Cloud-based Semantic Service-Oriented Content Provisioning Architecture for Mobile Learning

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Abstract

Exploiting mobile technologies for educational purposes has promises of realizing ubiquitous, unobtrusive, personal and situated learning. The advent of cloud computing has meant that all the information on web, and proprietary sources of information are available instantly. But mobile learning is non-trivial due to the challenges in the process of designing, communicating and presenting traditional e-learning resources to mobile learners. In this paper, we propose a generic semantics-based service-oriented infrastructure and show how semantic technologies, when used together with a cloud-based SOA, can provide mobile users with a fresh learning experience. The proposed architecture comprises a knowledge aggregation subsystem and a querying subsystem that are loosely coupled, and hence enables rapid deployment across domains with suitable domain ontologies. Furthermore, the service-oriented approach enables a pluggable platform that supports seamless integration of legacy content from possibly multiple vendors for customizable delivery. For illustration, we consider a mobile learning scenario in a zoo, and demonstrate how a mobile user can interact with the proposed system for m-learning.

Keywords: Mobile Learning, Semantic Technologies, Ontologies, Web Services, Data Virtualization, Cloud Computing.

1 Introduction

The proliferation of mobile devices has created a large demand for mobile information content as well as effective mobile information retrieval techniques [17], such as effective mobile social networking [18], data mining of novel information on mobile devices [13], and technologies that can enable mobile learning. Mobile learning (m-learning) involves "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" [19]. 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 [1]. The advent of cloud computing [9] has meant that all the information on web, and proprietary sources of information are available instantly. With the vast amount of information content available, the cloud paradigm together with mobile computing enables services that are scalable on demand, implemented on virtualized resources over the Internet. 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

Journal of Internet Services and Information Security, volume: 1, number: 1, pp. 59-69

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learning resources to mobile learners. 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]. Mobile learning developers need to consider the operational environment, as well as special requirements of mobile learners [20, 15]. 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.

For illustration, consider the scenario where a mobile user visits a Primates zone in a zoo, and wishes to learn more about Primates. Typically the user would connect to Google Mobile, say via 3G, and perform a keyword search for ‘primates’. The user would browse through the results, explore them, and often refine the keywords to get more targeted results for further browsing (See Figure 1).

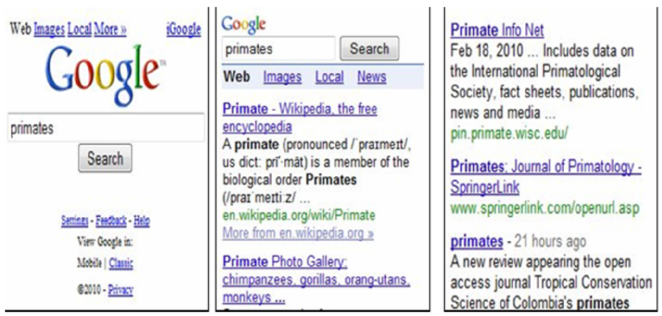


Figure 1: Google Mobile Search

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 [3, 16], 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. To handle scalability over large-sized learning content sources, and also to provide accessibility over wide variety of mobile devices, we adopt a Software-as-a-Service model deployed on a cloud infrastructure. Thus, this paper proposes a novel service-oriented architecture to show how semantic technologies, when used together with Web services on cloud, 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 cloud-based 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 KnowleMobiLe 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 cloud-based 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. [2] 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. [6] 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. [8] propose a similar middleware-based architecture for contextual lifelong learning. Lonsdale et al. [14], 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. [4] have proposed yet another context-aware mobile learning architecture using context, learner and content ontologies. Though the above review clearly underlines the importance of context-awareness as well as the utility of mobile Web services and ontologies, 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

Central to our approach is a system architecture that provides multi-modal interfaces for the learner and seamless integration of legacy content for the service providers.

As a key enabler of this vision, we adopt a mobile cloud-based 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 2). 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 cloud-based service-oriented approach enables seamless integration because: 1) 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, 2) 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) [7]. Furthermore, contextual information such as GPS can also be modelled as cloud 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 [11]. 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 Modeling 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

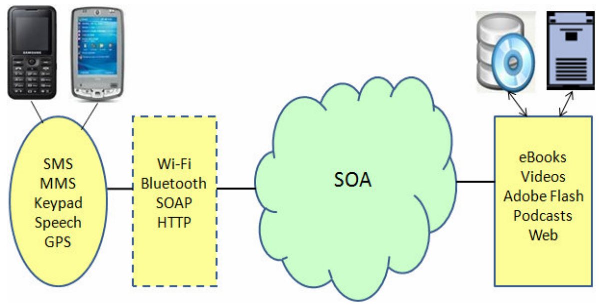


Figure 2: Our Approach to Mobile Learning

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 KnowleMobile: Ontology-Based Service-Oriented Architecture for Mobile Learning

Our proposed system, called KnowleMobiLe, comprises three major subsystems namely, 1) Pluggable ESB Architecture, 2) Multi-modal Mobile Client Services, and 3) m-Learning Content Services, as shown in Figure 3.

4.1 Pluggable ESB Architecture

Central to our cloud-based 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

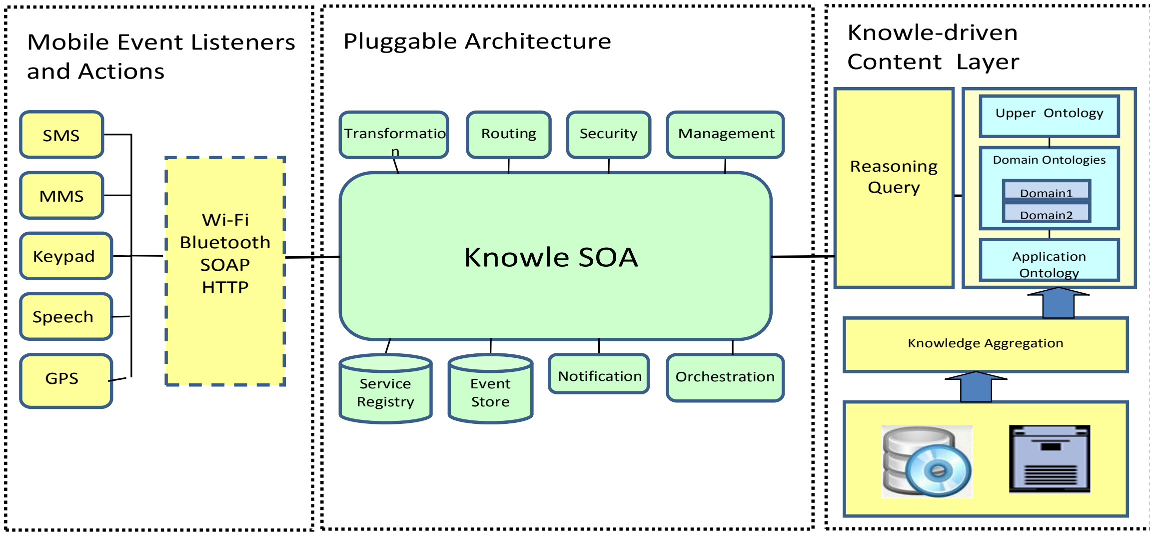


Figure 3: KnowleMobiLe Architecture

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

Knowledge Aggregation: The architecture makes use of a core ontology layer that comprises 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 generates the knowledgebase 'instances' through a sequence of operations involving data extraction, entity recognition and relation extraction [3, 16].

Knowledgebase Instantiation: The 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 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.

Knowledge 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 tableaux 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) [10].

Service Endpoints: A set of instance retrieval services 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.

Cloud Infrastructure: To handle large-scale content provisioning, we propose to harness the power and flexibility of cloud. The content layer can be provided via Data-as-a-Service infrastructure. Choosing a standard cloud hosting environments such as Amazon Web Services, Windows Azure or Hadoop platform, the ontological content can be hosted in a virtualized fashion. Apart from cloud benefits such as load balancing and self-scaling, the content virtualization enables the component ontologies can be hosted at the provider side, and the integration can happen on the fly if desired.

5 Case Study: Mobile Learning in a Zoo

We consider the scenario of Singapore Zoological Gardens where a visitor wishes to learn about an exhibit using a personal mobile device. The KnowleMobiLe solution primarily involves three steps: i) construction of an ontology-centric knowledgebase that integrates the background data with proper semantics, ii) exposing the content services via KnowleMobiLe SOA, and iii) development of an m-learning client that consumes the services.

5.1 Knowlebase Construction

Ontology modelling: The core OWL-DL ontology comprises sub-ontologies respectively modelling Animal Kingdom Taxonomy, Biological Classification, Geographical Location, Geo-Coordinate, and Zoo Areas. The Biological Classification and Animal Kingdom sub-ontology were created from Wikipedia (http://www.wikipedia.org). Geographical Location and Geo-Coordinate sub-ontologies were imported from standard ontologies. Geographical Location consists of Continent, Country, City and related concepts. Geo-cordinates comprise Longitude and Latitude concepts to model the GPS location information. The Zoo Area sub-ontology was custom created from Singapore Zoological Gardens website[1]. The upper ontology establishes the connections between the sub-ontologies via Object properties. The attributes of the concepts, e.g. the image URL of an animal, are modelled as datatype properties. The ontology had 96 classes, 15 object properties and 6 datatype properties. A Protege visualization of the ontology is shown Figure 4.

Ontology Population: We constructed a relational database of the available information viz. i) a table of 56 animals, their zoo areas and brief descriptions as found on the Singapore zoo website, ii) a table of their latitude and longitude geo-cordinates from Google Maps, iii) a table of Wiki page URL's, image URL's (both thumbnail and full), from model the taxonomy of zoo animals. Rules mapping the data to the right ontology entities were hand-coded and passed to the population pipeline to create the Knowledgebase.

Evaluation: The ontology was evaluated by comparing the triples extracted from the database, and the inferred triples generated by our OWL reasoner, RacerPro. We considered three kinds of triples viz. i) triples involving the subclass of property, ii) triples involving any object property, iii) triples involving the instance of property. The results are presented in Table1.

[1] `http://www.zoo.com.sg`

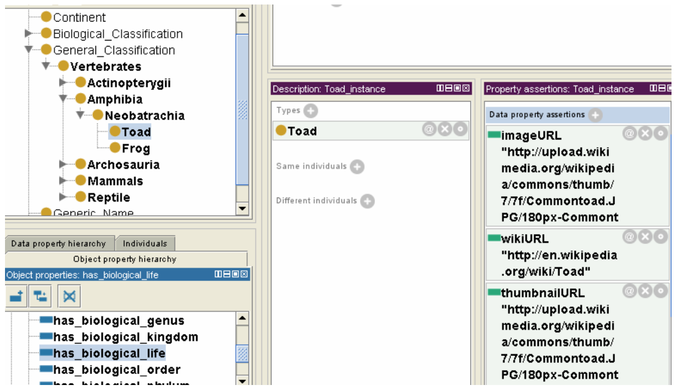


Figure 4: Protege Visualization of the Ontology

Table 1: Evaluation Results

Relation	Triples from DB	Inferred Triples
subClassOf	96	290
ObjectProperty (any)	15	327
instanceOf	66	299

The number of subclassOf triples increased over three fold, implying that the ontology can reveal more implicit knowledge via class inheritance. In contrast, the several fold increase in object property triples is not conclusive because it could be due to the sub-property inheritance or just by being defined on the top level classes. Since our ontology had only one sub-property hierarchy that had 8 properties, we conclude that the increase more due to the object property definitions themselves. However, the instanceOf relation results are more indicative. The 4.5 fold increase in inferred triples shows that A-Box reasoning can result in more comprehensive coverage than database querying.

5.2 m-Learning Client

We developed a mobile client using the Java Platform, Micro Edition together with Java Specification Request (JSR) 172, and the location API JSR 179.

To provide multiple interaction modes for the users' choice, we implemented four navigation interfaces: Keyword search, Location search, Combined search and Interactive browse.

In the Standard search (Figure 5, the m-learning user can enter a keyword or a set of characters, and KnowleMobiLe 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. 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 'Leopard' in Figure 6(a) returns and displays the leopard populated in the ontology (Figure 6(b)). Thus, with KnowleMobiLe, 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.

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

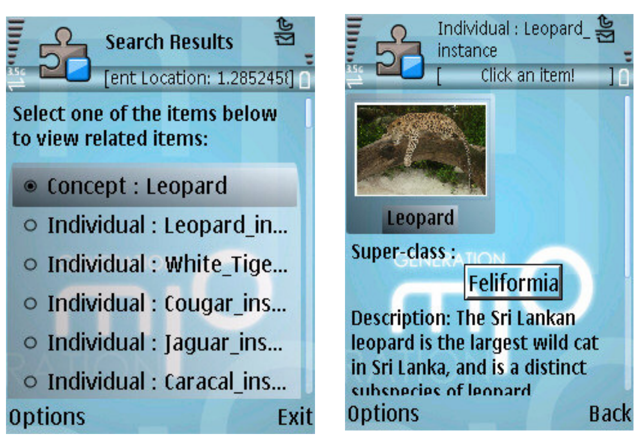
Figure 5: KnowleMobiLe Mobile Client Frontend

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. An example of location search is shown in Figure 7

The zoo animal learning task is selected to demonstrate KnowleMobiLe 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 Conclusion and Further Work

Cloud computing has advanced as a model for delivering Internet-based information and technology services in real time. 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



(a) Select (b) Display

Figure 6: KnowleMobiLe Standard Search

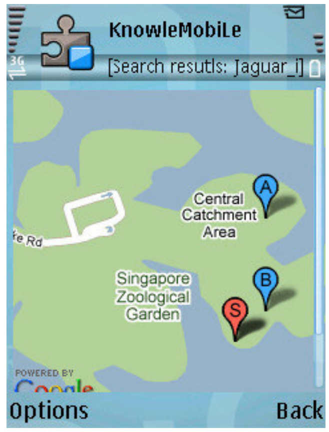


Figure 7: KnowleMobiLe Location Search

with cloud-based Web services, can provide mobile users with a fresh learning experience. The proposed cloud-based 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. However, 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 KnowleMobiLe architecture requires graphical interfaces to compose customized workflows. We are investigating these issues as part of our current work.

6.1 Acknowledgments

Special thanks to NTU Mobile Media group for providing us with GPS phones during the case study.

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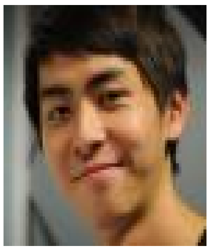

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