Promoting Semantic Interoperability of Contextual Metadata for Learner Generated Digital Content
Abstract

Technological advancements in computing have led to a reality where computational devices are more mobile, connected and context aware than ever before. Several of these devices are primarily designed for or support the creation of digital content via built-in or attachable sensors, e.g. mobile phones. The portability and connectivity of mobile devices make them suitable tools to support learning experiences; their features can be used to generate digital content and metadata related to the particular learning situation. These types of objects, referred to as Emerging Learning Objects (ELOs), introduce challenges in terms of metadata enrichment as their metadata should reflect aspects related to the particular learning situation in which they were created to be properly indexed. A claim made in this thesis is that semantic interoperability of ELO metadata is an integral concern that needs to be explored in order to benefit from these metadata outside custom tailored applications and systems. Therefore, the main research question explored in this thesis focuses on the ability to enrich ELOs with semantically interoperable contextual metadata.

This thesis is comprised of a collection of five peer-reviewed articles that describe interrelated stages of research in pursuit of an answer to the main research question. The overall research process consisted of three main stages: a literature review; the development a system artefact; and the exploration of the technological solution (Linked Data) applied in the system artefact. An instantiation of the Unified Process guided the development of the system artefact.

The outcomes of these activities provide insights on how to perceive the relationship between context and contextual metadata, as well as properties related to a particular technological solution, namely data distribution, flexibility and expressivity. In order to decouple the findings from a particular instance of technology, a generalization effort in the analysis identified two generic factors that affect the semantic interoperability of metadata: the level of ontological consensus and the level of metadata expressivity. The main conclusion of this thesis is that until the constituent parts of context are agreed upon, metadata expressivity is an important feature for promoting semantic interoperability of ELO contextual metadata.
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This thesis is dedicated to my loving family, my fiancée Hannah and my daughter Elvira. You make it all worthwhile.
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1. Introduction

Technological advancements in computing have led to a reality in which computational devices are becoming increasingly integrated into our everyday lives. From a world where a single computer, capable of performing simple arithmetic calculations, filled up an entire room we are now at a point where devices substantially more capable can be carried with us wherever we go. The miniaturization of processors, networking technologies, memory, displays and sensors even enable a move towards the vision of ubiquitous computing, where computing power is ‘invisibly’ embedded in the physical environment and adapts according to our needs (Ley, 2007). The impact of advancements in the area of computing can be illustrated with recent statistics: at the end of 2008, there were more than 4 billion mobile subscriptions and close to 800 million broadband Internet subscriptions registered worldwide (ITU, 2008). It is safe to say that we live in a reality where computational devices are more mobile, connected and context aware than ever before.

Many computational devices are primarily designed for or support the creation of digital content via built-in or attachable sensors. For example, people can use their digital camera or camera-enabled mobile phone to create and share photographs or video recordings whenever and wherever they like. Content created in this manner is commonly referred to as User-Generated Content (UGC) (Pereira, Vetro, & Sikora, 2008), and its role has become more interesting than ever through the rise of Web 2.0, often referred to as the people-centric Web or participative Web (Murugesan, 2007). While Web 2.0 is conceived both as a usage and technology paradigm, the active contribution of users is a property of Web 2.0 often contrasted with the passive consumption of Web 1.0; the functionality of Web 2.0 applications such as Twitter, Facebook and Flickr rely heavily on the active participation of their users (Oreilly, 2007).

Nowadays, the contribution and consumption of UGC are integrated features in a myriad of devices available on the market, ranging from mobile phones and digital cameras to gaming consoles (Microsoft Corporation, n.d.) and even certain models of televisions (Samsung, n.d.). As of 2009, the social networking application Facebook had more than 175 million active users worldwide (Kaplan & Haenlein, 2010), contributing continually to the ever-growing amount of UGC available on the Web. Consequently, finding relevant UGC across the breadth and depth of the Web is becoming an integral challenge (Smith, 2008). An accepted approach to support the retrieval and delivery of UGC is to formally describe them with metadata. Metadata, commonly defined as ‘data about data’ (Zeng & Qin, 2008), can be virtually any type of information that describes an object — e.g. where, when or by whom it was created — which can be used to enhance operations such as search, clustering and filtering processes.

Naturally, the quality of metadata-driven retrieval processes of UGC depends largely on the metadata available. The increased popularity of mobile devices has led to new opportunities to generate metadata from sensor readings upon UGC creation (Davis, King, Good, & Sarvas, 2004). Hence, readings from sensors can be used to generate metadata from aspects related to the physical world, commonly referred to as contextual metadata (Davis, et al., 2004; Naaman, Harada, Wang, Garcia-Molina, & Paepcke, 2004). Active research is being conducted into how to take advantage of these kinds of metadata to achieve powerful retrieval of UGC and to better understand the circumstances related to its origin (Davis, et al., 2004; Naaman, et al., 2004; Ntousias, Gioldasis, Tsinaraki, & Christodoulakis, 2008). The present thesis aims to contribute to this line of research within the scope of Technology Enhanced Learning (TEL), to be introduced in the upcoming section.
1.1 Scope
While the organization of UGC is a relevant concern across many research disciplines, the efforts presented in this thesis has been conducted within the research field of TEL. Researchers in TEL investigate how information and communication technologies can be used to support learning, teaching and competence development throughout life (CORDIS). As learning supported by technology involves both humans and computers, TEL is a multidisciplinary field that includes both social and technological aspects. This is illustrated in Figure 1, which highlights three categories of domain challenges in this area of research: namely, learning, social and cognitive challenges; technology and engineering challenges; and design and interaction challenges (Kurti, 2009).

Figure 1. TEL domain challenges (Kurti, 2009). Used with permission.

Recent advancements made in TEL have led to the estimation of mobile computing to enter into mainstream use for teaching, learning or creative inquiry within the very near future (Johnson, Levine, Smith, & Stone, 2010). In this estimation, portability and connectivity are emphasized as important properties that make mobile devices suitable tools to support learning experiences; fieldwork observations can be entered into the device on the spot and sent to analysis in real time, and their sensors can be used to generate UGC and UGC metadata related to a particular learning situation (Sharples, Arnedillo-Sánchez, Milrad, & Vavoula, 2009). These types of UGC, created by learners themselves during learning situations in partly unanticipated ways, are referred to as Emerging Learning Objects (ELOs) (Hoppe, 2006). The limited formal control related to ELO creation introduces challenges in terms of metadata enrichment, as ELO metadata should reflect aspects related to the particular learning situation in which it was created to be properly indexed (Hoppe, 2006). In an attempt to pursue this challenge, the research efforts presented in the present thesis have been geared towards the exploration of how to deal with these types of metadata.

1.2 Purpose
Along with the ability to benefit from contextual metadata in terms of search, clustering and filtering processes of ELOs there is the potential to generate novel opportunities for learning. One of these is to support learning through learner reflection (Boud, Keogh, & Walker, 1985; Lin, Hmelo, Kinzer, & Secules, 1999). As an example, ELO metadata can help to automate the generation of digital recreations of learning activities that have been carried out across different locations. Such digital recreations, e.g. a web page that
details events and ELOs created in various stages of a learning activity, can be incorporated into post activities to promote learning through reflection. Providing support for reflective activities is but one example of needs that have been introduced from applying this research to the domain of TEL. Section 3.1 gives a more elaborate discussion of why contextual metadata is important in this particular domain.

While it is technically possible to enrich ELOs with virtually any imaginable metadata, it is crucial to consider factors affecting their degree of interoperability to make them usable across systems (Pereira, et al., 2008). Interoperability refers to: ‘the compatibility of two or more systems such that they can exchange information and data and can use the exchanged information and data without any special manipulation’ (Taylor, 2003). While several categories of interoperability have been identified in research (see Section 2.1), the area of semantic interoperability continues to be a challenge in information exchange between information systems (Chbeir, Kosch, Andres, & Ishikawa, 2009; O'Sullivan & Lewis, 2003). Semantic interoperability ensures that: ‘the requester and provider have a common understanding of the “meanings” of the requested services and data’ (Heiler, 1995); e.g., an application that requests data about a person must share the provider’s meaning of what a ‘person’ is for the data to be interpreted and processed correctly. This form of interoperability raises a concern regarding contextual metadata for ELOs, especially when considering the vast amount of contextual aspects available in all imaginable learning situations. Therefore, the main research question to be discussed in this thesis is formulated as follows:

**How can ELOs be enriched with semantically interoperable contextual metadata?**

A claim made in this thesis is that semantic interoperability of ELO contextual metadata is an integral concern that needs to be explored in order to benefit from these metadata outside custom-tailored applications and systems. The above research question has been pursued on both the conceptual and implementation levels, resulting in the identification of factors that affect semantic interoperability of such metadata. These efforts are presented throughout the chapters of this thesis, whose structural layout is outlined in the next section.

### 1.3 Thesis overview

The present thesis is a compilation of five published, peer-reviewed conference articles. Its outline is illustrated in Figure 2, in which the five conference articles have been put into a logical sequence and grouped in the box entitled ‘Overview of research efforts’. The structure of the thesis is as follows: the following chapter introduces the theoretical foundations on which the efforts presented in this thesis are built; Chapter 3 states the research problem and clarifies the research approach taken to pursue this problem; Chapter 4 presents a description of the appended conference articles, which is followed by an analysis of their findings in Chapter 5; the final chapter presents conclusions made and provides directions for future research related to the subject of the present work.
1.4 Limitations and definitions

As discussed in Section 1.1, TEL is a multidisciplinary field in which three distinct domain challenges have been identified. The work presented in this thesis has a clear focus on the domain challenge of technology and engineering. While the other two domains are important they are not the focus of these research efforts.

Another limitation that needs to be made clear is the interpretation of the word context used in this thesis. According to the Oxford English Dictionary (http://dictionary.oed.com), the word is defined as ‘the circumstances that form the setting for an event, statement, or idea.’ However, the term has been subject to considerable different interpretations concerning its meaning, what it includes and what role it plays in interactive systems. This dilemma can be illustrated by how context is categorised; Dourish (2004) separates the notion of context into two views, the social context and the technical context, while Dix and colleagues (2000) have identified four forms of context, namely the infrastructure context, system context, domain context and physical context. To add to this discussion, the meaning of the word has been defined multiple times in the domain of computer science. Dey (2001) defines context as:

… any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.

Another interpretation of the word is ‘information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment at a specific time’ (Kurti, 2008). While the aim of this thesis is not to bring yet another definition to the table, the interpretation of the word needs to be made clear in order to limit the research scope. Thus, the interpretation used in this thesis is in line with the notion of physical and social contexts, i.e. concrete and abstract concepts related to the real world rather than to system and infrastructure contexts.

Furthermore, in this thesis, the word semantic is used frequently in conjunction with data and metadata, e.g. ‘semantics of data’. According to the Oxford English Dictionary, the word is related to signification or meaning, commonly considered to be a human trait closely connected with cognition. However, for the scope of the present thesis, semantics refers to the ability for machines to make use of data through knowledge representation techniques, e.g. ontologies. ‘Meaning’ in this sense is not connected with cognitive abilities, but rather with the ability for machines to benefit from formal semantics when
interpreting data. A distinction must be made between data semantics and semantic interoperability of data; the focus of this thesis is not on data semantics in terms of deep AI (Artificial Intelligence) approaches, but rather on promoting semantic interoperability of data (or metadata). The interpretation of semantic interoperability used in this thesis is in line with Heiler’s (1995) definition: semantic interoperability ensures ‘that the requester and provider have a common understanding of the “meanings” of the requested services and data’.

The following chapter introduces the theoretical foundations on which the work presented in this thesis is founded.
2. Theoretical foundations

The sections of this chapter constitute the theoretical foundations of this thesis. The outline of the chapter is as follows: the following section introduces the concept of metadata interoperability; Section 2.2 gives an overview of the Web from the perspective of semantic interoperability of data, which is followed by a literature review of digital content metadata standards and recommendations; the final section presents related work, to contextualize the efforts presented in this thesis.

2.1 Metadata interoperability

The organization of objects and concepts into classes or collections is an important human quality that we need in order to make sense of the world and to communicate. Humans use this quality to group abstract concepts logically, e.g., we can correctly refer to happiness and sadness as feelings, as well as concrete objects, e.g., we organize reports into appropriate sections in ringbinders that in turn have their dedicated location on shelves. Through the advent and rapid evolution of modern technology, a myriad of devices, such as digital cameras and mobile phones, allow anyone to easily create their own digital objects, e.g. photographs, and with little effort publish them on the World Wide Web (the Web). Thus, the organizational need of objects has expanded to include both physical and digital entities.

While a photo album application on a home computer should be able to facilitate the organization of thousands of photographs, the Web contained at least 20 billion web pages in January 2010 (http://www.worldwidewebsize.com). This enormous amount of digital objects (henceforth ‘digital content’) requires sophisticated indexing mechanisms in order to be found, for which a widely used approach is to enrich digital content with metadata. Metadata is commonly defined as ‘data about data’ or ‘information about information’ (Berners-Lee, 1997), and was invented to help computer systems and humans to better organize, access and interpret data (Smith & Schirling, 2006). Typical metadata for a music file would include information about the song, e.g. the title of the song, or the name of the performing artist. A music player application able to interpret these metadata can exploit them to, for example, organize music files by particular artists or display the name of the song currently played back to the listener.

Although metadata in the context of a single system can be considered useful, the notion of interoperability constitutes one of the most important principles in metadata implementation (Zeng & Qin, 2008). Interoperability refers to: ‘the compatibility of two or more systems such that they can exchange information and data and can use the exchanged information and data without any special manipulation’ (Taylor, 2003). Metadata interoperability is considered the prerequisite for uniform access to digital media across heterogeneous information systems (Haslhofer & Klas, 2010), for which the ability to promote their interoperability has been researched extensively (Amir, Bilasco, & Djeraba, 2009; Davies, Harris, Crichton, Shukla, & Gibbons, 2008; Konstantinou, Solidakis, Zafeiropoulos, Statthopoulos, & Mitrou, 2009), even in particular application domains, such as TEL (Al-Khalifa & Davis, 2006; Aroyo, et al., 2006). Furthermore, Sheth (1998) has broken down the concept of interoperability into four categories of challenges, namely:

- **Semantic interoperability**: lack of shared understanding of the meaning of terms used in the data exchange.
- **Structural interoperability**: heterogeneous model representations.
- **Syntactic interoperability**: differences in data formatting.
• **System interoperability:** heterogeneous systems and applications.

As stated in Section 1.4, the interpretation of semantic interoperability used in this thesis is ‘that the requester and provider have a common understanding of the “meanings” of the requested services and data’ (Heiler, 1995), which is clearly connected with the semantic interoperability challenge above. While the other three categories of interoperability constitute important areas of research, the main focus of the present thesis is on how to promote semantic interoperability of ELO contextual metadata. In order to promote this form of metadata interoperability there are many standards and recommendations providing guidelines for digital content metadata in general, as well as for specific types of content, e.g. multimedia and educational material. Moreover, extensive research efforts on mechanisms and constructs with the ability to automatically resolve the meaning of data have been conducted in the area of Semantic Web technologies (Allemang & Hendler, 2008). Aspects such as these are discussed throughout the remainder of chapter to set the theoretical foundation for the present work, starting with the evolution of the Web of data.

2.2 The evolution of the Web of data

The Web, as we know it today, consists of billions of interlinked hypertext documents primarily encoded in HTML (Hypertext Mark-up Language). This mark-up language contains a set of tags for defining the structural semantics of a document, thus allowing content such as paragraphs, lists and tables to be organized and rendered in a web browser. However, HTML does not contain any mechanisms to define the semantics of the data residing in these structures; when interpreted by a web browser, the textual contents of, for instance, a paragraph within an HTML document is considered nothing more than a set of characters.

While the notion of extending the Web with features for defining data semantics can be traced back to its initial proposal in 1989 (Berners-Lee, 1989), the idea was reintroduced roughly ten years later through the introduction the Semantic Web (Berners-Lee, Hendler, & Lassila, 2001). Around that time, the Web community in general regarded XML (eXtensible Mark-up Language) as the most important step towards semantic integration (Decker, et al., 2000). However, it was noted that XML has limited support for semantic interoperability. This limitation is still topical today; Taha and Elmasri (2009) report on challenges in the area of XML-based search engines, where relationships between XML entries based solely on their labels and proximity are considered insufficient. The main idea of the Semantic Web is to support a distributed Web at the level of data (Allemang & Hendler, 2008) for which its technology stack contains constructs for defining the semantics of data.

The data model used in the Semantic Web is called Resource Description Framework (RDF), which, as its name implies, facilitates the description of resources. Resources in the Semantic Web can be anything someone might want to talk about (Allemang & Hendler, 2008), such as people or things in the world, and are encoded in sets of triples in the form of subject, object and predicate (Berners-Lee, et al., 2001). The identification system of resources in RDF is a heritage from foundational Web technology; Universal Resource Identifiers (URIs), typically in the form of URLs (Universal Resource Links), are used to distinguish resources from each other. Apart from being an identification mechanism, the URL system is a crucial component for realizing the Semantic Web vision of a distributed Web of data; the URL system allows one data item to address another data item residing somewhere on the Semantic Web by using the existing Web infrastructure.
While the ability to structure uniquely identifiable resources in the form of triples is not contributing to resolve the semantic limitations of XML, Semantic Web technologies include approaches to tackle these. RDF Schema (RDFS) is a semantic extension of RDF and provides basic mechanisms to define resource types, i.e. classes, and their relationships, i.e. properties. OWL (Web Ontology Language) brings even more expressivity of logic to the Semantic Web, allowing detailed constraints to be expressed between various resource types (Allemang & Hendler, 2008). In the Semantic Web, collections of class and property definitions are referred to as vocabularies (Bizer, Heath, & Berners-Lee, 2009) or ontologies (Berners-Lee, et al., 2001).

Classes and properties defined in such ontologies are addressable via their URI, which means that the data is self-describing. This mechanism makes it possible for applications to resolve the semantics of the data, thus addressing the limitation of XML-based approaches mentioned earlier in this section. Popular ontologies include Friend Of A Friend (FOAF) (http://www.foaf-project.org), Simple Knowledge Organization System (SKOS) (http://www.w3.org/2004/02/skos/) and Semantically-Interlinked Online Communities (SIOC) (http://sioc-project.org), for modelling people, concepts and online communities respectively. While the Semantic Web is comprised of several more interrelated technologies, one central component that should be mentioned is the SPARQL (SPARQL Protocol and RDF Query Language) query language, contributing with mechanisms for querying a collection of RDF resources.

Although the concept of the Semantic Web has been subject to several interpretations over the years, the original goal of building a global Web of machine-readable data has remained constant throughout literature written on the topic (Bizer, et al., 2009). As a means to reach this goal, the Linked Data best practices were introduced in 2006. These consist of the following four principles (Berners-Lee, 2006) that define how to publish and connect structured data on the Web:

1. Use URIs as names for things.
2. Use HTTP (Hypertext Transfer Protocol) URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL).
4. Include links to other URIs so that they can discover more things.

The above points show that the Linked Data principles build on readily existing technologies on the Web, e.g. the HTTP protocol and the URL identification system. As the HTTP protocol contributes with a standardized data access mechanism for URLs, URL formatted RDF resources can be looked up and retrieved (Bizer, et al., 2009). This allows links between data to be expressed as RDF triples, e.g.:

Subject: http://localhost/mary
Predicate: http://xmlns.com/foaf/0.1/ knows
Object: http://remotehost/joe

The example above illustrates how data links are expressed, where the subject is linked to the object via a specific predicate. The ability to create such typed links between data from various sources is the fundamental idea of Linked Data. Numerous efforts are underway to build applications that exploit the Web of data, such as the Linked Data browsers and Linked Data search engines reported by Bizer and colleagues (2009). Alongside the Semantic Web movement, there exist several digital content metadata standards and recommendations that need to be discussed in the context of this thesis.
Therefore, the following section contains a literature review of digital content standards and recommendations to explore to what extent these can support semantically interoperable contextual metadata for ELOs.

2.3 Metadata standards and recommendations
The purpose of this section is to expand the theoretical foundations with a selection of metadata standards and recommendations for digital content to investigate to what extent these could support contextual metadata descriptions of ELOs. The section ends with an overview of the findings, summarizing the existing support for contextual metadata in the reviewed standards and recommendations.

2.3.1 Literature review
As a response to the call for improving the description of distributed information objects and repositories on the Web, the Dublin Core Metadata Element Set (DCMES) represents an interdisciplinary consensus on fifteen core metadata elements (http://dublincore.org). Examples of elements in this standard are ‘title’, ‘description’, ‘creator’ and ‘date’, all of which are optional and repeatable. Guidelines are available concerning the syntax of several DCMES bindings, e.g. plain text, XML, HTML and RDF. While the limited amount of elements in DCMES can be applied to virtually any domain, multimedia objects require more technical and content specific descriptions to facilitate their interoperability. A standard that should be mentioned in this context is the XML-based MPEG-7 (Moving Picture Experts Group) that targets the content description of multimedia objects. The content description mechanism in MPEG-7 relies on several tools, including descriptors (Ds) and description schemes (DSs) that specify the structure, relationships and constraints of the metadata (van Ossenbruggen, Nack, & Hardman, 2004). Ds and DSs are defined in the MPEG-7 Description Definition Language (DDL), which is based on the XML Schema Language. The DDL facilitates the declaration of syntactic rules for combining Ds and DSs, which allow users to create their own Ds and DSs to express spatial, temporal, structural, and conceptual relationships between the elements of a DS and between DSs (Pereira, et al., 2008).

Another important standard for storing interchange information in image files, especially those using JPEG (Joint Photographic Experts Group) compression, is the EXIF (Exchangeable Image File Format) standard (http://exif.org), which is used by most digital cameras on the market today to enrich photographs with information. The EXIF standard facilitates the description of image files with information such as camera settings, copyright information, and temporal and spatial details. This metadata is widely supported and interoperable, as it can be embedded directly into the particular image file. Apart from its embedded form, EXIF data can also be represented as RDF (W3C, 2003).

The Extensible Metadata Platform (XMP) is an effort based on open standards, implemented as a common metadata interchange platform for Adobe products that allows metadata to be embedded into the file itself (http://www.adobe.com/devnet/xmp/). The specification is applicable outside Adobe specific products; the rationale for XMP is to provide a common standard regarding the definition, creation and processing of metadata. The XMP data model is defined as a subset of RDF, meaning that while XMP data adheres to the RDF format a number of RDF features are not valid XMPs. The specification includes a set of RDF vocabularies and supports the creation of new, or the extension of existing, vocabularies.

In order to discuss digital content metadata in the domain of TEL an introduction to the fundamental concept of Learning Objects (LOs) should be in place. Wayne Hodgins originally coined the concept back in 1994, and his original vision of LOs sprang from watching his children play with LEGO™ where the individual blocks represent units of
learning that can be assembled and reassembled to fit the needs of the learner (Polsani, 2003). Polsani (2003) defines the concept as ‘an independent and self-standing unit of learning content that is predisposed to reuse in multiple instructional contexts’ (2003).

Details concerning the shape and form of digital resources can be expressed as metadata, and shortly after Hodgins introduced the concept of LO, several parties including the IEEE (Institute of Electrical and Electronics Engineers), IMS Global Learning Consortium (http://www.imsglobal.org) and ARIADNE (http://www.ariadne-eu.org) began to investigate the possibility of formalizing a common LO metadata structure to promote interoperability of LO metadata.

The parallel research efforts within the same problem space led to the development of multiple competing standards, but after several years, the involved parties reached a consensus on the metadata elements of a LO (Polsani, 2003) and, today, the most widely used LO metadata standard is the IEEE LOM (Learning Object Metadata) Standard ("IEEE Standard for Learning Object Metadata," 2002). The standard describes the IEEE LOM data model and details how metadata records should be expressed as XML and RDF. The IEEE LOM data model is comprised of nine categories of optional metadata terms, in which information such as technical requirements, educational characteristics and intellectual property rights of LOs may be defined. The standard has been globally adopted, adapted and implemented in many unexpected ways and applications (Duval & Hodgins, 2006).

While a digital LO, enriched with IEEE LOM records, constitutes a learning object that can be used to supporting learning, the standard does not include support for expressing details of how a learning object has been used. Research in this area has been conducted by Ochoa and Duval (2006), in which they propose and detail the use of Contextual Attention Metadata (CAM). CAM stems from a concept referred to as Attention Metadata, which can be used to represent user interactions with resources in the AttentionXML format (Çelik, 2005). The CAM extension provides the ability to enrich content with details relevant to learning objects, e.g. the tool that was used, what other users were doing at the time of interaction and to which community the interacting user belongs.

2.3.2 Literature review analysis
The literature review in the former section provided an overview of the complex domain of digital content metadata standards and recommendations. One important finding related to metadata interoperability is the various bindings specified in the metadata specifications. The bindings specified in each of the standards brought up in the literature can be seen in Table 1. Moreover, as the focus of this thesis is on contextual metadata, the right-hand column in Table 1 attempts to give an overview of the contextual metadata support in each specification respectively.

Table 1. Overview of the metadata specifications

<table>
<thead>
<tr>
<th>Name</th>
<th>Binding</th>
<th>Contextual metadata category</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCMES</td>
<td>XML or RDF</td>
<td>Personal, temporal</td>
</tr>
<tr>
<td>MPEG-7</td>
<td>XML</td>
<td>Definable in DDLs</td>
</tr>
<tr>
<td>EXIF</td>
<td>Embedded or RDF</td>
<td>Spatial, temporal</td>
</tr>
<tr>
<td>XMP</td>
<td>Embedded RDF subset</td>
<td>Definable in vocabularies</td>
</tr>
<tr>
<td>IEEE LOM</td>
<td>XML or RDF</td>
<td>Personal, temporal</td>
</tr>
<tr>
<td>CAM</td>
<td>XML</td>
<td>Events, temporal, personal</td>
</tr>
</tbody>
</table>
In the overview above there are three types of bindings involved, namely XML, RDF and embedded metadata. While XML facilitates syntactic interoperability, semantic interoperability is limited to concepts specified within the framework of a particular standard (Stamou, van Ossenbruggen, Pan, Schreiber, & Smith, 2006). Moreover, although metadata terms in MPEG-7 are not restricted to a pre-defined vocabulary set, the lack of formal semantics in its XML binding have been noted, potentially, to impact the semantic interoperability of these metadata (Pereira, et al., 2008). As the other dominant binding in Table 1, the RDF solution can support semantic interoperability through formal, machine-processable semantics (as discussed in Section 2.2).

The right-hand column in Table 1 illustrates a rough categorization of the contextual metadata support across the various specifications. As can be seen, these categories are spread out over several specifications, limiting the ability to achieve semantic interoperability to certain categories when relying solely on one of these. Moreover, pre-defined metadata elements in standards limit available contextual metadata terms to those included in the specifications. One exception is the MPEG-7 standard, where users can define their own metadata vocabulary in a DDL, but this solution suffers from a lack of application support that can benefit from these metadata (Stamou, et al., 2006). Furthermore, several of the discussed specifications are tailored towards specific application domains, e.g., EXIF is intended primarily for image metadata, while IEEE LOM facilitates the description of LOs.

In summary, the standards and recommendations presented in the literature review do provide for semantic interoperability for metadata terms defined within their vocabulary. However, this is not enough when it comes to ELO contextual metadata, as this should reflect aspects related to the particular learning situation in which it was created to be properly indexed. The following section looks at how others have tackled the challenge of semantic interoperability of ELO contextual metadata in order to position the efforts described in the present thesis.

2.4 Related Work
Extensive research has been conducted on how to promote metadata interoperability in the domain of TEL: Aroyo and colleagues (2006) discuss the issue of semantic interoperability of educational content on the Web by considering the integration of learning standards, Semantic Web technologies and adaptive technologies to meet learner’s requirements; Al-Khalifa and Davis (2006) have reviewed the evolution of metadata used in e-learning; Nilsson, Johnston, Naeve and Powell (2007) mention interoperability issues related to learning objects and contribute with some insights into how to address these in future learning object metadata standards. Despite considerable efforts spent on researching the interoperability of learning object metadata, which is an important area of research, far fewer efforts have been spent on researching how to promote the semantic interoperability of metadata for learner-generated digital content and what an improvement would actually mean in this respect.

When narrowing the scope even further to focus on ELO contextual metadata, the number of efforts reported in research is very limited. Findings reported in a recent literature study, investigating modern trends in contextual metadata enrichment of digital content, reveal a lack of consensus on formal computational representations of context and contextual metadata gathered in the reviewed initiatives, ending up in a variety of data structures (Svensson, 2009). For example, contextual metadata has been structured in faceted metadata hierarchies (Sarvas, Herrarte, Wilhelm, & Davis, 2004), domain-specific XML documents (Volgin, Hung, Vakili, Flinn, & Shin, 2005), relational databases (Karypidis & Lalis, 2006), and as RDF according to the FOAF vocabulary
(Monaghan & O'Sullivan, 2006). An example of a lack of consensus is the problematic situation of mapping the term ‘user name’, presented by Sarvas and colleagues (2004) to an instance of the concept ‘Person’ in the FOAF vocabulary depicted by Monaghan and O'Sullivan (2006). These both cases refer to a person but their representations differ. While mapping approaches have been suggested for bridging incompatible metadata models, the interoperability of metadata remains a central challenge (Haslhofer & Klas, 2010).

As revealed in the aforementioned literature, and made further visible in Section 2.3, there appears to be no golden standard or recommendation to rely on when it comes to representing context in the form of metadata for digital content; a statement which is backed up by Aroyo and colleagues (2006). Evidently, there is room for further research on how to promote the semantic interoperability of contextual metadata — an area in which the efforts presented in this thesis are focused. The motivation behind this research, along with the research objectives and approach, is detailed in the following chapter.
3. Research plan and objectives

This chapter aims to answer questions related to the why, what and how of the research presented in this thesis. The outline is as follows: the first section builds on the theoretical foundations to further illustrate the research need, which is followed by the formulation of the problem and research questions that have been pursued; Section 3.3 provides insights into the research context; and Section 3.4 outlines the chosen research methods. The chapter ends with a section clarifying the connection with the chosen methods and the research process used to carry out the work.

3.1 Research need

The previous chapter has shown that semantic interoperability of ELO contextual metadata is challenging to achieve and that there is room for further research in this area. A natural follow-up to that statement is to question why this matter constitutes an important research topic. One way to approach an answer is to elaborate on the specific requirements for metadata related to ELOs. Milrad and colleagues (2005) outline the following set of recommendations for the design of interactive environments for challenge-based, collaborative learning and distributed experimentation:

- **Authentic activities**: learning activities should be connected with real uses.
- **Construction**: learners should generate artefacts and share these with their community.
- **Collaboration**: learners should collaborate to promote knowledge construction through social negotiation.
- **Reflection**: learning activities should foster learner reflection.
- **Situating the context**: learner knowledge construction should be context and content dependent.
- **Multi-modal interaction**: learning activities should incorporate multiple representations of reality.

*Construction* involves the creation of artefacts in *authentic activities* that are *situated in context*. Constructed artefacts should be shared with the learner’s community, for which metadata can be used to accurately filter and recommend artefacts relevant to learners in the learner community. It has been made clear that the pre-defined metadata terms in the reviewed standards and recommendations have limited ability to express important contextual aspects related to the learning situation in which ELOs have been created. This has a negative impact on the ability to perform accurate filtering of ELOs.

Furthermore, digital artefacts that emerge from learning situations can play an important part for social negotiation between learners, where knowledge is constructed through learner *collaboration*. For example, a photograph of a tree branch can be used as a basis for a discussion between learners concerning the species of a particular tree. Here, contextual metadata can be used as a facilitator to accurately direct ELOs to target learners; e.g., a particular group of learners in a remote location should receive ELOs created by a specific learner while conducting observations of a certain tree. Similarly, as discussed in Section 1.2, metadata-driven filtering processes can be incorporated into applications and tools to support learner *reflection*. These and similar use cases contribute to the justification of the statement from Hoppe (2006): ‘ELO metadata should reflect aspects related to the particular learning situation in which they were created to be properly indexed’. 
In concluding that ELO contextual metadata is important to support interactive learning environments, the promotion of the semantic interoperability of these metadata would increase the likeliness for them to be usable across systems and applications. The next section formulates the problem and states the thesis research questions.

3.2 Research problem and activities
As discussed throughout the previous chapter, metadata standards and recommendations mainly facilitate the description of ELOs from a pre-defined set of elements across various data models and bindings. This insight raises a semantic interoperability challenge in order to depict aspects of context only available in some or none of these standards. An attempt to illustrate the research problem is seen in Figure 3: the photograph to the far left represents a field trip learning situation enhanced by ICT (Information and Communication Technologies), where learners use technology to generate ELOs. When an ELO is created, readings from available sensors related to the particular learning situation are used to generate contextual metadata for that particular ELO. This metadata constitutes an instance of aspects in the real world that systems can utilize to enhance operations, such as search, clustering and filtering operations of ELOs.

Therefore, the efforts presented in this thesis pursue the research need to promote semantic interoperability of ELO contextual metadata. The semantic interoperability challenge illustrated above is formulated explicitly in the main research question of this thesis:

*How can ELOs be enriched with semantically interoperable contextual metadata?*

In order to approach the main research question, two support questions have been identified:

A. *What are the current trends in the contextual metadata annotation of digital content?*

B. *How can emerging learning objects be depicted with contextual characteristics in a machine interoperable and interpretable manner, so that it is possible to preserve the meaning or semantics of these features?*
The angle from which the efforts in this thesis address the above research questions is, as mentioned in Section 1.4, from a technical and engineering perspective. The different activities that were carried out as a part of this research consisted of:

- A literature review
- Technical development
- Exploration

Question A has been pursued in the form of a literature review in order to gain knowledge about the current state of the field and to establish the background for the thesis. Based on the conclusions drawn and insights gained from this review, the engineering research approach of this thesis has involved the application of technology through technical development, while in the exploration activity, the usefulness of the applied technology has been investigated. Methods used to guide the research efforts are described after the following section, which states the context in which the work of the thesis has been performed.

3.3 Research context

The research efforts presented in this thesis have been conducted in the context of the CeLeKT (Center for Learning and Knowledge Technologies) research centre, located at the Linnaeus University, Sweden. Research activities at CeLeKT focus on aspects such as the exploration of new design approaches and innovative uses of mobile and ubiquitous technologies in a variety of collaborative educational settings. The actual use of such technologies is investigated regularly in the form of learning activities, in which learners are instructed and challenged to solve a set of tasks with the help of technology.

Over the years, as an active member of the CeLeKT group, the author has been involved in the development and implementation of several support systems facilitating such activities, particularly within the context of the AMULETS (Advanced Mobile and Ubiquitous Learning Environments for Teachers and Students) project (Spikol, Milrad, Svensson, Pettersson, & Persson, 2008; Svensson & Pettersson, 2008). The AMULETS project was based on the premise that the design of innovative mobile learning activities should be guided by collaborative learning scenarios in context and in authentic settings. From experience gained from being a part of the technical development team, this premise introduced several challenges of which context formalization was considered to be one of the major ones. Context formalizations were integral facilitators in these complex activities, as state changes in the activity control system were triggered based on the state of the learners. Additionally, these context formalizations were used heavily as metadata for ELOs, not only during the activity to control and filter ELOs as artefacts for collaboration purposes, but also for generating spaces for reflection for the learners during post-activity sessions.

For several iterations of the trials conducted within the AMULETS project, context formalizations were stored in a relational database on top of which the development team implemented reflection spaces where users could filter and view ELOs based on the data available in the database. This approach worked as intended and the development team was pleased with what it had done, until they realized that the next trial in line introduced new aspects of context that had to be supported. After several iterations of various trials within the scope of AMULETS, the database contained various aspects of context formalized in pairs of key-value, all of which lacked references to suitable metadata standards or recommendations. In connection with the notion of semantic interoperability there simply was none to speak of; the ability to exploit formalizations of context as metadata for ELOs required the development of custom applications, tailored
to the contents of the database. These and similar types of experiences motivated the choice of subject and contributed to the formulation of the research questions presented in Section 3.2. The following section motivates and defines the research methods that the present research effort has benefited from.

### 3.4 Research methods

A clear explanation of methods used in research activities is important for judging the reliability and soundness of research results, which is why this section presents and details the choice of methods that have been used to conduct the thesis work. Clarke (2000) outlines three major research traditions related to information systems: namely, *conventional scientific research; interpretivist research;* and *engineering research.* Among these, the research approach taken in this thesis positions itself within the field of engineering research, an area essentially concerned with technology, including artefacts, techniques and combinations of both of them. Particularly related to the topic of this thesis, the tradition of engineering research involves the *application* of technology for problem-solving (Clarke, 2000), as well as the conception, design and creation of an information technology artefacts or techniques to investigate their feasibility and usefulness (Järvinen, 1999).

In connection with the research activities outlined in Section 3.2, the *technical development* has been guided by the Unified Process (UP), which is a software engineering process that defines the *who, what, when and how* of developing software (Arlow & Neustadt, 2005). UP is an iterative, incremental and generic software development process that needs to be instantiated according to each particular project. Iterations in UP consist of five core workflows as visualized in Figure 4 — namely, Requirements, Analysis, Design, Implementation and Test — and, as a result of the generic nature of UP, additional workflows can be incorporated as well.

![Figure 4. The five core workflows in UP (inspired from Arlow & Neustadt, 2005)](imageurl)

The aim of the Requirements workflow is to capture the functionality of a system, which is refined and structured in the Analysis workflow. Design involves the realization of the requirements in a system architecture implemented in the Implementation workflow, which is then verified in the Test workflow. In UP, iterations occur within four distinct phases: Inception, Elaboration, Construction and Transition, each with a major milestone at the end.

In the *exploration* activity (Section 3.2), illustrative scenarios have been used as an instrument for exploring the potential of the technology applied in the technical development. Scenarios are represented in the form stories, in which *agents or actors* perform *actions* or react to *events* to fulfil a set of *goals or objectives* in a particular *setting* (Carroll, 2000). The outcomes of creating such narratives are stories that describe how the involved technology can be used. The connection between these methods and the research process of the thesis is explained in the following section.
3.5 Research approach

The research process of this thesis can be divided logically into three sequential stages, based on the research objectives stated in Section 3.2: Background, Implementation and Exploration (Figure 5). In the background stage, the state of the art in contextual metadata enrichment of digital content, i.e. research question A, will be investigated through a peer-reviewed literature review. Findings in this stage will be formulated as a set of requirements and serve as input for the implementation stage.

The desired outcome of the background stage is to identify a particular technology with promising features in terms of semantic interoperability. In the spirit of engineering research, this technological solution shall be applied in the form of a system artefact in the implementation stage. A small UP instantiation with phases and milestones excluded will drive the development. This produced artefact should offer mechanisms that exploit the technological solution to enrich ELOs with contextual metadata. While the thesis research process do not include testing in real learning environments, the third and final stage of the research process aims to pursue research question B through the exploration of the produced artefact’s use in educational settings via illustrative scenarios.

This chapter, building on the theoretical foundations provided throughout Chapter 2, has made clear that more research is needed on how to promote the semantic interoperability of contextual metadata for ELOs. Research methods have been discussed and connected with the thesis research process, and the research context has been explained to set the research described in this thesis in context. The following chapter gives an overview of the appended research publications and aligns them with the research process as described in Figure 5.
4. Overview of research efforts

This chapter provides an overview of the five appended research publications along with a summary of their findings. The flow of articles in relation to the thesis research process can be seen in Figure 6, which illustrates the logical connection between the articles and the three stages using dashed arrows. Paper I contributes to the research need and provides an insight into how ELOs were handled during a learning activity conducted at the CeLeKT research centre. Paper II presents and reflects on the findings at the background stage in the form of a literature review. Papers III and IV investigate and detail aspects related to the implementation of the system artefact, while Paper V explores its potential use in TEL environments.

Each of the five articles contains either a research question or a research aim that has been pursued. In connection with the two support research questions presented in Section 3.2, the research aim of Paper II and Paper V are connected directly with research question A and B respectively. The list below presents an extract of the research questions and aims posed in the articles:

- **This paper aims to describe and illustrate the design of ACS (Activity Controller System) and to explain how user-generated content and metadata were handled and used.** (Paper I)
- **The aim of this article is to review modern trends in contextual metadata annotation of digital content.** (Paper II)
- **What novel possibilities would the use of RDF as a data model in a learning content repository offer?** (Paper III)
- **How to increase the expressivity and interoperability of contextual metadata depicting mobile media objects in technology enhanced learning environments.** (Paper IV)
- **[..] how to depict emerging learning objects with contextual characteristics in a machine interoperable and interpretable manner, so that it is possible to preserve the meaning or semantics of these features.** (Paper V)

The following five sections briefly describe the individual papers, to highlight their purpose and main outcomes. The chapter ends with a summary of their findings to be analysed in Chapter 5.
4.1 Paper I

This paper illustrates the design of ACS (Activity Controller System) and explains how user-generated content and metadata were handled and used in an activity conducted within the AMULETS (Advanced Mobile and Ubiquitous Learning Environments for Teachers and Students) project. The process of structuring user-generated content and contextual data generated during ubiquitous learning activities was the overall motivation behind the article. While ACS stored digital content metadata in a relational database, our early elaborations with RDF formatted metadata are presented. An important conclusion drawn in this paper was that the pre-determined metadata descriptors available in existing current standards were insufficient to describe the relevant contextual characteristics of the learning activity.

4.2 Paper II

The purpose of this article was to review current trends in contextual metadata annotation of digital content. This was conducted through a literature review of current research, looking more closely at formal context models, contextual metadata gathering and contextual metadata formalization methods respectively. The findings revealed that the formal models were inconsistent with the contextual metadata gathered in approaches described in the reviewed literature, in which location (or spatial) metadata dominated. Furthermore, contextual metadata gathered in the reviewed initiatives ended up in a variety of data structures. As a potential explanation, Pereira and colleagues (2008) state that the most important factor for promoting interoperability is not the representation language, but rather the provision of a clear definition of what a certain term means and its relationship with other factors. This ontological dimension demands an unambiguous understanding of which terms constitute a metadata domain. An agreement of the constituent parts — or the ontological dimension — of context would allow for more standards and recommendations, promoting important features such as semantic interoperability, to emerge.

The article exemplifies one promising effort in approaching the ontological dimension of person with the FOAF recommendation. Its constituent parts include name, mail, homepage, title and the possibility to associate a person with other people or groups. Moreover, FOAF addresses problems with semantics of metadata as RDF resources are identified with unique URIs. A claim made in this paper is that by identifying and reaching a consensus of the constituent parts of the dimensions of context, we are well on our way towards improved digital content reusability, facilitated by semantically interoperable contextual metadata.

4.3 Paper III
In connection with the engineering approach taken in this thesis, the article explores the utility of using RDF as a data model in a learning content repository through the implementation of such a system. While not written explicitly in the text, the Pinetree content repository adheres to the Linked Data guidelines (Bizer, et al., 2009). The article details the various components of Pinetree and illustrates its use in a specific learning scenario, which indicates that a learning content repository, based on RDF, can be a flexible solution for digital content storage in terms of metadata expressivity, interoperability and data distribution. The article received a best full paper award at the ICALT 2009 conference.

4.4 Paper IV

This paper investigates further how to increase the expressivity and interoperability of contextual metadata depicting mobile media objects in technology enhanced learning environments. A conceptual scheme, introduced and discussed in this paper, presents an approach for addressing syntactic and semantic heterogeneities. The proposed scheme utilizes open standard technologies XML (to define syntax) and RDF (to define semantics) as complementary techniques and this approach is in line with current research efforts in Semantic Web community. Moreover, use of XML-based technologies is an advantage for mobile resources where performance is an issue. The conceptual scheme proposes that RDF reasoning and inference happen on the server side, thus not degrading the performance of the mobile clients. The article concludes that there is a clear added value of transforming syntactical context representations into RDF to help the issue of interoperability and reusability of the mobile media objects.

4.5 Paper V

This final article appended to the present thesis pursues the challenge of how to depict ELOs with contextual characteristics in a machine interoperable and interpretable manner, so that it is possible to preserve the semantics of these features. One of the trials conducted at CeLeKT is detailed in terms of ELO metadata, and illustrative scenarios are used to contrast this trial with the Linked Data approach. In the article, a conceptual model in which ELO metadata are distributed over three distinct systems supporting learning activities is presented. A list of key findings concerning the technological solution includes:

• Applications using the Linked Data approach do not need to implement mechanisms for data linkage, data merge and support for semantic interoperability, as these are integral mechanisms provided by the Linked Data technology stack.
• In contrast to the structural and syntactical constraints provided by the XML Schema, RDF Schema and OWL offer valuable flexibility for enriching ELOs with unanticipated metadata.

• Applications adhering to the Linked Data guidelines expose resource data via a generic interface.

4.6 Summary
The findings of the five papers outlined in the previous section show the progression through the three stages of the thesis research process. At the background stage, the literature review revealed a lack of consistency regarding contextual metadata enrichment of digital content. In reflecting on these results, the complexity of context in relation to contextual metadata led to the idea to perceive context as multidimensional. This insight influenced the choice of technology investigated at the implementation stage, in which a system artefact that facilitates metadata enrichment of ELOs was constructed as a Linked Data application (Section 5.2). This technical approach was further investigated, taking into consideration the limited performance of mobile clients in Paper IV. In the final stage, exploration, the potential of the applied technology was explored through illustrative scenarios. Moreover, the exploration stage introduced the idea of functionality decomposition facilitated by Linked Data, where ELO metadata can be distributed over three distinct mechanisms supporting learning activities. A summary of these findings, divided into different stages of research, can be seen in Table 2 below:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Main outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>• Lack of consistency regarding contextual metadata for digital content</td>
</tr>
<tr>
<td></td>
<td>• Dimensions of context; context is regarded as multidimensional</td>
</tr>
<tr>
<td>Implementation</td>
<td>• Implementation of a system artefact based on Linked Data, a technology</td>
</tr>
<tr>
<td></td>
<td>supporting formal, machine-processable semantics</td>
</tr>
<tr>
<td>Exploration</td>
<td>• Linked Data provide mechanisms for data linkage, data merge, support for</td>
</tr>
<tr>
<td></td>
<td>semantic interoperability and data distribution</td>
</tr>
<tr>
<td></td>
<td>• Learning activity support systems decomposition</td>
</tr>
</tbody>
</table>

The next chapter makes an attempt to consolidate and analyse the outcomes presented in Table 2 in order to provide an answer to the research questions posed in Section 3.2.
5. Analysis of research efforts

The aim of this chapter is to analyse the outcomes of the research efforts presented in the previous chapter (Table 2) to approach a generalization of these findings. An overview of the analysis process is illustrated in Figure 7, which is divided into two parts, conceptualization and realization, which denote research efforts on the conceptual and the realization levels respectively. Section 5.1 in this analysis elaborates on the idea emerging from Paper II to conceive context as multidimensional. Insights gained from this work influenced the choice of technology to investigate, and the analysis of this investigation is described in Section 5.2. In order to decouple the findings from a particular technological solution, an attempt to generalize the findings from the technology investigation is presented in the closing section of this chapter.

![Figure 7. Analysis process overview](image)

5.1 Dimensions of context

The idea behind the dimensions of context came during the analysis of results from the literature review described in Paper II, which had shown that there was a lack of consistency regarding contextual metadata for annotating digital content. For instance, in one of the cases that were presented, context data was stored in a relational database, while another effort formalized contextual metadata in domain-specific XML documents. A possible explanation of the diversity regarding contextual metadata annotation of digital content is connected with the literature review presented in Section 2.3: existing digital content metadata standards and recommendations with fixed or controlled vocabularies do not offer the extensibility required to describe the complexity of context.

In an attempt to perceive context as multidimensional was originally introduced in the reflection section of Paper II. While other research efforts have suggested context to consist of a set of categories (Kurti, 2009), the author of this thesis is yet to come across the idea of allocating contextual metadata to context dimensions. Dimensions of context have been inspired from the statement that the most important factor for promoting semantic interoperability is not the representation language, but rather the provision of a clear definition of what a certain term means and its relationships with other factors (Pereira, et al., 2008). This ontological dimension demands an unambiguous understanding of terms that constitute a metadata domain. Paper II states that such an agreement of the constituent parts (or the ontological dimension) of dimensions of context would allow for more standards and recommendations enabling semantic interoperability to emerge.
An illustration of the idea can be seen in Figure 8 below. The figure is comprised of two parts, **Metadata** and **Dimensions of Context**, which illustrate concrete metadata records and their relationship to abstract contextual dimensions respectively. The association between the upper and lower ellipses denotes an inheritance relationship; location metadata is contextual metadata and the environment dimension is a context dimension. Contextual metadata belongs to one or several ontological dimensions, which are represented by grey ellipses on the right-hand side. As revealed in the figure, location metadata is suggested to belong to the environment dimension of context. It should be noticed that the various metadata and dimensions outlined in the figure serve only as an example to illustrate the notion of allocating contextual metadata to context dimensions, i.e., there most certainly is other metadata besides location metadata that can be allocated into context dimensions.

Furthermore, Paper II states that data belonging to various dimensions of context should not be regarded as isolated but rather as interrelated. To illustrate this, a hypothetical scenario is presented in Figure 9, where a set of context dimensions, their contents and relations are presented. Please note that the concepts in the figure serve as examples only. In Figure 9, dimensions are represented as grey ellipses and contextual metadata belonging to these dimensions is represented as white ellipses. These dimensions can be conceived as focused sets of formal metadata specifications in which the ontological dimension is agreed upon, i.e., we have agreed which metadata belongs to a particular dimension. To exemplify this, the location metadata terms lat (latitude), long (longitude), alt (altitude) and distance are connected with the location dimension. The ellipse labelled ‘distance’ refers to a derived metadata term denoting the physical distance between two geographical positions. As the dimensions of context focus on various aspects of the context, such as location or person, there is an opportunity to combine these to form a more complete formal computational representation of the context. This is illustrated with associations between dimensions as solid lines in Figure 9. The relationship types between dimensions are not explicitly specified in the figure, as these may turn out to be very different. When considering the dimensions exemplified in the figure, the location dimension might be defined as a subset of the environment dimension. The relationship between activity and person, on the other hand, might consist of associations that connect people with activities.
As illustrated in Figure 9 above, the complexity of context can be decomposed into several interrelated and more tangible context dimensions. Such categorizations of context dimensions, for instance ‘person’, can be considered more tangible than ‘context’ to comprehend and, consequentially, to define. Thus, one imaginable path of research towards improved semantic interoperability of contextual metadata would be to start defining vocabularies for various context dimensions and to push for these to become recommendations or standards. While the author of this thesis recognises the importance of metadata standards and recommendations as a means to promote semantic interoperability, the research process of this thesis is set on the application of a particular technology (Section 3.5) rather than the definition of the constituent parts of context (Section 1.4).

Paper V provides a comparison between such mechanisms, in which ontology-based approaches were considered promising for the purpose of this thesis. The potential of ontology-based approaches, concerning syntactic and semantic interoperability, is captured quite clearly by Antoniou and van Harmelen (2003), who state that two of the main requirements for ontology languages are well-defined syntax and well-defined semantics. The practical implications of ontology-based approaches have been investigated through the implementation of a content repository called Pinetree, described in detail in Paper III and discussed further in the following section.

### 5.2 Technology investigation

This section focuses on the technology that has been utilized and the insights gained from the development of the Pinetree system artefact. The technological solution selected for the implementation of Pinetree is ontology-based and has been considered as an important step towards the envisioned Web 3.0 (Hendler, 2009), namely Linked Data (described in Section 2.2).

While the characteristics of ontology-based approaches have been made clear in research (Antoniou & van Harmelen, 2003), the motivation behind the construction of the Pinetree content repository was to get practical hands-on experience of the technology to better understand to what degree Linked Data can contribute, in terms of promoting semantic interoperability of contextual metadata depicting ELOs. For the interested reader, the technicalities of the system are explained in detail in Paper III. Although the Pinetree system has not yet been tested in an actual learning environment, the potential of Linked Data has been explored through illustrative scenarios in Papers III and V. Moreover, Paper IV investigated technologies in the Linked Data technology stack, such as RDF and RDF Schema.
One very relevant feature of Linked Data in relation to the challenge of semantic interoperability (Section 2.1) is expressivity (Al-Khalifa & Davis, 2006; Haslhofer & Klas, 2010; Monaghan & O'Sullivan, 2006), referring to the ability to enhance data with machine-processable semantics that applications can use to attempt to resolve their meaning. For instance, if an application encounters an unfamiliar RDF resource, it can access the relevant ontology and retrieve an explicit definition of the resource type. Moreover, as resources in RDF statements can be comprised of concepts from any available Semantic Web ontology, Linked Data provides flexibility, or extensibility, in terms of metadata enrichment (Al-Khalifa & Davis, 2006; Nilsson, et al., 2007), which is especially valuable when considering the multidimensional nature of contextual metadata. This feature is connected with the structural and syntactic interoperability challenges discussed in Section 2.1, rather than the challenge of semantic interoperability. Furthermore, the data distribution feature of Linked Data is one of the novel ideas that have been explored through the introduction of two mechanisms alongside of Pinetree in the system architecture presented in Papers III and V. These three mechanisms combined offer the core functionalities of the learning activity support systems that have facilitated trials at CeLeKT in the past (Paper I), where the major difference is the underlying technology, i.e. Linked Data, and the separation of concerns over three distinct systems. An updated version of the concept, originally introduced in Paper V, illustrating the learning activity support system’s decomposition, is depicted in Figure 10. It should be noticed that the notion of decomposing learning activity support systems is different from how ACS works, as described in Paper I, which uses a more centralised approach.

![Figure 10. Learning activity support system’s decomposition](image)

In the learning activity support system’s decomposition above, the user manager application is conceived as a system dedicated to the management of data coming from groups and users participating in various learning activities, while the responsibility of the task manager is to control and monitor the progress of the participants in the different learning activities. Pinetree is responsible for storing and representing the conceptions of ELOs that are created throughout learning activities, i.e. ELO metadata, as well as the actual files. The arrows in the figure denote data linkage between and within the involved applications. Apart from the ability to decentralize functionality, the decentralization of data can be traced to the idea of context as multidimensional. For example, in relation to the context dimensions exemplified in Figure 8, most of the data contained in and managed by the user manager and the task manager application can be categorised as data belonging to the person dimension and the activity dimension of
context respectively. Thus, a decomposition of learning activity support systems would be comprised of several applications whose data describes one or several dimensions of context. When aggregated using mechanisms in the Linked Data technology stack, as exemplified in Paper V, each of them contribute to a more complete formal computational representation of context that can be used as metadata for ELOs. Please note that the activity support systems decomposition is not by any means complete, meaning that there may be more applications across learning activity system architectures than the ones shown in Figure 10. Moreover, for the scope of the efforts presented in this thesis, the architecture in Figure 10 has been used as a tool to illustrate the data distribution feature of Linked Data, and not to advocate the soundness of such a system architecture in comparison to other alternatives. In connection with the interoperability challenges described in Section 2.1, this feature relates to the system interoperability category, as heterogeneity of applications and systems can be resolved through adhering to the Linked Data principles (see Section 2.2) to offer generic data interfaces. A more detailed explanation of how data can be interlinked between and within the above applications is presented in Paper V.

The current section has presented the insights gained from exploring a certain technology to promote semantic interoperability of ELO contextual metadata. Although insights related to a particular technological solution could be considered valuable, the following section attempts to generalize and decouple these insights from Linked Data to make these more generic.

5.3 Generalization

In order to decouple the findings from technologies and ideas related to Linked Data, this section attempts to generalize on the insights gained during the analysis so far. In the previous section, the features of data distribution, flexibility and expressivity were mentioned as important properties of the Linked Data approach. The mechanism to achieve data distribution is an integral part of Linked Data, owing to the fact that RDF resources are identified with URIs. Furthermore, the Linked Data principles clearly define HTTP as the transport layer, meaning that such data distribution is a property of this particular technology. Naturally, data distribution could be achieved through a combination of other technologies, e.g. Web Services. The second feature, flexibility, can also be considered as a property of the Linked Data technology not directly connected with semantic interoperability. Even if data distribution and flexibility features are valuable and important, the third and last feature can be considered as the most relevant in terms of semantic interoperability, namely expressivity. Expressivity is a central aspect in ontology languages, which allow users to write explicit, formal conceptualizations of domains models (Antoniou & van Harmelen, 2003) that applications can consult to attempt to resolve the semantics of data. Thus, the expressivity of contextual metadata is a factor that affects their semantic interoperability (Al-Khalifa & Davis, 2006; Haslhofer & Klas, 2010; Monaghan & O'Sullivan, 2006).

Returning to the inspiration source of the dimensions of context, Pereira and colleagues (2008) state that clear definitions of what metadata terms and their relationship with other factors mean are important to achieve semantic interoperability. This ontological dimension demands an unambiguous understanding of terms that constitute a metadata domain; the importance of common vocabularies for achieving semantic interoperability has been recognised in research (Aroyo, et al., 2006; Haslhofer & Klas, 2010; Konstantinou, et al., 2009). Thus, reaching an ontological dimension consensus is another factor affecting semantic interoperability of metadata. In order to visually represent these insights, Figure 11 shows these two factors as dimensions that affect semantic interoperability of metadata, namely whether or not metadata
expressivity (as defined above) is supported and whether or not a consensus regarding the ontological dimension (as defined above) of a metadata domain, e.g. a context dimension, has been reached. In the context of Figure 11, the notion of level is not used as a quantifier but rather as a means for categorization. The combination of these dimensions forms four distinct regions in the figure, labelled 1, 2, 3 and 4, in which properties of these factors are represented within clouds. Within these clouds, plus and minus signs denote positive and negative properties in terms of semantic interoperability.

As seen in region 1 of Figure 11, a high level of ontological dimension consensus and metadata expressivity makes it possible to benefit from common vocabularies and self-describing metadata, which both have a positive impact on semantic interoperability. An example belonging to region 1 in the figure would be metadata tied to a concept of the DCMES specification, which then can benefit from being an instance of a common vocabulary whose concepts are self-describing in the RDF binding. In contrast, approaches affected by the negative properties in region 3 can be exemplified with tags in a domain-specific XML document not tied to an XML Schema.

Apart from visually representing how the two factors affecting semantic interoperability are interrelated, the model can be used to allocate metadata into its four quadrants to determine their likelihood of being semantically interoperable across systems and applications. The importance of promoting metadata interoperability, semantic or not, has been thoroughly discussed in this thesis, for which the model in Figure 11 can be useful for identifying the soundness of a metadata approach, from the perspective of semantic interoperability. For example, when looking at metadata generated in the initiatives presented in Paper II, several of these can be categorised into region 3 of the model. When using the model to reflect on past efforts conducted at CeLeKT (Section 3.3), there is undoubtedly room for improvement; the majority of the metadata generated throughout the various learning activities can also be allocated to region 3.
Furthermore, Figure 11 clearly illustrates the soundness of ontology-based approaches, particularly Semantic Web technologies (Section 2.2), in terms of semantic interoperability of metadata, as Semantic Web technologies contain constructs for creating metadata vocabularies and for metadata to be self-describing. Although region 1 is desirable for all imaginable metadata, an agreement of the constituent parts of their respective dimensions is needed to benefit from common vocabularies. As discussed in Section 1.4, there is clearly a lack of consensus concerning the ontological dimension of context and, consequently, the ability to agree on and benefit from common vocabularies for various dimensions of context is limited. Until then, region 4 illustrates that at least some semantic interoperability of ELO contextual metadata, not defined in common vocabularies, can be achieved through metadata expressivity. Exploring what this means in practice within the domain of TEL will constitute a major part of my future research efforts. Research objectives related to these coming activities are outlined in the following chapter along with the main conclusions that summarize the work carried out in this thesis.
6. Conclusions and future directions

Throughout the chapters of this thesis the ability to promote semantic interoperability of ELO metadata has been explored. This chapter presents the conclusions based on the analysis presented in chapter five, followed up by a description of possible lines of future work. In the analysis in the previous chapter, two factors that affect semantic interoperability metadata have been identified, namely:

- **Level of ontological dimension consensus**
- **Level of metadata expressivity**

Concerning the first factor, a consensus on the ontological dimension of a metadata domain makes it possible to define its constituent parts and progress towards common metadata vocabularies to promote semantic interoperability. As the second factor, metadata expressivity refers to the ability to enhance data with machine-processable semantics that applications can use to attempt to resolve the ‘meanings’ of the data, which is in line with the definition of *semantic interoperability* given in this thesis (Section 1.4). The following paragraphs attempt to answer the research questions presented in Section 3.2, starting with the two support research questions.

**What are the current trends in contextual metadata annotation of digital content?**

Going back to research question A, semantic interoperability of contextual metadata are generally low with respect to the two factors that promote semantic interoperability as outlined above. The research efforts investigated in Paper II show a lack of consensus regarding the ontological dimensions of context, as the formal computational representations of context varied between all of the reviewed initiatives. Moreover, most of the efforts lacked metadata expressivity facilitated by ontology-based approaches, meaning that systems and applications have limited ability to resolve how to interpret these metadata. The recurring combination of low metadata expressivity and low ontological dimension consensus leads to the quite unpleasant situation of metadata being categorized into quadrant number 3 in Figure 11.

**How can emerging learning objects be depicted with contextual characteristics in a machine interoperable and interpretable manner, so that it is possible to preserve the meaning or semantics of these features?**

Research question B has been pursued through hands-on experimentation with the ontology-based approach, Linked Data. In the analysis chapter of this thesis (Section 5.2), three interesting features related to this particular technology have been identified, namely expressivity, flexibility and data distribution. These notions have been investigated through illustrative scenarios, in which ELOs are enriched with self-describing metadata. Insights gained during this activity underline the value of and illustrate how to preserve the ‘meanings’ of contextual characteristics for these types of objects in educational settings.

**How can ELOs be enriched with semantically interoperable contextual metadata?**

As Linked Data is an instance of a technological approach, the closing section of the analysis (Section 5.3) made an attempt to detach and generalize the findings in this
thesis. Through the generalization effort, the expressiveness of ontology-based approaches has been identified as an important factor for promoting semantic interoperability of metadata, which is particularly applicable in areas where there is a lack of consensus regarding the ontological dimension. The second factor, the ontological dimension consensus, demands an agreement on the terms that constitute a metadata domain. Therefore, until the constituent parts of context are agreed upon, the present thesis concludes that metadata expressivity is an important feature for promoting semantic interoperability of ELO contextual metadata. The upcoming section suggests lines of future work and provides some thoughts concerning coming research for the remainder of my doctoral studies.

6.1 Future directions

Conclusions made in the introduction of this chapter shed light on at least two interesting venues for further research in the area of promoting semantic interoperability of ELO metadata. Firstly, the limited ontological dimension consensus of context suggests that more research is needed in the identification of various context dimensions and their constituent parts to progress towards common vocabularies. Activities in this area most certainly have the potential to contribute with valuable results in terms of semantic interoperability of contextual metadata. Secondly, another interesting research path in this respect would be to better understand how we could benefit from machine-processable semantics that applications can use, to attempt to resolve the ‘meanings’ of contextual metadata.

In my upcoming research efforts I intend to apply the results from this thesis into practice to better understand the practical benefit of improved semantic interoperability of contextual metadata in the domain of TEL. While Linked Data has been shown to be a good candidate technology for my future efforts, I have chosen to exclude implementation details in the research objectives outlined below. The reason for this is captured in the initial chapter of this thesis: technology is evolving rapidly and it would be unwise to tie research objectives, spanning over several years, to a particular technological instance. In concrete, the coming research objectives are as follows:

- To further explore the usefulness of enhanced semantic interoperability of contextual metadata in the domain of TEL.
- To apply insights and results gained from this thesis in situated learning experiments.
- To evaluate the outcome of these research activities in order to improve their scientific rigor and validity.

Methodological considerations related to these activities are currently under investigation. The above research objectives will partly be pursued within the frame of current and upcoming research projects at CeLeKT; we are currently investigating how to apply the insights made in this thesis on systems and applications within the Learning Ecology through Science with Global Outcomes (LETS GO!) project (Vogel, Spikol, Kurti, & Milrad, 2010). Such and similar explorations will constitute future efforts of my doctoral studies in pursuit of a better understanding of how to benefit from improved semantic interoperability of ELO contextual metadata.
References


Collection of papers


Making Use of User-generated Content and Contextual Metadata Collected during Ubiquitous Learning Activities

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Abstract

During the last years significant research efforts have been conducted looking at how to standardize digital educational content. Due to better connectivity and computational power of mobile devices, new opportunities have emerged for collecting user-generated data based on the context and the environment where the content has been generated. While metadata standards for learning objects such as IEEE LOM make it possible to annotate digital content with pre-defined metadata tags, the ability to store custom user-generated or contextual metadata is not yet fully supported. The need for developing a flexible solution to deal with these problems motivated the design of our Activity Controller System (ACS), a rapid prototyping system and a task manager, which interprets, reacts to and stores contextual metadata and content extracted during learning activities. This paper presents how ACS facilitates coordination and reusability of user generated data, which we believe is as a valuable feature compared with existing standards and initiatives.

1. Introduction

The use of mobile devices to facilitate location-based learning has become a recent topic of research. The latest mobile devices tend to be equipped with many features such as photo and video cameras, GPS (Global Positioning System) and microphones, which can be used to catch user interaction in the environment [1]. This possibility has led to a shift of focus within technology enhanced learning research, thus moving from m-learning (mobile learning) towards u-learning (ubiquitous learning). As u-learning strives towards merging computing with the context of the user, there is a potential to generate and collect contextual metadata from such devices [1].

During the last two years, we have designed and conducted several learning activities within the AMULETS (Advanced Mobile and Ubiquitous Learning Environments for Teachers and Students) project. Within AMULETS we are exploring how to design, implement and evaluate innovative educational scenarios combining outdoors and indoors activities supported by mobile and ubiquitous computing [4]. The process of structuring user generated content and contextual data generated during ubiquitous learning activities, in a manner in which it provides for reusability, has been identified as a challenging task during our ongoing work. Such type of data can help systems to “understand” the learner’s context in order to support situation-awareness learning [1]. Furthermore, contextual data can be used as a basis to reproduce activity progress for reflection or monitoring purposes. All these issues motivated the design of ACS (Activity Controller System), a rapid prototyping system and task manager, which interprets, reacts to and stores contextual data and content extracted during ubiquitous learning activities. This paper aims to describe and illustrate the design of ACS and to explain how user-generated content and metadata was handled and used. The rest of the paper is organized as follows; in section two we provide some background information to our area of research while in section three we present an overview of the design and development aspects of our system. Section four and five describe the results of the educational trials in which we tested our system and how user-generated data came to use after the activity had been performed. Section six ends this paper by presenting some discussions and conclusions.

2. Background

In the context of supporting learning activities, collected metadata can be used to improve the classification of learning objects. Learning objects are
defined as “small, reusable content units relevant for learning” [2] – a broad definition that allows for many different interpretations. In order to make such units reusable and interoperable between different applications and systems, the need of a common standard in how to structure such data has been identified. The most renowned and widely accepted standard to date is the IEEE Learning Object Metadata (LOM) standard, which structurally defines roughly sixty optional metadata slots describing a learning object. Another important standard is the IMS Learning Design (IMS LD), an XML-based language with the purpose of formally describing learning processes of various pedagogical approaches. IMS LD allows for defining roles of users and structuring learning activities, which may involve learning objects, within learning processes. While standardization has proven to be a working concept for success [2], IEEE LOM and IMS LD have been noted to lack some expressiveness in terms of personalization of digital content to support the learning process [3]. Quite naturally, a pre-defined set of metadata slots restricts one from storing metadata not included in the model. In order to address this problem, other attempts to formalize learning object metadata has been conducted. One concrete example is the LOCO-Cite (Learning Object Context Ontologies) ontology – an ontology that captures learning object context to facilitate personalization [3]. The LOCO-Cite ontology makes it possible to capture information such as user characteristics and user evaluation and it has successfully been used to provide the best suited learning objects for a particular learner.

2.1 Context awareness in ubiquitous learning

Beale & Lonsdale have recently explored how context awareness techniques can be used in educational settings [5]. They developed a model of context conceived to support learning activities as part of the MOBIlearn project. The authors state the difficulty of implementing context-awareness to be twofold: 1) how do we get hold of contextual information? and 2) what do we do once we have it? To address these two aspects, Beale & Lonsdale believe that a model of context is needed as a common ground to discuss elements of context relevant for context-aware computing, and to facilitate context-aware reuse. The outcome of their efforts has resulted in the definition of a metadata schema in XML format, for contextual metadata storage and transfer. As an aid for creating context models to support context-aware ubiquitous computing applications, Henricksen & Indulska [6] have developed a number of techniques. They have created a graphical modeling language, the Context Modeling Language (CML), which assists designers in exploring and specifying context requirements of context-aware applications. Henricksen & Indulska explain how CML models can be abstracted to situation abstractions, which express conditions derived from the CML models in a novel form of predicate logic, and preference abstractions, which expresses user preference in a similar manner. To exemplify its usage, different programming models incorporating the situation and preference abstractions were presented in their article. In the next section we describe how the different aspects in this section have been used to guide the design of our system.

3. ACS conceptual design & development

Key requirements for designing ACS involved rapid prototyping of complex ubiquitous learning activities, along with the ability to store any kind of user-generated content and its associated metadata. In our initial design, standards such as IEEE LOM and IMS LD were not incorporated. Similarly to the motivation of the LOCO-Cite ontology mentioned earlier, personalization was considered more important than adhering to educational metadata standards. Instead, in order to make the system as flexible as possible, the starting point of the system development was set from a generic model of context. The following section will depict the ACS system design and the context model that it is based upon.

3.1 Modeling

The ACS context model has been conceived using the conceptual framework for designing ubiquitous learning activities developed by Kurti and colleagues [4]. This framework is based on the view of the “context” been defined as “information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment”. During the analysis phase of the development of ACS a conceptual model, as shown in Figure 1, was created to describe the relationship between the key concepts.
The leftmost part of the figure, labeled context, encapsulates the context model just discussed. As realizations of the context model may, and most probably will, change state, the snapshot concept was introduced. A snapshot can be thought of as a camera, which stores the state of the realized context model at a certain point in time. Additionally, a snapshot can be associated with a number of content and metadata concept instances. Content represents a set of rich-media content, such as images, videos or audio files, while metadata illustrates the possibility of detailing a snapshot further with custom metadata tags and values.

3.2 Implementation details

ACS was implemented on a LAMP server platform. An API was layered over the implemented classes to make easier for the programmer, with methods such as addActor(). Via an administrator interface, tasks and actors can be added, grouped and hierarchically structured. Furthermore, tasks can be sequentially ordered to create a main task flow. When satisfied with a specific activity structure, the author has the option to generate the activity, which creates PHP files – one activity file and one file per task – and makes the activity accessible on the Apache web server. The generated files, with access to the ACS API, can then be filled with application logic.

During the design phase it was decided that client devices would communicate with ACS using the HTTP protocol, and append the extension of requests as form data (post or get scope). As ACS stores the progress for each participant, it automatically branches its execution by including the task file relevant for the participant making the request. As a way to export data, ACS had the ability to generate RDF documents describing the state of the activities. This was made possible by using the RAP® (Rdf API for PHP), which offered functionality for generating RDF based on the data collected by the system. Figure 2 below illustrates the concept names and their range as defined by the RDF Schema, which generated RDF documents in ACS must conform to.

![Figure 2 – RDF Schema graph](http://sites.wiwiss.fu-berlin.de/suhl/bizer/rdfapi/)

Keeping the ACS system design in mind, the following section will describe how ACS was used to support a ubiquitous learning activity within AMULETS.

4. Results: AMULETS trial with ACS

Sixteen teacher students from an environmental science course at our university used smartphones and stationary computers to explore and to learn about those aspects related to tree morphology. ACS has been used to provide support for these activities.

4.1 Learning activity structure

The students were divided into four groups and each of these groups split into two subgroups. One group became the field group while the other part became the base group. The field group had two smartphones were one acted as the communication and messages device with the base group and the second phone as a camera. The learning activity was on how to teach tree morphology where the teacher students used a tree key to identify different species of trees by bark, type of buds, and the surrounding environment. The field group task was to locate the trees, send images back to the base group and collaboratively determine the tree species, as well as to negotiate answers to questions while performing tasks about the environment. After the field group completed two stations (from a total of 4) they returned to the base group and switched roles. Each station is represented by a birch tree in Figure 3, and the sequence in which the outdoor group went about the stations is noted by solid arrows. This gave the opportunity for all students to experience the field and base work.

![Figure 3 – Activity structure](image)

At each station the outdoor group had to describe the trees for the indoor group by using the mobile...
phones to generate content, and also to consult with them in deciding the tree species. The role of the indoor group was to support the outdoor group with relevant information using stationary computers. As these had Internet access, the indoor groups were encouraged use the Web for retrieving information for solving the tasks. A more detailed technological description is presented in the next section.

4.2 Technological aspects

As a side effect of the activity being very reliant on communication, everything needed to happen in real-time in the indoor group web based client. This is a hard thing to accomplish with regular web pages using only HTML and server side languages, thus the need for AJAX was identified to make the client on the indoor side behave as intended. The usage of AJAX based technology allowed the client to behave very much like a desktop application, and enabled the implementation of dynamically loading content created on the field by the outdoor group with their mobile phones. Since the technology budget is always an issue we chose to run the activity on standard Nokia 6630s.

The user-generated content was created via a custom built mobile application written in Python. The application supported the creation of photos and audio clips, which, upon creation, were transmitted to the ACS. Additionally, each outdoor group was equipped with an additional mobile phone for answering the questions put out on the field. The questions where triggered by the groups when scanning two-dimensional barcodes with the devices built-in camera. This particular implementation were called Semacodes and placed at strategic stations throughout the course. The use of Semacodes enabled the participants to trigger the questions in the activity.

ACS kept track of all the groups, their progress and the activity context. Each time an action was performed in the activity it was logged with timestamp and a snapshot according to the model presented in Figure 1. Content created by the participants was however redirected by ACS and sent to a content repository, where metadata belonging to the content were stored separately. If, for example, an image were submitted by one of the groups, ACS would react by calling a web service function residing at the content repository for image storage. The record on ACS would show when, and in what context, the image was created, while the content repository would store technical metadata, such as content size and image proportions.

The AJAX solution also enabled an administration page to be created, which visualized the progress of the different groups, and all of the content they had submitted in real-time. This was a great tool for monitoring the application as whole, since it was possible to follow the actions of each group in real-time, and, in the best-case scenario, correct them during the progress of the activity. Provided that the change did not have a big impact on the activity as whole. It was also a good pedagogical tool for the teachers to monitor the achievements of the participants while the activity progressed, instead of, or in complement to, analyzing their efforts after the activity was finished.

In order to handle all the user-generated content, such as photographs or audio clips, we chose to separate the content repository from ACS, since there was already a solution for this in-house. This solution also helped to ease the load on the server handling all the calls involved in the activity, and enabled us to implement other interesting functions, such as the RDF interface seen in Figure 4.

5. Test results

Each group completed the learning activity without any major technical difficulties, although some students had some trouble due to their lack of the inexperience with the technology. Detailed analysis and evaluations of the user experience and test results are reported in a recent paper published by Spikol and colleagues [7]. In section 4 we have shown how contextual metadata have been collected and managed in order to support situation-awareness learning. As ACS has the ability to generate RDF documents from the collected data, we used this feature to build a graphical interface that can be used to create learning spaces for reflection and activity monitoring purposes. A screenshot of the interface is shown in Figure 4.
photograph of a tree, which, by looking at its description, was taken on April 25th at 15:06. Furthermore, the RDF document made it possible to state valuable information such as; in which task a photograph was taken and the number of user-generated content the present group created during that task. Some user-generated content stored in the ACS was also tagged with GPS coordinates. If so, a link appeared in the web browser to a Google Map displaying the location in which the content was created. The RDF:SITE application was developed primarily to let students and teachers to visualize their results and then to reflect on the activities after they have been completed. As RDF documents can be generated at any time, they can also be used for monitoring learning activity progress.

6. Discussion & conclusion

The aim of this paper was to illustrate how ACS handled user-generated content and metadata collected during ubiquitous learning activities. This closing section highlights some issues related to the nature of our implementation and also proposes possible future lines of research.

In its current implementation, ACS does not provide for learning objects interoperability and reuse with other systems. This is because our actual learning activity ontology, based on the conceptual context model discussed earlier, is incompatible with IEEE LOM and IMS LD. The reason for us not adhering to these standards was, firstly, that we needed a rapid prototyping system for complex ubiquitous learning activities where learning activity reuse was less important than flexibility. Secondly, the predetermined metadata slots defined in the standards were considered insufficient when describing the necessary contextual and environmental characteristics that were needed, such as group progress in activities, custom metadata tags and user-generated content. The use of an in-house ontology naturally has a large impact on reusability in other systems.

As stated in section 1, standardization has proven to be a working concept for success. Duval & Hodgins [2] discussed the flexibility of IEEE LOM and compared it with a key success feature of HTML – the different HTML standards define a large amount of supported tags, while very few of them are mandatory. All of the IEEE LOM metadata slots are optional, which indeed makes it flexible for its cause. With these two in mind, the concept of optional metadata slots might be a viable solution for standardizing the representation of contextual characteristics? As such a contextual metadata standard most probably would consist of a wide range of metadata slots, a very general ontology, such as the SUMO\(^2\) (Suggested Upper Merged Ontology) ontology might be a starting point for this research. Jewiss and Clark-Keeffe [8] argue that reflection is a good way to help students examine personal perspectives in a school environment. With this in mind, more can be done around the post-activity in order to help students actually to reconstruct and to discuss what they have learned. This can also be a basis for discussion in the classroom at a later date. To promote and support this discussion a tool-set for recreating the activity still needs to be developed. This tool-set should have the ability to visualize the participant’s actions in the context of the learning activities.

7. References


\(^2\) http://www.ontologyportal.org/
Contextual Metadata in Practice

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Abstract—This article aims to survey the scene of contextual metadata annotation of digital content. This is performed through a literature review of current research, looking closer at formal context models, contextual metadata gathering and contextual metadata formalisation respectively. The findings of these efforts indicate that the reviewed context models have three elements of context in common. However, these formal models are inconsistent with the contextual metadata gathered in approaches described in the reviewed literature, in which location metadata are the most common. Furthermore, contextual metadata gathered in these initiatives end up in a variety of data structures. One reason for the dominance of location metadata might be the clear understanding of their ontological dimension. Therefore, the author introduces the notion of ontological dimensions in the area of contextual metadata. The proposed notion of conceiving contextual metadata as a set of ontological dimensions makes it possible to divide the endeavour of formalising elements of context into manageable information chunks. Through identifying and reaching a consensus of the constituent parts of these dimensions, it is the belief of the author that we are well on our way towards improved interoperability, metadata interpretability and digital content reusability facilitated by contextual metadata.

Context; contextual metadata; metadata annotation; digital content reusability

I. INTRODUCTION

With the spiralling amount of digital content available on the Internet comes the need for structure and organisation, in which metadata play a central role. Moreover, current mobile devices allow for the creation of on-the-spot digital content that can be published on the Web directly from the device. The latest integration of sensors with mobile devices creates the opportunity to associate contextual metadata, such as GPS (Global Positioning System) coordinates and environmental conditions (temperature, humidity etc.), with digital content that helps to denote the physical context in which the content was created. The notion of annotating digital content with contextual metadata is actively being researched, and it is an accepted fact that powerful retrieval of digital content can be facilitated through these kinds of metadata [1].

In 1999, Schmidt and colleagues stated that the most common contextual parameter used to approximate context and implement context-aware applications in mobile computing research was location [2]. The title of their paper, “There is more to Context than Location”, implies that other elements of context are important to consider as well. An experiment to identify what categories of contextual metadata are most useful for recalling and finding photographs has been performed at Stanford University [3]. Their findings show that the dimensions of contextual metadata with high ratings involved location and people, where data about whether the photo was taken indoors or outdoors was ranked highest. Results from their study provide a better understanding of the degree of relevance that different types of contextual metadata have for end-users managing their photo collections and underlines that other dimensions of contextual metadata besides location are important. It is worth pointing out that context is not restricted to physical context. Dix and colleagues have identified four forms of context: infrastructure context, system context, domain context and physical context [4].

The aim of this article is to review modern trends in contextual metadata annotation of digital content. The interpretation of “context” used in this article is in-line with the following definition of the word: “information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment at a specific time” [5]. While other context attributes excluded from this definition are certainly important, they are outside the scope of this study. The aim of this article is pursued through a qualitative approach in the form of a literature study. Collection of data has been conducted through searching three online research article databases for the criteria “contextual metadata”, “context metadata” and “context ontology”. Moreover, relevant articles identified through stray searches and recommended by colleagues have also been included. From this large amount of information, a set of articles which best fit the purpose of this article have been selected.

The rest of the paper is organised as follows. The next section presents the motivation behind the present efforts. The literature review, looking closer at formal context models in research, begins in Section 3. The two following sections narrow the scope to see which elements of context were gathered and how these were formalised. Section 6 discusses the findings, which is followed by the closing section containing conclusions and ideas on possible directions of future work.

II. MOTIVATION

The ability to formalise elements of context is one of the focus areas in our ongoing research within mobile and ubiquitous learning technologies [6]. Empirical data in our research are mainly gathered through conducting learning activity trials in which learners use mobile and ubiquitous
technologies to solve challenges. These challenges often require or promote the creation of digital content, such as photographs or video clips, as integral artefacts to solve tasks or as resources to promote learning through reflection in post-activity sessions. The ability to formalise elements of context and use these as contextual metadata to depict digital content is important in our research on improving content reusability. Our approach to contextual metadata formalisation has so far consisted of storing contextual metadata in a relational database structurally inspired by a definition of context [5]. When digital content is added to the system, the current state of the formal context is associated to the content object as metadata. The digital content and its metadata, formatted as RDF (Resource Description Framework), can then be retrieved to the server [7]. While our past and current efforts have successfully supported the different learning activities, we are still interested in refining them in order to improve content reusability through contextual metadata. This motivates the present literature study in which methods for gathering and formalising contextual metadata are in focus.

Three driving research questions have been identified and they served as a guide for reviewing the relevant literature. These questions are:

- What elements constitute context in formal context models?
- What elements of context are gathered when annotating digital content with contextual metadata?
- How are these contextual metadata formalised?

The first question, pursued in the following section, looks at formal context models in order to identify which kinds of elements are considered to constitute context. The following two questions, handled in Sections 4 and 5 respectively, tighten the focus to involve efforts detailing contextual metadata annotation of digital content and see if these efforts are consistent with the contextual elements considered important in the leading question.

III. CONTEXT AND FORMAL CONTEXT MODELS

The notion of context has been defined and used in different ways depending on the research discipline. One definition valid for our research field states that context is “any information that can be used to characterise the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves” [8]. Another definition describes context as “information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment at a specific time” [5]. This definition includes a model consisting of a three-layer structure with the attributes location/environment, activity/task and personal/interpersonal and involves time as an important factor.

Such definitions provide an opportunity to represent the elements of context in formal structures. Research on how to formalise elements of context is actively being investigated within the area of pervasive computing. In pervasive environments, computational entities need to adapt based on the current context, which calls for formal representations of context and contextual metadata. One of these models is an ontology-based generic context management model (GCoM), which aims to support pervasive applications [9]. This particular model consists of a set of generic entities including Person, Device, Network, Physical Environment, Activity, Location and Service, which can be extended to new entities in domain ontologies. The model has been realised using Semantic Web technologies and tools have been developed to support data reasoning. While each generic entity can be split into subclasses, the constituent parts of these are not explicit. Similarly, Gu and colleagues present another context model realised with Semantic Web technologies where there is a clear separation between generic and domain-specific elements [10]. The generic elements in this model include Location, Person, Activity and CompEntity, where CompEntity can in turn be Service, Application, Device, Network or Agent. The above initiative does not, intentionally, detail the constituent parts of their generic context elements.

An attempt to formalise the constituent parts of context is presented by Kurti [5] through the introduction of a context XML Schema that defines the structural organisation of elements in their proposed context model. This XML Schema is based upon the nodes location environment, activity task, personal interpersonal and snapshot. The first three nodes map to their context model and snapshot associates instances of these elements to a specific point in time.

In summary, all the presented models of context include the elements Person, Activity and Location related to the context definition scope of the present article presented in Section 1. The next section introduces how these models correspond to the area of contextual metadata annotation of digital content.

IV. GATHERING CONTEXTUAL METADATA

As Schmidt and colleagues stated, location was identified as one of the most frequently used parameters to gather contextual metadata. This section investigates current efforts in this direction in order to see how the situation is today. The first initiative to be described is a system supporting contextual metadata annotation of photographs called MMM (Mobile Media Metadata) [11]. In this system, contextual metadata are collected in three categories: spatial (where), temporal (when) and social (who) metadata. In practice, the MMM prototype has a camera application running on a cellular phone for taking pictures. When a photo is taken, it is sent to a server together with the cell tower identifier, date, time, user name and the main subject of the photo (the latter entered manually by the user). These metadata can then be processed in the MMM system to derive contextual metadata with a location-guessing or person-guessing algorithm. Pictures can be further annotated through a semi-automatic process where the MMM prototype offers XHTML
(Extensible Hypertext Markup Language) forms to confirm or update proposed metadata from cellular phones.

Another initiative concerning metadata annotation of digital photographs is presented by Volgin and colleagues [12]. Their approach offers automatic metadata association based on environmental data as well as manual metadata association. The network components in their system consist of environmental nodes, logical nodes and mobile nodes. The environmental nodes represent sensors responsible for generating environmental data, where environmental data are exemplified with light intensity, temperature and location by the authors. Sensor measurements are collected periodically as well as on-demand by the logical nodes, consisting of more powerful devices connected to a power supply. The final component in their system is made up of mobile nodes, which consists of mobile devices such as PDAs or cellular phones. When a photograph is created, the mobile device requests data from logical and mobile nodes within wireless range and generates metadata. Located mobile nodes are added as metadata for the image to denote users nearby when the image was taken.

Karypidis and Lalis detail a method for contextual metadata annotation of files created on mobile devices [13]. To exemplify their system, called OmniStore, a scenario involving a digital camera and a GPS navigator device is presented. Their example details how location and illumination data can be extracted and added as contextual metadata to OmniStore and describes how other types of metadata can be added to the system. Another effort incorporating location metadata, called mProducer, is depicted by Wu and colleagues [14]. The intended use of the mProducer tool is to archive and edit digital personal experiences from cellular phones equipped with a camera sensor at or immediately after the point-of-capture. Two types of contextual metadata are gathered in mProducer, namely location data from a GPS device and accelerometer data to compute the degree of camera shaking.

An alternative approach to gathering contextual metadata is introduced by Sarin and colleagues [15]. This approach integrates available resources in the ambient environment to automatically generate contextual metadata for photographs. In their semi-automatic photo metadata generation, photographs are required to be annotated with date, time and location metadata beforehand, for instance in the EXIF (Exchangeable image file format) header. These metadata are used as key pivots to extract relevant sources from the user's desktop with Google Desktop Search. The outcome is then processed in several steps, including Natural Language Processing, which ultimately results in 30 “contextual keywords” ranked by frequency. The aim of their work is to cover the Who, What, Where, When, Why and How questions about photographs, and in the present effort the authors state that answers to the Who, When, Where and Organisation questions could be extracted.

An approach focusing on the Who aspect, i.e. identifying subjects in a photograph, is presented by Monaghan and O’Sullivan [16]. They advocate using a combination of Semantic Web technologies and mobile device sensors to generate meaningful photograph metadata. In their scenario, people are equipped with at least one Bluetooth-enabled mobile device. The idea is to let the camera device scan its PAN (Personal Area Network) for nearby Bluetooth addresses to identify devices related to the photograph. The Bluetooth address of each device is then mapped to a profile on the web formalised according to FOAF (Friend Of A Friend), which is a machine-readable ontology for describing people, their activities and their relationship with other people and objects. The FOAF profile might then contain further metadata about the person and his or her social network. Monaghan and O’Sullivan claim that the Semantic Web can help solve problems in metadata annotation of photographs.

In reviewing the initiatives presented above, the statement made by Schmidt and colleagues still applies to a large extent, as location metadata are represented in the majority of the efforts. Some of the initiatives involved contextual metadata about people creating the digital content or being part of the context, which fits to the degree of relevance presented by Naaman and colleagues [3]. While the present section has focused on identifying those elements of context gathered, the upcoming section looks closer at formalisation details of these contextual metadata.

V. FORMALISING CONTEXTUAL METADATA

This section details how contextual metadata depicting digital content are formalised. Building on the efforts described in Section 3, the metadata gathered by the MMM prototype system ends up in a faceted metadata hierarchy with the root nodes Person, Location, Object and Activity [11]. In order to populate the location facet, the MMM system suggests textual representations of the location, such as city or object in the picture, after a photograph has been created based on the cell tower identifier data. The creator of the picture then has the option to add further contextual entries based on the predetermined facet categories. In the evaluation of the MMM prototype, the authors highlight an issue with ambiguity when allowing users to enter metadata as free text.

This dilemma has also been noted with the OmniStore system, in which metadata are stored as key-value pairs [13]. Two articles presented in Section 3 mention that the gathered metadata are structured in XML documents. In the work presented by Volgin and colleagues, contextual metadata end up in an XML structure consisting of the nodes “name” (file name), “time”, “loc” (location), "user" (user in proximity) and “temp” (temperature) as sub-elements of the node “picture” [12]. Their article does not contain any information about a matching XML Schema for structural constraints on the data. Metadata generated in the effort detailed by Sarin and colleagues are also formatted as XML – in their case adhering to the MPEG-7 MDS format – and stored in an XML database [15].

The above paragraph highlights that approaches to structuring contextual metadata vary. Boll and colleagues offer a potential solution, at least regarding the domain of photographs, by introducing a photo book domain model to manage photographs and their metadata [17]. Their model captures people, people’s photo collections and albums,
photo metadata and semantics. The photography metadata section of their model involves camera-specific metadata, location metadata and the possibility to add references to people depicted in the photo. The authors stress that the model should not be considered final and remains abstract, e.g. it is not clear how the association “knows” between instances of “Person” should be expressed. A solution for this is proposed by Monaghan and O’Sullivan’s idea of expressing people and their relationships as FOAF [16]. In connecting with the issue of semantics regarding metadata tags, they argue that RDF can provide a solution through its expressive machine-understandable annotations. Furthermore, the EXIF standard facilitates mobility by embedding metadata in photographs.

In summary, we can state that the reviewed efforts show much inconsistency in the formalisation of contextual metadata depicting digital content. The upcoming section discusses and reflects on the findings of the present literature study.

VI. DISCUSSION AND REFLECTION

Considering the three driving questions stated in Section 2, the findings show that formal context models share in common three concepts related to the definition of context in Section 1: Location, Person and Activity. However, these formal models are inconsistent with the contextual metadata gathered approaches described in the reviewed literature. Furthermore, Section 5 details that contextual metadata end up in a variety of, often domain-specific, data structures. Based on the findings presented in Section 4 and Section 5, location metadata still dominate the scene of contextual metadata, as this approach is described in a majority of the reviewed efforts. Overall, the reviewed articles did not present a clear case for their method of contextual metadata formalisation in terms of digital content reuse.

An overview of these findings is presented in Table 1. The column header Paper refers to a particular reference connected to a specific research effort. The header Gathered contextual metadata presents the metadata gathered in the effort described in a particular article. If this information is unavailable, the table cell contains “not applicable (n/a)”. The third column Formalisation approach provides an overview of how contextual metadata approaches are formalised in the different efforts. The purpose of the right-hand column Dimensions of Context is explained later in this section. Furthermore, the rows emphasised in grey constitute context models presented in Section 3, while a white background represents initiatives in gathering and formalising contextual metadata depicting digital content as presented in Section 4 and Section 5. The table clearly demonstrates the location-related metadata dominance, which raises the question of why these parameters are widely used.

According to Pereira and colleagues [18], the most important factor for promoting interoperability is not the representation language, but rather providing a clear definition of what a certain term means and its relationships with other factors. This ontological dimension, as the authors refer to it, demands an unambiguous understanding of which terms constitute a metadata domain. In this sense, a set of key terms in location metadata has been agreed upon – longitude, latitude and altitude – and there are standards and recommendations on how these should be formatted. One example is Keyhole Markup Language (KML), which allows for location metadata to be interoperable and understood outside domain-specific applications. Similarly, an agreement of the constituent parts – or the ontological dimension – of context would allow for more standards and recommendations promoting important features such as interoperability and interpretability to emerge.

The idea of conceptualising contextual metadata in dimensions is illustrated in Figure 1. The left-hand side of the illustration refers to metadata terms, while the right-hand side introduces the concept of dimensions of context. The association between the upper and lower ellipses denotes an inheritance relationship – location metadata are contextual metadata and the location dimension is a context dimension. Contextual metadata belong to one or several ontological dimensions, which are represented by grey ellipses on the right-hand side. As exemplified in the figure, location metadata belong to the location dimension of context. While the number of dimensions is certainly infinite, other dimensions of context might include, as Section 3 implies, dimensions such as activity and person.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Gathered contextual metadata</th>
<th>Formalisation approach</th>
<th>Dimensions of Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5]</td>
<td>n/a</td>
<td>Context model (XML Schema)</td>
<td>Location, Person, Activity</td>
</tr>
<tr>
<td>[9]</td>
<td>n/a</td>
<td>Context model (Semantic Web)</td>
<td>Location, Person, Activity</td>
</tr>
<tr>
<td>[10]</td>
<td>n/a</td>
<td>Context model (Semantic Web)</td>
<td>Location, Person, Activity</td>
</tr>
<tr>
<td>[11]</td>
<td>Cell tower id, time, user name, main subject</td>
<td>Faceted metadata hierarchy</td>
<td>Location, Person, Time</td>
</tr>
<tr>
<td>[12]</td>
<td>Light intensity, temperature, location, nearby devices</td>
<td>Domain-specific (XML)</td>
<td>Location, Lighting, Temperature, Person</td>
</tr>
<tr>
<td>[13]</td>
<td>Location, illumination</td>
<td>Key-value (Relational database)</td>
<td>Location, Lighting</td>
</tr>
<tr>
<td>[14]</td>
<td>Location, accelerometer</td>
<td>n/a</td>
<td>Location, Acceleration/Velocity</td>
</tr>
<tr>
<td>[15]</td>
<td>Location</td>
<td>MPEG-7 MDS</td>
<td>Location</td>
</tr>
<tr>
<td>[16]</td>
<td>Bluetooth address</td>
<td>FOAF (RDF)</td>
<td>Person</td>
</tr>
<tr>
<td>[17]</td>
<td>n/a</td>
<td>Photo book domain model</td>
<td>Location, Person</td>
</tr>
</tbody>
</table>

TABLE I. OVERVIEW OF THE FINDINGS IN RELATION TO DIMENSIONS OF CONTEXT
The right-hand column in Table 1 connects the findings of the article with the notion of ontological dimensions of context. Note that these dimensions are not final and serve only as an example of how different kinds of contextual metadata can be perceived into dimensions. For instance, metadata such as cell tower identification and GPS can be transformed to constitute a part of the location dimension, and user name and Bluetooth address can be converted into metadata to fit into the person dimension of context. The dilemma, which is highlighted in the column Formalisation approach, is the fact that there is no systematic approach to organising these metadata. One reason might be that several of the initiatives do not primarily focus on how to best organise the metadata. Additionally, the semantics of and possible relationship between metadata terms appear to differ from structure to structure, which has an impact on interoperability [18]. Consider, for instance, the problematic situation of mapping the term “user name” presented by Sarvas and colleagues [11] to an instance of person in the FOAF-based initiative depicted by Monaghan and O’Sullivan [16]. These both refer to a person but their ontological dimensions differ.

The proposed notion of conceiving contextual metadata as a set of ontological dimensions makes it possible to divide the endeavour of formalising elements of context into manageable chunks. To illustrate this, a hypothetical scenario can be seen in Figure 2, where a set of context dimensions is presented. Please note that the figure serves as a metaphorical example only, as the dimensions of context, their constituent parts and relationships are yet to be identified. Dimensions are represented as grey ellipses and contextual metadata belonging to these dimensions are represented as white ellipses. These dimensions can be conceived as focused sets of formal metadata specifications in which the ontological dimension is agreed upon, i.e. we know which metadata belong to a particular dimension. To exemplify this, the location metadata terms lat (latitude), long (longitude), alt (altitude) and distance are connected with the location dimension. The ellipse labelled “distance” refers to a derived metadata term denoting the physical distance between two geographical positions. As the dimensions of context focus on different aspects of the context, such as location or person, there is an opportunity to combine these to form a more complete formal representation of the context. This is illustrated with associations between dimensions. The relationship types between dimensions are not explicitly specified in the figure, as these may turn out to be very different. If we take the dimensions exemplified in the figure, the location dimension might be defined as a subset of the environment dimension. The relationship between activity and person, on the other hand, might instead consist of associations which connect persons with activities.

One promising effort in approaching the ontological dimension of person is the FOAF recommendation. Its constituent parts include name, mail, homepage, title and the possibility to associate a person with other persons or groups. Moreover, FOAF addresses problems with semantics of metadata highlighted by Sarvas and colleagues [11] and Karypis and Lalis [13] because resources in RDF are identified with unique URI (Uniform Resource Identifier) references. By identifying and reaching a consensus of the constituent parts of dimensions of context, it is the belief of the author that we are well on our way towards improved interoperability, metadata interpretability and digital content reusability facilitated by contextual metadata.

VII. CONCLUSION AND FUTURE WORK

The literature study has surveyed modern trends regarding research in the field of contextual metadata annotation of digital content. This effort has been modularised into three sections looking at context models (Section 3), which contextual metadata are gathered in practice (Section 4) and how these metadata are organised (Section 5). The findings in Section 3 show that the reviewed context models have three elements of physical context in common: Location, Person and Activity. In practice, however, these models are inconsistent with the contextual metadata gathered in the efforts presented in Section 4, which shows a clear domination of location metadata. Therefore, the statement of location metadata dominance made by Schmidt and colleagues [2] can still be considered true to a large extent. Furthermore, contextual metadata gathered in the presented initiatives ends up in a variety of structures, which has an impact on interoperability [18]. One reason for the dominance of location metadata might be the clear understanding of its constituent parts and its ontological dimension.
Based on our suggestion of ontological dimensions in the area of contextual metadata, the proposed notion of conceiving contextual metadata as a set of ontological dimensions makes it possible to divide the endeavour of formalising elements of context into manageable chunks. By identifying and formalising identified dimensions of context, it is the belief of the author that we can get closer towards improved interoperability, metadata interpretability and digital content reusability facilitated by contextual metadata. It should be stressed that the notion of dimensions of context is a suggestion and not yet a proposed ontology. We will elaborate on identifying contextual dimensions and their constituent parts in our future efforts.

In the literature review discussed, the exploration of the possible benefits of using contextual metadata has not been in focus but rather accepted as a powerful facilitator for content retrieval as stated by Ntousias and colleagues [1]. Still, the challenge of demonstrating the benefits of contextual metadata approaches in connection to digital content reusability remains. This latest fact raises the following important question: How can contextual metadata be generated in order to promote digital content reuse? In order to find answers to such a question, clear usage scenarios detailing the benefits of these kinds of metadata and their implementation in the domain of learning and knowledge production will be the focus of our coming research efforts.

REFERENCES


Paper III


*This paper received a best full paper award at the ICALT 2009 conference.*
Pinetree: a Learning Content Repository based on Semantic Web Technologies

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Abstract—During the last few years, mobile devices such as cellular phones and PDAs have become sophisticated tools for creating digital content. Moreover, their built-in or attachable sensor capabilities make it possible to derive metadata that denote the context of the user. The challenge of annotating digital content with contextual metadata is a central part of our current research efforts and the main rationale for the development of Pinetree. Pinetree is a learning content repository based on Semantic Web technologies. The aim of the article is to explore the utility of using RDF (Resource Description Framework) as a data model in a learning content repository. We describe the different components of Pinetree and illustrate its use in a specific learning scenario. Our initial results indicate that a learning content repository based on RDF can be a flexible solution for digital content storage in terms of metadata expressivity, interoperability and data distribution.

Content repository; metadata; metadata annotation; Semantic Web

I. INTRODUCTION

Concepts and ideas related to contextual metadata have been and still are key components in our past and current research efforts in the field of mobile and ubiquitous learning. Experiments in our research often take the form of learning activities in which participants use technology to solve challenges. In these trials, a large amount of user-generated content, including photographs, audio files and text messages, needs to be organised and annotated in order to improve their reusability. In our earlier efforts [1], digital content was stored in a traditional content repository and its metadata ended up in a relational database structured in pairs of key values. This approach led to several difficulties. As the structure of the data and the semantics of their relations in the relational database were implicit, thorough explanations were required to transfer this knowledge from person to person. Furthermore, the key-value structured data led to problems with ambiguity. For example, the value group1 used as group identifier in two different trials implies the same group, while in reality these were completely different.

According to Ntousias and colleagues [2], it is an accepted fact that powerful retrieval of multimedia can be facilitated through the integration of semantic and contextual metadata. This is even more important for content created on mobile devices, as such content objects are tied to their creation and usage context [3]. These statements, together with the insights of the type mentioned above, call for a change in our content and metadata storage approach. Following our previous elaborations on improving digital content reuse [1], we are currently exploring the notion of using RDF (Resource Description Framework) as a data model in a learning content repository. The outcome of this development is a learning content repository called Pinetree, in which metadata are formatted as RDF and organised according to an RDF Schema. In order to explore the utility of such a system, the aim of the present article is formulated in the following research question: what novel possibilities would the use of RDF as a data model in a learning content repository offer?

The next section contains an overview of current initiatives in line with ours and explains why Semantic Web technologies have been chosen for Pinetree. Section 3 introduces the system architecture and the RDF Schema used to organise content in Pinetree. Section 4 applies Pinetree as a learning content repository in a situated learning activity scenario. The findings are then discussed in Section 5 and concluded in Section 6 together with lines of future work.

II. BACKGROUND

The decision to use Semantic Web technologies in Pinetree is based on our past efforts and on statements made in current research. As stated by Monaghan and O’Sullivan, two problem areas in digital content annotation, in their case photographs, are expressivity and interoperability [4]. Expressivity and interoperability refer to the notion of syntactic descriptions of photographs offering very limited machine-understandable expressivity and inaccessibility of content metadata respectively. Monaghan and O’Sullivan argue that RDF is a viable solution to these issues; expressivity is facilitated through the machine-understandable nature of RDF and RDF Schema, while its application-independent syntax for data storage provides for interoperability. Furthermore, the main idea of the Semantic Web is to support distributed networks at the data level [5]. Information about a single resource can be decentralised and spread to several locations on the Web and linked together via its URI (Uniform Resource Identifier). In the context of learning, the ALOCoM ontology provides an explicit definition of Learning Objects (LOs) and their aggregated parts in order to facilitate repurposing of LOs [6]. Their ontology distinguishes between LOs, Content Objects (COs) and Content Fragments (CFs). CFs are core elements, such as text, pictures etc., while COs are made up of aggregated CFs. The COs can in turn be aggregated into an LO that
includes a learning objective. Their modular approach allows LOs to be reassembled in different constellations.

Another tool in current research relevant to the present paper is called Swecr (Semantic Web Content Repository) [7] – which is, as the name suggests, a Semantic Web content repository. It is currently under development at FZI (Forschungszentrum Informatik) in Karlsruhe, Germany. Swecr implements the SWCM (Semantic Web Content Model), which is defined as ‘[..] a content management meta-model combining the usability of the web with the expressivity and flexibility of the Semantic Web’ [7]. Sample functionality of their system includes the ability to store, annotate and retrieve binary content and XHTML documents. A particular feature is also the ability to annotate elements within XHTML documents. Furthermore, Swecr supports versioning and annotation of external web resources. SWCM and Swecr are used in the NEPOMUK project, working towards a social semantic desktop.

III. PINETREE

A first version of the Pinetree learning content repository has been implemented and is currently operational. The next section details the architecture of the system and Section 3B introduces the RDF Schema that defines the logical structure of digital content in Pinetree.

A. System architecture

Pinetree has been implemented through a combination of existing RDF and REST (Representational state transfer) frameworks, Sesame (http://www.openrdf.org) and Restlet (http://www.restlet.org) respectively, to facilitate RDF data storage and communication. The default setup of Pinetree (Fig. 1) consists of two main components, Core and REST, which are represented by the two grey boxes in the figure. Core is the main component of the system which acts as a wrapper for the RDF database and the Content storage. The RDF database contains the logical structure of content stored in the Content storage along with other types of metadata added to Pinetree. While the Core component is capable of functioning on its own, the REST component, bundled with the default setup of the system, facilitates interaction with the system over the HTTP protocol. This combination is natural, as RDF uses URIs to identify resources, but the decoupled communication and core components in Pinetree make it possible to replace or incorporate other communication components if needed.

Clients can add digital content to Pinetree through standard multipart POST requests to the REST component. After a successful request, the file ends up in the Content storage and RDF statements are added to the RDF database. The response returned from the REST component is based on the HTTP method of the request. For example, a GET method to a URI in Pinetree will return RDF data, an HTML page or the content item related to that specific resource depending on the client preference. Moreover, the REST component offers a service for performing SPARQL (SPARQL Protocol and RDF Query Language) queries on the data residing in Pinetree, returning the answer formatted according to SPARQL Query Results XML Format.

In order to make metadata management and the communication with Pinetree easier, we have developed a Java API alongside Pinetree called Forester. Forester can be included as a library in Java projects. Once the URI of Pinetree is specified in the code, Forester abstracts the communication with the system by simple function calls.

B. Pinetree core RDF Schema

The Pinetree learning content repository relies on the Pinetree core RDF Schema (Fig. 2), which defines the logical structure of content in the system. The schema is intentionally simple and applicable in other domains than learning in order to promote its reuse in other contexts. A detail which has been left out in Fig. 2 but is worth mentioning is the analogy of the name Pinetree; the alternative labels defined in the schema for the Repository, Cluster and Content classes are Tree, Branch and Cone respectively. Using this terminology, we see that content (cones) are organised in clusters (branches) in the repository (tree).

On a fresh system setup, the repository only contains an instance of the Repository class. In the Pinetree core RDF Schema, an instance of Repository is the root cluster that may contain references to Content and Cluster instances via the hasContent and hasCluster properties respectively. Digital content files are represented by instances of the Content class. The act of adding content to the Pinetree repository connects the generated Content instance to the Repository class via the hasContent property.

Besides adding content to the root cluster, i.e. uploading digital content to the learning content repository, the Pinetree core RDF Schema supports organisation of content in explicitly defined clusters. Explicit clusters are represented
by instances of the Cluster class, which are connected either to the Repository instance or to another Cluster instance via the hasCluster property. Digital content placed in explicitly defined clusters generates new instances of Content depicting their respective digital content file. This separation of content and metadata in explicit clusters makes it possible to add cluster-specific metadata for a particular digital content object. This feature is facilitated by the transitive extend property, through which metadata of a specific content object can be traversed.

Figure 2. Pinetree core RDF Schema

In comparison with Sweer, Pinetree differs quite a lot in its conceptual approach. With the SCWM model, the creators of Sweer are aiming at a model to unify the Web and the Semantic Web. Our model does not have that kind of ambition; the purpose of the Pinetree core RDF Schema is focused on the logical organisation of content. Additionally, the ability to annotate elements within XHTML documents is a particular feature of Sweer which has not yet been considered for Pinetree. Sweer also supports versioning on semantic models and content resources, which is a feature we are planning to outsource to a separate system.

In our understanding, Sweer does not support any type of user clustering of content in the repository, while Pinetree offers this through the notion of clusters. The categorisation of learning objects is something Pinetree can do, as content and clusters are annotated with such metadata. Pinetree has been conceived with flexibility in mind, which is why the implementation has not been steered towards concepts other than those in its core RDF Schema. The Pinetree content repository is fully compatible with existing RDF Schemas owing to the fact that resources in RDF can be instances of several types at once. An instance of Content can also be declared to be an instance of, for example, a class in the ALOCoM ontology. Moreover, OWL restrictions defined outside the Pinetree core RDF Schema can be applied to the metadata to infer new instance types. Therefore, the Pinetree core RDF Schema is not competing with existing learning ontologies; instead, it is meant to facilitate the organisation of content.

The description of the Pinetree system is hereby concluded; the next section applies Pinetree to a scenario in order to investigate potential novel possibilities of using Semantic Web technologies in a learning content repository.

IV. SCENARIO: BIOLOGY

The scenario is based on an actual location-based learning activity that took place in May 2007, when student teachers used mobile technology to learn about tree morphology. Students were divided into groups, which in turn consisted of two distinct groups: one indoor group in the lab and one outdoor group in the field. The outdoor group used mobile phones for conducting field observations, in which they could create audio notes, input relevant text and take photographs. Once created, the digital content was transmitted to a server, tagged with metadata, and made accessible to their respective indoor group via a stationary computer, whose responsibility was to analyze the findings. Content and metadata storage was implemented using traditional methods discussed in Section 1. The present scenario explores the notion of moving further away from these traditional methods and into the Semantic Web by exemplifying how Pinetree can act as a learning content repository in the biology learning activity. Please note that the scenario does not incorporate ontology-driven processes.

Fig. 3 illustrates a simplified RDF graph that depicts the final state of the metadata created throughout the scenario. The figure has two main parts; Pinetree represents the Pinetree system (Fig. 1) and User manager represents data stored as FOAF (Friend Of A Friend) in a user manager system. The user manager is introduced to discuss the data distribution feature of RDF. Grey ellipses in the figure represent classes and white ellipses represent instances. Furthermore, the URI of instances and the repository instance of the system have been left out of the figure for readability reasons. Prefixed ellipse labels declare a namespace; foaf stands for the Friend Of A Friend namespace, pinetree refers to the Pinetree core RDF Schema and dc is short for Dublin Core.

Figure 3. RDF data created in the scenario
The scenario begins as John and Mary are standing in front of a tree with their mobile devices. Moments before they had received instructions to take photographs of the tree and send it to their indoor group for further analysis. Through a camera application running in a mobile phone Jane takes a photo of the tree. The file is immediately transmitted to a server via HTTP along with GPS coordinates and the IMEI number of the phone. At server side, the photo is annotated with EXIF metadata and posted to Pinetree with the name photo. The data generated so far are illustrated in the rightmost section of the Pinetree part of Fig. 3. As a second step, the server sends another request to Pinetree with instructions to add an explicit connection between the photo and the existing cluster biologyTrial. This act generates the photoInTrial instance. Additionally, the server application matches the IMEI against a list of groups in the present activity to resolve their URI and adds these data to Pinetree as well. This is represented in Fig. 3 through the dc:creator property.

Sitting in front of a laptop indoors, Jane and Peter are eagerly awaiting observations made by the outdoor group. The web application running on the laptop is regularly refreshing the RDF data set provided by Pinetree via HTTP for any news. More specifically, the application fetches RDF formatted data from the URI of the cluster biologyTrial to see if there are any instances of type pinetree:Content associated with outdoorGroup1 via the dc:creator property. An alternative approach to check this would be to send a SPARQL query directly to Pinetree and parse the SPARQL Query Results XML Format returned from the repository. The web interface refreshes and a photo of a tree is rendered on the screen. Peter looks at the photo and consults a tree key provided by the teacher to determine the species of trees. Jane and Peter agree on the fact that the tree is a birch, and through an HTML form in the web application Jane enters ‘It’s a birch!’ and submits the form.

The comment is sent to the server together with the identity of the group. Matching similar to the IMEI matching is performed to identify the URI of the group, and the comment is added to Pinetree. John and Mary check the comment via a mobile phone to confirm their suspicion. Mary approaches one of the visual tags that read ‘Birch’ to complete the task.

V. DISCUSSION

The scenario has shown how Pinetree logically structures digital content with instances from the Pinetree core RDF Schema (Fig. 2). In connection with the research question of this paper, one of the novel possibilities which RDF generates is flexibility. Contextual metadata other than location metadata could easily have been added to the photo without violating any structural constraints. Furthermore, RDF provides a solution to the problem with ambiguity mentioned in Section 1. For example, outdoorGroup1 has one unique URI that refers to a specific group constellation, in this case John and Mary. This makes it possible to query the learning content repository for content related to outdoorGroup1 in different trials and activities. As visualised in Fig. 3, RDF offers the ability to merge graphs of data to expand the metadata description of the content. One potential scenario might be that John, Mary, Jane and Peter are registered users in a user manager system and grouped for the purpose of the scenario. The data instances outdoorGroup1 and indoorGroup1 then serve as connectors to merge the user manager graph and the Pinetree graph into one large graph of data. In this sense, RDF grants Pinetree powerful data distribution features by design, which would have required a lot of work to implement in our previous content repository. In order to benefit from the data distribution features of RDF, systems such as the exemplified user manager in the previous section must expose their data as RDF. Insights such as these are summarised in the coming section together with ideas on where we are heading next.

VI. CONCLUSION & FUTURE WORK

In connection with the research question of this paper, two findings related to the reuse of digital content can be summarised. The scenario depicted in Section 4 underlines that Semantic Web technologies can overcome problems in metadata expressivity and interoperability of digital content, and applies this statement in the context of Pinetree. Furthermore, the utility of the data distribution feature of the Semantic Web has been narrated through the scenario. Thus, results indicate that a learning content repository based on RDF could be a viable and multifaceted solution to support context metadata annotation of digital content in situated learning. Naturally, Pinetree needs further testing and evaluation before its utility can be measured and generalised.

On the basis of our first implementation, we have found that Pinetree is a valuable asset in the process of storing and annotating digital content. One of its most prominent features is the ability to annotate content and clusters with any kind of metadata using a W3C recommended format (RDF), and the metadata of content objects can be extended in clusters. Another aspect that the authors would like to stress is that the Pinetree learning content repository does not do any automatic clustering; instead the system supports manual clustering. Our future work will look more closely at incorporating more OWL features into the system in order to improve the ability to make inferences on the data. In terms of security, we are presently integrating authentication and authorization mechanisms for controlling create, read, update and delete permissions for content and clusters in the repository. Moreover, systems supporting the learning activities need to be able to expose their data as RDF in order to make use of the data distribution features discussed in the previous section. As a first step to pursue this we aim to implement a system similar to the user manager described in the scenario.

In the near future we plan to validate our efforts further by putting the system to the test as a component in a semantically-related provisioning system supporting several situated learning activities. This provisioning system, which has been under development during the last four months, is intended to facilitate forthcoming trials and to support visualisation of content and data relations. Provided that the
tests are successful, we are planning to investigate further the use of RDF as a data model in systems supporting our research within technology-enhanced learning. The experiences derived from this provisioning system combined with the previous efforts will be used as a stepping-stone towards providing a framework for the creation and orchestration of learning activities. The goal of this learning activity framework is to enable teachers and learning facilitators to realise and formalise their visions for learning activities and hosting them in an environment which promotes reusability and collaboration between both students and learning activity creators.

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Using contextual metadata for enhanced reusability of mobile media objects

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Abstract. Mobile phones are becoming “sensor packed devices”. With this possibilities for acquiring context has been widen. As a result of this, new computing paradigms are emerging. Moreover, mobile phones enable anyone in their possession to be a potential creator of mobile media objects. All this is having impact in the way human activities are performed and has changed the “social mobile media” landscape. The emerging mobile media objects are usually created in an unanticipated way. The challenge in these settings is the interoperability and reusability of these emerging mobile media objects. Since there is no formal control over the creation of these mobile media objects, we consider that use of contextual metadata will be beneficial for addressing the issue of reusability. Inspired from our dimensional model of context we introduce a conceptual scheme for enhancing the reusability of mobile media objects. This scheme is based upon open standards technologies such as XML, XMLSchema, RDF and RDFSchema. To illustrate the usefulness of depicting emerging mobile media objects with contextual metadata, we introduce an experimental scenario in learning domain.

Keywords: mobile devices, sensors, context, mobile media objects, reusability

INTRODUCTION

Current trends in technological (mainly mobile and ubiquitous one) developments have brought new possibilities when it comes to interaction and mobile media generation. Dix and colleagues (2004) refer to the changes in interaction that these technological trends introduced, as “continuous interaction” that has shifted computing from a “localized tool to a constant presence”. In these technology-enhanced environments with "continuous interaction" support the notion of context becomes a central concept (Huuskonen, 2009). Besides new interactions, new technologies offer wide possibilities for acquiring context instantiations. As a result of this, new computing paradigms are emerging. Cooper and colleagues (2008) suggests that these new paradigms have actually changed “the conception about what is computable”.

Mobile phones (as one representative of such technologies) are currently being perceived more than just a phone; they are now a music player, a radio, a camera, an Internet platform etc (Satyanarayanan, 2005; Ballard, 2007). Moreover with current trend of embeddings the mobile phones are beginning to be addressed as “sensor packed devices” (Nokia, 2008) and also mobile phones are perceived as devices for “context acquisition” (Zhdanova et al. 2006; Nokia, 2009). Beside context acquisition, mobile phones enable anyone in possession to be a potential content creator. All these changes in interaction capabilities, context acquisition and mobile media creation will have a strong impact in "social mobile media” landscape. These devices offer increased capabilities gaining access to different contextual instantiations that could serve as attributes for enriching the description of mobile media. Different authors (Davis et al. 2004; Karypidis and Latis, 2007; Lehikoinen et al. 2007) have been advocating the use of context instantiations for enriched description of mobile media objects in a form of metadata.

Inspired from these developments and based on the dimensional context model (Kurti, 2008) we have developed further upon these ideas with the aim to show that the increased expressivity and interoperability of contextual metadata can be useful for depicting of mobile media objects. In this paper we investigate the possibilities of using such approach to semantically enhance metadata depicting mobile media objects. As an instantiation case we illustrate the applicability of this approach with a scenario in the technology enhanced learning domain.

This paper follows with a formal definition of our research question and its relation to the application domain. It follows with a discussion of the related efforts done by other researchers in the field. Then we continue with a detailed explanation of our approach and its illustration with a scenario. In ending sections we discuss the potentials of this approach and implications for future research.
RESEARCH PROBLEM

Technological support enables that learning as a human activity to happen in both formal and informal settings. When happens in informal settings there little or not at all control over it. Nowadays learners are usually equipped with some sort of multipurpose mobile device that they use regularly in informal settings. In these circumstances every learner is a potential mobile media creator. Combination of these possibilities with ubiquitous computing environments that enable "continuous interactions" brings new possibilities for learning and experience sharing in a form of mobile media objects. The main research question in this paper will be:

"How to increase the expressivity and interoperability of contextual metadata depicting mobile media objects in technology enhanced learning environments"

In this paper we will focus in technical approaches related to digital content (i.e. media objects) created during the informal learning activities and by learners themselves. These mobile media objects are referred to in the literature as “emerging learning object” (Hoppe, 2009). Learners or group of learners usually creates these objects in an unanticipated way. Thus there is a challenge for their interoperability. Furthermore, Balatsoukas and colleagues (2008) suggest that “the lack of concrete specifications can impede interoperable exchange of content packages”. In this manner we suggest that enhanced expressivity and interoperability of contextual metadata retrieved by means of different sensors and actuators can be used for depicting of these emerging mobile media objects.

RELATED WORK

The ability to formalize elements of the physical context as metadata depicting mobile media is actively being researched. Potentially, these kinds of metadata can be used to improve the interoperability rate of mobile media by, for example, empowering search engines with more search criteria. One such approach is presented in the example of MMM (Mobile Media Metadata) prototype system (Davis et al, 2004). MMM implements a metadata creation process for photographs taken with cellular phones and automates this by incorporating metadata readily available on the phone. In their system, the reuse of the mobile media and their metadata is facilitated by similarity processing algorithms. The ability to apply algorithms and make inferences on contextual metadata has been elaborated on in a system called PhotoMap (Viana et al., 2008). The PhotoMap system is used to create metadata in key/value format to depict the context that existed when a photograph was taken. These metadata are then subject to spatial reasoning to infer new indexing terms. Another effort is the OmniStore system, which is a storage management system for Personal Area Network (PAN) computing (Karypidis and Latis, 2007). Their system contains a context management module that allows for contextual metadata annotation of mobile media formatted as key/value pairs. The actual uses of these contextual metadata are exemplified through scenarios where the OmniStore system supports mobile media delivery based on parameters such as location and person.

While efforts such as the ones above display the potential benefit of depicting mobile media with contextual metadata, concerns have been raised regarding expressivity and interoperability (Monaghan and O’Sullivan, 2006). Their view on expressivity refers to the fact that most of today’s search engines are keyword based. As keywords not in the context of a sentence may be ambiguous, the user performing the search most often needs to manually analyze the result. Moreover, as metadata often are stored in heterogeneous databases, the semantics of these and their relations are implicit for search engines. This is a serious concern in that a common understanding of the meaning of metadata terms and their possible relations has been considered the most important factor to promote interoperability (Pereira et al., 2008). A literature study on contextual metadata annotation further underlines the issue as the structure of these kinds of metadata varied between all of the reviewed efforts (Svensson, 2009). These areas of concern apply to the definition of "emerging learning objects", as these are created on the spot and there is no formal control over their creation. Thus use of contextual metadata for depicting of these mobile media object seems to be a viable approach for research.

Initially Decker et al. (2000) have been advocating for the use of XML and RDF (Resource Description Framework) for semantic interoperability. With reference to those to emerging issues, Monaghan and O’Sullivan (2006) suggest open standards based on XML technologies as feasible solution to challenges raised above. The work by Dong and Linpeng (2008) address the issues of interoperability by presenting a three-layer data model. This model consists of three levels, namely: syntactic, conceptual and semantic level. It is built using XML based technologies and addresses the issue of heterogeneous XML resources. The illustration of this layered data model is given in the Figure 1.
OUR APPROACH

Inspired from the context model (Kurti, 2008) and its serialization using XML Schemas, we propose a conceptual scheme to address the issue of contextual metadata and their applicability in mobile media objects. Our approach is built upon the layered integration model proposed by Dong and Linpeng (2008). We use XML-based technologies for conceptualizing different context instantiations serialized using XML Schemas. Due to the fact that emerging mobile media objects are created in an unanticipated way, top-down approaches cannot be used. Thus, we suggest the use of contextual metadata that would depict emerging mobile media objects. This approach could be regarded as a bottom-up approach. Our initial idea is illustrated in Figure 2.

Figure 2. Bottom Up approach

Defining syntax

Defining context has and continues to be a challenging task (Ferscha et al., 2004). In our prior research, we came up with context definition applicable in technology-enhanced learning environments. Our definition is led by the activity perspective that is scalable to computational attributes. Thus, we define context as “information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment at a specific time.” Our definition of context relies upon a three-dimensional structure. The three dimensions are: location/environment attributes, activity/task attributes, and personal/interpersonal attributes and are placed in a certain time. Inspired by dimensional analysis and the context definition, we used
dimensional data representation for modeling of context instances. Dimensions of context are defined by three pole structures and time. The time dimension becomes important especially when it comes to historical dependencies that could affect user profile (i.e. personal/interpersonal attributes), activity and its location/environment. Data representing context instantiations are retrieved using different resources (both hardware and software ones) available for context acquisitions. Contemporary devices posses multiple resources such as: GPS, different environmental sensors, accelerometers, cameras, calendar functions, tagging capabilities etc. that can be used to instantiate users context.

The dimensional analysis offered the possibility of data categorization according to the three-pole structure. Context data retrieved can be used as a metadata to enhance the depiction of mobile media objects created. The context model relies upon a time differentiated frames that through serialization can represents a fully described XML document, consisted of four nodes. The notion of serialization is a well known in the programming languages theory and it consist on the fact that an object can be represented as a stream of key/values pairs. Three nodes represent the three pole structure while the fourth node of the XML file represents the snapshot attribute (i.e. date and time). The activity node at this stage is designed applying the notions of Activity Theory for analyzing human activity (Engström, 1987). The composition of this node will evolve and we plan to use concepts related to graphML for defining this important node. Activity node is somehow more difficult to be serialized since its represent a complex social construct. The data structure based on the context model is serialized according to XML schema illustrated in Figure 3. The XML Schema provides a method to create precise descriptors that enable unambiguous declaration of data, attributes and their types. This enables syntactic definition of context data structure created with the aggregation of data collected from different sensors and actuators. This serialized XML document contains pairs of key/values of different context instantiations and as such they can be used as descriptors for emerging mobile media objects.

![Figure 3. XML schema used for serialization of context instantiations](image)

**Defining concepts**

The middle section of Figure 2, labeled Defining Concepts, illustrates the process of transforming elements in the XML Document into RDF resources. The mapping between XML elements and RDF resources is performed relating XMLSchema elements to RDF resources. The end result of this transformation is an RDF graph representing the context model instance. For example the serialized key value data of longitude and latitude and used to define the concept of Location.

The mapping between XML entities and RDF resources in our approach are based on the graph presented in Figure 4. Most of the classes and properties depicted in the figure are already defined in existing schemas, which are emphasized by a prefix in their name. A couple of new resources that we have not found in readily existing schemas have to be explicitly defined in a new RDF Schema. These resources are missing prefixes in the figure. Context is the core class whose instances binds instances of Location, foaf:Person and Activity to a specific point in time through the dc:created property. The purpose of the Location class is to depict the spatial dimension of the context through the properties geo:lat and geo:long and environmental details via the lightIntensity and humidity properties. Furthermore, the XML Schema node "Place" is translated to a title of the Location instance via the dc:title property. The next part that constitute context according to the
context model is person, in which we use the foaf:person definition readily existing in the FOAF specification. In order to match the XML Schema mapping, gender and age of persons are made explicit via the foaf:gender and age properties. Group membership is defined in accordance with the FOAF specification through the foaf:member property. The collaborationWith property has the range of foaf:Agent, which is a super class of both foaf:Group and foaf:Person. The third and last part of the context model is Activity, which has a set of subjects involved via the subjectsInvolved property. These subjects can be both persons and groups as the range of the property is a foaf:Agent.

Figure 4. Contextual metadata mapping from XML to RDF

Approaches of transforming XML documents to RDF include an W3C recommendation called GRDDL (Gleaning Resource Descriptions from Dialects of Languages). GRDDL introduces a markup for based on existing standards to specify that an XML document can be transformed into RDF via a linkage to algorithms to perform the mapping, where the mapping typically is facilitated through XSLT. By including such linkage to an XSL file in XML document instances of the context model XML Schema, the XSL transformation can produce RDF output matching the mapping as seen in Figure 4. These RDF data can then be subject to inference through RDF Schemas.

Defining semantics

The rightmost section of Figure 2 denotes the ability to combine RDF Schemas with the generated RDF. As the key idea of RDF Schema is to provide the ability to make sense of the data through inferences (Allemang and Hendler, 2008), this action facilitate conclusions to be drawn by applications. One common example seen in literature illustrates this feature through sub classes to infer class types. While RDF Schema is a powerful tool, there is an opportunity to incorporate even more meaning to the resources through defining ontology in OWL (Web Ontology Language). One of the strengths in OWL lies in dynamic class types based on the state of resources. In connecting with the context model, the resource Activity can be dynamically be typed as a ActiveActivity if the OWL ontology instance contains a definition of how an instance of Activity can be considered as active or not. Constructs such as this allow for even more inferences to be drawn by applications. In the present approach, we will not approach OWL modeling but instead focus on displaying the soundness of our approach by using RDF Schemas.

As RDF Schemas do not define any structural or syntactical restrictions by design, the RDF graph may be extended with resources not explicitly defined by the XML Schema. Therefore, in our approach, the box labeled “OWL / RDF Schema” in Figure 2 can be conceived as a combination of several RDF Schemas besides the ones defining the classes and properties in the mapping (Figure 4). Popular schemas that can be included as well are, for instance, FOAF (Friend Of A Friend), DC (Dublin Core) and SKOS (Simple Knowledge Organization System). The outcome of this process is a semantically enriched RDF graph, as can be seen in the rightmost box in Figure 2.

For the purpose of annotating mobile media objects with RDF formatted metadata we have already developed a content repository called Pinetree (Svensson et al., 2009). Related to the approach suggested in this paper, mobile media objects can be stored there together with the metadata produced during the step “Defining concepts” that were serialized from context instances as suggested in the step “Defining syntax”. Inferences on these RDF metadata are made by applications that are provided by Pinetree. The upcoming section introduces a simple use case in which mobile media content is generated and describes the metadata generation and transformation process.
USAGE SCENARIO

For explaining the usefulness and soundness of our approach we have developed a simple scenario in connection with ongoing LETS GO project. In this project we investigate the use of ubiquitous and mobile technologies to support “open inquiries” for learning in environmental domain. Based on this and inspired from guidelines regarding scenario-based design (Caroll, 2000) we have developed a realistic scenario to demonstrate the features and functionalities of our approach. With regard to the recommendations suggested by Caroll, we have defined the following characteristics for our experimental scenario:

- **Setting** – outdoors wood exploration.
- **Actors** – students
- **Goals or objectives** – To make inquiry regarding the health of the trees in the woods
- **Action and events** – Picture taking for documentation purposes,

Students of the K12 School as a part of their course regarding environmental sciences need to learn about basic concepts of ecosystems. They need to learn and understand the notions regarding the clime, biomass and soil for the nearby wood. For doing the experiment students need to take some pictures and investigate the health of the trees in that wood. For doing this inquiry they are equipped with smart phone. The wood area where they need to perform this inquiry is actually a ubiquitous computing environment that contains number of sensors to measure: humidity, temperature, pH values etc. As soon as student enters the ubiquitous environment, his/her mobile device starts a software application that will be in continuous interaction with the sensors in the environment. This interaction means that software application reads in continuous manner the values read from the sensors. Due to the inquiry nature of this field trip student needs to take pictures for documentation. When student takes a picture, application running in the mobile phone generates a snapshot of sensor values in the moment when picture was taken. These values are aggregated and stored as XML document complying with the predefined XML Schema rules. This document together with the picture taken is processed through a mobile mashup service (second stage of our approach). And in the end, the contextually enriched picture is uploaded to content repository.

After going back to class students start a discussion about their experiences while in the field trip. Moreover, while in the classroom, students need to reflect upon the data and content they have created. For doing that students have access to the historical data regarding that particular environment at the school in order to apply comparative approach to reflect upon the notion learned.

DISCUSSION

The experiment described in the previous section applies our approach in a practical example. In connecting with the research question of the present paper, the features of RDF and RDF Schema has, as discussed in the related work section, the ability to contribute to improve the expressivity and interoperability of mobile media and their metadata. Many of the resources in the mapping (Figure 4) are already defined in well-known RDF Schemas on the Web. These resources are particularly useful due to the higher possibility that various applications will understand their semantics. For other resources, such as the *Activity* class (Figure 4), we did not find any suitable existing definitions and these need to be defined in RDF Schemas. In occasions such as these it is important to define new resources as sub classes or sub properties of existing definitions if possible, or else RDF reasoners will have a hard time to make inferences. One example of this is the class *Location* declared as a sub class of `geo:SpatialThing`. As the `geo` namespace refers to a well-known RDF Schema for representing spatial data, RDF based applications have a higher probability to recognize the semantics of the data and react accordingly. One example of this would be for applications to detect spatial data formatted according to the `geo` schema to generate a map pointing out the location these data refers to. Another straightforward yet powerful mechanism facilitated by RDF Schema is to infer similarity between resource instances based on shared upper concept. For example, as the *Location* class in Figure 4 is defined as a sub class of `geo:SpatialThing`, similarity relationships can be generated between instances of *Location* and other class instances with `geo:SpatialThing` as super class.

As discussed in the previous section, the mobile media generated in the experiment is stored in a content repository called Pinetree. Pinetree organizes the mobile media using REST (Representational State Transfer) according to the Linked Data best practices (http://www4.wiwiss.fu-berlin.de/bizer/pub/LinkedDataTutorial/). The REST API allows for mobile media and their metadata to be fetched through HTTP GET requests to the URI (Uniform Resource Identifier) given to the mobile media when added to the content repository. In this way, Semantic Web browsers, such as Tabulator (http://dig.csail.mit.edu/2005/ajar/ajar/About.html) can be used to browse the data. And perhaps more importantly, the data can be subject to semantic searches using Semantic Web search engines, such as Sindice (http://sindice.com). Mechanisms such as these underlines the potential of Semantic Web technologies for improving expressivity and interoperability, and that these kinds of transformations as described in our approach are worth the while.
CONCLUSIONS AND FUTURE WORK

This paper presents our ongoing efforts related to reusability of mobile media objects using contextual metadata. The fact that there is limited and almost no control over the creation of emerging mobile media, makes their description a more complex task. Due to the technology advancements several possibilities for contextual data acquisition emerged. Use of contextual metadata proved to be a viable approach to address the issue of interoperability and reusability of emerging mobile media objects. The conceptual scheme presented and discussed in this paper presents a solid approach for addressing the syntactic and semantic heterogeneity. Use of open standard technologies XML (to define syntax) and RDF (to define semantics) as complementary techniques is inline with current research efforts in Semantic Web community. Moreover, use of XML based technologies is an advantage for mobile resources where performance is an issue. While the scheme proposes that RDF reasoning and inference to happen on the server side, thus not degrading the performance of the mobile clients. Overall with the experimental scenario it showed that there is a clear add-value of transforming syntactical context representations into semantically enriched RDF to help the issue of interoperability and reusability of the mobile media objects.

Nevertheless, since this is a work in progress there are more challenges to be addressed. This conceptual scheme brings into picture the idea of wireless sensors for context acquisition and mobile mashup services (for binding content with context). This brings numerous issues to be addressed such as: centralized vs. decentralized schema instances for syntactic integration, activity conceptualization, mobile mashup tools, architecture design etc. Some of these issues will be investigated in connection with our two upcoming projects where we will innovative solution for contextual metadata handling of digital science education objects.

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Enhancing Emerging Learning Objects with Contextual Metadata Using the Linked Data Approach

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Abstract—The latest developments in mobile technologies have increased the possibility for users to generate digital content at any location and time. In this paper we present our current research efforts related to the ability to enhance digital content that emerge when mobile devices are used to support different learning activities. We believe that these emerging learning objects should be enriched with contextual characteristics in a machine interoperable and interpretable manner in order to preserve the meaning, or semantics, of those features. There are a number of approaches to address this problem but in the present article we focus on exploring the potential added value of using Linked Data to depict emerging learning objects with contextual metadata. Our preliminary findings indicate that Linked Data offers a flexible approach for supporting important aspects of digital content related to data linkage, data merge and semantic interoperability.

Digital content metadata; Linked Data; Semantic Web; Emerging Learning Objects

I. INTRODUCTION

The increased portability and computational power of mobile devices has resulted in the fact that they are not anymore perceived as distinct objects but more as integrated tools in our everyday activities. Furthermore, technological advancements have generated a major shift referred to as "technological convergence", where the functionality of different devices has been blended to a single one. This converging technological evolution has generated, as suggested by Milrad [1], a "new mobile landscape". Mobile devices nowadays are not used for communication purposes only but also as content creation devices. They are not only perceived as phones or PDAs but they are also music players, radios, cameras, Internet platforms etc. [2]. This convergence has resulted in mobile devices becoming a central tool to support different human activities. Learning, as one of these activities, has also been subject to changes as a result of using these technologies. In our research, we have been exploring novel ways to use mobile devices to support communication and content creation in a wide range of learning activities.

Moreover, current mobile devices are increasingly enhanced with various sensor technologies (such as GPS, heart rate, etc.). Digital content created with such devices can potentially be enriched with metadata based on sensor readings. E.g., spatiotemporal and profile metadata features are commonly referred to as contextual metadata. Contextual metadata can be incorporated in queries and classifications of digital content that emerge during learning processes and activities, e.g. similarity measurements based on actions and shared interests of learners, to potentially increase the likelihood of digital content reuse [3]. Learning activities conducted as a part of our research efforts in the majority of cases were not restricted to only formal classroom settings. These trials were conducted both inside and outside of the classroom with limited or even without formal control over the digital content generated during the different activities. We refer to digital content created in this manner as "emerging learning objects" (ELOs) [4]. The limited formal control related to their creation, along with the complexity of representing contextual characteristics as metadata, makes the interoperability and expressivity of ELO metadata an important research topic.

II. RESEARCH PROBLEM

During the last four years, we have been investigating how to formalise aspects related to modelling the context in which learning activities takes place. As a result of these efforts, we have developed a context model that has been formalised as an XML Schema which can be used to validate the structure of contextual metadata [5]. Many prior studies in this field have discussed the notion of contextual metadata and its potentials [6,7,8]. Nevertheless, in one of our recent studies we concluded that there is very little consensus concerning the terminology used to describe metadata and their semantic mapping when it comes to enriching digital content with contextual attributes [9]. This insight raises the challenge of how to depict emerging learning objects with contextual characteristics in a machine interoperable and interpretable manner, so that it is possible to preserve the meaning or semantics of these features. In the scope of this paper, we define ELOs as digital media content (e.g. photographs or video clips) created during a learning activity by learners themselves with limited formal control from the teachers. In this analytical position paper we investigate if the Linked Data guidelines [10], consisting of best practices on how to expose, share and connect pieces of data on the Semantic Web, offers a viable and sound approach to address this challenge.

The following section gives an overview of existing metadata formalisation approaches in order to identify their respective strengths and weaknesses and introduces the
concept of Linked Data. Section IV illustrates our particular research problem by describing in detail how contextual metadata and ELOs were handled in one of the most recent trials conducted at our research centre. In Section V, we explore how Linked Data could have been used to depict ELOs generated during this trial, and the potential benefits of utilising such an approach are investigated. The elaborations of complementary scenarios are presented in Section VI. The final section concludes the paper with a closing discussion along with lines of future work.

III. BACKGROUND

A comprehensive survey on context modelling in ubiquitous computing environments highlights methods such as key-value models, markup scheme models and ontology-based models for contextual metadata [11]. While these should not be considered as exclusive but rather as complementary approaches, the present section aims to identify their respective strengths and weaknesses. A system supporting key-value representations of contextual characteristics can be considered straightforward to implement, however, the solution presents some deficiencies when it comes to semantic interoperability, ambiguity of metadata terms [9] and sophisticated data structuring [11]. Markup scheme models help to resolve data interoperability between systems through concept definitions in schemas. One of the more renowned technologies in this area is the XML Schema for validating the structure and syntax of XML documents. In the field of Technology-Enhanced Learning (TEL), the IEEE-LOM metadata specification (http://lsc.ieee.org/wg12/) is a popular standard for enriching learning objects with metadata to promote their reusability, discoverability and interoperability. Another approach to improve the reusability and interoperability of digital multimedia content was introduced with the MPEG-7 and MPEG-21 standards [12]. Markup standards and recommendations promote syntactical interoperability; applications can be tailored to fit the expected structure and syntax defined by the standards. In contrast, when stepping out of the terms supported by the schemas, there is a challenge to maintain the semantics of the data between systems. Moreover, the interpreting applications need to resolve eventual data incompleteness and ambiguity [11]. Considering that the amount of contextual characteristics may be infinite, it would be highly impractical, if not impossible, to define a metadata standard with fixed slots supporting all imaginable contextual characteristics.

Other approaches in the field of context awareness involve the representation of context attributes as instances of classes defined in ontologies [11]. Technologies frequently seen in research efforts using an ontology-based approach are OWL (Web Ontology Language) and RDF (Resource Description Framework) Schema, which provide a basis for creating ontologies that can be used to define entities in the world and how they are related [10]. Ontologies can help to address semantic interoperability and ambiguity issues in that they constitute “a formal, explicit specification of a shared conceptualization” [13] and have been considered promising for context modelling in ubiquitous computing environments [11]. One of the main challenges raised regarding ontologies is the tight bond between interoperability and a shared conceptualisation. People use terms differently and ontologies tend to overlap, creating one of the major bottlenecks in semantic integration [14] and interoperability among domain ontologies [15]. Common recommendations are to use classes and properties defined in well-known ontologies or to define new concepts as specialisations of existing classes and properties, which increase the likeliness for “smart” applications to be able to interpret the meaning of the data and to infer new relations between them.

Several research initiatives have shown that the promising features of ontology-based approaches can be applied in field of learning. Aroyo and Dicheva [16] provide an analysis of research trends concerned with the development of a homogeneous e-learning web space and they state that the vision of the educational semantic web propagates interoperability, reusability and shareability. Furthermore, Jovanovic and colleagues describe a research effort applying ontologies in the domain of learning [17], and Nešić and colleagues present a novel approach in which Semantic Web technologies are used to enhance office documents with semantic and social context metadata [18]. When compared to the key-value and markup scheme models, the ontology-based approach support flexible and semantically interoperable metadata and can therefore be considered sound to address the research problem of this paper.

Resources on the Semantic Web are defined as URIs (Uniform Resource Identifiers), which, if formatted as HTTP URIs, can facilitate data integration via the readily existing infrastructure of the Web. This feature is connected to the concept of Linked Data [10], which contribute to interoperability aspects of Semantic Web applications in that they provide a basic recipe for publishing and connecting data using the infrastructure of the Web while adhering to its architecture and standards [10]. Related to the notion of reusability, Bojars and colleagues exemplify how the generic infrastructure for interchange, integration and creative reuse of structured data facilitated by Semantic Web technologies can be used to interconnect data in Web 2.0 community sites [19]. In order to investigate the potential added value of using the Linked Data approach to support our current research efforts in the domain of TEL, the upcoming section concretises and illustrates the nature of our research problem by describing how contextual characteristics of the learning environment and activities were handled in one of our most recent trials in the field of tangible math supported by mobile technologies.

IV. GEM Trial

One recurring challenge we have been facing during the last years is directly related to the research problem formulated in Section II; ELOs that learners have created “on the fly” usually ends up in a content repository and are rarely (if ever) reused after the various stages of a learning activity are completed [20]. The activity outlined and illustrated in the present section was conducted within the scope of the
Geo Mathematics (GeM) project, an effort aiming to promote and enhance collaboration in the field of geometry by enabling learners to engage in mathematical activities across diverse settings through the use of mobile and ubiquitous technologies. This particular trial took place at the vicinity of Linnaeus University campus in May 2009, in which students explored and solved mathematical tasks related to geometrical concepts such as height, perimeter, area and volume. These activities were conducted in order to think about how to design a new building for the university [21]. The students, aged 11 to 14 years, were divided into groups and equipped with GPS and camera enabled mobile devices to perform geospatial measurements of the real world and digital pens to annotate and describe their actions.

In one of the assignments, the students were asked to measure the height of the Teleborg castle located on campus and submit their answer via an application running in the mobile phone in order to proceed further in the activity flow. The students had in beforehand been taught how to apply different methods to conduct various physical measurements, e.g. geometrical projections using a wooden stick. They also had the option to use a mobile application we developed for requesting the geographical distance between two of the mobile devices. Throughout the activity, one of the students in the group documented their progress with a camera phone, which, upon taking a photograph, directly sent the ELO together with GPS sensor readings and the IMEI (International Mobile Equipment Identity) of the phone to various repositories, including Flickr. The answers given by the group and their progress throughout the activity were logged in an XML document residing at a central server. Figure 1 below illustrates one of the activities of this trial.

According to the definition provided earlier in Section I, the photographs created by the students throughout the learning activity can be classified as ELOs. Location metadata were embedded in the EXIF (Exchangeable Image File Format) header of the photographs, and can therefore be considered as interoperable and interpretable by different systems. However, the IMEI number of the phone set as image title on Flickr can be considered quite the opposite; consumer applications need to be aware that the image title should be interpreted as an IMEI number to make proper use of it. Moreover, large amounts of contextual characteristics generated by sensors and actions of the participants involved in the learning activity could potentially have been transformed into metadata in order to enrich the different ELOs. For example, the creator of a particular photograph, the people nearby when it was created and the current task the creator was engaged in could have been formalised to further depict the photograph. For the implementation of this particular experiment, the small number of contextual attributes present in the log was not validated with a corresponding XML Schema. Thus, the semantics of the data were implicit and there were no machine-interpretable associations between the ELOs created and the data in the log. While trying to connect the ideas presented above with our particular research problem, it can be claimed that the approach used in this trials and described in this section limits the use of contextual metadata to improve the likeliness of ELO reuse due to few, separated and ambiguous contextual metadata.

The upcoming section introduces a conceptual model that will be use to exemplify how the contextual attributes generated in the GeM trial could have been formalised as linked data. The potential benefits of such an approach are then investigated in the scenarios presented in Section VI.

V. A LINKED DATA APPROACH

An illustration of the conceptual model using Linked Data to which we apply the trial presented in the previous section is shown in Figure 2. The circles in the figure represent Linked Data endpoints in three different systems with clear separation of concerns: a content repository, a user manager and a task manager. While e.g., a task manager system most likely has ability to control the flow of tasks in an activity, the proposed conceptual model below focuses on the data residing in these three systems. The arrows in Figure 2 denote data linkage between and within the involved systems to be described further on in this section.

![Figure 1. Students in the GeM trial](image1.png)

![Figure 2. Conceptual Model using Linked Data](image2.png)

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The content repository is responsible for storing and representing the conceptions of ELOs that are created throughout learning activities, i.e. metadata of ELOs, as well as the actual files. An initial implementation of the content repository node in this conceptual model can be found in [22]. The user manager manages users and groups participating in trials while the task manager controls the progress of participants in the learning activities. Each of these systems expose their data according to the Linked Data guidelines, as represented by pointed lines in the figure, and are interlinked via the data level using HTTP URIs. Please note that the conceptual model described in Figure 2 is elaborative and should be regarded only as basis for investigating the potential of Linked Data in the present paper. For the purpose of the current discussion, we assume the user manager have been populated with instances of foaf:Person that have been divided into groups via linkage to instances of foaf:Group from the FAOF (Friend Of A Friend) ontology. Similarly, instances of activities and tasks have been added to the task manager. As the students perform actions and progress in the learning activity, data are continuously added, generating linkage between the involved Linked Data endpoints.

Whenever the student responsible for documenting the learning activity takes a photograph, it is uploaded to the content repository and appropriate RDF statements are generated in the Linked Data applications to create linkage between the systems. For instance, the linkage between an ELO, in this case a photo, and its creator may be expressed via the foaf:made (and/or the inverse foaf:made) property. This can be seen in Figure 3, which illustrates a simplified instantiation of the conceptual model illustrated in Figure 2. Such data linkage enables Linked Data browsers to navigate seamlessly between the interconnected systems.

In Figure 3, the involved Linked Data applications are represented as dashed rectangles in which ellipses and rectangles denote class instances and literals respectively. Resources in the applications are illustrated with names instead of URIs for readability reasons, and their numbers have been kept to a minimum to promote clarity. Moreover, data types of instances have intentionally been left out, as the purpose of this section is not to propose a new ontology but rather to show the potential benefits of using the Linked Data approach in the field of TEL environments. Where prefixes are missing in the figure, the resource type either needs to be defined in an ontology or be replaced with an appropriate definition in readily existing ontologies. While not made explicit in the figure, there are inverse links between resources residing in separate systems, e.g. foaf:made and foaf:maker, where possible.

As we can see in Figure 3, the conceptual model described in Figure 2 has been integrated via the data level. Having in mind the research problem presented in Section II, the semantics of the contextual attributes are preserved through the use of classes and properties defined in ontologies. While the foaf:made link has already been discussed, the person_nearby links a photograph, photo1 in this particular case, to an instance of foaf:Person, joe, in the user manager. As the devices used in the scenario were able to communicate with each other, the GPS position of nearby mobile devices can be retrieved whenever a photograph is taken. The linkage is then added to the involved systems and this is preformed through a mapping between the IMEI number and the URI of the user of the device. In order to associate an ELO with the task in which this object has been created, the created_in property is used as an example of how to achieve such linkage. Similarly, the participant property connects a certain task, in this case GeM_task1, with a certain group, namely group1.

Measurements in a particular task are linked via the hasMeasurement property, e.g. measurement1. In this case, the measurement consists of the height of the castle, specified by the subjectOfStudy property, at a certain point in time denoted by the dc:created property. Figure 3 exemplifies how linkage to external Linked Data applications such as DBpedia (http://dbpedia.org) can be performed via the subjectOfStudy property. The potential benefits of the Linked Data approach described in this section are elaborated on in the next section in a set of use cases.

VI. ILLUSTRATIVE SCENARIOS USING THE LINKED DATA APPROACH

In order to investigate the potential added value of Linked Data in connection to our research problem, the three coming sub sections outline one scenario each to illustrate its potential and to exemplify its usefulness. The last sub section contains some general points and a summary of the findings based on the ideas presented in the scenarios.

A. Scenario 1

A teacher is interested in searching for information and ELOs related to various measurements of the Teleborg
castle. One option is to use a web browser to traverse the data available at the Linked Data endpoints illustrated in Figure 2. In accordance to the Linked Data guidelines, the preference of the client decides whether an HTML or RDF representation of the resource is returned when dereferencing the URL, and in his/her case the browser would display an HTML representation of the data. While browsing the data in this manner is rather tedious and not very human readable, he/she can instead choose to use existing Linked Data browsers available on the Web, such as Tabulator or Marbles. Another option to support cases like this one is to develop custom applications more tailored towards the conceptual model in Figure 2. There are readily existing libraries and tools that can be used or adapted for this purpose that make use of the powerful mechanisms in RDF. One of these mechanisms is graph merge, which facilitates the aggregation of data belonging to two or more linked resources allowing the description of a resource to evolve and be further enhanced. This facilitates an opportunity to better understand the role of a resource in the larger whole and to perform queries on aggregated resources. Thus, the metadata of ELOs does not need to be centralised in the content repository but may instead be distributed over several systems.

The teacher decides to use an application tailored to represent the data according to the conceptual model described in Figure 2. The interface provides the option to display measurements based on the study subject. After selecting “Teleborg castle”, the interface details that the castle has been subject to nineteen measurements, where thirteen of these were performed in the first task of the GeM trial, GeM_task1. He/She can see that the other five measurements were a part of another activity in which the area of the castle had been calculated, as the property area was used instead of height as a link to its value. Via the graphical interface, the teacher decides to view all ELOs related to his/her current selection.

It is important to point out that the application described above does not need to implement constructs for modelling data linkage, data merge and support for semantic interoperability, as these are integral mechanisms provided by the Linked Data technology stack. This can be put in contrast with the setup described in section four, in which the connection between the log file and content on Flickr most likely would be fit to one application exclusively and not understood by others as the semantics of the data are implicit.

B. Scenario 2

Another teacher wants to retrieve ELOs related to a student named Joe. By using again the tailored application introduced in the previous scenario, the teacher can see via a human readable representation of the link person_nearby that while Joe did not create any ELOs himself during the GeM trial he was nearby group1 when the photograph was taken. He/She takes a look at the picture, which depicts the Teleborg castle with Joe and another student, Mary, standing in front of it. As the application supports annotation of ELOs, the teacher adds a link between the resource Mary in the user manager and the photograph via the person_nearby property. After refreshing the interface it is clear that there are now four persons related to the photograph photo1, and their properties clarify in which way they are related: Nick is the creator, Jane was in the same group as Nick and Joe and Mary was nearby when the photograph was taken.

This scenario shows that classes and properties can be added to the Linked Data application without the risk of violating any structural and syntactical constraints. As RDF Schema and OWL are not intended to structurally and syntactically validate data as e.g. the XML Schema, RDF contribute with valuable flexibility when enriching ELOs with unanticipated metadata. Moreover, as class instances in RDF can be uniquely identified with URIs, ambiguity concerns are automatically addressed and the instance can be reused. For example, if Mary participates in future learning activities supported by the system, the data will make explicit that it is the same Mary who was nearby when a particular photograph was taken in the GeM trial.

C. Scenario 3

At a later stage of the learning activity and back in the classroom, the teacher instructs his/her students on how to use the tailored application in order to reflect on what they have learnt during the various trials. He/she asks the students to produce a multimedia presentation. Mary starts by filtering all ELOs related to her activities in one way or another using a geographical map interface presented in the application. The application informs her that she has created nine photographs, four video recordings and that she was nearby when eight other photographs were generated. She selects one of the photographs she had created during the GeM-trial and puts it in her presentation, along with reflections about how the trial helped her to improve her understanding of some aspects related to geometry. The interface informs her that the photograph was created just after her group had performed the height measurement of the castle, and she added a sentence to the slide concerning the result of that particular measurement. As there was still some space left on the presentation slide, she decides to look up more information about the castle itself. The subjectOfStudy link to DBpedia allowed her to directly interact with the tailored application to access more information about the castle. Mary learned that the castle was built as late as in 1900 and decides to add this information to her slide, and proceeds preparing her next slide.

This latest scenario exemplifies how the Linked Data approach can provide semantically rich contextual representations of learning activities to improve the likeliness of ELO reuse. While the data concerning the Teleborg castle is not directly related to the ELO photo1 as described in Figure 3, they can be considered to contribute to the understanding of its purpose in the larger whole. In the next section we summarise our findings based on the ideas and concepts described in the scenarios above.

D. General Points

Aside from the features lifted in relation to the scenarios, another strong argument for the choice of Linked Data stems
from the fact that it is an ontology-based approach, which inherently contribute with mechanisms to promote semantic interoperability and means to address data ambiguity. In this respect, ontologies for modelling learning designs and participants of learning processes are readily available on the Web, e.g. LOCO [17] (Learning Object Context Ontologies), which could be suitable for the Linked Data endpoints in the task manager and the user manager in Figure 2. Another valuable feature of ontology-based approaches is the ability to derive new ELO metadata through reasoning.

Throughout the different scenarios, we have seen examples of how semantically rich descriptions of ELOs can be utilised to promote the likeliness of their reuse. In connection to our research problem, this paper provide some initial indications that the Linked Data approach seems to be a promising solution to depict ELOs with contextual metadata. This indication is based upon the unique features described in the different scenarios. Those aspects are summarised in the following points:

- Applications using the Linked Data approach do not need to implement mechanisms for data linkage, data merge and support for semantic interoperability, as these are integral mechanisms provided by the Linked Data technology stack.

- In contrast to the structural and syntactical constraints provided by the XML Schema, RDF Schema and OWL offers valuable flexibility for enriching ELOs with unanticipated metadata.

- Applications adhering to the Linked Data guidelines expose resource data via a generic interface provided by the HTTP protocol, which promotes interoperability of distributed data.

The coming section discusses our view related to the possible added value of Linked Data and how this approach can contribute to support our future research and development. We conclude with highlights that describe some challenges directly associated to this approach along the coming lines of our future work.

VII. DISCUSSION AND FUTURE WORK

The potential impact of contextual metadata have on improving the reuse of ELOs is an insight we have gained from our past and ongoing research projects within the field of TEL with a focus on mobile learning. Compared to our current technological support for enriching ELOs with contextual metadata as described in the GeM trial, the implementation of a system infrastructure (based on the proposed conceptual model) interconnected via data linkage would provide a richer description of content based on the points summarised in the previous section. Our ongoing efforts in this direction have resulted in an early implementation of the content repository node (Figure 2) called Pinetree [22]. In Pinetree, ELOs can be annotated with RDF formatted metadata in accordance with the Linked Data guidelines. Our coming steps toward the implementation of a learning environment with new tools and applications inspired by the ideas presented in this paper include the realisation of the two remaining nodes as described in Figure 2. Our goal is to implement such a system in a near future in order to validate our approach and ideas described in this paper.

Overall, we consider Linked Data a promising approach for depicting ELOs with contextual metadata. Still, there are a couple of relevant challenges that have to be considered in our coming research efforts in order to improve the reusability of emerging learning objects. As the context constantly change throughout the learning activities, snapshots of the context are necessary in order to correctly represent the activity state and group constellations that are present at the moment an ELO was created. Another challenge related to the distributed nature of Linked Data is how to perform queries and assertions when relevant data are spread out over several distributed systems. Moreover, another relevant questions are; how do we control CRUD (Create, Read, Update and Delete) operations on resources in our Linked Data applications and still maintain interoperability between such systems? And what about authentication and authorisation regarding sensitive resources? While several of these aspects, e.g. privacy concerns, are not within our area of expertise, they constitute important research topics that need further attention in order to realise the vision of the Semantic Web.

REFERENCES


