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Ontology-based generated learning objects for mobile language learning

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Abstract. Adaptivity is an essential quality for any mobile learning process. When learning on the move, in short time intervals, the learning process is often limited, and content needs to be adapted in order to keep the interactions with the user simple, effective, and motivating. This paper presents a model for mobile adaptive language learning, with the main goal of improving the mobile language learning process using adaptive techniques. The presented model is designed in such a way to utilize unique opportunities for delivery of learning content in authentic learning situations. In order to allow adaptivity based on several parameters, an ontological framework is presented along with a format of lightweight learning objects for content delivery. A cloud and web-service based system for adaptation is envisioned on top of the ontological framework and presented, with some implementation suggestions and possibilities discussed.

Keywords: adaptive learning, mobile learning, ontologies, learning objects, cloud computing

1. Introduction

E-learning systems support complex learning processes, services, elements and users' roles. Learners are often diverse even if some learning contexts imply the existence of some similarities in their interests and demographic parameters. Various types of e-learning resources are also abundant, each possessing a different structure, and educational and presentational requirements. Accordingly, e-learning systems need to be able to mix and match learning resources in order to accommodate different types of learners.

Mobile learning systems are faced with the same problems, as well as those stemming from the characteristics of the mobile environment. Learning activities and resources must adapt to both the users' and devices' characteristics. Mobile learning is performed on the move, with time constraints and limited cognitive ability of learners, and all aspects of the learning process must adapt in order to keep the interactions with the user simple, effective, and motivating. Language learning also introduces a number of specifics stemming from the high granularity of the learning content, and concepts like learning objects and ontologies can help in describing the learning domain in a way conductive to adaptation algorithms.

The main goal of this paper is to improve the mobile language learning process by designing a model for adaptive learning. The second part of the paper outlines the theoretical background concerning the approaches to adaptivity and mobile language learning. The model for platform-independent adaptive learning, including an ontological framework, adaptation components, and a cloud-based infrastructure is given in third chapter. The final chapter discusses the presented model and possible future improvements.

2. Theoretical Background

Mobile technologies are a viable solution for learning performed on the move and with heavy time constraints, allowing the learners to control the preferred pace and the location of learning [1]. Such a push towards student-centred learning produces a new problem - increasing the learners' freedom increases the importance of their self-motivation and interest for the area of study. This puts additional importance on understanding the users' needs and interests, and mobile applications should use any means possible to additionally motivate the learners.

Learning resources are easy to access using web-enabled devices, but these resources are usually not very well suited for use in the mobile environment. The designers must adjust the learning environment and the presentation of educational content in order to find an optimum model of interaction with the users. Innovative methods of presenting information, imaginative interaction patterns and edutainment concept make the learning material more accessible to less motivated learners [2]. The success of such methods inherently depends on two factors - the learner and the device used for learning, and learning activities, lesson structure, extent, and presentation need to adapt to each specific user and device. Additionally, the mobile learning applications can utilize the learning context as a basis for further improvements of the learning process.

The domain of language learning also introduces a number of specifics that need to be considered. Learning vocabulary is an important goal of language learning which requires a high level of repetition from the learners. Language learning can benefit from multimodal learning, while the concept of learning paths is of less importance. Learning path, as a learner's route through course materials, is considered to be optimal only if it maximizes a combination of the learner's understanding and the efficiency of learning [3]. Highly granulated nature of the core educational content in language learning (words) makes it difficult to structure a learning path into meaningful units. Still, adequate adaptivity of the learning process and appropriate guidance can lead to better understanding of the studied objects and relationships among them [4].

Learning systems can be adaptable, allowing the learners to personally change various system parameters and behaviour, and adaptive, possessing some form of logic for automatic adaptation according to learners' behaviour. An e-learning system is considered to be adaptive if it can: 1) monitor users' activities; 2) interpret these activities using domain-specific models; 3) infer user requirements and preferences out of the interpreted activities; 4) represent them appropriately in associated model; 5) act upon available knowledge about the users and the subject matter in order to dynamically facilitate the learning process [5].

Adaptive e-learning systems come with a number of constraints [6]. Adaptive e-learning systems are complex and expensive to develop and integrate into the educational process. Learning content is often impossible to recreate and use anew, and different learning systems are not interoperable. Course administration, content authoring and other operations are more difficult to carry out in adaptive systems, and teachers/administrators are expected to have some preknowledge about the system. Time is an important factor, and adaptive systems need to know about the students' needs as soon as possible in order to maximize the time a student spend in a personalized environment.

In order to allow matching of appropriate educational content with user/environment characteristics for the purpose of adaptation, the content needs to be annotated at some, preferably smaller level. Learning objects are a concept of e-learning that can serve to this purpose. Learning objects (LOs) denote small, compact educational units focused on achieving a specific educational goal, and most authors put the emphasis on their characteristics – smaller scope, reusability, relative independence, and the possibility of aggregation [7]. These characteristics of learning objects, beneficial for the process of adaptation, are mostly enabled by their heavy reliance on metadata. Metadata can describe both the educational characteristics of learning objects, usable for finding the right content for a specific learner, and the technical characteristics, usable for device adaptation. Different metadata models and standards for learning objects have been developed, IEEE LOM [8] being among the most prominent. IEEE LOM standard is expandable and can be used to establish advanced semantic relations between educational resources.

Learning objects are usable in a mobile environment, especially when adjusted to a certain extent, especially in the domain of their presentation. A set of recommendations about the design of mobile learning objects is given in [9], mainly concerning different ways of displaying and repeating the content on a limited surface while avoiding the complexity of the user interface. An example of use of learning objects in a mobile environment for language learning can be found in [10].

The educational content model and metamodel need to be rich and flexible enough to support some higher level adaptation logic that could adjust its volume and complexity according to user and device capabilities. Ontologies, defined as formal, explicit specifications of a shared conceptualization [11] can be used for this purpose. Ontologies represent a linguistic infrastructure that can describe conceptual relations between course materials, and a number of applications exist in the educational domain. Ontologies can assist the automated construction and adaptation of a personalized learning path according to the difficulty level of course materials, learner prior knowledge and abilities, in order to avoid learner cognitive overload or disorientation [12]. By describing learning object attributes in an ontology, an appropriate amount of knowledge can be served to learners for consummation on the fly, using their mobile devices. An ontology can then serve as a backbone for the learning domain and support technology at the semantic level by facilitating context acquisition [13]. Multiple ontologies (e.g. user model ontology, domain ontology, learning design ontology, device ontology) can be combined to produce an ontological framework capable of representing context-specific metadata. An example of such framework is given by [14], where it is utilized to accumulate data about the context of LO usage, by attaching the learners' models to each LO they used. This accumulated data can then be used for advanced learning services, such as personalization or adaptation of content in accordance with the students' objectives, preferences, learning styles, and knowledge levels.

3. Related Work

Learning objects can be considered as pieces of a puzzle, where ontologies define each piece's connection points to other objects. When combining learning objects, the quality of the result will depend on the size and flexibility of individual units – the smaller they are, the easier it will be to mix them as needed. Although it would require a substantial effort, ideally the learning objects should be the smallest possible, while still retaining a number of semantic links to other objects. Language learning is somewhat specific in this regard, as the smallest learning units are individual words given by a vocabulary. Several machine readable, ontology-like vocabularies, "wordnets," exist, defining concepts, words and their relations in different languages. The original wordnet was developed by Princeton for English language and is described by its authors as a lexical database and titled WordNet [15]. Other authors often refer to it as an ontology and it has been linked to formal ontologies like SUMO upper ontology [16]. Similar projects in different languages have been modelled using the results of WordNet project, one of them being the EuroWordNet that encompasses eight languages. This wordnet is especially interesting for language learning since words in different languages are interconnected with interlingual links stored in a Interlingual Index (ILI) [17].

A model for ontology based language learning utilizing available wordnets as a starting point for construction of a language learning domain ontology is given in our previous work [18]. However, an implementation of such a system would likely be very complex, and a more general approach can be taken by parsing existing educational materials. The words can be roughly grouped by areas of interest (e.g. sports, cars, economics, politics), by word types (verbs, nouns, adjectives) or by difficulty as defined by existing lists and official learning materials. An example of a system performing adaptation using such parameters to match resources according to learners' interests, knowledge and learning style is given in [19].

Adaptation is usually performed based on a user model. In mobile learning, different devices posses a variety of technical characteristics, and the device model also need to be considered. By using a device based reasoning approach, combined with a standard user model, a technically and educationally appropriate selection of learning objects can be served to learners [20]. In order to facilitate device-based reasoning, device features need to be known for every device using the learning system. Projects like WURFL, OpenDDR, and Apache DeviceMap attempt to maintain databases of all device features for purposes of capability detection [21].

Mobile learning is often performed on the move, and mobile devices offer unique opportunities for delivering learning content in authentic learning situations. Modern devices and platforms have built-in GPS, cameras, sensors, accelerometers, and compasses that are valuable sources of context information [22]. Context information can be used in advanced adaptation scenarios, where content is organized according to some learner context parameter like location [23].

Mobile devices offer unique opportunities to deliver learning content in authentic learning situations. Apart from being able to play various kinds of rich multimedia content, they offer new ways of tailoring information to the learner's situation or context. This paper presents the results of a study of mobile media delivery for language learning, comparing two context filters and four selection methods for language content.

4. Model for Mobile Adaptive Language Learning

In order to design adaptive language learning system that would fully support mobile learning on different devices, all components must be selected appropriately. In this section we outline a model for adaptive mobile learning based on the following components:

- Learning objects for delivery of educational content to learners and institutions;
- An ontological framework, roughly composed out of an educational ontology and a user/device ontology;
- Web services as a platform-neutral, developer-friendly interface for accessing system functions;
- Internal services for managing the adaptation process and for processing and correlating user data;
- Cloud computing infrastructure for scalability support.

We base our suggestions on previous experiences in related areas, and especially on our previous work on designing a non-adaptive, ontology-based multimodal language learning system [18], [24]. Unlike some other comparable models available in literature [13], [14], the main determinants of the presented model are an orientation towards language learning and the use of mobile devices as the main type of client used in learning. Language learning implies the use of certain activities like vocabulary learning, writing exercises, learning grammar, as well as corresponding forms of educational materials - words, characters, grammar rules, etc. The orientation towards the mobile environment imposes the requirements of smaller size and complexity on the educational units. This feature allows them to be delivered efficiently through the supported communication channels.

Another core concept of the presented model is the separation of concerns, implemented by using learning objects. The learning objects are used only for the delivery of content and instructions, while the actual client applications decide how to present content (according to the received instructions). This is in contrast to the popular, standardized Sharable Content Object Reference Model (SCORM) learning objects that mostly contain browser-openable/HTML files, with content being mixed with markup and style data. The separation of concerns generally comes with a trade-off – components tasked with content presentation need to be developed specifically for each platform, but can utilize the device's capabilities much better than generic HTML files. On the other hand, the content is free from variation, can be stored in centralized repositories, and accessed by any number and type of clients.

Separation of concerns on the account of data storage and presentation also implies a more complex, two-part adaptation process. The core adaptation logic is stored on a centralized location and executed by a learning manager. This manager receives and processes requests for content from various clients. The learning manager can assemble appropriate learning objects and generic instructions for their adaptation depending on the input periodically received from each client. The clients receive the adapted learning objects and interpret the instructions as well as they can, while gathering further information about the user for the next cycle of communication with the learning manager. In order to allow such a scenario, all communication must be done through standard interfaces and based on a common ontology serving as a common language between the manager and the clients.

The following sections outline the learning objects used for delivery of adapted learning content, the ontology framework at the core of the system, the infrastructure and individual components of the system, and the core processes.

4.1. Learning Objects

Learning objects are used for delivery of adapted learning materials. In order to allow for an iterative development process and to provide the client applications with a certain degree of freedom in using the system, the learning objects were designed to work autonomously. This allows the development of a static repository filled with pre-designed learning objects before developing a full-fledged adaptation and generation service. From the perspective of the client applications, the system is a black box, and the origin of the learning objects (manual or generated) is not of importance. The objects were designed according to the language learning domain and the limitations of the mobile environment with the goal of achieving greater degree of reusability.

When designing a format of learning objects, two points need to be considered - the content structure model and the metadata model. Structure needs to be adapted according to the specific domain of use, but still allow simple access and various forms of presentation in different contexts. On the other hand, in order for metadata to be useful, it must be interoperable with existing systems, by applying or extending existing metadata standards.

The designed object structure is shown in figure 1. Every learning object contains a number of basic content elements which, depending on their type, can contain or reference other elements. Basic elements include words, characters (letters), grammar rules, supplementary interesting facts, multimedia objects, tests, as well as an additional component with instructions for presenting the content. Every basic element can be considered as a separate learning object at a lower level of aggregation and independent access can be allowed if certain client applications wish to combine elements themselves, ignoring the centralized adaptation system. Elements, their relations and attributes are generated based on the various parameters defined in the ontology framework. Client applications can ignore the presentation instructions if they are not capable of adjusting their presentation or if they do not understand the adaptation vocabulary defined by the ontology framework.

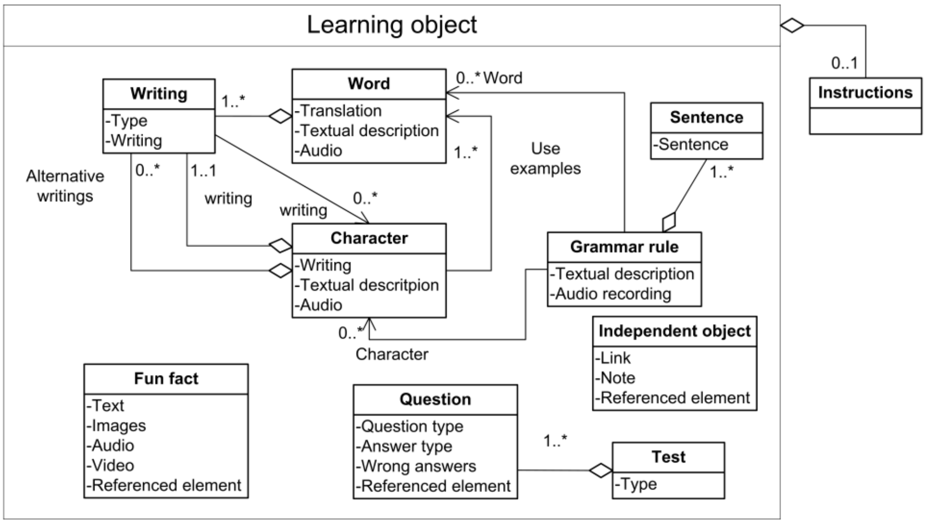

Fig. 1. Model of learning object structure

The basic elements have the following attributes and relations:

- **Word** – represents a single word. It contains a translation of the word and alternate writings in the original language, if that language uses different writing systems. For instance, Japanese words can be written down using the Latin script (called romaji) or one of the Japanese writing systems (hiragana, katakana, kanji). Additionally, every writing reference uses individual characters. Optional content includes a textual description that can clarify the context in which the word can be used, as well as the audio recording of its pronunciation.
- **Character** – represents a single character (letter) and can have relations to alternative writings using different writing systems. The "stroke order" describes the way the character is written, while the audio recording contains the pronunciation of the character.
- **Grammar rule** – a textual description of a single grammar rule, with an optional audio recording if the rule refers to pronunciation (accent, alternation), and one or more sentences that demonstrate the rule.
- **Supplementary interesting facts** – a short text with optional multimedia elements (images, audio, video recordings) that describes some interesting fact about the country and people whose language is being studied. Every interesting fact should be thematically related to one of the other elements, based on the relations defined in the ontology framework. For instance, the word "blue" can be connected to an interesting fact about Japanese traffic lights that use a blue light instead of a green one.
- **Independent object** – any atomic textual, audio, or video recording. It can refer to any existing element, or be independent. It can also contain an additional short summary of key points described in this element, which can then be used to generate questions in test activities.

- **Test** – contains test parameters (test difficulty, method of generating questions) and questions. Every question references one of the basic elements (word, character, grammar rule, key point).
- **Presentation instructions** – optional instructions that use terms defined by the ontology framework. They describe steps that need to be undertaken by the client application in order to adapt the presentation. If no instructions are present (i.e. the learning objects are static, used autonomously), the application can present the object content at will. For instance, the user can be allowed to freely browse, search and access any content unit.

Reusability is one of the core features of learning objects. In order to improve reusability, and allow easier integration into different contexts, learning objects should be smaller and less complex. Similar conclusions are given by [25], along with a model of learning object content hierarchy. This hierarchy consists of five distinct levels. Lower levels contain simpler and, accordingly, content that is easier to reuse, while higher levels build on top by adding more content and context. Typical learning objects are positioned somewhere in the middle of the hierarchy, where they aggregate smaller "information objects" and serve as discrete parts of larger units or lessons.

Learning objects presented in this paper correspond to such a hierarchy. Raw elements (writings, images, audio recordings, etc.) are combined to explain a single concept - a word, character, grammar rule. This combination represents a basic element and corresponds to an "information objects" in Hodgins' hierarchy [25]. By linking several of such elements and adding additional content for expressing the context of the learning situation, a standard learning object is produced. Higher levels can be achieved by aggregating the learning objects, but such actions produce objects too large and complex for the mobile environment.

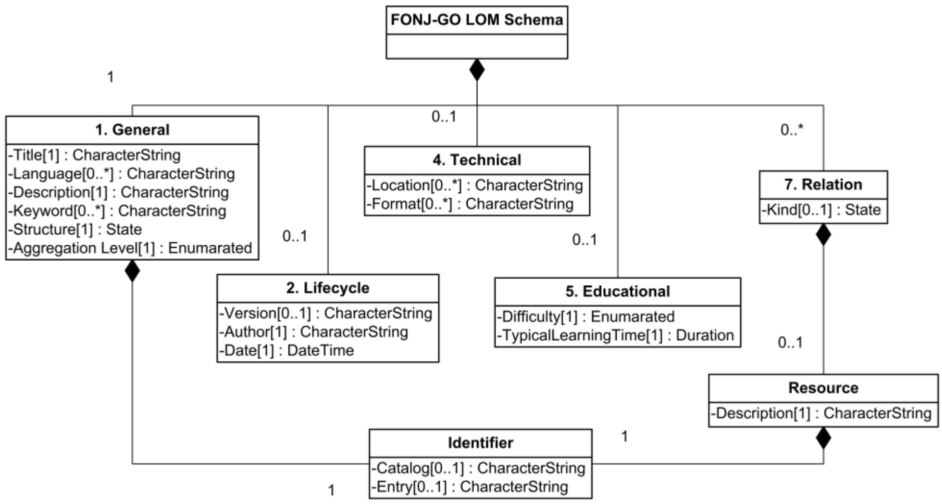

Fig. 2. Learning object metadata model based on the IEEE LOM

Learning objects differ by their purpose, usage, difficulty, target audience, and other parameters. These parameters can be described by using metadata. Metadata is a significant component of any learning object format, and allows storing, indexing, and searching learning objects in repositories based on various criteria; aggregating to produce larger, more complex objects; and reuse in different contexts and applications. A metadata model was developed as an application profile of the existing IEEE LOM [8] and is shown in figure 2.

The original model was simplified, and the following elements were removed: 3.Meta-Metadata, 6.Rights, 8.Annotation and 9.Classification. The remaining elements were kept, but in a reduced manner. In accordance to the language learning context, it was presumed that the learning objects intended for learning in a specific language will be of no use to learners that speak other languages, so the possibility of using multilanguage metadata was removed. Remaining elements keep the same meaning given to them by IEEE LOM.

4.2. Ontology Framework

The core component of the presented model is the ontology framework, composed out of following, interconnected and interdependent ontologies: educational content ontology, educational activity/learning design ontology, user knowledge ontology, user interest ontology, user behaviour ontology, device capabilities ontology, and context ontology. This framework can be extended, and when developing a new ontology, existing developments should first be explored and reused, if possible [26].

The language learning ontology must contain concepts like words, grammar rules, typical sentences and other atomic content units. These concepts directly translate into concepts defined in the learning object structure model shown in figure 1 and play a significant role during the process of generating adapted learning objects. Words can be described using wordnets, with the original, English wordnet, defining several relations, including synonymy, antonymy, hyponymy, meronymy, troponomy, and entailment [15]. These relations connect both the concepts (e.g. jet plane is a type of plane, toe is a part of foot), and the words (e.g. interrogate, interrogator, interrogation), providing rich semantics that can be utilized for generation of tailored learning resources. However, the level of detail and complexity of interconnections in a wordnet are likely larger than necessary for language learning, and wordnets do not describe other relevant concepts (grammar, sentences). Extensive modifications might be required for integration of wordnets with other ontologies, so we suggest developing a simplified ontology by extracting only some of the information from a wordnet or a simple vocabulary – word type, word difficulty (relatable to user knowledge), and a rough domain of use (relatable to user interest). Some guidelines for developing a content ontology can be found in [27].

The language learning ontologies is presented in the figure 3. Grey elements in the ontology originate from WordNet, while the white elements are related to language concepts, such as letters, sentences, grammatical rules, etc. Element Translation is used for connecting with ontologies of other languages. The concept of a Character was included due to the fact that some languages use multiple writing systems (e.g. Japanese).

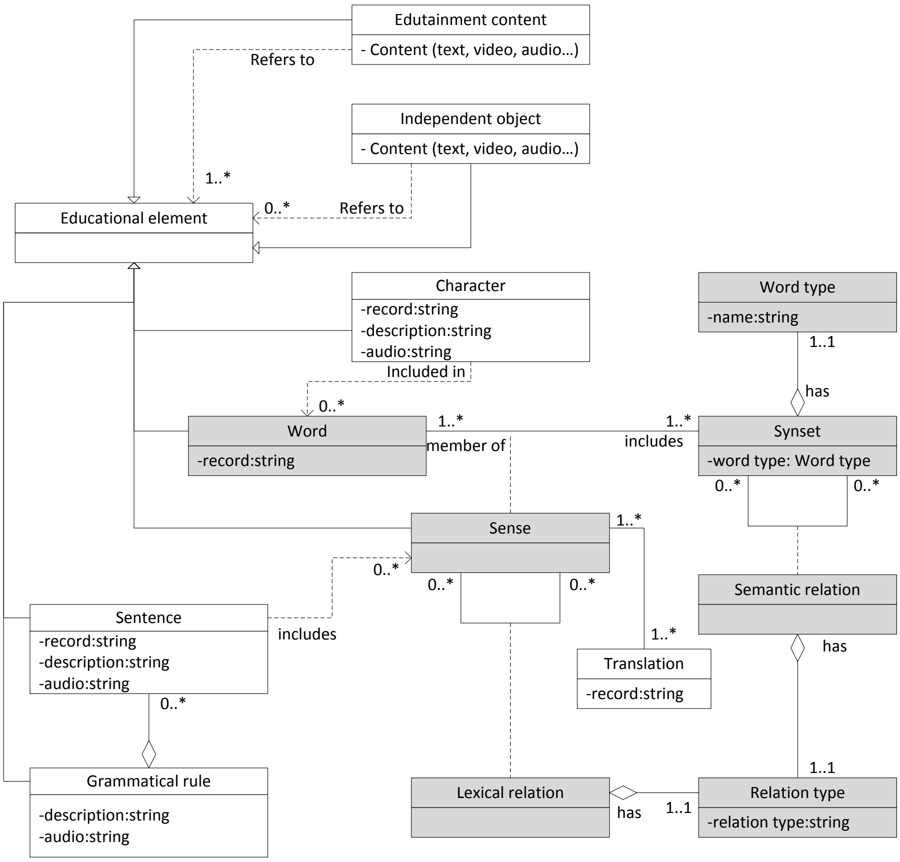

Fig. 3. The language learning ontology

The educational activity/learning design ontology should describe different types of activities the learner can take any method of structuring activities in order to produce a learning session. This ontology should also be connected to the language learning ontology and specify which types and units of content can take part in which activities. The user knowledge ontology should describe concepts needed for construction of the user knowledge model, and for inferring additional information about the user based on his results. The user interest ontology should roughly describe possible areas of interest of the user, and define relations to domains of use from the language learning ontology.

The user behaviour ontology describes possible learners' behaviours. Learners' behaviour implicitly provides information about their knowledge and their interest. For instance, a learner that spends more time learning words in a single, specific domain of use, likely has some interest in that domain. Likewise, if a learner takes more time to answer questions from a specific domain during a quiz, it can be inferred that his knowledge in that area is lacking, even if his actual results do not deviate as much. This ontology needs to be connected to most of the other ontologies. Behaviour will be related to doing specific tasks with specific units of content; it will imply interest and knowledge; and, finally, depending on the device capabilities, some behaviour won't be possible to perform using some clients. Learner behaviour, therefore, needs to be expressed using a generic language that can cover a large number of use scenarios.

User behaviour in e-learning is usually monitored through analysis of log files. Client applications should send information on user behaviour regularly, so that a learner model can be updated. An ontology used for this purpose is shown in the figure 4. The main concept is Behaviour. Behaviour can be directly connected to an Educational element, which can be used in an Educational activity, or Behaviour can be general, and describe the way of using the mobile language learning system. Element Usage is used for storing data on actions of a student, and interaction with the content.

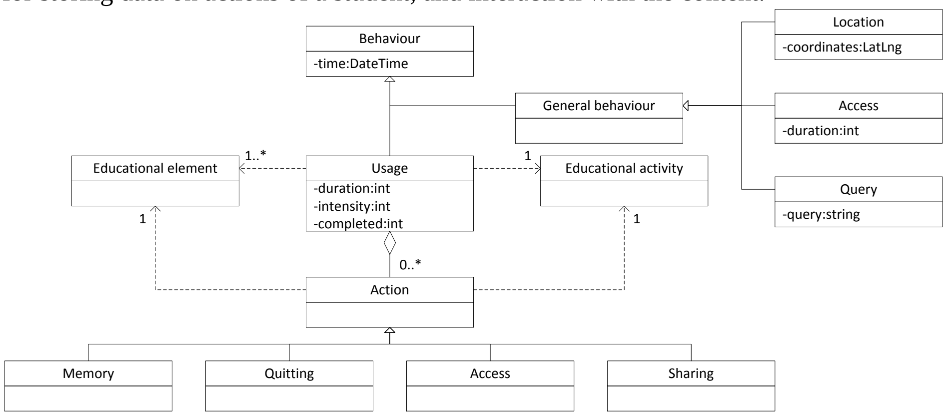

Fig. 4. The user behaviour ontology

The device capabilities ontology can rely on OpenDDR or a similar device capabilities database. However, like in the case of using wordnets for language content, such databases are likely more complicated than necessary for the needs of the language learning domain, and we suggest parsing the capability database and extracting only the minimum necessary information. Domain-specific capabilities should also be defined and associated with the requirements of specific learning activities.

Finally, context ontology should describe methods of gathering context information (e.g. GPS), related to the device capabilities, and enumerate possible detected contexts for each source of context information (e.g. learner is at the zoo or at the beach). On the other hand, the contexts should be connected to specific activities and domains of use so that the right activity/content can be presented at the right time.

4.3. System Components and Infrastructure

The use of ontologies provides many possibilities, with some added complexity. The designed adaptive system should be completely transparent for the users and they should be shielded from any added complexity. For a web-centric learning system this can be achieved by providing access to core concepts through Web services [28] operating with standard interchange formats like XML and JSON.

The global overview of the adaptive mobile language learning model is given in figure 5. The presented model relies on a cloud computing infrastructure, encompassing web services, web servers, programming languages, databases and other specific tools required by individual components of the model. The core components of the model are the language learning knowledge base, adaptation parameters knowledge base, management service and interface, learning manager, profile processor, and one or more client applications.

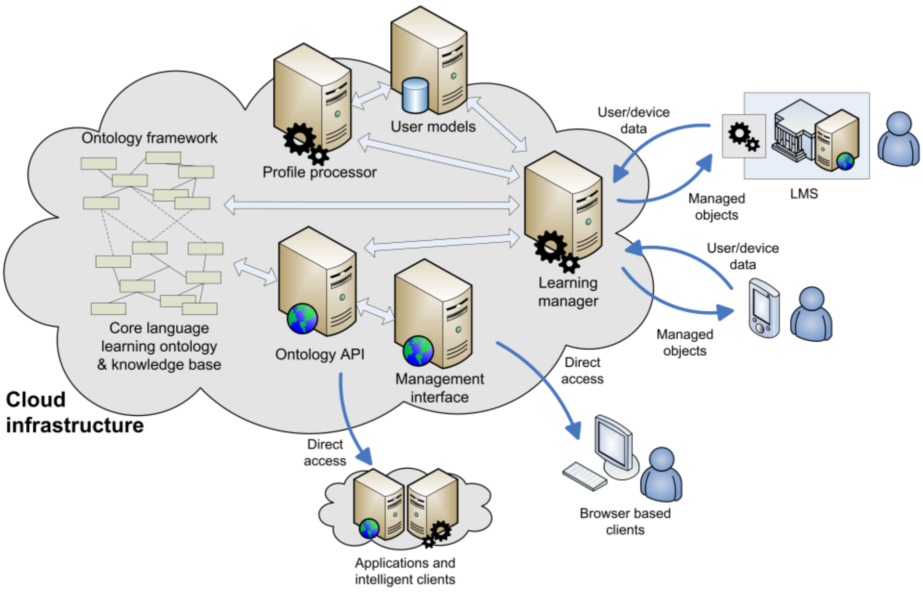

Fig. 5. Model for mobile adaptive language learning

The knowledge base is at the core of the presented model, and other components operate upon it. The knowledge base can be viewed as a database containing all educational materials and their semantic interconnections, structured according to the ontology framework. It also contains the ontology-defined vocabulary of concepts and attributes that can be assigned to any entity taking part in the learning process (educational materials, learners, devices, environment) and then used by the adaptation mechanism.

Access to knowledge base should be implemented in the form of a web service, in order to allow direct access to all database elements to various users. This type of access should be used for ontology/content management, and can be also used for other purposes by internal and external users. Basic internal users (clients) of the knowledge base are the learning manager and the management interface. External clients can encompass existing learning and educational systems and institutions that would participate in a knowledge exchange. Also, external clients are applications that do not require adaptivity, or applications that implement their own adaptation mechanisms. The management interface should provide all web service functionalities to internal users (administrators, teachers) through a simple user interface in order to allow system administration and management of learning materials.

The user model storage stores all reported information about the users of the system – their knowledge, interests and past behaviour. The profile processor accesses user model storage, reads and correlates user profiles in order to establish groups of learners similar by some criteria. This information can be used to infer conclusions about a learner based on the group he was assigned to.

The learning manager is the main component of the system, tasked with receiving client requests and reports, and generating and delivering personalized learning objects. The learning manager contains the adaptation logic, and uses the ontological framework in its decision-making. The learning manager also runs the profile processor after receiving a request from a client and updating the user model.

The clients of the system can run on different devices, and can even be different themselves, e.g. some clients can offer a full learning environment, while others can concentrate on a single aspect of language learning like vocabulary. As long as the clients use the standardized ontology to report the device's and their own capabilities, the centralized adaptation algorithm can select appropriate content and activities. Clients also need not be mobile; a special case of desktop clients can be considered as just another type of device on record. Existing learning management systems like Moodle LMS can also be modified through plugins in order to integrate with the system. Such plugins would take the role of gathering information, reporting, and downloading learning objects, while the presentation would be performed by standard LMS routines.

Learning systems must expand and evolve in order to adapt to changing requirements, and several types of expansion can be envisioned in the presented model: expansion of ontology concepts, expansion of knowledge base with additional educational content, supporting a growing number of users with different use patterns and frequencies, supporting a growing number of types of client systems. In order to support high flexibility and scalability of the entire system, the implementation can be placed on a cloud computing infrastructure [29]. Mobile learning can especially benefit from cloud computing since processing, storage, and adaptation of educational resources can be performed using cloud resources instead of those on heavily constrained devices [30]. Cloud provides a scalable, reliable, and secure IT environment that can host a multitude of learning services and allows integration of e-learning components through different cloud service models [31].

4.4. Processes and Mechanisms

A simplified overview of the core process of educational content adaptation and delivery is given in figure 6. The subprocesses include: 1) database creation and management; 2) user profile correlation; 3) content adaptation and constructing of learning objects; and 4) client mechanisms for interpreting received instructions and presenting the educational content. The results of the adaptation process are learning objects compliant with structure and metadata models presented in this work.

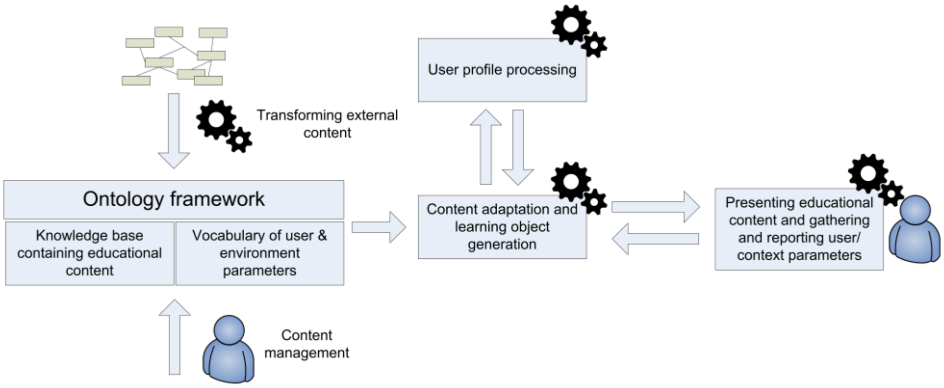

Fig. 6. A simplified overview of the core process of educational content adaptation and delivery

A system for mobile adaptive language learning depends heavily on the ontology-defined knowledge base, which contains language learning materials and rules, attributes, and relations used by the adaptation process to generate personalized learning objects. Knowledge base maintenance depends on two key processes - knowledge base development and content management. These two processes are strongly intertwined and interdependent; ontology development is often performed using an incrementally-iterative method where initially defined concepts are gradually developed and expanded. The development of an all-encompassing database of learning materials and other concepts would likely require a significant amount of time, while not being necessary for the system to be usable.

The process of knowledge base development should employ both automated and manual subprocesses. The development of the initial knowledge base can be done automatically, by developing transformation methods that would use existing vocabularies or wordnets to produce interconnected language learning materials. This transformation can be a one-time process, or achieved through a form of integration with the source used - when the source changes, the transformation method can update the knowledge base in the system. This way, the system can rely on external entities for keeping parts of the knowledge base up-to-date. For more complex learning materials like grammar rules, text, audio, and video files, an appropriate user interface should be provided to allow adding, tagging, and interconnecting new materials with the existing ones.

The separation of concerns regarding the content storage/delivery and presentation implies that the adaptation process should be also separated into two parts. The core part of this process is performed by the learning manager. The learning manager is tasked with recieving two types of requests from the system's clients through a predefined access point - the requests for learning object retrieval and user reports. User reports are forwarded to the user model storage, while the requests for learning objects initiate the process of generating and delivering adapted learning objects. When these objects are delivered to the client application, the second part of the adaptation process is performed. The client application adjusts the presentation of learning content according to the recieved instructions and capabilities of the client application.

The core resources and mechanisms for content adaptation and delivery are contained within the system, and accessible to various clients through standard web service interfaces. This allows the situation where a single user is accessing the system using several different devices through time. As a result, every client request for learning objects must contain device/application information, i.e. this information is not static and cannot be permanently tied in to the learner’s profile. Every request can also contain additional context information. The learning manager accepts this information, authorizes the user, and loads the profile that was built through previous requests and user reports. Information about the learner group in which the learner was placed by correlating his information with other users is also loaded and provided to the learning manager.

All of this information is used to build a query for the knowledge base, and retrieve learning materials from it. All content that the learner has already mastered is filtered out. Content that was previously presented, but posed a problem for the learner, is given a priority if it is possible to place it into a different context than the one it was presented in the first time. For instance, if the learner has had a problem to remember the word “ball” in the context of geometry, the same word can be presented to him again in a sports context, and tied in with an interesting fact about sports, preferably one related to the country whose language is being learned. New content should be filtered in a similar vein, by picking those content units that correspond best to learner’s parameters.

The selected set of learning content can potentially be great, and the next step is to filter it using the statistical information recieved from the profile processor (if such information exists). After this step, the final elements to be structured within a learning object should be selected, and presentation instructions for the client application added. The generation of learning objects heavily dependes on both the data/metadata models used, as well as the ontology framework as the source for the learning content. With all of the components at hand, producing a learning object requires only selecting an appropriate syntax for encoding the educational data in a textual format that can be transferred to clients. We suggest using lightweight objects appropriate for the mobile environment [32], but other formats could be generated, including SCORM. Generated learning objects are serialized using JSON or XML formats, and then sent to a client, which takes the responsibility for presentation and further information gathering.

The comparison of content hierarchy given by [25] and generated learning objects used in the presented model is shown in figure 7. Ontology-defined atomic units of content - words, characters, grammar rules, and others represent raw data elements and correspond to the attributes of individual elements of a learning object. When these raw elements are bound together (using semantic relations from the ontology), an element of a learning object is produced. This element corresponds to “information objects” in Hodgins’ hierarchy. An example of an information object is a single word with all its relations and attributes (translation, explanation, example, synonyms). By using higher level semantic relations, such elements can be intercombined to produce a complete learning object. An example would be a learning object about car parts, containing several car-related words.

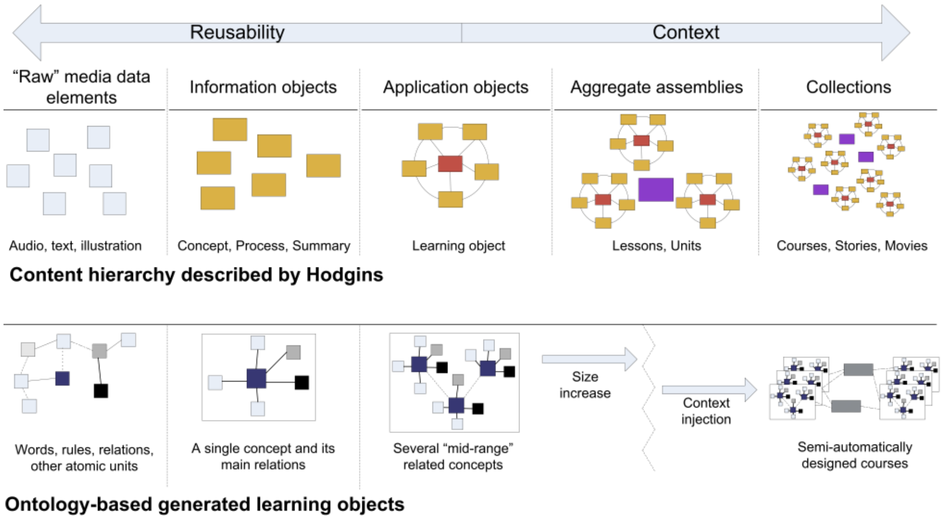

Fig. 7. Comparison of content hierarchy given by [25] and generated learning objects.

There is no limitation to the number of concepts and relations that can be included in a single learning object and a logical extreme would be to represent the entire knowledge base as a single learning object. In practice, the size of generated learning objects depends on the system implementation, and higher levels of content hierarchy [25] can, in system presented in this paper, be emulated by increasing their size and complexity. Larger educational units are not well suited for use in the mobile environment, but if needed, their quality can be increased by defining context elements within the knowledge base that are connected to some combinations of content elements. If all elements defined by the rules of the context element are added to a learning object, the context element can be added as well. Such context elements take on the role of the "glue" for other learning materials, and can be also manually added by teachers that wish to adapt materials to some specific purpose.

The generation of adapted learning objects relies on continuous input of information about the user. Some information pertaining to the current situation is received with learning object requests, as described previously, while other information is received through user reports. The structure of these reports is defined by the system, but their extent depends on the client application used to access the system. The reports should preferably be sent as often as possible in order to keep the user model up-to-date. Ideally, reports should be sent upon completion of any educational unit or activity, but this can be a problem in mobile environment where Internet connectivity is not guaranteed. The system should not depend on the frequency of reports for its functioning and should allow grouping and sending of multiple reports at a time.

The reports can include information about user knowledge, interest, and behaviour. Information about the knowledge requires identification of individual educational elements and results that the learner has achieved in knowledge testing activities. Such information can be reported after every use of the learning application. Information about the learner's interest is more difficult to collect through application use, and application can directly ask the learner to select topics he finds interesting, or assign them priorities. The client application can also implement some form of integration with popular social networks and, with permission from the learner, identify his interests that way. Integration with the social networks can also be centralized and implemented as a module within the system. Information about learner's interest can be reported less often and only in situations when the user makes manual changes, or when new information is detected through social networks. Finally, learner behaviour is discerned by tracking learner's favourite activities, time spent completing activities and providing answers to questions, and gathering other information that doesn't represent direct results of a learning activity, but can implicitly indicate learner's knowledge or interest. The client application should not make conclusions about the learner, but only track his behaviour and report it to the system, which can then correlate this data with other data from the user model.

The final part of the global learning process presented in this paper is the presentation of recieved learning objects on the client devices. This process represents the second part of the adaptation process. Client application recieves presentation instructions and interprets them in order to present the learning object. If no instructions were recieved, the application can choose some basic type of presentation, e.g. listing all elements from the learning object. Instructions use a vocabulary of generic terms like "test" and "game", and are generated according to the capabilities reported by the application while submitting a learning object request. If application declares itself unable to perform some type of learning activity, the adaptive learning system will not add this type of activity to the instructions. The actual implementation of learning activities provided by the client application can deviate to an extent from the generic instruction. For instance, if the system instructs the application to use an educational game for learning characters of some writing system, the client application can start a game of memory, or some other type of game where user has to select or input characters quickly in succession. The selected activity only needs to comply with the report structure concernig the learner's progress that will at some point be delivered to the system. The client application can additionally allow some form of manual personalization independently from the adaptation mechanisms that govern the selection of content and learning activities. This can include changing the color scheme, user interface structure, and other small changes. An example of the memory game adapted with respect to users' preferences stored within the ontological framework is presented in figure 8.

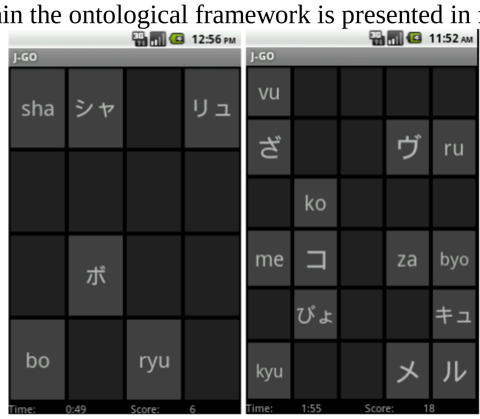

Fig. 8. An example of a memory game

Finally, the developed system is based upon the fact that mobile learning heaviliy relies on the learner's motivation and their capability to control the learning pace [33]. Well designed mobile applications motivate learners to study more often, even in informal learning contexts [34]. A powerful motivation tool in learning is entertainment, and this should be maintained in mobile learning applications [35]. A memory game presented in the figure 8 is an example of this approach. Additionally, motivation can be boosted using rewards and competitions among learners.

5. Discussion and Conclusion

This paper presented a model for mobile adaptive language learning based on an ontological framework and several criteria of adaptation. Used criteria encompassed learner knowledge, interest, behaviour, device capabilities, and context, and all related concepts were defined using ontologies in order to provide a standard, generic vocabulary of terms. This vocabulary was then utilized to enable a separation of concerns between the core system, and mobile and other client applications. Some suggestions were given concerning the development and integration of educational ontologies, with the goal of producing an optimal and efficient ontology. In order to account for possible expansions of ontologies, content, users, and client types, the infrastructure was envisioned as cloud and web-service based, providing needed scalability and generic access.

The main contribution presented in this paper is a model of a system for adaptive mobile language learning which is based on ontologies and learning objects. The model is oriented and specifically designed for mobile language learning, which is its main advantage comparing to similar models available in literature [13], [14]. The proposed approach can be applied on all levels of formal studies, as well as in informal learning. Ontological framework and integration of wordnets have enabled rich semantic networks as a basis for designing complex adaptation mechanisms. Having in mind that adaptation in real education systems can be performed upon numerous criteria, this approach gives flexibility with higher precision in selection of content. In addition, the ontological framework was designed in a way that preserves the structure of WordNet, so that the developed structure could be automatically updated with new versions of WordNet, as well as extended with other other WordNet compatible ontologies.

Table 1 shows the characteristics of the developed approach compared with other solutions found in the literature. Comparative analysis is shown with respect educational domain, platform, learning objects, ontologies and adaptivity. Basic advantages of the model proposed in this paper is that its focus on mobile language learning, where it is expected to bring the best benefits. The model heavily relies on the developed ontologies, which gives it flexibility for adaptation. On the other hand, more generic approaches, such as [13], [36] are applicable in wider areas, while approaches that are not based on ontologies, such as [19], [37] are much simpler for implementation.

Table 1. Comparison with other approaches

	Educational domain	Platform	Learning objects	Ontologies	Adaptivity
Gomes et al, 2006[36]	Any	Web	SCORM	Domain ontology integrated with user model	Static adaptivity upon personal, cognitive, and pedagogical characteristics. Dynamic adaptivity upon knowledge and performance
Petersen and Markiewicz, 2008[37]	Language learning	Mobile, web	No	No	Static adaptivity upon age, language, interests. Dynamic adaptivity upon location, time, device.
Basaeed et al. 2007.[13]	Any	Any, with focus on mobile	Adapted IEEE-LTSC LOM.	- Educational content ontology - Technology ontology	Adaptivity based on tasks, user profiles, devices and network connectivity.
Li et al. 2010[19]	Japanese language (Kanji)	SMS	No	No	Static adaptivity upon interests Dynamic adaptivity upon knowledge and time of learning
The proposed approach	Language learning	Mobile	Adapted IEEE LOM	- Language learning ontology - The educational activity/learning	Adaptivity based on learning objects. Learning objects can be

	design ontology - The user behaviour ontology - The device capabilities ontology - Context ontology	adapted upon any criteria stored in ontologies.

Future research should be directed towards exploration of existing educational ontologies and development of individual components of the ontological framework. Thanks to the separation of concerns, the minimal implementation of the system can be developed and tested manually, without the existence of actual clients, while individual clients can use a dummy web interface during the development of user tracking and reporting functionalities. A possibility of adapting existing learning applications should also be explored, especially for established learning management systems like Moodle. Other options of gathering information about learners like social networks are also a possible direction of future research.

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