X-Learn: an XML-based, multi-agent system for supporting “user-device” adaptive e-learning

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Abstract. In this paper we present X-Learn, an XML-based, multi-agent system for supporting “user-device” adaptive e-learning. X-Learn is characterized by the following features: (i) it is highly subjective, since it handles quite a rich and detailed user profile that plays a key role during the learning activities; (ii) it is dynamic and flexible, i.e., it is capable of reacting to variations of exigencies and objectives; (iii) it is device-adaptive, since it decides the learning objects to present to the user on the basis of the device she/he is currently exploiting; (iv) it is generic, i.e., it is capable of operating in a large variety of learning contexts; (v) it is XML based, since it exploits many facilities of XML technology for handling and exchanging information connected to e-learning activities. The paper reports also various experimental results as well as a comparison between X-Learn and other related e-learning management systems already presented in the literature.

1 Introduction

E-learning can be defined as the activity that supports a learning experience by either developing or applying Information & Communication Technology (ICT). It is playing a more and more relevant role in the ICT market and its importance is becoming crucial for organizing training in businesses. Indeed, market dynamism compels organizations to avoid medium-to-long term programming and to work in a project-shaped, short-to-medium term perspective.

In order to realize projects which it is involved in, an organization continuously needs new “know how” and competences; owing to the growing “skill shortage”, these can be found on the external market only with a great difficulty and a high cost. As a consequence, the capability to internally construct the necessary know how has become a must for an organization.

E-learning is a particularly suitable solution to these exigencies. More specifically, an e-learning platform should initially determine the competence gap of
the human resources assigned to a project; after this, it should fill such a gap by constructing suitable personalized and flexible learning programs that can be dynamically adapted to the feedback received by the user.

In such a context, in order to guarantee the maximum flexibility and, contemporarily, the highest efficiency to e-learning activities, it has been proposed to organize learning contents into independent units, named *learning objects*, that can be dynamically combined for constructing personalized learning programs. In order to successfully perform such an activity, an efficient and effective organization of available learning objects appears crucial. In other words, it appears necessary to define and construct a meta-knowledge that allows to classify available learning objects (documents, slides, simulations, role games, questionnaires, tests, registered lessons, etc.) on the basis of their objectives, arguments, exploited media and so on.

In order to both simplify learning object exploitation and foster platform interoperability, important international organizations have proposed to associate suitable descriptors, named LOM (Learning Object Metadata), with learning objects [2]. LOM allow information about learning objects to be obtained without the necessity to directly analyze them. More specifically, the Instruction Management System (IMS) [3], an authoritative organism for LOM standardization, has proposed to describe learning objects by means of an XML document which a suitable XML Schema is associated with. Such a proposal has been favourably accepted by the e-learning community and, presently, almost all commercial e-learning platforms support it.

LOM paradigm has largely facilitated e-learning activities, in particular the automatic construction of learning programs. However, in order to improve the efficiency and the effectiveness of e-learning activities, some important problems, often involving research areas quite far from computer science, should be faced. As an example, new didactic methodologies, based on the learning object paradigm and well suited to automatically realize learning programs, should be defined [14]. In addition, a continuous and pervasive e-learning activity should carefully consider and support the different devices that users might exploit during their learning process. With regard to this, it is worth observing that, in the Personal Digital Assistant era, limiting users to perform e-learning activities only by a Personal Computer connected to the organization’s LAN unjustifiably reduces the flexibility and, consequently, both the efficiency and the effectiveness of the e-learning process.

In our opinion, some of these challenging issues can be successfully faced by exploiting the agent technology. The present paper aims at showing the feasibility of this idea; in particular, it presents *X-Learn*, an XML-based Multi-Agent System for supporting “user-device adaptive” e-learning. More specifically, X-Learn has been conceived for assisting users to learn new “know how” and competences to fill the gap between their present knowledge and that required by a new project which they have been assigned to.

In *X-Learn* user assistance is guaranteed by constructing personalized, flexible and dynamic learning programs taking into account the background knowl-
edge of a user, her/his didactic objectives as well as devices and connection
typologies she/he intends to exploit for carrying out her/his e-learning activity.

**X-Learn** is characterized by the following features that, in our opinion, are
extremely relevant for a new e-learning system:

- **It is highly subjective**: indeed, it handles quite a rich and detailed user profile
  which records her/his background knowledge and future learning objectives
  and, consequently, plays a key role in the definition of learning programs.
- **It is dynamic and flexible** since it is provided with mechanisms for reacting
to variations of both user and organization exigencies and objectives.
- **It is device adaptive** since it decides the typology (in particular, the “multi-
  media degree”) of learning objects to present to the user on the basis of the
  device she/he is currently exploiting.
- **It is generic**, i.e., it is capable of operating on a large variety of learning
  contexts.
- **It is XML-based**, since (i) the agent ontologies are stored as XML documents;
  (ii) the communication language exploited by the various agents is ACML [9],
a language obtained by combining XML and KQML [7]; (iii) the extraction
  of information from the various data structures is carried out by means of
  XQuery [4]; (iv) the manipulation of agent ontologies is performed by means
  of the Document Object Model (DOM) [1]; (v) information relative to the
  learning activities is represented and handled by means of the IMS standard
  [3] (see above).

This paper is organized as follows: the next section presents some preliminary
definitions; a detailed description of all agents involved in **X-Learn** is provided
in Section 3. Section 4 is devoted to describe a series of experiments we have
performed for testing our system performances. In Section 5 we present related
literature and compare **X-Learn** with various other systems already proposed in
the past. Finally, in Section 6 we draw our conclusions.

## 2 Preliminaries

In this section we provide some preliminary definitions necessary to understand
both the architecture and the behaviour of **X-Learn**.

**Definition 1.** A **skill** indicates an ability that a user wants to achieve. Examples of skills are “C++ programmer”, “Webmaster”, etc. Each skill requires the
knowledge of a set of subjects. We say that a user acquires a skill when she/he
knows all the subjects associated with it.

**Definition 2.** A **subject** denotes a high level topic of a skill. Examples of subjects are “C++ functions”, “C++ Classes”, “C++ Class Inheritance”, etc. Each
subject may have one or more pre-requisites; these are other subjects whose
knowledge is necessary for studying it. As an example, in order to study the
subject “C++ Class Inheritance”, it is necessary to know the subject “C++
Classes”. Analogously, a subject can be a pre-requisite for one or more subjects.
We say that a subject is **basic** if it has no pre-requisites.
Definition 3. A learning object is an elementary learning unit relative to a specific subject. In this paper we assume that:

- each learning object is relative to only one subject;
- various learning objects could be associated with the same subject; they could differ for the associated learning methodology, for their multimedia degree, and so on. However, all learning objects associated with the same subject are considered equivalent from a didactic point of view.

A learning object consists of two components, namely the learning object descriptor and the learning object content. The former describes the characteristics of the learning object (e.g., the associated subject, the multimedia format, etc.). The latter corresponds to the actual information content associated with the learning object and that the user must study for learning the subject associated with it.

As previously mentioned, subjects can be characterized by some pre-requisites which are, in their turn, other subjects. As a consequence, a user can study a subject only if she/he knows all the corresponding pre-requisites. We have seen that studying a subject corresponds to study one of the learning objects associated with it. As a consequence, it is possible to introduce the concept of learning program which allows to formally define the (partially ordered) set of learning objects that a user must study for learning a subject starting from her/his background knowledge.

Definition 4. A learning program \(LP\) is a set of pairs of learning objects \((LObj_s, LObj_t)\) such that \(LObj_t\) can be studied only after \(LObj_s\) or, in other words, such that the subject associated with \(LObj_s\) is a pre-requisite of the subject relative to \(LObj_t\).

Note that, in \(LP\), more tuples \((LObj_{s1}, LObj_{t1}), (LObj_{s2}, LObj_{t2}), \ldots, (LObj_{sn}, LObj_{tn})\) could exist having \(LObj_{t1}\) as their second component; this indicates that \(LObj_{t1}\) can be studied only after \(LObj_{s1}, LObj_{s2}, \ldots, LObj_{sn}\) have been learned. In this way, \(LP\) specifies also a partial order according to which the learning objects must be studied.

3 The X-Learn Architecture

3.1 General Overview

X-Learn consists of three agent typologies, namely:

- a User-Device Agent (hereafter \(UDA\)), that handles an e-learning session carried out by a user \(U\) by means of a device \(D\);
- a Skill Manager Agent, (hereafter \(SMA\)), that supports a user to determine the skills of her/his interest, as well as the subjects she/he has to study for attaining a given skill, on the basis of her/his background knowledge;
a Learning Program Agent, (hereafter LPA), that generates personalized learning programs for a specific user \( U \) needing to study a particular subject \( S \), having a certain background knowledge and exploiting a device \( D \) for her/his e-learning activity.

In addition, \( X\text{-}Learn \) is provided with a Learning Object Repository (LOR), storing all learning objects it handles.

As previously pointed out, the role of XML in \( X\text{-}Learn \) is crucial. Indeed:

– The agent ontologies are stored as XML documents; as a consequence, they are light, versatile, easy to be exchanged and can reside on different devices and software platforms. In spite of this simplicity, the information representation rules embodied in XML are powerful enough to allow a sophisticated information management.

– The agent communication language is ACML \([9]\); this is the XML encoding of FIPA Agent Communication Language \([8]\). The exploitation of ACML guarantees various benefits to \( X\text{-}Learn \); two of the most relevant ones are the following:

  • Developing and managing tools capable of carrying out ACML message parsing is extremely simple; indeed, these tools can be constructed by exploiting the numerous off-the-shelf XML parsers available over the Internet. Vice versa, in order to construct parsers for not XML-based ACL versions, it is generally necessary to exploit a Lisp-like encoding (see \([9]\) for all details) whose supports are more difficult to be found over the Internet.

  • Integrating Agents with a large variety of Web technologies (such as Secure Socket Layer - SSL, for handling both the authentication of agents' identities and the encryption of ACL messages) is very simple to be realized. Vice versa, addressing the same issues with a not XML-based Agent Communication Language would imply heavy constraints on the agent infrastructure (think, for example, to the great overload to be put in the ACL messages for handling these issues).

– The extraction of information from the various data structures is carried out by means of XQuery \([4]\). This is becoming the standard query language for the XML environment. Since it is based on the XML framework, XQuery can handle a large data variety. It has capabilities typical of database query languages as well as features typical of document management systems. Finally, it is provided with various high level constructs for simplifying querying over the Web; among them, we cite constructors, that allow the creation of XML structures within a query, and FLWR expressions, that support iteration and variable binding.

– The manipulation of agent ontologies is performed by means of the Document Object Model (DOM) \([1]\). This is a platform- and language-neutral interface that allows programs and scripts to dynamically access and update the content, structure and style of XML documents. DOM makes it possible for programmers to write applications working properly on all browsers and servers as well as on a large variety of hardware and software platforms.
Learning Object Metadata are represented and handled by means of the IMS standard [3]. As pointed out in the Introduction, such a standard describes learning objects by means of XML documents, validated with respect to an XML Schema. The exploitation of XML allows to manipulate and manage learning object descriptors using the most recent XML technologies such as DOM, for data manipulation, SAX, for data parsing, XQuery, for data querying, and so on.

In the following subsections we provide a detailed description of the various agent typologies which X-Learn consists of.

### 3.2 The User-Device Agent

A User-Device Agent $UDA_{ij}$ is associated with a user $U_j$ exploiting a device $D_i$; it supports $U_j$ during her/his learning activities carried out by means of $D_i$.

**Ontology** The ontology of $UDA_{ij}$ consists of a pair $(DP_i, UP_j)$, where:

- $DP_i$, the Device Profile of $D_i$, stores some characteristics of $D_i$ such as the maximum bandwidth and the medium typology (e.g., video, audio, etc.) it can handle;
- $UP_j$, the User Profile of $U_j$, stores some characteristics of $U_j$ such as the skill she/he wants to acquire, her/his background knowledge and the maximum time she/he can spend for a learning program.

Table 1 illustrates the parameters characterizing the ontology of $UDA_{ij}$ in more detail. The corresponding XML Schema is shown in Figure 1.

**Behaviour** $UDA_{ij}$ is activated by $U_j$ when she/he wants to acquire a new skill. In this case $UDA_{ij}$ contacts $SMA$ and sends it the set of skills already acquired.
by $U_j$. In its turn, $SMA$ sends $UDA_{ij}$ the list of skills $U_j$ might acquire; these are shown to $U_j$ who can select one of them. When this happens, $UDA_{ij}$ adds the selected skill to $UP_j$ and the learning session starts. In order to illustrate the exploitation of ACML, in Figure 2 we show the ACML message that $UDA_{ij}$ sends to $SMA$. In the following, due to space limitations, we cannot present the other ACML messages exchanged by the various agents; however, they are analogous to that shown in Figure 2.

$UDA_{ij}$ can be activated by $U_j$ also when she/he wants to continue a previously interrupted learning program. In this case $UDA_{ij}$ exploits information stored in its ontology for re-starting the learning program.

A learning session is carried out as follows. $UDA_{ij}$ sends to $SMA$ both the set of subjects already known by $U_j$ and the skill she/he desires to acquire. $SMA$ identifies the subjects $U_j$ must attain for acquiring the desired skill and returns an ordered list of them to $UDA_{ij}$. The list order reflects the pre-requisite relationships existing among subjects. At this point, $U_j$ can choose the next subject to learn.

After this, $UDA_{ij}$ contacts $LPA$ and sends it the device profile $DP_i$, the user profile $UP_j$ and the subject $Sub_{jk}$ that $U_j$ desires to learn. $LPA$ determines the Best Learning Program $BLP_{ijk}$ allowing $U_j$ to learn $Sub_{jk}$ by means of $D_i$ and sends it to $UDA_{ij}$ (see Section 3.4). This extracts each learning object of $BLP_{ijk}$ from the Learning Object Repository and presents it to $U_j$. When she/he ends to study a learning object of $BLP_{ijk}$, $UDA_{ij}$ updates $UP_j$ by adding the corresponding subject to the set of subjects already known by $U_j$.
Fig. 2. The ACML message that UDA sends to SMA.

After $U_j$ has studied all learning objects of $BLP_{ijk}$, and, consequently, has acquired $Subj_k$, she/he can decide to interrupt the learning session or, alternatively, to continue it by studying a further subject relative to the current Desired Skill. In the former case, $UDA_{ij}$ is de-activated; in the latter case, it contacts $LPA$ for determining the new learning program.

Finally, when $U_j$ knows all subjects associated with the current Desired Skill, $UDA_{ij}$ updates $UP_j$ by adding it to the set of acquired skills.

3.3 The Skill Manager Agent

A Skill Manager Agent $SMA$ supports User-Device Agents in the selection of skills and subjects to be learned by the corresponding users.

Ontology The ontology of $SMA$ consists of a set of skills $SkillSet = \{Sk_1, \ldots, Sk_q\}$. Each skill $Sk_i$ is characterized by a name $SkName_i$ and the list $SkSubjList_i$ of subjects to be learned for attaining it. Subjects in $SkSubjList_i$ are ordered on the basis of the pre-requisite relationships existing among them. The XML Schema associated with this ontology is analogous to that relative to the ontology of $UDA_{ij}$; due to space limitations we do not show it.
**Behaviour** SMA is activated by a User-Device Agent $UDA_{ij}$ when $U_j$ wants to choose a new skill to acquire or when she/he wants to learn a new subject relative to her/his current Desired Skill.

In the former case, SMA receives from $UDA_{ij}$ the set of skills attained by $U_j$ in the past and returns to $UDA_{ij}$ the skills present in X-Learn not yet acquired by $U_j$. The query for skill extraction, expressed in XQuery, is shown in Figure 3.

In the latter case, SMA receives from $UDA_{ij}$ the set of subjects $U_j$ already knows and the skill she/he desires to acquire; it selects from its ontology the list of subjects necessary to be learned for attaining the current desired skill of $U_j$, filters out those already known by $U_j$ and returns the remaining ones to $UDA_{ij}$. The associated query is illustrated in Figure 4.

```xml
<SkillSet>
  for $i$ in document("http://www.mat.unical.it/X-learn/SMAOntology.xml")/*/Skill
  where empty (document("http://www.ing.unirc.it/user/UDAOntology.xml")/*/AcqSkillSet [AcqSkill eq $i/@Name])
  return
  <Skill>
    $i/@Name
  </Skill>
</SkillSet>
```

**Fig. 3.** The query SMA executes for selecting the skills present in X-Learn and not yet acquired by $U_j$

```xml
<SubjectSet>
  let $uda:=document("http://www.ing.unirc.it/user/UDAOntology.xml")
  let $skill:=document("http://www.mat.unical.it/X-learn/SMAOntology.xml")
  //*/Skill[Name eq $uda/*/DesSkill]
  for $subject in $skill/SkSubjList/Subject
  where empty ($uda/*/KnownSubjSet [Subj/@Name eq $subject])
  return
  <Subject>
    $subject
  </Subject>
</SubjectSet>
```

**Fig. 4.** The query SMA executes for selecting the list of subjects of the current desired skill not already known by $U_j$

### 3.4 The Learning Program Agent

The Learning Program Agent $LPA$ is activated by a User-Device Agent $UDA_{ij}$ whenever $U_j$ wants to study a new subject $Subj_k$. It is in charge of providing $U_j$ with a personalized learning program for studying $Subj_k$ on the basis of
The ontology of LPA consists of a pair $\langle \text{SubjSet}, \text{LObjSet} \rangle$, where:

- $\text{SubjSet}$ represents the set of subjects currently available in X-Learn. Each subject is characterized by a code, a name, the set of its pre-requisites and the set of learning objects associated with it.
- $\text{LObjSet}$ is the set of learning objects currently present in X-Learn. Each learning object is characterized by an identifier, a name, the subject it refers to, the URI where it can be accessed, its data format, size and duration. Metadata for describing learning objects have been defined according to IMS specifications [3]. Table 2 illustrates the parameters characterizing the ontology of LPA in more detail. The corresponding XML Schema is analogous to that relative to the ontologies of $UDA_{ij}$ and $SMA$; due to space limitations we do not show it.

### Table 2. The Ontology of LPA

| Field       | Description                                           |
|-------------|-------------------------------------------------------|
| SubjId $l$  | the Identifier of Subj $l$                           |
| SubjName $l$| the Name of Subj $l$                                 |
| SubjPrereqSet $l$ | the Set of Pre-requisites of Subj $l$                |
| SubjLObjSet $l$ | the Set of learning objects relative to Subj $l$     |
| LObjId $m$  | the Identifier of LObj $m$                           |
| LObjName $m$| the Name of LObj $m$                                 |
| LObjSubject $m$ | the Subject which LObj $m$ refers to                |
| LObjLocation $m$ | the URI where LObj $m$ can be accessed              |
| LObjVC $m$  | the Video Component field of LObj $m$. It is set to 1 if LObj $m$ has a video component, 0 otherwise |
| LObjAC $m$  | the Audio Component field of LObj $m$. It is analogous to LObjVC $m$ but for audio |
| LObjTC $m$  | the Text Component field of LObj $m$. It is analogous to LObjVC $m$ but for text |
| LObjSize $m$| the Size, in bytes, of LObj $m$                      |
| LObjDuration $m$ | the Duration of LObj $m$. It is defined as the time, in seconds, that LObj $m$ takes when it is played |

Behaviour LPA is activated by $UDA_{ij}$ whenever a user $U_j$ wants to study a subject $Subj_k$ by means of a device $D_i$. LPA receives $Subj_k$, $UP_j$ and $DP_i$ from $UDA_{ij}$. It returns to $UDA_{ij}$ the Best Learning Program $BLP_{ijk}$ allowing $U_j$ to study $Subj_k$ by means of $D_i$. The construction of $BLP_{ijk}$ consists mainly of three steps.

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1 Recall that a learning object is related to only one subject but one subject might have various learning objects associated with it.
Step 1 During the first step LPA constructs a support graph, named Subject Dependency Graph SDG$_{jk} = \langle$NS$_{jk}$, AS$_{jk}\rangle$. SDG$_{jk}$ is constructed for guiding U$_j$ to learn Subj$_k$ starting from basic and/or already known subjects.

As a consequence, for each list of subjects \(\{\text{Subj}_1, \text{Subj}_2, \ldots, \text{Subj}_n\}\), such that:

- Subj$_l$ is a pre-requisite of Subj$_{l+1}$, $1 \leq l \leq n - 1$;
- Subj$_1$, \ldots, Subj$_n$ are not known by U$_j$;
- Subj$_1$ is either a basic subject or a subject whose pre-requisites are already known by U$_j$;
- Subj$_n$ = Subj$_k$.

Subj$_1$, \ldots, Subj$_n$ are added to NS$_{jk}$ and arcs (Subj$_1$, Subj$_2$), \ldots, (Subj$_{n-1}$, Subj$_n$) are added to AS$_{jk}$, if not already present.

Step 2 During the second step LPA exploits SDG$_{jk}$ for determining the Best Learning Program BLP$_{ijk}$. Such a task is carried out by suitably selecting a learning object for each subject in SDG$_{jk}$. The learning object selection is performed according to the following guidelines:

- U$_j$ should exploit as much available bandwidth as possible. The available bandwidth for U$_j$ is determined by computing the minimum between the bandwidth BM$_{ax}$ guaranteed by D$_i$ and the bandwidth BN$_{et}$ available on the network for U$_j$. The bandwidth required by each learning object is computed as the ratio between its size and its duration.
- The time required to U$_j$ to learn BLP$_{ijk}$ must be lower than MaxTime$_j$, i.e., the maximum time U$_j$ can spend for a learning program.
- The format of each selected learning object must be compatible with the characteristics of D$_i$.
- In BLP$_{ijk}$ exactly one learning object must be selected for each subject of SDG$_{jk}$.

The construction of BLP$_{ijk}$ can be properly formulated as the following optimization problem:

\[
\begin{align*}
\text{maximize} & \quad \sum_{r=1}^{\mid\text{NS}_{jk}\mid} \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \frac{\text{LObjSize}_r}{\text{LObjDuration}_r} x_{rs} \\
\text{s.t.} & \quad \sum_{r=1}^{\mid\text{NS}_{jk}\mid} \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \text{LObjDuration}_r x_{rs} \leq \min\{\text{BM}_{ax}, \text{BN}_{et}\} \\
& \quad \sum_{r=1}^{\mid\text{NS}_{jk}\mid} \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \text{LObjDuration}_r x_{rs} \leq \text{MaxTime}_j \\
& \quad \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \text{LObjVC}_r x_{rs} \leq \text{VE}_i, \quad 1 \leq r \leq \mid\text{NS}_{jk}\mid \\
& \quad \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \text{LObjAC}_r x_{rs} \leq \text{AE}_i, \quad 1 \leq r \leq \mid\text{NS}_{jk}\mid \\
& \quad \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} \text{LObjTC}_r x_{rs} \leq \text{TE}_i, \quad 1 \leq r \leq \mid\text{NS}_{jk}\mid \\
& \quad \sum_{s=1}^{\mid\text{SubjLObjSet}_r\mid} x_{rs} = 1, \quad 1 \leq r \leq \mid\text{NS}_{jk}\mid \\
& \quad x_{rs} \in \{0, 1\}
\end{align*}
\]

Here, the variable $x_{rs}$ represents the learning object LObj$_s$ associated with the subject Subj$_r$. $x_{rs} = 1$ if LObj$_s$ belongs to BLP$_{ijk}$.

$^2$ In the following we shall use the same name for indicating both a subject and the associated node in SDG$_{jk}$, when this is not confusing.
Step 3 During the third step $LPA$ simply returns $BLP_{ijk}$ to $UDA_{ij}$.

4 Experiments

We have carried out various experiments for verifying the performances of $X$-Learn. Most of these experiments have been conceived for verifying the capability of our system to adapt its behaviour to both bandwidth availabilities and the characteristics of the devices exploited by users.

In these experiments, 72% of learning objects available at the Learning Object Repository of $X$-Learn had a text component, 72% of them had an audio component and, finally, 72% of them had a video component.

A first experiment has been performed for measuring the fraction of selected learning objects having a text (resp., an audio, a video) component. Before carrying out the experiment we thought that, if the available bandwidth increases, the fraction of selected learning objects having an audio and/or a video component increases as well, whereas the percentage of selected learning objects having a text component should be quite constant and high.

The results we have obtained for this experiment are shown in Figure 5. They confirm our intuition. Indeed, it is possible to observe that:

- The fraction of selected learning objects having a text component is quite constant and high; indeed, it is always greater than 80%.
- The percentage of selected learning objects having an audio component slightly increases when the bandwidth increases; it is quite high, since it is always greater than 60%.
- In presence of a bandwidth increase, the increase of the fraction of selected learning objects having a video component is enormous and rapid.

A second experiment has been carried out for verifying how the selection of learning objects depends on the device exploited by the user. In this experiment, the set of available learning objects is the same as that taken into account in the previous one.

We have considered four device typologies handling (i) text and audio, (ii) text and video, (iii) audio and video, (iv) text, audio and video. In addition, we have considered three situations for bandwidth availability, namely (a) low bandwidth (i.e., 9-10 kbytes/s), (b) medium bandwidth (i.e., 50-60 kbytes/s), (c) high bandwidth (i.e., over 120 kbytes/s).

Results obtained when the available bandwidth is low are shown in Table.

In this table there is a row for each device typology; columns are associated with text, audio and video. The element corresponding to the row “Text and Audio” and to the column “Audio” specifies the fraction of learning objects, having an audio component, which are selected if a device handling only text and audio is exploited. Observe that, in case of a low bandwidth, if the device

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3 Remember that a learning object might contemporarily have a text, an audio and a video component.
Fig. 5. Variation of the fraction of selected learning objects having a video (resp., audio, text) component against the variation of available bandwidth

can handle text and audio (resp., video), text is preferred to audio (resp., video). Analogously, if the device can handle video and audio, audio is preferred to video. Finally, if the device can handle text, audio and video, video is totally filtered out, audio is partially considered whereas text is generally selected. These results are reasonable if we consider that, in this experiment, available bandwidth is low and video components generally require a high bandwidth.

|                  | Text | Audio | Video |
|------------------|------|-------|-------|
| Text and Audio   | 0.85 | 0.60  | 0.00  |
| Text and Video   | 1.00 | 0.00  | 0.00  |
| Audio and Video  | 0.00 | 1.00  | 0.00  |
| Text, Audio and Video | 0.85 | 0.60 | 0.00 |

Table 3. Results returned when the bandwidth is low

Results returned when the available bandwidth is medium are reported in Table 4. Observe that, since available bandwidth is higher w.r.t. the previous case, the fraction of selected learning objects having an audio and/or a video component is higher than that returned previously.

Results obtained in presence of a high bandwidth are shown in Table 5. In this case, when the device is capable of handling text and audio, all selected learning objects have both a text and an audio component. This is justified by considering
that both text and audio require quite a limited bandwidth. When the device handles both video and audio, generally, audio is preferred to video even if a high percentage of selected learning objects have also a video component. Finally, when the device handles text, audio and video, a large fraction of selected learning objects has also an audio and/or a video component.

Table 4. Results returned when the bandwidth is medium

|                      | Text | Audio | Video |
|----------------------|------|-------|-------|
| Text and Audio       | 1.00 | 0.80  | 0.00  |
| Text and Video       | 1.00 | 0.00  | 0.26  |
| Audio and Video      | 0.00 | 0.65  | 0.18  |
| Text, Audio and Video| 1.00 | 0.60  | 0.20  |

Table 5. Results returned when the bandwidth is high

|                      | Text | Audio | Video |
|----------------------|------|-------|-------|
| Text and Audio       | 1.00 | 1.00  | 0.00  |
| Text and Video       | 1.00 | 0.00  | 0.75  |
| Audio and Video      | 0.00 | 0.95  | 0.65  |
| Text, Audio and Video| 1.00 | 0.90  | 0.65  |

5 Related Literature

The convergence of mobile communications and handheld computers offers new interesting opportunities in e-learning activities; in this section we focus on some adaptive e-learning systems and we try to highlight their similarities and differences w.r.t our approach. More details on adaptive e-learning systems can be found in [5].

In [12] the authors propose an handheld learning device and an appropriate software infrastructure to support children education. The main components of the proposed architecture are: (i) a learning manager, which stores a local cache of learning objects extracted by a repository and exploits specific software agents to search and organize learning objects, (ii) a communication manager, which creates direct voice and data communication channels for disseminating learning materials and handles resource sharing.

Similarly to X-Learn, [12] develops a technology for assisting individuals and groups to learn anytime and anywhere; in addition, in both the approaches, learning materials follow the IMS standard and might have different multimedia formats. In spite of these similarities, the approach of [12] and X-Learn appear
complementary; indeed, in [12], the authors modify an existing handheld device to support learning activities whereas X-Learn adapts the learning objects distribution to the device characteristics.

In [10] a multi-agent prototype called CITS (Confidence Intelligent Tutoring Agent) is proposed. CITS approach aims at being adaptive (i.e., it can adjust learning materials to meet user needs) and dynamic (i.e., it adapts the offered service to user current behaviour). CITS architecture consists of five kinds of agents, namely: (i) a Cognitive Agent, that creates a model for each learner, representing her/his level and learning style; (ii) a Behaviour Agent, that monitors learner behaviour during her/his interaction with the system for improving the model produced by the Cognitive Agent; (iii) a Guide Agent, that selects and classifies information potentially useful for the learner; (iv) an Information Agent, that searches over the Internet for extra information required by the learner and, (v) a Confidence Agent, that is in charge of strengthening the confidence between the learner and the system. In CITS learning information is fragmented in simple pieces called knowledge targets; these might have different multimedia formats.

Both CITS and X-Learn are XML-based multi-agent systems and both of them support the dissemination of learning materials having different multimedia formats. The main differences existing between them are the following: (i) CITS knowledge targets and X-Learn learning objects are different in their characteristics and purposes; (ii) CITS offers more “freedom degrees” in the learning program definition; (iii) CITS does not support device adaptivity.

[6] proposes a device-aware e-learning system as a part of a more complex e-learning platform, named KnowledgeSea. The core of the system proposed in [6] is a self-organized hyperspace map, i.e. an automatically-built map that provides a concise navigation support for a relatively large learning hyperspace. The map may help a user to find and access on-line educational resources by means of mobile wireless devices.

The approach of [6] is quite similar to X-Learn; indeed, both of them take into account the device a user is exploiting for accessing educational resources. The main differences existing between them are the following: (i) the self-organized hyperspace map provides a more flexible mechanism for selecting learning objects; however, it does not handle pre-requisite relationships possibly existing among learning objects; (ii) [6] does not handle the construction of a complete learning program; vice versa, in X-Learn, LPA has been conceived exactly for this purpose.

In [11] the authors propose IDEAL (Intelligent Distributed Environment for Active Learning), a multi-agent system for active distance learning. IDEAL consists of: (i) a personal agent, handling the profile (i.e., the background knowledge, the interests and the learning style) of a learner; (ii) a course agent, managing both the materials and the teaching technique of a course; (iii) a teaching agent, behaving as an intelligent tutor for a learner. In IDEAL, course materials are decomposed into small components called Lecturelets. These are XML documents
containing JAVA code; they are dynamically assembled to cover course topics according to learner progress.

IDEAL and X-Learn share various similarities; indeed, both of them are XML based and exploit user modeling techniques. The main differences existing between them are the following: (i) the Curriculum Sequencing Activity of IDEAL and the Best Learning Program construction of X-Learn are based on different philosophies and strategies; (ii) IDEAL exploits non-standard and complex constructs for managing course contents (i.e. LectureLets) whereas X-Learn uses the concept of learning object, derived from IMS standard.

In [15] an approach for exploiting web-mining techniques to build a software agent supporting e-learning activities is presented. The proposed agent acts as a recommender system, i.e. it can produce both suggestions (helping the learner to better navigate through on-line materials) and shortcuts (helping the learner to quickly find needed resources). In order to perform all these activities, the system intensively exploits a user profile taking into account learner access history. X-Learn and [15] share some important features; in particular, both of them exploit a user profile and operate by constructing the most appropriate learning program. The main differences existing between X-Learn and [15] are the following: (i) [15] is a single-agent architecture whereas our approach is multi-agent; (ii) the learning program construction is based on data mining techniques in [15], whereas is performed by means of graph-based strategies in X-Learn.

In [13] the system ELETROTUTOR is proposed; this is a multi-agent system implemented on a JADE platform. ELETROTUTOR consists of the following agents: (i) a Pedagogical Agent, performing learning activities, such as the distribution and the dissemination of examples and exercises; (ii) a Remote Agent, managing the communication between the learner and the system; (iii) a Communication Agent, handling agent communications, and (iv) a Student Model Agent, handling a student profile and exploiting it for performing the learning activities. Both X-Learn and ELETROTUTOR are multi-agent systems and both of them adapt the dissemination of learning contents to user profiles. As for differences between ELETROTUTOR and X-Learn, we observe that the former does not handle device adaptivity and multimedia information that are, instead, managed by the latter.

6 Conclusions

In this paper we have proposed X-Learn, an XML-based multi-agent system for supporting e-learning activities.

We have seen that, in X-Learn, three typologies of agents are present, namely (i) a User-Device Agent, that handles an e-learning session carried out by a user $U$ by means of a device $D$; (ii) a Skill Manager Agent, that supports a user $U$ to determine the skills and the subjects she/he has to study; (iii) a Learning Program Agent, that generates personalized learning programs for a specific user $U$ needing to study a particular subject $S$, having a certain background knowledge and exploiting a device $D$ for her/his learning activities.
We have shown that X-Learn is adaptive w.r.t. the profile of both the customer and the device she/he is exploiting for carrying out the learning activities. Finally, we have seen that it is XML-based since: (i) the agent ontologies are stored as XML documents; (ii) the communication language exploited by the various agents is ACML; (iii) the extraction of information from the various data structures is carried out by means of XQuery; (iv) the manipulation of agent ontologies is performed by means of DOM; (v) learning objects are represented and handled by means of IMS standard.

As for future work, we plan to study the possibility to enrich the proposed multi-agent model with other features capable of improving its effectiveness and completeness in supporting a large variety of activities related to e-learning. As an example, it might be interesting to define various learning strategies to allow a user to specify the preferred learning strategy and, finally, to consider such a preference when the Best Learning Program is constructed.

As a second improvement, particularly interesting when X-Learn is exploited for managing employee learning in an organization, it could be possible to define career paths for the various employees and to relate learning programs with them.

As a final extension, it could be possible to provide X-Learn with a team building functionality capable of assigning employees to project teams on the basis of the skills acquired during e-learning activities.

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