Web Intelligence and Artificial Intelligence in Education

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Abstract

This paper surveys important aspects of Web Intelligence (WI) in the context of Artificial Intelligence in Education (AIED) research. WI explores the fundamental roles as well as practical impacts of Artificial Intelligence (AI) and advanced Information Technology (IT) on the next generation of Web-related products, systems, services, and activities. As a direction for scientific research and development, WI can be extremely beneficial for the field of AIED. Some of the key components of WI have already attracted AIED researchers for quite some time – ontologies, adaptivity and personalization, and agents. The paper covers these issues only very briefly. It focuses more on other issues in WI, such as intelligent Web services, semantic markup, and Web mining, and proposes how to use them as the basis for tackling new and challenging research problems in AIED.

Keywords

Web intelligence, Ontologies, Semantic Web, Educational Web services, Pedagogical agents.

Introduction

The scope of WI as a research field, as proposed by Zhong et al. (2002), encompasses Web information systems environments and foundations, ontological engineering, human-media interaction, Web information management, Web information retrieval, Web agents, Web mining and farming, and emerging Web-based applications. It also aims at deepening the understanding of computational, logical, cognitive, physical, and social foundations as well as the enabling technologies for developing and applying Web-based intelligence and autonomous agents systems (Liu et al., 2003).

We can study Web intelligence on at least four conceptual levels (Zhong et al., 2002):

- network level – Internet-level communication, infrastructure, and security protocols, where intelligence comes from the Web adaptivity to the user's surfing process;
- interface level – intelligent human-Internet interaction, e.g. personalized multimedia representation;
- knowledge level – representing (in machine-understandable formats) and processing the semantics of Web data;
- social level – studying social interactions and behavior of Web users and finding user communities and interaction patterns.

Although WI certainly overlaps with other research fields and directions, the keyword here is deepening – WI covers some more specific and emerging issues related to otherwise broad, general fields. For example, WI researchers (http://wi-consortium.org/) are interested in manipulating the meaning of data (i.e., machine-understanding and machine-processing of data items, entities, and their relationships), means of creating distributed intelligence, balance between Web technology and intelligent agent technology, agent self-organization, learning, and adaptation, agent-based knowledge discovery, agent-mediated markets, autonomy-oriented or autonomic computing, security issues in Web and agent systems, Semantic Web, Web services and interoperability, grid computing technology, emergent behavior, knowledge management, networks, and communities, ubiquitous computing, and social intelligence.

In education, we should pay close attention to such developments and trends. This paper surveys some of the important issues related to WI, and discusses their implications for Web-based teaching and learning. It also presents the background and context for developing WI-empowered educational systems, describes the current state of the development, indicates some existing applications and tools, and introduces some research issues stemming from numerous possibilities for cross-pollination between WI, IT, and AIED.

Semantic Web

An important part of the background and context for discussing the relationship between WI and AIED is the Semantic Web (http://www.semanticWeb.org/). It is the new-generation Web that makes possible to express information in a precise, machine-interpretable form, ready for software agents to process, share, and reuse it, as well as to understand what the terms describing the data mean. It enables Web-based applications to interoperate both on the syntactic and semantic level (Hendler, 2001).

Key components of the Semantic Web technology are (Preece and Decker, 2002):

- a unifying data model; currently, RDF (Resource Description Framework, http://www.w3.org/RDF/) is most frequently used data model on the Semantic Web;
- ontologies of standardized terminology to represent domain theories; they enable construction of support tools that assist the generation and processing of semantic markup of Web resources;
- languages based on RDF, such as DAML+OIL (DARPA Agent Markup Language plus Ontology Inference Layer), http://www.daml.org/2001/03/daml+oil-index, for developing ontologies and for marking up Web resources; semantically annotated Web resources, in turn, enable semantically rich service-level descriptions (such as DAML-S, the DAML-based Web Service Ontology, http://www.daml.org/services/).

Ontologies and semantic markup are the core of the network of knowledge on the Semantic Web, because marked up Web pages point to ontologies and ontologies point to each other, Figure 1.

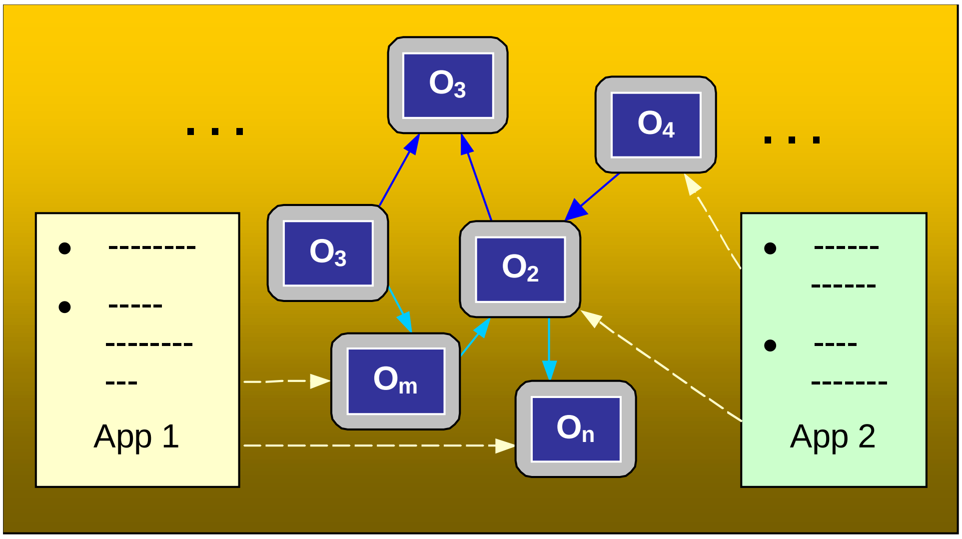

Figure 1. Semantic markup provides mappings between Web pages and ontologies (Oi - ontologies)

Languages

There are a lot of languages for developing ontologies and semantically annotating Web pages. One way or another, most of them are based on XML (eXtensible Markup Language), XML Schemas, RDF (Resource Description Framework), and RDF Schemas, all four developed under the auspices of the World-Wide Web Consortium (W3C) and using XML syntax (Gómez-Pérez and Corcho, 2002). Another important branch of languages is that for supporting WI-infrastructure issues, such as WSDL (Web Services Description Language), WSFL (Web Services Flow Language), UDDI (Universal Description, Discovery, and Integration), SOAP (Simple Object Access Protocol), and PSML (Problem Solver Markup Language) – see (Zhong et al., 2002; Liu et al., 2003; Preece and Decker, 2002) for starting points on the use of these languages to support development of WI.

The most recent relevant facts related to the language issues are the following:

- Web Ontology Language, or OWL (http://www.w3.org/2001/sw/WebOnt/), the language developed by W3C for representing ontologies on the Web in an XML-based syntax became a W3C recommendation on 10th February 2004;

- Web Services Description Language v2 (WSDL) was published on 10th November 2003.

WI-related Work in AIED

AIED community has already started studying a number of issues generally relevant to WI. Of course, AIED researchers study such issues in the context of teaching and learning theories and systems. For example, there is an extensive research and development effort in pedagogical agents, autonomous software entities aimed at supporting human learning by interacting with students/learners and authors/teachers and by collaborating with other similar agents, in the context of interactive learning environments (Johnson et al., 2000). Pedagogical agents can help very much in locating, browsing, selecting, arranging, integrating, and otherwise using educational material on the Web.

The work in Web-based intelligent tutoring systems (ITS) also has a long tradition. Web-based ITS are generally important for WI since they demonstrate how different intelligent techniques can be deployed to support a number of issues highly relevant for the learning and teaching processes on the Web, such as personalization, adaptivity, and collaboration, to name but a few. Although in Web-based ITS all such issues are learner-centered, their importance overcomes the domain of education. With some effort, parts of the Web-based ITS technology can be transferred to other application domains.

First-wave Web-based ITS like ELM-ART (Brusilovsky et al., 1996) and PAT Online (Ritter, 1997), to name but a few, were followed by a number of other learning environments that used Web technology as means of delivering instruction. More recent Web-based ITS address other important issues, such as integration with standalone, external, domain-service Web systems (Melis et al., 2001), using standards and practices from international standardization bodies in designing Web-based learning environments (Retalis and Avgeriou, 2002), and architectural design of systems for Web-based teaching and learning (Alpert et al., 1999), (Mitrović and Hausler, 2000). Rebai and de la Passardiere try to capture educational metadata for Web-based learning environments (Rebai and de la Passardiere, 2002).

A rapidly growing branch of AIED research is teaching and learning ontologies and ontology-aware authoring tools. Generally, ontologies provide the necessary armature around which knowledge bases should be built, and set grounds for developing reusable Web-contents, Web-services, and applications (Devedžić, 2002). The most notable classical work in the AIED community related to the development of educational ontologies comes from the Mizoguchi Lab at Osaka University, Japan (e.g., see (Mizoguchi and Bourdeau, 2000)), and from Tom Murray (1998).

In order to better justify some of the WI-related issues stipulated in the remaining of the paper, it is also important to mention the idea of educational gateways and portals, such as GEM (the Gateway to Educational Materials), http://www.geminfo.org. Started as a U.S. Department of Education initiative, GEM is a teacher-oriented educational portal that "expands the educator's capability to access Internet-based lesson plans, curriculum units and other educational materials" by providing "The Gateway" to well-organized, quality collections of various educational resources related to different fields of study. GEM does not use ontologies yet, but makes good use of metadata (specified in RDF), such as title, description, grade levels, resource type, and so on.

Setting for WI-AIED systems

Figure 2 shows a likely setting for teaching, learning, collaboration, assessment, and other educational activities on the Web supported by WI (Devedžić, 2003). Educational material may be distributed among different *educational servers* – specific Web applications running on physical servers and responsible for management and administration of, as well as access to the material. As with educational gateways and portals, teachers and learners can access the educational material residing on educational servers from the client side. However, unlike educational gateways and portals it is pedagogical agents that are supposed to provide the necessary infrastructure for knowledge and information flow between the clients and educational servers. On behalf of learners, pedagogical agents should access *educational content* on the servers by using high-level e*ducational services*. Educational content is any educational material pedagogically organized and structured in such a way that interested learners can use to get introduced to a knowledge domain, deepen their understanding of that domain, and practice the related problem-solving skills. Educational service is a Web service designed specifically to support a learning or teaching goal (see the sections "Intelligent Web Services" and "Intelligent Educational Servers and Portals" for details).

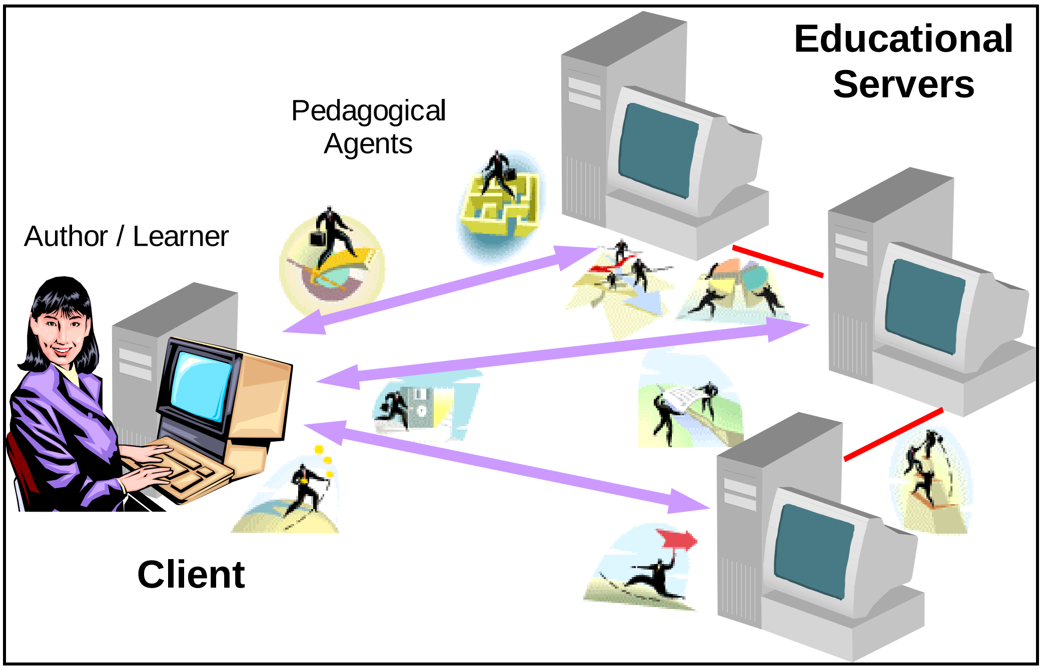

Figure 2. The setting for Web-based education

Educational servers should be created to possess enough intelligence to arrange for *personalization* of the learning tasks they support. In fact, from the learner's perspective the server should appear to act as an intelligent tutor with both *domain* and *pedagogical* knowledge to conduct a learning session. It should use a *presentation planner* to select, prepare, and adapt the domain material to show to the student. It also must gradually build the *student model* during the session, in order to keep track of the student's actions and learning progress, detect and correct his/her errors and misconceptions, and possibly redirect the session accordingly.

It is easy to map Figure 1 onto the setting shown in Figure 2 – Web-based educational applications and services on the Semantic Web can reside on different educational servers, yet they can be easily interconnected and semantically integrated based on the network of ontologies. Semantic markup of educational material, Web pages, and other learning resources should be done by using appropriate tools. Ideally, such tools should be integrated with authoring tools, transparent to the learning material author, and should let him annotate his Web-based learning material automatically, as part of his everyday work, without even thinking about semantic markup. The Briefing Associate tool (Tallis et al., 2002) and ITtalks application (Scott Cost et al., 2002) are good examples of how to design and use such tools.

The following sessions elaborate on the setting from Figure 2 and some of its important concepts in the context of WI.

WI and Personalization of Learning

Adaptivity of Web-based systems plays an important role in WI (Liu et al., 2003). Important issues related to adaptivity of Web-based learning environments, such as providing adaptive navigation support to the learner, links annotation, and adaptive curriculum sequencing, have been already studied in the AI community (Brusilovsky, 1999). In the setting from Figure 2, an essential aspect of educational servers' adaptivity is *personalization* – they should be able to personalize interactions with each learner by keeping track of his recent visits/activities and relating the topics he learns and the sites he accesses during different learning sessions. Moreover, an intelligent educational server should actively help the learner and interact with him when executing these tasks. Since educational servers are interconnected, a specific server may personalize the session with a particular learner by pre-fetching the material the learner needs from other servers. This is an adaptive process based on observations of the learner's surfing behavior during previous sessions. It belongs to *network-*

level WI, and is different from *interface-level WI*, which is related to adaptive cross-language processing, personalized multimedia representation, and multimodal data-processing capabilities (Zhong et al., 2002).

In the AIED community, Trausan-Matu et al. have recently proposed an ontology-based approach to enhancing network- and interface-level WI within the EU INCO Copernicus project in computer-aided language learning (Trausan-Matu et al., 2002). Since the Web information on a certain topic changes dynamically and unpredictably, they extract, annotate, and integrate new information with the old one in the domain ontology, and use it along with the student model to personalize each learning session.

Ontological Engineering

Developing and deploying ontologies to support Web-based educational applications is not just a matter of domain expertise – it is an engineering discipline in itself. Ontological engineering comprises a set of activities that are conducted during conceptualization, design, implementation and deployment of ontologies (Devedžić, 2002).

A good theoretical foundation for ontological engineering of AIED systems (Mizoguchi and Bourdeau, 2000), an early ontology-aware authoring tool (Chen et al., 1998), as well as several other, practical, working ontologies and ontology-based systems (Mizoguchi and Kitamura, 2001), all developed in the Mizoguchi Lab, Osaka University, Japan, have stimulated ontological engineering of other Web-based AIED applications as well. Examples of good engineering design of ontological support for Web courseware authoring include the recently ontology-enhanced AIMS architecture (Aroyo et al., 2002) and the Ontology Editor (Bourdeau and Mizoguchi, 2002) that enables collaborative ontological engineering involving both a domain expert and an instructional-design expert.

Note, however, that developing ontologies manually is anything but easy. WI suggests automating this process by letting educational ontologies *gradually evolve* (Trausan-Matu et al., 2002) as well by *ontology learning* (Maedche and Staab, 2001). This latter idea is to use machine learning, data mining, and statistical tools to import, extract, prune, refine, and evaluate ontologies from the Web. Ontology learning can be from free text, dictionaries, XML documents, and legacy ontologies, as well as from reverse engineering of ontologies from database schemata.

Intelligent Web Services

Roughly speaking, Web services are activities allowing both end users and, under appropriate circumstances, software agents to invoke them directly (Preece and Decker, 2002). In the traditional Web model, users follow hypertext links manually. In the Web services model – and Figure 2 comprises using *that* model – they invoke tasks that facilitate some useful activity (e.g., meaningful content-based discovery of learning material, fusion of similar educational material from multiple sites, or commercial activities such as course advertising and registration for distance learning). Technically, Web services are autonomous, platform-independent computational elements that can be described, published, discovered, orchestrated, and programmed using XML artifacts for the purpose of developing massively distributed interoperable applications. Platform-neutral and self-describing nature of Web services and particularly their ability to automate collaboration between Web applications make them more than just software components.

Note, however, that in WI-enhanced Web-based ITS the idea is to employ *intelligent* Web services – to go beyond XML/RDF infrastructure of Web pages, to explore Web services that can be enabled by intelligent systems technology. With WI, the learners, the teachers, and the authors alike will be able to see the Web as if it was turned into a collection of educational resources, each with a well defined interface for invoking its services (Vinoski, 2002). We may even envision development of an education-oriented dialect of WSDL called EWSDL (Educational Web Services Description Language)! Pedagogical agents will continue to facilitate automatic service discovery, invocation and composition (Figure 2), but as educational Web services evolve, they too will acquire standard interaction models (McIlraith et al., 2001).

An example of a *service-oriented architecture* of Web-based ITS, elaborated after (Vinoski, 2002), is shown in Figure 3. Educational services should advertise themselves in the registry, allowing learners' agents to query the registry for service details and interact with the service using those details. WI community has already developed an ontology of Web services – DAML-S, DAML-based Web Service Ontology (http://www.daml.org/services/).

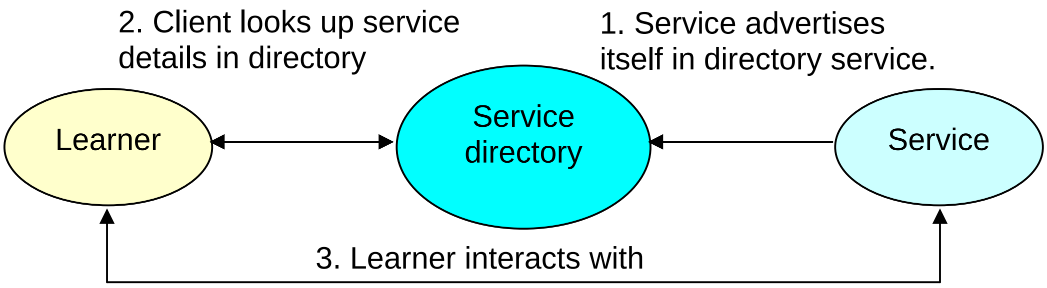

Figure 3. Service-oriented architecture of educational Web servers

Using service-oriented architecture from Figure 3 in Web-based ITS development can greatly enhance the traditional ITS development process, since the client-side system can be built based on educational Web services even if these services are not yet available or they are not known by the ITS developers. This is due to the fact that each Web service is described through a service description language such as WSDL, dynamically discovered by applications that need to use it, and invoked through the communication protocol defined in its interface. In Figure 3, the central component of the educational Web server is the service directory – an information pool pertaining to different educational services, dynamically organized, but highly structured (e.g., as a tree, or as a table/database). The underlying assumption is that at each point in time the directory lists those services that are ready to be invoked by the learner; the services are supposed to advertise their readiness and availability to the directory. Hence a pedagogical agent can find out about the available services by looking up the directory. Then it can decide whether to automatically invoke a suitable service on the learner's behalf, or merely to suggest the learner to interact with the service directly.

Intelligent Educational Servers and Portals

Summarizing the WI ideas from the previous sections, our initial proposal of the *INtelligent Educational Servers* architecture (INES) is depicted in Figure 4. The associated (non-exhaustive) Table 1 describes the services shown. An INES-based server (portal) can offer teachers, learners, and authors service-oriented access to educational content in (a) specific domain(s) of interest. Through presentation services, the content can be adaptively organized and shown in numerous ways. INES enables *knowledge-level WI* (Zhong et al., 2002) for all users: agent-based search, aggregation, classification, filtering, managing, mining, and discovery of educational material. Through agents and ontologies, INES also enables intelligent educational services to automatically self-delegate their functional roles to other services, along with their corresponding spatial or temporal constraints and operational settings (Liu et al., 2003). Note that, just like educational contents, educational services need to be semantically described by their own ontologies (e.g., ontology of assessment, or ontology of library access) and marked-up accordingly in order for pedagogical agents to locate them and invoke them when accessing Web pages of educational servers.

In order to illustrate the envisioned use of INES-based servers, consider the following hypothetical scenario. A learner is engaged in deepening his/her knowledge of Greek mythology. His/her agent realizes the learner's goal either by being told explicitly, or by observing the learner's interactions with the Web and comparing them to the learner's previous activities it knows about. Presumably, the learner's personal agent knows enough about the learner's goals or can access such information elsewhere, e.g. in the students database. The agent then contacts educational servers it knows about. Alternatively, it can contact other similar pedagogical agents it is aware of, such as a facilitator agent that may help the learner's agent find another educational server. When contacting an INES-based server, the agent first queries learning services in order to identify the ontology of Greek mythology and return it to the learner. The learner may browse the ontology and refine his/her search to the concept of *god*. The agent then invokes different learning and reference services from the INES server in order to build for the learner an initial selection of suitable and available learning resources in the form of a dynamically generated multimedia HTML page. All contents on that page are marked-up with ontological information coming from the server side. The learner may proceed by selecting *Titans* on that initial page, which triggers the agent to interact with INES services that acquire, integrate, and arrange the corresponding learning material from heterogeneous sources, build the initial learner model, and select and invoke a suitable tutor on the server side to begin the learning session. The learner's agent monitors the session and intelligently assists the learner in all administration and communication with the INES server. It also takes care of the changes in the learner's focus and dynamically checks the availability of INES services, thus making the underlying technical complexity of the session fully transparent to the learner. The learner can concentrate on his/her learning goals.

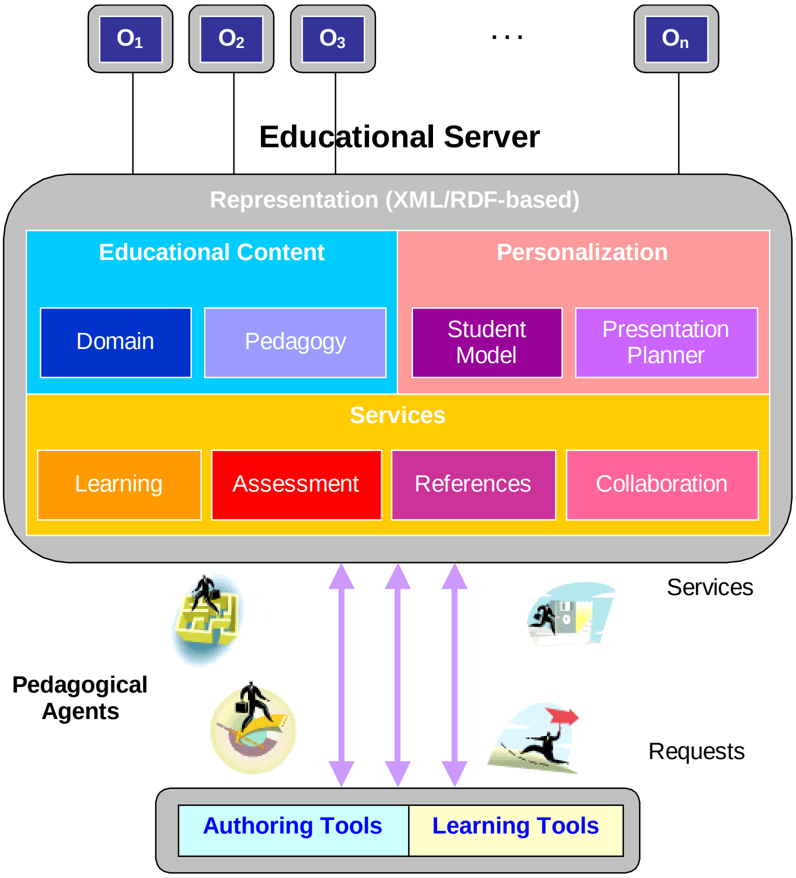

Figure 4. INES architecture: inside an intelligent educational server (Oi - ontologies)

Table 1. Partial classification of educational services

Service category	**Learning**	**Assessment**	**References**	**Collaboration**
Services	Course offering, integration of educational material, (creating lessons, merging contents from multiple sources, course sequencing), tutoring, presentation	On-line tests, performance tracking, grading	Browsing, search, libraries, repositories, portals	Group formation and matching, class monitoring

In Figure 4, pedagogical agents are external to the educational server. This may limit the pedagogical aspects of the provided services only to educational characteristics of the provided content. However, all the services provided by an educational server – including assessment and collaboration – should be affected by pedagogy. Hence an alternative approach is to include some pedagogical agents inside the architectural block of the educational server, as an intermediate interface between the requests and the services. These internal pedagogical agents may collaborate with the external ones to enable pedagogical support for all the services.

Web Mining and Social Networks

Web mining is the process of discovering potentially useful and previously unknown information and knowledge from Web data (Cooley et al., 1997). It encompasses tasks such as automatic resource discovery, automatic extraction and pre-processing of desired data from Web documents, discovery of common patterns across different Web sites, and validation and/or interpretation of discovered patterns (Chakrabarti et al., 1999). Figure 5 shows the most important categories of Web mining.

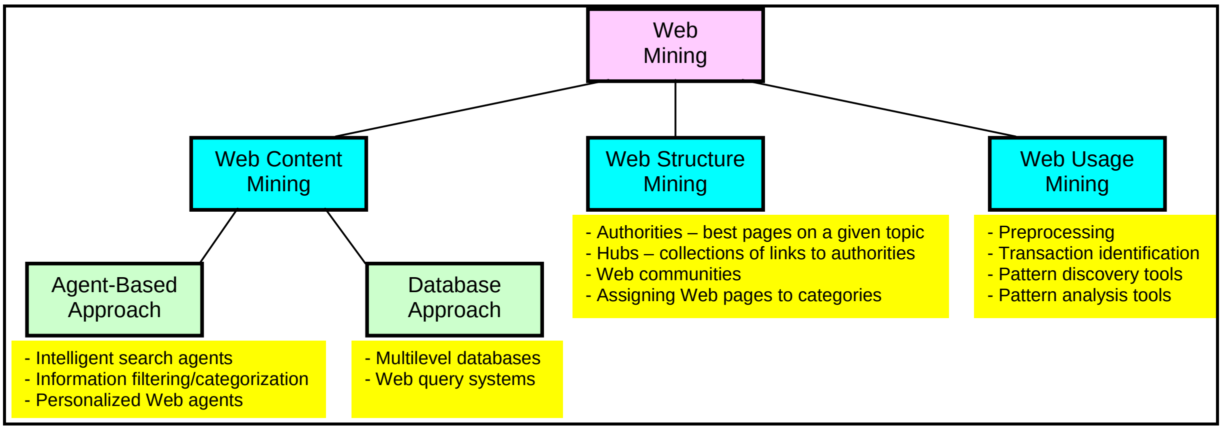

Figure 5. Web mining categories (after (Cooley et al., 1997) and (Chakrabarti et al., 1999))

All categories of Web mining are of interest for AIED. Personalized, ontology-enabled pedagogical agents can be deployed to continuously go *Web content mining* to collect globally distributed content and knowledge from the Web (large Web data repositories such as documents, logs, and services) and organize it into educational Web servers. The collected data can then be incorporated with locally operational knowledge/databases to provide a dedicated community of learners with centralized, adaptable, intelligent Web services. A pioneering work in this direction (albeit not directly related to Web services) is presented in (Trausan-Matu et al., 2002). The idea is that the knowledge the learners need to learn is not static but changes dynamically due to the continuous development and change of available resources on the Web, hence any sequencing of the learning material in a Web-based ITS should reflect that dynamics accordingly. Sticking to the hypothetical example of learning about Greek mythology from the previous section, consider what happens if an agent discovers some contents related to Zeus and previously unknown to the INES server. Using the ontology of Greek mythology, the agent will filter the new content and will categorize the relevant information as related to the concept of god and insert it correctly into a local database. The server itself may run some data mining over that database in order to discover relevant patterns among its contents (e.g., "The learner with such-and-such learning goal and such-and-such learner model, who was presented that other material about Zeus, should be presented the new one as well.") Likewise, the newly discovered content may be matched against the ontology and possibly used to improve the ontology through machine learning (see (Maedche and Staab, 2001) for further elaboration of ontology learning).

Further possibilities stem from deploying *Web structure mining* on the INES server side "in the background". The server can continuously mine the Web for refreshing the information in its database about the availability of external educational services, ranking the most authoritative Web pages and services on a given topic, or (re)organizing its local hub of links to such external pages and services. Moreover, such hubs are ontology supported and reflect not only the structure of related links, but also the hierarchy of related concepts and their instances (e.g., the hierarchical chain *deity-god-Zeus*). It is the relevant ontology that enables correct semantic assignment of Web pages and services, both already known and newly discovered, to a category in the hub. Reference services from the INES server can make direct dynamic use of such hubs, and collaboration services may start from the hubs to help the learner automatically discover peers on the Web who are interested in the same topic. This may result in creating and maintaining Web communities of human learners, but also in organizing and maintaining the related communities of pedagogical agents!

Probably the most attractive Web mining category for Web-based education is *Web usage mining*, which is related to discovering typical patterns of how the users browse, access, and invoke Web pages and services. All user activity is stored in log files on Web servers, hence such files represent a rich source of data for automatic pattern discovery using suitable data mining techniques. For example, suppose an INES server can select among several pedagogical strategies when conducting sessions with the learners. Through Web usage mining, it is possible to discover patterns about the learners' activities and the problems they encountered during the sessions and possibly relate them to the teaching strategies used. Also, patterns related to updating the student model, automatic service invocation, dynamic curriculum sequencing, and using various collaboration techniques can be also discovered in this way.

For Web-based AIED, the notion of *social networks* is essential. Social networks create a self-organizing structure of users (in our case – learners), information, and expert communities (authors, teachers, educational institutions) (Raghavan, 2002). Social relationships – such as friendship, co-working (co-learning, group formation), or exchanging information about common interests – connect these entities (Zhong et al., 2002). Such networks make a great basis for combining next-generation educational portals, ontologies, and search agents with functions such as Web mining, and knowledge management to create, discover, analyze, and manage the knowledge of different domains on the Web, presented in educational material.

Conclusions

The field of Web Intelligence creates a context for encompassing many different AIED efforts and sheds another light on both well-studied and emerging research and development problems in AIED (Devedžić, 2003). Of course, a trade-off exists between the positive effects of introducing ideas from another field into one's research directions and interests, and the effort needed to master the new ideas and practices. Still, there are a number of open WI issues and new research challenges – intelligent Web services, social networks, and Web mining, to name but a few – for AIED community to tackle and possibly incorporate into educational Web-based systems. Hence WI represents a very stimulating context for AIED research. It also enables *social-level WI* for AIED systems, since it encompasses issues central to social network intelligence, i.e. establishing social networks that contain communities of people, organizations, or other social entities – this is exactly the case of Web-based AIED systems.

The key advantages of applying WI techniques to AIED are enhanced adaptivity and enhanced learner comfort. WI enables course sequencing and material presentation not only according to the learner model, but also according to the most up-to-date relevant content from the Web. Automatic discovery, invocation, and composition of educational Web services can free the learner from many time-consuming activities that often disrupt the learning process itself. Finally, ontology-supported learning process greatly increases automation of a number of learners', teachers', and authors' activities related to Web-based learning environments.

True, a number of issues covered in the paper look as a wish list at the moment. For example, pedagogical agents are still not a common facility, neither are educational ontologies and services, hence educational servers are at best an experiment. Fortunately, this is highly likely to change in the foreseeable future. The reason is the fact that the enabling Web technologies are evolving rapidly. Moreover, it took just a couple of years to get from XML and XML Schema to much more abstract representational languages like OWL. With the advance of the upcoming, XML-based educational modeling languages (http://eml.ou.nl/forums/showthread.php?s=&threadid=60, http://www.e-learningcentre.co.uk/eclipse/vendors/modelling.htm), authors will be able to structure and organize educational material on the Web more easily, according to whatever formal or informal pedagogical model.

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