An overview of adaptive e-learning systems

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An overview of adaptive e-learning systems

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Abstract—Due to the emergence of information and communication technologies in various fields, which have also affected the educational sector, adaptive e-learning systems are recognized as one of the most interesting research areas in distance web-based education. This research direction enables developers to build a model of goals, preferences and knowledge of each individual user in order to adapt the learning to his/her needs and characteristics. The objective of this paper is to present the state of the art in adaptive e-learning systems as an alternative to the traditional learning by describing its dimensions, design, architecture and theoretical approaches. We also highlight some prospects for our future work by studying, analyzing and criticizing existing systems.

Keywords—Adaptive learning, e-learning, context parameters, learner characteristics, intelligent tutoring systems, adaptive hypermedia systems.

I. INTRODUCTION

Learning is one of the research areas that have attracted the attention of many researchers over the past few decades. In spite of its complexity, several works have raised interesting problems, especially the issue of learning resources accessibility to guarantee "learning for all". According to [1], learning challenge is not only to make resources available to everyone, anywhere, at anytime and in different formats, but also to offer the learning in the place, time and appropriate manner. As a result, researches have given more importance to distance education, and in particular to e-learning in order to improve learners' performance and achieve their satisfaction [2].

In this perspective, the contextualization of learning is a new paradigm for adaptive systems in order to remedy the traditional learning limits [3] which is no longer able to provide interactivity, real-time execution, self-control, personalization of educational content, adaptive format of presentation and learning navigation. Adaptive systems aim to adapt the learning's traditional approach in order to satisfy the learners' needs [4].

The main objective of this paper is to study the concept of adaptive learning, to define its dimensions and to analyze the systems developed since 2010. To achieve this objective, we must ask the following questions: What is an adaptive learning system? What is the architecture on which any adaptive e-learning system is based? What are the approaches that we can use to implement these models and architectures? And finally, what are the typical solutions for each approach?

In response to these questions, this article is structured as follows: The first section draws on the concept and the definition of adaptive e-learning systems. The second section presents the architecture and the main components of these systems. The third section discusses the theoretical approaches to model the adaptive learning as well as the typical systems of each approach. The last part deals with the related works as well as some comments about our future developments.

II. ADAPTIVE LEARNING SYSTEMS

A. Electronic learning (e-learning)

The majority of researches define learning by the increase of knowledge in a quantitative way, memorizing information, acquiring skills and methods that can be used when necessary, interpreting and understanding reality in a different way [5][6]. In 1984, the author in [7] defined learning as a process whereby knowledge is created through the transformation of experience. This process is defined as a four-stage cycle that represents the way of perceiving, thinking, feeling, and acting which appears when we face new experiences. The four stages include being involved in a new experience, developing observations, creating theories to explain the observations, to solve problems and take decisions.

According to [8], e-learning is another way to teach and learn. In [9], the author states that e-learning is based on three basic criteria. First, e-learning is networked and that gives the ability to real-time upgrading, storing and retrieving, distributing and sharing information. Second, it's delivered to the user via his/her device using internet technology. Third, it focuses on the largest view of learning that exceeds the traditional paradigms of education.

B. Adaptive e-learning system

Research in adaptive systems can be traced back to the early 1990s. At that time, the two major areas of hypertext and user modeling created rich research ideas as a result of the degree of improvement they reached. A large number of research teams recognized static hypertext problems in different application domains and had began to study various ways to adapt the behavior of hypertext systems to users in an individual way [10].

Currently, scientific research in the field of e-learning is oriented toward learning platforms where learner's expectations, motivation, learning styles, habits and needs are increasingly taken into consideration [11]. These factors highlight the idea of adaptive learning systems [12] as an alternative to the traditional approach «one-size-fits-all» in the development of teaching materials. The authors in [13] define adaptation as the ability of a system to alter its behavior

according to the learner's needs and other characteristics. The main components of each adaptive system are described as follows:

1) Source of adaptive learning

According to [14], the source of adaptation (learner, environment or device) is related to the objectives of each system as well as the desired result. If the goal is the learner, we give more importance to his characteristics. Relevant ones are encapsulated in the learner model which is an essential component for each e-learning system to be adaptive [15].

Learner's characteristics have been the subject of various researches in adaptive e-learning systems and education areas. The choice of characteristics depends on the system. According to [14], in the case of a static system, the mechanism of adaptation is a traditional one using the characteristics predefined by the learner during his/her first use of the system, including personal information, learning style, goals and preferences. It's made before the learning process begins. However, dynamic adaptation requires a process of interaction between the user and the system. In that case, the use of dynamic characteristics updated in real-time is required. Example: skills, emotions, level of knowledge, history, navigation and test results [16] [17]. The author in [18] states that the difference between these characteristics appears in the duration. Static characteristics are used on a long-term basis because they represent general information, while dynamic characteristics are used on a short-term basis because they are changeable, specific and interactive. In some research works, and for more efficiency and integrity, learner characteristics are combined with context parameters. For example: location, detected noise, connectivity, hardware used and user's movements [17].

2) Target of adaptive learning

The authors in [17], [19] and [20] state that the most widely applied adaptation target is the learning material itself (learning content). In this case, courses are presented in a different way to each learner. The degree of difficulty of pedagogical supports is also taken into consideration according, for example, to the learner's knowledge level. Other studies have asserted that accompanying supports can be adapted to each learner by adapting recommended links as well as additional pedagogical materials while using the system [17] [21] [22]. In other works, the learning format (content presentation) can be an adapted text or a multimedia content (image, video, audio, animation). The user interface can also be adapted to the learner preferences [17] [23] [24] [25]. In addition, the learning navigation can be adapted by distinguishing between global navigation (redirection to external sources) and local navigation (using the same system) [14] [25]. The work presented in [17] indicates that collaborative learning can also be a sort of adaptation by creating groups of learners with common characteristics in order to assign each new learner to the appropriate group.

3) Pathways of adaptive learning

In [25], the author classifies different methods and adaptation techniques studied since 1992. This classification depends mainly on the adaptation target. For content adaptation, the method used requires to break down courses into segments. Next, it uses the techniques of inserting,

removing, dimming or altering fragments to provide the learner with the part he/she needs. The methods used to adapt the assistance during the learning process make the system able to display, hide or delete the learning links. Concerning the adaptation of the learning material format, defined functions and rules are used with several parameters, generally learning styles, preferences, skills and context characteristics. These functions are executed to generate the appropriate learning materials. Concerning the adaptive navigational support, it includes several techniques, such as adaptive link sorting, generating, hiding (disabling, removal) or map adaptation.

III. ARCHITECTURE OF ADAPTIVE E-LEARNING SYSTEMS

We have summarized the main components of adaptive e-learning systems that we present in the following diagram (figure 1):
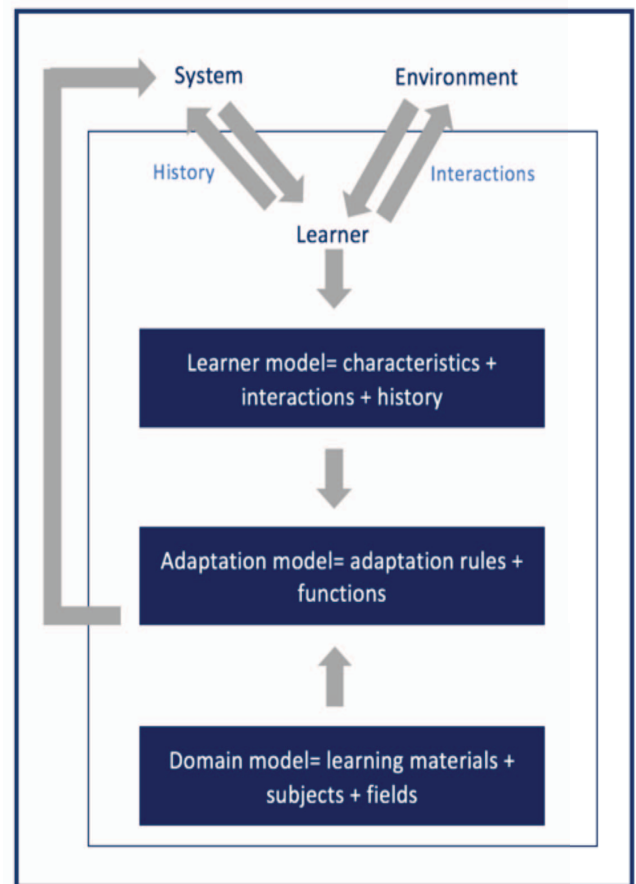

Figure 1: adaptive e-learning systems' components

A. Learner model

In [26], the author defines the learner model as a component that provides a structured presentation of the learner characteristics. This component is the core of the intelligent tutoring systems since 1970 [27]. In fact, objectives, knowledge background and preferences have been modeled and used by many systems to adapt the learning since 1996 [25]. Other characteristics have been added, such as learning styles, reasoning styles, experiences, physical skills, emotions, needs, habits, motivation, culture, personality, interests, cognitive styles and social context [2] [17] [16] [28].

B. *Domain model*

A domain model is a set of structured knowledge that converts a real world part into an abstract representation. It is a structured content related to a specific domain. [29]

C. *Adaptation model*

This model is the bridge between the learner/domain models by combining learners' needs and characteristics with the learning materials [3]. It includes predefined adaptation rules and functions that help to select the appropriate pedagogical materials in the domain model and to determine when and how to deliver it [30].

IV. ADAPTIVE LEARNING APPROACHES

In the overviews of [14] and [31], three common approaches have been described:

A. *Macro-Adaptive Approach*

According to [32], this approach assumes that the process of adaptation exists to allow learners to move from a course to another with an adapted rate. This is because learners differ from each other in their learning capacities. Other characteristics are also taken into consideration, such as objectives, preferences, level of knowledge, intellectual abilities, learning styles, cognitive styles, academic motivations, personality, experiences and achievements [33] [34].

The general model of this approach is based on a standard sequence initiated by the teacher. For example, explaining or presenting specific information, giving examples, asking questions, and then providing feedback to learners' questions. This repeated sequence in the teaching process by reciting and presenting the course in an academic way and using static methods, is the disadvantage of this approach [35].

B. *Aptitude-Treatment Interaction (ATI) Approach*

This approach is based on the theory mentioned in [36]. The goal of the ATI approach is to identify the main learner's aptitudes through analyzing and understanding his/her behavior. It also suggests to alter treatments to maximize the system's interaction with learners' abilities, to facilitate their life in learning situations and to increase their satisfaction.

According to [31], one of the most important aspects of the ATI approach is the user's control over the learning process. The author has mentioned that several studies have also suggested that the self-control's success depends on the learner abilities. It's better to limit the control (total or partial) for students with low-prior knowledge and/or to enhance learning for students who have high performance. In this context, the work presented in [37] defines three levels of control: complete independence, partial control within a given task scenario and fixed tasks with the control of pace.

Intelligent Tutoring Systems (ITS) are based on the ATI approach over the detection of users' skills. The implementation of ITSs is based on the architecture of adaptive e-learning systems, which contains the learner model and the domain model. Besides, ITSs use the adaptation model to generate and to present adapted materials to each learner [38]. Adaptive hypermedia systems are also an example of this approach. The goal is to design learning solutions which integrate hypermedia content in ITSs in order to adapt it to each learner's profile [31].

C. *Micro-Adaptive Approach*

This approach allows to diagnose the specific learners' needs in order to provide them with the most appropriate learning process [34]. Unlike the macro-adaptive approach, this approach is dynamic due to the use of quantitative, temporal and real-time learner's characteristics. This is possible by analyzing and monitoring the learner's reactions and behavior over the system in order to adapt the pedagogical design of the learning process [33]. This approach includes various characteristics more than the macro-adaptive approach, including motivation, learner errors, emotional status and others [35] .

According to [34], this approach is based on 2 main processes:

1) Diagnostic process: it detects the learner's characteristics (aptitudes, abilities, motivation, knowledge, preferences, learning style, ...).

2) Optimization process: it optimizes the learner's interaction with the system while adapting the learning content and sequence.

In [35], the author mentions that ITS and adaptive hypermedia systems are relevant examples of this approach. They use the micro-adaptive approach in the diagnostic process in order to extract the learner's characteristics. This process begins with the collection of context data, analyzes and compares them with the predefined ones to assign each new user to the appropriate category. Finally, it generates the adaptation process by adapting content, format or navigation.

V. RELATED WORK

In recent years, various needs of adaptive e-learning have attracted the attention of many researchers in computer sciences and education fields. As a result, a number of works have been done toward adaptive e-learning systems, which are presented below.

In [39], the authors present an intelligent e-learning system based on the macro-adaptive approach. It allows to adapt the learning sequence and process to each user's profile based on his/her static characteristics, and in particular to the learning style. In addition to this, and after each learning unit, the user takes an assessment test to determine his/her weaknesses and needs.

Another solution in [40] called WELSA (Web-based Educational System with Learning Style Adaptation) is based on the ATI approach. It is a learning platform designed to adapt the learning format, the structure and the learning process sequence. This solution is based on both static and dynamic characteristics including learning style, learner's history, learner's actions and interactions over the system. It analyzes and interprets them in order to get an implicit identification of the user. In WELSA, teachers can add courses to the database and adapt specific parameters to each course (e.g. the degree of difficulty) in order to take it into account during the adaptation process. The platform also provides the possibility to share learning resources and to get a discussion forum.

In [41], the presented work focuses on the development of a hypermedia learning system based on the micro-adaptive approach. The system uses learners' profile, learning styles and knowledge levels to adapt the format of presentation (text, image, audio, video), the learning content (by the decomposition of courses into segments) as well as the navigation (by generating HyperText links).

The work presented in [42] is an e-learning framework called LearnFit based on micro-adaptive approach. It takes first the learner preferences (according to each personality) using the Myers-Briggs Type Indicator (MBTI) method, the learner's objectives, knowledge level, favorite language and the learner's identity. In LearnFit, each type of personality is matched with an appropriate learning strategy to adapt the learning process as well as the support format to be provided. Based on the learner's results, the framework changes teaching strategy if the learner does not reach the minimum threshold in assessment tests.

The authors in [43] discuss the development of an e-learning system based on the micro-adaptive approach. This solution takes into consideration the learner's objectives, preferences, reasoning, learning style, knowledge background and performance. This system adapts the learning materials' content, learning sequence and the navigation over the system. Learners can take assessment tests to update their knowledge and performance status.

In [44], the authors suggest a learner modeling in an intelligent learning system based on the ATI approach, taking into account the technological, educational, personal and cultural learner context. This modeling aims to adapt the learning content, interface, presentation, navigation and the assistance offered to each participant during his/her use of the system. This is possible by analyzing and interpreting all static and dynamic characteristics (interest, preferences, learning style, nationality, languages, knowledge, skills, location) as well as the characteristics of the device (type of device, browser version, connectivity, bandwidth, screen resolution). In addition to this, the proposed solution takes into account the user interaction over the system for high precision.

Another work in [45] presents an adaptive e-learning system that uses the ATI approach. It's an inspired recommender e-learning system that uses the e-commerce recommender web site techniques. This system adapts learning resources to the user's interests, knowledge level, learning style, habits, preferences and interactions with the system. The recommendation mechanism estimates the appropriate supports (courses, practical exercises, details, explanations and illustrations) to each user in real time execution. The system gives the possibility to take quizzes, benefit from a chat space as well as sharing information and learning resources.

The work proposed by [46] presents an adaptive user interface for online learning in higher education sector. It uses the ATI approach to adapt the learning content. The mechanism of this work is inspired from the problem of different knowledge levels in a heterogeneous group of students. It aims to provide students with beginners' courses in math after taking a test that helps to determine their knowledge backgrounds and skills. As a result, the system presents the appropriate chapters of the course and hides the parts that shouldn't be learned for each participant.

A solution called MALO (Model of Adaptation of Learning Objects) [47] aims to adapt the content, format of presentation as well as the learning path. This work is based on the micro-adaptive approach using the updated knowledge background of each student as well his/her skills in order to adapt the learning objects in an individual way. The adaptation process of this solution starts with the determination of the previous competences of each user, then it sets the objective to be achieved (desired competence) as a source to establish the adaptation process to be executed.

More recently, the authors in [48] introduce an new version of e-learning systems based on the ATI approach. This solution extends the Felder-Silverman Learning Style Model by adding a new dimension that reflects the emotional and social learning styles of each learner. The paper also describes the integration of this new learning style index into an adaptive e-learning system to be more effective. It shows the importance of the students' learning styles in the improvement of their learning performance by providing them with different learning activities according to their preferences.

VI. ANALYSE AND DISCUSSION

By analyzing the adaptive e-learning systems presented above, we can conclude that some limitations of the existing models are related to the lack of a mechanism for detecting learner's history and interactions over the e-learning system. The majority of these systems need a space of sharing and collaborative learning as well as making teachers able to follow-up with their students. For the solutions that propose the calculation of the duration spent on a learning page, it's better to predict the learner's activities according to his/her location and motions. A mechanism of evaluation during the learning activities to monitor the learner's progress is also needed for this kind of systems.

In addition, the implementation of such solutions allows to take into consideration only few learner's characteristics which are not enough to determine the most appropriate learning materials for each user. In this case, it would be more effective if we integrate other characteristics according to the objective of each system. For example, the work presented in [47] aims to adapt the format, the content and the learning path but it uses only skills and knowledge background as a source of adaptation. In this case, the integration of the user's learning style will be helpful to determine the most suitable learning path and format of presentation.

Another example described in [48] needs the integration of other characteristics such as the knowledge background in order to improve and to give an effective learning solution. Unlike [43], there is a lack of information updates in the solutions described in [47] and [48]. These systems use the knowledge level as a main feature to adapt the learning, in this case, an assessment test should be taken by each user in order to update his/her knowledge level after each learning activity.

Regarding the solutions that use the learning styles, the integration of different learning style models other than Felder–Silverman index, or the combination of different learning style models into the same adaptive e-learning system can improve its efficiency and performance [49].

VII. CONCLUSION

In this paper, we have presented the mechanism of adaptive e-learning systems based on the concept of contextualization. We have highlighted the main components of adaptive e-learning systems represented in the source, target and adaptation path. We have also discussed the architecture of these systems composed of three main models (learner, domain, adaptation). Adaptation approaches were also presented by detailing the different theories and existing implementations. Finally, we have discussed an overview of the contributions made in this research area during the 2010-2017 period.

We can conclude that the development of information and communication technologies, and in particular internet and web technologies have a great impact on the educational sector, making adaptive e-learning possible and necessary. However, the huge number of available resources makes learners lost. In the majority of cases, they become demotivated since their first use of the system. Furthermore, learners are most of the time in mobility, which slows their learning process down when they use an e-learning system.

In this context, the authors in [14] state that the challenge of adaptive e-learning developers is to find the learner characteristics that are crucial for an effective learning and to show the influence of these characteristics on the process and the learning performance. Currently, there are several methods and techniques to model the learner. The choice of methods depends on the solution's objective and the desired result as well as the effectiveness of the technique.

Concerning mobility issue, researches are currently oriented toward mobile learning (m-learning) which can provide learning resources anywhere and at anytime [17]. It represents a modern-day generation which prefers the use of mobile devices. This topic will be discussed in our future work.

ACKNOWLEDGMENT

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