OntoMobiLe: A Generic Ontology-centric Service-Oriented Architecture for Mobile Learning

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ABSTRACT
Creation of pedagogical learning models to handle the specificity of mobile learning and the inherent constraints of mobile devices is a fundamental challenge in mobile learning. In this paper, we propose a generic semantics-based service-oriented architecture (SOA) and show how ontologies, when used together with Web services, can provide mobile users with a fresh learning experience. The proposed SOA is flexible and loosely coupled. It facilitates pluggable context-aware learner services that are multi-modal, as well as content services that support seamless integration of legacy content from possibly multiple vendors for customizable delivery. As illustration, we consider a mobile learning scenario in a zoo, and demonstrate how a mobile device user can interact with the proposed system for m-learning.

Keywords
Mobile Learning, Semantic Technologies, Ontologies, Web Services, SOA, Data Integration

1. INTRODUCTION
Mobile learning (m-learning) deals with “any activity that allows individuals to be more productive when consuming, interacting with or creating information mediated through a compact digital portable device that the individual carries on a regular basis, has reliable connectivity and fits in a pocket or purse” [1]. The recent advances in broadband wireless technologies and the explosion of power and capacity of the new generation mobile devices have much facilitated the m-learning paradigm and its promises of ubiquitous, unobtrusive, personal and situated learning [2]. However, the application of theory to the use of mobile technologies for educational purposes has been quite limited due to the challenges in the process of designing, communicating and presenting learning resources to mobile learners. Mobile learning developers need to consider the operational environment, as well as special requirements of mobile learners [3] [4]. Mobile learning is a time-constrained exercise, and usually done on-the-fly using mobile technologies which restrict significantly the presentation features. Most learning resources already in use in desktop/laptop-based learning cannot be simply ported onto mobile devices. Hence, considerable effort is needed to develop new learning models dedicated to mobile environments.

A fundamental challenge facing the m-learning research community is the creation of pedagogical learning models to handle the specificity of mobile learning and the inherent constraints of mobile devices [5]. For illustration, consider the scenario where a mobile phone user wishes to learn about Primates from the Web. Typically he would connect to Google Mobile, say via Wi-Fi, and perform a keyword search to locate relevant Web sites and browse them to know more. However, such navigation of large data resources using iterative, task specific elemental queries is primitive and in fact not mobile device-friendly. In recent work [6] [7], we reported on the combination of semantic-based technologies: text mining, ontology population and knowledge representation; in the construction of a knowledgebase upon which we deployed data mining algorithms and visual query functionality. Integrated together, these technologies can serve as a platform to integrate information embedded in heterogeneous data sources into semantically indexed aggregate of knowledge, facilitating vertical search. We adopt this framework in this paper and illustrate the potential of semantic technologies as powerful learning mediums. To overcome the limitations of lightweight devices, we employ a distributed client-server architecture using Web services that enables sharing of computing capability and database with the server. Thus, this paper proposes a novel service-oriented architecture to
show how semantic technologies, when used together with Web services, can provide mobile users with a fresh learning experience. In addition, the proposed architecture comprises the knowledge aggregation subsystem and the querying subsystem that are loosely coupled, and this enables rapid deployment across domains with suitable domain ontologies. Furthermore, the service-oriented approach enables a pluggable platform for easier integration with legacy systems.

We organize this paper as follows. Works related to this paper are summarized in section 2. In section 3, we detail our approach to mobile learning. This is followed by the presentation of the OntoMobiLe architecture in section 4. In section 5, we explain how we model and populate a zoo animal multimedia ontology for mobile learning. We then present a case study of ontology-based mobile learning, utilizing the service-oriented architecture. Lastly, conclusions are drawn and further research work is suggested.

2. RELATED WORK
Several mobile learning methodologies and systems that adopt Web services - with and without semantics - have been proposed in the literature. Alvarez-Cavazos et.al [8] have proposed an architecture for accessing digital libraries on the move using a mobile XML-RPC client written in Java ME so as to address the mobile device limitations. Another architectural approach, called eBag proposed by Brodersen et.al [9] targets the school domain for nomadic learning using Bluetooth proximity. Berri et.al [5] have proposed an architecture that employs ontologies, which are rule-based and are driven by a learner profile, and a search agent that searches distributed learning object repositories. This approach puts more emphasis on the user needs through the use of user profile in an ontology that helps to contextualise learning content. Dimakopoulos et.al [10] propose a similar middleware-based architecture for contextual lifelong learning. Lonsdale et.al [11], along similar lines use context information to provide filtered content appropriate to users’ goals, settings and resources. Holzinger et.al [12] have presented a mobile learning engine that is constructed so as to be used without any online help. More recently, Benlamri et.al [13] have proposed yet another context-aware mobile learning architecture using context, learner and content ontologies.

This review clearly underlines the importance of context-awareness as well as the utility of mobile Web services and ontologies. However, the state of the art is still far from solving issues such as: i) design of multi-modal mobile interfaces that support user preferences; ii) seamless integration of legacy content from possibly multiple vendors for customizable delivery; iii) a flexible, loosely coupled SOA that facilitates pluggable learner and content services. The focus of our work is to address these challenges.

3. OUR APPROACH
The central theme to our approach is based on building a system architecture that provides multi-modal interfaces for the learner and seamless integration of legacy content for the service providers.

Figure 1: Our Approach to Mobile Learning

As a key enabler of this vision, we adopt a mobile Service-Oriented Architecture (SOA) that is based on the standard distributed client-server architecture whereby the content Web services reside on the server, and the client services run on the mobile device (Figure 1). The data layer is assumed to reside on the server side and is accessed via thin clients so as to minimize the amount of memory consumed by the mobile device. The service-oriented approach enables seamless integration because:

- A vendor’s existing learning content residing on disparate sources; e.g., eBook libraries, Video repositories, Podcast servers, etc., can be provided as services to be consumed on the client side.
- The mobile user is not required to get familiar with a new Virtual Learning Environment (VLE), as his/her current user-preferred interfaces; e.g., SMS, MMS, Speech or just Keypad inputs can also be provided as client services that access the server-side services via an Enterprise Service Bus (ESB) [15].

Furthermore, contextual information such as GPS can also be modelled as services to be used for personalized content-aware pedagogic framework. We also provide for a semantic integration of m-learning content that may possibly reside on heterogeneous data sources, using formal ontologies [17].

A formal ontology consists of: i) facts representing explicit knowledge, consisting of concepts, their properties (which can be subdivided into scalar attributes and non-scalar relations), and instances that represent entities described by concepts; ii) axioms and predicates representing implicit knowledge, by rules used to add semantics and to derive knowledge from facts on demand. They represent the main add-ons to conventional information models like entity-relationship models (ERM) and Unified Modelling Language (UML) models.
As ontologies are conceptual models or conceptual building blocks in the domain being modelled, they can become powerful learning mediums. In theory, any media object domain can be modelled using ontologies. We demonstrate below that the composition of these ontologies, in conjunction with the set of ontology-related Web services which we have developed, allows us to achieve our goal of enabling ontology-based mobile learning. Among the important functionalities which will facilitate mobile learning are the population, reasoning and querying of ontologies.

4. ONTOMOBILE: ONTOLOGY-BASED SERVICE-ORIENTED ARCHITECTURE FOR MOBILE LEARNING
Our proposed system, called OntoMobiLe, comprises three major subsystems namely, 1) Pluggable ESB Architecture, 2) Multi-modal Mobile Client Services, and 3) m-Learning Content Services (See Figure 2).

4.1 Pluggable ESB Architecture
Central to our SOA is the Enterprise Service Bus (ESB) pluggable architecture. ESB is a software infrastructure that provides basic services for complex architectures via an event-driven messaging engine. ESB is standards-based and flexible, supports many transport protocols, and provides loose coupling between the component services and the transport mediums.

The ESB provides a flexible and loosely-coupled connection between the mobile device and the learning content. At the user end, ESB provides several mobile event listeners to capture the mobile device’s inputs. It could be the user’s direct inputs or context-aware information such as GPS. The event listener ports are customizable and extensible. On the provider side, the contents from legacy databases are populated into the ontology. Through this architecture, the m-learning user can retrieve media-related data from the ontologies through the messaging standards supported by the ESB. This architecture enables a light mobile device, which supports the Connected, Limited Device Configuration (CLDC), to gain access to the immense descriptive capabilities offered by ontological data. Another advantage is the user does not need to know about modeling or populating ontologies. The roles of the ontology developer and m-learning users are clearly separated and well-defined.

4.2 Multi-modal Mobile Client Services
Multi-modal mobile client services allow the mobile user to stick to the preferred way of communication, be it SMS, MMS, Speech interface or just Keypad. This is made possible by the use of event handlers/listeners. For instance, if the user wants to do an image query, the image can be sent via MMS. This will activate the MMS event listener and the corresponding handler will be invoked. At the backend, each event is represented by an object that gives information about the event and identifies the event source. Regardless of which input mode is used, the same desired response can be triggered from the device.

4.3 m-Learning Content Services
4.3.1 Knowledge Aggregation
The architecture makes use of an upper-ontology that imports sub-ontologies on contextual knowledge, learner’s inputs, and target learning content. The population of the ontology is achieved through the coordination of content acquisition, content analysis and knowledgebase instantiation strategies. The content acquisition engine can aggregate documents from heterogeneous sources such as Web sites (semi-structured), relational databases (structured) and text collections (unstructured). Retrieved collections of documents are converted from their original formats to ascii text, and made ready for content analysis by a customized document converter. Content analysis

Figure 2: OntoMobiLe System Architecture
generates the knowledgebase ‘instances’ through a sequence of operations involving data extraction, entity recognition and relation extraction.

Instantiation comprises of three stages: Concept Instance Generation, Property Instance Generation, and Population of Instances. In the context of OWL-DL, Property Instances are assertions on individuals which are derived from relations found in predicate argument structures in mined sentences.

Concept instances are generated by first extracting the named entities from the documents and then normalizing and grounding them to ontological concepts. Our entity recognizer typically uses a gazetteer that processes retrieved full-text documents, recognizes entities by matching term dictionaries against the tokens of processed documents, and tags the terms found. Relations between the entities are detected using a custom rulebase. In the final population step, we collect all the mined knowledge from the previous steps to instantiate the ontology. The grounded entities are instantiated class instances into the respective ontology classes (as tagged by the gazetteer), and the relations detected are instantiated as Object Property instances.

4.3.2 Knowledge Navigation via Ontology Query and Reasoning

Derivation of contextual insights about data instances from associated meta-data, or from meta-data units themselves, is achieved using logical inference and relies on a series of logic-based tableau algorithms. These algorithms are designed primarily for identifying subsumption (subconcept/super-concept) relationships, checking for inconsistency in knowledge representations (i.e. assertions and terminological axioms are non-contradictory), as well as for determining class-instance relationships and binary instance relations (ABox reasoning) [18].

A set of instance retrieval from a relational database, as well as description-logic-based reasoning Web services are published. These services include a set of standard reasoning methods to retrieve annotation, datatype and object property instances. An automatic query syntax formulator, that creates and modifies a reasoning query language based on user inputs, can be used to formulate more complex and nested reasoning queries. A path finding algorithm for ontologies, Automatic Recursive Queries (ARQ) can be used for finding all the paths that connect a concept or an individual.

5. CASE STUDY: MOBILE LEARNING IN A ZOO

We consider the scenario of a zoo visitor, who on seeing an exhibit, wishes to learn more using his/her personal mobile device. The problems faced by m-learning content providers are: i) integrating heterogeneous, media-related data from disparate sources to form a knowledgebase; ii) extracting just the right amount of relevant data from the knowledgebase when needed, and presenting it conjointly with multimedia. We address these through the use of ontologies.

For ontology modelling, we first created an Animal Kingdom ontology based on Wikipedia (http://www.wikipedia.org) to model the taxonomy of zoo animals. The Wikipedia pages and images (both thumbnail and full) of the animals are modelled as datatype properties. To further enrich the knowledge, we created the following ontologies: i) a news specification ontology to index related published news; ii) a video specification ontology to represent video news reports; iii) a video transcript ontology to index the transcription of all the words being translated. A timestamp is given to associate all the keywords for easy retrieval, so that the actual video can be "forwarded" to the time where each keyword is being mentioned. An URL indicates where the video can be

Figure 3: Ontology Model
found in the public domain; iv) a geographical specification ontology to capture the country and region information so as to classify the videos geographically, based on the contents of the news being reported. An upper-level reference ontology is then created to import all the sub-ontologies mentioned above and facilitate population and reasoning services over the multiple ontology sources. A mind map of the ontology model is shown Figure 3.

For this study, we considered the population of Animal Kingdom and image specification sections of the ontology. Our content acquisition employed a Web crawler to retrieve the image information from Wikipedia. The actual animals and their classification were extracted from the curated database provided by the Mobile Media group in Nanyang Technological University, Singapore. The crawled content and the extracted data were instantiated using Jena (http://jena.sourceforge.net/), the most-widely used OWL programming framework.

We developed a mobile client to show that the ontology-related Web services can be invoked from a mobile device, providing an intuitive interface for ontology-based mobile learning. For practical purposes, we used the Java Platform, Micro Edition together with Java Specification Request (JSR) 172.

Figure 4: Mobile Portal Front-end

To provide multiple interaction modes for the users’ choice, we implemented three navigation interfaces: Standard search, Instant search and Interactive browse (Figure 4). In the Standard search, the m-learning user can enter a keyword or a set of characters, and OntoMobiLe will return a list of lexically matched concepts in the order of relevance. When the user clicks on the desired concept, the ontology view of the concept is displayed that contains subclasses and superclasses (Figure 5(a)). This provides a rapid way of understanding the animal’s immediate taxonomic structure. Now any concept can be explored to visualize the animal instances. For example, selecting ‘Primates’ in Figure 5(a) returns and displays the four primates populated in the ontology (Figure 5(b)). Thus, with OntoMobiLe, a simple keyword search can provide a clear mobile learning experience about the zoo animal. In contrast, a user doing a Google mobile search would have to navigate through many Web pages on the small mobile screen, often iteratively.

Figure 5(a) and 5(b): Results for the Query “Primates”

The Instant search function is designed specifically to occupy the user’s idle time. It allows the user the fun of trying out different queries, and receiving different responses each time. It is based on the proposition that m-learning is usually done in an adventitious manner, when the user is waiting for something. To use this function, the user simply enters a set of characters or a word, and a random screen as shown in Figure 6 will be retrieved based on that input. The user can repeat this process over again with a different query. Finally, the Interactive browse mode allows the user to navigate through a list of animal classes and retrieve media-related data on concepts and instances that he/she would like to know more.

Figure 6: A Display Screen of Instant Search

The zoo animal learning task is selected to demonstrate OntoMobiLe on a simple application. As the architecture shows, the system is much more powerful and capable of tackling complex situations involving context-aware components, multi-modal user interfaces and heterogeneous vendor databases.
6. CONCLUSIONS AND FUTURE WORK
Our work was motivated by the challenges in building a pragmatic system that provides familiar mobile interfaces for the learner, seamless integration of legacy content for the service providers, and natural connections between the two sides of the divide. In this paper, we proposed a generic semantics-based service-oriented architecture and showed how ontologies, when used together with Web services, can provide mobile users with a fresh learning experience. The proposed SOA is flexible and loosely coupled such that it facilitates pluggable context-aware learner services that are multi-modal, and content services that support seamless integration of legacy content from possibly multiple vendors for customizable delivery. As illustration, we considered the mobile learning in a zoo scenario, and demonstrated how a mobile device user can interact with the proposed system for m-learning. Admittedly, more complex scenarios involving arbitrary queries pose challenges in ontology design and user-friendly contextual browsing strategies. In addition, building sophisticated context-aware, personalized, and continually-evolving mobile learning applications on OntoMobiLe SOA requires graphical interfaces to compose customized workflows. We are investigating these issues as part of our current work.

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8. REFERENCES