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Celestijnenlaan 200 A — B-3001 Leuven

AN ARCHITECTURE AND FRAMEWORK FOR FLEXIBLE REUSE OF LEARNING OBJECT COMPONENTS

Promotoren :
Prof. Dr. ir. E. DUVAL
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Proefschrift voorgedragen tot
het behalen van het doctoraat
in de ingenieurswetenschappen

door

Katrien VERBERT

February 2008

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Preface

Barriers and enablers for the reusability of learning objects are important research topics in the learning technology community. In various publications, it is argued that reuse not only saves time and money, but also enhances the quality of digital learning experiences, resulting in efficient, economic and effective learning.

It is commonly accepted that there is an inverse relationship between the size of a learning object and its reusability. Fine-grained learning objects or learning object components have the potential to be flexibly assembled into new learning objects, whereas entire courses are often not suitable for use in a different context.

Many shared learning objects are coarse-grained and therefore difficult to reuse. Typically, authors reuse parts of a learning object by copy-and-paste actions. This method of reuse is possible in any authoring tool, but is limited in several ways: the approach is non-scalable in terms of maintenance, tends to be error-prone, and due to its inherent monotony, easily becomes both bothering and time consuming.

To support learning object reuse in a more methodological way, a component-based reuse approach is investigated in this dissertation. A number of interrelated fundamental research issues are investigated: (1) a learning object content model, that identifies different kinds of learning object components at different levels of granularity; (2) a component architecture that enables structuring of composite learning objects; and (3) the processes of aggregation and disassembly, to produce composite learning objects and to isolate their components, so as to enable automatic reuse of learning objects that were originally produced as aggregates.

Interoperability aspects are strongly emphasized throughout this work, as the interoperation of learning objects is critical in the creation of a global component architecture for learning objects. The ultimate goal is a learning object economy characterized by searchable repositories of reusable learning objects that can be exchanged and reused across various learning systems.

The dissertation is organized as follows: Chapter 1 introduces the learning object domain and presents challenges and issues impeding learning object reuse on a global scale.

Chapter 2 presents the generic ALOCOM content model that defines learning object granularity in a precise way. A number of learning object content models have been reviewed that define learning objects and their components. Based on a comparative analysis, the content models have been mapped to the generic ALOCOM model to enable their interoperability.

Chapter 3 presents the RAMLET reference model for structuring of learning objects. The reference model enables interoperability between different content packaging specifications that define the structure of a collection of learning content. A common nomenclature and conceptual model have been defined and crosswalks among various content packaging specifications that enable their interoperation.

Chapter 4 presents the ALOCOM decomposition and aggregation framework for learning objects. The framework automates learning object reuse by enabling on-the-fly access to learning object components contained in composite learning objects. Prototypes of tools have been developed to validate the approach. Plug-ins for Microsoft PowerPoint, Microsoft Word and the Reload Editor integrate learning object reuse in the workflow of authors.

Chapter 5 presents user and quality evaluations that validate the approach. The goals of the evaluations were threefold: (i) to assess the efficiency and effectiveness of the approach for reusing learning objects; (ii) to assess the subjective acceptance of the ALOCOM plug-ins; (iii) to determine to which level of granularity decomposition is relevant.

Finally, Chapter 6 concludes this dissertation with a summary of contributions, a discussion on the possible impact of the research, and an exploration of the potential it offers for future research.

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The work on this dissertation has been extensive and sometimes challenging, but in the first place exciting, enlightening, and fun. Without help, support, and encouragement from several persons, I would never have been able to finish this work. It is now my great pleasure to take this opportunity to thank them.

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Contents

List of Acronyms

ADL	Advanced Distributed Learning
ALOCOM	Abstract Learning Object Content Model
ARIADNE	Association of Remote Instructional Authoring and Distribution Networks for Europe
CMI	Computer Managed Instruction
IEEE	Institute of Electrical and Electronics Engineers
IMS	Instructional Management Systems
IMS CP	IMS Content Packaging
ISO	International Organization for Standardization
LMS	Learning Management System
LOM	Learning Object Metadata
LOR	Learning Object Repository
LTSC	Learning Technology Standards Committee
METS	Metadata Encoding and Transmission Standard
MPEG	Moving Pictures Experts group
MPEG-21 DID	MPEG-21 Digital Item Declaration
MPEG-21 DIDL	MPEG-21 Digital Item Declaration Language
NLII	National Learning Infrastructure Initiative
OASIS	Organization for the Advancement of Structured Information Standards
OWL	Web Ontology Language
RAMLET	Resource Aggregation Model for Learning, Education and Training
RDF	Resource Description Framework
RELOAD	Reusable eLearning Object Authoring & Delivery
RTS	Runtime System
SCORM	Sharable Content Object Reference Model
SQI	Simple Query Interface
W3C	World Wide Web Consortium
XML	Extensible Markup Language
XSLT	Extensible Stylesheet Language Transformation

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Chapter 1

Introduction

David Wiley [Wiley, 2002] captured the essence of the learning object approach when he observed that:

> "...the fundamental idea behind learning objects is that instructional designers can build small (relative to the size of the entire course) instructional components that can be reused a number of times in different learning contexts."

The idea of small, self-contained, reusable components that can be aggregated with other components has been adopted from object oriented programming [Sosteric and Hesemeier, 2004]. Boyle [Boyle, 2003] elucidates the approach by identifying software engineering design principles that have direct relevance to the development of learning objects:

- The first principle is *cohesion*: each unit should do one thing and only one thing [Sommerville 2000]. A direct link can be made to the idea of learning objectives in pedagogical theory. The mapping suggests that each learning object should be based on one learning objective or clear learning goal.

- The second principle is *minimized coupling*. This principle states that the unit (software module/learning object) should have minimal bindings to other units. Thus, the content of one learning object should not refer to that of another learning object in such a way as to create necessary dependencies.

Both principles are crucial in design for reuse [Boyle, 2003]. The principle of cohesion helps to decide how to partition learning content into reusable components. This process is often referred to as "granularization", and refers to both the size of the learning object and the decomposition process. The goal of this dissertation is to investigate granularization as a basic underlying principle of the learning object paradigm. Before going into the details of challenges and issues impeding the approach, the learning object domain is briefly introduced.

The chapter is organized as follows: Section 1.1 outlines learning object definitions. The concept of learning object metadata and learning object repositories is presented in Section 1.2 and Section 1.3. Important learning object standards are outlined in Section 1.4. Section 1.5 summarizes challenges and issues that are tackled in this dissertation. Finally, Section 1.6 provides an overview of the subsequent chapters.

1.1 Learning Object Definitions

There are many definitions of learning objects. One of the first definitions, defined by the IEEE Learning Technology Standards Committee [IEEE, 2002], states that a learning object is "any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning".

David Wiley argues that this definition is too broad, because it "fails to exclude any person, place, thing, or idea that has existed at anytime in the history of the universe". He suggests a more refined definition as "any digital resource that can be reused to support learning" [Wiley, 2002].

Other definitions focus on the components of the learning object: a learning objective, a unit of instruction, and a unit of assessment [L'Allier, 2003]. The Wisconsin Online Resource Center uses a time element in its definition and defines learning objects as smaller units of learning, typically ranging from 2 minutes to 15 minutes [Chitwood et al., 2000].

Although there is no generally accepted definition, there is common consensus that a learning object should be [Rehak and Mason, 2003]:

- Reusable - can be modified and versioned for different courses;
- Accessible - can be indexed and retrieved using metadata;
- Interoperable / portable - can operate across different hard/software;
- Durable - remains intact across upgrades of hard/software.

These characteristics are often referred to as the RAID principle. Similar characteristics are defined by Downes [Downes, 2004], who argues that learning objects are, or ought to be:

- sharable: may be produced centrally, but can be used in many different courses;
- digital: can be distributed using the Internet;
- modular: capable of being combined with other resources;

- interoperable: capable of being used by different institutions using different tools and systems; and
- discoverable: users can easily locate the object.

These attributes are a useful starting point in the context of this dissertation. Discoverability of learning objects is enabled by learning object metadata (Section 1.2) and learning object repositories (Section 1.3), as illustrated in the mind map of Figure 1.1. Interoperability and sharability are the main objectives of important standardization work in the e-learning domain. Important standards with respect to these characteristics are briefly described in Section 1.4. Modularity is discussed in Section 1.5.

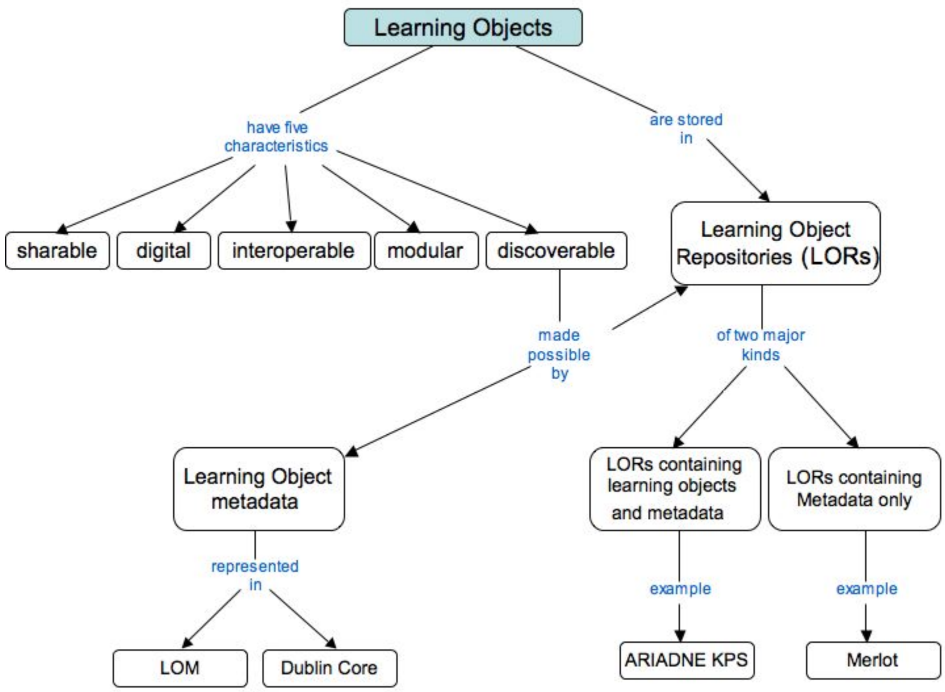


Figure 1.1: Overview (based on [Downes, 2004])

1.2 Learning Object Metadata

Learning object metadata are a schema used for describing learning objects. The purpose of learning object metadata is to support discoverability of learning objects, and hence to facilitate their reusability.

The IEEE Learning Object Metadata (LOM) standard [IEEE, 2002] is the primary standard for the description of learning objects [Wiley, 2007]. Relevant attributes of learning objects to be described include: type of object, author, owner, terms of distribution, format, and pedagogical attributes, such as teaching or interaction style. The elements are organized into nine categories:

1. General: description of the learning object as a whole;
2. Lifecycle: the history and current state of the learning object;
3. Meta-Metadata: information about the metadata instance;
4. Technical: technical requirements and characteristics;
5. Educational: educational and pedagogical characteristics;
6. Rights: intellectual property rights and conditions of use;
7. Relation: the relationship with other learning objects;
8. Annotation: comments on the educational use of the learning object;
9. Classification: relation to a particular classification system.

Some e-learning initiatives use the Dublin Core metadata element set (DCMES) [Weibel et al., 1998] for the description of learning objects. DCMES is an ISO standard for metadata, intended for cross-domain resource description. The metadata standard includes two levels: Simple and Qualified. Simple Dublin Core comprises fifteen elements: *title, creator, subject, description, publisher, contributor, date, type, format, identifier, source, language, relation, coverage* and *rights*. Qualified Dublin Core includes three additional elements (*audience, provenance* and *rightsholder*), and a group of element refinements that make the meaning of an element narrower or more specific.

The education working group [Weibel and Koch, 2000] of the Dublin Core Metadata Initiative is developing education specific elements, element qualifiers and controlled vocabularies to be used with DCMES for describing educational materials. Among others, the DC-Education proposal recommends the use of three elements from the LOM metadata standard: *Interactivity type*, *Interactivity level* and *Typical learning time.*

1.3 Learning Object Repositories

Learning objects are stored in databases called learning object repositories. There are two major types of such repositories: those containing both learning objects and learning object metadata, and those containing metadata only. In the latter case, the learning objects themselves are located at an external location and the repository is used as a tool to locate learning objects. These repositories are often called referatories. In the former, the repository may be used to both locate and deliver the learning object [Downes, 2004].

Two major models for learning object repositories exist. The most common form is a centralized form in which learning object metadata are located on a single server. An alternative model is distributed, in which learning object metadata are contained in a number of connected servers.

The following are examples of learning object repositories:

- Multimedia Educational Resource for Learning and Online Teaching: Merlot [Cafolla, 2002] is a centralized repository containing metadata only and pointing to objects located at external locations. Merlot uses its own metadata format for the description of learning objects.
- Campus Alberta Repository of Educational Objects: CAREO [Friesen and McGreal, 2002] is a centralized collection of learning objects intended for educators in Alberta, Canada. CAREO contains metadata and provides access to learning objects located on external web servers. CAREO uses the LOM standard for the description of learning objects.
- Education Network Australia Online: EdNA Online [Adcock et al., 2000] is an Australian centralized referatory. EdNA Online uses a metadata format that is based on DCMES.
- ARIADNE Knowledge Pool System: The ARIADNE Knowledge Pool System (KPS) is a distributed repository of learning objects and associated metadata [Duval et al., 2001]. ARIADNE uses the LOM standard for the description of learning objects.
- Edutella: Edutella [Nejdl et al., 2002] is a distributed peer-to-peer repository, containing metadata only. The referatory relies on an RDF binding of LOM.

Current research on learning object repositories focuses, amongst others, on learning object discovery [Ochoa and Duval, 2006] [Orzechowski et al., 2007], interoperability between repositories [Hatala et al., 2004] [Prause et al., 2007], and long-term preservation [Lorie, 2001]. Research on long-term preservation is concerned with archival of both content and programs that read the content, such that they will still be readable somewhere in the future. Interoperability research focuses on connecting and using learning objects located in heterogeneous and unaligned repositories. For instance, through the Simple Query Interface [Ternier and Duval, 2006], a protocol for searching repositories, the ARIADNE KPS, Merlot and EdNA Online are currently interconnected. Finally, research on discovery of learning objects is concerned with user profiling for more accurate learning object discovery [Orzechowski et al., 2007], enhanced search mechanisms [Zimmermann et al., 2007], ranking and recommendation of learning objects [Ochoa and Duval, 2006] and information visualization techniques to enable flexible and efficient access to learning object repositories [Klerkx et al., 2004].

1.4 Standardization Efforts

This section provides an overview of major organizations that contribute to the development of e-learning standards: IEEE LTSC, IMS, ADL, and ARIADNE. Important standardization efforts with respect to learning object reusability and interoperability are briefly described.

1.4.1 IEEE LTSC

Since 1996, the IEEE Learning Technology Standards Committee (IEEE LTSC) [IEEE, 2002] develops internationally accredited technical standards, recommended practices, and guides for learning technology. The LOM standard is the most widely acknowledged IEEE LTSC specification. IMS, ADL and ARIADNE use LOM elements and structures in their specifications.

In addition to LOM, the LTSC is in the process of developing standards for a variety of learning technology aspects:

- Digital Rights Expression Languages (DREL): A Digital Rights Expression Language is a way of expressing and managing conditions and permissions of learning objects. By standardizing such information, the rights assigned by an author or publisher to a learning object may be preserved across a variety of systems where the object may be used.

- Computer Managed Instruction (CMI): The Computer Managed Instruction working group is developing a multi-part standard that covers, amongst others: describing course content, organizing and sequencing individual lessons in a single course, course management software, and communication between CMI software and lessons.

- Reusable Competency Definition (RCD): This standard defines a data model for describing, referencing, and sharing competency definitions, primarily in the context of online and distributed learning.

Of interest in this dissertation is the CMI work, as it includes the development of standards that will enable lessons, that are developed with different tools by different people, to be brought together and used in a single course.

1.4.2 IMS

In 1997, the National Learning Infrastructure Initiative of Educause [Oblinger, 2005] began a project to create a set of widely adopted standards for exchanging college learning content. The specifications published to date and ongoing projects address requirements in a wider range of learning contexts, including K-12 schools and corporate and government training. The acronym IMS originally stood for Instructional Management Systems, but the full term is now rarely used.

The mission of IMS is to support the adoption and use of learning technology worldwide by the development of open technical specifications for interoperable learning technology. These specifications include:

- IMS Content Packaging: The IMS Content Packaging Specification provides the functionality to describe and package learning objects, such as an individual course or a collection of courses, into interoperable, distributable packages. Content Packaging addresses the description, structure, and location of online learning objects and the definition of some particular content types.

- IMS Digital Repository: The purpose of the IMS Digital Repositories specification is to provide recommendations for the interoperation of the most common repository functions.

- IMS Learning Design: The IMS Learning Design specification supports the use of a wide range of pedagogies in online learning, by providing a generic and flexible language for expressing such pedagogies.

- IMS Question & Test Interoperability (QTI): The IMS QTI specification describes a data model for the representation of question and test data and corresponding results reports, enabling their exchange between authoring tools, learning systems and assessment delivery systems.

- IMS Simple Sequencing: The IMS Simple Sequencing specification defines a method for representing the intended behavior of an authored learning experience. The specification incorporates rules that describe the branching or flow of instruction through content, according to the outcomes of learner interactions with content.

The IMS Content Packaging specification is important in the context of this dissertation, as the specification enables to describe the structure of a collection of learning objects or learning object components into a coherent, structured, whole. The IMS Simple Sequencing specification can be used for describing the intended behavior of such a collection.

1.4.3 ADL

The Advanced Distributed Learning (ADL) initiative [Looms and Christensen, 2002] was established in 1997 to develop a Department of Defense (DoD) strategy for using learning and information technologies to modernize education and training and to promote cooperation between government, industry and academia.

The most widely accepted ADL publication is the Sharable Content Object Reference Model (SCORM) [SCORM, 2004]. The SCORM specification combines elements of IEEE LTSC and IMS specifications. The SCORM standard is comprised of four major elements (see Figure 1.2):

- Part 1 provides an overview, containing high-level conceptual information, the history, current status and future directions of ADL and SCORM.
- Part 2, the SCORM Content Aggregation Model, describes content components used in a learning object, how to package those components for exchange from system to system, how to describe those components to enable search and discovery, and how to define sequencing rules for the components.
- Part 3 outlines how to sequence and navigate learning objects. It describes how SCORM-conformant content may be sequenced to the learner through a set of learner-initiated or system-initiated navigation events.
- Part 4 covers the SCORM run-time environment. The purpose of the run-time environment is to provide a means for interoperability between learning content and Learning Management Systems (LMSs). It describes the LMS requirements in managing the run-time environment, such as the content launch process, standardized communication between content and LMSs, and standardized data model elements used for passing information relevant to the learner experience with the content.

Of particular interest is the SCORM Content Aggregation Model, as it addresses the creation, discovery and aggregation of reusable learning objects. The SCORM CAM integrates:

- A Content Model, that defines content components at different levels of granularity and how these components are aggregated into higher level units of instruction. The model is described in detail in the next chapter;
- Content packaging, using the IMS Content Packaging specification;
- Metadata, using IEEE LOM; and
- Sequencing and Navigation, using the IMS Simple Sequencing specification.

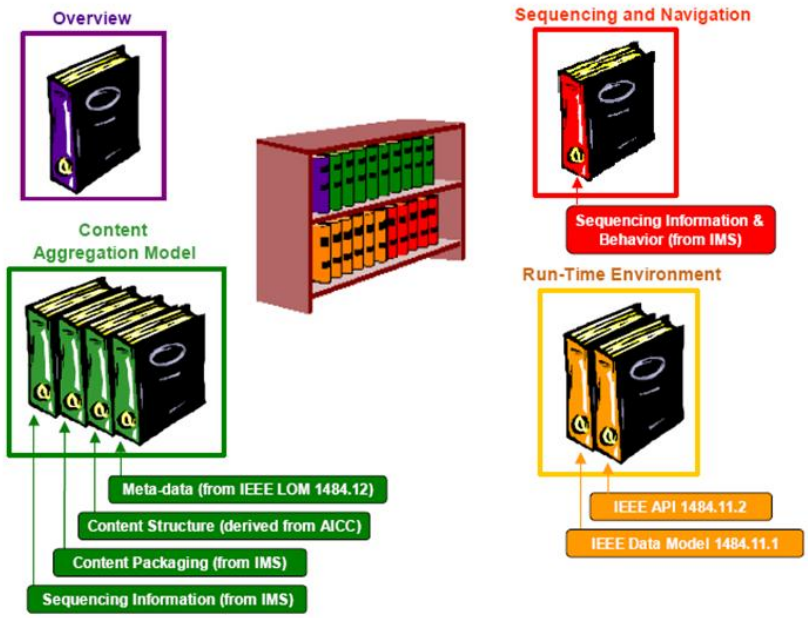


Figure 1.2: The SCORM parts

1.4.4 ARIADNE

ARIADNE (Association of Remote Instructional Authoring and Distribution Networks for Europe) [Duval et al., 2001] is an association whose aim is to promote share and reuse of learning objects. The core of the ARIADNE infrastructure is a distributed network of learning object repositories. In collaboration with IMS, ARIADNE submitted in 1998 a joint proposal and specification to the IEEE LTSC, which was the basis for the LOM standard [Cardinaels, 2007]. Current research in ARIADNE focuses, amongst others, on:

- Metadata and how they enable flexible access to learning objects, with a specific focus on both automatic metadata generation and "attention metadata", that describe user interactions with content;

- Access to distributed collections, through federated search based approaches or metadata harvesting;

- Information visualization, as a means to enable analysis of the overall content of a large-scale repository;

- Content models, that define learning object components and how they can be aggregated, so as to enable reuse and repurposing;
- Social information retrieval techniques for flexible access to large-scale collections of content.

The content models research is presented in this dissertation. Automatic generation of metadata is required to realize reuse of learning object components, as components have to be described to enable their retrieval. The automatic metadata generation framework is described in Chapter 4. Attention metadata enables building user attention profiles that represent actual interests of users based on content they worked with. The use of such profiles enables a personalized ranking mechanism for finding learning object components.

1.5 Issues and challenges

Duval & Hodgins [Duval and Hodgins, 2003] have listed a number of interrelated research issues that are important for enabling learning object reuse on a global scale. This section outlines the issues and challenges that have been addressed in this dissertation.

1.5.1 Learning Object Granularity

There is an inverse relationship between the size of a learning object and its reusability [Wiley, 2002]. As the size of the learning object decreases, its potential for reuse increases. Indeed, fine-grained learning objects or learning object components, such as images, definitions or exercises, have the potential to be assembled into new learning objects, whereas entire courses are often not suitable for use in a different learning context. Size is thus an important factor for enabling successful learning object reuse.

There is no agreement in the literature on how to define the size of learning objects. The LOM standard [IEEE, 2002] identifies four different levels of learning object aggregation or "functional granularity", from the finest grained, such as a single image or other digital asset, to the largest level of a complete certificated course:

1. The smallest level of aggregation, e.g. raw media data or fragments.
2. A collection of level 1 learning objects, e.g. a lesson.
3. A collection of level 2 learning objects, e.g. a course.
4. The largest level of granularity, e.g. a set of courses that lead to a certificate.

SCORM defines Assets as basic building blocks, Sharable Content Objects (SCOs) as aggregations of one or more Assets and Activities as aggregations of one or more SCOs or Assets. SCOs are intended to be small units, such that potential reuse in different learning experiences, to fulfill different learning objectives, is feasible. Activities are intended to form a higher-level unit of instruction, that fulfills higher level learning objectives.

Others use a time element to define learning object granularity: the Wisconsin Online Resource Center defines learning objects as smaller units of learning, that range from 2 minutes to 15 minutes.

The heterogeneity of definitions is a barrier for learning object reuse on a global scale, as it is unclear whether learning objects or learning object components defined according to different specifications can be assembled together to create new learning objects. In addition, the granularity definitions are rather vague. A SCORM activity is intended to fulfill a higher-level learning objective, but can still range from a few lines of text to highly interactive learning resources, as SCORM claims to be neutral about the complexity of content. Also the time based determinations seem arbitrary.

It has repeatedly been observed that granularity should be defined more precisely and uniformly [Halim et al., 2007] [Schluep, 2005], as it has a direct impact on the reusability of learning objects in different contexts. In this dissertation, an abstract learning object content model (ALOCOM) has been developed that defines learning object granularity in a precise way. A number of learning object content models have been reviewed that define learning objects and their components. Based on a comparative analysis, the content models have been mapped to the generic ALOCOM model to enable their interoperability.

1.5.2 Learning Object Structure

In order to aggregate learning object components into coherent learning objects, it is necessary to develop a flexible architecture that enables describing the structure of learning objects.

An important general principle in hypermedia systems is the separation of content, structure and presentation. Structural aspects of aggregate learning objects can be based on the IMS Content Packaging specification [IMS CP, 2004], the Metadata Encoding and Transmission Standard (METS) [Cundiff, 2004], the Synchronized Multimedia Integration Language (SMIL) [Bulterman et al., 2005] or OpenDocument [Durusau et al., 2007].

The specifications enable to describe the structure of a collection of learning content. In addition, multiple structures can be specified to provide different learning paths through the same learning object.

A limitation of the specifications is relied in the fact that they cannot interoperate. For instance, learning objects structured in an IMS Content Package cannot be reused in a METS context.

The Resource Aggregation Model for Learning, Education and Training (RAMLET) has been developed to describe the structure of learning objects in a uniform way. Interoperability is achieved by the definition of crosswalks among various content packaging specifications. The model has been developed by the IEEE LTSC CMI working group, in which the author has been involved.

The RAMLET model enables to assemble and structure ALOCOM components into coherent learning objects. In addition, interoperability is achieved with many content packaging specifications, that facilitates sharing and reuse among systems.

1.5.3 Learning Object Aggregation and Disassembly

As indicated in Section 1.5.1, there is a broad consensus that smaller learning objects are more easily reusable. However, the majority of shared learning objects are coarse-grained compositions that are difficult to reuse [Motelet, 2004]. Typically, authors reuse parts of the learning object by copy-and-paste actions. This method of reuse is possible in any authoring tool, but is limited in several ways: the approach is non-scalable in terms of maintenance, as each time content is copied, a new place is created that needs to be maintained. In addition, the approach tends to be error-prone, and due to its inherent monotony, easily becomes both bothering and time consuming.

The authors are in a much better position if on-the-fly access to learning object components is provided, and their re-composition is made, at least partially, automatic. The main idea in our view is that learning objects are created by selecting learning object components from a repository. These learning objects can then be assembled into a new learning object. This can be referred to as authoring-by-aggregation [Duval and Hodgins, 2003].

To enable authoring-by-aggregation, support is needed for automatic decomposition of learning objects, to extract components of learning objects that were originally produced as aggregates. A possible approach employs a more reusability prone format of learning objects that makes their structure explicit. An explicit content structure allows to disaggregate a learning object into its constituent components. Those components, enriched with fine-grained descriptions, and stored in learning object repositories, can then be selected to create new learning objects.

There are a number of issues that need to be dealt with to realize the approach. First of all, there is the question of how far it is useful to decompose learning objects into components. As pointed out by [Rockley, 2002], sentence fragments or individual words may not be appropriate for reuse. However, single paragraphs may constitute definitions, examples or exercises that are reusable. Secondly, the transformation of semi-structured or unstructured learning objects into an explicitly structured format needs to be investigated. Thirdly, integration of assembling learning object components into the workflow of authors needs to be examined.

This dissertation investigates both decomposition and assembly of learning object components. In addition, prototypes of tools have been developed that enable to validate the approach. Plug-ins have been developed for Microsoft PowerPoint, Microsoft Word and the Reload Editor [Milligan et al., 2005], a packaging tool for composition of SCORM content packages, that enable authors to search and reuse components from within the authoring tools.

User and quality evaluations have been conducted that validate the approach. The goals of the evaluations were threefold: (i) to assess the efficiency and effectiveness of the approach for reusing learning objects; (ii) to assess the subjective acceptance of the ALOCOM plug-ins; (iii) to determine to which level of granularity decomposition is relevant.

1.5.4 Learning Object Interoperability

In order to enable widespread reuse, interoperability issues are extremely important [Duval and Hodgins, 2003]. Standardization work presented in Section 1.4 focuses on interoperability between learning objects and learning management systems and interoperability between learning object repositories. An important, and currently somewhat neglected, kind of interoperability is interoperability *between* learning objects [Duval and Hodgins, 2003]. Examples include:

- Content objects from different original creation/authoring tools working together when assembled together into a learning object.
- Learning objects being able to work properly when moved among systems using different specifications.

Interoperability is required at different levels:

- Learning object content: content defined according to different learning object definitions should be able to interoperate.
- Learning object structure: learning objects structured and packaged according to different content packaging specifications should be able to interoperate.
- Learning object output formats: learning objects stored in different application specific formats should be able to interoperate.

The three kinds of interoperability are investigated in this dissertation. Interoperability of learning object content is described in Chapter 2. The ALOCOM content model is described and mappings between content models that enable their interoperation.

Interoperability of learning object structure is described in Chapter 3. The RAMLET model is described and mappings to other content packaging specifications that enable their interoperation.

Finally, interoperability of learning object output formats is described in Chapter 4, in the context of the (de-)composition framework for learning objects. Such interoperability is a condition to realize the vision of an open, large-scale learning object infrastructure with sufficient critical mass [Duval and Hodgins, 2003].

1.6 Outline

This dissertation describes conceptual designs and prototypes of tools that have been developed to validate the approach. Earlier versions of the chapters have been published, in whole or in part, in recent years. Among the most important, in the context of this dissertation, are: [Verbert and Duval, 2004] [Verbert et al., 2004a] [Verbert et al., 2005] [Verbert et al., 2005a] [Jovanovic et al., 2005] [Verbert et al., 2005b] [Verbert et al., 2006] [Verbert and Duval, 2007] [Verbert et al., 2008] and [Verbert and Duval, 2008].

The remaining chapters are organized as follows: Chapter 2 tackles the issue of learning object granularity. The generic ALOCOM content model is presented, and content model mappings that enable the interoperation of learning content definitions.

Chapter 3 presents the RAMLET model for content packaging specifications and mappings to other content packaging formats. Use cases illustrate the level of interoperability that can be achieved.

Chapter 4 presents a decomposition and aggregation framework for learning objects. The framework automates learning object reuse by enabling on-the-fly access to learning object components contained in composite learning objects.

Chapter 5 presents user and quality evaluations that measure the impact of the approach on effective and efficient content reuse.

Finally, Chapter 6 concludes this dissertation with a summary of contributions, a discussion on the possible impact, and an exploration of the potential it offers for future research.

Chapter 2

ALOCOM: a Generic Content Model for Learning Objects

2.1 Introduction

Barriers and enablers for the reusability of learning objects are important research topics in the learning technology community. In various publications, it is argued that reuse not only saves time and money [Downes, 2001] [Robson, 2004], but also enhances the quality of digital learning experiences, resulting in efficient, economic and effective learning [Duval and Hodgins, 2003].

There is an inverse relationship between the size of a learning object and its reusability [Wiley, 2002]. As the size of the learning object decreases, its potential for reuse increases. Size is thus an important factor for enabling successful learning object reuse. However, this size is only vaguely defined by learning object definitions [Schluep, 2005].

According to the Learning Object Metadata (LOM) standard, a learning object is "any entity, digital or non-digital, that may be used for learning, education or training" [IEEE, 2002]. This definition allows for an extremely wide variety of granularities [Schluep, 2005]. In one sense, this is appropriate, as there are a number of common themes to content components of all sizes. In another sense though, this vagueness is problematic, as it is clear that authoring, deployment and repurposing are affected by the granularity of the learning object [Duval and Hodgins, 2003].

Learning object content models address this problem. The models define different kinds of learning objects at different levels of granularity and are based on the belief that we can create independent and self-contained learning content, which may be used alone or dynamically assembled, to provide "just enough" or "just-in-time" learning. On top of that, these learning components can be combined to form longer educational interactions or can be reused in different learning contexts [Tan, 2002].

However, there are many different content models and learning object definitions across these models vary considerably. Some models define learning objects as lessons, while others relate learning objects to concepts, principles, facts, procedures or processes. The heterogeneity of definitions is a barrier for learning content reuse on a global scale, as it is unclear whether content can be reused or repurposed in a different context.

In order to address heterogeneity problems, we have developed an abstract learning object content model (ALOCOM) for content model interoperability. Existing content models have been investigated and mapped to the generic ALOCOM model. Mappings have been implemented according to the method introduced in [Bucella et al., 2003]. The method has three main stages:

- building a global ontology that covers existing content models,
- building local ontologies for each content model, and
- defining mappings between the ontologies.

Mappings can enable share and reuse of learning objects across repositories. Learning object components stored in a SCORM [SCORM, 2004] repository can, for instance, be identified and potentially repurposed in the context of a Cisco [Barrit et al., 1999] or NETg [L'Allier, 2003] learning system.

To facilitate the description and comparison of learning object content models, we first briefly introduce content classification schemes that are used by the investigated content models for defining granularity levels. In Section 2.3, the content models that were included in the investigation are presented and Section 2.4 presents a comparative analysis. The method used for implementing mappings is described in Section 2.5. The global ALOCOM content model is presented in Section 2.6, local content model ontologies in Section 2.7 and mappings in Section 2.8. Use cases are described in Section 2.9 and related work is discussed in Section 2.10. Finally, conclusions are drawn in Section 2.11.

2.2 Background

Learning object content models define different levels of content components, the properties of these components, such as granularity, and how these components can be aggregated [Schluep, 2005]. In order to define granularity levels, different classification schemes are used by current content models, such as the Structured

Writing methodology developed by Robert Horn [Horn, 1993], the classification of Ballstaedt [Ballstaedt, 1997], classifications defined in LOM [IEEE, 2002] and the component display theory [Merrill, 1983]. The classifications are briefly introduced in this section.

2.2.1 Structured Writing

The Structured Writing method of Robert Horn [Horn, 1998] was developed for instructional developers and business writers to prepare clear and concise training manuals, proposals, reports and memos. The methodology should enable managers, sales people, office personnel, and technicians to learn new products, services, and operating procedures rapidly and precisely.

In the methodology, a paragraph is replaced by an information block, a chunk of information that is organized around a single subject, containing one clear purpose. Horn defined 200 types of information blocks, including: *analogy, block diagram, checklist, classification list, classification table, classification tree, comment, cycle chart, decision table, definition, notation, objectives, outlines, parts-function table, parts table, prerequisites to course, procedure table, purpose, rule, synonym*, and *theorem.*

In addition, a set of content analysis categories and question types were defined based on seven information types [Horn, 1993]:

1. Concept: A "concept" describes an abstract or generic idea generalized from particular instances. A concept is used for teaching a group of objects, symbols, ideas, or events which are designated by a single word or term, share a common feature and vary on irrelevant features [Barrit et al., 1999].

2. Fact: A "fact" provides information based on real occurrences; it describes an event or something that holds without being a general rule [Ullrich, 2005].

3. Classification: A "classification" is a sorting of items into categories. An example is "overview of technologies within medical imaging" [Ceusters and Bouquet, 2000].

4. Structure: A "structure" is a physical object or something that can be divided into parts and has boundaries. A typical example is "the anatomy of the human brain" [Ceusters and Bouquet, 2000].

5. Principle: A "principle" is a basic generalization that is accepted as true and that can be used as a basis for reasoning or conduct [Ullrich, 2005].

6. Procedure: A "procedure" consists of a specified sequence of steps or formal instructions to achieve a goal. Typical examples are "Euclid's algorithm" or "instructions to operate a machine" [Barrit et al., 1999] [Ullrich, 2005].

7. Process: A "process" describes a sequence of events. A process provides information on a flow of events that describes how something works and can involve several actors. Typical examples are "the process of digestion", and "how a computer system responds to commands" [Ullrich, 2005].

Guidelines were developed that identify which key information blocks are necessary to fully understand a topic. The underlying research focused on a deep understanding of the basic units of a subject matter and provides an easy to understand taxonomy. Developed in 1967, Structured Writing can claim to be the first to define and develop precise modular information blocks, that are firmly grounded in a taxonomy of information types [Horn, 1993].

2.2.2 IEEE LOM

The IEEE Learning Object Metadata Standard [IEEE, 2002] is a widely adopted standard that specifies the syntax and semantics of learning object metadata [Cardinaels, 2007]. The standard contains two elements that are relevant for describing learning object granularity [Schluep, 2005]: Aggregation Levels and Learning Resource Types.

Aggregation levels are defined as an enumeration of four types, identified by a number:

1. The smallest level of aggregation, e.g. raw media data or fragments.
2. A collection of level 1 learning objects, e.g. a lesson.
3. A collection of level 2 learning objects, e.g. a course.
4. The largest level of granularity, e.g. a set of courses that lead to a certificate.

Learning Resource Types describe specific kinds of learning objects by a predefined vocabulary. The following items are included: *exercise, simulation, questionnaire, diagram, figure, graph, index, slide, table, narrative text, exam, experiment, problem statement, self-assessment,* and *lecture.*

Given its status as an internationally recognized, accredited technical standard, the IEEE Learning Object Metadata Standard is emerging as the primary metadata standard for learning objects [Wiley, 2007]. Many learning object content models use LOM metadata for the description of content components.

2.2.3 Ballstaedt

Ballstaedt [Ballstaedt, 1997] provides a classification of knowledge representation for paper based educational books. The distinction is made between textual and non-textual representations. Textual representations are categorized into oral and written texts.

Written texts are further divided into the following categories:

1. Expository texts: these texts contain factual representations of the subject matter to be taught. Such texts may contain definitions and explanations.
2. Narrative texts: narrative texts are subjective descriptions of personal experiences related to some subject matter.
3. Instructions: instructions provide a detailed description of how to perform a procedure step-by-step.
4. Supplementary didactic texts: these texts are didactically motivated elements that support the learning process, classified as: learning objectives, advanced organizers, summaries, examples, excursions, glossaries and self-assessments.

Non-textual representations of learning content include: charts, tables, diagrams, figures, icons, and maps.

In contrast to Structured Writing and IEEE LOM, the research is not widely disseminated: only the dLCMS content model [Schluep, 2005] refers to the classification. The classification might be useful in defining a global content model for learning objects, though, as it is specifically targeted at classifying learning content.

2.2.4 The Component Display Theory

The Component Display Theory of David Merrill [Merrill, 1983] classifies learning along two dimensions: content and performance (see Table 2.1). Four types of content (concept, fact, principle, procedure) are crossed with four types of learning performance (remember generality, remember instance, use, find). The content types are contained in the Structured Writing classification.

In addition, the theory specifies four primary presentation forms: rules (expository presentation of a generality), examples (expository presentation of instances), recall (inquisitory generality) and practice (inquisitory instance). Secondary presentation forms include: prerequisites, objectives, helps, mnemonics, and feedback.

The theory specifies that instruction is more effective to the extent that it contains all necessary primary and secondary forms. Thus, a complete lesson would consist of an objective, followed by a combination of rules, examples, recall, practice, feedback, helps and mnemonics appropriate to the subject matter and learning task. The theory suggests that for a given objective and learner, there

	Facts	Concepts	Procedures	Principles
Find		*Define a class, or set of objects or events*	*Derive, create a procedure or technique for achieving a goal*	*Discover cause and effect relations*
Use		*Classify new examples*	*Perform the procedure*	*Solve a Problem Make an inference*
Remember Generality	*Remember the facts*	*Remember the definition*	*Remember the steps*	*Remember the guidelines*
Remember Instance	*examples*	*examples*	*examples*	*examples*

Table 2.1: Content-Performance Matrix

is a unique combination of presentation forms, that results in the most effective learning experience [Merrill, 1983].

The Component Display Theory provides the foundation for Ruth Clark's performance matrix [Clark, 1989]. Clark's performance matrix, along with Merrill's Component Display Theory, can help designers classify instructional outcomes and are developed in some content models, such as the Cisco [Barrit et al., 1999] and Learnativity [Wagner, 2002] models.

2.3 Overview of Learning Object Content Models

In this section, nine content models are presented that were included in the investigation. Models defined by some of the major players in the e-learning field are presented first, followed by models that were developed for academic purposes.

2.3.1 NETg Learning Object Model

NETg [L'Allier, 2003], the National Education Training Group, is a worldwide leader in blended learning solutions. In NETg, a course is structured as a matrix (Figure 2.1) divided into three major components: units (the vertical), lessons (the horizontal) and topics (the cells) [Tan, 2002].

Each unit, lesson and topic in this structure is defined, in part, by its relationship to the other components.

1. Course: Made up of units

2. Unit: Made up of lessons

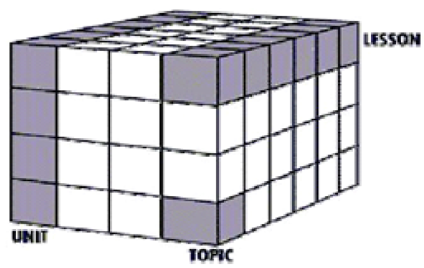


Figure 2.1: A NETg course structure [Tan, 2002]

3. Lesson: Made up of topics
4. Topic: Contains a single objective, a learning activity and an assessment (see Figure 2.2).

A topic is known as a NLO (NETg Learning Object), which is defined as the smallest independent instructional experience that contains an objective, a learning activity and an assessment.

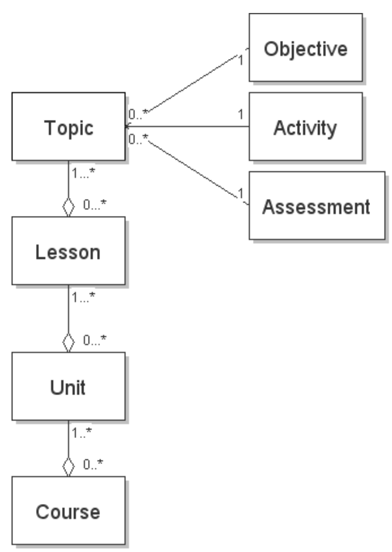


Figure 2.2: UML representation of the NETg Learning Object Model

The term learning objective is an instructional design concept that derives from the work of Robert Frank Mager [Mager, 1984], Benjamin Bloom [Bloom et al., 1956] Robert Gagne [Gagne, 1985], Walter Dick and Lou Carey [Dick and Cary, 1990] and many others. A learning objective is a single measurable or verifiable step on the way to a learning goal. Learning objectives say what a learner is expected to be able to do and how an acceptable level of achievement will be verified.

NETg is a member of the IMS Global Learning Consortium and has assembled its own group of Learning Management System (LMS) developers whose systems are being designed to work with the NLO architecture. Using a tool like NLO+, NETg content can be mixed and matched from various courses to create a new course, tailored to the needs of the learner. When the learner needs a piece of information, she can navigate to the repository, type in a request, and get relevant NLOs. If the learner needs a full course on a subject, the system will build a course based on the NLOs needed [Tan, 2002].

Approximately 3000 courses are currently available that are NETg conformant. Course topics include: Microsoft, Cisco, and Novell Certification training; networking; COBOL and Java programming; databases; Web development; and e-commerce implementation. These courses contain approximately 75000 learning objects. Examples of learning objects, contained in a NETg course on Microsoft Windows 2003, include "Exploring the Word window" and "Creating and saving documents". Such learning objects are designed to take learners 5-7 minutes to complete and are available in a NETg specific format.

2.3.2 Learnativity Content Model

The Learnativity foundation has developed a content model that provides a comprehensive description of granularity [Wagner, 2002]. Learnativity is a small research institute and advisory services practice.

The model defines a five level content hierarchy, as illustrated in Figure 2.3:

1. "Raw" Data & Media Elements are the smallest level and relate to content elements that reside at a pure data level. Examples include a single sentence or paragraph, images, and animations.

2. An information object combines raw data & media elements and focuses on a single piece of information. Such content might explain a concept, illustrate a principle, or describe a process. Exercises are often considered to be information objects.

3. Based on a single objective, information objects are assembled into the third level of Application Objects. At this level reside learning objects in a more restricted sense than the aforementioned definition of the LOM standard suggests [Duval and Hodgins, 2003]. Learning Objects are a collection of Information Objects and relate to a single learning objective.

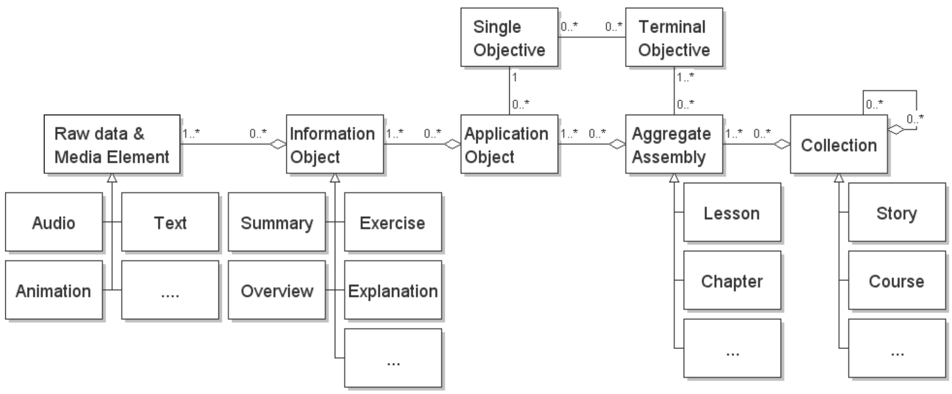


Figure 2.3: UML representation of the Learnativity Content Model

4. The fourth level refers to Aggregate Assemblies that deal with larger (terminal) objectives. This level corresponds with lessons or chapters.

5. Lessons or chapters can be assembled into larger collections, such as courses and curricula. The fifth level refers to these Collections.

The Learnativity model incorporates concepts found in Structured Writing [Horn, 1998] and the vocabulary of the LOM Learning Resource Type [IEEE, 2002]. Themes found in the work of Clark [Clark, 1989] and in a corporate training white paper published by Cisco Systems [Barrit et al., 1999] are developed in the Learnativity model [Collier et al., 2007].

The model has gained considerable acceptance in both training and education communities. The model is used as a basis for a model defined in the Reusable Learning Project [Collier et al., 2007] and has been adopted by the NLII Learning Object Virtual Community of Practice, that is now known as the Educause Learning Initiative (ELI) [Oblinger, 2005].

2.3.3 SCORM Content Model

The most widely implemented set of specifications, intended to allow learning content to be developed independently of a particular delivery platform, is the Sharable Content Object Reference Model (SCORM) [SCORM, 2004], a collection of specifications and standards that is documented and maintained by the Advanced Distributed Learning initiative [Looms and Christensen, 2002]. SCORM includes a content aggregation model that features:

- Assets
- Sharable content objects (SCOs)

- Activities
- Content aggregations

A UML representation of the SCORM content model is shown in Figure 2.4.

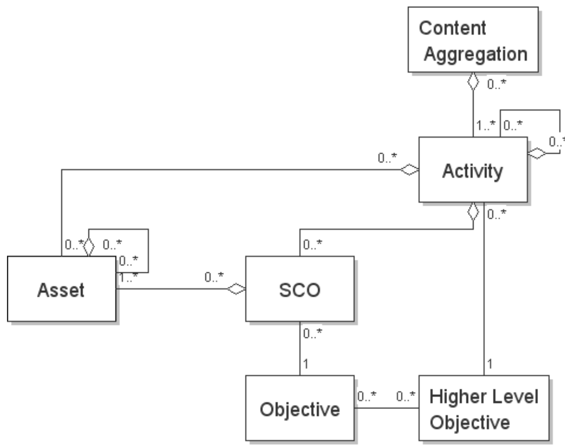


Figure 2.4: UML representation of the SCORM Content Model

SCORM Assets are raw data & media elements and information objects in the Learnativity model. SCOs are self-contained learning objects or learning components that meet additional technical requirements needed for interoperability with learning delivery platforms. To improve reusability, a SCO should be independent of its learning context. For example, a SCO could be reused in different learning experiences to fulfill different learning objectives.

An Activity aggregates SCOs and Assets to form a higher-level unit of instruction, that fulfills higher level learning objectives. In the Learnativity content model, an Activity could be an Aggregate Assembly. An Activity contained in a Spanish course can, for instance, deal with the order of adjectives. Examples of SCOs included in the lesson are an explanation of the grammar, a practical exercise and a revision of the previously learned concepts [Rey-López et al., 2006]. Text, audio and video fragments contained in the SCOs are the Assets.

The Spanish course can be represented in a SCORM content aggregation, containing the Assets, SCOs, Activities, information on the order in which these should be delivered and metadata about the entire aggregation and its individual components. SCORM uses the IMS Content Packaging specification [IMS CP, 2004] to define the format for content aggregations.

One of the goals of SCORM was to enable an "object based" economy for learning objects that could be shared and reused across the Department of Defense (DoD). According to a February 2006 ADL survey of SCORM content within the Services, the Army Training Support Center has 161 SCORM conformant courses and 152 under development, the Army Defense Language Institute has 1230 SCORM conformant lessons in 12 languages and 576 under development, the Navy has an estimated 442 SCORM conformant courses and 330 under development, and the Air Force has 168 SCORM conformant courses [Brooks et al., 2006].

2.3.4 Navy Content Model (NCOM)

The Navy has refined the SCORM content model, providing more specific content definitions for granularity levels that are identified as critical for the Navy Interactive Learning Environment [Conkey, 2006]. As the model builds upon SCORM, Navy content is SCORM compliant.

The Navy Content Model distinguishes between Learning Object Aggregations, Terminal Learning Objects (TLOs), Enabling Learning Objects (ELOs), and Assets (see Figure 2.5):

1. A Learning Object Aggregation is the top-level grouping of related content, containing TLOs and ELOs.
2. A TLO is an aggregation of one or more ELOs. A TLO satisfies one terminal objective and correlates to a SCORM activity. Terminal learning objectives are typically associated with lessons.
3. An ELO is an aggregation of one or more Assets. An ELO satisfies one enabling objective and correlates to a SCORM SCO. Examples include illustrations and exercises.

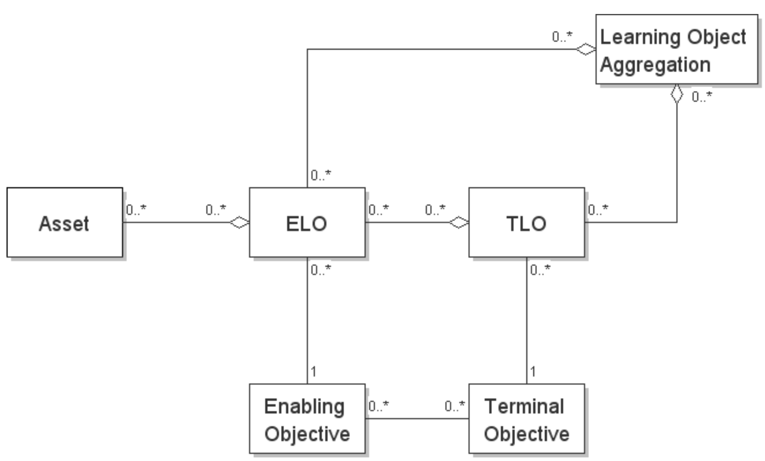


Figure 2.5: UML representation of the Navy Content Model

4. An Asset is a single text element or a single media element (e.g. an assessment object, a video, and other data elements).

A terminal objective is a major objective for a topic or task, describing the overall learning outcome. An enabling objective supports a terminal objective. Such an objective describes specific behaviors (single activities) that must be achieved.

The Navy Content Model uses SCORM as its foundation. Table 2.2 presents the relationship between the SCORM and NCOM hierarchy. NCOM correlates a single enabling objective to a SCO and a single terminal objective to a SCORM Activity. ELO and TLO content is thus more restrictive.

SCORM	**NCOM**
Content aggregation	Learning Object Aggregation
Activity	Terminal Learning Object (TLO)
Sharable Content Object (SCO)	Enabling Learning Object (ELO)
Asset (with metadata)	Asset

Table 2.2: Relationship between the SCORM and NCOM hierarchy (Source: [Conkey, 2006])

2.3.5 Cisco RLO/RIO Model

Cisco Systems, Inc. [Barrit et al., 1999] has also adopted an object-based strategy for developing and delivering learning content. As illustrated in 2.6, Cisco defines "Lessons" as Reusable Learning Objects (RLOs) and "Topics", of the lesson, as Reusable Information Objects (RIOs).

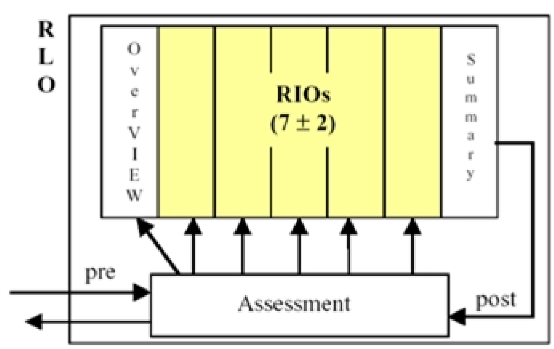


Figure 2.6: The RLO and RIO structure [Barrit et al., 1999]

RIOs relate to a single learning objective and contain content, practice, and assessment items. Cisco further classifies each RIO as a concept, fact, procedure, process, or principle. Content items are classified as a definition, example, review, next steps, analogy, topology illustration, block diagrams, additional resources, cycle charts, instructor notes, introduction, principle statement, illustration, importance, outline, fact list, objectives, non-example, table, job-based scenario, prerequisites, guideline, procedure table, decision table, demonstration, staged table, or combined table.

To build a lesson or RLO, five to nine RIOs are grouped together with an overview and summary (see Figure 2.6). For RIO types, and RLO Overviews and Summaries, guidelines are provided that describe which content items are required and which may be used optionally (see Table 2.3).

RLO-RIO type	**Content Items**
RLO Overview	Introduction (r), importance (r), objectives (r), prerequisites (r), scenario (o), outline (r)
RLO Summary	Review (r), next steps (o), additional resources (o)
Concept RIO	Introduction (r), facts (o), definition (r), example (r), non-example (o), analogy (o), instructor notes (o)
Fact RIO	Introduction (r), facts (r), instructor notes (o)
Procedure RIO	Introduction (r), facts (o), procedure table (r), decision table (r), combined table (r), demonstration (o), instructor notes (o)
Process RIO	Introduction (r), facts (o), staged table (r), block diagrams (r), cycle charts (r), instructor notes (o)
Principle RIO	Introduction (r), facts (o), principle statement (o), guidelines (r), example (r), non-example (o), analogy (o), instructor notes (o)

Table 2.3: Overview of content items to be used for RIO types, RLO Overview and RLO Summary (Source: [Schluep, 2005]); (r)=required, (o)=optional

A RIO can function as an independent learning component that can be called up by a learner who needs a specific piece of information. Such RIOs can be combined together to build custom RLOs that meet the needs of individual learners. RLOs can be sequenced to create a course on a particular subject [Tan, 2002].

The Cisco model is grounded in the learning object thinking of David Merrill [Merrill, 1983] and Ruth Clark [Clark, 1989]. RIO and RLO classifications and guidelines for their construction are based on the Structured Writing methodology developed by Robert Horn [Horn, 1998].

A RIO correlates to a NETg topic, a SCORM SCO, and an NCOM ELO. Content items relate to NCOM and SCORM assets and both raw data & media elements and information objects in Learnativity. An RLO correlates to a Learnativity aggregate assembly and a NETg lesson. RLOs can be combined to form units and courses.

2.3.6 dLCMS Component Model

The dynamic Learning Content Management System (dLCMS) project [Schluep, 2005] aims to provide a modularization strategy combined with structured markup to enhance the reusability of learning content.

A component model is included that defines three aggregation levels (see Figure 2.7):

1. Assets are media elements, such as images, videos, animations, or simulations. They are binary data objects, which cannot easily be divided into smaller components. They contain pictorial or auditory information, which can be static (image, graph) or dynamic (video, audio, animation).

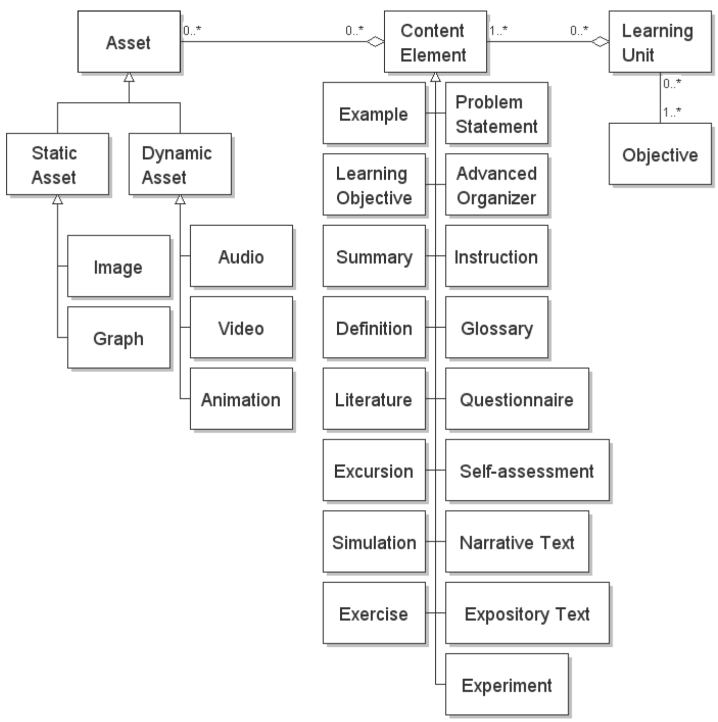


Figure 2.7: UML representation of the dLCMS Component Model

2. Content elements are defined as small, modular pieces of learning content, which: (1) serve as basic building blocks of learning content, (2) can be aggregated into larger, didactically sound learning units, (3) are self-contained, (4) are based on a single didactic content type, (5) are reusable in multiple instructional contexts, and (6) may contain assets. Examples include exercises, experiments, questionnaires and summaries.

3. A learning unit is defined as an aggregation of content elements, which is presented to the learner. Typically, a learning unit serves as an online lesson and may be used to teach several learning objectives. A learning unit provides a way to define a chapter-like, hierarchical structure of nodes. Each node will be associated to a content element through reference. The content elements are not copied into the learning unit, but are referenced by links. The component model does not define any further levels for the aggregation of learning units.

The dLCMS model defines a set of Content Elements categories that are related to Gagné's Nine Instructional Events (see Table 2.4).

Instructional Event	**Related Didactic Content Type**
Gaining Attention	Example[13], problem statement[2]
Informing learners of the objective	Learning objective[1]
Stimulating recall of prior learning	Advanced organizer[1]
Presenting the stimulus	Expository text[1], definition[3], narrative text[12], instruction[1]
Providing learner guidance	Example[13], excursion[1], glossary[1], literature, experiment[2]
Eliciting performance	Exercise[123], self-assessment[2], simulation[2]
Providing feedback	(Feedback of self-assessment and simulations)
Assessing performance	Questionnaire[2]
Enhancing retention and transfer	Summary[1]

Table 2.4: Classification of didactic content types and their possible relations to Gagné's Nine Instructional Events [Schluep, 2005]

The content categories are based on the classification of Ballstaedt[1] [Ballstaedt, 1997], the vocabulary of the LOM Learning Resource Type[2] [IEEE, 2002] and ContentModule types of LMML[3] (see Section 2.3.9) [Süβ et al., 2000]. Literature is added to the classification.

The dLCMS model provides a well-defined hierarchy of learning object content: Assets are assembled into Content Elements and Content Elements are assembled into Learning Units. Learning units may be of any size and may be used for multiple learning objectives. dLCMS does not define a learning object level that relates to a single learning objective.

The model has been developed for academic purposes. A prototype demonstrates how to handle and process modular learning content that is compliant to the dLCMS model. The implementation supports learning object authoring, storage, assembly and linking, and publishing and export functionalities.

2.3.7 New Economy Didactical Model

Another content model developed for academic environments is the New Economy didactical model [Löser et al., 2002], developed in the context of the New Economy research project, which is supported by the German Federal Ministry for Education and Research. The aim of the project is the creation of new curricula and the development of interactive multimedia-based material for online and blended learning MBA studies. The project partners belong to 7 German universities and research institutes.

The model defines eight component types, as shown in Figure 2.8:

1. An Information Object is defined as a small learning object, without complex logical structures, which sums up physical media (picture, video, text) to didactically appropriate units.

2. A Learning Component is defined as a small learning object, that combines a small number of information objects, in order to form one of the following features: motivation, basic knowledge or theory, example, exercise, reference, further material, open question, problem, and virtual laboratory.

3. A Learning Module is defined as a logical structure with a didactic aim, consisting of individual Learning Components. A Learning Module is related to a Cisco RLO or lesson.

4. A Learning Unit is defined as a structure designed to mediate complex content. A Learning Unit combines Learning Modules and Learning Components. An example is a case study containing three learning modules, combined with a virtual laboratory.

5. A Course combines Learning Modules and Learning Units and can be part of a Curriculum.

6. A Curriculum is a composition of Courses and Learning Units according to one or more academic specifications.

7. A Learning Path is a structure consisting of Learning Modules and Learning Units, that can be individually adjusted to the learner.

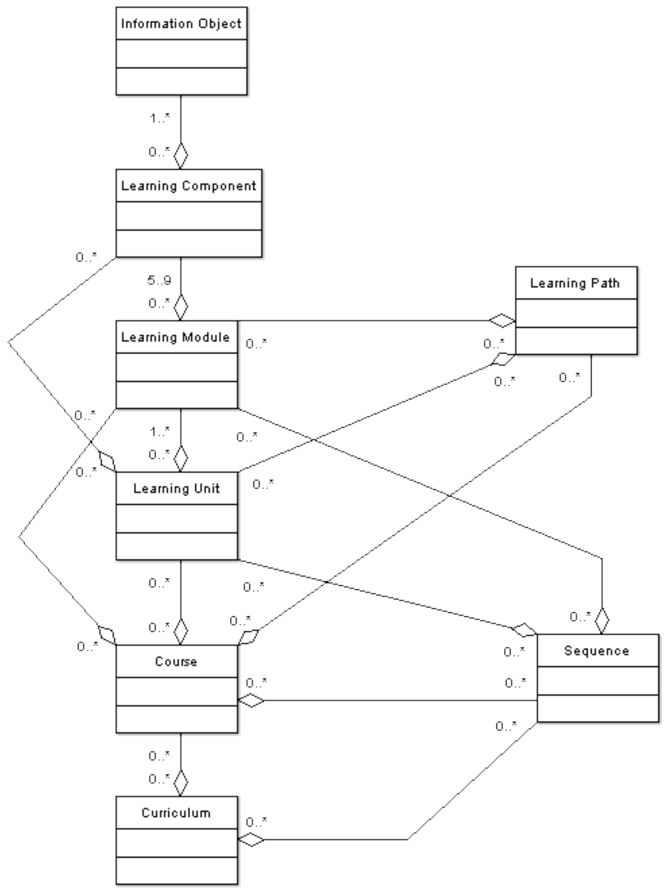


Figure 2.8: UML representation of the New Economy Didactical Model

8. A Sequence is defined as a result of individual research within different repositories, in order to extend personal knowledge. It is part of the informal, but organized, learning procedure.

In addition, the following characteristics are defined (see Table 2.5):

1. Number of combined elements: describes the number of individual elements, such as video clips, pictures, or texts, that are combined.

2. Type of the combined objects: describes types of the learning objects, which can be combined, in order to form this learning object.

3. Relationship logical structure/contents: describes the portion of logical structures in relation to content wise elements.

4. Possible didactical learning model: manufactures the connection between the learning object and learning theory.

5. Reusability in other learning objects: describes the possibility of reuse within other learning objects.

6. Reusability in other contexts: describes the possibility of the use of learning objects in other domains.

From a content perspective, six aggregation levels are defined. Learning Path and Sequence are pure structural elements. According to the authors of the model, an Information Object correlates to a Learnativity Information Object, a Learning Component to a Cisco RIO and a Learning Module to a Cisco RLO.

The defined characteristics derive from the work of David Wiley [Wiley, 2002]. The classifications are based on the didactical concept of problem based learning.

The New Economy project is the conceptual design and implementation of a multimedia-based curriculum for online classes regarding new economy in the fields of economics, media and communications, as well as computer sciences. Modules of the curriculum are available for workshops and for distance learning. Integration of the program into regular lectures is intended.

2.3.8 Semantic Learning Model (SLM)

The Semantic Learning Model is aimed at supporting decomposition of learning objects and has been developed for academic purposes [Fernandes et al., 2005].

The model is illustrated in Figure 2.9 and defines 6 categories:

1. The lowest granularity level is an Asset. Assets can be pictures, illustrations, diagrams, audio and video files, animations, and text fragments.

2. Pedagogical information is defined as "a group of assets that express the same meaning". An example is a figure associated with a comment.

3. A pedagogical entity is defined as "a pedagogical information component, associated with a pedagogical role". Four roles are defined: concept, argument, solved problem and simple text.

4. A pedagogical context is defined as "a semantic structure (or network) in which pedagogical entities are grouped".

5. A pedagogical document contains a pedagogical context, associated with prerequisites.

	Information Object	**Learning Component**	**Learning Module**	**Learning Unit**	**Course**	**Curriculum**	**Learning Path**	**Sequence**
1	One-very few	Few	7±2	Few	Some-many	Many learning units	Many	Many
2	Physical media objects such as text and pictures	Information objects	Learning components: at least motivation and theory	Learning modules, Learning components	Learning unit, learning module, sequence, learning path	Learning unit, sequence	Learning unit, learning module	Learning unit, learning module
3	Content and fragments			Logical structures for the grouping and nesting of learning objects				
4	None	Depends on component type, for example *Instructivistic*, *Problem Oriented*, *Constructivistic*	Arbitrary	Arbitrary	Arbitrary	Arbitrary, conclusion oriented	Goal oriented learning	Arbitrary
5	All	All, except Information Objects	Predominantly in learning units and all other structure-based types	Course, curriculum learning path and sequence	Curriculum	None	Curriculum, Course, Learning Unit	Curriculum, Course, Learning Unit
6	High	Medium	Low	Low	Low	Low	Medium	Medium

Table 2.5: New Economy Didactical Model

6. Many pedagogical documents are grouped in order to make a curriculum. This group is called pedagogical schema.

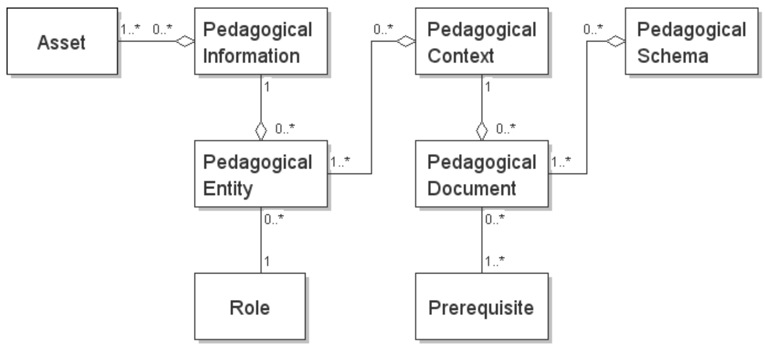


Figure 2.9: UML representation of the Semantic Learning Model

From a content perspective, 4 aggregation levels are defined. A pedagogical entity and a pedagogical document represent respectively a single pedagogical information component and a single pedagogical context. Pedagogical roles and prerequisites are added as metadata.

According to the authors of the model, an asset correlates to a Learnativity raw data & media element, a pedagogical information component to a Learnativity information object, a pedagogical entity to a Learnativity application object, a Pedagogical context to a Learnativity aggregate assembly and a pedagogical document to a Learnativity collection.

2.3.9 PaKMaS

The Passauer Knowledge Management System (PaKMaS) [Süβ et al., 2000] is an hypermedia content management system that provides search, editing, evaluation and exchange facilities for learning material for teachers and students.

A content model is defined that distinguishes between Media Objects, Content Modules, and Structuring Modules (see Figure 2.10):

- Media Objects are defined at the lowest granularity level. Such elements are classified as text, audio, animations and images.

- Content Modules contain Media objects and are classified as motivations, definitions, remarks, paragraphs, examples, exercises, and illustrations. Their content can be structured as lists or tables.

- Content Modules are grouped into Structuring Modules that realize multiple teaching strategies. Their content is structured into sections and collections. Structuring Modules are categorized into GuidedTours, Collections, Glossaries and Indexes.

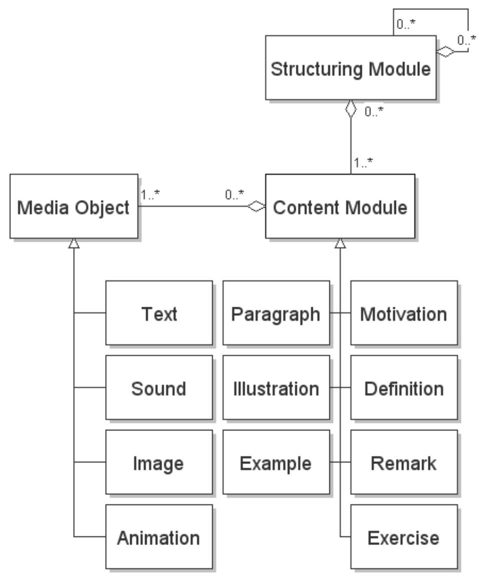


Figure 2.10: UML representation of the PaKMaS Model

The model defines its own classification. Some of the concepts can be found in Structured Writing (definition, remark, example) [Horn, 1998], the classification of Ballstaedt (example, glossary) [Ballstaedt, 1997] and the vocabulary of the Learning Resource Type in IEEE LOM (exercise, index) [IEEE, 2002].

A knowledge management system has been developed that provides search, editing, evaluation and exchange facilities for learning objects. Content Modules and Structuring Modules are stored in LMML (Learning Material Markup Language) documents [Süß et al., 2000] or CMI software components. The model is used in university education, further education and company training.

2.4 Comparative Analysis

Table 2.6 aligns content model aggregation levels. The NETg Learning Object model consists of four levels. The model specifies three levels for the aggregation of learning objects, or Topics, but provides only an abstract definition of their content, as no learning object components are defined.

The other models define learning object components in one or two levels. SCORM, NCOM, Cisco, and New Economy define one level. Cisco describes the content types of this level conceptually, but no specification is given from a technical point of view [Schluep, 2005]. The models seem to agree that this level consists of individual, reusable, resources. In SCORM, Assets can aggregate other Assets, too.

The Learnativity, SLM, PaKMaS and dLCMS models define a second level for learning object components, that aggregates first level components. The models define this component level as an aggregation of assets that focus on a single piece of information, but not necessarily relating to a specific learning objective.

The dLCMS and PaKMaS models define learning objects as aggregations that relate to one or more learning objectives. The other content models define learning objects consistently as content aggregations that relate to a single learning objective. These models define aggregations of learning objects into an additional level, that relates to multiple or larger learning objectives. Lessons are commonly associated with this aggregation level. Learnativity, NCOM, and SCORM define a third aggregation level for learning objects, representing courses and curricula. Finally, the NETg and New Economy models define a content hierarchy for this granularity level (*unit, course* and *learning unit, course, curriculum* respectively).

	LO Component		**Learning Object**				
	CF	**CO**	**Single-Objective**	**Larger-Objective**	**LO Aggregations**		
SCORM	Asset		SCO	Activity	Content Aggregation		
NETg			Topic	Lesson	Unit	Course	
Learnat-ivity	Raw media	Information Object	Application Object	Aggregate Assembly	Collection		
NCOM	Asset		ELO	TLO	Learning Object Aggregation		
Cisco	Content Item		RIO	RLO			
New Econ.		Information Object	Learning Comp.	Learning Module	Learning Unit	Course	Curri-culum
SLM	Asset	Pedagogical Informa-tion	Pedagogical Entity	Pedagogical Context	Pedagogical Document		Ped. Schema
PaKMaS	Media Object	Content Module	Structuring Modules				
dLCMS	Asset	Content Element	Learning unit				

Table 2.6: Content Model Comparison

2.5 Ontology-based Approach for Content Model Interoperability

2.5.1 Introduction

Learning object definitions provided by the reviewed content models vary considerably:

- Granularity is defined in 3 to 6 levels;
- Different terms are used to refer to the same concept: a Learnativity Information Object is, for instance, equivalent to a PaKMaS Content Module;
- Different classifications are used: derived from Structured Writing [Horn, 1998], LOM [IEEE, 2002] and the classification of Ballstaedt [Ballstaedt, 1997];
- Different constraints on content levels are imposed. For example, Cisco defines learning object content strictly as an aggregation of 7±2 RIOs.

The interoperation of learning content is essential for enabling a learning object economy characterized by searchable repositories of reusable learning objects that can be exchanged and reused across various learning systems. Ontologies offer a great potential in enabling such interoperability. Contents, essential properties and relationships can be expressed and mappings or equivalences can be defined between models.

In [Bucella et al., 2003], a method is introduced to integrate data using ontologies. The method is illustrated in Figure 2.11 and has three main stages:

- building a global ontology that covers the content models,
- building local content model ontologies, and
- defining mappings between the ontologies.

The rest of this section briefly explains the method and how we used it for content model integration.

2.5.2 First Stage: Building the Global Ontology

This stage contains three main steps: analysis of models, search for terms and defining the global model. The analysis has been presented in Section 2.3 and Section 2.4. The global model should define the different granularity levels and their interrelationships. Also content classifications defined for granularity levels should be represented. We develop such an ontology in the next section.

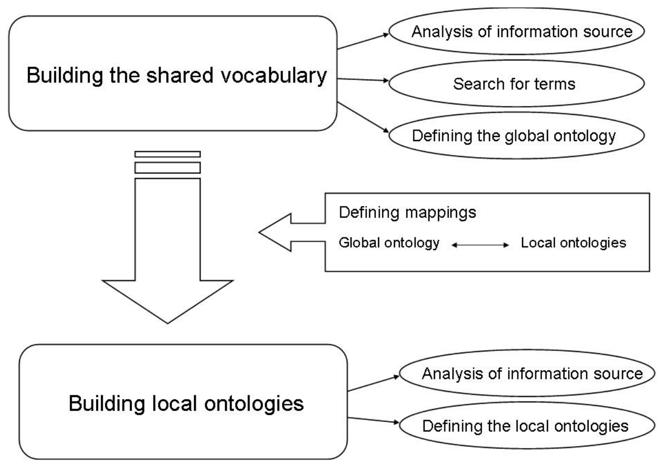


Figure 2.11: Ontology construction method [Bucella et al., 2003]

2.5.3 Second Stage: Building Local Ontologies

In this stage, an independent analysis of each content model is made, without taking the other content models into account. An ontology is created for each content model, defining its own classes and relationships according to the specification of the model. Section 2.7 illustrates the development of local ontologies.

2.5.4 Third Stage: Defining mappings

In this stage, mappings (and relationships) are defined between the classes defined in the global ontology and classes defined in the local ontologies. This stage must solve heterogeneity problems by making connections between the two stages. Such mappings are presented in Section 2.8.

2.6 Abstract Learning Object Content Model (ALOCOM)

2.6.1 Introduction

A global content model should define the different granularity levels that are present in current content models and their interrelationships. We have developed such a model in the ontology language OWL [Bechhofer et al., 2004], as we use ontologies as a means to implement content model mappings.

To define granularity levels, we applied a top-down approach. Starting from the aligned content model representation presented in Table 2.6, we defined learning object granularity levels in a hierarchical structure. These granularity levels are presented in Section 2.6.2. Relationships between the levels are detailed in Section 2.6.3. In the next step, concept hierarchies were defined for the aggregation levels. For defining these taxonomies, we investigated different classification schemes and the extent in which they are used by the content models. The content classifications are detailed in Section 2.6.4, followed by a brief discussion on the ontology creation process.

2.6.2 Granularity Levels

As indicated in the aligned content model representation presented in Table 2.6, the distinction should be made between Learning Object Components and Learning Objects. These top-level granularity levels correspond, for instance, to SCORM Assets and PaKMaS Structuring Modules. Both Learning Object Components and Learning Objects are further subdivided to represent narrower granularity definitions of other content models. Two subclasses are defined for Learning Object Components, that correspond to the component granularity levels of Learnativity, dLCMS, PaKMaS and SLM. Three subclasses are defined for Learning Objects. Figure 2.12 present the hierarchy.

Learning Object Components are subdivided into:

1. Content fragments, defined as individual content components such as text, images, audio and video fragments.
2. Content objects, defined as learning object components that aggregate content fragments. Content Objects focus on a single piece of information and can be used to explain a concept, illustrate a principle, or describe a process.

Learning Objects are subdivided into:

1. Single-objective LOs, defined as aggregations of learning object components that relate to a single learning objective. Examples are concepts, facts, principles, processes and procedures.
2. Larger-objective LOs aggregate single-objective LOs and relate to larger learning objectives. Examples are chapters and lessons.
3. LO aggregations represent the largest granularity level for learning objects. Units, courses and curricula are defined as subclasses of LO aggregations. Such hierarchies are, for instances, represented in the NETg and New Economy content models.

How these aggregation layers correspond to granularity levels of the reviewed content models is detailed in Section 2.8.

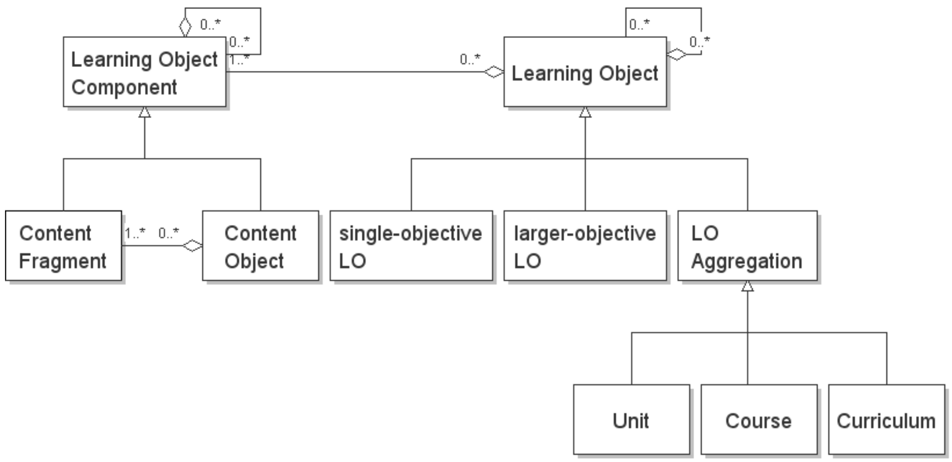


Figure 2.12: The ALOCOM Aggregation Levels

2.6.3 Relationships

Aggregation relationships are defined in the form of "hasPart" and "isPartOf" properties. Content fragments are aggregated by Content Objects. Both Content Fragments and Content Objects are aggregated by Learning Objects and Learning Objects also aggregate other Learning Objects. Single-objective LOs are aggregated by larger-objective LOs and both single and larger-objective LOs are aggregated by LO-aggregations.

2.6.4 Content Classifications

Classifications have been defined for Content Fragments, Content Objects and single-objective LOs. The classifications are detailed in the rest of this section.

Content Fragments

The ALOCOM model defines Content Fragments at the lowest level of granularity. Content Fragments are uncombined content components that are digital representations of media. These content components are commonly classified as [Pazandak and Srivastava, 1997]:

- Text
- Graphic: examples are photographs, diagrams, graphs, symbols, maps, pictographs, timelines, charts, etc.
- Animation

- Video
- Audio

None of the content models define a complete classification for content fragments. Instead, the component types are used as examples.

Content Objects

Content models use (part of) the following classification schemes to define content objects:

- the vocabulary of the Learning Resource Type in IEEE LOM [IEEE, 2002],
- the classification of Ballstaedt [Ballstaedt, 1997], and
- Structured Writing [Horn, 1998]

Cisco, dLCMS, PaKMaS, New Economy and Learnativity use part of this Structured Writing classification. Cisco uses a subset that contains 29 of the 200 defined component types: *overview, summary, definition, example, review, analogy, topology illustration, next steps, block diagrams, additional resources, cycle charts, instructor notes, introduction, principle statement, illustration, importance, outline, fact list, objectives, non-example, table, job-based scenario, prerequisites, guideline, procedure table, decision table, demonstration, staged table,* and *combined table*. The New Economy model uses *examples, references,* and *further material* that relates to *additional resources.* dLCMS uses *objectives, summaries, examples* and *definitions*, and PaKMaS uses *definitions, remarks, examples,* and *illustrations.* Learnativity uses the classification to exemplify information objects, but no precise specification of component types suitable for defining learning content is provided.

The IEEE Learning Object Metadata Standard [IEEE, 2002] defines a vocabulary for Learning Resources Types that is partially used by the dLCMS, PaKMaS, Learnativity and New Economy content models. *Exercises, simulations, questionnaires, narrative text, experiments, problem statements* and *self-assessments* are used by the dLCMS content model. *Exercises* can be found in PaKMaS and *exercises* and *simulations* can be found in the Learnativity model. Finally, *problem statements, simulations* and *exercises* can be found in the New Economy model.

The classification of Ballsteadt is used by the dLCMS model. The New Economy content model uses the term *theory* or *basic knowledge* to denote *advanced organizers*. Finally, the following concepts are used by the dLCMS and/or New Economy content models that are not represented in the Structured Writing, Ballstaedt or LOM Learning Resource Type classifications: *motivation, open question, paragraph,* and *literature*. The content object classification defined by the global content model represents the union of these used concepts, and is shown in Figure 2.13. The combination of these elements is briefly discussed in Section 2.6.5.

Figure 2.13: The ALOCOM Model

Learning Objects

Single-objective LOs are commonly classified as *concepts, facts, principles, processes* and *procedures*. These content types derive from the work of Robert Horn [Horn, 1998], who defined seven information types: *concept, fact, classification, structure, principle, procedure* and *process*. None of the content models explicitly define *structure* and *classification* as learning object types.

Current content models do not classify larger-objective learning objects. The only examples that can be found are lessons and chapters. Hierarchies for LO aggregations, such as *unit, course, curriculum*, are defined by some models.

2.6.5 Discussion

Constructing a global content model that covers existing content models is a complex task, as different interpretations of learning object granularity need to be integrated. Some content models define few granularity levels, each covering a wide variety of learning objects, while others employ narrow granularity definitions in multiple layers.

To combine both broad and narrow approaches, we have defined a hierarchical granularity structure. The goal of such structure is to enable one-to-one content model mappings. A content model, that distinguishes between single and larger-objective learning objects, can find corresponding classes at the second level. Content models that employ a single granularity definition for learning objects can map these objects to the top-level learning object class. Mapping details that validate the approach can be found in Section 2.8.

For defining content classifications, we have combined the concepts that are used by the reviewed content models. Single-objective learning objects are commonly categorized into five content types. Content objects, on the other hand, have diverse classifications that are based on Structured Writing, the classification of Ballsteadt and IEEE LOM. As the classifications overlap to some extent and use the same terms to denote equivalent concepts, we merged the concepts into a single taxonomy. New concepts, introduced by the dLCMS and PaKMaS models, were also added. This merged taxonomy is definitely not the only or the "perfect" classification approach. However, it is a first step in the support of a global content model for learning objects and can adequately cover existing definitions. Further research is required to determine to which extent this classification can cover learning content in every subject matter.

2.7 Local Ontologies

2.7.1 Introduction

In the second stage of the method, local ontologies are defined for each content model, representing concepts and relationships defined by the model. The local ontology of the Cisco model is detailed in this section. Other local ontologies are defined analogously. Their UML representations can be found in Section 2.3.

2.7.2 The Cisco Ontology

The Cisco ontology defines Cisco components and their interrelationships. An excerpt of the UML representation of the ontology is shown in Figure 2.14. Concepts, concept hierarchies and aggregation relationships are represented in the UML diagram, and in other UML diagrams presented throughout this chapter. Constraints imposed on content components are presented in the axiom set below and are expressed in first order logic. The constraints indicate, for instance, that a Cisco concept should contain an introduction, definition and example, and may contain a fact list, non-example, analogy and instructor notes. Cardinality constraints are included in the UML diagrams.

$$
\begin{aligned}
A^O = \{&(\forall x)Concept(x) \wedge (\forall y)haspart(x,y) \rightarrow Introduction(y) \vee fact\_list(y) \vee definition(y)\\
&\vee example(y) \vee non-example(y) \vee analogy(y) \vee instructor\_note(y),\\
&(\forall x)Overview(x) \wedge (\forall y)haspart(x,y) \rightarrow Introduction(y) \vee importance(y)\\
&\vee objectives(y) \vee prerequisites(y) \vee scenario(y) \vee outline(y),\\
&(\forall x)Summary(x) \wedge (\forall y)haspart(x,y) \rightarrow Review(y) \vee next\_steps(y) \vee additional\_resources(y),\\
&(\forall x)RLO(x) \wedge (\forall y)haspart(x,y) \rightarrow Overview(y) \vee Summary(y) \vee RIO(y),\\
&(\exists^{\leq 9} y)haspart(x,y) \wedge RIO(y) \wedge RLO(x), (\exists^{\geq 4} y)haspart(x,y) \wedge RIO(y) \wedge RLO(x),\\
&(\forall x)Concept(x) \rightarrow (\exists y)Introduction(y) \wedge (\exists z)Definition(z) \wedge (\exists w)Example(w)...\}
\end{aligned}
$$

2.8 Mappings

2.8.1 Introduction

In the last step, ontology mappings are defined between the global ALOCOM model and local content model ontologies.

Ontology mappings are often defined as: "Given two ontologies A and B, mapping one ontology with another means that for each concept in ontology A, we try to find a corresponding concept, which has the same or similar semantics, in ontology B and vice versa" [Su, 2006].

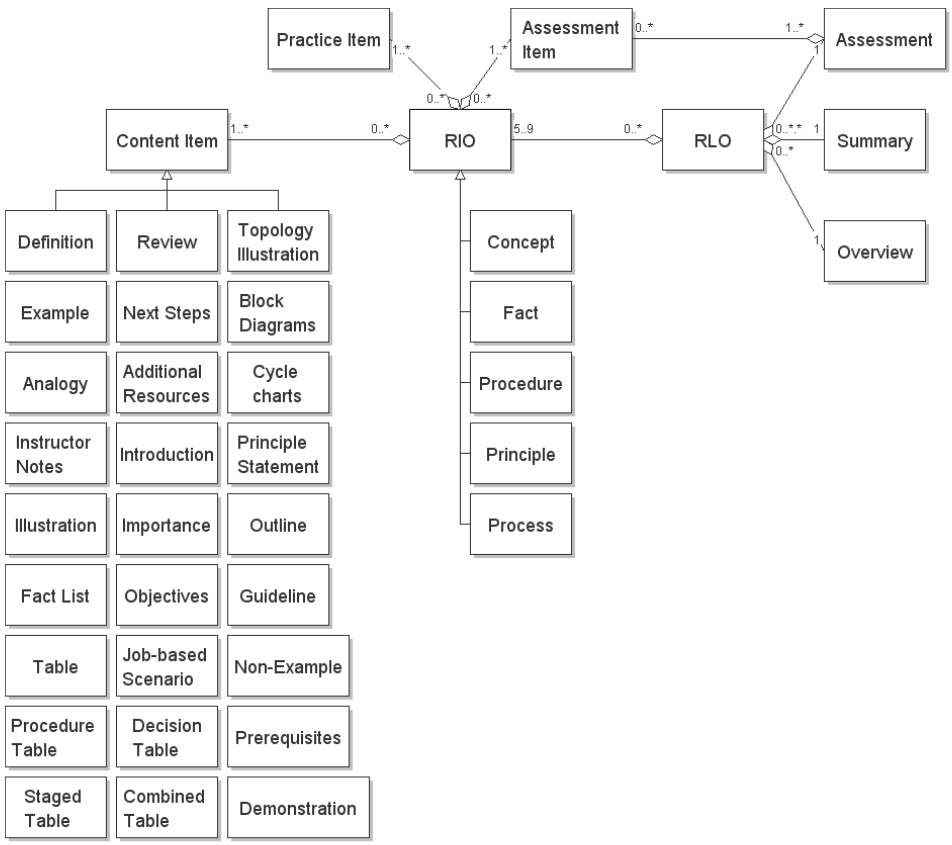


Figure 2.14: UML representation of the Cisco RLO-RIO Model

Formally, an ontology mapping function can be defined as:

- map: $O_{i1} \rightarrow O_{i2}$
- map(e_{i1j1}) = e_{i2j2} , if sim(e_{i1j1}, e_{i2j2}) > t, with t being the threshold, entity e_{i1j1} is mapped to e_{i2j2}

Mappings defined between the global ALOCOM ontology and local content model ontologies are bi-directional. The Content Object and Learning Object mappings are partially represented in Figure 2.15 and Figure 2.16. The Content Fragment mapping is not shown, as most content models use similar terms to denote these component types (text, audio, video, animation...). The complete mapping can be found in Appendix A.

2.8.2 Learning Object Component Mappings

Cisco content items, SCORM assets and NCOM assets are mapped to the ALOCOM LO_Component class, as the granularity levels constitute both ALOCOM Content_Fragments (e.g. block diagram and cycle chart in Cisco) and ALOCOM Content_Objects, such as examples, definitions, introductions and demonstrations.

Learnativity raw data & media elements, dLCMS assets, PaKMaS media objects, and SLM assets are equivalent to ALOCOM Content Fragments. Learnativity information objects, PaKMaS content modules, SLM pedagogical information elements, New Economy information objects and dLCMS content elements are equivalent to ALOCOM Content Objects.

Content Object subclasses are often represented with the same name. Semantically related concepts are, amongst others:

- alocom:simulation → neweconomy:virtual_laboratory
- alocom:overview → neweconomy:basic_knowledge
- alocom:overview → dlcms:advanced_organizer
- alocom:remark → cisco:instructor_note.

2.8.3 Learning Object Mappings

SCORM SCOs, NETg Topics, NCOM ELOs, Cisco RIOs, Learnativity Application Objects, and SLM Pedagogical Entities relate to single learning objectives and are mapped to the ALOCOM Single_Objective_LO class. ALOCOM Single_Objective_LO subclasses have equivalent Cisco (and Learnativity) classes.

According to the authors of the New Economy content model, New Ecomomy Learning Components relate to Cisco RIOs and would have to be mapped to the

Figure 2.15: Learning Object Component Mappings

ALOCOM Single_Objective_LO class. However, if we consider the content elements that a New Economy Learning Component constitutes (motivation, theory, example, exercise, references, further material, open questions, problems, and virtual laboratory), the elements relate to ALOCOM Content_Objects. To resolve the inconsistency, New Economy Learning Components are mapped to the union of ALOCOM Content_Objects and Single_Objective_LOs.

SCORM Activities, Learnativity Aggregate Assemblies, NCOM TLOs, Cisco RLOs, SLM Pedagogical Contexts and New Economy Learning Modules represent learning objects relating to several or larger objectives and are mapped to the ALOCOM Larger_Objective_LO class.

NCOM LO Aggregations, SLM Pedagogical Documents and SCORM Content Aggregations are semantically equivalent to ALOCOM LO_aggregations. Classifications of this top level granularity level are similar in most content models. The NETg and New Economy hierarchies *unit, course* and *unit, course, curriculum* are represented in ALOCOM and are mapped to their equivalent classes. An SLM Pedagogical Schema is mapped to the ALOCOM Curriculum class. Finally, the PaKMaS Structuring Module and dLCMS Learning Unit classes are mapped to the ALOCOM Learning_Object superclass, as no distinction is made between single and larger objective learning objects.

2.8.4 Discussion

Most content models map easily onto the ALOCOM model. The Cisco, NETg, NCOM, Learnativity, dLCMS, and PaKMaS content models provide clear granularity definitions and examples that facilitated their analysis, the construction of the global ALOCOM content model and the implementation of mappings. Some difficulties were encountered in mapping the SCORM, SLM and New Economy content models:

- SCORM defines Assets as its basic building blocks, SCOs as aggregations of one or more Assets and Activities as aggregations of one or more SCOs or Assets. SCOs are intended to be subjectively small units, such that potential reuse in different learning experiences, to fulfill different learning objectives, is feasible. Activities are intended to form a higher-level unit of instruction, that fulfills higher-level learning objectives.

  Based on this intended use, SCORM can be mapped to ALOCOM. However, SCORM components do not have to comply with these guidelines. Strictly speaking, the only difference between an Asset and a SCO is that a SCO communicates with an LMS. SCORM claims to be neutral about the complexity of content: Content Aggregations or Activities can range from a few lines of text to highly interactive learning resources. Applying these broad definitions, the SCORM to ALOCOM mapping might not be valid.

Figure 2.16: Learning Object Mappings

- The definition of content components in SLM is rather fuzzy: 6 aggregation levels are defined, but only 4 can aggregate more than one content component. Furthermore, it is unclear what is meant by the definition of a pedagogical context, i.e. "a semantic structure in which pedagogical entities are grouped". The lack of precise definitions and examples were a bottleneck in the analysis of the content model. For mapping the SLM content model, we solely relied on its relationship to the Learnativity content model, as proposed by the authors.

- As indicated in Section 2.8.3, the definition of New Economy Learning Components is somewhat contradictory. The authors define Learning Components as motivations, theories, examples, exercises, references, further material, open questions, problems, and virtual laboratories. In addition, they relate the component type to Cisco RIOs, that constitute concepts, facts, principles, processes and procedures. To resolve the inconsistency, we mapped the component type to the union of ALOCOM Content_Objects and ALOCOM Single_Objective_LOs.

2.9 Usage Scenario

Implementing content model mappings is useful in several ways. First of all, share and reuse of learning object components is enabled across systems. For instance, an LMS using SCORM content can be aligned with a Cisco repository at the content level (see use case 1 in Figure 2.17). Equivalent components can be identified and potentially repurposed within different contexts.

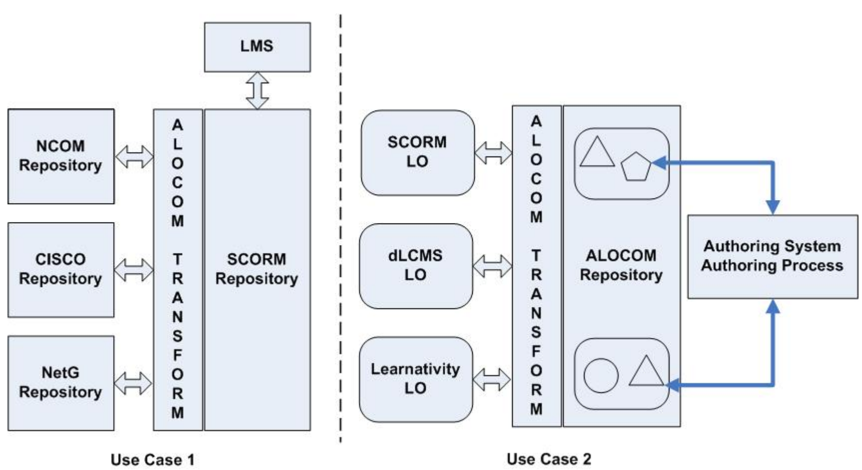


Figure 2.17: Use Cases

Secondly, the ontology is useful as an underlying component model for a global learning object repository. A decomposition architecture can deconstruct learning objects from different origins according to the ALOCOM model. The availability of these components enables reuse on a global scale. Authoring systems can connect to the repository, enabling on-the-fly retrieval of relevant components from within authoring tools.

A typical usage scenario goes as follows: Suppose an author is creating a learning object on differential equations. She wants to start with a definition, followed by three examples. The author enters "differential equations" as keywords and selects "definition" and "example" as component types. The system then searches the repository and retrieves all components of the selected types, dealing with the selected topic. The author then chooses the most relevant components and includes them into the learning object.

2.10 Related Work

Some researchers have adopted our initial content model comparison approach presented in [Verbert and Duval, 2004]. In [Schluep, 2005], the Methodenlehre-Baukasten model [Schulmeister, 2003] is added to the comparison. Furthermore, the comparison is used as the basis for the development of a new content model, dLCMS. Similar to our work, it is argued that at least three aggregation layers are required for enabling successful aggregations of learning object components.

In [Fernandes et al., 2005], IMS Learning Design [IMS LD, 2003] is added to the content model comparison. The authors of the SLM model used the comparison table to compare and contrast their model to existing content models. No changes to the comparison are proposed. Hence, the researchers seem to agree that the alignment of content models included in the first investigation (SCORM, Cisco, NETg and Learnativity) is valid.

Besides content model investigations, ontologies have been built that try to classify learning object components. Overlaps exist between the ontology on instructional items [Ullrich, 2005] and the ALOCOM model. This ontology defines component types that are situated at the Content_Object and Single_Objective_LO levels. Another example of such an ontology is used in the TRIAL-SOLUTIONS project [Lenski and Wette-Roch, 2001]. This ontology defines component types for mathematical learning objects, including definition, lemma, theorem, proof, corollary, scholium, comment, theory, axiom, postulate, thesis, method, rule, criterion, open question, paradox, example, and solution. The ontology would be a meaningful extension of the ALOCOM model when dealing with mathematical content.

2.11 Conclusion

In this chapter, the ALOCOM content model has been presented that defines learning objects and their components at different levels of granularity. The Content Fragment and Content Object component levels are important for enabling flexible learning object reuse, as these fine-grained components can be aggregated to create new learning objects.

The ALOCOM model and ontology mappings presented in this chapter are an attempt to align existing learning object content models and are aimed at enabling their interoperability. The ontology connects content model specifications that are currently available. Such an ontology is never completely stable and should evolve over time. Furthermore, as it is an attempt to integrate different viewpoints, the mappings are subject to discussion. We may hope that interested parties help to improve this work, so as to bring it to its full potential.

Chapter 3

RAMLET: A Model for Structuring of Learning Object Components

3.1 Introduction

The previous chapter has presented a content model for learning objects and their components and is an important step towards supporting flexible reuse of learning object components that can be aggregated to create new learning objects. In order to realize the full potential of the approach, it is necessary to develop an architecture that enables describing the structure of such aggregations.

Resource aggregation is the process of gathering resources and describing their structure, so that the resulting aggregate can be used for transmission, storage, and delivery to users [RAMLET, 2005]. The resource aggregate specifies how the resources fit together into a coherent, structured, whole. In addition, learning object components comprising the resource aggregate can be structured in more than one way.

Different communities, such as the multimedia, library, technical documentation, and learning technology community, have created their own specifications and standards for resource aggregates. Examples include the Metadata Encoding and Transmission Standard (METS) [Cundiff, 2004], an initiative of the Digital Library Federation [Greenstein, 2002]; the IMS Content Packaging (IMS-CP) specification [IMS CP, 2004], that is predominantly used in the educational domain; and the MPEG-21 Digital Item Declaration (MPEG-21 DID) [Bekaert, 2006], an ISO standard for the audio-visual content industry. OASIS OpenDocument [Durusau et al., 2007] and the W3C Synchronized Multimedia Integration Language

(SMIL) [Bulterman et al., 2005] also fit into this mould.

Without a common nomenclature and conceptual model to inform the interpretation of these formats and specifications, it is difficult to create applications that can interoperate. A reference model can facilitate interoperability by representing a variety of resource aggregation formats and specifications in a common way. Interoperability can be achieved by facilitating the creation of crosswalks among various aggregation formats and specifications.

The Resource Aggregation Model for Learning, Education and Training (RAMLET) defines such reference model for digital aggregates of resources for learning, education, and training applications. Crosswalks have been defined between the RAMLET model and other resource aggregation formats, that enable their interoperability. The approach enables to assemble and structure ALOCOM components and to export the aggregate for use in existing IMS CP, METS, or MPEG-21 applications.

The RAMLET model has been developed in the context of a project to produce an IEEE standard, in which the author has been involved. The project has been undertaken by the LTSC Computer Managed Instruction (CMI) Working group. The model has been developed using the integration method presented in the previous chapter (see Section 2.5). Different resource aggregation formats, such as IMS CP, METS, and MPEG-21 DID, were analyzed and a global ontology was constructed that covers the specifications. Local ontologies were developed for the resource aggregation formats and finally mappings were implemented between the global RAMLET model and local resource aggregation ontologies.

At the time of this writing, the RAMLET model is close to finalization. The projected completion date for submittal to the IEEE Standards Review Committee is April 2008. The description of the RAMLET reference model, and mappings to other resource aggregation specifications, are based on the following ontology draft versions:

- RAMLET Core Ontology: version 0.9.8[1]
- RAMLET Core to CP mapping: version 0.9.96[2]
- RAMLET Core to METS mapping: version 0.2.92[3]
- RAMLET Core to Atom mapping: version 0.1.7[4]

[1] http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET-OWL-CORE.owl/view

[2] http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET-CPmapping.owl/view

[3] http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET-METSmapping.owl/view

[4] http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET-AtomMapping.owl/view

- RAMLET Core to MPEG-21 DID mapping: version 0.9.83[5]

The chapter is organized as follows: Section 3.2 presents use cases of the RAMLET model. Section 3.3 outlines the resource aggregation formats that were used in the development of RAMLET. Section 3.4 presents the RAMLET model and the mappings. Finally, the use cases are revisited to clarify the RAMLET transformation process and the level of interoperability that can be achieved, followed by some concluding remarks.

3.2 Use Cases

3.2.1 Introduction

This section presents use cases that illustrate the need of a common reference model for structuring of learning object components. The first use case illustrates exchange and reuse of resource aggregates among systems using different specifications. Use case 2 illustrates the relation between RAMLET and ALOCOM. ALOCOM components are assembled in a structured RAMLET aggregate and exported to various resource aggregation formats. Use case 3 illustrates how the use of RAMLET can enable interoperability of systems that use their own internal format for resource aggregates.

3.2.2 Use Case 1

The use case addresses exchange and reuse of resource aggregates among systems using different specifications. For example, a system using METS might import resource aggregates that use IMS CP, and MPEG-21 DID, and create a new resource aggregate.

Usage scenario

A content author in a university is developing a new resource aggregate and wishes to include resources from different sources, including learning resources, reference materials, and research data. The author searches for appropriate materials and retrieves each resource to an authoring system. The resources are exported from their repositories in resource aggregation formats specific to their respective repositories. The authoring system interprets the incoming resource aggregation formats and converts them to its native format.

The author then creates the new resource aggregate, including the imported resources, and makes the new resource aggregate available to the local learning management system (LMS) or run-time system (RTS). The new resource aggregate

[5] http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET-MPEG21mapping.owl/view

is in the resource aggregation format used by the authoring system. Figure 3.1 illustrates this scenario.

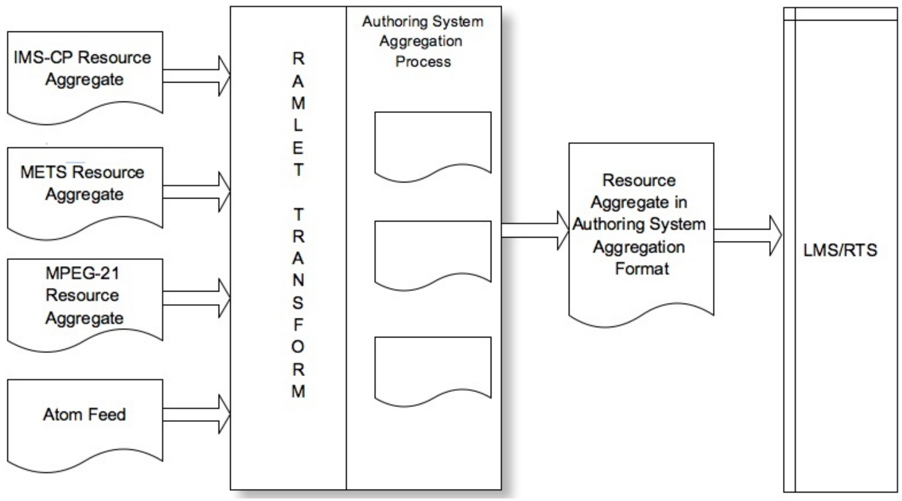


Figure 3.1: Use case 1

Use case summary: retrieve-interpret-aggregate-deploy

This use case addresses retrieving resource aggregates from diverse resource repositories that provide resource aggregates in different resource aggregation formats. The retrieved resource aggregates are interpreted, and converted into a single format that can be used by an authoring system and then aggregated into a new resource aggregate. The new resource aggregate can be deployed by an RTS that is limited to a single resource aggregation format.

3.2.3 Use case 2

This use case illustrates the relation between ALOCOM and RAMLET. The use case addresses retrieving content from diverse repositories. The retrieved learning objects are disaggregated into ALOCOM components and made available for reuse. Authoring tools can connect to the repository, enabling on-the-fly aggregation of relevant components from within authoring tools. RAMLET enables to describe the structure and to deploy the resource aggregate to an LMS that is limited to a single resource aggregation format.

Usage scenario

A content author in a university is developing a learning object on differential equations. She wants to start with a definition, followed by three examples. The author enters "differential equations" as keywords and selects "definition" and "example" as component types. The system then searches the ALOCOM repository and retrieves components of the selected types, dealing with the selected topic. The components have been made available by decomposing SCORM [SCORM, 2004], Cisco [Barrit et al., 1999] and NETg [L'Allier, 2003] learning objects. The author then chooses the most relevant components and includes them into the learning object.

RAMLET comes into the scenario when the author wants to export the learning object to a repository specific format. Using RAMLET, the author is free to choose the publishing format of the generated resource aggregate among IMS CP, METS, MPEG-21 DID and Atom. Figure 3.2 illustrates this scenario.

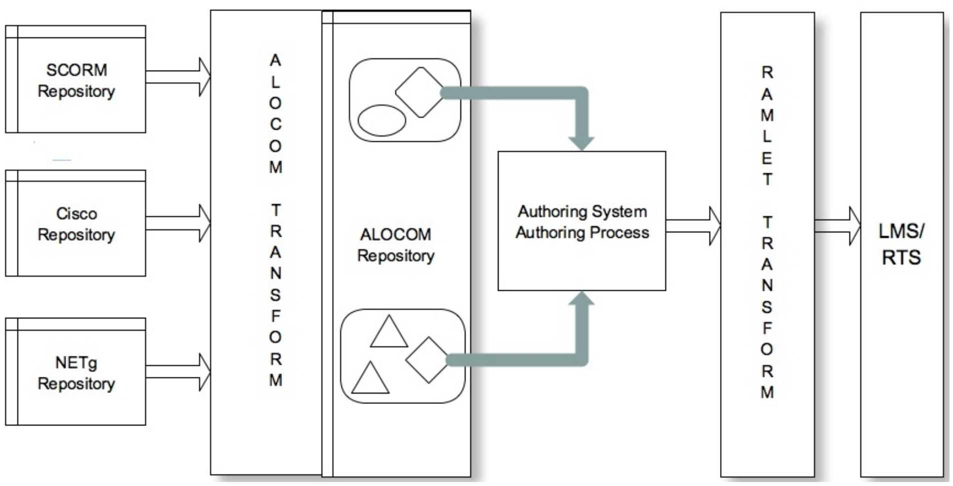


Figure 3.2: Use case 2

Use case summary: retrieve-disaggregate-aggregate-deploy

This use case addresses retrieving learning objects from diverse repositories that are composed according to different content models. The retrieved learning objects are disaggregated, and components are stored individually, enriched with metadata. Components are then aggregated and structured into a new learning object. The new aggregate can be deployed by an RTS that is limited to a single resource aggregation format.

3.2.4 Use case 3

An LMS creates a resource aggregate just in time and will import, store, and make available resource aggregates from systems using different specifications. For example, a system using its own internal format might import resource aggregates that use IMS CP, METS, MPEG-21 DID, and the format used by a student-information store at the time they are required in the learning path.

Usage scenario

An LMS supports a learner by using and providing learning resources that are appropriate in the respective context of the learning situation and the individual requirements of the learner at a particular time. Such requirements may include accessibility preferences or needs in order to access the material. The LMS retrieves, provides, and aggregates required resources just in time and makes use of different sources that provide resources in different resource aggregation formats. Figure 3.3 illustrates this scenario.

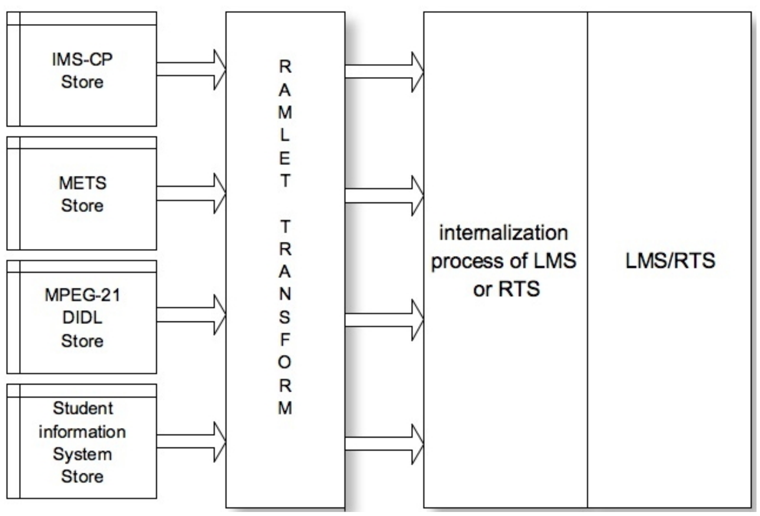


Figure 3.3: Use case 3

Use case summary: retrieve-interpret-internalize-deploy

This use case avoids building a complete resource aggregate prior to deployment. The RAMLET specification supports the transformation and interpretation of retrieved resource aggregates in diverse aggregation formats into a single format.

The delivery system is able to produce an internal representation of the resource aggregate and to render the resources.

3.3 Resource Aggregates

3.3.1 Introduction

This section briefly outlines the resource aggregation formats that were used in the development process of RAMLET: IMS CP [IMS CP, 2004], METS [Cundiff, 2004], MPEG-21 DID [Bekaert, 2006] and Atom [Sayre, 2005]. The structures and properties of the resource aggregation formats are described. Simple examples are included to illustrate the different constructs. Note that these examples are incomplete and much simpler than real world applications.

3.3.2 IMS Content Packaging

IMS Content Packaging (IMS CP) is a specification that enables learning resources to be transported between educational environments [IMS CP, 2004]. The IMS Content Packaging specification was developed by the IMS Global Consortium and plays a central role in the learning technology community.

An IMS Content Package contains two major components: an XML document, called manifest file, that describes the content structure and associated resources of the package, and the content making up the content package. The manifest file is composed of four sections:

1. Metadata: Data describing the content package as a whole. Metadata are usually included using IEEE LOM [IEEE, 2002], though strictly speaking it can rely on other schemas.

2. Organizations: Contains the content structure or organization of the learning resources making up a stand-alone unit or units of instruction.

3. Resources: Defines the learning resources bundled in the content package.

4. (sub)Manifest(s): Describes any logically nested units of instruction, which can be treated as stand-alone units.

The organizations section describes zero, one, or multiple organizations of the resource aggregate, as illustrated in Figure 3.4. Multiple organizations can provide learners with a variety of alternative structures for content. Each organization within the organizations section specifies how resources fit together into a hierarchically-arranged sequence of items. These items point to a resource in the resource section, that lists the resources that together comprise the content of the resource aggregate. An example is presented Listing 3.1.

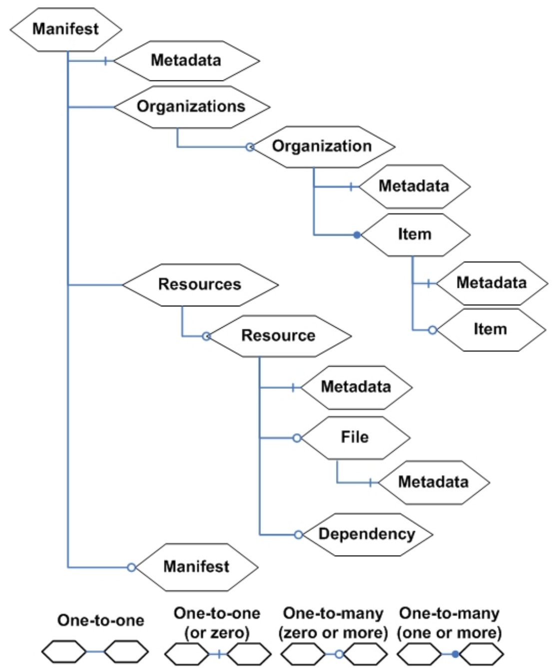


Figure 3.4: Conceptual description of elements in a manifest document

Listing 3.1: A simple manifest document

```
<manifest>
  <organizations default="learning_seq">
    <organization identifier="learning_seq" structure="hierarchical">
      <title>Summer Pictures</title>
      <item identifier="item1" ... identifierref="res1">
        <title>Loch Katrine</title>
      </item>
      <item identifier="item2" ... identifierref="res2">
        <title>Ben Ledi</title>
      </item>
    </organization>
  </organizations>
  <resources>
    <resource identifier="res1" type="webcontent" href="five.html">
      <file href="five.html" />
      <file href="supp/reloadhelp.css" />
    </resource>
  </resources>
</manifest>
```

3.3.3 METS

The Metadata Encoding and Transmission Schema (METS) is a standard for encoding descriptive, administrative, and structural metadata regarding resources within a digital library [Cundiff, 2004]. The standard is developed as an initiative of the Digital Library Federation [Greenstein, 2002].

A METS document consists of seven sections [Cundiff, 2004], as illustrated in Figure 3.5:

1. METS Header - The METS Header contains metadata describing the METS document itself, including information such as the creator, editor, etc.

2. Descriptive Metadata - The descriptive metadata section may point to descriptive metadata external to the METS document, or contain internally embedded descriptive metadata, or both.

3. Administrative Metadata - The administrative metadata section, also embedded or external to the METS document, provides information regarding how the files were created and stored, intellectual property rights, metadata regarding the original source object from which the resource aggregate derives, and information regarding the provenance of the files comprising the resource aggregate. Such metadata records modifications that have been made to a resource during its life cycle.

4. File Section - The file section lists all files containing content that comprise the resource aggregate. <file> elements may be grouped within <fileGrp> elements, that can be used to organize individual file elements into sets. File groups can, for instance, store multiple versions of the files.

5. Structural Map - The structural map is the heart of a METS document. As in IMS CP, it outlines a hierarchical structure for the resource aggregate, and links the elements of that structure to content files and metadata that pertain to each element. Multiple structures of content can be specified.

6. Structural Links - The Structural Links section of METS allows METS creators to record the existence of hyperlinks between nodes in the hierarchy outlined in the Structural Map.

7. Behavior - A behavior section can be used to associate executable behaviors with content in the METS object. Such sections link resources with applications or programming code that are used to render or display the resource.

The similarity between METS and IMS CP is great. Both resource aggregation formats specify how resources fit together into a hierarchically structured whole,

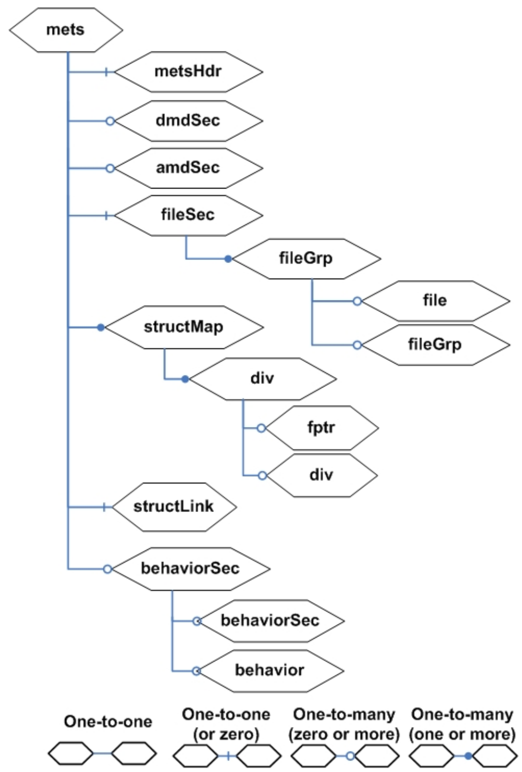


Figure 3.5: Conceptual description of elements in a METS document

express metadata pertaining to the content and provide an inventory of files. The administrative and descriptive metadata segmentation of METS cannot be found in IMS CP. Behavioral information is also not available in IMS CP.

An example of a simple METS document is illustrated in Listing 3.2. The *mets* element is the root element of the aggregation. The *structMap* element corresponds to the IMS CP *organization* element. Like the IMS CP *organization* element, the structural map represents the structure of content in a hierarchically-arranged sequence of divisions (*div* elements). In the example, the structural map simply analyses the dictation into a sequence of two physical pages. Each page division points to a single file by means of a *fptr* element in the file section, that corresponds to an IMS CP *resources* element.

Listing 3.2: A simple METS document (from [Yee and Beaubien, 2004])

```
<mets:mets LABEL="Dictation from Amelia Hartman Saunders">
  <mets:fileSec>
    <mets:fileGrp USE="REFERENCE">
      <mets:file ID="FID1" ADMID="ADM1">
        <mets:FLocat xlink:href="http://sunsite.berkeley.edu/3a_b.jpg"
        LOCTYPE="URL"/></mets:file>
     <mets:file ID="FID2" ADMID="ADM1">...</mets:file>
    </mets:fileGrp>
  </mets:fileSec>
  <mets:structMap TYPE="physical">
    <mets:div LABEL="Dictation from Amelia Hartman Saunders"
    DMDID="DMD1">
      <mets:div TYPE="page" LABEL="Page [1]">
        <mets:fptr FILEID="FID1"/>
      </mets:div>
      <mets:div TYPE="page" LABEL="Page [2]">
        <mets:fptr FILEID="FID2"/>
      </mets:div>
    </mets:div>
  </mets:structMap>
</mets:mets>
```

3.3.4 MPEG-21 DID

MPEG-21 is a comprehensive standard framework for networked digital multimedia, designed by the Moving Picture Experts Group [Burnett et al., 2003]. MPEG-21 describes a standard that defines the description of content and also processes for accessing, searching, storing and protecting the copyrights of content.

The basic architectural concept in MPEG-21 is the "digital item". Digital items are structured resources, including a standard representation, identification and metadata. Digital items are defined by the MPEG-21 Digital Item Declaration (DID) [ISO/IEC 21000-2:2005], a subpart of the standard, that defines the following entities (illustrated in Figure 3.6):

- Container: A *container* is a structure that allows *digital items* and/or *containers* to be grouped. Like in METS and IMS CP, such organization contains a hierarchically-arranged sequence of items. *Descriptors* allow for "labeling" of containers with information that is appropriate for the purpose of the grouping, such as delivery instructions for a package, or category information.

- Item or Digital Item: An *item* is a grouping of sub-items and/or *components*, that include *resources* and their descriptions. In IMS CP and METS, resources are listed separately.

- Component: A *component* is a *resource* bound to all of its relevant *descriptors*. These *descriptors* are information related to a specific resource instance. Such descriptors will typically contain control or structural information about the resource, such as bit rate, character set, start points or encryption information.

- Resource: A *resource* is an individual datastream, such as a video file, image, audio clip or textual asset.
- Fragment: A *fragment* designates a specific point or range within a resource. For example, a fragment may specify a specific point in time of an audio track.
- Descriptor: A *descriptor* construct introduces an extensible mechanism that can be used to associate textual metadata with other entities. Examples of metadata include information supporting discovery, digital preservation and rights expressions.

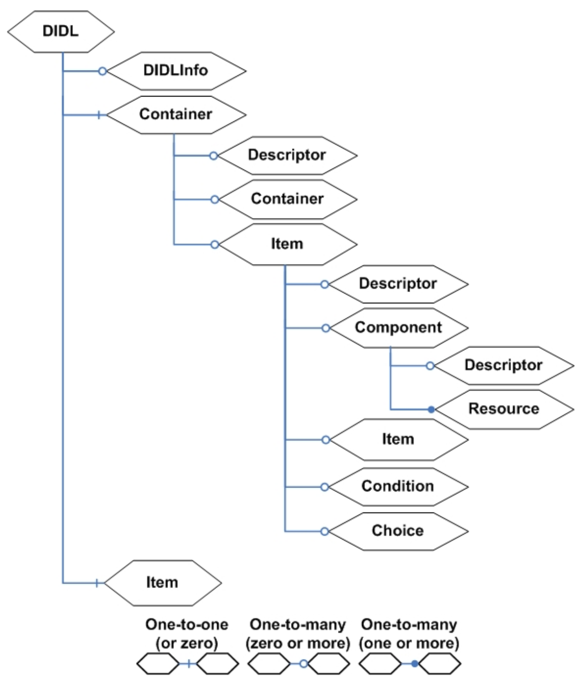


Figure 3.6: Conceptual description of elements in an MPEG-21 DID document

Another set of entities, containing *choice, selection, condition* and *assertion*, allows describing a digital item (or a part thereof) as being optional or available under specific conditions. For example, a *choice* may represent the choice between a high bandwidth internet connection and a dial-up connection. Based on the *selection* made by a user, the *conditions* attached to an entity of a digital item may be fulfilled and the entity may become available. Dependent on the nature of the *conditions*, the entity could contain a high resolution datastream or a compressed file, respectively [Bekaert, 2006]. Such conditional behavior is not available in METS or IMS CP.

Listing 3.3: A simple MPEG-21 DID document

```
<DIDL xmlns="urn:mpeg:mpeg21:2002:01-DIDLNS">
  <Container>
    <Descriptor>
      <Statement mimeType="text/plain">
        Album title
      </Statement>
    </Descriptor>
    <Item id="track01">
      <Descriptor>
        <Statement mimeType="text/plain">
          Song title 01
        </Statement>
      </Descriptor>
      <Component>
        <Resource ref="track01.mp3" mimeType="audio/mpeg"/>
      </Component>
    </Item>
    <Item id="track02">
      <Descriptor>
        <Statement mimeType="text/plain">
          Song title 02
        </Statement>
      </Descriptor>
      <Component>
        <Resource ref="track02.mp3" mimeType="audio/mpeg"/>
      </Component>
    </Item>
  </Container>
</DIDL>
```

Listing 3.3 presents an example of an MPEG-21 DID document. The *DIDL* element is the root element of the aggregation. A *container* element corresponds to an IMS CP *organization* and METS *structMap* element and describes the structure of the resource aggregate. In the example, the *container* element groups two *item* elements, track01 and track02. MPEG-21 *items* corresponds to IMS CP *items* and METS *div* elements. These *items* bind *components* to *descriptor* elements. Such *components*, then, correspond to IMS CP *Resource* and METS *file* elements.

3.3.5 Atom

Atom is an XML-based document format that describes lists of related information, known as "feeds" [Sayre, 2005]. Feeds are composed of a number of "entries", each with an extensible set of metadata. For example, each entry has a title.

The primary use case that Atom addresses is the syndication of Web content, such as weblogs and news headlines, to Web sites and users.

Listing 3.4 illustrates a brief, single-entry, Atom feed document. The *feed* element is the root element of the aggregation. Metadata associated with the feed are represented by *title*, *link*, *updated*, *author* and *id* elements in the example. Feeds aggregate *entries*, that are containers for information relating to one content element. Such *entries* correspond to IMS CP *file*, METS *file* and MPEG-21 *resource* elements.

Listing 3.4: An Atom feed document

```
<?xml version="1.0" encoding="utf-8"?>
<feed xmlns="http://www.w3.org/2005/Atom">
    <title>Example Feed</title>
    <link href="http://example.org/"/>
    <updated>2003-12-13T18:30:02Z</updated>
    <author>
      <name>John Doe</name>
    </author>
    <id>urn:uuid:60a76c80-d399-11d9-b93C-0003939e0af6</id>

    <entry>
      <title>Atom-Powered Robots Run Amok</title>
      <link href="http://example.org/2003/12/13/atom03"/>
      <id>urn:uuid:1225c695-cfb8-4ebb-aaaa-80da344efa6a</id>
      <updated>2003-12-13T18:30:02Z</updated>
      <summary>Some text.</summary>
    </entry>
</feed>
```

3.3.6 Discussion

Atom documents act as a container for metadata and content associated with the feed. The structure of an Atom feed is limited to a simple sequence of entries. MPEG-21, METS and IMS CP support more advanced structural relationships. The resource aggregation formats specify how the resources fit together into a hierarchically structured whole. In addition, they allow content files comprising the resource aggregate to be structured in more than one way, thereby providing the user with different possible approaches to, and experiences of, the same content.

Atom, METS and MPEG-21 DID support embedding content into the resource aggregate. In IMS CP, resource aggregates act as a table of contents that only links to content that is stored in separate files.

METS, MPEG-21 DID and IMS CP allow metadata to be expressed using external standards. The communities that use the resource aggregation standards are likely to favor the use of certain metadata standards. The learning community, for instance, strongly favors the use of LOM metadata in IMS CP documents. Libraries using METS are likely to favor MODS [Gartner, 2003], Dublin Core [Weibel et al., 1998], or MARCXML [De Carvalho et al., 2004] for describing content and MIX [ANSI/NISO Z39.87, 2006] or textMD [McDonough 2007] for capturing technical metadata [Yee and Beaubien, 2004].

Parsing out MODS and MIX metadata into LOM categories and elements, and vice versa, is beyond the scope of RAMLET. The RAMLET reference model focuses on the structures of the various resource aggregation specifications by analyzing and describing the properties of common structural concepts. Such reference model will enable to transform a resource aggregate of one specification into the structure of another, enabling to move resources aggregates between systems, and thereby allowing easier reuse and sharing. Such transformation produces valid resource aggregates, as the resource aggregation formats do not restrict the format of metadata. Metadata translation, or extraction of embedded content, will need to be considered in some cases. For instance, an editor for IMS Content Packages might not be able to display Dublin Core metadata correctly. As we use RAMLET for structuring and exchange of learning object aggregations, such translation is less important in the context of this dissertation.

3.4 RAMLET

3.4.1 Introduction

The RAMLET model defines a common nomenclature and an ontology that can be used to represent different resource aggregation formats and specifications. Interoperability is achieved by mappings, that have been defined between the RAMLET model and other resource aggregation formats.

The model has been developed using the integration method presented in the previous chapter. Different resource aggregation formats, such as IMS CP, METS, MPEG-21 DID, were analyzed and a global ontology was constructed that covers the specifications. Local ontologies were developed for the resource aggregation formats and finally mappings were defined between the global RAMLET model and local resource aggregation ontologies.

This section presents the RAMLET model and the mappings that are currently available. Definitions of RAMLET terms, abbreviations and acronyms can be found in Appendix B.

3.4.2 The RAMLET Model

The RAMLET model currently covers IMS CP, MPEG-21 DID, Atom and METS and has been implemented in OWL [Bechhofer et al., 2004]. OWL is used as a formalism for expressing structural concepts of RAMLET and their interrelationships. Coverage of IMS CP, MPEG-21 DID, Atom and METS implies that all elements of the resource aggregation formats are represented in RAMLET, so as to enable a lossless transformation from the specifications to RAMLET.

The RAMLET model is presented in Table 3.1. The *TopNode* element represents the root element of an aggregation and corresponds, for instance, to an IMS CP Manifest and MPEG-21 DIDL element. *DescriptorObject* is a wrapper for metadata, usually expressed using external standards. The distinction is made between *administrative* and *descriptive* metadata to represent the functional metadata segmentation of METS. Other subclasses of the descriptorObject class define metadata elements that appear as XML attributes in the source of resource aggregation formats. Most metadata elements are derived from METS, including information regarding how the files were created and stored, intellectual property rights and metadata regarding the original source object from which the aggregate derives. *GeneratingTool, HumanLanguage, partyEmail* and *textType* derive from Atom. *ContentEncoding* and *nodeVisibility* derive respectively from MPEG-21 and IMS CP.

Classes for representing identifiers are defined for the aggregation (*aggregationID*), local elements (*elementID*) and structural nodes (*nodeID*). NodeIDs are a special kind of local identifiers and can be found in METS. *StaticStructure* is the construct for representing the structure of the resource aggregate into a hierarchically-arranged sequence of *StructureNodes*. *DynamicStructure*, and its subclasses, allow describing a resource aggregate (or a part thereof) as being optional or available under specific conditions.

Definitions of the RAMLET elements are included in Table 3.1. These definitions are based on a draft of August 9 and are not finally agreed upon by the working group yet. They are included as they help to clarify the different elements.

Table 3.1: RAMLET CORE Draft August 9.

Class Number	Class Name	Annotation	Associated superclasses
1	topNode	The highest level of aggregation defined by a given aggregation format.	owl:Class
2	descriptorObject	A container for metadata schemas.	owl:Class
2.1	administrative	A container for information about the management of the object.	descriptorObject
2.2	aggregationFormat	Identifying string for an aggregation's defining format or profile.	descriptorObject

Table 3.1: RAMLET CORE Draft August 9.

Class Number	Class Name	Annotation	Associated superclasses
2.3	aggregationFormat-Version	Identifying string for an aggregation's defining format or profile version.	descriptorObject
2.4	aggregationType	Category for the resource being aggregated.	descriptorObject
2.5	alternateID	Contains an identifying string by which the associated element component is also known in another system.	descriptorObject
2.6	checksum	A value that can be used to check the integrity of the associated resource.	descriptorObject
2.7	checksumType	Information about the algorithm by which the associated checksum was calculated.	descriptorObject
2.8	creationDate	Element that contains the date when an associated element was created.	descriptorObject
2.9	descriptive	Container for information to support finding, identifying, selecting and obtaining the resource.	descriptorObject
2.10	encodingType	An element that indicates the method by which the associated resource has been serialized within the aggregation.	descriptorObject
2.11	fileSize	Indicates the size of a component file referenced in the aggregation instance.	descriptorObject
2.12	generatingTool	Identifies the tool used to make the aggregation instance.	descriptorObject
2.13	humanLanguage	Indicates the human language in which a resource is rendered.	descriptorObject
2.14	intendedUse	Indicates the function an associated set of digital resources is intended to have in the aggregation.	descriptorObject
2.15	mdTypeIndicator	Categorizes the metadata contained in an element belonging to an aggregation format.	descriptorObject
2.16	mimeType	Indicates the electronic media format of a component file referenced in the aggregation instance.	descriptorObject
2.17	modificationDate	Contains the last date of modification of associated entities.	descriptorObject

Table 3.1: RAMLET CORE Draft August 9.

Class Number	Class Name	Annotation	Associated superclasses
2.18	nodeVisibility	Indicates whether a structure node in the aggregation should be rendered for the user.	descriptorObject
2.19	party	A person or group performing a role in relation to a specific community or domain.	descriptorObject
2.19.1	partyEmail	Indicates an email address with which a party can be contacted.	party; descriptorObject
2.19.2	partyName	States the name of the party.	party; descriptorObject
2.19.3	partyRole	Specifies the relationship a party has with regard to the aggregation.	party; descriptorObject
2.19.4	partyType	Describes the nature of a party, e.g., a person or an organization.	party; descriptorObject
2.19.5	partyURI	Identifies the party by its Uniform Resource Identifier.	party; descriptorObject
2.20	provenance	Information about circumstances related to the creation and custody over time of the described resource or its components.	descriptorObject
2.21	resourceProcessing	Expressions of statements and instructions required to make the resource useable, e.g., transformation.	descriptorObject
2.21.1	resourceProcessing-Algorithm	Identifies the routine used to process the resource and make it useable.	resourceProcessing; descriptorObject
2.21.2	resourceProcessing-Behavior	Locates an element that describes transformation behavior.	resourceProcessing; descriptorObject
2.21.3	resourceProcessing-Key	Describes a required parameter for a resource processing algorithm to access the resource.	resourceProcessing; descriptorObject
2.21.4	resourceProcessing-Type	Describes what kind of processing the resource requires before rendering, e.g., decompression or decryption.	resourceProcessing; descriptorObject
2.22	rights	Statements of the rights, obligations, and restrictions governing the archiving and use of the described resource.	descriptorObject
2.23	source	Information about the original source of the described digital resource.	descriptorObject

Table 3.1: RAMLET CORE Draft August 9.

Class Number	Class Name	Annotation	Associated superclasses
2.24	status	Indicates the state of the associated element.	descriptorObject
2.25	structureNodeType	Indicates a category that describes a component of an aggregation structure	descriptorObject
2.26	technical	Information about the technical format of the described digital resource.	descriptorObject
2.27	textType	Indicates the type of text used in an associated container node, e.g., plain text or rtf.	descriptorObject
2.28	wholeAggregation	Information about the resource aggregation instance itself, rather than the resources it aggregates.	descriptorObject
2.28.1	identiferType	Identifies the identifier scheme of an associated identifier.	wholeAggregation; descriptorObject
3.0	aggregateID	Identifier for the aggregation.	owl:Class
4.0	elementID	Element that provides a local identifier.	owl:Class
4.1	nodeID	Identifier for a structural node.	elementID
5.0	digitalResource	The digital resource(s) that an aggregation format instance aggregates.	owl:Class
5.1	digitalResource-Fragment	A component of a digital resource which is an entity specifically addressed within the structure of an aggregation instance.	digitalResource
6.0	staticStructure	The structural relations between entities described in a staticStructure always hold true regardless of the state of the aggregation.	owl:Class
6.1	staticStructureType	Categorization of the nature of the structure describing the relations between entities within an aggregation instance.	staticStructure
7.0	staticStructureSet	Contains collection(s) of static structures.	owl:Class
8.0	dynamicStructure	Relations between entities in a dynamicStructure depend on factors that are only true for one state, e.g., as calculated at runtime.	owl:Class
8.1	dynamicStructure-Type	Categorizes the nature of a dynamic structure.	dynamicStructure

Table 3.1: RAMLET CORE Draft August 9.

Class Number	Class Name	Annotation	Associated superclasses
8.2	dynamicStructure-ID	Identifier for entities that are eligible to be included in a dynamic structure.	dynamicStructure
8.3	assertion	Declares a particular state of the aggregation during processing to be true or false.	dynamicStructure
8.4	condition	Indicates that an associated component is to be included within a dynamic structure.	dynamicStructure
8.5	choice	Indicates that a component of a dynamic structure is one option of a set of components that a processing application can choose to render or process.	dynamicStructure
8.6	selection	Indicates a set of components of a dynamic structure that a processing application can choose to select, depending on a number of parameters.	dynamicStructure
8.7	maxSelections	Indicates the maximum number of components that a processing application can select.	dynamicStructure
8.8	minSelections	Indicates the minimum number of components that a processing application can select.	dynamicStructure
8.9	defaultSelection	Indicates which of the associated components should be chosen by a processing application in the absence of any parameters, that suggest choosing something else.	dynamicStructure
8.10	require	Indicates a set of required components of a dynamic structure.	dynamicStructure
8.11	except	Indicates a set of excluded components of a dynamic structure.	dynamicStructure
9.0	dynamicStructure-Set	Contains collections of dynamic structures and relations between them.	owl:Class
10.0	structureNode	A component of a structure describing the entities within an aggregation instance. The component may be either a conceptual or physical node.	owl:Class

3.4.3 Mappings

Mappings have been defined between the RAMLET model and the IMS CP, METS, MPEG-21 DID and Atom standards. The definition of ontology mappings presented in the previous chapter applies here, too. Mappings defined between RAMLET and the resource aggregation formats are bi-directional.

The mappings are represented in Table 3.2. Concepts defined by RAMLET are presented in the first column. The second column presents corresponding elements of IMS CP, the third corresponding elements of METS, the fourth corresponding elements of MPEG-21 DID, and the last column presents corresponding elements of Atom.

The IMS CP *Manifest*, METS *mets*, MPEG-21 *DIDL* and Atom *feed* elements represent the root node of an aggregation and are mapped to RAMLET *TopNode*. IMS CP *metadata*, METS *mdWrap*, MPEG-21 *Annotation, Statement* and *Descriptor*, and Atom *category* elements are wrappers for metadata and are mapped to the RAMLET *descriptorObject* class. The MPEG-21 *Annotation, Statement* and *Descriptor* classes are assigned the same target as they have similar semantics, i.e. representing metadata elements.

The other mappings proceed analogously. All different elements of IMS CP, METS, MPEG-21 DID and Atom have been represented in the global RAMLET model and are mapped to their equivalent classes. If elements have similar semantics, such as *role* - *otherRole*, the classes are mapped to the same class.

Table 3.2: Resource aggregation specification mappings

RAMLET	IMS CP	METS	MPEG-21	Atom
1. topNode	Manifest	mets	DIDL	feed
2. descriptorObject	Metadata	mdWrap	Annotation; Statement; Descriptor	category
2.1 administrative		amdSec		
2.2 aggregationFormat	Schema	profile	Schema	
2.3 aggregationFormatVersion			SchemaVersion	
2.4 aggregationType		metsType		
2.5 alternateID		ownerID; altRecordID		
2.6 checksum		checksum		
2.7 checksumType		checksumType		
2.8 creationDate		versDate; createDate; created		published
2.9 descriptive		dmdSec		summary; subtitle

Table 3.2: Resource aggregation specification mappings

RAMLET	IMS CP	METS	MPEG-21	Atom
2.10 encodingType			encoding; contentEncoding	
2.11 fileSize		size		
2.12 generatingTool				generator
2.13 humanLanguage				hreflang
2.14 intendedUse		use		
2.15 mdTypeIndicator		mdType; otherMdType		scheme
2.16 mimeType		mimeType	mimeType	link.type
2.17 modificationDate		lastModDate		updated
2.18 nodeVisibility	isVisible			
2.19 party		agent		
2.19.1 partyEmail				email
2.19.2 partyName		name		name
2.19.3 partyRole		role; otherRole		contributor; author
2.19.4 partyType		otherType; agentType		
2.19.5 partyURI				uri
2.20 provenance		digiprovMD		source
2.21 resourceProcessing		transformFile		
2.21.1 resourceProcessingAlgorithm		transformAlgorithm		
2.21.2 resourceProcessingBehavior		transformBehavior		
2.21.3 resourceProcessingKey		transformKey		
2.21.4 resourceProcessingType		transformType		
2.22 rights		rightsMD		rights
2.23 source		sourceMD		
2.24 status		status; recordStatus		
2.25 structureNodeType		divType		
2.26 technical		techMD		
2.27 textType				type; text.type
2.28 wholeAggregation		metsHdr	DIDLInfo	

Table 3.2: Resource aggregation specification mappings

RAMLET	IMS CP	METS	MPEG-21	Atom
2.28.1 identiferType		IdType		
3.0 aggregateID		objID	DIDL-DocumentId	id
4.0 elementID	Identifier	Id	Identifier; Target	
4.1 nodeID		contentIDs		
5.0 digitalResource	File	file	Resource	entry
5.1 digitalResource-Fragment		area	Fragment; Anchor	
6.0 staticStructure	Organization	structMap	Container	
6.1 staticStructure-Type		structMapType		
7.0 staticStructureSet	Organizations			
8.0 dynamicStructure		behavior		
8.1 dynamicStruc-tureType		btype		
8.2 dynamicStruc-tureID			ChoiceId; SelectId	
8.3 assertion			Assertion	
8.4 condition			Condition	
8.5 choice			Choice	
8.6 selection			Selection	
8.7 maxSelections			maxSelections	
8.8 minSelections			minSelections	
8.9 defaultSelection			default	
8.10 require			require	
8.11 except			except	
9.0 dynamicStruc-tureSet		behaviorSec		
10.0 structureNode	Item	div; fptr	Item	

3.5 Discussion

The RAMLET model adequately covers the IMS CP, METS, MPEG-21 and Atom formats. However, translating resource aggregates into the structure of another format will not always be lossless. For instance, the transformation of an IMS CP document into an Atom feed can only preserve content and (part of the) metadata. Structural relationships between content files will be lost.

In this section, the use cases presented in Section 3.2 are briefly revisited, required transformations are outlined and information losses are described.

3.5.1 Use Case 1

The use case addressed exchange and reuse of resource aggregates among systems using different specifications. For example, a system using METS might import resource aggregates that use IMS CP, and MPEG-21 DID, and create a new resource aggregate.

Transformation summary: The import of an IMS CP and MPEG-21 DID resource aggregate proceeds in two steps. In the first step, the IMS CP and MPEG-21 DID aggregates are transformed into a representation compliant with the RAMLET model. The RAMLET resource aggregate is then transformed into METS.

3.5.2 Use Case 2

The use case addressed retrieving content from diverse repositories. The retrieved learning objects are disaggregated into ALOCOM components that are re-assembled into new learning objects. RAMLET enables to deploy the resource aggregate to an LMS that is limited to a single resource aggregation format.

Transformation summary: The structure of assembled ALOCOM components is described in a RAMLET resource aggregate and is then transformed into an IMS CP, MPEG-21 DID, METS or Atom aggregate.

3.5.3 Use Case 3

An LMS creates a resource aggregate just in time and will import, store, and make available resource aggregates from systems using different specifications. For example, a system using its own internal format might import resource aggregates that use IMS CP, METS, MPEG-21 DID and Atom.

Transformation summary: Atom, IMS CP, METS and MPEG-21 DID resource aggregates are transformed to RAMLET. The RAMLET resource aggregate is then transformed into the internal representation format of the LMS. To enable such interoperability, a mapping between the internal format and RAMLET needs to be implemented.

3.5.4 Information Losses

As described above, transformations between resource aggregate formats proceed in two steps: first, the resource aggregates are transformed into a representation compliant with the RAMLET model. Second, the RAMLET resource aggregate is transformed into another aggregation format, such as MPEG-21 DID, METS, IMS CP and Atom.

The first transformation is lossless. All different elements of resource aggregation formats have been represented in RAMLET and can be mapped to their equivalent classes. Additional properties allow distinguishing between classes that have been assigned the same target class, such as *role* and *otherrole*. There is a potential information loss in the second mapping, depending on the source and target format of the resource aggregate.

The rest of this section details structural and behavioral information losses of different transformations.

- MPEG-21→RAMLET→METS: the mapping cannot preserve conditional behavior that is attached to structure nodes and resources in MPEG-21. Selection, condition, assertion and other elements for describing behavior are not available in METS.
- MPEG-21→RAMLET→IMS CP: conditional behavior attached to structure nodes and resources in MPEG-21 can be represented in the IMS Simple Sequencing specification, that is used in combination with IMS CP. The mapping cannot preserve *fragment* information of MPEG-21, that represents a specific location or part of a resource. For example, a fragment may specify a specific point in time of an audio track.
- METS→RAMLET→{MPEG-21, IMS CP}: the mapping cannot preserve file transformation descriptions of behavior sections in METS. METS resource aggregates can contain transformation information needed to render content. This may include unpacking a file.
- IMS CP→RAMLET→{MPEG-21, METS}: the mapping of structural relationships is lossless. There may be differences in the metadata of resource aggregates.
- {METS, MPEG-21, IMS CP}→RAMLET→Atom: the mapping can only preserve content and part of the metadata. Structural relationships of METS, MPEG-21 and IMS CP cannot be represented in Atom
- Atom→RAMLET→{METS, MPEG-21, IMS CP}: the mapping is lossless. Metadata elements that are represented as XML attributes in Atom can be represented in the metadata schemas used by METS, MPEG-21 and IMS CP.

3.6 Conclusions

In this chapter, the RAMLET model for structuring of learning object components has been presented. The model enables to assemble and structure ALOCOM components and to export the aggregate for use in IMS CP, METS, Atom or MPEG-21 applications. In addition, aggregates available in different resource aggregation formats can be imported. Such interoperability is essential for enabling share and reuse on a global scale. Although the transformation between resource aggregates is not always lossless, important structural relationships are often preserved.

Previous attempts to enable such interoperability are limited to a crosswalk between IMS CP and METS, expressed in XSLT [Yee and Beaubien, 2004]. Such direct crosswalk cannot scale. If n is the number of resource aggregation formats, 2n transformation implementations are required for each new format to enable its interoperability with the other resource aggregation formats. RAMLET is providing a generic approach that can scale as the number of resource aggregation formats increases, as only 2 transformation implementations are needed for a new format.

The conceptual model of RAMLET currently covers the IMS CP, METS, MPEG-21 and Atom formats. Interesting future directions include extending the model for coverage of other aggregations formats, such as OASIS OpenDocument [Durusau et al., 2007] and SMIL [Bulterman et al., 2005], that are conceptually and technically less similar to the currently covered aggregation formats.

Finally, it is worth noting that the work presented in this chapter is still in early stages. The conceptual transformations described in this chapter will need to be implemented and evaluated in a real world environment. We may hope that software developers and others will do the required work once the RAMLET model is published as an IEEE standard.

Chapter 4

An Aggregation and Disassembly Framework for Learning Objects

4.1 Introduction

In the previous chapters, the ALOCOM and RAMLET models have been presented that enable the interoperation of learning content and structure available in different e-learning formats. Such interoperability is important for supporting content reuse on a global scale, as learning objects can be exchanged and reused across various learning systems.

However, the majority of content available on the World Wide Web is stored in unstructured or semi-structured formats, such as Microsoft Word, PowerPoint or HTML formats. To enable their reuse, we have developed a framework that transforms such formats into a representation compliant with the ALOCOM model. In this transformation process, the framework decomposes learning objects and provides direct access to content components, enabling their automatic reuse in new learning objects.

There are a number of issues that need to be dealt with to realize the approach:

1. First of all, there is the question of how far it is useful to decompose learning objects into components. As pointed out by [Rockley, 2002], sentence fragments or individual words may not be appropriate for reuse, as their added value for reuse is questionable. Complete sections or chapters on the other hand may be too coarse-grained for use in a different context. The issue of finding an appropriate granularity level for decomposition is further described in Section 4.2.2.

2. Secondly, as decomposition requires explicit structure, the transformation of semi-structured or unstructured learning objects into an explicitly structured format needs to be supported [Lenski and Wette-Roch, 2001].

3. Thirdly, because authors will rely on mainstream authoring tools, integration of assembling content components into the workflow of authors needs to be examined [Kienreich et al., 2005].

This chapter presents a framework that enables both decomposition and assembly of learning object components. The framework supports extracting content components from existing learning objects. In addition, reuse is detected to avoid duplicates and metadata are automatically added to components. Prototypes validate the approach for presentations, Wikipedia pages and IMS/SCORM content packages [IMS CP, 2004]. Plug-ins for Microsoft PowerPoint, Microsoft Word and the Reload Editor [Milligan et al., 2005], a packaging tool designed for composition of SCORM content packages, enable authors to search and reuse components from within the authoring tools.

The chapter is organized as follows: The next section presents the framework. Section 4.3 describes the Microsoft PowerPoint, Microsoft Word and Reload plug-ins that support the aggregation process. Related work is discussed in Section 4.4. Finally, conclusions and remarks on future research directions conclude this chapter.

4.2 The ALOCOM Framework

4.2.1 Introduction

The ALOCOM framework facilitates content reuse by decomposing learning objects into smaller, reusable, components and storing the components individually, enriched with metadata. Furthermore, on-the-fly access to these components is provided. The server relies on the ARIADNE Knowledge Pool System [Duval et al., 2001] for storage of components and their metadata. The framework is depicted in Figure 4.1 and consists of the following components:

1. Client side applications (Figure 4.1 - (1)) within authoring tools that enable content uploading to and component retrieval from the repository. Plug-ins have been developed that provide these functionalities for Microsoft PowerPoint and Reload. A plug-in for Microsoft Word enables automatic reuse of Wikipedia components in text documents (see Section 4.3).

2. The Disaggregation module (Figure 4.1 - (2)) supports the actual decomposition. Presentations are decomposed into slides, and slides are further decomposed into images, tables, diagrams, audio and video sequences, and

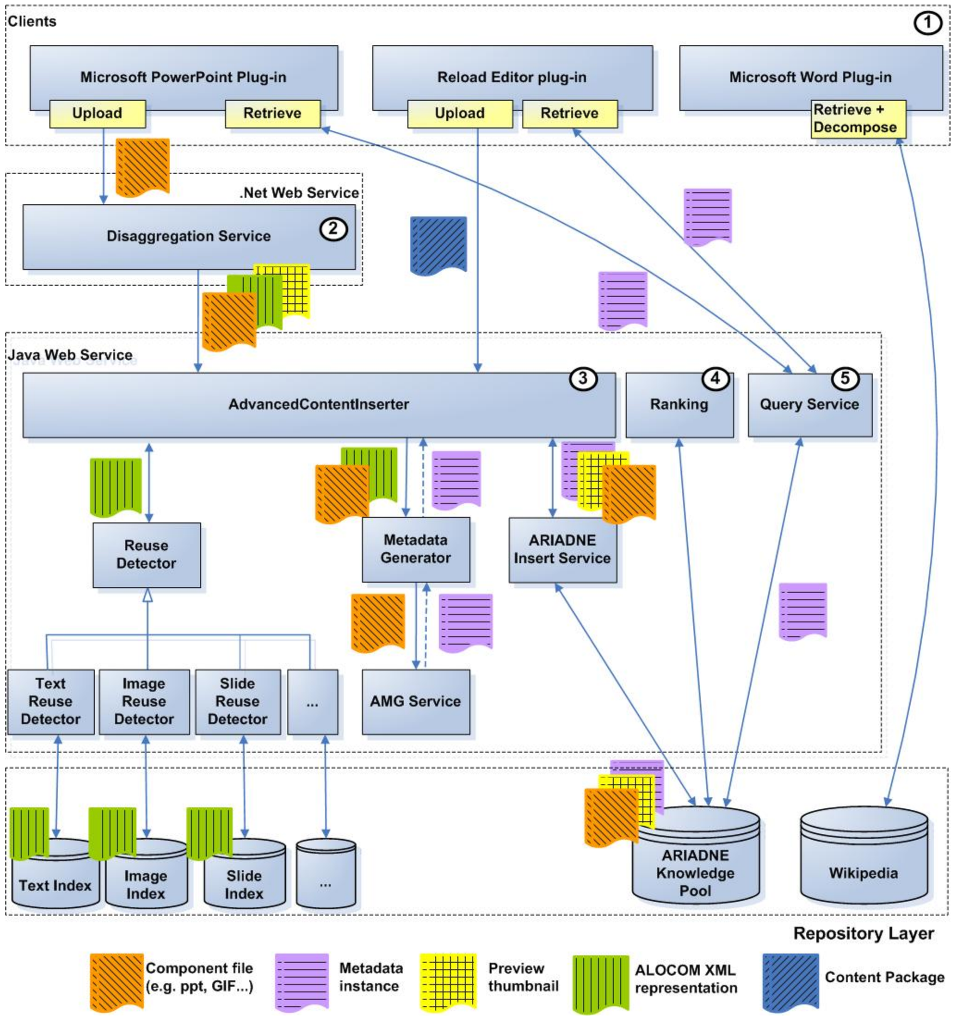


Figure 4.1: The ALOCOM Framework

text fragments. Text documents are decomposed into sections and subsections, and each section is further decomposed into paragraphs, images, tables, diagrams, etc. The current implementation of this module supports the approach for PowerPoint presentations and Wikipedia pages. Components are extracted, preview thumbnails are generated and results are stored through the AdvancedContentInserter (see Section 4.2.2).

3. The AdvancedContentInserter (Figure 4.1 - (3)) provides support for storing not only complete learning objects, but also components that are contained in the learning object, for instance components stored in a SCORM content package or components that were extracted by the Disaggregation module. The AdvancedContentInserter supports reuse detection for different component types, adds metadata to each component, and stores the components and preview thumbnails in the repository (see Section 4.2.3).

4. The Ranking module (Figure 4.1 - (4)) assigns ordering values to components based on their reuse and enables ranking of components in result lists when a user searches for relevant objects, placing components with a high relevancy at the top of the list (see Section 4.2.4).

5. The Query Service (Figure 4.1 - (5)) enables retrieval of components. Both descriptive keywords and a component type, such as definition, example, slide, image, diagram or table, can be specified when searching for components. Also advanced queries are supported that enable searching by author, title, main concepts, duration, etc. (see Section 4.2.3).

The rest of this section details the server components. The client applications are described in Section 4.3.

4.2.2 Disaggregation Module

The disaggregation module automates decomposition of composite learning objects. Granularity is an important factor in this process. The size of a component can vary between a chapter and a single line. The more fine-grained the structure, the more flexible possibilities for learning object reuse are obtained. However, more fine-grained also results in a larger set of components and is more complex to manage [Dahn et al., 2001] [Rockley, 2002].

As pointed out by [Rockley, 2002], sentence fragments or individual words may not be appropriate for reuse. However, single paragraphs may constitute definitions, examples or exercises that are reusable. That is why we decompose to the level of paragraphs. For the approach to remain scalable, modules for detection of reuse, generation of accurate metadata and ranking are incorporated in the framework (see Section 4.2.3 and 4.2.4).

Figure 4.2 illustrates the decomposition process. Presentations are decomposed into slides, and slides are further decomposed into images, tables, diagrams, animations, audio and video sequences and text fragments. Text documents are decomposed into sections and subsections, and each section is further decomposed into paragraphs, images, tables, diagrams, etc. The type of information contained in components, such as definition or example, and other relevant information for component retrieval, is determined by the metadata generation module (see Section 4.2.3).

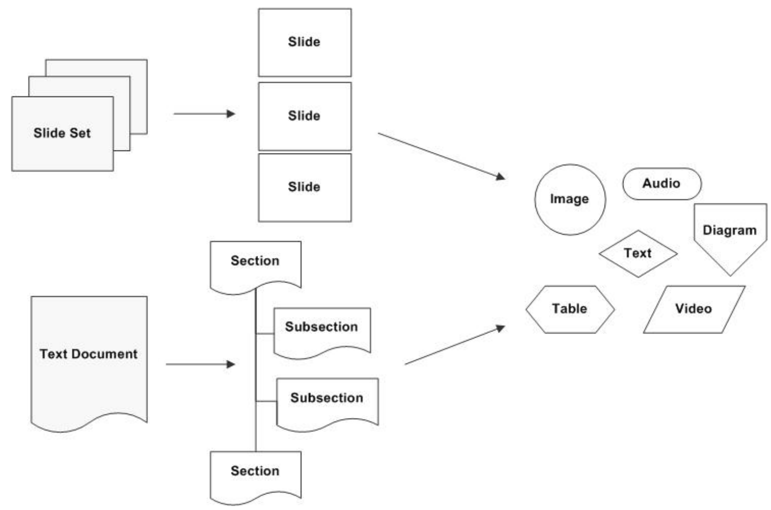


Figure 4.2: The Decomposition Process

The current implementation of this module automates decomposition of Microsoft PowerPoint presentations and Wikipedia pages. The latter are decomposed on-the-fly at the client side (see Section 4.3). Decomposition of presentations is performed on the server. The module is implemented as a .Net web service and uses the PowerPoint API [Khor and Leonard, 2005] to retrieve content and structure from a presentation.

The decomposition method iterates over the slides and slide shapes of a PowerPoint presentation object. Each slide is stored in the PowerPoint format to enable lossless reuse. Images are extracted and stored in their original format and text fragments and tables are stored in an XML format containing their content and structure. For slides, an XML representation is generated to enable their reuse in other applications and for detecting reuse between slides (see Section 4.2.3). Finally, preview thumbnails are generated for each component, using built-in export functions of the PowerPoint API. These thumbnails are used in the search interface of client applications (see Section 4.3).

In the next step, the generated components are sent to the AdvancedContentInserter for storage and indexation.

4.2.3 AdvancedContentInserter

The AdvancedContentInserter is part of a Java web service that relies on the ARIADNE Knowledge Pool System [Duval et al., 2001] for storage of learning object components. The module automates reuse detection for individual components and metadata are added by an extended version of the Automatic Metadata Generation (AMG) framework [Cardinaels et al., 2005].

Individual components can be sent to this service, provided with the identifier of the parent component, but also complete resource aggregates such as SCORM/IMS [IMS CP, 2004], METS [Cundiff, 2004], or MPEG-21 DID [Bekaert, 2006] aggregates. Each of them is based on the idea of a central XML manifest file that either references or contains the data files that make up the package. In the latter case, the AdvancedContentInserter processes the manifest file and components are stored individually.

Reuse Detection

Components that are reused in different documents would result in duplicate components in the repository. Reuse detection is used to avoid these duplicates.

The problem of finding near-duplicate documents has been a subject of research in the database and web-search communities for some years [Yang and Callan, 2006]. The applications range from plagiarism detection in web publishing [Hoad and Zobel, 2003] [Shivakumar and Garcia-Molina, 1995] to redundancy detection in large datasets [Foo et al., 2007] [Yan et al., 2004]. Common duplicate detection techniques are classified into two categories: Full text-based and Fingerprint-based. The approaches are briefly presented in the rest of this section, followed by a brief discussion of their application in ALOCOM.

Duplicate Detection Using Full Text. Full text-based approaches use methods originally developed for search engines. An example of such an approach is the vector-space model, which treats a document as a bag-of-words. Similarity is commonly determined by the cosine similarity measure [Shivakumar and Garcia-Molina, 1995] [Yang and Callan, 2006]. The approach represents each document as a vector in an n-dimensional space. Document similarity to another document is then defined as the distance between the two vectors:

$$sim(R,Q) = \frac{\sum_{i=1}^{N} \alpha_i^2 * F_i(R) * F_i(Q)}{\sqrt{\sum_{i=1}^{N} \alpha_i^2 * F_i^2(R) * \sum_{i=1}^{N} \alpha_i^2 F_i^2(Q)}}$$

where α_i is the weight associated with the occurrence of the i^{th} word and $F(D)$ (size n) is the frequency vector. $F_i(D)$ is the number of occurrences of word w_i in text fragment D. Currently, uniform weights for words ($\alpha = 1$) are assumed. Intuitively, the higher the frequency of a word, the less it contributes towards matching similarities [Shivakumar and Garcia-Molina, 1995].

To illustrate the similarity computation, consider a registered text fragment R="a b c" and new text fragments S_1="a b c" and S_2="c d e". Using the cosine similarity measure for the example and assuming uniform weights, $sim(R, S_1) = \frac{1*1+1*1+1*1}{\sqrt{3*3}} = 1$ and $sim(R, S_2) = \frac{0*1+0*1+1*1}{\sqrt{3*3}} = 0,3$.

Identical text fragments have a similarity value 1, while text fragments that do not have much overlap have a low value (e.g. 0,3 in the example).

The approach has been extended by researchers to incorporate term frequencies [HE and Ounis, 2003], document length [Singhal et al., 1996], and term frequency/inverse document frequency weighting [Salton and Buckley, 1988]. Such extensions improve the effectiveness of similarity comparisons.

Duplicate Detection Using Fingerprints. A second commonly used approach is based on fingerprints. A fingerprint of a document is a set of integers, each of which is the hash value for a substring or image extracted from the document [Yang and Callan, 2006]. Similarity between two documents is then measured by counting the number of common integers. Algorithms are different in their choices of hash functions, substring size, substring number, and substring selection strategy:

- Several commonly used hash functions are MD5 and SHA-1 [Manku et al., 2007]. These functions have three desirable properties for duplicate detection: they can be calculated on arbitrary document lengths, are easy to compute, and have very low probabilities of collisions.
- Substring size is defined as the length of each substring extracted from a document. Some approaches use single words as the unit for fingerprinting [Shivakumar and Garcia-Molina, 1995], whereas others use full sentences [Brin et al., 1995].
- Substring number is the number of substrings extracted from a document to build a fingerprint. Some techniques use a fixed number of substrings for efficiency, while many others use a variable number of substrings for a more accurate representation of the document.
- Substring selection strategy is the way to select which substrings to hash. A position-based approach, for instance, selects substrings based on their offsets in a document.

Reuse detection in ALOCOM. We use a full text-based approach for detecting reuse between text fragments. A Lucene index [Gospodnetic and Hatcher, 2005] is used for storage of text fragments. New text fragments are compared against fragments stored in the index. The cosine similarity measure is used for overlap computation. As the text fragments are fine-grained, the technique works well. A fingerprint-based approach can be employed when dealing with larger documents or for improving efficiency.

For images, a duplicate detection technique has been implemented that uses the MD5 hash value of the file. This technique enables to detect identical images. As adaptations to images are much less frequent than adaptations to text fragments, the current technique is working reasonably well. The approach can be improved by incorporating techniques for detecting near-duplicate images, that are often based on color histograms or local feature descriptors of images [Yan et al., 2004] [Foo et al., 2007]. Incorporating such approach would enable to detect common transformations, such as changing contrast, saturation, scaling, cropping, and framing.

Metadata Generation

During decomposition, metadata are added to each component. LOM metadata [IEEE, 2002] are generated by the Automatic Metadata Generation (AMG) framework [Cardinaels et al., 2005]. The idea behind the framework is to combine metadata, generated from different sources, into a single metadata instance. The first source is the learning object itself; the second is the context in which the learning object is used. Metadata derived from the learning object are obtained by content analysis, such as keyword extraction and language classification. The contexts typically are content management systems or author institution information.

Additional information gained by the decomposition process is used in the annotation process. For instance, Microsoft PowerPoint provides "place holders" to type the title of a slide. This title is added to the metadata instance as the title of the component.

The metadata describing a component can also be deduced from the metadata for its parents. For instance, each slide in a presentation inherits the author, language, etc. from the presentation to which it belongs. For this purpose, an extension of the framework has been developed that combines metadata by an inheritance mechanism. In addition, we have added support for categorizing content components into component types defined in ALOCOM. The categoization approach is detailed in the next section.

Finally, dependency relations between learning object components are described as relationship metadata. Through additional attributes, we can distinguish different relations between parent and child components ("isPartOf", "hasPart") and between components ("ordering").

Categorization of content

We apply a pattern-based approach for inferring component types. Patterns have been implemented for recognizing component types situated at the Content Object level in ALOCOM. For categorizing definitions, we rely on a system called Definder [Muresan and Klavans, 2002] and its rule-based techniques to extract definitions. Definder uses cue-phrases, such as *is the term for*, *is defined as*, or *is called*, and text markers (e.g. $--$, ()), in conjunction with a finite state grammar. Based on this system and other related research [Liu et al., 2003], we identified patterns that are suitable for recognizing content objects.

The following patterns are used to identify definitions:

1. {is|are} [*adverb*] {called | known as | defined as} {*concept*}
2. {*concept*} {refer(s) to | satisfy(ies)} ...
3. {*concept*} {is|are} [*determiner*] ...
4. {*concept*} {is|are} [*adverb*] {being used to | used to | referred to | employed to | defined as | formalized as | described as | concerned with | called} ...
5. {What is} [*determiner*] {*concept*}?
6. {*concept*} {- | : } {*definition*}
7. {definition} [of] {*concept*} {- | : } ...

Legend:
{} - compulsory field
[] - optional field
adverb - e.g., usually, normally, generally, ...
determiner - e.g., the, one, a, an, ...

For example, using pattern number five of the presented pattern list, content of a slide with title ”What is an ontology?” is categorized as a definition of the ontology concept. Similarly, a list item containing the text ”an ontology is a specification of a shared conceptualization”, will be classified as being a definition, according to the third pattern.

Although some authors use braces (e.g. () <> []) to wrap definitions, they are not used for detecting definitions in our work. Braces are also used to wrap examples, illustrations and descriptions, so they will not help in distinguishing between these component types.

To identify examples, the following patterns are used:

1. {example, instance, case, illustration, sample, specimen} [of] {*concept*}
2. {for instance | e.g. | for example | as an example} [,] [*determiner*] {*concept*} ...
3. {*concept*} {illustrates | demonstrates | shows | exemplifies} ...
4. {*concept*} {is|are} [*adverb*] {illustrated by | demonstrated by | shown by} ...
5. {Example} {- | : } {*example*}

References are often formatted according to guidelines, enabling easy identification. For instance, references can be preceded by the sequence ”[identifier]”, where identifier is a number or character sequence. Other formatting guidelines use the sequence "Name (Year)" to start the reference. This results in the following two identification patterns for references:

1. {[}{*identifier*}{]} {*reference*}
2. {*Name*} {(}{*Year*}{)} {*reference*}

Legend:
identifier - number or character sequence, e.g., 1, 2, Nam01 ...
reference - literature reference

Besides this pattern-based approach, simple heuristics are applied to determine the type of components. For instance, if the title of a slide contains "Content", "Outline" or "Overview", the slide is assigned the alocom:overview type. Similarly, if the title of a slide is "Summary" or "Conclusion", the alocom:summary type is added to the metadata instance of the component. In general, a set synonyms and semantically related concepts are used for identifying component types.

The effectiveness of the heuristics has been evaluated in [Jovanovic, 2006] and results indicate that the approach generally proved satisfactorily effective, except for recognizing definitions. There was a different comprehension of the semantics of the term definition among the interviewed authors. Some authors think of definitions as strict, "mathematical", concepts, whereas others understand definitions as any text that formally or informally defines a concept from the subject matter. As we had the latter view in mind when formulating patterns for definition mining, only a subset of the classified definitions was correctly identified by some participants of the evaluation.

The Query and Insert Service

The ARIADNE query service [Ternier et al., 2003] is used for retrieval of content components and the insert service for inserting components in an ARIADNE Knowledge Pool [Duval et al., 2001]. The insert service supports inserting, updating and deleting components and their metadata.

The ALOCOM repository is currently filled with 62841 components that were extracted from 814 learning objects. These components include 18149 slides, 7028 images, 226 tables, 30 diagrams and 35460 text fragments.

4.2.4 Ranking

Learning object decomposition results in a repository filled with numerous components. Hence, there is a need for a ranking mechanism, so that searches are only confronted with relevant components and the approach remains scalable. The ranking function assigns a value to a component based on three metrics:

- The number of times that the component has been reused directly.

- The number of times that the component has been reused as part of a bigger component.
- The number of different authors that have reused the component.

While these metrics measure the historical probability that a component will be reused, a more useful approach is to calculate the probability that a component will be selected on a specific date. This probability is calculated providing a time frame, for example the previous month or year, where reuse will be measured. The rationale for this strategy is that successful components are often updated with new, improved versions, for example yearly time series charts with information for a new year. To avoid recommendation of old and potentially deprecated components, only fresh reuse information is used. Old components that are still actively reused are not affected by this time-based bias.

The implementation is based on the ideas of Learning Object popularity ranking, explained in [Ochoa and Duval, 2006]. Reuse information is converted into a graph structure where components are linked to components that include them. For example, a table is linked to the slides that contain it. If the component does not have a higher container, it is linked to the users that created or reused the component. The edges of this graph are annotated with the date the reuse took place. The edges are then pruned according to the desired time-frame and the resulting graph is used to calculate the different reuse metrics explained above, based on the incoming edges of a component and the links between components and users.

The metrics are calculated a priori because they are not user or query specific. Results are stored in the repository and are used to rank result lists of components when a user searches for relevant objects, placing components with a high probability at the top of the list. Evaluation results are presented in the next chapter.

4.3 Client Side Applications

Client side applications have been developed that enable content upload and component retrieval from within authoring tools. Such applications have been developed for Microsoft PowerPoint, Microsoft Word and the Reload Editor. The plug-ins are detailed in the rest of this section.

4.3.1 Microsoft PowerPoint Plug-in

A plug-in has been developed for Microsoft PowerPoint that enables authors to reuse components stored in the ALOCOM repository from within the application. As shown in Figure 4.3, a custom Office Task Pane (on the right side) is used for integrating this functionality. This is accomplished with Visual Studio 2005 Tools for the Microsoft Office System [Carter and Lippert, 2006].

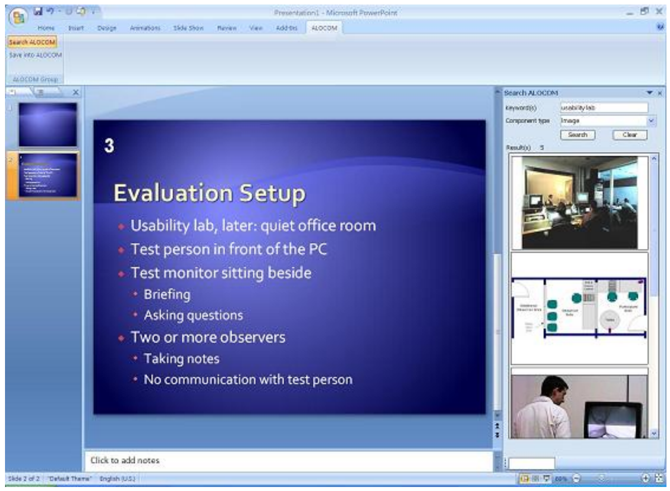


Figure 4.3: The ALOCOM plug-in for MS Powerpoint

The plug-in enables authors to search the repository for components they wish to reuse in the presentation they are editing. An author can specify both the component type, such as reference, definition, example, slide, image, or text fragment, and descriptive keywords. Thumbnails of components that satisfy the search criteria are displayed in the ALOCOM Task Pane. Metadata associated with a component are shown when the user hovers the mouse pointer over a component in the result list.

The author can incorporate a component into the current presentation by a single mouse-click. The original component is then retrieved and automatically added using built-in copy-and-paste functions of the PowerPoint API. Doing so, all original content, structure and layout information, including transitions in a slide, is preserved.

In the opposite direction, authors can add presentations to the repository by clicking the "Save into ALOCOM" button that has been added to the standard PowerPoint menu. When this button is clicked, the presentation is sent to the .Net disaggregation service for decomposition and storage.

4.3.2 Microsoft Word Plug-in for Reusing Wikipedia Content

A similar plug-in has been developed for Microsoft Word that automates reuse of Wikipedia components. All definitions, images, references, and text fragments can be individually retrieved. In fact, Wikipedia pages are easy to disaggregate, as the pages have a consistent structure and are stored in well-formed HTML. The first part of the page provides a general definition of the concept. Further content is divided into smaller, clearly labeled, sections.

In contrast to decomposition of presentations, which takes place when they are stored in the ALOCOM server, decomposition of Wikipedia pages is performed upon request at the client side. The Wikipedia search engine is used for retrieval of relevant pages. An HTML parser processes pages that are found and retrieves their content and structure. The first part of the page is retrieved when searching for a definition. Other sections are retrieved when searching for text fragments, disaggregated to the level of single paragraphs, labeled with the title of the subsection to which they belong. Images on Wikipedia have in most cases "alt" attributes that provide a short description. Finally, references are retrieved by parsing the "reference" section of a page.

Similar to the Microsoft PowerPoint plug-in, a custom task pane is defined that enables retrieval of Wikipedia components from within the authoring tool (see Figure 4.4). A user can specify both keywords and the component type. When searching for text fragments, paragraphs are shown individually, with their surrounding paragraphs. The complete section to which the paragraph belongs is also retrievable. This support is required, as not many paragraphs are written as standalone pieces of content and often refer to other paragraphs. By showing the surrounding paragraphs, an author is provided with sufficient context to understand the content and chooses whether a paragraph can be reused as a standalone component or should be reused in combination with other paragraphs.

4.3.3 Reload Editor Plug-in

The key aim of the Reload project is the implementation of a SCORM/IMS Content Package and Metadata Editor. The Reload Editor enables users to organize, aggregate and package learning objects in SCORM content packages tagged with metadata [Milligan et al., 2005].

A SCORM content package is a self-contained ZIP file. Mandatory Content Package contents are an XML manifest file (imsmanifest.xml), schema definition files referenced by the manifest file and all component files used by the content package.

The manifest file describes the structure and contents of the package. The Reload Editor allows authors to create and edit such manifest file with a convenient graphical interface to visualize the content. A plug-in has been developed for this editor that enables retrieval of components stored in the ALOCOM repository (see Figure 4.5). A user can enter descriptive keywords and a component type and results are shown in an integrated window. Components in the result list can be dragged and dropped into a specific location in the manifest file. When a component is added, the original component file is retrieved and stored on the

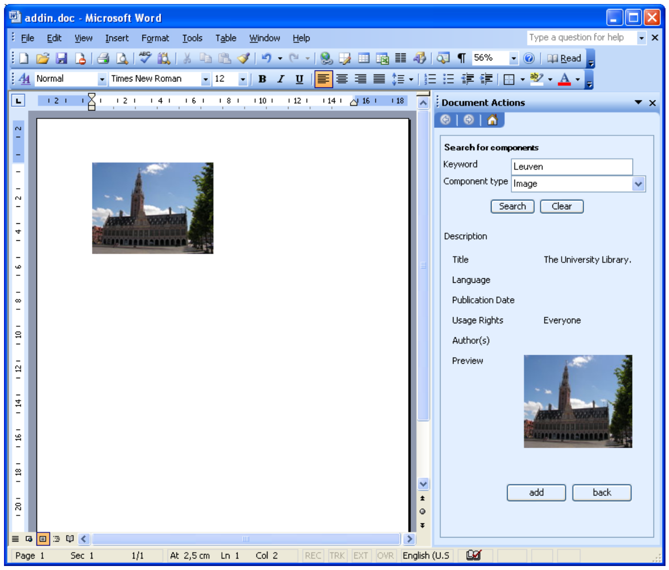


Figure 4.4: The ALOCOM plug-in for MS Word

client machine. Metadata associated with the component are automatically added to the manifest file.

In the opposite direction, support for decomposing SCORM content packages is provided. This decomposition process is straightforward, as components in the content package are already stored individually and described by metadata. The AdvancedContentInserter unpacks the package and stores the components in the repository. Metadata are generated by the AMG framework and merged with metadata that the author might have provided in the manifest file.

4.4 Related Work

In recent years, a lot of research has been dedicated to develop flexible learning objects that are generated by assembling smaller, reusable, components. However, few approaches support automatic decomposition of existing learning objects. Instead, guidelines are often provided to decompose content manually or to create new components suitable for reuse. Such guidelines are, for instance, described by the dLCMS project [Schluep, 2005]. Some commercial content management systems, such as Vasont [Freeman, 2005], also use a manual transformation process to support content reuse. The approach presented in this chapter is more scalable, as it attempts to automate content reuse for pre-existing learning objects.

MagIR [Kienreich et al., 2005] is a system that supports automatic content

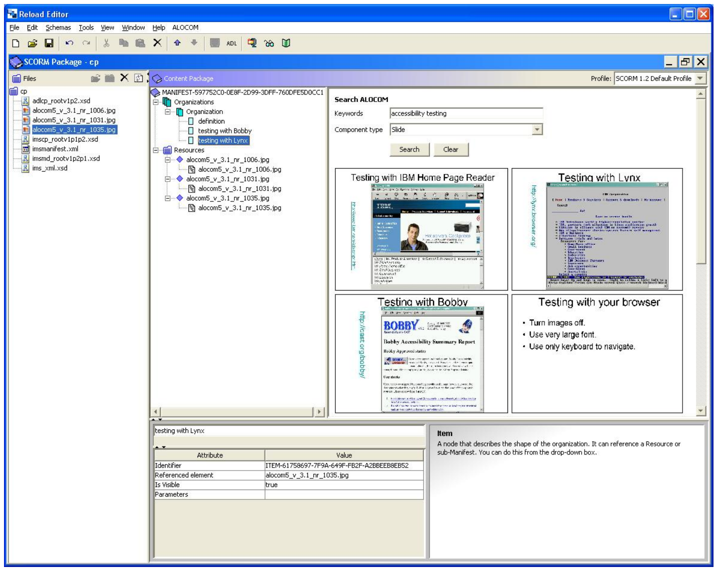


Figure 4.5: The ALOCOM plug-in for the Reload Editor

transformations. Like in ALOCOM, these transformations are supported for PowerPoint presentations and include content decomposition. Decomposition is supported to the level of slides only, while ALOCOM also extracts smaller components, such as tables, diagrams, images and text fragments. MagIR is used for creation, administration and reutilization of PowerPoint slides in a corporate context and is aimed at reducing storage costs.

Slide executive [Slide Executive, 2007] is a commercial product that also supports reutilization of Microsoft PowerPoint slides. Individual slides can be retrieved in a browser and dragged and dropped in a PowerPoint presentation. Like MagIR, decomposition is supported to the level of slides. Add-ins are provided to export PowerPoint slides to images in different formats and to import multiple images at once. However, no tight integration for component searching from within the application is supported.

The TRIAL-SOLUTION project is developing tools to create and deliver personalized teaching materials that are composed from a library of existing documents on mathematics at undergraduate level [Lenski and Wette-Roch, 2001]. The focus of the project is on document (de-)composition and exchange for reuse. The TRIAL-SOLUTION System contains a splitter that decomposes document source files into a hierarchy of slices. In this decomposition process, the presentation style of a particular author is taken into account. It also takes care of counters and key phrases assigned by the author. In addition, decomposed content is manually revised. The main difference is that the methodology for decomposing content is semi-automatic and therefore less scalable.

The Legacy Document Conversion (LegDoC) project is offering advanced techniques to automate conversion of legacy documents to XML [Lecerf and Chidlovskii, 2006]. Layout-oriented formats like PDF, PS and HTML are automatically converted to semantic-oriented annotations. The table of contents of a document is used as a basis for document structuring. The approach is promising, as no assumptions are made about the structure of source documents. Integrating such approach into the ALOCOM framework would enable structuring and decomposition of unstructured or semi-structured documents that contain a table of contents.

4.5 Conclusions

The ALOCOM framework presented in this chapter enables flexible content reuse by decomposing presentations, Wikipedia pages and SCORM content packages into reusable components and supporting their on-the-fly reuse in mainstream authoring tools.

There are several contributions to the field:

- The framework supports reuse of learning object components that are stored in application specific formats, such as the MS PowerPoint format. The approach enables to automate reuse of many available learning objects, stored in such formats.

- Decomposition is supported to the level of single text fragments, images or tables. Other approaches for decomposition of presentations only decompose to the level of slides. The approach presented in this chapter enables more fine-grained, and thus more flexible, content reuse.

- A repository architecture has been designed to enable share and reuse of learning object components on a global scale. An accurate reuse detection mechanism is integrated to avoid duplicates, components are precisely described by the automatic metadata generation module to enable their retrieval and a ranking mechanism is included, so that searches are only confronted with relevant components and the approach remains scalable.

- Reuse of learning object components is tightly integrated into mainstream authoring tools, such as MS PowerPoint, MS Word and the Reload Editor. Up to date, very little approaches support such integration, although the demand is high. Instead, users often have to learn to work with new authoring tools.

An evaluation of the approach for presentation reuse is presented in the next chapter. Enabling such content reuse for other learning object formats, such as PDF or MS Word documents, is an interesting future direction of the research. The patterns for classifying content object types can also be improved, as only an initial attempt has been made to identify such components.

Chapter 5

Validation

5.1 Introduction

In this chapter, an evaluation is presented of the ALOCOM approach for reusing presentation components. As described in the previous chapter, reuse is automated by decomposition of legacy content and storage of individual components, enriched with metadata. The automatic assembly of these components is supported in Microsoft PowerPoint. The evaluation presented in this chapter aims to assess the effectiveness and efficiency of such content reuse for presentations.

Two evaluations have been conducted: a user evaluation and a quality evaluation. The user evaluation assessed the usability and utility of the ALOCOM plug-in for Microsoft PowerPoint. The goals of the evaluation were threefold: (i) to assess the efficiency and effectiveness of the approach for reusing presentations; (ii) to assess the subjective acceptance of the ALOCOM interface; (iii) to determine to which level of granularity decomposition is relevant. A follow-up evaluation was necessary to confirm the results and to assess the quality of the created presentations.

The chapter is organized as follows: The user evaluation is presented in the next section. The setup of the evaluation is described and results are outlined. The quality evaluation is presented in section 5.3. A discussion of the results is presented in Section 5.4 and related work is described in Section 5.5. Conclusions are drawn in Section 5.6.

5.2 User Evaluation

5.2.1 Study Description

The study was conducted in October 2006 at K.U. Leuven. Each session involved one participant, who performed two tasks during a single session. There were 20 participants in the study, which typically results in a reasonably tight confidence interval [Nielsen, 2006]. Participants were mainly members of the junior staff of the Computer Science Department at K.U. Leuven.

Tasks

Each participant was asked to create two presentations: one on inheritance and one on exceptions in the programming language Java. The participants were divided into two groups. The first group created the presentation on exceptions in Java without ALOCOM support, and the presentation on inheritance in Java with ALOCOM support. They could use all information available on the World Wide Web for both presentations. The second group did the same, but in a different order. This group created the presentation on inheritance in Java without ALOCOM support, and the presentation on exceptions in Java with ALOCOM support.

The presentation created without ALOCOM support is referred to as *without-alocom presentation* and the presentation created with ALOCOM support as *with-alocom presentation* in the remainder of this chapter.

78 presentations on both topics were gathered by a Google-search and uploaded to the repository: as described in the previous chapter, they were automatically decomposed and the components were automatically described. In total, 10281 components were made available for reuse, including 2964 slides, 933 images, 6367 text fragments, 12 tables and 5 diagrams.

Data Collection

Camtasia Studio [Cox, 2004] was used to record participant interactions, capturing the screen, voice and webcam video. Participants were also asked to complete a questionnaire after the tasks. The questionnaire was adopted from a usability evaluation of the ARIADNE search tool [Najjar et al., 2005].

Measurements

The following characteristics were measured for the experiment:

- Time-on-task: represents the time needed to finish each task. The aim of the time comparison is to investigate whether the use of the ALOCOM plug-in can lead to savings in time. We are aware that time is influenced by other factors; however, we included this comparison to obtain a first indication of improvements for time-on-task.

- Manual versus semi-automatic reuse: The distinction is made between manually reused components and semi-automatically reused components. Manually reused components are components that were added to the presentation by copy-pasting or reproducing existing content, typically found through Google. Semi-automatically reused components are those components that were found and inserted using the ALOCOM plug-in. By measuring and comparing both types of content reuse, a success rate indication is obtained of the ALOCOM approach for reusing content, as authors typically tried the semi-automatic approach first and inserted content manually when no relevant components were found through the ALOCOM plug-in.

- Component granularity: the granularity of semi-automatically reused component types is measured in order to determine to which level of granularity decomposition of presentations is relevant.

- Satisfaction: user satisfaction was assessed through a questionnaire filled in by each participant after finishing the tasks. Questionnaire questions intended to measure the overall satisfaction on the usage of the plug-in.

5.2.2 Results

Time

Table 5.1 shows the average time participants spent on creating *without-alocom* and *with-alocom* presentations. At first sight, the difference is relatively limited: on average, 20.03 minutes were spent creating the *without-alocom* presentation and 17.79 minutes creating the *with-alocom* presentation. However, not all participants created presentations similar in length, covered sub-topics or quality in general.

Size normalizations were applied that were adopted from the software quality field [ISO/IEC 9126 -2, 1998]. A simple normalization that takes into account the number of slides in the presentation shows that on average 3.32 minutes were spent per slide in a *without-alocom* presentation, whereas 2.2 minutes were spent per slide created with ALOCOM support.

A second normalization was applied that takes into account the number of sub-topics. Some participants created presentations covering many sub-topics, such as polymorphism and dynamic binding for the presentation on inheritance, while others provided only a definition and an example. If we consider the number of sub-topics, we see that on average 4.5 minutes were spent on a sub-topic in a *without-alocom* presentation and 2.9 minutes on a *with-alocom* presentation sub-topic.

	without-alocom	**with-alocom**	**Sig.(2-tailed)**
Total time	20.03	17.79	0.147
Time normalized by number of slides	3.32	2.2	0.001
Time normalized by number of sub-topics	4.5	2.9	0.016

Table 5.1: Time (in minutes)

To statistically establish whether the difference between these average values is real or a by-product of natural variance, a paired-samples t-test was applied. The null hypothesis is that there is no difference between the required creation time for *with-alocom* and *without-alocom* presentations. The alternative hypothesis is that there is indeed a difference. Results were normally distributed. Normality was tested with the Kolmogorov-Smirnov test [Massey, 1951].

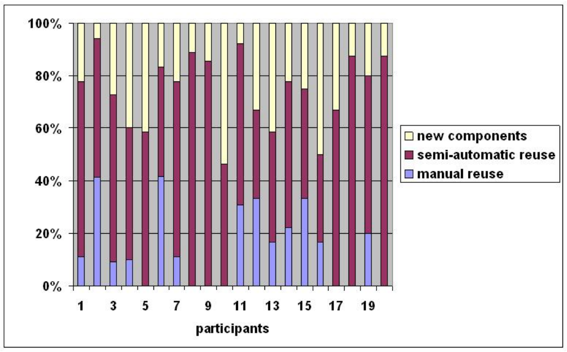
The null hypothesis can be rejected for normalized time values, as shown in the right column of Table 5.1 (significance < 0.05). Thus, taking into account the size of presentations, significant time savings are realized when creating presentations with support to automatically reuse existing presentation components. To validate these results, a second evaluation has been performed that assessed the quality of the created presentations. This evaluation is presented in Section 5.3.

Reuse in With-Alocom Presentations

With-alocom presentations were further analyzed. The distinction is made between manual reuse, semi-automatic reuse and new components. Manually reused components are components that were added to the presentation by copy-pasting or reproducing existing content, found by a web search. Semi-automatically reused components are those components that were found and inserted using the ALOCOM plug-in. New components represent content the participant created from scratch, without using an existing resource.

Figure 5.1 (left) shows reuse patterns of individual participants. Some participants reused about the same amount of components manually as semi-automatically. The amount of new components is also high for some participants (more than 40%). Few participants created presentations without manual reuse.

Table 5.2 shows that on average 57% of presentation components were semi-automatically reused using the ALOCOM plug-in. 18% of the components were reused manually, whereas 25% are new components. There is no significant difference if we compare this data for the presentation on exceptions in Java and the presentation on inheritance in Java, although more components were available covering topics on inheritance. The values were normally distributed and compared



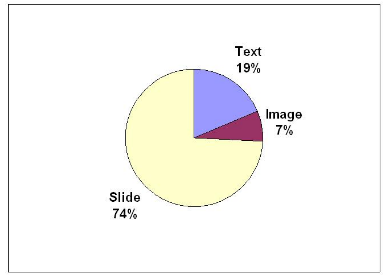


Figure 5.1: reuse patterns (left) reuse/component type (right)

with a paired-samples t-test.

Comparing manual and semi-automatic reuse, we see that 76% of reused components were reused semi-automatically, whereas 24% were reused by copy-paste actions or reproduction of content. These values are a success rate indicator of the ALOCOM approach for reusing content, as participants typically tried the semi-automatic approach first and inserted content manually if no relevant components were found through the ALOCOM plug-in.

	Manual	**Semi-automatic**	**New**
Overall	0.18	0.57	0.25
Presentation on inheritance (1)	0.19	0.58	0.23
Presentation on exceptions (2)	0.18	0.55	0.27
Comparing means (1) and (2) Sig. (2-tailed)	0.737	0.121	0.791

Table 5.2: Reuse in with-alocom presentations

Granularity

Figure 5.1 (right) shows the reuse rate for semi-automatically reused component types. Complete slides were most often reused, probably because many slides represent a single idea or topic and are thus easy to reuse in a new context. Reuse of text fragments was also significant. This is an interesting result, as it illustrates that breaking content down to the level of a single text fragment is useful. Images were not frequently reused; however, this result is probably influenced by the topic of the presentations.

Effectiveness of the Ranking Algorithm

As illustrated in Figure 5.2, 27% of selected components were presented in the top position of the result list of a query, 16% in position 2, 8% in position 3, 12% in position 4 and 13% in position 5. Summing up these values, 76% of selected components were presented in the top 5.

This result is consistent with previous findings [Ochoa and Duval, 2007] that indicate that reuse popularity of a learning object is highly correlated with its relevance for a closely related group of users, in this case computer scientists from the same department, performing a similar task. Also interesting, a non-negligible amount of components (10%) were retrieved from positions between 15 and 52. This result goes against the accepted belief that users select only results in top positions. This can be explained as the experimental setup interfering with the normal behavior of users.

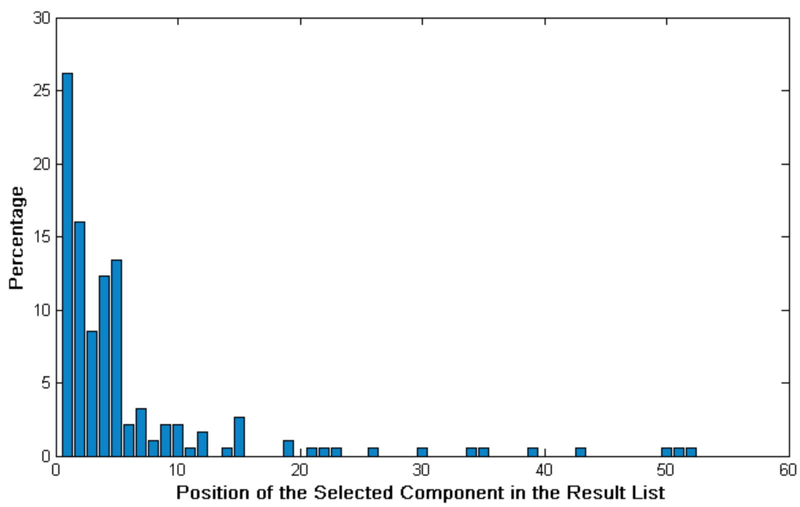


Figure 5.2: Effectiveness of the ranking

Findings and Recommendation

In this section, findings and recommendations of the participants are discussed.

Lack of Context. Some participants remarked that more context is required for successful content reuse. They want to be able to retrieve the next and previous slide for a specific slide in the result list, or even the complete presentation(s) to which the slide belonged. Similar support is needed for other component types.

Behavior Change. It was noted that this way of reusing content requires a behavior change, as it is different from the usual practice of copy-pasting or reproducing content. It was reported that savings in time would be remarkable; however, a period of adaptation is required.

Drag and Drop Support. Many participants expected drag and drop support for inserting components. There is click-support for inserting a component: clicking a component in the result list will insert the component at the currently selected location. However, it is not possible to drag a component to a different location in the presentation, due to limitations of the PowerPoint API [Khor and Leonard, 2005].

Garbage Content. Not all components are reusable. As components are created by decomposing existing content automatically, it was expected that not all components are valuable for reuse. Results are ranked according to the number of times a component is reused. Hence, the impact of this issue will decrease over time, as components that are not reused will be displayed in lower positions of result lists.

Less Consistent Layout. Some participants noted that it is hard to keep the layout of different components consistent. The layout of slides is automatically adapted to the template the author is using. However, if the author changed, for instance, the font color of a text fragment in one particular slide, this modification is preserved when reusing the slide. Although desirable in some cases, this was reported as a difficulty.

More Valuable for Reuse of Own Content. Participants remarked that the use of the ALOCOM plug-in would be most valuable for reusing their own presentations.

5.2.3 Overall Satisfaction

Table 5.3 presents the responses of participants to questions concerning the overall use of the ALOCOM plug-in. The questionnaire was adopted from a usability evaluation of the ARIADNE search tool [Najjar et al., 2005]. The popular attitude scale with seven points (ranging from 1 - poor to 7 - good) was used to measure the response of participants on the overall use of the plug-in.

The mean for the level of ease-of-use was higher than 6, meaning that participants found the ALOCOM plug-in easy to use. The level of information organization and search and reuse of learning object components was perceived as moderate (mean 5.23 and 5.69 respectively). We believe that this is related to the fact that there is a lack of context (it is not possible to automatically retrieve the

	Mean (ranging from 1-7)	Standard deviation
Ease of use	6.15	0.69
Information organization	5.23	0.93
Use of terminology	4.92	1.5
Navigation	6.07	1.04
Search and reuse of components	5.69	1.49
Result list easy to read	4.92	1.5

Table 5.3: Satisfaction

original component to which a component belonged) and the fact that there is no drag and drop support.

Result lists were found rather difficult to read (mean 4.92). This result is a consequence of the fact that preview thumbnails of slides containing much content are difficult to read. We have worked on a solution that enables users to enlarge individual components. Each component in the result list has a context menu item that provides this functionality. This solution will resolve the issue if only few components are difficult to read.

5.3 Quality Evaluation

In a follow-up evaluation, the quality of *with-alocom* and *without-alocom* presentations was assessed by a group of 19 participants. This evaluation was necessary for obtaining a more accurate estimation of the effectiveness and efficiency of the ALOCOM approach for reusing presentations.

5.3.1 Study Description

Following a common practice to reduce subjectivity in a quality evaluation, an evaluation framework was used. In [Knight and Burn, 2005], an overview is provided of the most common dimensions of Content Quality frameworks. Four dimensions that were relevant in the context of the experiment were used to evaluate the quality of the presentations: accuracy, completeness, relevancy and conciseness.

In an accurate presentation, the content contained in the presentation is correct, reliable and free of error. Completeness is defined as the extent to which information is not missing and is of sufficient breadth and depth for the task at hand. Relevancy measures whether the content contained in the presentation is applicable and helpful for the task at hand. Finally, in a concise presentation, content is broken up into smaller chunks that can be easily shared with an audience.

Participants in the experiment were requested to read the definition of each parameter before grading the presentations. The definitions were also available during the evaluation process.

The experiment was carried out online using a web application. After logging in, the system presented users with instructions. After reading the instructions, users were presented with a list of 20 randomly selected presentations. Once users had reviewed a presentation, they were asked to give grades on a 7-point scale, from "Extremely low quality" to "Extremely high quality", for each parameter. Only participants that graded all presentations were considered in the experiment.

The experiment was available for 2 weeks. During that period, 24 participants entered the system, but only 19 completed the evaluation. From those 19 participants, 13 were postgraduate students, 1 had a Ph.D. degree and 5 were active in software development. All participants had a degree in computer science.

5.3.2 Data Analysis

Because of the inherent subjectivity in measuring quality, the first step in the analysis of the data is to estimate the reliability of the evaluation [Meire et al., 2007]. In this kind of experiment, the evaluation is considered reliable if the variability between the grades given by different reviewers to a particular presentation is significantly smaller than the variability between the average grades given to different presentations. To estimate this difference, we use the Intra-Class Correlation (ICC) coefficient [Shrout and Fleiss, 1979], which is commonly used to measure the inter-rater reliability. The average ICC measure is calculated using the two-way mixed model, given that all reviewers grade the same sample of presentations. In this configuration, the ICC is equivalent to another widely used reliability measure, the Cronbachs alpha [Cronbach, 1951]. The results for each quality parameter are reported in Table 5.4.

Parameter	**ICC (average, two-way mixed)**
Completeness	0.927
Accuracy	0.766
Conciseness	0.881
Relevancy	0.837

Table 5.4: Intra-Class Correlation (ICC) coefficient for measuring the reliability

Generally, ICC values above 0.75 indicate good reliability between measures. None of the values fall below this cut-off value. Hence, the ICC suggests that reviewers provided similar values and further statistical analysis can be performed.

The second step is to assess whether there is a difference between the average grade given to *with-alocom* presentations and the average grade given to *without-alocom* presentations. These average values are presented in Figure 5.3. To statistically establish whether the difference between average values is real or a by-product of natural variance, we applied a paired-samples t-test. Our null hypothesis is that there is no difference between the grades given to *with-alocom* and *without-alocom* presentations. Our alternative hypothesis is that there is indeed a difference. The results are presented in Table 5.5. Results were obtained with a normal distribution.

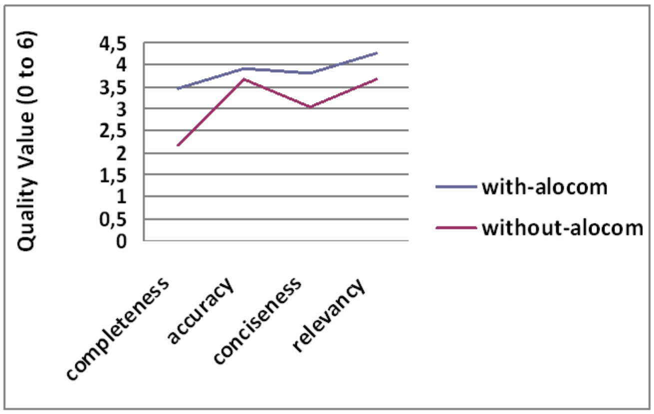


Figure 5.3: Average quality grade for the different parameters

Parameter	**T-value**	**Significance (2-tailed)**
Completeness	-8.094	0.0
Accuracy	-1.412	0.160
Conciseness	-4.352	0.0
Relevancy	-2.981	0.003

Table 5.5: Significance of the difference between the given grades

The null hypothesis can be rejected for most of the parameters (completeness, conciseness and relevancy). The significant difference found in the completeness parameter indicates that users were able to create more complete presentations when provided with support to reuse presentation components. The significant difference found in the conciseness parameter indicates that content extracted from existing presentations is more suitable for reuse, as it is already presented in a form that can be shared with an audience. Furthermore, users were able to find more relevant content for *with-alocom* presentations. No significant difference was found in the accuracy parameter. As the presentations were created by members of the junior staff of the Computer Science Department at K.U. Leuven, it was expected that no major mistakes would be made in creating presentations on inheritance and exceptions in Java.

5.4 Discussion

Although no direct saving in time was perceived, results of the quality evaluation indicate that providing on-the-fly access to presentation components in an authoring process enhances the quality of presentations. Presentations created with ALOCOM support are significantly more complete, concise and relevant. The results in completeness are consistent with the size normalizations applied to time values. Hence, there is also a significant improvement in time savings.

Results of the user evaluation indicate that the plug-in can be used in a successful way: 76% of reused components were reused semi-automatically. However, usability issues need to be resolved in order to make this kind of content reuse more efficient. Most important is the context issue. The user interface should be extended with the functionality to retrieve the parent component to which a component in the result list originally belonged. Furthermore, it is important to enable navigation in the original structure of presentations. For instance, support is needed to retrieve the next and previous slide for a specific slide in the result list.

The consistent layout issue cannot be improved, as built-in copy and paste functions of the PowerPoint API are used for adding an existent slide to a presentation. If a user would manually copy-paste a slide, the same problem with consistency arises. Drag and drop support is also difficult to integrate.

The method used can be classified as a "discount usability engineering" approach [Nielsen, 1989], as it is definitely not "the perfect" method for evaluation and will not give absolute results. However, it enabled us to obtain a good indication of improvements towards savings in time or enhancements of quality and to highlight usability issues.

The evaluation of the ranking algorithm indicates that ranking based on aggregation relationships provides an easy and effective way to rank results when the components in the repository are covering similar topics. Nonetheless, a small, but non-neglectable, amount of components were not ranked according to their relevance to the users in the experiment. These errors could be solved when more usage data is fed into the popularity ranking algorithm or by using more advanced techniques, for instance personalized or contextual relevance ranking [Ochoa and Duval, 2007], during the ranking calculation.

To enable such mechanism, the Contextualized Attention Metadata (CAM) framework [Wolpers et al., 2007] can be used for capturing the attention a user spends on content. ALOCOM client applications already generate such streams that capture activities within the application with timestamp and content-related data. For instance, the time a user spends working on a learning object, the queries that are performed and the components that are reused by the user, are captured. This data can be used for building user attention profiles that represent actual interests of users based on content they worked with. The use of such profiles would enable personalized ranking.

5.5 Related Work

Reuse is considered to be an effective strategy for building high-quality content [Freeman, 2005]. However, there is currently a lack of evaluation methods and metrics for measuring the impact of content reuse in terms of productivity and quality gains.

In the software engineering field, researchers have worked on metrics for measuring reuse benefits. Size, reuse rate and effort metrics are used for calculating these benefits. Furthermore, many frameworks have been presented that measure quality, both in software and information quality fields. In this chapter, we have applied techniques and frameworks that are valid in our context.

In [Melo et al., 1995], an empirical evaluation is presented that assesses the impact of reuse on quality and productivity in object oriented systems. Similar to our evaluation, amount of reuse and total amount of hours spent on a system are measured. In [Devanbu et al., 1996], an analytical and empirical evaluation of software reuse metrics are presented. Software measures are categorized along orthogonal axes that measure attributes of the software product, such as quality of code, and attributes of the software process, such as cost of design review. In our case, the quality evaluation assessed product/content attributes, and time-on-task is an attribute of the process. Furthermore, reuse metrics that measure the amount of reuse, like our reuse measurements presented in Section 5.2, are commonly used to estimate savings [Devanbu et al., 1996].

In the content management field, content reuse is reported to lead to savings in time and improvements of quality. Vasont [Freeman, 2005] is a commercial content management system that enables organizations to create, manage and store their content for component-level reuse and delivery in multiple outputs. In the case study, Freeman reports that substantial content reuse resulted in time savings in content creation, revisions, delivery, and translation. According to the study, content reuse varies by industry. Technology companies, such as software developers, have been found to achieve an average of 70% content reuse, while manufacturing companies achieve approximately 93% content reuse. Like many other commercial content management systems, the system supports reuse by manual transformation of content.

In contrast to Vasont, MagIR [Kienreich et al., 2005] is a system that supports automatic content transformations. Like our system, these transformations are supported for Microsoft PowerPoint presentations and include content decomposition. Decomposition is supported to the level of slides, while our system also extracts smaller components, such as tables, diagrams, images and text fragments. Results of our user evaluation indicate that these fine-grained components are also often reused. MagIR is used for creation, administration and reutilization of PowerPoint slides in a corporate context and is aimed at reducing storage costs. The system has been evaluated in that context and results indicate that storage costs are significantly reduced.

5.6 Conclusions

In this chapter, an evaluation has been presented of the ALOCOM approach for reusing presentation components. The goal of the evaluation was to measure the actual impact of enabling on-the-fly reuse of fine-grained components extracted from pre-existing presentations. More precisely, the goals of the evaluation were to:

- Assess the efficiency and effectiveness of the approach;
- Assess the subjective acceptance of the ALOCOM interface;
- Determine to which level of granularity decomposition of presentations is relevant.

Efficiency and effectiveness was measured in terms of the required creation time and the quality of presentations. The analysis of the results indicates that there are significant improvements. The presentations created with ALOCOM support are significant more complete, relevant and concise. In addition, participants needed less time to create presentations.

Participants found the ALOCOM plug-in easy to use. However, there are usability issues that need to be resolved. Most importantly, support is needed for navigation through the original structure of the presentations to which components belonged.

Presentations are decomposed to the level of a single text fragment, image or table. The results of the evaluation indicate that these fine-grained components are often reused. It can be concluded that decomposing presentations to this level of granularity is useful.

The investigation examined only benefits of reusing presentation components. In order to generalize the findings, evaluations have to be performed to assess whether related approaches, such as the plug-ins for MS Word and the Reload Editor, result in a similar impact on effective and efficient content reuse.

Chapter 6

Conclusion

In this dissertation, learning object granularity and interoperability issues have been investigated to enable learning object reuse on a global scale. This chapter concludes the dissertation with a summary of contributions, a discussion on the possible impact of the research, and an exploration of the potential it offers for future research.

6.1 Research Issue 1: Learning Object Granularity

In Chapter 2, different learning object content models have been investigated that define learning objects and their components. The first contribution is a comparative analysis of the content models. Such comparison enables the alignment of content models and addresses interoperability questions of their heterogeneous content definitions.

The second, and most important, contribution is the development of the generic ALOCOM content model. In contrast to some of the reviewed content models, learning object granularity is defined in a precise way. The distinction is made between learning object components and learning objects. Both granularity levels are further subdivided and content classifications have been defined that detail granularity. The learning object component levels are important for enabling flexible learning object reuse, as such components have the potential to be flexibly aggregated into new learning objects.

In addition, the ALOCOM model is a solid basis to build upon as it is not restrictive and quite flexible. The model enables to clearly model learning objects and is the basis for the proposed disassembly and aggregation processes. As such, the objective of this research issue has been reached. New perspectives concerning the interoperability between content models have been worked out. An ontology integration method has been employed to formalize mappings between content models.

Since the publication of the first study presented in [Verbert and Duval, 2004], several efforts have been stated that build upon the insight gained from this study. A few are briefly described in the rest of this section. In [Schluep, 2005], the Methodenlehre-Baukasten model [Schulmeister, 2003] is added to our content model comparison. Furthermore, the comparison is used as the basis for the development of a new content model, dLCMS. Similar to our work, it is argued that at least three aggregation layers are required for enabling successful aggregations of learning object components.

In [Fernandes et al., 2005], IMS Learning Design [IMS LD, 2003] is added to the comparison. No changes to our comparison are proposed. Hence, the researchers seem to agree that the alignment of content models included in the first investigation (SCORM, Cisco, NETg and Learnativity) is valid.

The ALOCOM ontology is currently used in a project that is concerned with the integration of learning design and learning objects [Knight and Burn, 2005]. In this project, new levels of learning object reusability are explored by combining the ALOCOM ontology with an ontology for IMS Learning Design. To conclude this section, in [Lee and Lim, 2005] our work is referred to as: *"The most interesting and promising work in this area is Verbert & Duval's (2004) global component architecture for learning objects. This architecture is unique in the sense that it maps and unifies different learning object standards to result in only one unified standard."*

6.2 Research Issue 2: Learning Object Structure

In Chapter 3, the RAMLET model for structuring of learning object components has been presented. There are several contributions. First of all, the model enables to assemble and structure ALOCOM components into coherent learning objects. In addition, learning object components can be structured in more than one way, thereby providing the user with different learning paths through the same content.

Secondly, the resource aggregates can be exported for use in IMS CP, METS, Atom or MPEG-21 applications, enabling to use the aggregates in a variety of existing applications. In addition, resource aggregates from different origins can be interpreted and reused. Such interoperability is a condition to realize a large-scale learning object infrastructure with sufficient critical mass. Although the transformation between resource aggregates is not always lossless, important structural relationships are often preserved.

Thirdly, RAMLET is providing a generic approach for enabling interoperability between resource aggregation formats. Previous attempts to enable such interoperability are limited to a crosswalk between IMS CP and METS, expressed in XSLT [Yee and Beaubien, 2004]. Such direct crosswalk cannot scale. If n is the number of resource aggregation formats, 2n transformation implementations are required for each new format to enable its interoperability with the other resource aggregation formats. RAMLET is providing a generic approach that can scale as the number of resource aggregation formats increases, as only 2 transformation implementations are required for a new format.

Finally, as RAMLET is part of important standardization work, we may hope that the model will have a great impact once it is published as an IEEE standard.

6.3 Research Issue 3: Learning Object Aggregation and Disassembly

In Chapter 4, we conceptualized both disassembly and aggregation processes for learning objects and components defined in ALOCOM. Automatic decomposition has been studied for pre-existing learning objects, that are often coarse-grained and stored in semi-structured or unstructured formats. Few approaches support such decomposition. Instead, guidelines are often provided to decompose learning objects manually or to produce new components that are suitable for reuse. The automatic approach contributes to enabling learning object reuse on a global scale, as it has the potential to automate reuse of many learning objects available on the Web.

The component-based reuse approach is a challenge in terms of scalability, as decomposition results in numerous components that have to be managed. The chapter contributes to the field by describing a repository architecture that has been designed to enable scalable reuse of learning object components. An accurate reuse detection mechanism is integrated to avoid duplicates, components are precisely described by the automatic metadata generation module to enable their retrieval and a ranking mechanism is included so that searches are only confronted with relevant components and the approach remains scalable.

In addition, prototypes have been described that enable to validate the approach for presentations, Wikipedia pages and SCORM content packages. Plug-ins have been developed for Microsoft PowerPoint, Microsoft Word and the Reload Editor [Milligan et al., 2005], that allow authors to search and reuse components from within the authoring tools.

In Chapter 5, an evaluation has been presented of the approach for reusing presentations. Results indicate that there is a significant impact in terms of quality and required creation time of presentations. Presentations created with ALOCOM support are significantly more complete, concise and relevant. In addition, participants needed less time to create presentations.

6.4 Research Issue 4: Learning Object Interoperability

The dissertation has addressed learning object interoperability at different levels. Interoperability contributions can be summarized as:

- Interoperability of learning object content: In Chapter 2, interoperability of learning object content has been addressed by the generic ALOCOM content model. Mappings have been defined that enable the interoperation of content defined according to different content models.
- Interoperability of learning object structure: In Chapter 3, the interoperability of different resource aggregation formats has been addressed by the generic RAMLET model. The RAMLET model provides a common nomenclature and a conceptual model that can be used to represent a variety of content packaging formats in a uniform way. Interoperability is achieved by the definition of mappings among the resource aggregation formats.
- Interoperability of learning object output formats: In Chapter 4, interoperability of learning objects stored in application specific formats has been investigated. A prototype has been developed that makes it possible to transform and decompose learning objects stored in the MS PowerPoint format.

6.5 Further Research Topics

There are several avenues and issues for future work. The most relevant possibilities for further study are: copyright issues of learning object components, enabling learning object aggregation and disassembly for a wider range of learning object types and validation of RAMLET in a real world environment.

A more exhaustive list includes the following research opportunities:

- Research on the ALOCOM ontology: The most obvious research recommendation is to continue the process of integrating content model specifications that define learning objects and their components, so as to enable global interoperability of learning content definitions.
- Extending coverage of RAMLET: The conceptual model of RAMLET currently covers the IMS CP, METS, MPEG-21 and Atom formats. Interesting future directions include extending the model for coverage of other aggregations formats, such as OASIS OpenDocument and SMIL, that are conceptually and technically less similar to the currently covered aggregation formats.

- Validation of RAMLET: The conceptual RAMLET transformations will need to be implemented and evaluated in a real world environment. We may hope that software developers and others will do the required work once the RAMLET model is published as an IEEE standard.
- Copyright of learning object components: The most important research issue that needs to be addressed is the copyright of learning object components. The exchange and reuse of components of learning objects in terms of usage restrictions has to be studied in order for the automatic decomposition and assembly processes to work on a large scale.
- Classification patterns for learning object component types: An initial attempt has been made to classify content components into ALOCOM types situated at the content object level, such as definitions, examples, introductions, references, conclusions and others, using simple heuristics. Improving the patterns would be an interesting future direction of the research.
- Aggregation and disassembly for additional learning object types: Prototypes have been developed that support learning object aggregation and disassembly processes for presentations, Wikipedia pages and SCORM content packages. Enabling such component-based reuse for a wider variety of learning object types is an interesting research opportunity.

6.6 Final Reflection

The work presented in this dissertation provides a fundamental framework for reuse of learning objects. The framework has the potential to enable reuse of many available learning objects.

In my opinion, the research can have a great impact. So far, the results are promising: the approach proved to have a significant impact on efficient and effective content reuse for presentations. However, there are issues that need to be dealt with for the approach to really work. Management of copyright and usage restrictions of content components needs to be investigated. In addition, enabling component-level reuse not only requires technical infrastructures, also a behavior change of authors is required. As automated reuse is very different from the usual copy-and-paste process of authors, further research will have to show whether the approach can be adopted. Finally, further research is required to generalize disassembly for a wider variety of learning objects, for instance learning objects stored in PDF or MS Word formats. Decomposing such learning objects, that are often inconsistently structured, remains a challenge.

Chapter 7

Een Architectuur en Raamwerk voor Flexibel Hergebruik van Leerobject-Componenten

7.1 Inleiding

Hergebruik van digitaal leermateriaal is al een aantal decennia zowel een doel als een probleem [Strijker, 2004]. In verscheidene studies [Robson, 2004] [Downes, 2001] wordt geargumenteerd dat hergebruik kan leiden tot belangrijke tijdwinsten en een verhoging van kwaliteit. Beschikbaar leermateriaal is echter vaak moeilijk herbruikbaar omwille van de grove granulariteit van het materiaal [Schluep, 2005]. Bovendien is het materiaal moeilijk toegankelijk: er wordt veel tijd geïnvesteerd in het zoeken naar geschikt materiaal en het manueel overnemen van interessante delen met copy&paste. Ook het gebrek aan interoperabiliteit tussen verschillende opslagvormen, zoals PDF, HTML en Microsoft Office formaten, vormt een belangrijke barrière voor flexibel hergebruik.

Dit doctoraatswerk onderzoekt granulariteit- en interoperabiliteitsaspecten van leerobjecten. Een aantal gerelateerde onderwerpen worden aangepakt: (1) een generisch inhoudsmodel, dat leerobjecten en componenten definieert op verschillende granulariteitsniveaus; (2) een generisch model voor structurering van componenten in coherente leerobjecten; en (3) aggregatie en decompositie van leerobjecten, zodat hun componenten voor hergebruik kunnen ontsloten worden. Daarenboven wordt interoperabiliteit van leerobjecten onderzocht op vlak van inhoud, structuur en uitvoerformaten. Dergelijke interoperabiliteit is een vereiste om leerobject-componenten van verscheidene oorsprong samen te kunnen assembleren.

De onderwerpen en resultaten van dit doctoraatsonderzoek worden in de volgende secties toegelicht.

7.2 Granulariteit van Leerobjecten

7.2.1 Inleiding

Er is een omgekeerd verband tussen de grootte van een leerobject en zijn herbruikbaarheid [Wiley, 2002]: als de grootte van het leerobject daalt, stijgt zijn potentieel voor hergebruik in een nieuwe context. Grootte is dus een belangrijke factor voor flexibel hergebruik van leerobjecten.

Er is geen overeenstemming in de literatuur over het bepalen van dergelijke grootte. De Learning Object Metadata (LOM) standaard [IEEE, 2002] identificeert vier verschillende niveaus van aggregaties van leerobjecten of "functionele granulariteit", van het kleinste niveau, zoals een figuur of een tekstfragment, tot het grootste niveau van een volledige cursus.

Het Sharable Content Object Reference Model [SCORM, 2004] definieert Assets als basisbouwstenen voor inhoud, Sharable Content Objecten (SCOs) als aggregaties van een of meer Assets en Activiteiten als aggregaties van een of meer Assets of SCOs. SCOs worden verondersteld kleine eenheden te zijn, om hergebruik in andere contexten toe te laten. Activiteiten vormen leereenheden van een hoger niveau, gekoppeld aan grotere leerobjectieven.

De heterogeniteit van definities vormt een barrière voor hergebruik op grote schaal, waar het uitwisselen en samen assembleren van leerobjecten van verscheidene oorsprong van belang zijn. Bovendien zijn de granulariteitsdefinities eerder vaag. Een Activiteit in SCORM is bedoeld om een groter leerobjectief te kunnen vervullen, maar kan nog steeds variëren van een paar regels tekst tot uitgebreid interactief leermateriaal.

Er is herhaaldelijk vastgesteld dat granulariteit op een preciese en uniforme manier gedefinieerd moet worden [Schluep, 2005] [Halim et al., 2007], aangezien het een rechtstreekse impact heeft op de herbruikbaarheid van leerobjecten. Deze onderzoeksuitdaging werd aangepakt in een aantal stappen. In een eerste stap werd er een vergelijkende analyse gemaakt van bestaande inhoudsmodellen. Gebaseerd op deze vergelijking, werd een abstract leerobject content model (ALOCOM) opgesteld, dat leerobjecten en componenten op verschillende granulariteitsniveaus definieert. Tenslotte werden ontologie-afbeeldingen uitgewerkt, die overeenkomsten tussen het generische ALOCOM model en andere inhoudsmodellen formaliseren. Dergelijke afbeeldingen zijn belangrijk om interoperabiliteit te verwezenlijken tussen verscheidene inhoudsmodellen.

7.2.2 Vergelijkende analyse van inhoudsmodellen

Negen inhoudsmodellen werden geanalyseerd en vergeleken:

1. Het SCORM (Sharable Content Object Reference Model) model [SCORM, 2004] is het meest bekende en gestandaardiseerde inhoudsmodel voor leerobjecten. Het model definieert vier granulariteitsniveaus.

2. Het NCOM (Navy Content Model) model [Conkey, 2006] is een verfijning van het SCORM model. Het model definieert vier granulariteitsniveaus.

3. Het NETg (National Education Training Group) model [L'Allier, 2003] is een inhoudsmodel ontwikkeld door een belangrijke speler in het e-learning domein. Het model definieert vier granulariteitsniveaus.

4. Het Learnativity model [Wagner, 2002] werd ontwikkeld door de Learnativity stichting, met een aanzienlijke aanvaarding in zowel de opleiding- als onderwijsgemeenschappen. Het model definieert vijf granulariteitsniveaus.

5. Het Cisco model [Barrit et al., 1999] is het meest restrictieve inhoudsmodel. Het model definieert drie granulariteitsniveaus.

6. Het New Economy model [Löser et al., 2002] werd ontwikkeld in de context van het New Economy onderzoeksproject, dat gesteund wordt door het Duitse Federale Ministerie voor Onderwijs en Onderzoek. Het model definieert acht granulariteitsniveaus.

7. Het PaKMaS (Passauer Knowledge Management System) model [Süβ et al., 2000] werd ontwikkeld voor onderzoeksdoeleinden. Het model definieert drie granulariteitsniveaus.

8. Het dLCMS (dynamic Learning Content Management System) model [Schluep, 2005] werd ontwikkeld voor onderzoeksdoeleinden. Het model definieert drie granulariteitsniveaus.

9. Het SLM (Semantic Learning Model) model [Fernandes et al., 2005] werd eveneens ontwikkeld voor onderzoeksdoeleinden. Het model definieert zes granulariteitsniveaus.

Tabel 7.1 aligneert de inhoudsmodellen. Het NETg inhoudsmodel bestaat uit vier granulariteitsniveaus. Het model specificeert drie niveaus voor aggregaties van leerobjecten (zogenaamde Topics): lessen, eenheden en cursussen. Het model definieert geen componenten van leerobjecten.

De andere inhoudsmodellen definiëren zulke componenten in één of twee niveaus. SCORM, NCOM, Cisco, en het New Economy inhoudsmodel definiëren een enkel granulariteitsniveau voor leerobject-componenten, dat bestaat uit individuele, herbruikbare, inhoudselementen. De Learnativity, SLM, PaKMaS en dLCMS inhoudsmodellen definiëren een tweede niveau voor leerobject-componenten dat basisinhoudselementen samenvoegt, maar niet noodzakelijk gerelateerd is aan een bepaald leerobjectief.

Leerobjecten zijn consistent gedefinieerd als aggregaties van leerobject-componenten, gerelateerd aan leerobjectieven. dLCMS en PaKMas leggen geen verdere beperkingen op. De andere inhoudsmodellen definiëren leerobjecten consistent als inhoudsaggregaties, gerelateerd aan een enkel leerobjectief. Deze modellen definiëren een bijkomend niveau, gerelateerd aan meerdere of grotere leerobjectieven. Lessen worden algemeen met dit niveau geassocieerd.

Learnativity, NCOM en SCORM definiëren een derde niveau voor dergelijke samenvoegingen, om cursussen en curricula voor te stellen. NETg en het New Economy model definiëren tenslotte een hierarchie voor dit granulariteitstype: respectievelijk *eenheid, cursus* en *leereenheid, cursus, curriculum.*

	LO Component		**Learning Object**				
	CF	**CO**	**Single-Objective**	**Larger-Objective**	**LO Aggregations**		
SCORM	Asset		SCO	Activity	Content Aggregation		
NETg			Topic	Lesson	Unit	Course	
Learnativity	Raw media	Information Object	Application Object	Aggregate Assembly	Collection		
NCOM	Asset		ELO	TLO	Learning Object Aggregation		
Cisco	Content Item		RIO	RLO			
New Econ.		Information Object	Learning Comp.	Learning Module	Learning Unit	Course	Curriculum
SLM	Asset	Pedagogical Information	Pedagogical Entity	Pedagogical Context	Pedagogical Document		Ped. Schema
PaKMaS	Media Object	Content Module	Structuring Modules				
dLCMS	Asset	Content Element	Learning unit				

Table 7.1: Vergelijking van inhoudsmodellen

7.2.3 Ontologie-gebaseerde aanpak voor interoperabiliteit

De onderzochte inhoudsmodellen definiëren leerobjecten en hun componenten aanzienlijk verschillend:

- Granulariteit wordt gedefinieerd in 3 tot 6 niveaus.
- Verschillende termen worden gebruikt voor hetzelfde concept: een Learnativity informatie-object is bijvoorbeeld equivalent aan een PaKMaS content module.

- Verschillende classificatieschema's worden gebruikt om granulariteit te definiëren: afgeleid van pioneerwerk van Robert Horn [Horn, 1998], een classificatie gedefinieerd door de LOM standaard [IEEE, 2002] en de classificatie van Ballstaedt [Ballstaedt, 1997].
- Er worden verschillende beperkingen opgelegd. Cisco definieert leerobjecten bijvoorbeeld strict als aggregaties van 7±2 RIOs (Reusable Information Objects).

Interoperabiliteit van leerinhoud is essentieel om leerobjecten op grote schaal te kunnen uitwisselen en hergebruiken. Ontologieën bieden een groot potentieel om dergelijke interoperabiliteit te verwezenlijken, aangezien inhoud, essentiële eigenschappen en overeenkomsten kunnen uitgedrukt worden.

In [Bucella et al., 2003] werd een methode geïntroduceerd om gegevens te integreren door middel van ontologieën. De methode bestaat uit drie fasen:

1. het bouwen van een globale ontologie die bestaande modellen overdekt,
2. het bouwen van lokale ontologieën voor elk inhoudsmodel, en
3. het definiëren van afbeeldingen tussen de globale en lokale ontologieën.

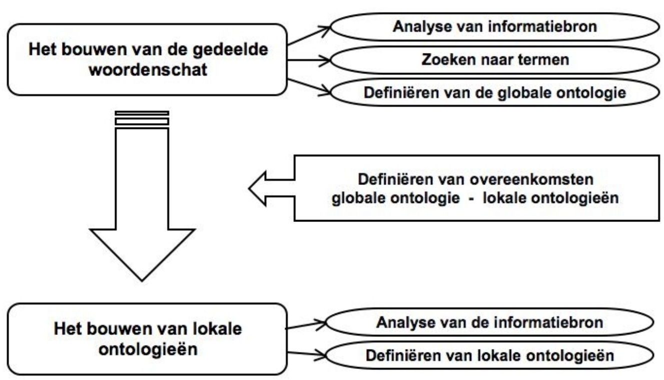


Figure 7.1: Ontologie-constructiemethode [Bucella et al., 2003]

Fase 1 bestaat uit drie stappen (Figuur 7.1): een analyse van inhoudsmodellen, het zoeken naar termen en het definiëren van het globale model. Het globale model wordt in Sectie 7.2.4 voorgesteld. In fase 2 worden ontologieën ontwikkeld voor individuele inhoudsmodellen. Deze ontologieën definiëren concepten en hun onderlinge relaties volgens de specificaties van de modellen. In fase 3 worden dan overeenkomsten gedefinieerd tussen klassen van het globale model en klassen van de lokale ontologieën. Het afbeeldingproces wordt toegelicht in Sectie 7.2.5.

7.2.4 Het ALOCOM inhoudsmodel

Het ALOCOM inhoudsmodel definieert granulariteitsniveaus voor leerobjecten en hun componenten. Componenten van leerobjecten zijn onderverdeeld in:

- Content Fragmenten: gedefinieerd als individuele inhoudselementen, zoals tekst-, beeld- en geluidsfragmenten.
- Content Objecten: gedefinieerd als samenvoegingen van Content Fragmenten, die zich concentreren op een enkel stuk informatie. Content Objecten kunnen gebruikt worden om een concept te verklaren, een principe te illustreren, of een proces te beschrijven.

Leerobjecten zijn onderverdeeld in de volgende granulariteitsniveaus:

1. Single-Objective-LO: gedefinieerd als samenvoegingen van leerobject-componenten, gerelateerd aan een enkel leerobjectief. Voorbeelden zijn concepten, feiten, principes, processen en procedures.
2. Larger-Objective-LO: gedefinieerd als samenvoegingen van single-objective-LOs, gerelateerd aan grotere leerobjectieven. Voorbeelden zijn hoofdstukken en lessen.
3. LO-aggregaties: stellen het grootste granulariteitsniveau voor. Eenheden, cursussen en curricula zijn gedefinieerd als subklassen van LO-aggregaties.

Inhoudsclassificaties werden gedefinieerd voor de Content Fragment, Content Object en Single-Objective-LO niveaus (Figuur 7.2). De classificaties zijn gebaseerd op de Structured Writing classificatie [Horn, 1998], de classificatie van Ballstaedt [Ballstaedt, 1997] en een classificatie gedefinieerd door de LOM standaard [IEEE, 2002].

7.2.5 Ontologie-afbeeldingen

Ontologie-afbeeldingen formaliseren overeenkomsten tussen het generische ALOCOM model en andere inhoudsmodellen.

Dergelijke afbeeldingen worden vaak gedefinieerd als: "Gegeven twee ontologieën A en B, het afbeelden van één ontologie op een andere ontologie betekent dat voor elk concept in ontologie A, een overeenkomstig concept in ontology B gezocht wordt met dezelfde of gelijkaardige betekenis, en vice versa" [Su, 2006].

Afbeeldingen gedefinieerd tussen ALOCOM en andere inhoudsmodellen zijn bidirectioneel. Een fragment van de afbeelding is weergegeven in Figuur 7.3. SCORM *SCOs*, NETg *Topics*, NCOM *ELOs*, Cisco *RIOs*, Learnativity *Application*

Figure 7.2: Het ALOCOM Model

Figure 7.3: Afbeeldingen van leerobjectniveaus

Objects, en SLM *Pedagogical Entities* zijn gerelateerd aan een enkel leerobjectief en zijn afgebeeld op de ALOCOM *Single_Objective_LO* klasse.

SCORM *Activities*, Learnativity *Aggregate Assemblies*, NCOM *TLOs*, Cisco *RLOs*, SLM P*edagogical Contexts* en New Economy *Learning Modules* stellen leerobjecten voor die gerelateerd zijn aan meerdere of grotere leerobjectieven. De concepten zijn afgebeeld op de ALOCOM *Larger_Objective_LO* klasse.

NCOM *LO Aggregations*, SLM *Pedagogical Documents* en SCORM *Content Aggregations* zijn equivalent aan ALOCOM *LO_aggregaties*. Classificaties van dit granulariteitsniveau zijn gelijkaarding in de meeste inhoudsmodellen. De NETg en New Economy hierarchieën *unit, course* en *unit, course, curriculum* zijn voorgesteld in ALOCOM en zijn afgebeeld op hun equivalente klassen. De PaKMaS *Structuring Module* en dLCMS *Learning Unit* klassen zijn afgebeeld op de ALOCOM *Learning_Object* superklasse, aangezien geen onderscheid gemaakt wordt tussen enkele en grotere leerobjectieven.

7.2.6 Besluit

In deze sectie werd het ALOCOM inhoudsmodel voorgesteld, dat leerobjecten en hun componenten op verschillende niveaus van granularity bepaalt. De Content Fragment en Content Object componenten-niveaus zijn belangrijk om flexibel hergebruik van leerobjecten mogelijk te maken, aangezien deze componenten samengesteld kunnen worden om nieuwe leerobjecten te creëren.

Het ALOCOM model en ontologie-afbeeldingen integreren bestaande inhoudsmodellen en zijn ontwikkeld voor interoperabiliteitsdoeleinden. De ontologie verbindt specificaties die momenteel beschikbaar zijn. Dergelijke ontologie is nooit volledig en zou in de tijd moeten evolueren. We hopen dat geïnteresseerden helpen dit werk te vervolledigen, om het tot zijn volledige potentieel te brengen.

7.3 Structurering van Leerobjecten

7.3.1 Inleiding

Een belangrijk principe in hypermedia-systemen is de scheiding van inhoud, structuur en presentatie. Structurele aspecten van samengestelde leerobjecten kunnen gebaseerd zijn op de *IMS Content Packaging* (IMS CP) specificatie [IMS CP, 2004], de *Metadata Encoding and Transmission Standard* (METS) [Cundiff, 2004], de *Synchronized Multimedia Integration Language* (SMIL) [Bulterman et al., 2005] of *OpenDocument* [Durusau et al., 2007].

De specificaties ondersteunen het beschrijven van de structuur van een collectie leerinhoud. Bovendien kunnen meerdere structuren gedefinieerd worden, om verschillende leerpaden doorheen hetzelfde leerobject te voorzien.

Een beperking van de specificaties is hun heterogeniteit. Leerobjecten, gestructureerd in een IMS inhoudspakket, kunnen bijvoorbeeld niet hergebruikt worden in een METS context.

Het Resource Aggregation Model voor Learning, Education en Training (RAMLET) werd ontwikkeld om structuur op een uniforme manier te beschrijven. Interoperabiliteit wordt bereikt door ontologie-afbeeldingen tussen verscheidene specificaties. Het model werd ontwikkeld in samenwerking met Kerry Blinco (University of Southern Queensland), Wilbert Kraan (Centre for educational technology interoperability standards), Scott Lewis (Old World Aviaries, Austin, TX) en Nancy Hoebelheinrich (Stanford University) in de context van een IEEE-standaardisatieproject. In april 2008 zal het RAMLET model voorgelegd worden aan de IEEE-reviewcommissie voor standaarden.

De volgende sectie geeft een overzicht van het RAMLET model. Ontologie-afbeeldingen worden in Sectie 7.3.3 beschreven.

7.3.2 Het RAMLET Model

Het RAMLET model definieert een gemeenschappelijke nomenclatuur en een conceptueel model voor structurele aspecten van leerobjecten. RAMLET overkoepelt momenteel IMS CP [IMS CP, 2004], MPEG-21 DID [Bekaert, 2006], METS [Cundiff, 2004] en Atom [Sayre, 2005] en is geïmplemeteerd in OWL [Bechhofer et al., 2004]. Overdekking van IMS CP, METS, MPEG-21 DID en Atom houdt in dat concepten en onderlinge relaties van de specificaties in RAMLET zijn voorgesteld.

Een vereenvoudigd overzicht van het RAMLET model is weergegeven in Figuur 7.4. Het *TopNode* element stelt het wortelelement van een aggregatie voor. *DescriptorObject* is een container voor metadata, dat het pakket in zijn geheel en individuele componenten beschrijft. Metadata wordt gewoonlijk uitgedrukt door middel van externe standaarden, zoals LOM of Dublin Core. RAMLET maakt verder een onderscheid tussen *administratieve* en *beschrijvende* metadata. Dergelijk onderscheid komt onder meer voor in de METS specificatie.

Klassen voor de voorstelling van identifiers zijn gedefinieerd voor het pakket (*aggregationID*), lokale elementen (*elementID*) en structuurknopen (*nodeID*). *StaticStructure* en *StaticStructureSet* zijn constructies om de structuur van een inhoudspakket te definiëren, in een hiërarchisch geordende opeenvolging van StructuurKnopen (*StructureNodes*). *DynamicStructure* laat toe om een pakket, of een bepaald onderdeel, als optioneel of beschikbaar onder bepaalde voorwaarden te beschrijven.

DigitalResource stelt een digitaal bronbestand voor. *DigitalResourceFragment* specificeert tenslotte een specifiek punt of een bereik in een bronbestand. Een fragment kan bijvoorbeeld een specifiek tijdspunt van een audiofragment aanduiden.

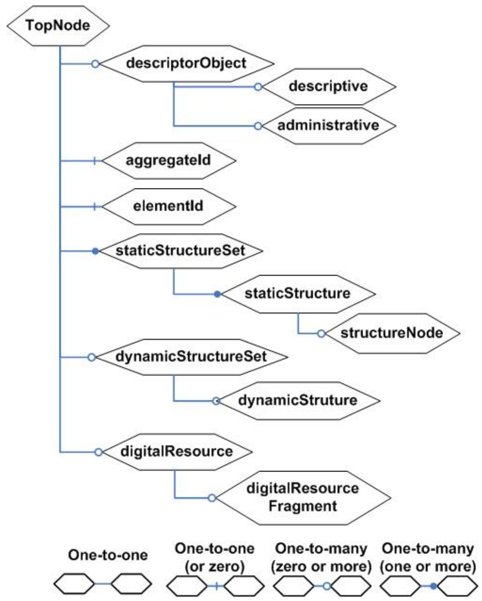


Figure 7.4: Conceptueel overzicht van het RAMLET model

7.3.3 Overeenkomsten van Structurele Aspecten

Overeenkomsten werden gedefinieerd tussen het RAMLET model en de IMS CP, METS, MPEG-21 en Atom standaarden, volgens de integratiemethode voorgesteld in Sectie 7.2.3.

Een fragment van de afbeelding is voorgesteld in Tabel 7.2. Concepten gedefinieerd in RAMLET zijn voorgesteld in de eerste kolom. De tweede kolom stelt overeenkomstige elementen van IMS CP voor, de derde overeenkomstige elementen van METS, de vierde overeenkomstige elementen van MPEG-21 DID en de laatste kolom stelt overeenkomstige elementen van Atom voor.

De IMS CP *Manifest*, METS *mets*, MPEG-21 *DIDL* en Atom *feed* elementen stellen de wortelknoop van aggregaties voor en zijn afgebeeld op de RAMLET *TopNode* klasse. IMS CP *metadata*, METS *mdWrap*, MPEG-21 *Annotation, Statement* en *Descriptor*, en Atom *category* elementen zijn containers voor metadata en zijn afgebeeld op de RAMLET *descriptorObject* klasse. De MPEG-21 *Annotation, Statement* en *Descriptor* zijn afgebeeld op dezelfde klasse, omdat ze een gelijkaardige betekenis hebben, namelijk het voorstellen van metadata.

De andere afbeeldingen verlopen analoog. De verschillende elementen van IMS CP, METS, MPEG-21 DID en Atom zijn vertegenwoordigd in het globale RAMLET model en zijn afgebeeld op hun overeenkomstige klassen. Als de elementen een gelijkaardige betekenis hebben, zoals *fragment* en *anchor*, worden de klassen afgebeeld op dezelfde klasse.

Table 7.2: Afbeeldingen

RAMLET	IMS CP	METS	MPEG-21	Atom
1. topNode	Manifest	mets	DIDL	feed
2. descriptorObject	Metadata	mdWrap	Annotation; Statement; Descriptor	category
3.0 aggregateID		objID	DIDL-DocumentId	id
4.0 elementID	Identifier	Id	Identifier; Target	
4.1 nodeID		contentIDs		
5.0 digitalResource	File	file	Resource	entry
5.1 digitalResource-Fragment		area	Fragment; Anchor	
6.0 staticStructure	Organization	structMap	Container	
6.1 staticStructure-Type		structMapType		
7.0 staticStructureSet	Organizations			
8.0 dynamicStructure		behavior		
8.1 dynamicStructureType		btype		
8.2 dynamicStructureID			ChoiceId; SelectId	
8.3 assertion			Assertion	
8.4 condition			Condition	
8.5 choice			Choice	
8.6 selection			Selection	
8.7 maxSelections			maxSelections	
8.8 minSelections			minSelections	
8.9 defaultSelection			default	
8.10 require			require	
8.11 except			except	
9.0 dynamicStructureSet		behaviorSec		
10.0 structureNode	Item	div; fptr	Item	

7.3.4 Besluit

In deze sectie werd het RAMLET model voor structurering van leerobjecten voorgesteld. Het model laat toe ALOCOM componenten te assembleren en te structureren in coherente leerobjecten. Het pakket kan geëxporteerd worden voor gebruik in IMS CP, METS of MPEG-21 applicaties. Bovendien kunnen inhoudspakketten, beschikbaar in verschillende formaten, geïmporteerd en hergebruikt worden. Dergelijke vorm van interoperabiliteit is belangrijk voor hergebruik op grote schaal.

Het conceptuele model van RAMLET overkoepelt momenteel de IMS CP, METS, MPEG-21 en Atom formaten. Een interessante onderzoeksrichting omvat het uitbreiden van het model voor overdekking van andere pakketformaten, zoals OASIS OpenDocument [Durusau et al., 2007] en SMIL [Bulterman et al., 2005], die conceptueel en technisch minder gelijkaardig zijn aan de huidige formaten.

7.4 Aggregatie en Decompositie van Leerobjecten

In de vorige secties werden de ALOCOM en RAMLET modellen voorgesteld om interoperabiliteit van leerinhoud en structuur te verwezenlijken. Dergelijke interoperabiliteit is belangrijk om leerobjecten te kunnen uitwisselen en hergebruiken.

Nochtans is de meerderheid van leermateriaal opgeslagen in ongestructureerde of semi-gestructureerde opslagvormen, zoals Microsoft Word, PowerPoint of HTML formaten. Om hun hergebruik te ondersteunen, werd een raamwerk ontwikkeld dat dergelijke formaten omzet naar instanties van het ALOCOM model. In dit transformatieproces ontbindt het raamwerk leerobjecten en verleent toegang tot hun componenten, wat automatisch hergebruik in nieuwe leerobjecten mogelijk maakt. Om de aanpak te valideren, werden zoekfuncties geïntegreerd in bestaande auteurtools, zoals Microsoft Word en PowerPoint.

De volgende sectie licht het decompositieproces toe. Plug-ins die het aggregatieproces ondersteunen worden voorgesteld in Sectie 7.4.2. Secties 7.4.3 en 7.4.4 stellen een gebruiker- en kwaliteitsevaluatie van de aanpak voor presentatiehergebruik voor.

7.4.1 Het ALOCOM Raamwerk

Het ALOCOM raamwerk vergemakkelijkt inhoudshergebruik door leerobjecten te ontbinden in kleinere, herbruikbare, componenten. Componenten worden verrijkt met metadata en worden individueel opgeslagen in een ARIADNE repository [Duval et al., 2001]. Het raamwerk is weergegeven in Figuur 7.5 en bestaat uit de volgende componenten:

1. Plug-ins voor auteurtools (Figuur 7.5 - (1)) laten toe componenten te zoeken en te hergebruiken. Bovendien kunnen leerobjecten doorgestuurd worden voor opslag in de repository. Beide functionaliteiten worden ondersteund door een plug-in voor Microsoft PowerPoint en een plug-in voor een SCORM-editor (Reload). Een plug-in voor Microsoft Word laat automatisch hergebruik van Wikipedia componenten in tekstdocumenten toe (zie Sectie 7.4.2).

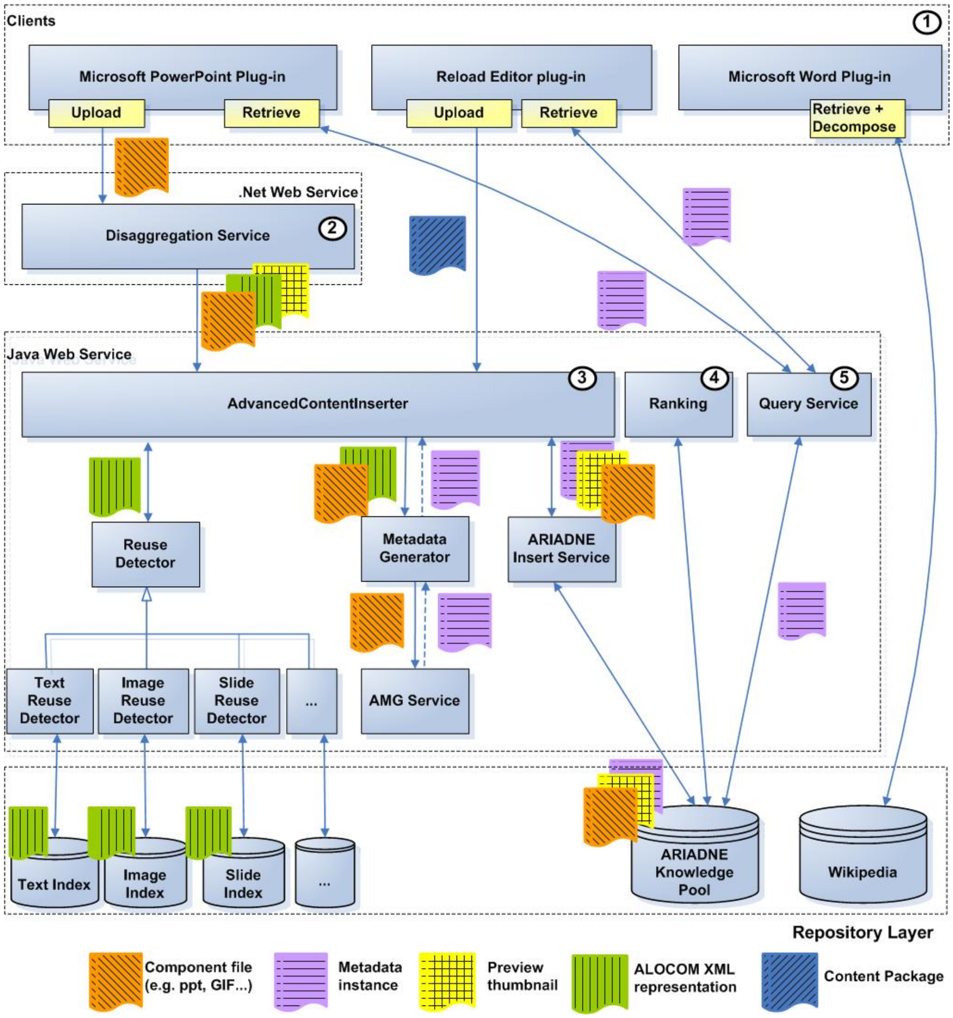


Figure 7.5: Het ALOCOM Raamwerk

2. De decompositie-module (Figuur 7.5 - (2)) ontbindt leerobjecten in componenten. Presentaties worden ontbonden in slides en slides worden verder ontbonden in figuren, tabellen, diagrammen, tekst, audio- en videofragmenten. Tekstdocumenten worden ontbonden in secties en deelsecties en elke sectie wordt verder ontbonden in paragrafen, figuren, tabellen, diagrammen, enz. De aanpak wordt momenteel ondersteund voor PowerPoint presentaties en Wikipedia pagina's. Voor elke component wordt verder een

miniatuur (thumbnail) geproduceerd, die gebruikt wordt in resultaatlijsten van zoekvragen. De resultaten van de decompositie worden opgeslagen via de AdvancedContentInserter.

3. De AdvancedContentInserter (Figuur 7.5 - (3)) ondersteunt het opslaan van leerobjecten en hun componenten. Hergebruik wordt gedetecteerd om duplicaten te vermijden en leerobjecten en componenten worden automatisch gemetadateerd met behulp van het Automatisch Metadata Generatie raamwerk [Cardinaels et al., 2005]. Gemetadateerde leerobjecten en componenten worden tenslotte opgeslagen in de repository via de insert-service.

4. De Ranking module (Figuur 7.5 - (4)) laat het rangschikken van componenten in resultaatlijsten toe wanneer een gebruiker zoekt naar relevante componenten. Vaak hergebruikte componenten worden bovenaan geplaatst.

5. De Query service (Figuur 7.5 - (5)) laat het opvragen van componenten toe. Sleutelwoorden en een componenttype, zoals definitie, voorbeeld, slide, figuur of tabel, kunnen gespecificeerd worden. Geavanceerde zoekvragen, zoals zoeken op auteur, titel, hoofdconcepten, of duur, worden ook ondersteund.

7.4.2 Het Aggregatieproces

Zoekfuncties werden geïntegreerd in auteurtools, die een auteur gebruikt om leerobject-componenten te assembleren in nieuw leermateriaal.

Een plug-in werd ontwikkeld voor Microsoft PowerPoint, die auteurs toelaat componenten te hergebruiken vanuit de toepassing. Een auteur kan een type specificeren, zoals verwijzing, definitie of voorbeeld, en beschrijvende sleutelwoorden. Miniaturen van componenten die aan de zoekcriteria voldoen worden getoond in de resultatenlijst (zie Figuur 7.6). De auteur kan een component toevoegen aan de huidige presentatie door de component aan te klikken.

Een gelijkaardig plug-in werd ontwikkeld voor Microsoft Word om hergebruik van Wikipedia componenten te automatiseren. Het eerste deel van de pagina wordt teruggegeven als definitie. Andere secties worden teruggegeven bij het zoeken naar tekstfragmenten, ontbonden tot op het niveau van een enkele paragraaf, gelabeld met de titel van de sectie waartoe ze behoren. Figuren hebben vaak "alt"-attributen die een korte beschrijving voorzien. Tot slot worden referenties weergegeven door het ontleden van de referentie-sectie van een pagina.

Een laatste plug-in werd ontwikkeld voor Reload, een editor voor SCORM-pakketten. Een gebruiker kan opnieuw sleutelwoorden en een componenttype specificeren. Resultaten worden in een geïntegreerd venster getoond. Als een gebruiker een component toevoegt aan het SCORM-pakket, wordt het bronbestand opgehaald en lokaal opgeslagen. Metadata geassocieerd met de component wordt automatisch toegevoegd aan het SCORM-pakket.

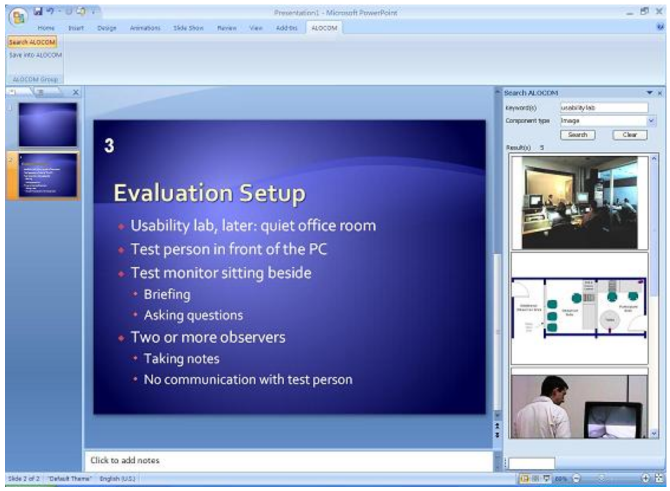


Figure 7.6: De ALOCOM plug-in voor MS Powerpoint

7.4.3 Gebruikersevaluatie

Een gebruikersevaluatie werd uitgevoerd om de aanpak te valideren voor presentatiehergebruik. De doelstellingen van de evaluatie waren drievoudig: (i) het beoordelen van de efficiëntie en de doeltreffendheid van de aanpak, (ii) het beoordelen van de gebruikersinterface van de ALOCOM plug-in; en (iii) bepalen tot op welk niveau van granulariteit decompositie relevant is.

Studiebeschrijving

De studie werd uitgevoerd in oktober 2006 in K.U. Leuven. Er waren 20 deelnemers, wat typisch resulteert in een redelijk nauw betrouwbaarheidsinterval [Nielsen, 2006].

Elke deelnemer werd gevraagd twee presentaties uit te werken: een eerste over overerving en een tweede over uitzonderingen in de programmeertaal Java. De deelnemers werden verdeeld in twee groepen. De eerste groep creëerde de presentatie over uitzonderingen in Java zonder ALOCOM ondersteuning en de presentatie over overerving in Java met ALOCOM ondersteuning. De tweede groep deed hetzelfde, maar in omgekeerde volgorde. Deze groep creëerde de presentatie over overerving in Java zonder ALOCOM ondersteuning en de presentatie over uitzonderingen in Java met ALOCOM ondersteuning.

De volgende karakteristieken werden gemeten:

- Tijd: Het doel van de tijdvergelijking is te onderzoeken of het gebruik van de ALOCOM plug-in kan leiden tot tijdbesparingen.

- Manueel versus semi-automatisch hergebruik: Het onderscheid wordt gemaakt tussen manueel en semi-automatisch hergebruikte componenten. Manueel hergebruikte componenten zijn componenten die gevonden werden via Google en manueel gekopieerd werden. Semi-automatisch hergebruikte componenten zijn componenten die gevonden en toegevoegd werden via ALOCOM. Door beide vormen van hergebruik te meten en te vergelijken, verkrijgen we een aanwijzing van de succesfactor van de ALOCOM aanpak voor hergebruik.

- Granulariteit: De granulariteit van semi-automatisch hergebruikte componenten werd gemeten om een gepast niveau voor decompositie te bepalen.

- Tevredenheid: Gebruikerstevredenheid werd gemeten door een vragenlijst.

Resultaten

Tijd Tabel 7.3 toont de gemiddelde tijd die deelnemers besteedden aan het uitwerken van beide presentaties. Op het eerste zicht is het verschil vrij beperkt: gemiddeld werden 20,03 minuten besteed aan een *zonder-alocom* presentatie en 17,79 minuten aan een *met-alocom* presentatie. Niet alle deelnemers creëerden echter gelijkwaardige presentaties op vlak van lengte, behandelde deelonderwerpen of kwaliteit in het algemeen.

Grootte-normalisaties werden toegepast die overgenomen werden van het software-kwaliteit onderzoeksgebied [ISO/IEC 9126 -2, 1998]. Een eenvoudige normalisatie die het aantal slides van een presentatie in rekening brengt, toont aan dat gemiddeld 3,32 minuten werden gespendeerd aan een slide van een *zonder-alocom* presentatie en 2,2 minuten aan een slide van een *met-alocom* presentatie.

Een tweede normalisatie werd toegepast die het aantal deelonderwerpen beschouwt. Sommige deelnemers creëerden presentaties die talrijke deelonderwerpen behandelen, zoals polymorfisme en dynamische binding voor de presentatie over overerving, terwijl anderen enkel een definitie en een voorbeeld toevoegden. Als we het aantal deelonderwerpen beschouwen, zien we dat gemiddeld 4,5 minuten besteed werden aan deelonderwerp in een *zonder-alocom* presentatie en 2,9 minuten aan een deelonderwerp in een *met-alocom* presentatie. Om de resultaten te bevestigen, werd een tweede evaluatie uitgevoerd die de kwaliteit van de presentaties beoordeelde (zie sectie 7.4.4).

Hergebruik in met-alocom presentaties Tabel 7.4 toont dat 57% van presentatie-componenten semi-automatisch hergebruikt werden via de ALOCOM plug-in. 18% werd manueel hergebruikt en 25% zijn nieuwe componenten.

	met-alocom	**zonder-alocom**	**Significantie**
Totale tijd	20,03	17,79	0,147
Tijd genormaliseerd door het aantal slides	3,32	2,2	0,001
Tijd genormaliseerd door het aantal deelonderwerpen	4,5	2,9	0,016

Table 7.3: Tijd (in minuten)

Als we manueel en semi-automisch hergebruik vergelijken, zien we dat 76% semi-automatisch hergebruikt werd en 24% manueel werd gekopieerd. Deze waarden vormen een succesfactor van ALOCOM, aangezien deelnemers typisch eerst de semi-automatische aanpak probeerden en manueel inhoud toevoegden als geen relevante componenten via ALOCOM werden gevonden.

	Manueel	**Semi-automatisch**	**Nieuw**
Algemeen	0,18	0,57	0,25
Presentatie overerving (1)	0,19	0,58	0,23
Presentatie uitzonderingen (2)	0,18	0,55	0,27

Table 7.4: Hergebruik in *met-alocom* presentaties

Granulariteit Volledige slides werden het vaakst hergebruikt (74%), waarschijnlijk omdat ze vaak een enkel onderwerp behandelen en zo gemakkelijk in een nieuwe context kunnen gebruikt worden. Hergebruik van tekstfragmenten was eveneens beduidend (19%). Dit is een interessant resultaat, omdat het aantoont dat decompositie tot op het niveau van een tekstfragment nuttig is. Figuren werden minder vaak hergebruikt (7%).

Tevredenheid Tabel 7.5 toont resultaten van de vragenlijst over de bruikbaarheid van de ALOCOM plug-in. De vragenlijst werd overgenomen van een bruikbaarheidsevaluatie van de ARIADNE finder [Najjar et al., 2005].

Het gemiddelde voor gebruiksvriendelijkheid was hoger dan 6, wat betekent dat deelnemers de ALOCOM plug-in gemakkelijk te gebruiken vonden. Het niveau van informatieorganisatie en zoeken en hergebruiken van leerobject-componenten werd als matig waargenomen (gemiddelde van 5,23 en 5,69 respectievelijk).

Deelnemers vonden de resultatenlijsten eerder moeilijk te lezen (gemiddelde 4,92). Dit resultaat is een gevolg van het feit dat miniaturen van slides die veel

	gemiddelde (van 1 tot 7)	**Standaardafwijking**
Gebruiksvriendelijkheid	6,15	0,69
Informatie-organisatie	5,23	0,93
Terminologie-gebruik	4,92	1,5
Navigatie	6,07	1,04
Zoeken naar en hergebruik van componenten	5,69	1,49
Leesbaarheid van resultatenlijst	4,92	1,5

Table 7.5: Tevredenheid

inhoud bevatten moeilijk te lezen zijn. Er werd een oplossing uitgewerkt die gebruikers toelaat componenten te vergroten.

7.4.4 Kwaliteitsevaluatie

In een vervolgevaluatie, werd de kwaliteit van *met-alocom* en *zonder-alocom* presentaties beoordeeld door een groep van 19 deelnemers. Deze evaluatie was noodzakelijk om een nauwkeurigere inschatting te verkrijgen van de doeltreffendheid en efficiëntie van ALOCOM.

Studiebeschrijving

Om subjectiviteit in de kwaliteitsevaluatie te verminderen, werd een evaluatieraamwerk gebruikt. In [Knight and Burn, 2005] wordt een overzicht gegeven van gemeenschappelijke dimensies van inhoudskwaliteit-raamwerken. Vier dimensies, relevant in de context van dit experiment, werden gebruikt om de kwaliteit van presentaties te beoordelen: nauwkeurigheid, volledigheid, relevantie en beknoptheid.

Het experiment werd online uitgevoerd via een web-toepassing. Deelnemers beoordeelden 20 willekeurig geselecteerde presentaties op basis van de vier geselecteerde parameters. Het experiment was 2 weken beschikbaar. 19 deelnemers voltooiden de evaluatie, waaronder 13 doctoraatstudenten, 1 post-doctoraal onderzoeker en 5 actief in software-ontwikkeling.

Resultaten

Omdat meten van kwaliteit inherent subjectief is, is de eerste stap in een analyse het meten van de betrouwbaarheid van de evaluatie. De intraclass-correlatiecoëfficiënt (ICC) [Shrout and Fleiss, 1979] werd gebruikt om betrouwbaarheid te meten. De resultaten voor elke kwaliteitsparameter zijn weergegeven in Tabel 7.6.

Parameter	Intraclass-correlatiecoëfficiënt
Volledigheid	0,927
Nauwkeurigheid	0,766
Beknoptheid	0,881
Relevantie	0,837

Table 7.6: Intraclass-correlatiecoëfficiënt voor het meten van betrouwbaarheid

ICC waarden boven 0,75 wijzen op een goede betrouwbaarheid tussen metingen. Aangezien geen van de waarden onder deze grens valt, kan een verdere statistische analyse uitgevoerd worden.

De tweede stap is het beoordelen van het verschil tussen de gemiddelde waarden toegekend aan *met-alocom* en *zonder-alocom* presentaties. Deze gemiddelde waarden zijn weergegeven in Figuur 7.7. Een paarsgewijze t-toest werd toegepast om te bepalen of er een significant verschil is. De resultaten zijn voorgesteld in Tabel 7.7. Normaliteit werd getoetst met behulp van de Kolmogorov-Smirnovtoets [Massey, 1951].

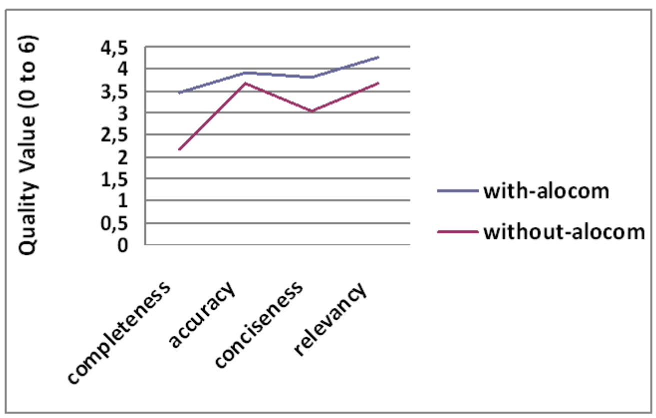


Figure 7.7: Gemiddelde kwaliteitswaarde voor de verschillende parameters

Parameter	T-waarde	Significantie
Volledigheid	-8,094	0,0
Nauwkeurigheid	-1,412	0,160
Beknoptheid	-4,352	0,0
Relevantie	-2,981	0,003

Table 7.7: Significantie van het verschil

De nulhypothese kan verworpen worden voor de meeste parameters (volledigheid, beknoptheid en relevantie). Het significante verschil voor de volledigheidsparameter duidt aan dat gebruikers volledigere presentaties uitwerkten met ALOCOM ondersteuning. Het significante verschil voor de beknoptheidsparameter wijst erop dat inhoud, die uit bestaande presentaties wordt gehaald, erg geschikt is voor hergebruik, aangezien dergelijke inhoud reeds in een vorm is voorgesteld die met een publiek kan gedeeld worden. Verder konden gebruikers meer relevante inhoud vinden via ALOCOM. Er werd geen significant verschil waargenomen op vlak van nauwkeurigheid.

7.4.5 Besluit

In deze sectie werd het ALOCOM raamwerk voor flexibel hergebruik van leerobjecten beschreven. Daarenboven werd een evaluatie van de doeltreffendheid en efficiëntie van de aanpak voor presenatiehergebruik voorgesteld.

De analyse van de resultaten wijst erop dat er significante verbeteringen zijn. Presentaties gecreëerd met ALOCOM zijn significant vollediger, relevanter en beknopter. Bovendien hadden de deelnemers minder tijd nodig om presentaties uit te werken.

Presentaties worden ontbonden tot op het niveau van een enkele tekstfragment, een figuur of een tabel. Resultaten van de evaluatie duiden aan dat deze kleine componenten ook vaak worden hergebruikt.

Om de bevindingen te veralgemenen, moeten evaluaties uitgevoerd worden om te beoordelen of gerelateerde aanpakken, zoals plug-ins voor MS Word en Reload, een gelijkaardige impact op efficiënt en doeltreffend inhoudshergebruik hebben.

7.5 Besluit

In deze verhandeling werden granulariteit- en interoperabiliteitaspecten van leerobjecten onderzocht om flexibel hergebruik te ondersteunen. Deze sectie besluit dit doctoraatswerk met een samenvatting van de onderzoeksbijdragen en een exploratie van verdere onderzoeksopportuniteiten.

7.5.1 Granulariteit van Leerobjecten

In Sectie 7.2 werden verschillende inhoudsmodellen voor leerobjecten onderzocht. De eerste bijdrage is een vergelijkende analyse van de modellen. Dergelijke vergelijking laat toe bestaande modellen te aligneren en pakt interoperabiliteitskwesties van hun heterogene definities aan. De tweede, en belangrijkste, bijdrage is de ontwikkeling van het generische ALOCOM inhoudsmodel. In tegenstelling tot de meeste inhoudsmodellen die onderzocht werden, wordt granulariteit op een nauwkeurige manier gedefinieerd. Het onderscheid werd gemaakt tussen leerobject-componenten en leerobjecten. Beide granulariteitsniveaus werden verder onderverdeeld en inhoudsclassificaties werden bepaald. De componentenniveaus zijn belangrijk om flexibel hergebruik te ondersteunen, aangezien dergelijke componenten kunnen geassembleerd worden in nieuwe leerobjecten.

Het ALOCOM model laat toe leerobjecten duidelijk te modelleren en is de basis voor de voorgestelde decompositie- en aggregatieprocessen. De doelstelling van deze onderzoekskwestie werd bereikt. Daarenboven zijn nieuwe perspectieven betreffende de interoperabiliteit van inhoudsmodellen uitgewerkt. Een ontologie-integratiemethode werd toegepast om overeenkomsten tussen inhoudsmodellen te formaliseren.

7.5.2 Structuur van Leerobjecten

In Sectie 7.3 werd het RAMLET model voor structurering van leerobjecten voorgesteld. Er zijn een aantal onderzoeksbijdragen. Het model laat toe ALOCOM componenten te structureren in coherente leerobjecten. Bovendien kunnen meerdere structuren gespecificeerd worden voor eenzelfde leerobject en kan dynamisch gedrag geassocieerd worden aan inhoud.

Pakketten kunnen geëxporteerd worden voor gebruik in bestaande IMS CP, METS, Atom of MPEG-21 toepassingen. Bovendien kunnen inhoudspakketten van verscheidene oorsprong geïmporteerd worden. Dergelijke interoperabiliteit is belangrijk om hergebruik op grote schaal te kunnen verwezenlijken.

7.5.3 Decompositie en Aggregatie van Leerobjecten

In Sectie 7.4 werden decompositie- en aggregatieprocessen voor leerobjecten voorgesteld. Automatische decompositie werd onderzocht voor beschikbare leerobjecten, die vaak in semi-gestructureerde of ongestructureerde formaten zijn opgeslagen. Weinig aanpakken ondersteunen dergelijke decompositie. Vaak worden richtlijnen voorzien om leerobjecten manueel te ontbinden of nieuwe componenten te produceren die voor hergebruik geschikt zijn.

De component-gebaseerde hergebruiksbenadering is een uitdaging op vlak van schaalbaarheid, aangezien decompositie resulteert in talrijke componenten. Een repository-architectuur werd ontworpen om schaalbaar hergebruik van leerobjecten te ondersteunen. Een mechanisme voor hergebruikdetectie werd geïntegreerd om duplicaten te vermijden, componenten worden nauwkeurig beschreven door de module voor automatische metadatering en een ranking mechanisme werd toegevoegd voor een meer transparante en doelgerichte aanwending van inhoud.

De resultaten van de evaluatie van presentatiehergebruik wijzen erop dat er een grote impact is in termen van benodigde tijd en kwaliteit. Presentaties gecreëerd met ALOCOM zijn beduidend volllediger, beknopter en relevanter. Bovendien hadden deelnemers minder tijd nodig om presentaties uit te werken.

7.5.4 Verdere onderzoeksonderwerpen

Er zijn verschillende opportuniteiten voor verder onderzoek:

- Uitbreiden van ALOCOM: De meest voor de hand liggende onderzoeksaanbeveling is het verderzetten van het integreren van inhoudsmodellen, om globale interoperabiliteit van inhoudsdefinities te ondersteunen.

- Uitbreiden van RAMLET: Het RAMLET model omvat momenteel de IMS CP, METS, MPEG-21 en Atom specificaties. Een interessante onderzoeksrichting omvat het uitbreiden van het model om andere formaten te ondersteunen, zoals OASIS OpenDocument en SMIL, die minder gelijkaardig zijn aan de huidige specificaties.

- Validatie van RAMLET: De conceptuele RAMLET transformaties zullen moeten geïmplementeerd en geëvalueerd worden. We hopen dat de softwareontwikkelaars en anderen het vereiste werk zullen doen van zodra RAMLET als IEEE standaard gepubliceerd is.

- Auteursrecht van leerobject-componenten: De belangrijkste onderzoekskwestie is auteursrecht van leerobject-componenten. Uitwisseling en hergebruik van leerobject-componenten in termen van gebruiksbeperkingen moet onderzocht worden om automatische decompositie en aggregatie op grote schaal te kunnen ondersteunen.

- Aggregatie en decompositie voor andere types van leerobjecten: Prototypes werden ontwikkeld om decompositie en aggregatie van presentaties, Wikipedia pagina's en SCORM inhoudspakketten te ondersteunen. Verder onderzoek is vereist om decompositie te veralgemenen voor een grotere verscheidenheid leerobjecten, bijvoorbeeld leerobjecten opgeslagen in MS Word en PDF formaten. Het ontbinden van dergelijke leerobjecten, die vaak inconsistent gestructureerd zijn, blijft een uitdaging.

Bibliography

[Adcock et al., 2000] Adcock, G., Ip, A. & Mason, J. Modeling Information to Support Value-Adding: EdNA Online. *WebNet Journal: Internet Technologies, Applications & Issues*, 2(3):38-45, Charlottesville, VA: AACE, 2000.

[Ament, 2003] Ament, K. Single Sourcing: Building Modular Documentation. Norwich NY: William Andrew Publishing, 2003.

[ANSI/NISO Z39.87, 2006] ANSI/NISO Z39.87 - 2006. Data Dictionary - Technical Metadata for Digital Still Images. National Information Standards Organization, December 18, 2006, NISO Press, Bethesda, Marylang, 107 pages. ISBN: 978-1-880124-67-3.

[Ballstaedt, 1997] Ballstaedt, S.-P. Wissensvermittlung die Gestaltung von Lernmaterial. Weinheim, Beltz PsychologieVerslagsUnion, 1997.

[Barrit et al., 1999] Barrit, C., Lewis, D., Wieseler, W. CISCO Systems Reusable Information Object Strategy Version 3.0, Cisco Whitepaper, 1999. Retrieved November 26, 2007, from http://www.cisco.com/warp/public/779/ibs/solutions/learning/whitepapers/el_cisco_rio.pdf

[Barta and Gil, 1996] Barta, D., and Gil, J. A System for Document Reuse. In Beeri, C., Winokur, M. and Levi, S., editors, *Proceedings of the 7th Israeli Conference on Computer systems and Software Engineering*, pages 83-94, Washington, DC, USA: IEEE Computer Society Press, 1996.

[Bechhofer et al., 2004] Bechhofer, S., van Harmelen, F., Hendler, J. A., Horrocks, I., McGuinness, D. L., Patel-Schneider, P.F., Stein, L. A. (Auth.), Dean, M., Schreiber, G. (Ed.). OWL Web Ontology Language Reference, World Wide Web Consortium, Recommendation REC-owl-ref-20040210, February 2004.

[Bekaert, 2006] Bekaert, J. *Standards-based interfaces for Harvesting and Obtaining assets from Digital Repositories.* PhD Thesis, Ghent University, April 25th 2006. PhD Advisors: Mil De Kooning and Herbert Van de Sompel

[Bloom et al., 1956] Bloom, B.S., Mesia, B.B. and Krathwohl, D. R. Taxonomy of Educational Objectives. The classification of educational goals: Handbook I, cognitive domain. New York, Longmans, Green, 1956.

[Boyle, 2003] Boyle, T. Design principles for authoring dynamic, reusable learning objects. *Australian Journal of Educational Technology*, 19(1):46-58, 2003. Retrieved November 26, 2007, from http://www.ascilite.org.au/ajet/ajet19/boyle.html

[Branting and Lester, 1996] Branting, L. and Lester, J. C. Justification Structures for Document Reuse. In Ian F. C. Smith, and Boi Faltings, editors, *Proceedings of the Third European Workshop on Case-Based Reasoning (EWCR-96)*, pages 76-90, London, UK: Springer-Verslag, 1996.

[Brin et al., 1995] Brin, S., Davis, J. and Garcia-Molina, H. Copy detection mechanisms for digital documents. In Carey, M. and Schneider, D., editors, *Proceedings of the 1995 ACM SIGMOD international conference on Management of data*, New York, NY, USA: ACM press, pages 398 - 409, 1995.

[Brooks et al., 2006] Brooks, J., Jesukiewicz, P. SCORM Reuse: Current Reality, Challenges, and Best Practices. In *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*, December 4 - December 7, 2006, Florida.

[Bucella et al., 2003] Buccella, A., Cechic, A., Brisaboa, N.R. An Ontology Approach to Data Integration. *Journal of Computer Science and Technology*, 3(2):62-68, 2003.

[Bulterman et al., 2005] Bulterman, D., Grassel, G., Jansen, J., Koivisto A., Layaïda, N. , Michel, T., Mullender, S. and Zucker, D. (editors) Synchronized Multimedia Integration Language (SMIL 2.1), W3C Recommendation, 13 December 2005.

[Burnett et al., 2003] Ian Burnett, Rik Van de Walle, Keith Hill, Jan Bormans, Fernando Pereira. MPEG-21: Goals and Achievements. *IEEE MultiMedia* 10(4):60-70, October/December, 2003.

[Cafolla, 2002] Cafolla, R. Project Merlot: Bringing Peer Review to Web-based Educational Resources. In C. Crawford et al., editors, *Proceedings of Society for Information Technology and Teacher Education International Conference*, pages 614-618, Chesapeake, VA: AACE, 2002.

[Cardinaels et al., 2005] Cardinaels, K., Meire, M., and Duval, E. Automating Metadata Generation: the Simple Indexing Interface. In Ellis, A. and Hagina, T., editors, *Proceedings of the 14th International World Wide Web Conference*, pages 548-556, New York, NY, USA: ACM press, 2005.

[Cardinaels, 2007] Cardinaels, K. *A dynamic learning object life and its implications for automatic metadata generation.* Ph.D. Thesis, Department of Computer Science, K.U.Leuven, Leuven, Belgium, June, 2007, xvi + 163pages

[Carter and Lippert, 2006] Eric Carter and Eric Lippert. Visual Studio Tools for Office: Using Visual Basic 2005 with Excel, Word, Outlook, and InfoPath. Addison Wesley Professional, April 26, 2006, ISBN: 0-321-41175-7

[Ceusters and Bouquet, 2000] Ceusters, W., Bouquet, L. Language Engineering and Information Mapping in Pharmaceutical Medicine. *Journal of the Belgian Medical Informatics Association*, 7(1):26-34, 2000.

[Chitwood et al., 2000] Chitwood, K., May, C., Bunnow, D. and Langan, T. Battle stories from the field: Wisconsin online resource center learning objects project. In Wiley, D. A., editor, The Instructional Use of Learning Objects, 2000.

[Clark, 1989] Clark, R. Developing Technical Training: A Structured Approach for the Development of Classroom and Computer-Based Instructional Materials. Performance Technology Press, 1989.

[Collier et al., 2007] Collier, C., Muramatsu, B., Robson, R. The Reusable Learning Project. Retrieved from http://www.reusablelearning.org on May 21, 2007.

[Conkey, 2006] Conkey, C., Smith, B., DuBuc C., Smith, P.A. Integrating Simulations into Sharable Content Object Reference Model Learning Environments. In *Proceedings of the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC)*, December 4 - December 7, 2006, Florida.

[Cox, 2004] Cox, Christopher. From Cameras to Camtasia: Streaming Media Without the Stress. *Internet Reference Services Quarterly*, 9(3/4): 193-200, The Haworth Information Press, 2004.

[Cronbach, 1951] Cronbach, L. J. Coefficient alpha and the internal structure of tests. *Psychometrika*, 16(3):297-334, 1951.

[Cundiff, 2004] Cundiff, Morgan, V. An introduction to the Metadata Encoding and Transmission standard (METS). *Library Hi Tech*, 22(1):52-64, 2004.

[Dahn et al., 2001] Dahn, I., Armbruster, M., Furbach, U., and Schwabe, G. Slicing Books - The Authors' Perspective. In Bromme, R. and Stahl, E., editors, *Writing Hypertext and Learning: Conceptual and Empirical Approaches.* New York, Oxford: Pergamon Press, 2001.

[De Carvalho et al., 2004] De Carvalho, Joaquim Ramos, Maria Ines Cordeiro, Antonio Lopes, Miguel Vieira. Meta-information about MARC: an XML framework for validation, explanation and help systems. *Library Hi Tech* 22(2):131-137, 2004.

[Devanbu et al., 1996] Devanbu, P., Karstu, S., Melo, W. and Thomas, W. Analytical and Empirical Evaluation of Software Reuse Metrics. In Maibaum, T. and Zelkowitz, M., editors, *Proceedings of the 18th International Conference on Software Engineering*, pages 189 - 199, Washington, DC, USA: IEEE Computer Society Press, 1996.

[Dick and Cary, 1990] Dick, W., and Cary, L. The Systematic Design of Instruction. Third Edition, Harper Collins, 1990.

[Downes, 2001] Downes, Stephen. Learning Objects: resources for distance education worldwide. *International Review of Research in Open and Distance Learning*, 2(1), 2001. http://www.irrodl.org/index.php/irrodl/article/viewFile/32/81

[Downes, 2004] Downes, S. The Learning Marketplace: Meaning, Metadata and Content Syndication in the Learning Object Economy, 2004. Retrieved November 2, 2007, from http://www.downes.ca/files/book3.htm

[Durusau et al., 2007] Durusau, P., Brauer, M. and Oppermann, L. (editors) Open Document Format for Office Applications (OpenDocument) v1.1, February 2007.

[Duval et al., 2001] Duval, E., Forte, E., Cardinaels, K., Verhoeven, B., Van Durm, R., Hendrikx, K., Wentland-Forte, M., Ebel, N., Macowicz, M., Warkentyne, K. and Haenni, F. The ARIADNE Knowledge Pool System. *Communications of the ACM*, 44(5):72-78, 2001.

[Duval and Hodgins, 2003] Duval, E. and Hodgins, W. A LOM research agenda. In Hencsey, G. and White, B. and Chen, Y. and Kovacs, L. and Lawrence, S., editors, *Proceedings of the 12th International World Wide Web Conference*, pages 659-667, New York, NY, USA: ACM press, 2003. http://www2003.org/cdrom/papers/alternate/P659/p659-duval.html.html

[Fernandes et al., 2005] Fernandes, E., Madhour, H., Miniaoui, S., Forte, M.W. Phoenix Tool: A Support to Semantic Learning Model. In Proceedins of the Workshop on Applications of Semantic Web Technologies for e-Learning (SW-EL@ICALT'05), July 5-8, 2005, Kaohsiung, Taiwan

[Foo et al., 2007] Foo, J. J., Zobel, J., Sinha, R., and Tahaghoghi, S. Detection of Near-duplicate Images For Web Search. In N. Sebe and M. Worring, editors, *Proceedings of the 6th ACM International Conference on Image and Video*

Retrieval (CIVR 2007), pages 557-564, New York, NY, USA: ACM press, 2007.

[Freeman, 2005] Bret Freeman. Quantitative Goals for Content Management Implementations. *CIDM Information Management News*, October 2005.

[Friesen and McGreal, 2002] Norm Friesen, and Rory McGreal. International E-learning Specifications. *The International Review of Research in Open and Distance Learning*, 3(2), 2002.

[Gagne, 1985] Gagne, R. The Conditions of Learning and Theory of Instruction. New York: CBS College Publishing, 1985.

[Gartner, 2003] Gartner, R. MODS: Metadata Object description Schema. *Libraries and the Academy*, 3(1):137-150, 2003.

[Gospodnetic and Hatcher, 2005] Otis Gospodnetic and Erik Hatcher. Lucene in Action. *Manning Publications Co.*, 2005.

[Greenstein, 2002] Greenstein, Daniel, and Thorin, Suzanne E. The Digital Library: A Biography. Washington, DC: Council on Library and Information Resources, Library of Congress, 2002. Retrieved November 30, 2007, from http://www.clir.org/pubs/reports/pub109/pub109.pdf

[Halim et al., 2007] Abdul Halim and Chaudhry, Abdus Sattar. Learning Objects Application Profile for Granularity and Reusability. In Sutton, Stuart A., Chaudhry, Abdus Sattar, and Khoo, Christopher, editors, *Proceedings of the International Conference on Dublin Core and Metadata Applications*, pages 116-122, Singapore, National Library Board, 27-31 August 2007.

[Hatala et al., 2004] M. Hatala, G. Richards, T. Eap, and J. Willms. The interoperability of learning object repositories and services: Standards, implementations and lessons learned. In Stuart I. Feldman, Mike Uretsky, Marc Najork and Craig E. Wills, editors, *Proceedings of the 13th International World Wide Web Conference*, pages 19-27, New York, USA, May 2004. http://citeseer.ist.psu.edu/hatala04interoperability.html

[HE and Ounis, 2003] HE, B. and Ounis, I. (2003). A study of parameter tuning for term frequency normalization. In Ophir Frieder, Joachim Hammer, Sajda Quershi, and Len Seligma, editors, *Proceedings of the Twelfth international Conference on information and Knowledge Management* (New Orleans, LA, USA, November 03 - 08, 2003), pages 10-16, New York, NY: ACM Press, 2003.

[Hoad and Zobel, 2003] Hoad, T. and Zobel, J. (2003). Methods for identifying versioned and plagiarized documents. In *Journal of the American Society or Information Science and Technology*, 54(3), 2003.

[Horn, 1993] Horn, R. Structured Writing at Twenty-five. *Performance and Instruction*, (32):11-17, 1993.

[Horn, 1998] Horn, R. E. Structured writing as a paradigm. In Alexander Romiszowski and Charles Dills, editors, *Instructional Development: State of the Art*. Englewood Cliffs, N.J., 1998.

[IEEE, 2002] 1484.12.1 IEEE LTSC Draft Standard for Learning Object Metadata, 2002. Retrieved November 17, 2007, from http://ltsc.ieee.org/wg12/files/LOM_1484_12_1_v1_Final_Draft.pdf.

[IMS CP, 2004] IMS Content Packaging. Information Model, Best Practice and Implementation Guide, XML Binding Schemas, Version 1.1.4 Final Specification, IMS Global Consortium Inc. Retrieved November 26, 2007, from http://www.imsglobal.org/content/packaging

[IMS LD, 2003] IMS Learning Design Best Practice and Implementation Guide, Version 1.0 Final Specification, IMS Global Learning Consortium, Inc., 20 January 2003. Retrieved November 20, 2007, from http://www.imsglobal.org/learningdesign/

[ISO/IEC 21000-2:2005] ISO/IEC 21000-2:2005. Information technology - Multimedia framework (MPEG-21) Part 2: Digital Item Declaration. Retrieved November 26, 2007, from http://standards.iso.org/ittf/PubliclyAvailableStandards/c041112_ISO_IEC_21000-2_2005(E).zip

[ISO/IEC 9126 -2, 1998] ISO/IEC 9126 -2 1998 Software quality characteristics and metrics - External metrics.

[Jovanovic et al., 2005] Jovanovic, J., Gasevic, D., Verbert, K., and Duval E. Ontology of learning object content structure. In Looi, C.-K. and McCalla, G. and Bredeweg, B. and Breuker, J, editors, *Proceedings of the 12th International Conference on Artificial Intelligence in Education*, pages 322-329, Amsterdam: IOS press, 2005.

[Jovanovic, 2006] Jovanovic, J., Gasevic, D., and Devedzic, V.. Ontology-based Automatic Annotation of Learning Content. *International Journal on Semantic Web and Information Systems* 2(2):91-119, 2006. http://fon.fon.bg.ac.yu/ devedzic/IJSWIS2006.pdf.

[Khor and Leonard, 2005] Siew Moi Khor, and Art Leonard. Installing and Using the Office 2003 Primary Interop Assemblies. Microsoft Office 2003 Technical Articles. Retrieved July 30, 2007, from http://msdn2.microsoft.com/en-us/library/aa159923(office.11).aspx

[Kienreich et al., 2005] Kienreich, W., Sabol, V., Ley, T., Lindstaedt, S., Koronakis, P. and Droschl, G. MagIR: Distributed Creation, Administration and Reutilization of Multimedia Presentation Content. In Althoff, K.-D., Dengel, A., Bergmann, R., Nick M. and Roth-Berghofer, T., editors, *Proceedings of WM 2005: Professional Knowledge Management - Experiences and Visions, Contributions to the 3rd Conference Professional Knowledge Management - Experiences and Visions*, pages 481-486, Kaiserslautern: DFKI, 2005.

[Klerkx et al., 2004] J. Klerkx, E. Duval, and M. Meire. Using information visualization for accessing learning object repositories. In Banissi, E., Börner, K., Chen, C., Dastbaz, M., Clapworthy, G., Faiola, A., Izquierdo, E., Maple, C., Roberts, J., Moore, C., Ursyn, A. and Zhang, J., editors, *Proceedings of Information Visualization (IV04)*, pages 465-470, IEEE/Computer Society Press, July 2004.

[L'Allier, 2003] L'Allier, J.J. Frame of Reference: NETg's Map to the Products, Their Structure and Core Beliefs. NetG Whitepaper. Cited in Polsani, Pithamber R. The Use and Abuse of Reusable Learning Objects. *Journal of Digital Information*, 3(4), 2003.

[Lecerf and Chidlovskii, 2006] Lecerf, L. and Chidlovskii, B. Document annotation by active learning techniques. In Dick C. A. Bulterman, and David F. Brailsford, editors, *Proceedings of the 2006 ACM Symposium on Document Engineering*, pages 125-127, New York, NY, USA: ACM press, 2006. http://www.xrce.xerox.com/Publications/Attachments/2006-022/al-shortpaper-final2-(2).pdf

[Lee and Lim, 2005] Chien-Sing Lee and Wei-Ching Lim. Ontology-based 3-d visualisation of composited concepts. In P. Kommers and G. Richards, editors, *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2005*, pages 3953-3960, Montreal, Canada, June 2005. AACE.

[Lenski and Wette-Roch, 2001] Lenski, W. and Wette-Roch, E. The TRIAL-SOLUTION Approach to Document Re-use Principles and Realization. In *Proceedings of Electronic Media in Mathematics*, 2001.

[Liu et al., 2003] Liu, B., Chin, C. W., and Ng, H. T. Mining topic-specific concepts and definitions on the web. In Hencsey, G. and White, B. and Chen, Y. and Kovacs, L. and Lawrence, S., editors, *Proceedings of the 12th International World Wide Web Conference*, pages 251-260, ACM Press, New York, NY, 2003.

[Looms and Christensen, 2002] Looms, T. and Christensen, C. Emerging and Enabling Technologies for the Design of Learning Object Repositories Report. Advanced Distributed Learning, November 26, 2002.

[Lorie, 2001] Lorie, R. A. Long term preservation of digital information. In E.A. Fox and C.L. Borgman, editors, *JCDL 01: Proceedings of the 1st ACM/IEEE-CS joint conference on Digital libraries*, pages 346-352, New York, NY, USA. ACM Press, 2001.

[Löser et al., 2002] Löser, A., Grune, C., Hoffmann, M. In Michael E. Auer and Ursula Auer, editors, *Proceedings of the International Workshop of Interactive Computer Aided Learning (ICL)*, Villach, Austria, 2002.

[Knight and Burn, 2005] Knight, S.A. & Burn, J.M. Developing a Framework for Assessing Information Quality on the World Wide Web. *Informing Science Journal*, 8:159-172, 2005.

[Mager, 1984] Mager, R.F. Preparing instructional objectives. (2nd ed.). Belmont, CA: David S. Lake, 1984.

[Manku et al., 2007] Manku, G. S., Jain, A., and Das Sarma, A. Detecting near-duplicates for web crawling. In Carey L. Williamson, Mary Ellen Zurko, Peter F. Patel-Schneider, and Prashant J. Shenoy, editors, *Proceedings of the 16th international Conference on World Wide Web*, pages 141-150, New York, NY, USA: ACM Press, 2007.

[Massey, 1951] Massey, F.J. The Kolmogorov-Smirnov Test for Goodness of Fit. *Journal of the American Statistical Association*, 46(253):68-78, 1951.

[McDonough 2007] McDonough, J. Text Technical Metadata Version 2.2. Retrieved 15 October, 2007, from http://dlib.nyu.edu/METS/textmd.xsd

[Meire et al., 2007] Meire, M., Ochoa, X. and Duval, E. SAmgI: Automatic Metadata Generation v2.0. In C. Montgomerie and J. Seale, editors, *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2007*, pages 1195-1204, Chesapeake, VA: AACE, 2007.

[Melo et al., 1995] Melo, W.L., Briand, L.C., and Basili, V.R. Measuring the Impact of Reuse on Quality and Productivity on Object-Oriented Systems. Technical Report CS-TR-3395, University of Maryland, 1995, 16 pages.

[Merrill, 1983] Merrill, M.D. Component Display Theory. In Reigeluth, CM, editor, Instructional Design Theories and Models, Hillsdale, NJ, 1983.

[Milligan et al., 2005] Milligan, C.D., Beauvoir, P., and Sharples, P. The Reload Learning Design Tools. *Journal of Interactive Media in Education* (Advances in Learning Design. Special Issue, eds. Colin Tattersall, Rob Koper), July 2005. ISSN:1365-893X [http://jime.open.ac.uk/2005/07].

[Motelet, 2004] Motelet, O. Enabling the Reuse of Learning Material in the Classroom, PhD Thesis proposal, 2004.

[Muresan and Klavans, 2002] S. Muresan and J.K. Klavans. A Method for Automatically Building and Evaluating Dictionary Resources. In Manuel González Rodríguez and Carmen Paz Suárez Araujo, editors, *Proceedings of the Language Resources and Evaluation Conference*, ELRA - European Language Resources Association, pages 231-234, 2002.

[Najjar et al., 2005] Najjar, J., Klerkx, J., Vuorikari, R. and Duval, E. Finding Appropriate Learning Objects: An Empirical Evaluation. In Rauber, A., Christodoulakis, S. and Min Tjoa, A., editors, *Proceeding of the 9th European Conference on Research and Advanced Technology for Digital Libraries*, pages 323-335, Springer, 2005.

[Nejdl et al., 2002] Nejdl, W., Wolf, B., Qu, C., Decker, S., Sintek, M., Naeve, A., Nilsson, M., Palmér, M., and Risch, T. EDUTELLA: a P2P networking infrastructure based on RDF. In Lassner, D., De Roure, D. and Iyengar, A., editors, *Proceedings of the 11th international Conference on World Wide Web*, pages 604-615, ACM, New York, NY, 2002.

[Nielsen, 1989] Nielsen, J. Usability engineering at a discount. In Salvendy, G., and Smith, M.J., editors, *Designing and Using Human-Computer Interfaces and Knowledge Based Systems*, pages 394-401, Amsterdam: Elsevier Science Publishers, 1989.

[Nielsen, 2006] Nielsen, J. Quantitative Studies: How Many Users to Test? In Alertbox, June 26, 2006, Retrieved 30 July, 2007, from http://www.useit.com/alertbox/quantitative_testing.html

[Oblinger, 2005] Diana G. Oblinger. Learners, Learning, and Technology: The EDUCAUSE Learning Initiative. *EDUCAUSE Review*, 40(5):66-75, September-October 2005.

[Ochoa and Duval, 2007] Ochoa, X. and Duval, E. Relevance Ranking Metrics for Learning Objects. In Klamma, R., Duval, E. and Wolpers, M., editors, *Proceedings of the Second European Conference on Technology Enhanced Learning*, pages 262-276, London, UK: Spinger-Verslag, 2007.

[Ochoa and Duval, 2006] Ochoa, X. and Duval, E. Use of contextualized attention metadata for ranking and recommending learning objects. In Duval, E., Najjar, J. and Wolpers, M, editors, Proceedings of the 1st international workshop on Contextualized attention metadata, pages 9-16, New York, NY, USA: ACM press, 2006.

[Orzechowski et al., 2007] Orzechowski, T., Ernst, S. and Dziech, A. Profiled Search Methods for e-Learning Systems. In F. van Assche, editor, P*roceedings of the First International Workshop on Learning Object Discovery & Exchange*, September 18, 2007.

[Pazandak and Srivastava, 1997] Pazandak, P., Srivastava, J. Evaluating Object DBMSs for Multimedia. *IEEE MultiMedia*, 4(3):34-49, 1997.

[Prause et al., 2007] Christian Prause, Stefaan Ternier, Tim de Jong, Stefan Apelt, Marius Scholten, Martin Wolpers, Markus Eisenhauer, Bram Vandeputte, Marcus Specht, and Erik Duval. Unifying Learning Object Repositories in MACE. In F. van Assche, editor, *Proceedings of the First International Workshop on Learning Object Discovery & Exchange*, September 18, 2007.

[RAMLET, 2005] The RAMLET project - Developing a reference model for resource aggregation for learning, education, and training, Institute of Electrical and Electronics Engineers, 11 October 2005. Retrieved November 22, 2007, from http://www.ieeeltsc.org/working-groups/wg11CMI/ramlet/Pub/RAMLET_project_description.pdf

[Rehak and Mason, 2003] Rehak, D. R., and Mason, R. Keeping the learning in learning objects. In Littlejohn, A., editor, *Reusing online resources: a sustainable approach to e-Learning*, pages 22-30, Kogan Page, London, 2003.

[Rey-López et al., 2006] Rey-López, M., Fernández-Vilas, A., Daz-Redondo, R., and Pazos-Arias, J. Providing SCORM with adaptivity. In Les Carr, David De Roure, Arun Iyengar, Carole A. Goble and Michael Dahlin, editors, *Proceedings of the 15th international Conference on World Wide Web*, pages 981-982, ACM Press, New York, 2006.

[Robson, 2004] Robson, R. Context and the Role of Standards in Increasing the Value of Learning Objects. Chapter in McGreal, R., editor, *Online Education Using Learning Objects*, London: Routledge/Falmer, 2004.

[Rockley, 2002] Rockley, A. Managing Enterprise Content: A Unified Content Strategy, Indianapolis: New Riders, 2002.

[Salton and Buckley, 1988] Salton, G. and Buckley, C. Term-weighting approaches in automatic text retrieval. *Information Processing & Management*, 24(5):513523, 2005.

[Sayre, 2005] Sayre, R. Atom: the standard in syndication. *Internet Computing, IEEE.* 9(4):71-78, 2005.

[Schluep, 2005] Schluep, S. Modularization and structured markup for web-based learning content in an academic environment. Aachen: Shaker Verlag, 2005.

[Schulmeister, 2003] Schulmeister, R. Lernplattformen für das virtuelle Lernen. Evaluation und Didaktik. München, Oldenbourg, 2003.

[SCORM, 2004] SCORM. Sharable Content Object Reference Model (SCORM) 2004 2nd Edition. Retrieved November 26, 2007, from http://www.adlnet.gov/scorm/.

[Shivakumar and Garcia-Molina, 1995] Garcia-Molina H. and Shivakumar N. The SCAM Approach To Copy Detection in Digital Libraries. D-lib Magazine, November, 1995.

[Shrout and Fleiss, 1979] Shrout, P. E., and Fleiss, J. L. Intraclass Correlations: Uses in Assessing Rater Reliability. *Psychological Bulletin*, 68(2):420-428, 1979.

[Singhal et al., 1996] Singhal, A., C. Buckley, and Mandar Mitra (1996). Pivoted Document Length Normalization. In y Hans-Peter Frei et al., editors, *Proceedings of the Nineteenth Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*, pages 21-29, New York: ACM Press, 1996.

[Slide Executive, 2007] Slide Executive. The PowerPoint Presentation Management Library. Retrieved 28 November, 2007, from http://www.slideexecutive.com/

[Sommerville 2000] Sommerville, I. Software engineering. 6th Ed. Addison-Wesley, 2000.

[Sosteric and Hesemeier, 2004] Sosteric, M., and Hesemeier, S. A first step towards a theory of learning objects. In R. McGreal, editor, *Online education using learning objects*. London:Routledge Falmer, 2004.

[Strijker, 2004] Strijker, A. Reuse of Learning Objects in Context: Technical and Human Aspects. PhD dissertation, Faculty of Behavioural Sciences, University of Twente, Enschede, Netherlands, 2006, ISBN 90-365-2090-9

[Su, 2006] Su, X., Gulla, J.A. An information retrieval approach to ontology mapping. *Data and knowledge engineering*, 58(1):47-69, 2006.

[Süβ et al., 2000] Süβ, C., Kammerl, R., and Freitag, B. A Teachware Management Framework for Multiple Teaching Strategies. In Bourdeau, J., Heller, R., editors, *Proceedings of the 12th ED-MEDIA 2000 World Conference on Educational Multimedia, Hypermedia and Telecommunications*, pages 1101-1106, Chesapeake, VA: AACE, 2000.

[Tan, 2002] Tan, G. H. Getting Started with Learning Objects. Publication incorporated into SeLF (Singapore e-Learning Framework), 2002. http://ole.tp.edu.sg/courseware/teaching_guide/resources/article/gekhua/Getting%20Started%20with%20LO.pdf

[Ternier et al., 2003] Ternier, S. Neven, F. and Duval, E. Web services for Learning Object Repositories: a Case Study - the ARIADNE Knowledge Pool System. In King, I. and Maray, T., editors, *Proceedings of Twelfth International World Wide Web Conference*, pages 203-204, New York, NY, USA: ACM Press, 2003.

[Ternier and Duval, 2006] Ternier, S. and Duval, E. Interoperability of Repositories: The Simple Query Interface in ARIADNE. *International Journal on E-Learning*, 5 (1):161-166. Chesapeake, VA: AACE, 2006.

[Ullrich, 2005] Ullrich, C. The Learning-Resource-Type is Dead, Long Live the Learning-Resource-Type! *Learning Objects and Learning Designs*, 1(1):7-15, 2005.

[Verbert and Duval, 2004] Verbert, K., and Duval, E. Towards a global architecture for learning objects: a comparative analysis of learning object content models. In Cantoni, L. and McLoughlin, C., editors, *Proceedings of the 16th ED-MEDIA 2004 World Conference on Educational Multimedia, Hypermedia and Telecommunications*, pages 202-209, Chesapeake, VA: AACE, 2004.

[Verbert et al., 2004a] K. Verbert, J. Klerkx, M. Meire, J. Najjar and E. Duval. Towards a global component architecture for learning objects: an ontology based approach. In Meersman, R., Tari, Z. and Corsaro, A., editors, *Proceeding of On the Move to Meaningful Internet Systems 2004: OTM 2004 Workshops*, pages 713-724, Lecture Notes in Computer Science, Springer, 2004.

[Verbert et al., 2005] K. Verbert, D. Gasevic, J. Jovanovic, and E. Duval. Ontology-based learning content repurposing. In Ellis, A. and Hagina, T., editors, *Proceedings of the 14th international conference on World Wide Web - Alternate Track Papers & Posters*, pages 1140-1141, New York, NY, USA: ACM Press, May 10-14, 2005.

[Verbert et al., 2005a] K. Verbert, J. Jovanovic, D. Gasevic, E. Duval and M. Meire. Towards a global component architecture for learning objects: a slide presentation framework. In Kommers, P. and Richards, G., editors, *Proceedings of the ED-MEDIA 2005 World Conference on Educational Multimedia, Hypermedia and Telecommunications* (June 27 - July 2, 2005, Montreal, Canada), pages 1429-1436, Chesapeake, VA: AACE, 2005.

[Verbert et al., 2005b] K. Verbert, J. Jovanovic, D. Gasevic, and E. Duval. Repurposing Learning Object Components. In Meersman, R., Tari, Z. and Corsaro, A., editors, *Proceedings of On the Move to Meaningful Internet Systems 2005: OTM Workshops*, pages 1169-1179, Lecture Notes in Computer Science, Springer, 2005.

[Verbert et al., 2006] Verbert, K., Jovanovic, J., Duval, E., Gasevic, D. and Meire, M. Ontology-Based Learning Content Repurposing: The ALOCoM Framework. *International Journal on E-Learning,* 5 (1):67-74, Chesapeake, VA: AACE, 2006.

[Verbert and Duval, 2007] K. Verbert and E. Duval. Evaluating the ALOCOM Approach for Scalable Content Repurposing. In Klamma, R., Duval, E. and Wolpers, M., editors, *Proceedings of the Second European Conference on Technology Enhanced Learning*, pages 364-377, Lecture Notes in Computer Science, London, UK: Springer-Verslag, 2007.

[Verbert et al., 2008] Verbert, K., Ochoa, X. and Duval, E. The ALOCOM Framework: Towards Scalable Content Reuse. Accepted for publication in the *Journal of Digital Information.*

[Verbert and Duval, 2008] Verbert, K. and Duval, E. ALOCOM: A Generic Content Model for Learning Objects. Accepted for publication in the *International Journal on Digital Libraries (Special Issue on DL and Education).*

[Vercoustre and McLean, 2005] Vercoustre, A., and McLean, A. Reusing Educational Material for Teaching and Learning: Current Approaches and Directions. *International Journal on E-Learning*, 4(1):57-68, 2005.

[Wagner, 2002] Wagner, E. D. Steps to Creating a Content Strategy for Your Organization. *The e-Learning Developers' Journal*, 2002.

[Weibel et al., 1998] S. Weibel, J. Kunze, C. Lagoze, and M. Wolf. RFC 2413 - Dublin Core Metadata for Resource Discovery. Technical report, Internet Engineering Task Force (IETF), 1998.

[Weibel and Koch, 2000] Stuart L. Weibel and Traugott Koch. The Dublin Core Metadata Initiative Mission, Current Activities, and Future Directions. *D-Lib Magazine*, 6(12), December 2000.

[Wiley, 2002] Wiley, D. A. Connecting Learning Objects to Instructional Design Theory: A Definition, a Metaphor, and a Taxonomy. The Instructional Use of Learning Objects. Bloomington, 2002.

[Wiley, 2007] Wiley, D. A. The Learning Objects Literature. http://opencontent.org/blog/wp-content/uploads/2007/07/wiley-lo-review-final.pdf Last accessed: 10 September, 2007

[Wolpers et al., 2007] Wolpers, M., Najjar, J., Verbert, K., and Duval, E. Tracking Actual Usage: the Attention Metadata Approach. *Educational Technology & Society*, 10(3):106-121, 2007.

[Yan et al., 2004] Yan, K., Sukthankar, R., and Huston, L. Efficient Near-duplicate Detection and Subimage Retrieval. In Schulzrinne, H., Dimitrova, N., Sasse, A., Moon, S.B., Lienhart, R., editors, *Proceedings of ACM International Conference on Multimedia*, pages 869-876, New York, NY, USA: ACM press, 2004

[Yang and Callan, 2006] Yang, H. and Callan, J. 2006. Near-duplicate detection by instance-level constrained clustering. In Efthimis N. Efthimiadis, Susan T. Dumais, David Hawking, and Kalervo Järvelin, editors, *Proceedings of the 29th Annual international ACM SIGIR Conference on Research and Development in information Retrieval* (Seattle, Washington, USA, August 06 - 11, 2006), pages 421-428, New York, NY: ACM press, 2006.

[Yee and Beaubien, 2004] Raymond Yee and Rick Beaubien. A preliminary crosswalk from METS to IMS content packaging. *Library Hi Tech*, 22(1):69-81, 2004.

[Zimmermann et al., 2007] Birgit Zimmermann, Marek Meyer, Christoph Rensing, and Ralf Steinmetz. Improving Retrieval of Reusable Learning Resources by Estimating Adaptation Effort. In F. van Assche, editor, *Proceedings of the First International Workshop on Learning Object Discovery & Exchange*, September 18, 2007.

Appendix A

Content Model Mappings

	ALOCOM	Cisco	dLCMS	SCORM	NCOM	Learnativity
1	LO Component	Content Item		Asset	Asset	
1.1	Content Fragment		Asset			Raw Media
1.2	Content Object		Content Element			Information Object
1.2.1	Definition	Definition	Definition			
1.2.2	Literature		Literature			
1.2.3	Explanation					Explanation
1.2.3.1	Remark	Instructor Note				
1.2.3.2	Overview	Overview	Advanced organizer			Overview
1.2.3.3	Introduction	Introduction				
1.2.3.4	Summary	Summary	Summary			Summary
1.2.4	Example	Example	Example			
1.2.5	Paragraph					
1.2.6	Additional Resources	Additional Resources				
1.2.7	Interactivity					
1.2.7.1	Simulation		Simulation			
1.2.7.2	Self-assessment		Self-assessment			
1.2.7.3	Questionnaire		Question-naire			
1.2.7.4	Exercise					Exercise
1.2.7.5	Open Ques-tion					
1.2.8	Review	Review				
1.2.9	Experiment		Experiment			
1.2.10	Excursion		Excursion			
1.2.11	Demonstration	Demonstration				

	ALOCOM	Cisco	dLCMS	SCORM	NCOM	Learnativity
1.2.12	Guideline	Guideline				
1.2.13	Illustration	Topology illustration				Illustration
1.2.14	Objective	Objective	Learning Objective			
1.2.15	Outline	Outline				
1.2.16	Importance	Importance				
1.2.17	Problem Statement		Problem Statement			
1.2.18	Principle Statement	Principle Statement				
1.2.19	Motivation					
1.2.20	Next Steps	Next Steps				
1.2.21	Scenario	Job-based scenario				
1.2.22	Glossary		Glossary			
1.2.23	Reference					
1.2.24	Prerequisite	Prerequisite				
1.2.25	Analogy	Analogy				
1.2.26	Table	Table; Staged Table; Decision Table; Combined Table; Procedure Table;				
1.2.27	Non-example	Non-example				
2	Learning Object		Learning unit			
2.1	Single-Objective LO	RIO		SCO	ELO	Application Object
2.1.1	Concept	Concept				
2.1.2	Principle	Principle				
2.1.3	Process	Process				
2.1.4	Procedure	Procedure				
2.1.5	Fact	Fact				
2.2	Larger-Objective LO	RLO		Activity	TLO	Aggregate Assembly
2.2.1	Lesson	Lesson				Lesson
2.2.2	Chapter					Chapter
2.3	LO Aggregation			Content Aggregation	LO Aggregation	Collection
2.3.1	Module	Module				
2.3.2	Unit	Unit				
2.3.3	Course	Course				Course
2.3.4	Story					Story
2.3.5	Curriculum	Curriculum				

	ALOCOM	New Economy	SLM	NETg	PaKMas
1	LO Component				
1.1	Content Fragment		Asset		Media Object
1.2	Content Object	Information Object	Pedagogical Information		Content Module
1.2.1	Definition				
1.2.2	Literature				
1.2.3	Explanation				
1.2.3.1	Remark				Remark
1.2.3.2	Overview	Basic knowledge			
1.2.3.3	Introduction				
1.2.3.4	Summary				
1.2.4	Example	Example			Example
1.2.5	Paragraph				Paragraph
1.2.6	Additional Resources	Further Material			
1.2.7	Interactivity				
1.2.7.1	Simulation	Virtual laboratory			
1.2.7.2	Self-assessment				
1.2.7.3	Questionnaire				
1.2.7.4	Exercise				Exercise
1.2.7.5	Open Question	Open Question			
1.2.8	Review				
1.2.9	Experiment				
1.2.10	Excursion				
1.2.11	Demonstration				
1.2.12	Guideline				
1.2.13	Illustration				Illustration
1.2.14	Objective				
1.2.15	Outline				
1.2.16	Importance				
1.2.17	Problem Statement	Problem			
1.2.18	Principle Statement				
1.2.19	Motivation	Motivation			Motivation
1.2.20	Next Steps				
1.2.21	Scenario				
1.2.22	Glossary				
1.2.23	Reference	Reference			
1.2.24	Prerequisites				
1.2.25	Analogy				
1.2.26	Table				
1.2.27	Non-example				

	ALOCOM	New Economy	SLM	NETg	PaKMas
2	Learning Object				Structuring Module
2.1	Single-Objective LO	Learning Component	Pedagogical Entity	Topic	
2.1.1	Concept				
2.1.2	Principle				
2.1.3	Process				
2.1.4	Procedure				
2.1.5	Fact				
2.2	Larger-Objective LO	Learning Module	Pedagogical Context	Lesson	
2.2.1	Lesson			Lesson	
2.2.2	Chapter				
2.3	LO Aggregation		Pedagogical Document		
2.3.1	Module				
2.3.2	Unit	Learning Unit		Unit	
2.3.3	Course	Course		Course	
2.3.4	Story				
2.3.5	Curriculum	Curriculum	Pedagogical Schema		

Appendix B

RAMLET Definitions: Terms, abbreviations and acronyms

aggregation format

A documented method of aggregating digital resources into a complex object that can be exchanged among systems. An aggregation format may be defined by a formal specification or standard, but may also be informal. The defining characteristic is that an aggregation format specifies how to combine digital resources into a structured whole, without prescribing the kinds of digital resources, their internal structures, or their intended uses.

data attribute

A characteristic of a unit of data. In RAMLET, a data attribute corresponds to an attribute in a typical XML document.

class

A category of items that share one or more common properties. These properties need not be explicitly formulated in logical terms, but can be described in a text called a scope note. A class cannot be defined by enumerating its instances, because it is generally beyond our capabilities to know all instances of a class in the world and, indeed, that the future can bring new instances into being at any time (open world). See also: instance, property, open world, scope note.

complement

For a given class A, the set of all instances of its superclass, B, that are not instances of class A. In terms of set theory, the complement of a class is the extension of the superclass minus the extension of the class. Compatible extensions of this standard need not to declare any class as the complement of one or more other classes. To do so would violate the goal of describing an open world. For example, for all possible cases of human gender, "male" need not to be declared as the complement of "female" or vice versa. See also: open world.

disjoint

Having no common instances in any possible world. A set of classes that are disjoint cannot have any properties in common.

digital resource

Any resource that can be expressed in an electronic format, such as binary formats, XML, plain text, any number of encodings (e.g, base64), media-specific formats (e.g., JPEG and MP3), and compressed archives (e.g., zip files). See also: aggregation format.

domain

A constraint on a property that limits the instances to which the property can be applied. Instances of a property are applicable to instances of its domain. For example, if property A has only the classes X and Y as a domain, then only instances of classes X and Y classes can have property A. See also: class, instance, property, range.

extension

The set of all real-life instances belonging to a class that fulfills the criteria of the class's intension. An extension is an open set in the sense that it is generally impossible to know all instances of a class. In an open world, new instances of a class may be created at any time. See also: class, intension, instance, open world.

data element

A uniquely named and defined component of the data model of an aggregation format into which data items (actual values) can be placed. See also: aggregation format.

component

Any data attribute or data element as described by the data model of an aggregation format. See also: data attribute, data element.

instance

An instantiation of a class. An instance of a class has properties that meet the criteria of the intension of the class. The number of instances of a class declared in an information system is usually less than the total number of instances in the real world. For example, although an individual is an instance of "person", the individual may not be mentioned in all information systems describing "persons". See also: class, property.

intension

The intended meaning of a class or property. The intension consists of the common characteristics shared by all instances of the class or property. The intension need not to be explicitly formulated as properties in the case of a class or as the domain and range in the case of a property. Instead, the intension can simply be described in a a scope note that refers to a conceptualization shared by domain experts. See also: class, property, scope note.

multiple inheritance

The inheritance of properties by a class from more than one immediate superclass. If multiple inheritance is used, the resulting class hierarchy is a directed graph and not a tree structure. If multiple inheritance in a class hierachy is represented as an indented list, then some classes will inevitably be repeated at different positions in the indented list. For example, "person" could be a member of both the classes "critic" and "author", and, therefore, would be repeated at different positions in the indented list. See also: class, property, superclass.

open world

An assumption that an ontology and its instances are incomplete with regard to the world it attempts to describe. As a consequence, the open-world assumption states that everything that is not known is undefined. By contrast, a closed world assumption implies that everything that is not known is false.

property

A defining characteristic that defines a relationship of a specific kind between two classes. A property has exactly one domain and one range. Which class is selected as the domain and which as the range is arbitrary. In other words, a property can be interpreted in both directions with two distinct, but related interpretations. Property names are designed to be semantically meaningful and grammatically correct when read from domain to range. The inverse property name is designed to be semantically meaningful and grammatically correct when read from range to domain. Properties can also be specialized in the same manner as classes, resulting in parent-child relationships between superproperties and their subproperties. Like a class, a property is characterized by an intension, which is conveyed by a scope note. See also: class, domain, intension, range, scope, subproperty, superproperty.

range

The set of instances to which a property can be applied. A property can link only to instances of the class that serves as its range. See also: class, domain, instance, property.

scope note

A textual description of the intension of a class or property shared by domain experts. Scope notes are not formal constructs, but are provided to help explain the intended meaning and application of classes and properties. See also: class, intension, property.

strict inheritance

properties inheritance that allows no exceptions

subclass

specialization of another class, i.e. the superclass

subproperty

specialization of another property, i.e. the superproperty

superclass

generalization of one or more other classes, i.e. the subclasses

superproperty

generalization of one or more other properties, i.e. the subproperties

Publications

1. Verbert, K., and Duval, E. Towards a global architecture for learning objects: a comparative analysis of learning object content models. In Cantoni, L. and McLoughlin, C., editors, *Proceedings of the 16th ED-MEDIA 2004 World Conference on Educational Multimedia, Hypermedia and Telecommunications*, pages 202-209, Chesapeake, VA: AACE, 2004.

2. Verbert, K., Klerkx, J., Meire, M., Najjar, J. and Duval, E. Towards a global component architecture for learning objects: an ontology based approach. In Meersman, R., Tari, Z. and Corsaro, A., editors, *Proceeding of On the Move to Meaningful Internet Systems 2004: OTM 2004 Workshops*, pages 713-724, Lecture Notes in Computer Science, vol. 3292, Springer, 2004.

3. Najjar, J., Klerkx, J., Ternier, S., Verbert, K., Meire, M. and Duval, E. Usability evaluation of learning object indexation: the ARIADNE experience. In Remenyi, D., editor, *Proceedings of ECEL 2004 European Conference on e-Learning*, pages 281-290, 2004.

4. Verbert, K., Gasevic D., Jovanovic, J., and Duval, E. Ontology-based learning content repurposing. In Ellis, A. and Hagina, T., editors, *Proceedings of the 14th international conference on World Wide Web - Alternate Track Papers & Posters*, pages 1140-1141, New York, USA: ACM Press, May 10-14, 2005.

5. Verbert, K., Jovanovic, J., Gasevic, D., Duval, E. and Meire, M. Towards a global component architecture for learning objects: a slide presentation framework. In Kommers, P. and Richards, G., editors, *Proceedings of the ED-MEDIA 2005 World Conference on Educational Multimedia, Hypermedia and Telecommunications* (June 27 - July 2, 2005, Montreal, Canada), pages 1429-1436, Chesapeake, VA: AACE, 2005.

6. Klerkx, J., Meire, M., Ternier, S., Verbert, K., and Duval, E. Information Visualisation: Towards an Extensible Framework for Accessing Learning Object Repositories. In Kommers, P. and Richards, G. editors, *Proceedings of*

the ED-MEDIA 2005 World Conference on Educational Multimedia, Hypermedia and Telecommunications, (June 27 - July 2, 2005, Montreal, Canada), pages 4281-4287, Chesapeake, VA: AACE, 2005.

7. Jovanovic, J., Gasevic, D., Verbert, K., and Duval E. Ontology of learning object content structure. In Looi, C.-K. and McCalla, G. and Bredeweg, B. and Breuker, J., editors, *Proceedings of the 12th International Conference on Artificial Intelligence in Education*, pages 322-329, Amsterdam: IOS press, 2005.

8. Verbert, K., Jovanovic, J., Gasevic, D. and Duval, E. Repurposing Learning Object Components. In Meersman, R., Tari, Z. and Corsaro, A., editors, *Proceedings of On the Move to Meaningful Internet Systems 2005: OTM Workshops*, pages 1169-1179, Lecture Notes in Computer Science, vol. 3762, Springer, 2005.

9. Verbert, K., Jovanovic, J., Duval, E., Gasevic, D. and Meire, M. Ontology-Based Learning Content Repurposing: The ALOCoM Framework. *International Journal on E-Learning,* 5 (1):67-74, Chesapeake, VA: AACE, 2006.

10. Klerkx, J., Verbert, K. and Duval, E. Visualizing Reuse: More than Meets the Eye. In Klaus Tochtermann and Hermann Maurer, editors, *Proceedings of the 6th International Conference on Knowledge Management,* 6-8 September 2006, Graz, Austria.

11. Wolpers, M., Najjar, J., Verbert, K., and Duval, E. Tracking Actual Usage: the Attention Metadata Approach. *Educational Technology & Society*, 10(3):106-121, 2007.

12. Verbert, K. and Duval, E. Evaluating the ALOCOM Approach for Scalable Content Repurposing. In Klamma, R., Duval, E. and Wolpers, M., editors, *Proceedings of the Second European Conference on Technology Enhanced Learning*, pages 364-377, Lecture Notes in Computer Science, vol. 4753, London, UK: Springer-Verslag, 2007.

13. Duval, E., Ternier, S., Wolpers, M., Najjar, J., Vandeputte, B., Verbert, K., Klerkx, J., Meire, M., and Ochoa, X. Open Metadata for Open Educational Resources in an Open Infrastructure. In McAndrew, P. and Watts, J., editors, *Proceedings of the OpenLearn2007 Conference*, pages 36-38, 2007.

14. Verbert, K., Ochoa, X. and Duval, E. The ALOCOM Framework: Towards Scalable Content Reuse. Accepted for publication in the *Journal of Digital Information.*

15. Verbert, K. and Duval, E. ALOCOM: A Generic Content Model for Learning Objects. Accepted for publication in the *International Journal on Digital Libraries (Special Issue on DL and Education).*