 23rd 2009. *MTDL 2009* will take place in conjunction with the annual ACM International Conference on Multimedia (*ACMMM 2009[36]*), which is a top international ranking conference on its field (A+ tier in the CORE[37] Ranking of ICT Conferences 2007). The *MTDL 2009* workshop will be published by ACM Press along with the proceedings of the *ACMMM 2009* conference.

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[35] http://mtdl2009.mine.tku.edu.tw/

[36] http://www.acmmm09.org/

[37] http://www.core.edu.au/rankings/Conference%20Ranking%20Main.html

Implementing Accessibility in Educational Videogames with <e-Adventure>

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ABSTRACT

Web-based distance education (often identified as e-learning) is being reinvented to include richer content, with multimedia and interactive experiences that engage the students, thus increasing their motivation. However, the richer the content, the more difficult it becomes to maintain accessibility for people with special needs. Multimedia contents in general and educational games in particular present accessibility challenges that must be addressed to maintain e-learning inclusivity. Usually the accessibility of multimedia content in courses is addressed with the definition of simpler but more accessible content that diminishes the benefits of the richer content. Hence we need new, accessible multimedia technologies that guarantee that the learning experience is motivating and engaging to all students. We will focus our work on educational games, trying to leverage their engaging narratives to produce educational experiences that are attractive to all students, including people with special needs. Nonetheless the development of accessible games is a major challenge, due mostly to the additional development cost it involves. In this paper we present how the <e-Adventure> game platform facilitates the development of educational videogames for e-learning, simplifying the introduction of accessibility from the design stage of the game development process.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, graphical user interfaces (GUI), natural language, screen design*;

K.3.1 [**Computers and Education**]: Computer uses in education – *distance learning, computer-managed instruction*;

K.8.0 [**Personal Computing**]: General – *games*.

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D.1.7 [**Programming Techniques**]: Visual programming;

General Terms

Design, Economics, Human Factors.

Keywords

Accessibility, <e-Adventure>, e-learning, distance learning, game authoring tools, game-based learning, online learning, videogames.

1. INTRODUCTION

For the last decades, information systems in general and the Internet in particular have experienced rapid expansion. These systems have become a fundamental tool in daily life, but this advance sometimes signifies a marginalization for people with special needs who cannot access the content that new technologies provide (be it as a consequence of personal characteristics or contextual issues). This has caused an increasing effort in the development of the technologies that enhance the accessibility of information systems for people with special needs.

Nevertheless, the creation of accessible technologies has focused unequally on different fields of software development. While the accessibility of websites is reasonably covered, other areas such as interactive multimedia (and especially videogames) are still trying to find the most suitable way to create accessible products. While it is true that there are some videogames that include accessibility characteristics, the high cost involved in acquiring some of these features is hindering their widespread adoption. One of the possible interventions is to provide all the information, even the small details, through several alternative channels at the same time, which is usually achieved by combining subtitles and sound/voices. However, this approach requires a considerable investment in gathering all the audio recordings (a videogame may have hundreds or thousands of information lines), which often makes this approach unaffordable in contexts where the budget is limited.

These problems are especially important in educational videogames. The need for enhanced accessibility in any kind of educational content is more pressing than in purely entertainment-driven developments (and even more in e-learning environments).

According to the 2007 US Census Bureau[1], 18% of the US population and 11% of children from 6 to 14 have some level of disability, with 12% of the total population having a severe disability. If videogames are to play a role in education, accessibility cannot be left aside. In addition, the higher cost of accessible games is harder to assume in an educational videogame, given that most educational gaming projects often have a limited budget, which makes the issue far more serious. These contexts require methodologies, design patterns, and tools that facilitate the creation of accessible videogames, without compromising the cost. In contrast, a survey of the domain reveals that such elements are rare and have received scarce attention in the literature.

In fact, game-based learning is still an emerging field being discussed in academic environments, with both supporters and detractors [1]. Therefore, developers are still more concerned with creating appropriate games for learning than in making them accessible, assuming that accessibility could be eventually addressed in the future. However, we consider that educational videogames, and especially web-oriented games, should take accessibility aspects into account from the very beginning if they are to become a real alternative or complement to other educational approaches.

The aim of our work is to create a system based on natural language processing to allow the introduction of accessible features in the development of educational videogames without compromising development costs. The system offers different pre-made input/output modules such as a voice interface for recognizing voice commands, a text interface for recognizing text orders, and a voice synthesis module for transmitting audio feedback without additional development efforts. The system has been integrated into <e-Adventure>, a game authoring platform designed to facilitate the creation of educational *point-and-click* adventure games for e-learning environments.

This work is structured as follows: Section 2 provides some context, focusing on the potential issues and current trends in accessibility, games and education. Section 3 describes a general framework for web-oriented accessible games in education, which has served as a base for the integration of accessibility features into the <e-Adventure> platform, as described in section 4. Section 5 presents a concrete case study, in which a pre-existing game is enhanced with accessibility features using <e-Adventure>. Finally, section 6 presents some conclusions and future lines of work.

2. CONTEXT: ACCESSIBILITY, GAMES AND EDUCATION

The accessibility of information systems is rapidly becoming a key issue, since it is one of the potential sources of digital division. In this context, the accessibility of educational technologies can seriously affect the future opportunities of individuals with limited means of access. While traditional teaching methods are often able to cope with accessibility aspects (often through the effort of dedicated instructors), the current trend towards increasingly complex educational technologies is continuously growing the challenge.

[1] http://www.census.gov

2.1 Web Accessibility

The emergence of the World Wide Web (WWW) and the posterior interest in e-learning environments was initially disruptive in this sense, leaving students with special needs unable to access these systems. Screen-reading tools partially resolved that issue. However, parallel to the evolution of the Web, e-learning environments grew more complex and started to include advanced multimedia content that increased the importance of accessibility measures.

To that end, these e-learning web-based tools can benefit from the ongoing efforts fulfilled by different public and private organizations to improve WWW accessibility. Highly influential organizations as the W3C are presenting the necessary requirements to create accessible web content [2, 3], along with webmaster-oriented tools to check the accessibility of web-based content [4].

There are also initiatives that specifically deal with digital educational contents for web environments. A very thorough approach was undertaken by the IMS Global Consortium in their *IMS AccessForAll* set of specifications [5, 6]. Unfortunately, these efforts are principally focused on the most common types of educational content (including many forms of multimedia content), but do not adequately cover highly interactive content such as educational games.

2.2 Input Device Adaptation for Videogames

The most common approach to increasing the accessibility of videogames is to seek their compatibility with assistive technologies [7]. Some examples would be screen-reading tools, mouse emulators or virtual keyboards. There are also tools that can be used to substitute the usual gamepads provided by game consoles (e.g. vocal joysticks or tongue sensors).

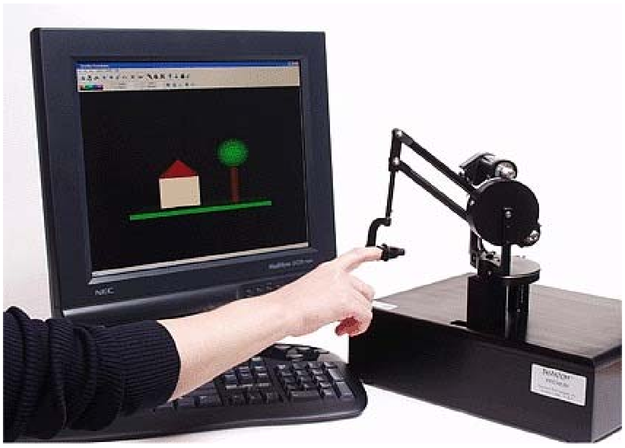

Fig 1. The *PHANToM™* device, created by SensAble Technologies Inc.

In this line, the work presented in [8] shows the use of the *PHANToM™* device (Figure 1), as an example of how *haptic* devices (which provide human-computer interaction based on body movements and the sense of touch) can increase accessibility. This approach not only facilitates access to the games for a wide range of people with impaired mobility (controlling the videogames with easy movements of one finger), but can also be useful to visually impaired people because the device offers them the possibility of perceiving 3D objects by means of movements of a device.

Another approach consists of adjusting the games without requiring specific devices (e.g. adding subtitles). However it is possible to bring both conceptions together. In this line we find *auditory games*, (also known as "audio - games") [9] which are specially designed for people with visual impairments, where the information from the game is transmitted through audio [10]. In some of those games the indications are given with abstract sounds, but the games with major acceptance are those which give users voice descriptions reproduced through text synthesizers.

Another way to provide audible information is with descriptive sounds. Specific sounds, which are used intensively throughout the game, are given special meanings so it is easy to remember the association between sounds and meanings. Other games receive input through voice or by means of specific devices [11].

2.3 Methodologies, Tools and Design Patterns for Accessible Videogames

Other works, such as [12], have focused on providing some design guidelines such as how to design interfaces or some simple methodologies for accessible videogame development [9, 13]. There are also design patterns and web initiatives providing indications on how to create accessible videogames, although they have not been translated into broadly accepted standards or specifications yet.

The *International Game Developers Association* (IGDA) has a *Special Interest Group* that focuses on accessibility issues[2] and published a white paper which provides a good analysis of the field [14]. This document provides a general overview, covering what accessibility in games means, why it is necessary, and what kind of disabilities can be tackled at the videogame creation stage. That work also gives some indications about how to adapt an already created game to improve its accessibility through adding subtitles and customizing text fonts, or how the textual information and subtitles can be recorded or synthesized. Along with these ideas, they encourage the use of other approaches to gather user input such as use voice recognition or other specific devices. However, the report does not propose any concrete pattern or methodology to create accessible games.

A unique approach from a technological point of view is proposed by *FORTH* (Foundation for Research and Technology - Hellas) [13], and is based on the *Unified User Interface Design* (UUID) [15]. UUID proposes a design pattern where the game tasks are initially considered in an abstract device-independent way. In later design phases, the interaction for each game task is designed and includes the selection of input/output devices. Several games have been developed following these guidelines, achieving accessibility for people with a wide range of special needs. These are the universally accessible games (*UA-Games*). An example is *Access Invaders* [16], which supports different game settings depending on the potential disabilities of each player, such as blindness (in which case the game will be loaded with the appropriate characteristics of the Audio-Games), damaged vision, cognitive disabilities or motor disabilities.

[2] http://www.igda.org/accessibility/

As far as development tools are concerned, the market is populated with many authoring environments for the development of videogames. There are development frameworks for game programming (such as *Microsoft XNA*™[3]), game development environments which allow people without technical knowledge to develop their own videogames (like *Game Maker*™[4] or *Unity3D*™[5]) and even simple editors oriented to specific game genres like *The FPS Creator*[6] or *Adventure Game Studio*[7]. However, none of these initiatives includes pre-configured features targeting game accessibility. This means that accessibility has to be implemented from scratch for every individual game.

2.4 Accessibility in Commercial Videogames

There are some commercial videogames that implement features to enhance accessibility or that have been modified after being published for this purpose. The creators of *Half Life 2*™ introduced accessibility for people with hearing problems during the development process after they received some complaints concerning the first issue of the saga. The reason is that in *Half Life*™ certain information that was essential to complete the game was transmitted across cut-scenes (videos) without subtitles, making it impossible for people with hearing impairments to reach the end of the game [17].

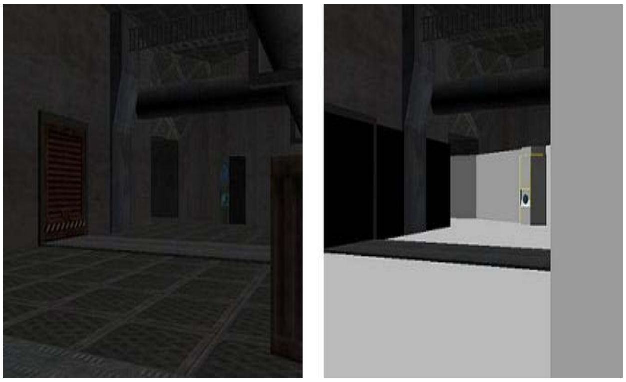

Fig 2. *Terraformers* game: left image shows normal mode, and right image shows the same scene with high contrast.

Terraformers™ was directly designed with accessibility features at an early stage. It includes a normal mode in which visual graphics are reproduced as usual in first-person 3D games, but it also has an accessible mode. In that mode, a sonar is activated to tell players what is in front of them and the contrast of the graphics is increased for vision-impaired people [18]; this mode also allows the player to select objects from the inventory orally.

3. DESIGNING ACCESSIBLE VIDEOGAMES FOR E-LEARNING

There are several considerations that must be taken into account when designing accessibility for a videogame. If the game is to be embedded in an e-learning scenario, some additional peculiarities

[3] http://www.xna.com/
[4] http://www.yoyogames.com/make
[5] http://unity3d.com/
[6] http://www.fpscreator.com/
[7] http://www.adventuregamestudio.co.uk/

must be considered. For instance, dealing with cognitive impairments, which is rarely covered in entertainment-driven videogames, becomes a very important issue in education as cognition and learning are closely related. In this section we will discuss these and other general considerations. First we will discuss the user model to be used to model the needs of each student (that is, what the user can or cannot do). Then we will discuss what to adapt in the games according to the user model. Finally we will discuss some other relevant issues such as the choice of appropriate game genres.

3.1 Input Data for Accessibility. User model definition

The first issue that must be considered when designing accessibility for a videogame is to identify the data that will serve as input to adapt the game. The most obvious (and probably most important) is the *user model*. That is, what the system knows about the user. This is a crucial factor as the game will need to know what the special needs of each student are in order to adapt the game experience.

But adaptation cannot be limited to students' impairments that are not expected to change over time. Even though the term accessibility is usually associated with personal disabilities, it can also be a result of the environment (i.e. context). A hearing impaired person is as challenged by audio content as any other person in a loud environment without earphones. Therefore the *environment settings* must also be taken into account. The adaptation will be more effective if the input data provided is focused on *what the user can or cannot do in that precise moment and context.*

The user model should also include some *user preferences* that may help to make the game accessible to the student, including *preferred and forbidden settings*. This is indispensable to facilitate access to the games for students with "minor" needs that might not be able to play a game due simply to small details that could be easily fixed by adapting the configuration of the game slightly. If students are able to play the game but only with great effort, they could get frustrated after a while. For instance, color-blind students may not be able to read a text or recognize an enemy approaching when a specific combination of colors is used.

Most of the information about accessibility that the user model should contain can be classified in four categories according to the group of impairments of a particular student in a particular context. Those are visual, hearing, mobility and cognitive impairments. Table 1 represents a fragment of a simple user model, including a categorization of the user (compulsory) and some preference attributes (optional) under each category. Although this is a simplified example, it illustrates some of the most relevant situations.

Table 1. Accessibility-attributes for the user model

Group	Attribute	Accepted values
Visual impairments	Vision level	*Low-vision* (unable to read normal text but who would be able to read it with some aids); *Complete impairment* (unable see anything on the screen).
Visual preferences	Preferred color combination	Preferred text and background colors for the student
	Forbidden color combination	Text and background colors that would impede or make the student's access to the game the difficult.
Hearing impairments	Hearing level	*Low hearing* (able to hear background sounds, requires subtitles for conversations); *Complete Impairment* (requires full subtitles for every event)
Hearing preferences	Preferred sound level	0-100
Mobility impairments	Hand-arm mobility level	*Difficulties using mouse*; *Difficulties using keyboard*; *Cannot move hands*

Note that, as previously indicated, this information is not fixed for each student and can change in runtime to cover environmental or context issues.

3.2 Maintenance and Persistence of the User Model

An important design issue is how (and when) to produce and maintain the data that will be used for accessibility. For a desktop game, the persistent data about the user can be obtained directly from the student when the game is installed, by storing the information on disk for further execution of the game (or other similar games). In these cases, the student is responsible for providing and maintaining the information.

In some other games, the instructor may be aware of the special needs of a group of students, and pre-configure the game before distributing it to the students.

Finally, in web-based e-learning environments, it would make more sense to keep the data about the user in a central location independent of the student's computer. The current e-learning environments have evolved into the so-called Learning Management Systems (LMS), such as *Moodle*™, *Sakai*™ or *Blackboard*™, with features far more sophisticated than the initial content repositories used in web-based e-learning. A modern LMS stores information about the students and their progress, and can deliver customized information to each client. These systems can thus store the user models centrally and deliver it to the clients each time the game is executed.

Thus, depending on the context, the user model may be maintained by the students themselves, by the instructor, or stored in a centralized location, with all three approaches presenting different advantages for different scenarios. However, environmental restrictions cannot be computed a priori in any approach. These restrictions should either be automatically inferred or introduced by the student at the beginning of each execution of the game.

3.3 What to Adapt

An accessible game will require some modifications that typically will be different for each user and context. However, in most cases, the adaptations focus on game-user interaction channels. That is, the *input* and *output* systems of the game. Since a game is mostly an interactive experience, these adaptations can pose a significant challenge.

The multiple input/output scenario forces game designers to design game tasks and activities in a device-independent manner [13]. All the aspects of game design must be considered abstractly, with no explicit or implicit binding to any input/output mechanism.

Adapting input and output systems in a game could involve two different tasks. Sometimes it would require providing alternative input/output systems according to the user and environmental models previously defined. The game will decide at runtime what input/output alternatives are used. This is the typical case for visual, hearing and mobility impairments. To design these alternatives methodologically, game designers first need to think about the input/output system that will be provided for each attribute. Then they need to define the input/output systems that will be enabled or disabled in any case.

However, in many other cases, accessibility issues can be addressed by simply adjusting some game parameters. Some “minor” visual, hearing and mobility impairments will fall into this category. For instance, people with reduced hand mobility may not be able to control a mouse or the keyboard fast enough to cope with the quick reaction times often found in action games. In these cases, it would be enough to adjust the time pressure to allow impaired students to interact with the game at their own pace.

Nevertheless, there are cases where adapting the input and the output will not be enough and the own game structure will require adaptation. Cognitive and mental impairments may require lessening the difficulty of the game, skipping some activities, adjusting the text or speech speed, etc. Just as happens with other educational approaches, this is the most challenging accessibility adaptation, and possibly requires changes in the core of the game experience. These challenges are difficult to address in a systematic manner, and the specific approach will be dependent on the specific topics presented by the game.

3.4 Deciding the Game Genre

Accessibility requirements are very different depending on the game genre. In educational gaming, game genre is always a crucial factor, as not all games are equally appropriate for learning. Given that some game genres are more suitable for accessibility than others, the choice of a game genre becomes even more relevant.

As described in the previous, activities in games must be designed abstractly without committing to any specific device or input/output system. Thereby, when possible, it is better to focus on game genres where engagement and immersion are obtained thanks to the attractiveness of game tasks, activities and the flow of the game itself, moving away from some features such as being visually attractive or providing intensive action. Educational games must capture the attention and motivate students even when their accessibility features are activated. Otherwise, their positive effects for learning will be lost.

Point-and-click adventure games, such as the classic *Monkey Island*© or *Myst*© sagas, meet these requirements. This kind of games captures the players’ attention by developing an engaging and motivational plot narrative that players unblock as they advance in the game. Graphics, sounds, or special effects are part of these games as well, but only as peripheral features to enhance immersion in the game. In addition they promote reflection instead of action, which is very convenient for people with motor impairments, who have plenty of time to solve puzzles with no time pressure. Besides, *point-and-click* adventure and story-telling games are especially adequate for education [19]. In our opinion, adventure games are a good candidate when planning the development of an accessible educational game, as they are adequate both for educational purposes and for introducing accessibility.

3.5 General considerations

Finally any development of an accessible game must be carried out following some general design guidelines. The adaptation that is performed in the game must be as user-customized as possible. If different alternatives may be feasible for a certain kind of disability, the optimum one must be chosen, while considering aspects such as which one best preserves engagement and immersion factors in the game or which alternative will make the game less effort-consuming for people with that disability. A possible methodology to achieve this would be completing a cross-table that matches all the possible disabilities identified in the user model with all the possible adaptations, indicating if each option is optimum, valid or not valid at all [13].

Besides, settings in the game must be as flexible as possible. Either by direct action of the user or by automatic inference, the game should permit the easy configuration of the text font settings (color, size, etc.), audio settings, time response gaps, and input/output settings (e.g. screen size and resolution).

Another important consideration is that an accessible game must always be compatible with adapted input/output devices, especially if the game is to be accessible to people with severe mobility impairments.

Tutorials on how to use the games for each possible adaptation setting must be designed, implemented and embedded in the game to ensure that all the students will be able to play.

Finally, how the game is going to be delivered, installed and accessed must be considered as well. Accessible games should be extremely easy to install and execute. In e-learning settings we can take advantage of the web to deliver and distribute the games. Accessing a game that is embedded in a web page would be easier for students with special needs as it does not require any installation and they usually have hardware or software aids to navigate the web.

4. THE <E-ADVENTURE> APPROACH

We have implemented the ideas presented in this paper in the <e-Adventure> platform. <e-Adventure> [20] is an educational game platform developed by the <e-UCM> research group at the Complutense University of Madrid (Spain) which has been used in the development of several educational games [21, 22]. The platform is composed of two applications: a game authoring editor (used to create the educational games) and a game engine (used to execute the games). The editor is completely instructor-oriented; hence it does not require any technical background or programming skills to be used [23].

The platform has some features to facilitate accessible game development, especially for e-learning applications. First, it is focused on the *point-and-click* adventure game genre, which is one of the specially suited types of games for accessibility, as discussed in section 3.4. As well, <e-Adventure> provides instructors with special features that enhance the educational possibilities of the platform, including a mechanism to adapt the game experience to the needs of different students [24]. These adaptations can focus on adapting the content (to suit different learning objectives or different levels of initial knowledge) or adapting the interaction modes to support users with special needs.

Finally <e-Adventure> games can be deployed via web and integrated with an LMS [25], which makes the platform ideal to integrate accessible educational games in e-learning courses.

4.1 General Architecture

The <e-Adventure> platform includes several *pre-configured input/output modules* to facilitate the inclusion of accessibility in the games. The idea is that game authors should be able to define various interaction mechanisms that coexist in the game, so that people with special needs can play easily. In addition <e-Adventure> includes some *in-game tools* that can be included in the games as an aid for impaired people. These modules are activated/deactivated by means of a user model.

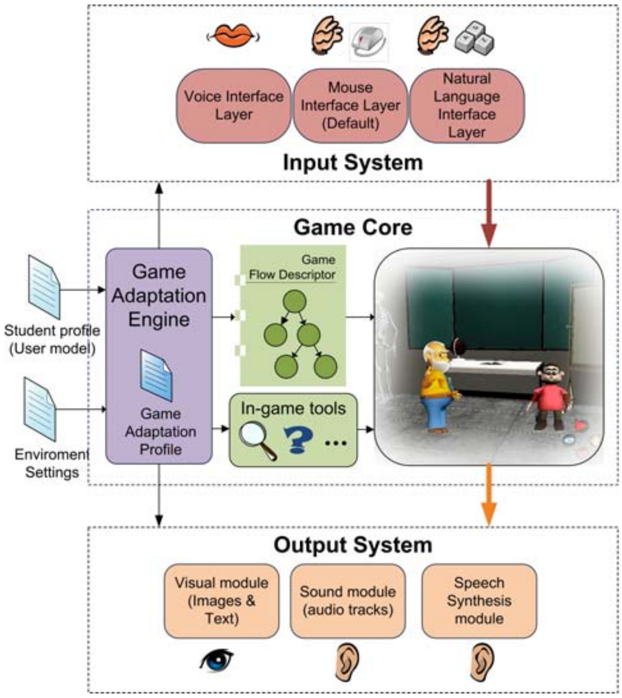

Fig 3. Architecture of the game engine (game application).

<e-Adventure> contemplates a user model which contains information about the student. The game engine expects to receive a user model which can be integrated with the game through the <e-Adventure> editor, imported from the e-learning environment or gathered from the student before the game starts. The model is separated into two parts. The *student profile* contains all the information concerning the permanent special needs of the student (i.e. things that are not expected to change in time such as the impairments of the student). The *environment or context settings* describe circumstantial needs that are related to the scenario where the game is going to be played (e.g. the environment is noisy or sound is not allowed) or momentary special requirements of the student (e.g. the student has a broken arm). Next sections present in detail all the input/output modules in the <e-Adventure> platform.

4.2 Description of the Input/Output Modules

The input modules supported by the <e-Adventure> platform are three: the *Mouse Interface* module (MI), the *Voice Interface* module *(VI)* and the *Natural Language Interface* module *(NLI).*

The MI is the classical interaction mechanism in *point-and-click* adventure games, where students usually need to point the mouse over NPCs (Non-Player Characters) and objects they find on their way in order to trigger any kind of in-game interaction. Therefore students need to be able to move the mouse and to see the elements on the screen in order to play the games, which may make them inaccessible to students with visual or mobility impairments. The VI is controlled by speech so students only need to be able to speak to control the games. Using a microphone, students can directly "give orders" to trigger any interaction in the game (e.g. "go to the library" or "grab the notebook"). The VI does not depend on the student's voice to work so students do not need to train the system, which is always an excruciating task. Besides, the VI accepts diverse synonymous orders for the same action (e.g. examine the scene or describe the scene) so students do not really need to learn how to use the VI, which is a typical problem in voice recognition. Table 2 shows an example of typical orders that the system would recognize in an <e-Adventure> game.

Table 2. Example of natural language commands that the VI and NLI modules recognize

Order	Description
Examine the table	The game will provide a description of the object "table", if it exists in the scene.
Go to the left	The student's avatar in the game will move in that direction, discovering new items that were still hidden.
Grab the pencil	The game will take out the object "pencil" from the scene and put it in the student's inventory[8].
Name items in the scene	The game will tell the student which items have already been discovered so he or she can interact with them.

The NLI accepts the same orders as the VI, but uses the keyboard as the input device. Thus students can interact with the game using text in natural language, which is helpful if students have speech and visual impairments or they are not allowed to speak due to environment circumstances (e.g. at a library). Table 3 summarizes all the input modules according to the special requirements they can cover.

Likewise, <e-Adventure> includes three output modules: the *visual* module, the *sound* module and the *speech synthesis*

[8]The inventory is an element that is usually present in point-and-click adventure games. Players use the inventory to store objects they find on their way and keep them for a later use.

module. The visual module is not only used to print images on the screen (the background image for the scene, for the characters and objects, etc.) but also text. Text is a key element in *point-and-click* adventure games, as most of the information is provided through conversations with other characters which are usually textually represented on the screen. Accessibility could be added to conversations by recording all the dialogues by using the sound module (which can play audio tracks in mp3 format), but it would significantly increase the cost of the games, which is a problem when the budget is very limited (as is usually the case for many educational projects). This is why the speech synthesis module is helpful, as it allows the introduction of accessibility for visually impaired students at a low cost. Nonetheless higher-budget projects can use the standard sound module (which plays mp3 files) for increased sound quality.

Table 3. Summary of input/output modules

Input/output module	Senses Required	Adequate for…
Mouse Interface		Speech impaired students.
Voice Interface		Visually and/or mobility impaired
Natural Language Interface		Visually, speech impaired

4.3 The Game Adaptation Engine and In-Game Tools

Although adapting the input and output systems of the game can cover several physical or contextual impairments, other students will require different approaches. Such is the case regarding cognitive impairments. In these situations it is the game flow which needs to be adapted. Some students will need to lower the difficulty of the games, skip some tasks, receive additional guidance, etc. The <e-Adventure> platform supports this kind of adaptation through the definition of *flags*, which are used to establish conditions that block or unblock game elements or arcs in the game flow [20]. The game author can define a set of adaptation rules (i.e. *adaptation profile*) using data about the student as conditions (e.g. cognitive impairments in this case).

Fig 4. Example of the in-game tool "screen magnifier" in the *1492* <e-Adventure> game.

<e-Adventure> also provides game authors with other interesting tools for accessibility issues. For instance, game authors can provide students with a screen magnifier. To avoid breaking the game-immersive atmosphere, it is represented as an object that is put into the student's inventory (Figure 4). The student can use it to turn the mouse pointer into a magnifying glass that can move around in the game.

In addition, <e-Adventure> allows for a flexible configuration of visual items (e.g. text color) and time interaction gaps, and provides mechanisms for introducing simple hints and aids in the games. All these elements are very effective for making the game accessible to students with slight impairments, such as color-blindness, poor vision or slight cognitive impairments.

All the adaptation processes that <e-Adventure> supports (i.e. input/output adaptation, game flow adaptation and in-game tools) are carried out by a special module in the game engine core, the *Adaptation Engine*. The adaptation engine is configured through the *game adaptation profile*, which defines the set of adaptation rules. This profile includes the definition of the adaptation measures supported by the game, and receives as inputs the *student profile* and the *environment settings* previously described.

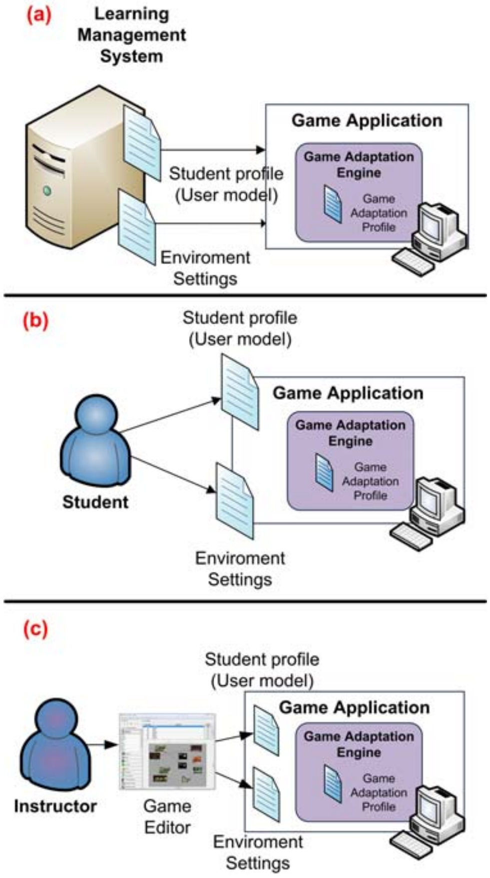

Fig 5. Three different mechanisms for providing input for the adaptation engine

The adaptation profile is defined by the game author, using the game editor just like any other resource file for the game. Therefore it is always distributed within the game package. The inputs that guide the choices from the adaptation profile (student profile and environment settings) can however be received in diverse manners according to the scenarios outlined in section 3.2. Both elements can be defined with the game editor and be included within the game package along with all the other resources of the game (e.g. art assets, game description files, etc.), or they can be delivered by an LMS or introduced manually by the student when the game is executed (Figure 5).

All three input methods are appropriate for different situations, which adds flexibility to the platform. For instance, packaging the inputs along with the game will be adequate for creating standalone versions of the game to be played offline. The inconvenience is that each student with special needs would require that the instructor create a custom version of the game for them. The second option is appropriate for situations where a LMS is available, as the game can be adapted without requiring any intervention of the student. Finally the third option allows game authors to produce a single offline version of the game, but students will need to introduce the input data manually each time they play the game.

4.4 Using the Game Editor to Introduce Accessibility

Authoring an accessible adventure game with the <e-Adventure> game editor is a very simple task. Moreover, the <e-Adventure> game editor can be used to introduce accessibility in existing games with little effort.

The first step is obviously to design and develop the game. It is recommended not to relegate the decision about accessibility to the last instant, but to think about the accessibility features that are going to be introduced in the game during the design phase, especially if they will require adapting the game flow, which would involve providing alternative paths, dealing with difficulty settings or providing additional aid in some situations.

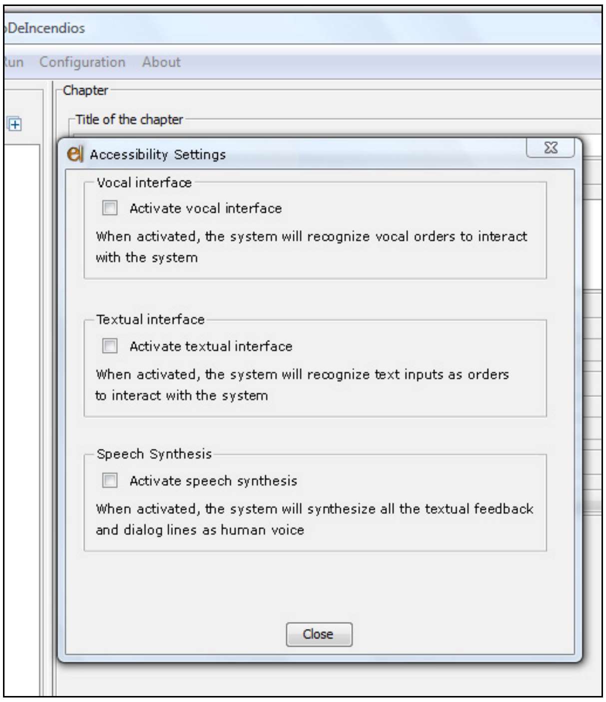

Fig 6. Edition of the Input/Output settings with the <e-Adventure> editor.

When the game is designed, the game authors must select the input/output modules and the in-game tools that they want to be active in the game. The game editor uses these settings to optimize the exportation process so no unneeded modules will be packaged within the game.

If visual accessibility is considered, it is very important that all the visual elements of the game receive an alternative description. When the player enters a scene the game engine will use these descriptions along with some extra information that it computes from the game definition (e.g. number of elements in the scene) to create a complete description of what the student is supposed to see. The complete description is synthesized and played using the audio system.

Finally, game authors need to create the game adaptation profile which will determine under which circumstances the game must be adapted, and how the adaptation must be carried out.

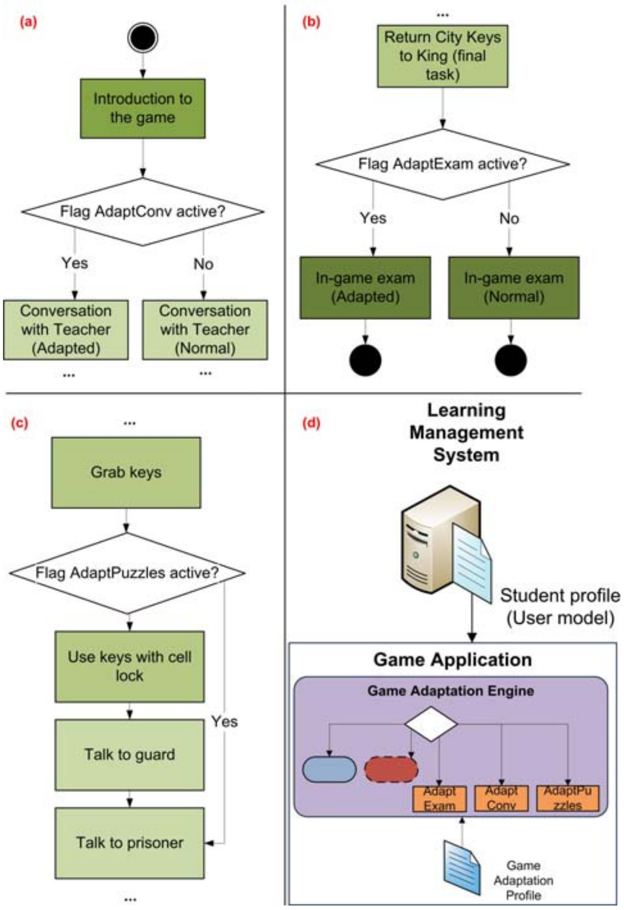

Fig 7. Figures (a), (b) and (c) are examples of how adaptation for cognitive impairments is carried out in the game flow using flags for the game 1492. Figure (d) depicts how the adaptation engine will activate or deactivate flags according to the adaptation rules (game adaptation profile) and the student profile with the disability information (input).

5. CASE STUDY

As a case study to test <e-Adventure> accessibility features we introduced accessibility in a pre-existing game. Following the ideas described in section 4, we introduced accessibility for people with different degrees of visual, hearing and mobility impairments in the game *1492*, an educational game about Spanish history [26]. *1492* focuses specifically on the feats occurring in 1492, such as the discovery of the American continent. These are notable events in the history of Spain, so it is a compulsory subject in primary education, which is an additional, strong motivation to make the game accessible. However, the purpose of the experiment was not to test how the accessibility implemented in <e-Adventure> works in a real scenario with actual students (e.g. check student satisfaction or learning outcomes), but to check its feasibility and effectiveness from a technical perspective (e.g. measure voice recognition accuracy).

1492 was not initially designed as an accessible game. However, it is simple to add accessibility using <e-Adventure>. The first step was to decide what impairments (and what severity level) we were going to target and then activate/deactivate the necessary input/output modules and/or in-game tools using the game editor. For this case study we considered visual, hearing, mobility and simple cognitive adaptations.

As cognitive impairments are very complex and may require very different adaptations, we just considered two possibilities in order to test the game adaptation system: students with low memory capacity, and students with non-severe reasoning problems. In the first case we defined alternative conversations that lessened the amount of information that the student gathers at any moment, thus increasing the focus on relevant information and reducing the amount of "superfluous" information. In the second case we defined alternative game paths with simpler riddles and *puzzles*. Besides, the original *1492* game included an in-game multiple-choice examination at the end of the game through a conversation between the main character (a student called Cristobalín) and his teacher. For both types of cognitive impairments, we provided an alternative, less difficult exam.

In order to cover the rest of potential special requirements, the game is distributed with all of the input/output modules and the screen magnifier. For this to work, we also had to provide alternative descriptions of the visual elements found in each scene, so that they could be passed to the speech synthesizer. This increased attention to descriptions brings the game closer to interactive story-telling games, which often do not have graphical interfaces but intense narrations that engage players.

Finally we produced the rules that adapt the game when the student profile (which is received in the game as input) requests any of the adaptations discussed above. In this case the most difficult task is to define the adaptation rules related to cognitive impairments. This is an issue that is closely related to the game's semantics and flow, so it cannot be abstracted easily. This was achieved by providing alternative versions of several elements in the game (original and adapted conversations, original and adapted puzzles, and original and adapted exams) that are enabled or disabled when the corresponding adaptation rules are triggered.

The resulting game serves as the prototype of an accessible game, and its development helped us to assess the potential and limitations of the accessibility features offered by <e-Adventure>. The most important result is that adding accessibility features that covered a wide range of potential impairments required very little effort and no programming at all. The platform facilitated the creation of a fully-captioned game, where every action can be triggered through a voice command and where feedback can be delivered through a speech synthesizer. The adaptation system allows the creation of a single game that can be played with different levels of cognitive difficulty, including fine-grained adaptations that can be controlled separately, giving the author great control over which sections are modified.

6. CONCLUSIONS AND FUTURE WORK

The current trend in learning technologies towards increasingly complex multimedia and interactive contents presents a significant accessibility challenge. Even though there is an ongoing effort to reduce accessibility barriers in information systems, some of the most innovative media (such as complex interactive multimedia contents or educational videogames) are not receiving enough attention. Entertainment driven games can afford to ignore accessibility concerns, but educational games should be inclusive and available to everyone regardless of their individual conditions.

Nevertheless, the development of accessible games comes at a cost. In educational settings, with limited budgets and markets, the problem becomes greater. In addition, accessible videogames are a relatively new idea, and the existing research in the field is still young and isolated. In this work we have presented the foundations of our approach to accessible educational gaming, which proposes a general framework for accessible videogames and provides a tool to facilitate the inclusion of those accessibility features in educational videogames.

However, the system is still in the prototype stage, and the quality of the results depends on the effectiveness of the supporting technologies. For example, <e-Adventure> is supported by different opensource tools (FreeTTS, Sphinx, Stanford Parser), and the quality of the results is highly dependent on their strengths and weaknesses. Fortunately, these supporting tools are evolving rapidly, and their improvement will bring benefits to the accessibility of any kind of content.

At this stage, our future lines of work will focus on facilitating the process of inputting and maintaining the data from the user model and the context. An interesting approach would be to detect when a student is being challenged excessively by the game or if the student repeatedly fails to react to some outputs from the game, and then load the adaptation features required to compensate those problems.

Finally, our next research will also include coping with cognitive impairments more explicitly. It is an important issue which is rarely covered in the development of accessible IT systems due to its high complexity. Although the effects of ignoring cognitive impairments in entertainment-driven developments might be affordable, they cannot be left aside in educational settings where all the students need to achieve the learning goals. Moreover dealing with cognitive impairments in videogames is interesting as it could improve significantly the learning outcomes of students with such needs, given the close relation between cognition and learning.

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