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ON EVALUATION OF ADAPTATION ENGINES

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ABSTRACT
At the core of adaptive learning systems is an adaptation engine which decides the adaptations based on the learner's profile, educational activity, infrastructure and/or environment. This paper presents a model for adaptation engines. Then it presents 17 criteria for the evaluation of an adaptation engine.

KEY WORDS
adaptation engine; adaptive learning; evaluation.

1. Introduction

Building adaptive educational systems that adapt to different learning characteristics is not an easy task [1]. Open research questions include on how to identify the relevant learning characteristics, to model the learner, or to change the learning environment for users with different learning characteristics. It is known that learner's characteristics (e.g. cognitive style of learning) actually influence his performance (e.g. navigational behaviour in the training module) [2].

Most previous studies on adaptive learning propose to adapt the interface, the learning flow or sequencing, the content [3] or even the exams [4]. Next, such previous proposals are briefly presented. Link annotation was adapted to the individual user in order to help him find an appropriate path in a learning space [5]. Guidance and navigation in InterBook (an authoring tool for developing adaptive electronic textbooks on the Web) were adapted to the user [6]. DCG (Dynamic Course Generation) allowed automatic generation of individualised courses according to the learner's goal and previous knowledge, and adapted the course according to the learner's success in acquiring knowledge [7, 8]. GTE (Generic Tutoring Environment) adapted the presentation of the contents [7]. ELM-ART (Episodic Learner Model- Adaptive Remote Tutor) provided adaptive navigation support, course sequencing, individualized diagnosis of student solutions, and example-based problem-solving support [9].

The learner would choose the learning tools and companion learners, on-demand learning of various types, control over the elements of the systems and the possibility of controlling the amount of control [1]. Content was adapted to the device and modality of a user's preference [10]. Navigation support was adapted to device characteristics (such as screen size, interface design, and means of interaction), and its context of use [11]. Content was presented in a variety of ways based on both student prior competencies (pre-requisite knowledge and skills) and preferences [12]. The knowledge path that a student should follow was adapted according to his needs and capabilities [13].

CoCoA (Concept-based Courseware Analysis) checked the consistency and quality of a course at any moment of its life and assisted course developers in some routine operations [8]. Content was adaptively structured for access via mobile devices, accounting for variations in communication channels, end-user device capabilities and user profiles [14]. A Learning Companion Agent (LCAg) type was chosen according to the student profile. Similarly were chosen the support to the conceptual maps navigation, and the speech acts used by the LCAgs in the feedback messages [15]. The presentation was adapted to facilitate learners' spatial reasoning on geometric topics [16]. CASA (Contract-based Adaptive Software Architecture) provided a framework for the development of adaptive applications that were able to adapt their functionality and/or performance dynamically in response to runtime changes in their execution environments [17]. Material for self-assessment was adapted to the needs of the individual learner [18].

In computer adaptive testing, if the examinee answers correctly a question, then the next question is harder. Otherwise, the next question is easier [4]. It would be useful for the examinee to know his current status. The amount and timing of this orientation information revealed to the examinees may be adapted to his learning characteristics [19]. Also, the system may provide adaptive feedback to the examinee tailored to his needs [20]. Furthermore, his confidence in answering the question could be considered [21]. In adaptive mobile learning, the educational activity and the infrastructure would be adapted either deterministically or probabilistically [22]. Learning automata would be employed as probabilistic adaptation engines.

Multiple representations of complex or hidden subjects were used in [23]. Adaptive tools based on teacher's model for authoring, curriculum setting, co-teaching and privileges setting, reward setting, assessment setting and

information sharing setting were proposed [24]. Different adaptive presentation strategies were used for students with different learning activities [25].
Implicitly in these systems, an adaptation engine decides when, what, and how adaptations will be made. This adaptation engine is the core of adaptive learning systems. However, not much attention has been given on the specifications of the adaptation engine. Furthermore, there is a need to develop a common framework in order to evaluate all these adaptation models. This paper tries to develop such an evaluation framework for adaptation engines.

2. Adaptation engine

In this paper, we consider that an adaptation engine adapts some parameters of the educational activity and the infrastructure according to the current state of the context. The context would include the learner's state, the educational activity's state, the infrastructure's state, and the environment's state (Table 1). It becomes input to the adaptation engine. Based on the input variables and the adaptation decision algorithm, the adaptation engine produces an output. The output would be the adapted educational activity's state, and the adapted infrastructure's state.

Table 1. Input and Output of the Adaptation Engine

Input U(t)	**Output O(t+1)**
L(t): Learner's state, A(t): educational Activity's state, I(t): Infrastructure's state, and E(t): Environment's state.	A(t+1): adapted educational Activity, I(t+1): adapted Infrastructure.

The states of the learner, educational activity, infrastructure, and the environment are described in detail in another paper. The following Table 2 presents examples of adapting the educational activity and/or the infrastructure according to various states of the learner, educational activity, infrastructure, and/or the environment.

Table 2. Adaptation decisions and examples

Adaptation decisions	**Example**
If the learner's state is Lk, then the educational activity's state should become Am'	If the learner is performing perfectly in an exam, then the exam may become more difficult and challenging in order to suit to his superior achievements.
If the learner's state is Lk, then the infrastructure's state should become In'	If the learner has difficulty in reading the text on the screen of his handheld device, then the interface may increase the size of the fonts.
If the educational activity's state is Am, then the infrastructure's state should become In'	If the educational activity requires intensive video communication with rapidly changing pictures, then the network should reserve sufficient bandwidth to transfer this traffic.
If the infrastructure's state is In, then the educational activity's state should become Am'	If there is not enough available bandwidth in the network to support video communication, then the educational activity should be adjusted to support only voice communication.
If the environment's state is Ev, then the educational activity's state should become Am'	If it is raining, then the educational activity should alter the outdoor activities to indoor activities.
If the environment's state is Ev, then the infrastructure's state should become In'	If the learner is moving in a gorge, then the communication network should switch to satellite communications in order to keep on communication connectivity.

3. Evaluation of adaptation engine

Having defined the input, the output and the adaptation decision algorithm of the Adaptation engine, it is time to define criteria for evaluating it. So, in this section, we define criteria for the evaluation of adaptation engines (Chart 1).
The first criterion for evaluating the adaptation engine is the comprehensiveness of the input (context). The adaptation engine should base its decisions on a variety of input data. We have described the input to the adaptation engine as the combined learner's state, educational activity's state, infrastructure's state and environment's state. However, the more input data are used in the adaptation engine the more accurate but complicated the context becomes. So, the question arises about the right amount and variety of useful input data.
The second criterion is the degree of harmonious integration of the learner's state, the educational activity's state, the infrastructure's state and the environment's state. The right integration of the input data to describe the context is important. It is an open research problem to effectively combine the input data into the context. If the adaptation decisions are based on partial input data then discrepancies and contradictions may occur. For example, one adaptation decision may call for video and picture presentation, while another one for low bandwidth communication lines. However, video cannot be transmitted over low bandwidth communication lines. Therefore, the adaptation decisions should be based on the full context.

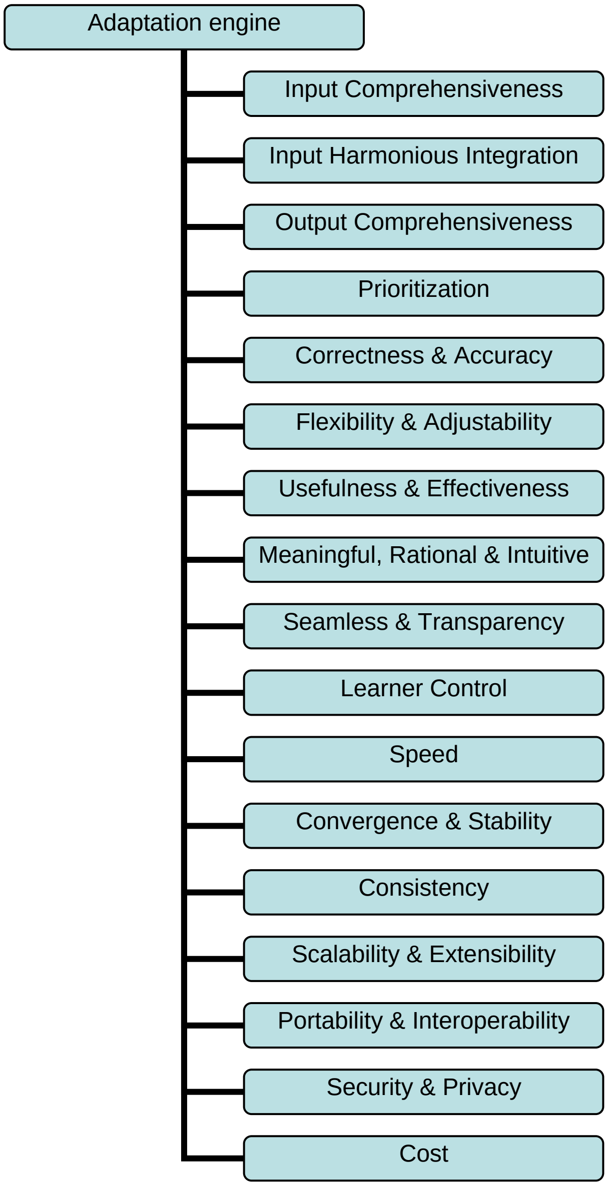

Chart 1: Evaluation criteria for adaptation engines.

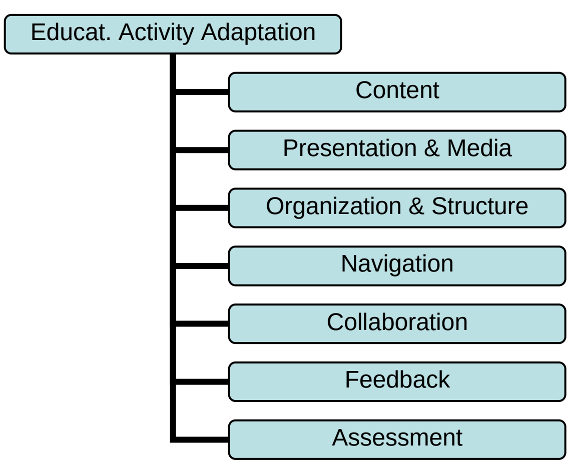

Chart 2: Adaptation dimensions of Educational Activity.

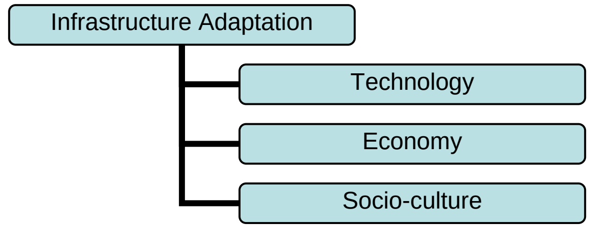

Chart 3: Adaptation dimensions of Infrastructure.

The third criterion is the comprehensiveness of the output. We have described the output of the adaptation engine as the combined educational activity's state and infrastructure's state. In other words, the adaptation engine produces a new adapted educational activity and a new adapted infrastructure. So, the question arises about the parameters and features of the educational activity and the infrastructure that would be useful to be adapted. In Chart 2, we consider the various areas of the educational activity that would be adapted: content, organization, presentation, navigation, collaboration, feedback, assessment. So, the adaptation engine would provide adapted content of the educational activity, adapted presentation of the educational material, adapted organization and structure of the educational material, adapted navigation through the educational activity and material, adapted collaboration among the learners, adapted feedback to the learner, adapted assessment of the learner, as well as other adapted features.

Regarding the infrastructure, it consists of the user interface, wearable and handheld devices, networks, software, applications, and other resources. The adaptation engine would adapt each one of these across 3 areas: i) technology, ii) economy, and iii) socio-culture (Chart 3). Regarding technology, the adaptation engine would adapt the technology used, input/ output devices, transmission rate, capacity, antenna range, quality, platform, media used, accessibility, security and privacy, etc. to the input data (context). For example, the adaptation engine would provide educational material with plenty of video and pictures to visual learners (learner's state). Regarding economy, the adaptation engine would adapt the cost of using the educational activity, the networks, the resources, and the pricing policy (volume, support, duration, guarantees, etc.) to the input data. For example, the adaptation engine would use low cost communication lines for low income learners (learner's state). Regarding socio-culture, the adaptation engine would adapt the norms of interaction to the input data. For example, the adaptation engine would provide flexible (not strict) deadlines to learners from societies with loose time restrictions.

The various features of the educational activity and the infrastructure may have different importance for the learner. So, there should be prioritization among the features in case of constraints or conflicts. The adaptation engine may decide to adapt some features and not others.

The adaptation engine should produce correct and accurate output. The adaptation decisions should be accurately based on the context. The adapted educational activity and infrastructure should be correct. If it is impossible to tailor exactly the educational activity and the infrastructure to the context, then the difference in tailoring should be very small, otherwise wrong decisions may be done. For example, if the adapted infrastructure terminates a text or video communication and establishes only an oral communication due to insufficient bandwidth, a learner with low verbal and linguistic abilities may perform lower than his true abilities.

On the other hand, the adaptations should be flexible and adjustable. If the adaptation engine cannot produce a precise output due to constrains, then an acceptable approximation should be available. For example, if there is not sufficient communication bandwidth for video transmission, then at least text communication should be provided.

The results of the adaptations should be useful and effective. The adaptations should improve the learning, the equity, the learner's satisfaction, the learner's motivation, etc. On the other hand, they should reduce the cost, the learner's anxiety, the learner's drop out, etc.

Furthermore, the adaptation results should be meaningful, rational and intuitive. The learner should trust and not wonder about the correctness and validity of the adaptations.

The learner should not be disturbed by the adaptations. The adaptation engine should decide and produce the adaptations in a seamless and transparent way. There should be no need for the learner to manually make changes in configurations, run programs, etc. Also, any transitions from one state to another should be done as smoothly as possible.

On the other hand, the learner may be allowed to have control over the adaptations. So, the learner would determine the degree, quantity, form and type of adaptation. For example, it would be possible that the adaptation engine proposes adaptation alternatives and the learner selects only those that he agrees with and likes.

The adaptation speed is also important. After sensing and measuring the context, the sooner the adaptation implementation the better. The adaptation engine should fast track the context and make appropriate adaptations. The adaptations should be based on the current context and not on outdated and obsolete input data. So, the convergence speed of the adaptation algorithm to the optimal is significant. Furthermore, the adaptation algorithm should converge and be stable.

The adaptation engine should produce similar results for similar input data. The adaptations should be consistent. Similar context should result to similar adaptations. For example, similar learners in the same situation should see similar educational activities. Also, the same learner in similar situations should see similar educational activities.

Another criterion is the scalability and extensibility of the adaptations. The adaptation engine should be scalable and efficiently incorporate many learners, educational activities, objects, devices, networks, etc. Also, it should be easily extended and upgraded to manage other types of context.

The interoperability, openness and portability are also important issues. The adaptation engine should easily interoperate with other systems in order to receive or provide information about the context. Based on an open architecture and standards, it would easily connect to other hardware and software systems. It should accept input data from a variety of sources and export data to a variety of destinations.

The adaptation should also comply with security and privacy issues of the learning system. It should not bypass any security and privacy restrictions on the hardware and software resources.

Finally, the cost of adaptation is important. The decision and implementation of the adaptation has some cost. If this cost is prohibitively large, then a question arises about implementing the adaptation. Of course, the cost is related to the achieved results. If the results (e.g. learning) justify the cost, then the adaptation should be implemented.

4. Conclusions

Previously proposed adaptive learning systems adapt the content, the course sequencing, the presentation and the navigation to the user profile and his devices. It is implied that an adaptation engine gathers information about the current state and appropriately adapts some parameters based on this information. This paper tries to develop a common framework in order to evaluate the adaptation engine. This evaluation framework includes 17 criteria. Using these criteria, one can evaluate how well the adaptation engine adapts some parameters of the educational activity and the infrastructure according to the current state of the context. Future work would be the evaluation of previously proposed adaptation engines using this framework. However, most systems do not explicitly describe their adaptation engines. Further work would also be the development of an adaptation engine taking into consideration these criteria.

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