國立交通大學

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以知識內涵為核心之數位博物館建構模式

Framework of Knowledge-based Digital Museum

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以知識內涵為核心之數位博物館建構模式

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摘要

近年來許多國內外博物館紛紛投入發展數位典藏計畫，運用數位科技對人類珍貴的文化遺產及大自然寶藏作更有效地保存及維護，這些數位典藏計畫是博物館發展數位博物館的前導工程，數位博物館不僅是以大量數位典藏內容為基礎，應用各類資訊及通訊技術，發展創新性應用與服務，廣義上更是新世代博物館運用尖端數位科技與資訊科技，整合博物館中生生不息的數位知識內容及眾多知識工作者的無限創造力，藉以擴展及帶動博物館整體經營服務視野的具體概念與做法。

然而無論是國內外數位博物館計畫，在各專業人員、領域、部門及應用系統間缺乏知識整合建構、加值及傳播的整體架構，大都以個別主題或應用為主及分散建構模式發展，因缺乏統整式建構環境及一致且多元之知識表達與組織的方法及工具，而產生在活動後大量知識流失及個別發展造成之桶倉式內容陷阱問題，導致彼此間內容、服務、技術資源及使用者應用模式均無法整合、分享與再利用。這些問題的產生，主要關鍵在於缺乏一套有效率且實際能解決博物館對內對外全面性且長期經營的知識管理方法，涵括整合知識建構與管理、再利用與傳播，以及分享與擴展等過程，發展兼具知識建構、管理、加值、傳播及行銷整體面向之知識管理方法與架構。

本論文的目的在於提出一個以知識內容為核心之數位博物館建構模式，以同時解決博物館所產生之桶倉式內容陷阱及導入知識管理過程中所產生的相關問題。此建構模式

不僅提供上述問題的解決方法，同時也提供博物館運用長期累積之大量數位知識內容，發展虛實合一之營運模式，開創以知識經濟為導向之無限機會與競爭力。

此建構模式包含知識本體化知識庫層、可調適代理服務層及無所不在數位博物館應用服務層，可經由下列具體方法逐步建構。第一，建立統整式知識內容管理模式及多層式再利用知識內容結構，提供各專家、應用系統、專案及領域間知識表達、建構、管理、組織、再利用及發佈的共通作業流程及方法。第二，建立以知識內容為核心之學習服務模式，經由一群代理服務之協力運作，結合後端統整式知識庫內容的再利用及傳播方法，提供各類使用者族群研究、教育、展示與娛樂應用系統無所不在、主動式與可調適之多元服務。第三，建立知識本體化知識再利用與分享方法，運用正規概念分析(FCA)進行專業知識的獲取及以知識本體網頁描述邏輯語言(OWL-DL)共通標準化之知識表達工具，建構知識本體，提供跨領域、跨社群與跨機構間知識庫的整合、分享及推演方法，以分享及擴展博物館社群間彼此涵括的知識領域範圍。

經由上述方法，發展出一套有效率且實用的整體長遠知識建構與管理、再利用與傳播、分享與擴展的發展模式，建構以知識內涵為核心，且兼具博物館經理、專業、管理、行銷及社會功能之數位博物館，此發展模式已在國立自然科學博物館成功建構應用。

關鍵詞：數位典藏，數位博物館，內容管理，知識管理，知識本體，網頁知識本體語言，無所不在學習，環境感知，個人化

Framework of Knowledge-based Digital Museum

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Abstract

Over the recent decade, numerous digital archives projects have been conducted in museums worldwide to preserve and sustain natural treasures and human cultural heritage. Such undertakings are considered to be the prerequisite and foundation for developing digital museums from which the functions of museums can be enhanced using innovative digital technologies. However, the content silo trap problem occurs among individuals, domains, departments, and applications owing to most projects being developed independently and dispersedly. Consequently, contents, services, applications, and technical resources cannot be integrated and shared.

Furthermore, museums with storehouses of knowledge are considered one of the most important creators and deliverers of knowledge in modern society. However, few of them can apply unified knowledge management approaches to accumulate, manage, organize, reuse, share and integrate the vast quantity of existent and growing knowledge assets from both global and long-term perspectives. Accordingly, knowledge contents are widely dispersed and even became lost following numerous activities. Notably, this result limits museum development and impacts its competitiveness. The key problem is the lack of an effective and practical methodology for knowledge creation and management, reuse and diffusion, and sharing and exploration.

This study develops a knowledge-based digital museum framework that provides solutions for the above knowledge management issues in a museum. The proposed framework comprises an ontological knowledge base layer, adaptive service agent layer, and ubiquitous digital museum service layer that can be constructed via the following approaches. First, the unified knowledge content management (UKCM) model with multi-layer reusable knowledge content structures is designed to represent, create, manage, organize, and publish global knowledge content for all specialists, applications, projects, and domains. Second, a knowledge-based learning service model incorporating a set of collaborative service agents is designed by reusing and diffusing the unified knowledge bases to serve various users and applications ubiquitously, proactively, and adaptively. Third, an ontological knowledge reuse and sharing approach is designed to integrate and share knowledge bases among related domains, communities and institutes by using FCA (Formal Concept Analysis) for knowledge acquisition and OWL-DL (Ontology Web Language-Description Language) to facilitate representation for ontology construction.

This study uses the above approaches to devise an effective and practical methodology covering the processes of knowledge creation and management; reuse and diffusion; and sharing and exploration. The KBDM framework with curatorial, professional, administrative, promotional, and social functions has been successfully developed to demonstrate its practicability and benefits in the National Museum of Natural Science, Taiwan. Additionally, this study can strongly impact the development of digital museums worldwide. This dissertation discusses the KBDM framework in more detail.

Keywords: Digital archives, digital museum, content management, knowledge management, ontology, ontology web language, ubiquitous learning, context-awareness, personalization

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

As storehouses of both objects and knowledge, museums are considered vital knowledge asset and learning facilities in modern society. This chapter summarized some definitions regarding to “What is knowledge?” and “What is knowledge management?” to approve the instinctively knowledgeable properties of museums. Knowledge workers in museums dealing with various domains are attempting to create and deliver knowledge that is studied and excavated from collections through academic research activities. These knowledge assets are then further organized, reused and diffused to the public for study, education, and enjoyment via exhibition and education activities. Based on the instinctive knowledge properties and a series of knowledge creation, communication and delivery activities, the property of “knowledge-based museums” is justified.

Over recent decades, museums have applied information and communication technologies, including various management information systems, multimedia systems, and web-based systems, to enhance their business functionality. Previously, digital technologies and visionary were widely applied in museums worldwide. Numerous digital archives programs have been conducted in museums around the world to preserve and sustain natural treasures and human cultural treasures; popularize fine cultural landmarks; encourage information/knowledge sharing; invigorate cultural content and value-added services, and enhance literacy, creativity and quality of life. These programs are considered to be the prerequisite and foundation for developing digital museums, which can be used to enhance the curatorial, social, professional, administrative and promotional goals of museums through digital technologies.

Recently, numerous enterprises have applied knowledge management approaches to improve business performance and productivity. For museums, implementing knowledge management is complex and tedious. Few museums can apply knowledge management approaches to accumulate, manage, organize, reuse, share and integrate the vast body of existent and growing knowledge assets from both global and long-term perspectives. However, some of these museums apply content management techniques in their projects, and content silo trap problem result from most of the digital museum projects being developed in an independent and dispersed manner. Consequently, the development of contents, services, applications, and technical resources cannot be integrated and shared among individuals, domains, departments, and applications. Knowledge content is lost following various activities owing to a lack of knowledge representation structures and flexible tools for knowledge workers to use for organizing and expressing them. To overcome these problems, knowledge management techniques based on unified approaches that cover knowledge creation and management, knowledge reuse and diffusion, knowledge sharing and exploration processes are considered the key technique to solve above problems for knowledgeable museums. This study defines a knowledge-based digital museum as a new generation of digital museum that utilizes unified knowledge content to provide proactive, adaptive, ubiquitous and collaborative services for various types of users via global knowledge management process in actual and virtual accessible spaces.

This study proposes a knowledge-based digital museum (KBDM) framework designed to provide solutions to the content silo trap problem and global knowledge management issues in museums. The proposed framework attempts to achieve the following goals:

1. Unifying abundant and growing knowledge content acquisition, representation, creation, organization, and publication for all specialists, departments, projects, applications, and communities among various domains based on both global and long-term perspectives.
2. Reusing unified knowledge content to develop various value-added applications in

research, exhibition, education, and entertainment, and diffusing them to various users proactively, adaptively and ubiquitously.

1. Sharing knowledge content among domains, communities, and institutions to enhance their utilization; and exploring implicit and innovative knowledge in their knowledge bases to expand knowledge domain coverage.

The framework detail is discussed in Chapter 2, and the practical methodology for achieving its goals is discussed in Chapters 3, 4, 5.

1.1 Background

1.1.1 Defining knowledge and knowledge management

1. Defining knowledge

According to Webster's Dictionary, knowledge is "the fact or condition of knowing something with familiarity gained through experience or association." Wikipedia noted that “The Theaetatus, a dialogue among Plato, Socrates, Theodorus of Cyrene and Theaetetusin in 399 BC, defined “knowledge” as justified true belief. Socrates considered this definition to be one of the most notable candidates among various definitions of knowledge. Knowledge must not only be true, but must also be believed to be true. Socrates argued that true belief is insufficient; additionally a reason or justification is required for what belief” [83]. The definition of knowledge remains an important debate among philosophers. Alchin [2] also noted that “justified, true belief” is applied as a tentative definition in his study, while in reality it is known to be a limited definition.” However, Alchin used it to set out the parameters of inquiries regarding belief, justifications for belief, and the likelihood of beliefs being true.

Ackoff [1] positions the data, information, knowledge and wisdom (DIKW) model into a pyramid of increasing usefulness. The Data Information Knowledge and Wisdom Hierarchy has been gaining popularity in the information science and knowledge management domains. The DIKW model of Ackoff is used as an aid for research and analysis by applying the following chain of action [1]:

- Data comes in the form of raw observations and measurements.
- Information is created by analyzing relationships and connections between the data. It is capable of answering simple "who/what/where/when/why" style questions. Information is a message, and there is an implied audience and a purpose.
- Knowledge is created by using the information for action. Knowledge answers the question "how." Knowledge is a local practice or relationship that works.
- Wisdom is created through the use of knowledge, through the communication of knowledge users, and through reflection. Wisdom answers the questions "why" and "when" as they relate to actions. Wisdom takes care of the future, and it takes implications and lagged effects into account.

Some further definitions also follow from perspectives knowledge presentation and interpretation. Davenport [18] defined knowledge as "information combined with experience, context, interpretation, and reflection. Knowledge is a high-value form of information that is ready for application to decisions and actions." Williamson [85] pointed out that knowledge can be classified as follows: tacit or implicit knowledge, which is instinctively known without being verbalized; and explicit knowledge, which is communicated to others and held in written documents and procedures.

2. Defining knowledge management

Numerous definitions of knowledge management (KM) have been presented at conferences, in print, and on the Web. No standard definition of KM exists. This study attempts to identify some following definitions related to knowledge management issues in museums in this study.

Skyrme [72] defined knowledge management as “the explicit and systematic management of vital knowledge and its associated processes of creating, gathering, organizing, diffusion, use and exploitation. Knowledge management involves turning personal knowledge into corporate knowledge that can be widely shared throughout an organization and appropriately applied.” Mezei [63] noted that “Organizational knowledge management is a process of transforming individual intellect into organizational intellectual capital. Enterprise knowledge management describes the strategy, process or technologies used to acquire, share and re-use enterprise knowledge and understanding.” Bellinger [8] observed that “The value of knowledge management relates directly to the effectiveness with which the managed knowledge enables organization members to deal with current situations and effectively forecast and create a future.” Wikipedia [83] summarizes the main objectives of the KM process as follows:

- Identifying, collecting and organizing existing knowledge,
- facilitating new knowledge creation, and
- initiating innovation through reusing and leveraging expertise across organizations to enhance business performance

1.1.2 Knowledge-based museums

Based on the definitions of knowledge and knowledge management given above, this study correlates the concept of “knowledge-based museum” with the definition to demonstrate instinctively knowledgeable property of museums and the coverage of knowledge creation, management, reuse, diffusion, sharing, and exploration processes in various activities.

One of the earliest theoretical museology scholars, Geo Brown Goode, in 1895 while inspecting the basic principles of museum administration defined a “museum” as “an institution for the preservation of those objects which best illustrate the phenomena of nature and the work of man, and the utilization of these to increase knowledge, and enlighten the people." Cannon-Brookes [11] stressed the fundamental role of museums in assembling and maintaining objects within a specific intellectual environment, and stressed that museums are storehouses of both knowledge and objects. Museums Australia in 2004 devised a new definition based on the previous definition used by International Council of Museums (ICOM), which defined museums as institutions possessing the following characteristics [5]:

- Helping people understand the world by using objects and ideas to interpret the past, present and explore the future.
- Preserving and researching collections, and makes objects and information accessible in actual and virtual environments.
- Being established in the public interest as permanent, not-for-profit organizations that contribute long-term value to communities.
- Playing a vital role in the development and well being of society.

Therefore, museums provide a link through which the public can access their heritage and provide opportunities for them to better understand and rationalize their world. Museums exploit the spread of knowledge content as an authoritative means of demonstrating the trust from users. According to the report by Market & Opinion Research International (MORI) conducted for the Common Information Environment (CIE) group [16], individuals have a high level of trust in museums. This trust results from the belief that the knowledge content created and delivered by museums possesses the characteristic of justified true belief.

This study emphasizes that a museum is knowledge-based, meaning that museums are not only knowledgeable but also their entire knowledge management processes covering creation, management, reuse, diffusion, sharing, and exploration in business. From the knowledge creation and management perspective, museums employ knowledge workers, including directors, curators, museum educators, museum registrars, conservators, exhibit designers, and collections managers, who have the ability and skills to accumulate and manipulate large bodies of knowledge [24]. These knowledge workers explore vast quantities of knowledge from collections. This abundant knowledge is then managed, classified, organized, and informed via exhibition and education activities involving the public.

From the knowledge reuse and diffusion perspective, museum knowledge comprises a form of social capital. Audiences interact with knowledge based on experience, observation, perception, and inference of knowledge. The spread of this knowledge is realized by reusing the vast quantity of knowledge for research, exhibition, education, and leisure activities. Diffusion of innovations explores the factors that lead people to increase their awareness of, try, and adopt new ideas and practices.

From the knowledge sharing and exploration perspective, the correlation of knowledge content among domains, institute, or museums should be integrated and shared to sufficiently utilize abundant knowledge. Museums must also explore implicit and correlated knowledge with others to increase knowledge domain coverage to create a knowledgeable community.

From the above discussion, the concept of a knowledge-based museum (see Figure 1.1), which includes knowledge creation and management, reuse and diffusion, and sharing and exploration perspectives, can be clarified.

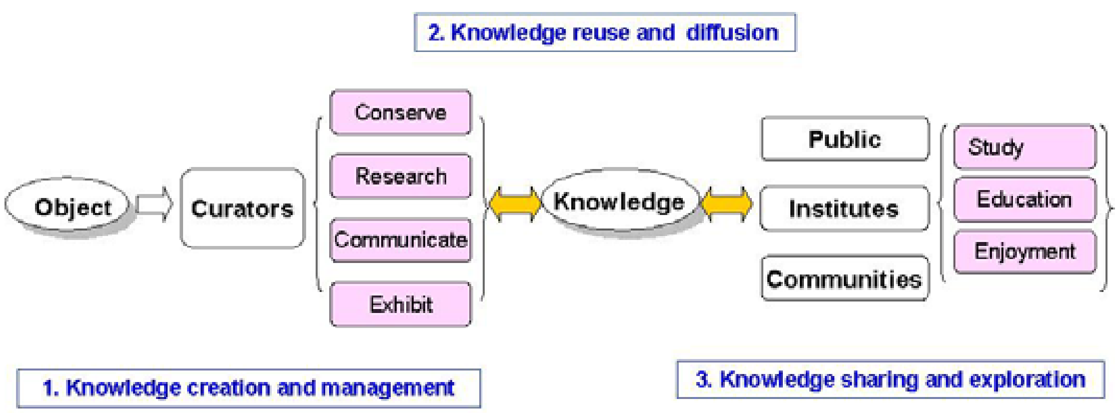


Figure 1.1 The concept of a knowledge-based museum

1.1.3 Knowledge-based digital museum

The emergence of information and communication technology (ICT) has resulted in significant changes and progress in human life. Museums worldwide have been affected by this trend of applying ICT, particularly digital technologies, to manage and enhance museum functions and enrich the knowledge content and services perceived by the public. MacDonald [53] pointed out that “The opportunities of digital technologies for the dissemination of knowledge are on a scale never before possible, and the pressures to conform to audience and social expectations, will be key factors in transforming museums. Such transformation does not mean that we lose what museums are, but have to offer, today as physical sites conveying knowledge of heritage through the medium of material objects and information highway.” Undoubtedly, the innovative ICT enables museums to organize existing knowledge and create new knowledge for realizing the curatorial, social, professional, administrative and promotional goals of museums, and creating unlimited possibilities and imaginations to shape the future.

A digital museum extends research, exhibition, education, and enjoyment functions of a physical museum via ICT to provide 24 hours services. MacDonald [53] noted that as network speeds continue to increase, digital museum designers will create virtual exhibitions using digital images, web pages, 3-D animation, video clips, virtual reality and other multimedia gadgets, and will emphasize providing users with highly educational and motivating exhibitions, learning applications and research resources using telecommunication systems. By developing innovative management information systems, multimedia applications systems, and web-based application systems, digital museums provide numerous excellent opportunities for museums in both actual and virtual spaces. Recently, museums worldwide have placed increasing emphasis on knowledge management techniques, which are considered the key approach for presenting the instinctive knowledge property and creating new opportunities for museums.

This study restates the aims of knowledge management process noted by Tanichka from Wikipedia, as follows [84]:

- Identifying, collecting and organizing existing knowledge,
- facilitating new knowledge creation, and
- initiating innovation through reusing and leveraging expertise across organizations to enhance business performance

These aims are consonant with the concept of knowledge-based museum described above. A digital museum should apply knowledge management from a global perspective, as described below:

- Knowledge creation and management

  To create and manage a vast body of knowledge content from a global and long-term perspective, a well-defined common and standard process of acquisition, representation, creation, organization, and publication for all specialists, departments, projects, domains, applications, and communities, should be established and managed using a unified approach.

- Knowledge reuse and diffusion

  To reuse and diffuse the vast amount of knowledge content as comprehensively as possible, various value-added applications in research, exhibition, education, and entertainment can be established by reusing global unified knowledge content. These applications are diffused proactively, adaptively and ubiquitously via the actual and virtual accessible space.

- Knowledge sharing and exploration

  To integrate and share knowledge assets as widely as possible, common and standard knowledge acquisition, knowledge representation and knowledge retrieval techniques must be created among domains, communities, and institutes. Therefore, the knowledge bases from different sites should be integrated and shared, and implicit and innovative knowledge should be further excavated among their knowledge bases.

Therefore, this study defines a knowledge-based digital museum as a new generation of digital museum that utilizes unified knowledge content to provide proactive, adaptive, ubiquitous and collaborative services for various user types via global knowledge management processes actual and virtual accessible spaces.

1.2 Problems and challenges

During the last decade, numerous digital museum projects have been conducted in museums worldwide. Like in numerous countries around the world, numerous museums in Taiwan have long been conducting digital museum projects. The National Science Council (NSC) Digital Museum Program [47] is the predecessor of NDAP (National Digital Archives Program), which was introduced in 1998. The NSC Digital Museum Program provides funding and opportunities for institutions such as museums, libraries, and universities by issuing digital museum projects in their expert domains. This program establishes the concept and vision of digital museums, and spreads it over those institutes. These projects are considered to be the chance to enhance the curatorial, social, professional, administrative and promotional goals of museums through digital technologies. Especially, museums with storehouses of knowledge are endeavoring to become important knowledge deliverers and learning facilities in modern society via digital museums.

However, most projects endeavor to apply innovative multimedia, web and communication technologies to develop digital museum projects for learning and exhibition [15, 28, 41, 56, 57, 82]. Some of museums apply content management techniques in their projects [39, 40], which can lead to content silo trap problems owing to most digital museum projects developing independently and dispersedly. Recently, museums place importance on implementing knowledge management but it is complex and tedious to consider content, services, technologies, and business perspectives at the same time [61, 80]. Few can apply knowledge management approaches to accumulate, manage, organize, reuse, share and integrate the vast body of existent and growing knowledge assets from a global and long-term perspective. Consequently, the development of contents, services, applications, and technical resources cannot be integrated and shared among individuals, domains, departments, and applications. Knowledge content is lost following numerous activities owing to a lack of defined knowledge representation structures and flexible tools that knowledge workers can use to organize and express them sufficiently.

This study summarizes the above common problems in the digital museum projects of Taiwan and worldwide museums as follows:

1.Knowledge creation and management

- Content cannot be accumulated and managed centrally for long-term utilization and application development.
- Content cannot be created based on common workflow and standard specifications.
- Digital content is managed at a data or information level for preservation, but not at a knowledge level for creation, organization, sharing and reuse.

- Systems are developed separately and repetitiously, and are poorly integrated, leading to redundant overhead costs and resource spending.

2.Knowledge representation

- No standard and formal specifications exist that represent all knowledge elements.
- No common and sharable knowledge concept exists between users and content expert for supporting application services.
- There are no efficient and standard tools that domains, communities, and institutes can use to acquire and represent knowledge content for integration and sharing.

3. Knowledge organization and publication

- No flexible authoring tool exists for content experts to organize and publish all content types.
- No unified concept hierarchy exists for all domain content experts to organize and present global content.

4.Knowledge reuse and sharing

- Content and resources created by diverse individuals, groups, departments, projects, applications, or communities cannot be shared and reused among one another.
- Knowledge bases created by domains, institutes, and communities cannot be integrated and explored.

5.Knowledge retrieval

- Users cannot access related and integrated content from a single entry point.
- Users cannot acquire additional content via a dynamic knowledge inference and discovery mechanism.
- Digital content is uniform and constrained to specific domains; users cannot access most relevant knowledge.

6.Integrated service

- The service is provided only onsite or outside the museum via the Internet, and cannot provide both for users.
- The service cannot adapt to the needs and context of specific individuals or groups.
- The service cannot track user behavior and deliver content to them proactively.
- Digital museum services cannot collaborate with physical museums to provide an actual and virtual accessible environment.

To solve these problems, several challenges must be overcome. First, it is essential to unify the acquisition, representation, creation, organization, reuse, and publication of a large and growing body of knowledge content from all specialists, departments, projects, and applications. Consequently, a unified knowledge content management model should be created to support the needs of various user, project, application, and domain based common workflow and standard specifications.

Second, museums around the world are endeavoring to develop solutions to enhance their curatorial, social, professional, administrative and promotional functions, and to strengthen reliability and user satisfaction via digital services. Thus, a knowledge-based digital museum framework that closely collaborates with the functions of physical museums in terms of academic research, exhibition, education, and entertainment can be developed. These applications are diffused proactively, adaptively and ubiquitously through the actual and virtual accessible space.

Finally, content productivity is limited owing to limited funding and manpower of knowledge specialists at a single museum. Consequently, users are not satisfied with the content quality and quantity. Intelligent knowledge sharing and discovery mechanisms must be designed to facilitate the integration and sharing of knowledge bases from different sites, as well as the further exploration of implicit and innovative knowledge.

1.3 Goals

The National Science Council (NSC) of Taiwan has sponsored the National Digital Archives Program (NDAP) (http://www.ndap.org.tw) since 2002. The NDAP aims to promote and coordinate content digitization and preservation at leading museums, archives, universities, research institutions, and other content holders in Taiwan (http://www.ndap.org.tw/index_en.php). National Museum of Natural Science (NMNS) has been one of nine participants in the NDAP since 2002. A total of 20 domains, including zoology, botany, geology and anthropology, participate in the digital archives project of NMNS. NMNS thus tries to rethink digital museum projects using a unified knowledge management process from a long-term and museum-wide perspective. This study not only attempts to solve the content silo trap problem, but also attempts to design a practical and effective knowledge management process model from the long-term and global perspectives for use in both NMNS and worldwide museums.

This study aims to establish an innovative framework and practical system to fit the requirements of NMNS and to provide a reference model for other museums that face similar problems and challenges. This framework is designed to construct a knowledge-based digital museum (KBDM) with the following vision:

(1) Utilizing unified and global knowledge content based on multi-layer reusable knowledge content structures for content to represent and organize the vast amount knowledge content around knowledge specialists.

(2) Developing research, exhibition, education, and entertainment applications for various types of users, including the general public, students, teachers, and the industry, by reusing and diffusing vast amounts of knowledge content.

(3) Providing proactive, adaptive, ubiquitous and collaborative services between digital and physical museums to create both real and virtual accessible environments.

(4) Integrating and sharing knowledge content among domains, communities, and institutes to expand knowledge domains coverage.

Figure 1.2 shows the vision surrounding the knowledge-based digital museum.

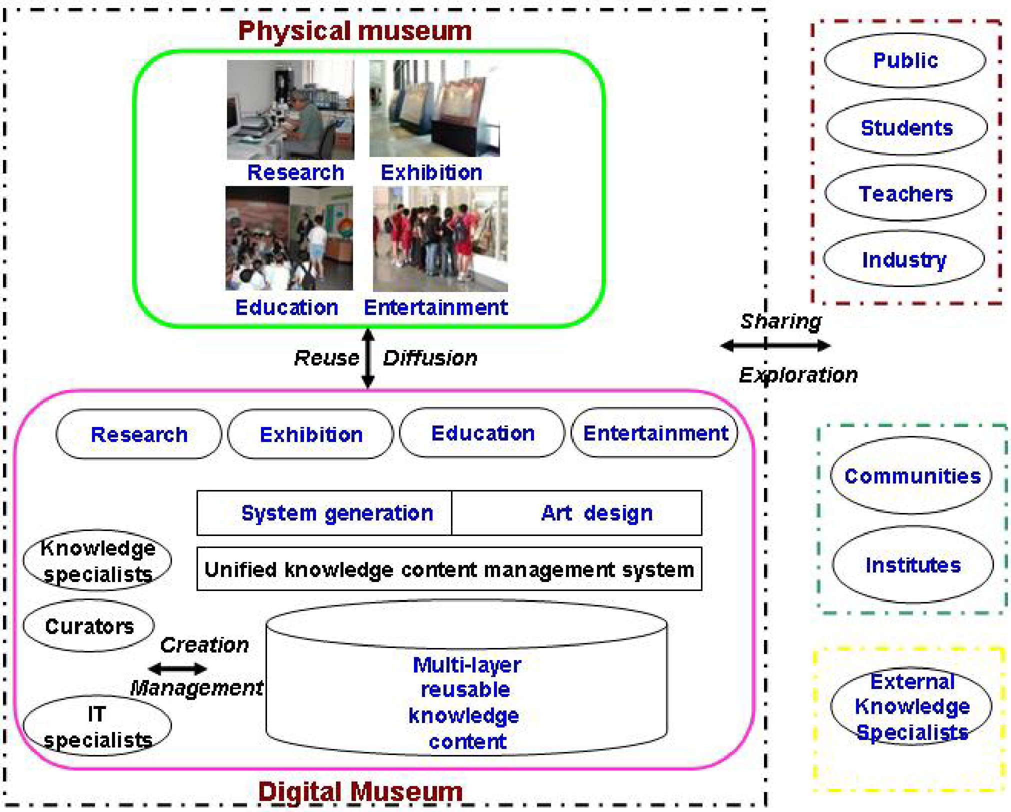


Figure 1.2 The vision of knowledge-based digital museum

The goals of the proposed framework are summarized from the content, service, technology, and business perspectives as follows:

1. Content perspective

- Unifying content from individuals, departments, projects, applications, and domains based on a common and standard process.
- Providing multi-layer knowledge content structures for knowledge workers to effectively represent, create, organize and present their implicit and explicit know-how.
- Constructing versatile content for sharing and reuse among research, education, and enjoyment applications and satisfying the needs of various user groups.
- Constructing ontology to serve as a common and sharable knowledge concept for communicating among content experts, applications, services, and users.

2. Service perspective

- Providing ubiquitous services for users to access content and services without temporal and spatial constrains.
- Providing personalized services for individuals and various user groups to meet their requirements proactively and intelligently.
- Integrating all contents and applications in a single service portal with a systematic and intelligent interface.
- Creating a digital and physical museum collaborative service model to expand and promote the business of museums in both the virtual and real worlds.

3. Technology perspective

- Establishing a standard workflow for knowledge workers to collect, create, organize, and publish their content via a unified process.
- Developing a single knowledge-based content management system to integrate content creation, management, and publication process for the entire museum.
- Designing a multi-layer content, service, and application and modular architecture that cover functions from backend knowledge bases to front-end service portals.
- Supporting unified and reusable content creation and ubiquitous, context-aware, and personalized intelligent services.
- Discovering new knowledge among various domains and mining related resources from the Internet to enrich museum content.

4. Business perspective

- Combining digital content and services to expand the business functions of physical museums.
- Improving service quality and strengthening the connection with audiences via diverse digital content and service.
- Transferring various knowledge content and services into value-added commercial products to create knowledge economy opportunities for the museum.

The above framework can be used to realize a practical, knowledge-based digital museum according to the global perspective based on unified knowledge management issues, including knowledge creation and management, knowledge reuse and diffusion, and knowledge sharing and exploration. From a long-term perspective, a business model can be created to collaborate with the service function of physical museums based on the knowledge-based digital museum. This model can also be referenced and extended to other museums with storehouse of knowledge and objects. The details of this framework are discussed in Chapter 2.

1.4 Dissertation organization

The remainder of this dissertation is organized as follows. Chapter 2 describes a framework for a knowledge-based digital museum comprising an ontological knowledge base layer, adaptive service agent layer, and ubiquitous digital museum service layer to support knowledge creation, management, reuse, diffusion, sharing, and exploration from the perspective of the museum as a whole. Moreover, Chapter 3 presents a unified knowledge content management model that comprises unified knowledge content processes, multi-layer reusable knowledge content structures and integrated knowledge-based content management system for supporting knowledge creation, management, and publication from a global perspective for an entire museum. Chapter 4 then describes a knowledge-based ubiquitous learning service model that provides ubiquitous, context-aware and personalized service by reusing unified knowledge bases. Next, Chapter 5 employs ontological techniques to restructure current digital contents into corresponding knowledge bases for sharing and reusing knowledge content among KBSs (Knowledge base system) and communities. Finally, the results of this study are discussed and future research directions are drawn.

Chapter 2

Knowledge-based digital museum framework

2.1 Conceptualization

The previous chapter defined a knowledge-based digital museum as a new generation of digital museum that employs unified knowledge content to provide proactive, adaptive, ubiquitous and collaborative services for various user types via global knowledge management in actual and virtual accessible spaces.

This chapter first aims to clarify the conceptualization of knowledge-based digital museum framework before practical construction. This framework is constructed in a collaborative environment involving knowledge specialists, IT engineers, knowledge engineers, and knowledge consumers. For a museum, knowledge consumers may include the public, students, teachers, researchers, museums, institutes, industry, and so on. IT engineers cooperate with knowledge engineers to develop a knowledge-based digital museum framework, which knowledge specialists can use to create various contents efficiently and productively. Based on the requirements of various types of knowledge consumers, knowledge specialists in various domains create and organize content that ranges from simple to complex using common processes and standardizations. The vast amount of knowledge content is reused to develop diverse applications and is diffused to consumers in a ubiquitous, proactive, and adaptive environment.

The knowledge-based digital museum framework includes three key components, namely a unified knowledge repository, a set of service agents, and a knowledge-based digital museum service portal. The unified knowledge repository is created using a unified process, multi-layer reusable knowledge content structures, and an integrated knowledge content management system involving a large group of knowledge specialists. All knowledge specialists should follow common and standard workflow to acquire, digitize, edit, organize, and publish content. To provide tools for enabling knowledge specialists to express and organize accumulated knowledge efficiently and productively, multi-layer reusable knowledge content structures should be defined. These structures are used to model various granularities of knowledge content ranging from basic core knowledge elements to complex ones to present various knowledge concepts. All contents are created and managed using a common knowledge concept and knowledge management system.

Various research, exhibition, education, and entertainment applications can be designed depending on consumer requirements by reusing the content from the unified knowledge repository. Knowledge consumers can access the unified knowledge repository via the intelligent digital museum service portal. The service portal is supported by a set of service agents, including agents for content organization service, content presentation service, ubiquitous service, context-aware service, and personalized service. These services collaborate to provide a ubiquitous, adaptive, proactive service environment while accessing various applications.

To excavate implicit and innovative knowledge in the unified knowledge repository within domains, further intelligent knowledge classification, discovery, inference, and organization mechanisms should automatically be supported by the system. The knowledge acquisition, knowledge representation, and knowledge retrieval tools based on standard and sharable knowledge concept is also needed to integrate and share knowledge bases among specialists, domains, communities, and institutes. Figure 2.1 illustrates the conceptualization of the knowledge-based digital museum.

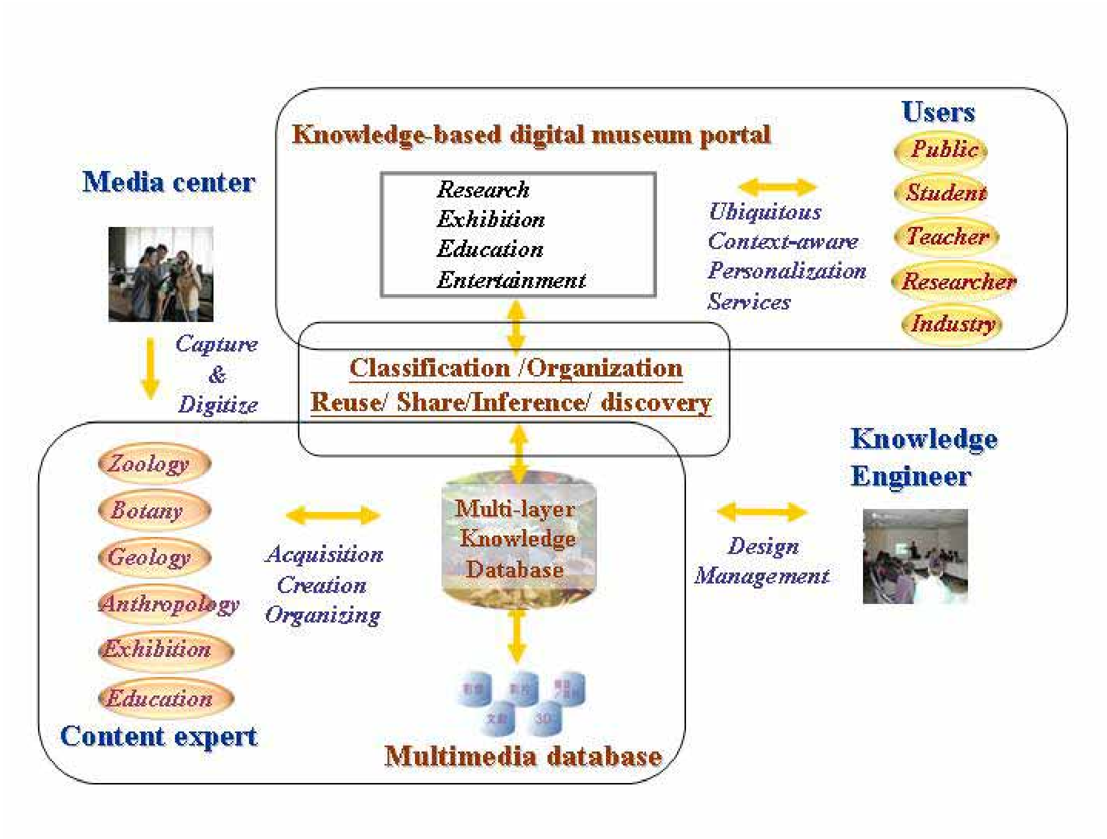


Figure 2.1 The conceptualization of knowledge-based digital museum

2.2 System framework

Base on the conceptualization of the knowledge-based digital museum described in the previous section, this study proposes a knowledge-based digital museum (KBDM) framework (see Figure 2.2) comprising an ontological knowledge base layer, adaptive service agent layer, and ubiquitous digital museum service layer, to realize the concept of a knowledge-based digital museum. Using this framework, the objective is not only to solve the content silo trap problem in digital museum projects but also to provide a methodology for museums to deal with global knowledge management issues, including creation and management, reuse and diffusion, and sharing and exploration.

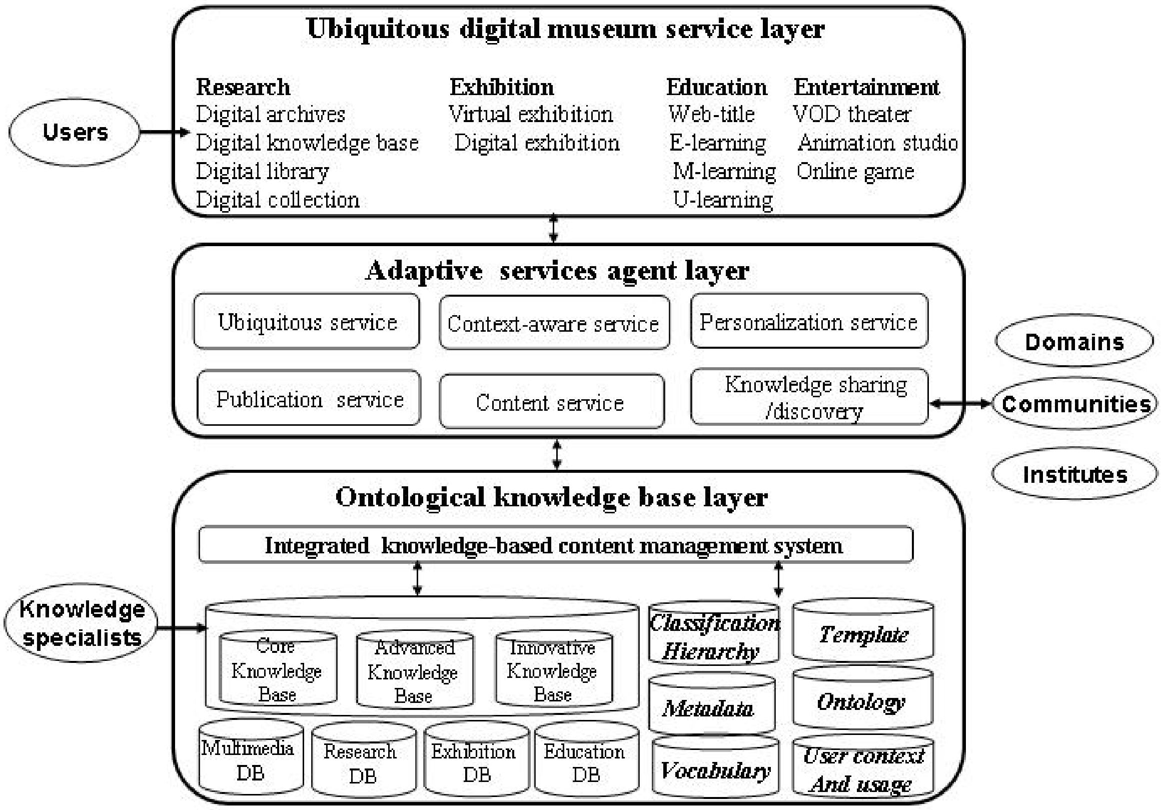


Figure 2.2 Knowledge-based digital museum framework

2.2.1 Ontological knowledge base layer

Ontology has previously been applied in digital archives, digital museums and museum-related e-learning projects to provide shared and reusable knowledge standards. Ontology integrates various contents from inter-domains and intra-domains, services, applications, and users based on a common and sharable knowledge concept. Ontology plays several significant roles in this study. First, ontologies provide a sharable thesaurus describing entities, attributes, relationships and events for various content types in the unified knowledge base and user context. Second, ontologies maps content onto a simplified and standard specification, and processes it consistently among application services with common knowledge concept. Third, the concept hierarchy of ontologies can be employed to design user interfaces. Finally, the concept tree can be applied to calculate the similarity of concept definitions based on the user context and the unified knowledge base for patterns discovery and content recommendation in the personalization service.

The ontological knowledge base layer is based on a unified knowledge content management (UKCM) model that comprises the unified knowledge content processes, multi-layer reusable knowledge content structures and an integrated knowledge-based content management system. This layer focuses on solving the problem of content silo trap and dealing with knowledge creation and management issues.

The unified knowledge content process provides a common workflow among knowledge specialists, IT specialists and users. All specialists must employ a standard process to create knowledge content using well-defined knowledge content structures. The unified knowledge content processes can be considered a knowledge management life cycle that includes collection, digitizing, editing, organizing, publishing, and access phases

The multi-layer reusable knowledge content structures define the spectrum of knowledge content as comprising core, advanced, and innovative knowledge elements for expression and organization by all participants. Knowledge content is based on core knowledge content, which comprises a multimedia object and semantic metadata. Advanced and innovative elements are manually authored or automatically inferred from existing content.

The integrated knowledge-based content management system manages all types of knowledge contents. This system comprises a creation subsystem for constructing ontology, vocabulary, metadata, content, authoring templates, classification hierarchy, and user bases; a management subsystem for managing the various types of knowledge content, and the above-mentioned resources for creating and publishing those contents, and a publishing subsystem for transferring all the authored content into a publishable format for presentation on the Web or in other medias.

2.2.2 Adaptive service agent layer

To effectively and intelligently support digital museum applications, the entire framework requires a set of service agents for generating integrated and appropriate content for the user. The services agents serve as a bridge linking users with content. The adaptive service agent layer comprises a set of service agents designed for serving various users and applications. These service agents adapt to user requirements to provide a ubiquitous, proactive, and adaptive service environment collaboratively. Services can be added flexibly according to the extension of applications and user requirements.

The general services support personalized, proactive, and adaptive service environments, including ubiquitous, context-aware, personalization, content, publication, and knowledge sharing and discovery services. A ubiquitous service supports users in accessing applications and contents without constraints of time, place or device. Such services enable any application to serve all users both inside and outside the museums 24/7 without temporal and spatial constraints. Meanwhile, a context-aware service serves users depending on their context, including demographic characteristics, preferences, and environmental situation. Context-aware service works together with content service to dynamically and proactively retrieve and generate appropriate content for users. User actions and behaviors are also tracked to dynamically update user context and usage base to provide more accurate and adaptive content in the future. Personalization services cooperate with ubiquitous service and context-aware service to recommend content to individuals or groups among all applications adaptively and proactively based on up-to-date user context and usage information. The content service retrieves related knowledge content from the unified knowledge bases depending on application type and user context. The content service generates semantic content structures for presentation and interchangeable formats for sharing and reuse among domains, communities and institutes. The publication service cooperates with content services to generate formats for content presentation. Moreover, the knowledge sharing and discovery service discovers implicit and innovative knowledge in the knowledge bases and meaningful usage patterns in user content and usage bases.

2.2.3 Ubiquitous digital museum service layer

A ubiquitous digital museum service portal integrates research, exhibition, education, and entertainment applications in a single portal. Such a portal enables users to access all contents and applications without temporal and spatial constraints. The ubiquitous digital museum service layer sends user requests to the adaptive service agent layer. Users can use a navigation method to access and present content based on the classification hierarchy or ontological knowledge map. Additionally, users can employ various types of query methods to obtain all related content. The query methods include keyword search, full text search, natural language search, and visual interface search. Keyword search identifies content based on metadata for each domain. Both full text and natural language search extract phrases from the query and then identify identical or similar content. Moreover, the visual interface uses graphical patterns to represent metadata in each domain. Consequently, users can express queries by combing several instinctive and understandable graphical patterns. All applications, services and content are accessed and controlled using a digital right management or membership mechanism. Consequently, each user can obtain permitted contents and define their personal portal and presentation style within accessible content and service scopes authorized by system. The combination of personalized, ubiquitous, and context-aware services monitors the access process of all users and recommends appropriate content for adaptive and proactive service.

This study attempts to provide an effective and practical methodology covering knowledge creation and management; reuse and diffusion, and sharing and exploration issues for museums to reference and follow. This study realizes this framework via the following approach. First, the unified knowledge content management (UKCM) model with multi-layer reusable knowledge content structures is designed for representing, creating, managing, organizing, and publishing global knowledge content for all specialists, applications, projects, and domains. Chapter 3 discusses the details. Second, a knowledge-based learning service model with a set of collaborative service agents is designed by reusing and diffusing the unified knowledge bases to serve various users and applications ubiquitously, proactively, and adaptively. Chapter 4 discusses the details. Third, an ontological knowledge reuse and sharing approach is designed to integrate and share knowledge bases among related domains, communities and institutes by using FCA (Formal Concept Analysis) for knowledge acquisition and OWL-DL (Ontology Web Language-Description Language) for knowledge representation to construct ontologies. Chapter 5 discusses the details.

Chapter 3

Unified knowledge content management model

3.1 Introduction

Numerous digital archives programs in museums are conducted worldwide to preserve and sustain mankind's cultural heritage. Such programs aim to preserve cultural heritage and collections; popularize fine cultural landmarks; encourage information/knowledge sharing; invigorating cultural content and value-added services, and improve literacy, creativity and quality of life. They are considered as the prerequisite and foundation for developing digital museums from which a museum's conventional functions in academic research, exhibition, education, and entertainment can be extended and developed through information technologies [3, 13, 36, 60, 70].

Most digital archives programs in museums incur some of the following problems:

- Content and resources created by diverse individual, groups, departments, projects, or applications cannot be shared and reused among each other.
- Content cannot be accumulated and managed centrally for long term utilization and applications development.
- Digital content is managed at a data or information level for preservation, but not in a knowledge level for creation, organization, sharing and reusing.
- Systems are developed separately and repetitiously, and lack integration, leading to redundant overhead costs and spent resources.
- Users cannot access related and integrated content from a single entry point.

Content silo trap largely accounts for the above problems, owing to the content is created by individuals working in isolation from other individuals within a project. Walls are erected among content domains and even within the same content domain. Rockley [69] proposed the unified content strategy (UCS) to avoid the content silo trap. UCS focuses on the need for effective content acquisition, representation, organization, publication and sharing in a global view among projects, applications, users, contents and organizations in an institute. The system framework of UCS described by Rockley comprises three components: unified process, content management system (CMS), and reusable content.

The UCS was developed to fit a general enterprise needs, but it needs be extended to consider the characteristics of knowledge management and application for museums. As a knowledge creator, a museum's most important mission is to accumulate and integrate tremendous existed and growing knowledge content. The processes include collecting, creating, organizing, reusing, and publishing knowledge content among all specialists, departments, projects, and domains for developing various applications in academic research, exhibition, and education for users. Our previous works in some digital archives projects applied CMS [39. 40] to exhibition applications. Many museums have implemented CMS to manage amassed content and to enhance functionality and accessibility of a Web site [38. 78]. These projects only handle partial participants, processes, content, technologies, domains and applications. They not only lacked the application of knowledge management techniques, but also neglected the integration and long-term prospective of content management considerations for all domains and applications from entire museum's viewpoint.

This study extends Rockley's UCS to fit museums' global needs for various domains and applications through knowledge management, and proposes a knowledge-based content management (UKCM) model. The UKCM model contains unified knowledge content processes, the multi-layer reusable knowledge content structures and the integrated knowledge-based content management system. The model aims to satisfy the knowledge management issues among various domains and academic, exhibition, and education applications in museums.

The purpose on this chapter is to solve content silo trap problem and global knowledge management issues on creation and management discussed in section 1.2. This chapter also wants to provide a practical approach to construct unified and multi-layer reusable knowledge bases that can be reused by various research, exhibition, education, and entertainment applications. This rest of this chapter is organized as follows. Section 3.2 describes the knowledge-based content management system model. Sections 3.3, 3.4 and 3.5 describe the three components of the proposed model — the unified knowledge content processes, the multi-layer reusable knowledge content structures and the integrated knowledge-based content management system respectively. Section 3.6 details the application of the Extended Entity-Relationship (EER) modeling tool to conceptually design the integrated knowledge system across the domains of a museum, and the multi-layer reusable knowledge content structures. Section 3.7 demonstrates a practical implementation of our approach.

3.2 UKCM model

Knowledge management framework in museums not only aims to manage these knowledge assets but also to manage the processes that act upon the assets. These processes include developing, preserving, using and sharing knowledge [55, 59]. This study proposes a unified knowledge-based content management (UKCM) model (see Figure 3.1) to extend the UCS and achieve knowledge management among various domains and for long-term digital museum applications developing perspective. The three components in this model are unified knowledge content processes, an integrated knowledge-based content management system and multi-layer reusable knowledge content structures. The three components are described briefly below and are detailed in the following Sections.

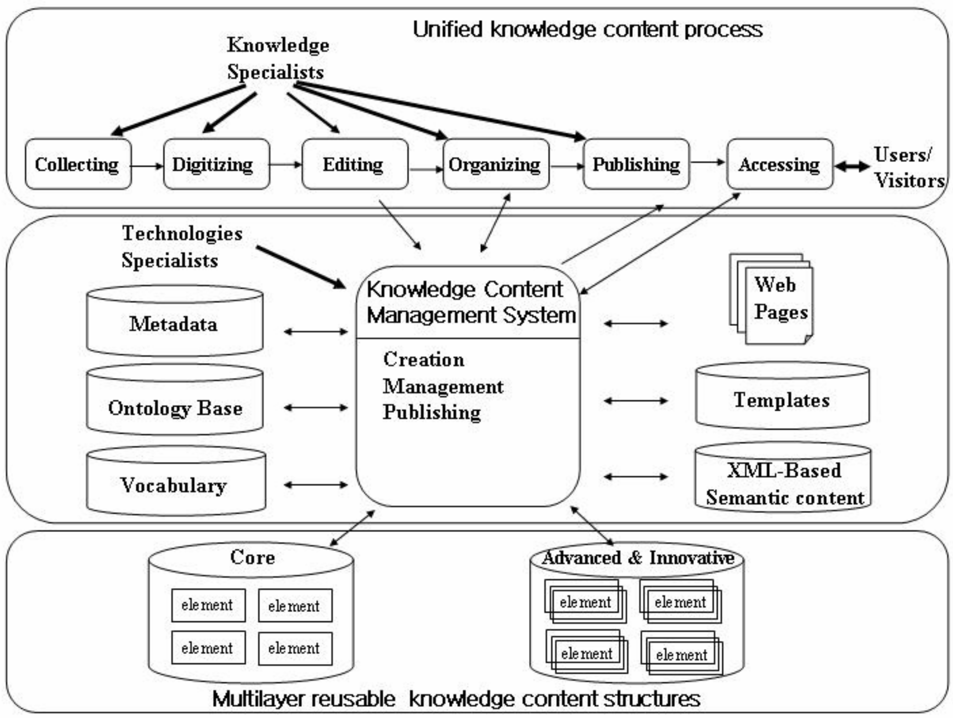


Figure 3.1 Unified knowledge-based content management model

The unified knowledge content process functions as a common workflow among participants and projects that includes knowledge content collection, digitization, editing, organizing, publishing and accessing stages.

The multi-layer reusable knowledge content structures define the spectrum of knowledge content for all participants to follow, from core knowledge elements to advanced and innovative elements. A core knowledge element is the basis of knowledge content and comprises a multimedia object and semantic metadata. Advanced and innovative elements are further manually authored or automatically inferred from existing content.

The integrated knowledge-based content management system works to integrate the entire system. This system comprises the creation subsystem for constructing vocabulary, metadata, content and the classification hierarchy; the management subsystem for managing the entire knowledge content and resources for creation and publishing, and the publishing subsystem to transfer the authored content into the publishing structure and Web pages for all departments and projects.

Aside from those advantages shown by Rockley such as faster time to publish, better use of resources, reduced costs, improved quality and usability of content, increased opportunities to innovate, improved workplace satisfaction and increased customer satisfaction, additional benefits from the proposed model for digital archives projects in museums include the following:

- Establishing a knowledge-based content creation, management and publication process to closely connect the collaboration among knowledge and IT specialists for all projects.
- Constructing an integrated, formal, explicit domain knowledge system to unify and integrate all domain specialists under a common conceptual model.
- Providing standard and consistent multi-layer knowledge content structures for specialists to fully express and create their spectrum of knowledge content.
- Integrating and managing knowledge content created from projects, specialists and applications centrally for others to share and to reuse.
- Improving the effectiveness of business for museums and satisfying the needs of audiences.

3.3 Unified knowledge content processes

In Rockley's UCS, the unified processes eliminate the silo walls and create a collaborative environment to ensure that authors are aware of reusable content and for all departments to follow a repeatable and transparent workflow. For museums, unified knowledge content processes must be defined providing common and collaborative workflows among knowledge specialists, IT specialists and museum users. Knowledge specialists require a standard, consistent, repeatable, sharable and transparent environment to collect, digitize, edit and organize knowledge content. IT specialists require an integrated and collaborative system development environment to design an efficient, automatic, scalable, and interoperable system for supporting content creation, management, and publication. Users require organized, categorized, integrated and systematic knowledge content via classification hierarchy browsing and metadata searching across related domains.

To satisfy the needs of knowledge specialists, IT specialists and users, all specialists must follow a standard process to create and maintain knowledge content with well-defined knowledge content structures autonomously. The unified knowledge content processes can be regarded as a life cycle that comprises knowledge content collecting, digitizing, editing, organizing, publishing, and accessing phases (see Figure 3.2).

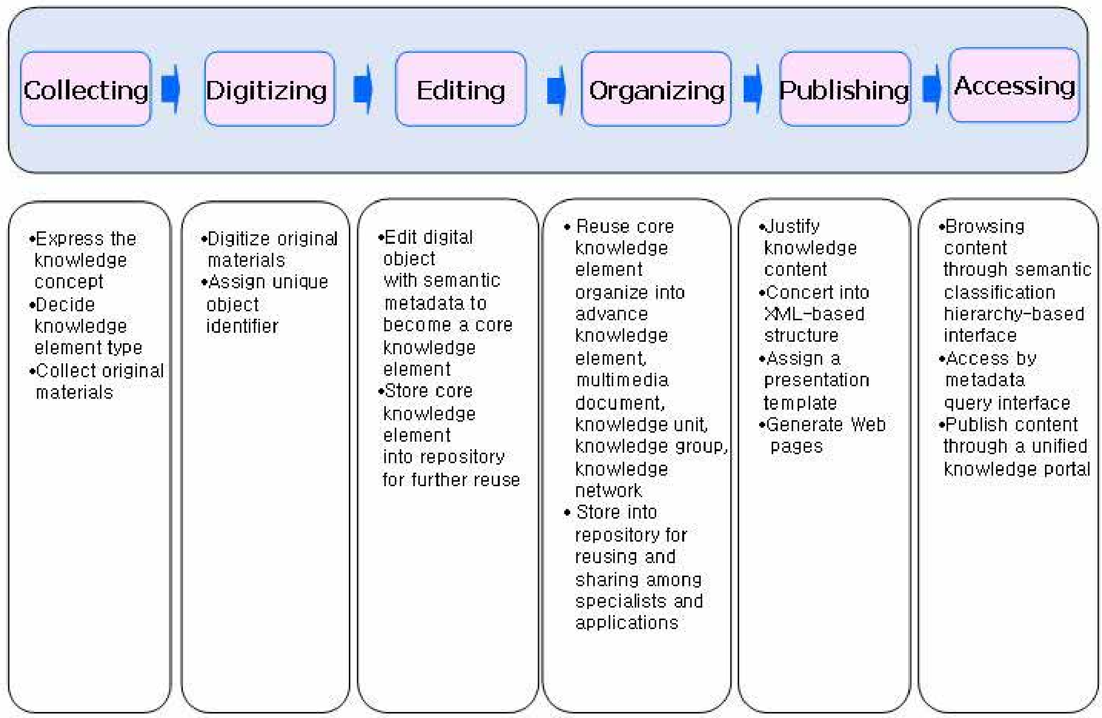


Figure 3.2 The unified knowledge content processes

The major tasks of each phase are summarized as follows:

1. Collecting stage

- To express the knowledge concepts for a particular application and user group, the variety of knowledge element must be decided in advance.
- To collect original materials such as slides, photographs, audio, video, or documents for the target content type and prepared under a standard knowledge content structure.

2. Digitizing stage

- To digitize the original materials into digital objects using standard formats.
- To assign a meaningful and unique object identifier for each digital object.

3. Editing stage

- To interpret each digital object with semantic metadata to make it a core knowledge element.
- To store core knowledge elements in the core knowledge element repository for further organization and reuse.

4. Organizing stage

- To reuse and organize core knowledge elements into advanced knowledge elements, which can be a multimedia document, knowledge unit, knowledge group, and knowledge network.
- To use a multimedia document composed of a set of digital objects for interpreting a subject relating to an artifact.
- To organize a set of multimedia documents into a knowledge unit for interpreting an artifact.
- To arrange a set of knowledge units to create a knowledge group with the same characteristics for a particular exhibition topic.
- To link the above elements to other related elements to form a knowledge network.

- To store multimedia documents, knowledge units and knowledge groups in advanced knowledge repositories with their semantic metadata to be reused and shared among specialists and applications.

5. Publishing stage

- To justify knowledge content before delivering to users.
- To convert each knowledge element into XML-based content structure by the system.
- To allow specialists to assign a presentation template to each knowledge element.
- To generate Web pages from combining the XML-based content and the specified presentation template.

6. Accessing stage

- To allow users to access knowledge content through an integrated semantic classification hierarchy-based browsing interface to share the common knowledge concepts with specialists.
- To design a metadata query interface for each knowledge repository for each domain.
- To publish knowledge content from various domains through a unified knowledge portal.

3.4 Multi-layer reusable knowledge content structures

In Rockley's UCS, the reusable content is limited in documents that can be broken down into the smallest reusable object (section, paragraph, and sentence). For a museum, the content can be defined as any type or unit of digital information, such as text, image, graphics, video and sound, or anything that will probably be organized and published across an inter-, intra- and/or extranet. Two major considerations must be made when constructing knowledge content for museums. One of these is how to create a versatile and complete structural representation; the other is how knowledge can be reused among specialists and various applications. To provide a content creation and organization model that enables the sharing and reuse of content among specialists of coexistent domains, knowledge content must be expressed in formal and consistent structures, by which the entire spectrum of knowledge content from basic to complex can be expressed and organized efficiently and completely. Therefore, this study defines a multi-layer reusable knowledge content structure to facilitate specialists to organize knowledge content from a core knowledge element into advanced or innovative knowledge elements (see Figure 3.3).

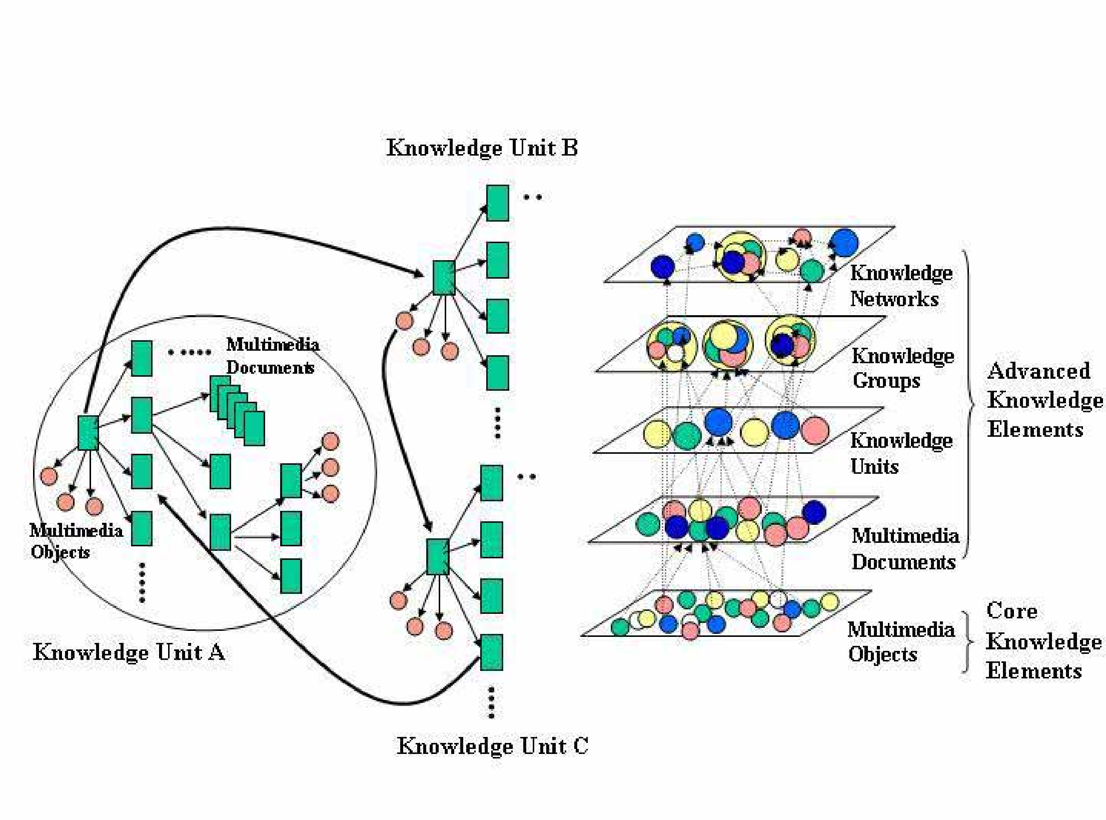


Figure 3.3 The multi-layer reusable content structures

Core knowledge elements are created during the editing phase; advanced knowledge elements are organized in the organizing phase manually; however, the system, exploiting data mining techniques, dynamically and automatically discovers, organizes and classifies innovation knowledge elements. From the requirements of content recreation and maintenance, authorized specialists can change and reorganize any knowledge content at will. The structures of core, advanced and innovative knowledge element are described below:

- Core knowledge element

  A core knowledge element is a basic and individual multimedia object (image, audio, video, text, animation or 3D object) associated with semantic metadata that interprets the context of a multimedia object.

- Advanced knowledge element

  An advanced knowledge element is further organized from a set of core knowledge elements. An advanced knowledge element can be a multimedia document, a knowledge unit, a knowledge group or a knowledge network. A multimedia document is set of core knowledge elements for describing a topic relating to an artifact. A knowledge unit possesses hierarchical structures and is employed to organize all relating topics that are organized as multimedia documents. A knowledge group is formed by a set of knowledge units having the same characteristics for presenting a research, education, or exhibition topic. The cross-relationships between any pair of the above various elements within intra domain or inter domains can be specified by specialists with links to form a knowledge network.

- Innovative knowledge element

  A large amount of implicit and correlating knowledge exists among coexistent domains. Innovation knowledge elements can be built automatically from core and advanced knowledge elements. Innovative knowledge elements have the same structures as advanced knowledge elements. The difference is that innovative knowledge elements are created, classified, and organized automatically, but for advanced knowledge elements the process is manual.

3.5 Integrated knowledge-based content management system

Content Management attempts to follow a given model for effectively creating, editing, managing, and publishing content [68]. Knowledge can be regarded as a kind of content to be managed. Content management can be considered as an infrastructure to amass and distribute knowledge [9].

No single list of the best requirements exists for a content management system. Every organization has its own needs. A classification scheme comprising content creation, content management, and publication and presentation has worked well for museums. The major requirements of content creation include integrated authoring environment, separation of content and presentation, multi-layer content structure, multi-user authoring, content reusing, metadata creation and powerful cross-linking. The key requirements of content management include version control, effective indexing, manage diverse content, integration with coexistent domains, adequate security and pro-active reports. The major requirements of publication and presentation include page templates, exchange support, and effective accessibility.

Considering the unique content management and knowledge management viewpoint of museums, the knowledge-based content management system includes the content creation subsystem, the content management subsystem, and the design of the publishing and presentation subsystem (see Figure 3.4).

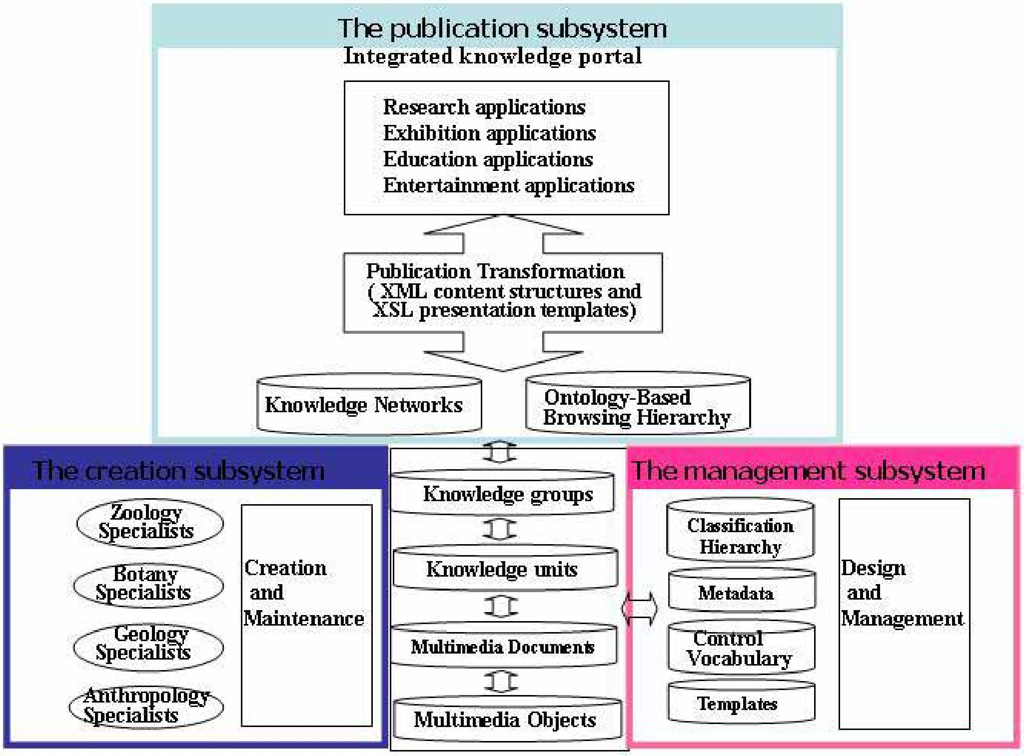


Figure 3.4 The architecture knowledge-based content management system (adapted from Rockley's)

The functionalities of each subsystem are described as follows:

(1) The content creation subsystem

- Editing the global classification hierarchy for various domains
- Editing core knowledge content elements with semantic metadata
- Organizing advanced knowledge content elements

(2) The content management subsystem

- Managing indexing structures of knowledge content
- Managing metadata repositories
- Managing vocabulary repositories
- Managing core and advanced knowledge content repositories
- Managing a global view of the classification hierarchy for all domains

- Managing authoring template databases

(3) The publication and presentation subsystem

- Converting knowledge elements into XML-based content structure
- Publishing Web pages from XML-based content and assigned XSL templates
- Building the classification hierarchy-based browsing structure
- Creating the metadata-based query interfaces

3.6 Conceptual modeling

Conceptual modeling means identifying relevant concepts of the real world with an abstract model. Conceptual modeling intends to integrate different views of an organization into one global and consistent model where entities and relationships are explicitly defined. The conceptual modeling of a unified knowledge-based content management system for digital archives in the proposed model is designed to construct both enterprise domain knowledge systems and multi-layer reusable knowledge content structures by adopting a thorough syntax, a semantic tool, and models that concretely express and interpret them.

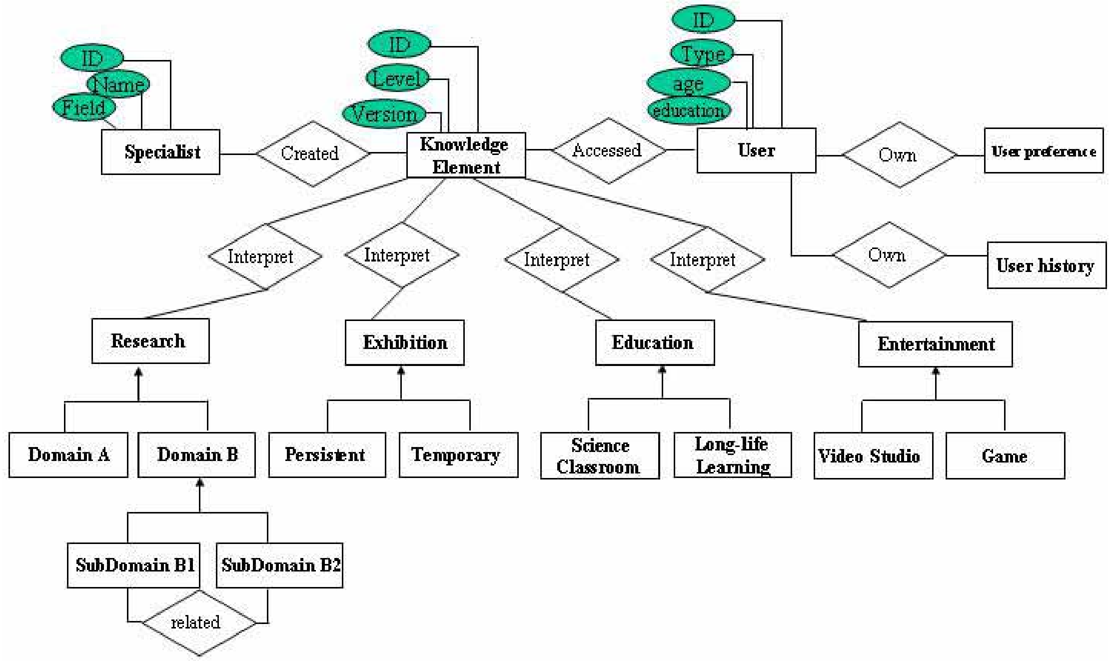
The ER Model (ERM) can be considered to be the ancestor of all modern modeling methods [14]. Since its original inception ERM has derived many descendents aimed at enhancing the conceptual design of relational databases. Due to the popularity of the object-oriented programming concept, the Object-Oriented Model (OOM) [25] and Extended Entity-Relationship Model (EERM) [71] have been proposed. EERM possesses the features of ERM and OOM, including aggregation abstraction, generalization abstraction, and association abstraction. Aggregation abstraction defines a PART-OF relationship between an entity and its components. Generalization abstraction defines a subset or IS-A relationship between entities, and establishes a hierarchy from a generic entity to its subsets. Association abstraction defines a multi-valued feature of attributes. Due to the many advantages of EERM, it has been applied in the conceptual modeling of database applications [7, 26]. Huang [42] also successfully applied EERM to conceptually model the multimedia databases of museum applications. This Study also uses EERM as a conceptual modeling tool in this paper.

3.6.1 Conceptual modeling of enterprise domain knowledge system

The conceptual modeling of a knowledge system (see Figure 3.5) across domains and applications in a museum can be summarized as having the following features.

- A top-down approach is used to construct the global knowledge system across domains.
- The relationships and constraints can be constructed between entities within a domain or across domains.
- The attributes of knowledge content can be specified as metadata annotated by specialists of each domain.
- To support efficient administration and personalized services, profiles of specialists and users must be specified.

After completing the system conceptual design, the knowledge hierarchy and relationships in a domain or between domains can be organized to construct the global knowledge system. The knowledge system can be constructed for application requirements and can also be viewed as the knowledge classification hierarchy system (Guarino, 1995) to represent them. The knowledge classification hierarchy system plays the common view among specialists and users. The knowledge element entities contain a set of core and advanced knowledge elements specified in Section 3.4. The next section reveals their conceptual modeling process.



3.5 The conceptual modeling of enterprise knowledge system

3.6.2 Conceptual modeling of multi-layer reusable knowledge content structures

The multi-layer reusable knowledge content structures shown in Section 3.4 provides a set of formal structures from elementary to complex for specialists to express and organize knowledge content for particular concepts. The knowledge element entity denotes the superclass of all knowledge content, and comprises the core knowledge elements, the advanced knowledge elements and the innovative elements.

The core entity denotes the class of core knowledge elements, each of which is a set of multimedia objects with semantic metadata. The multimedia object entity encompasses the entities of image, audio, video, text and animation. An instance of the advanced entity comprises a set of instances in the core entity. The advanced entity comprises of the multimedia document subclass, the knowledge unit subclass and the knowledge group subclass. The instance of the latter subclass is organized from a set of instances of the former subclass. Section 3.4 details the usage of the above three subclasses. Any instance in the core entity, advanced entity, or innovative entity may have a set of related link to instances of itself or to others to form a set of knowledge networks. The innovative entity with the same types of instances is inferred from the core and advanced entity. The conceptual modeling of multi-layer reusable knowledge content structures is shown as Figure 3.6.

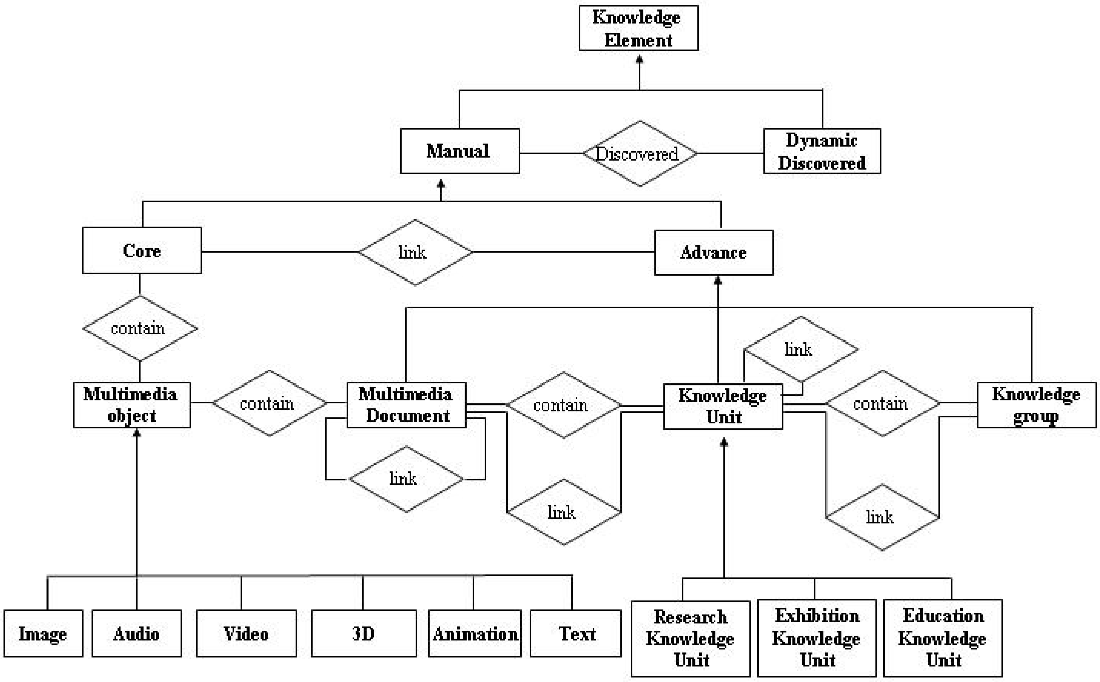


Figure 3.6 The conceptual modeling of multi-layer reusable knowledge content structures

3.7 A practical implementation

The unified knowledge content management approach for a digital archives project has been implemented in the National Museum of Natural Science (NMNS) in Taiwan (http://digimuse.nmns.edu.tw). NMNS is one of the nine primary participants of the Taiwan

NDAP introduced in Section 1.5. A total of fifteen domains in zoology, botany, geology and anthropology participate in the digital archives project of NMNS. All domains are coordinated and integrated by the information technology integration project to achieve unified processes, content structures, and knowledge-based management system development.

The unified process shown in Section 3.3, including the collecting, digitizing, editing, organizing, publishing, and accessing phases has been specified through discussions. All specialists in each domain must follow the standards and specifications of each stage. A single and integrated knowledge-based content management system (KCMS) was developed, by which the content creation, management, and publication described in Section 3.5 was fulfilled collaboratively among all content specialists and IT specialists. A multi-layer reusable knowledge content structures including core, advanced, and innovative knowledge elements defined in Section 3.4 was designed. These structures are managed and maintained by KCMS. All specialists applied them to edit, organize, and maintain content under a standard and consistent process. All the finished and verified content created by specialists was converted into XML-based content structures for publication. All knowledge content constructed under a single global classification hierarchy-based system and the interchange formats among institutes was also converted into XML-based structures. The XML-based content with assigned XSL templates was transformed into Web pages during accessing. Users could access content through the integrated knowledge portal through a classification hierarchy-based browsing and metadata search query interface. Figure 3.7 shows the entire implementation system. Figure 3.8 shows the global concept hierarchy and metadata creation. Figure 3.9 shows the creation of a core knowledge unit. Figure 3.10 shows the creation of an advance knowledge unit. Figure 3.11 shows an example of knowledge unit for interpreting the knowledge content of a species of vascular plant. Figure 3.12 shows an example of organizing a knowledge group for present an exhibition topic of vascular plant by the color of their flower. Figure 3.13 shows an example of organizing a knowledge network for present an relating knowledge units between insect and vascular plant.

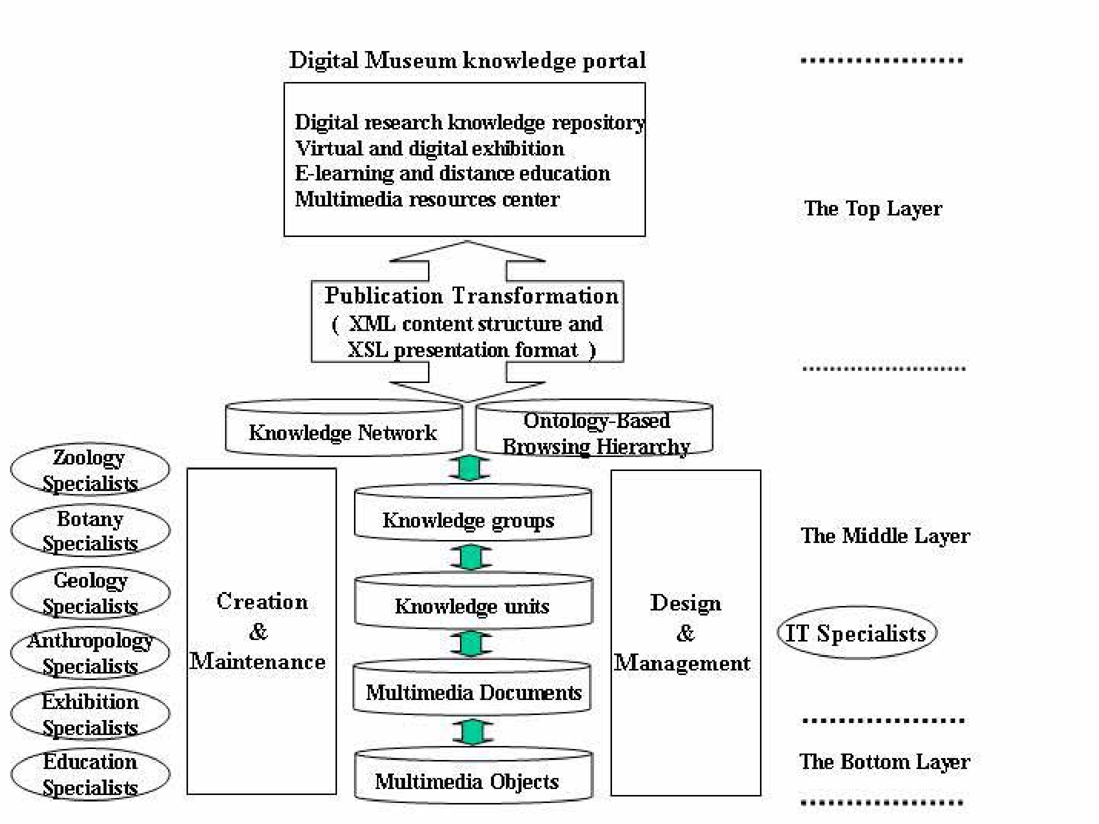


Figure 3.7 Implementation system of UKCM model

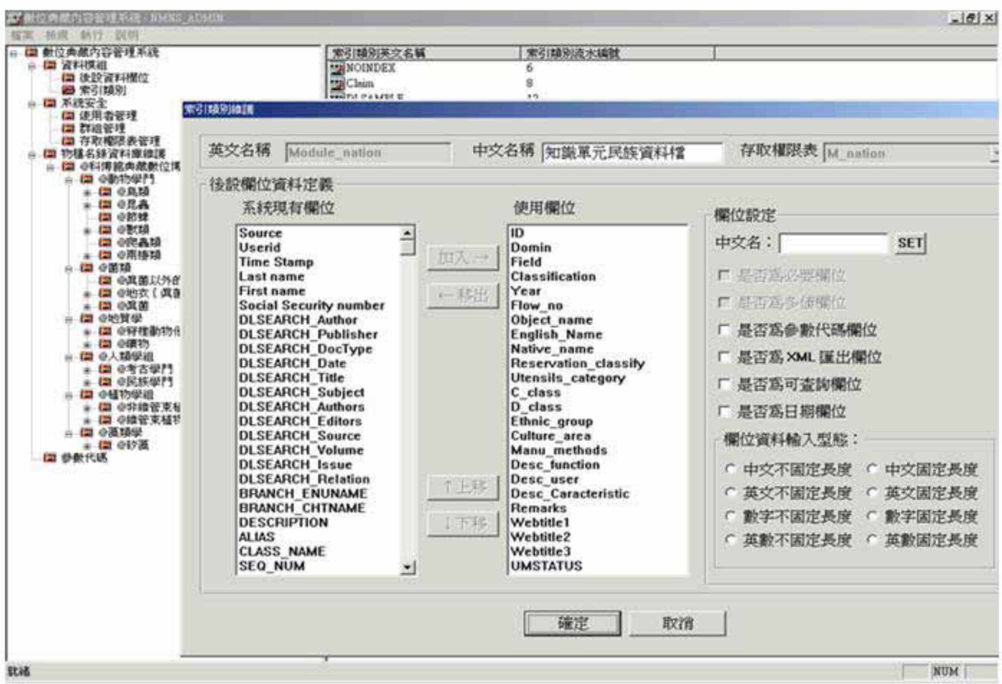


Figure 3.8 Global concept hierarchy and metadata creation

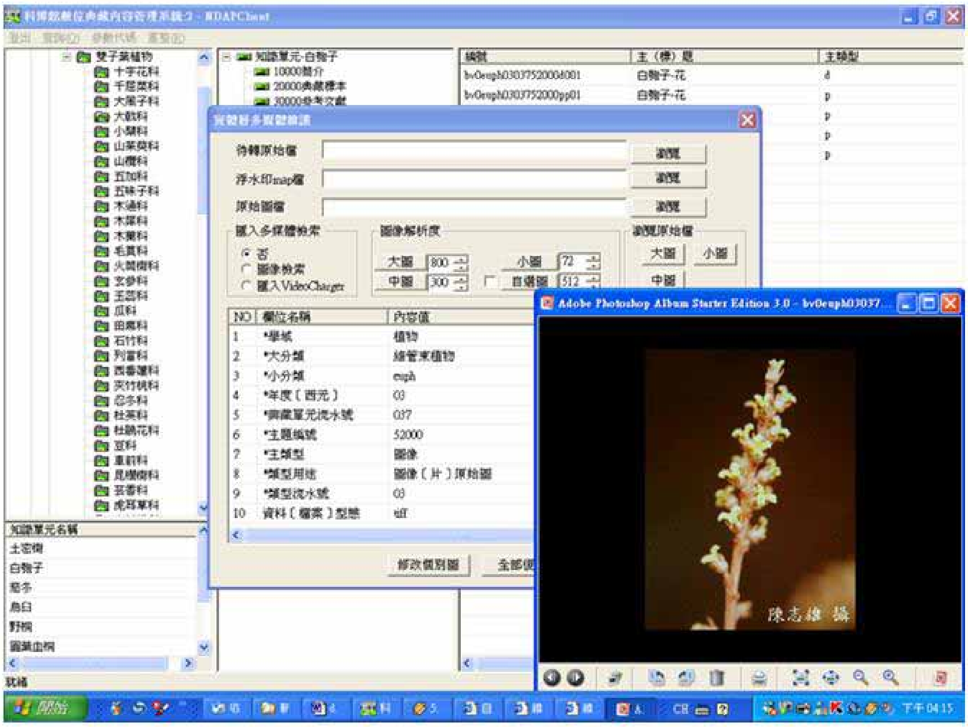


Figure 3.9 Creating a core knowledge element

Figure 3.10 Authoring an advanced knowledge element

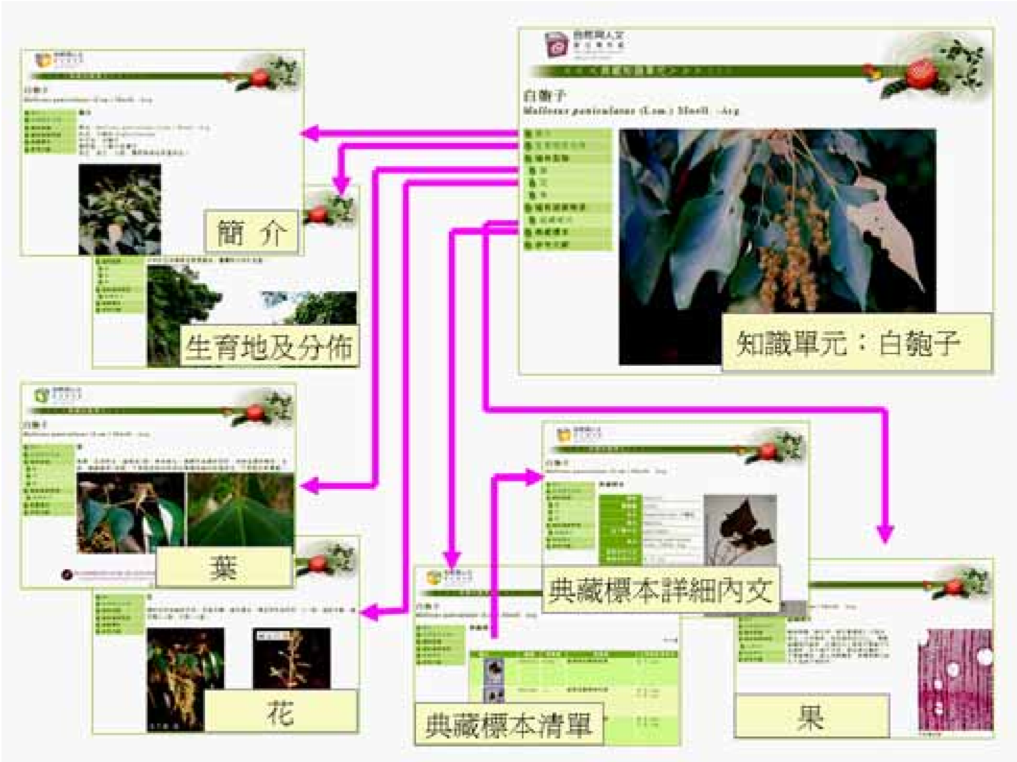


Figure 3.11 An example of knowledge unit of a species of vascular plant

Figure 3.12 Authoring a knowledge group

Figure 3.13 Authoring a knowledge network

Chapter 4

Knowledge-based ubiquitous learning service model

4.1 Introduction

Using the UKCM model described in Chapter 3, large quantities of knowledge content can be created and managed via a unified approach. Based the unified knowledge bases, numerous applications can be developed through system generation or art design. However, this approach remains inadequate to fulfill the goals of creating a knowledge-based digital museum. This chapter establishes a ubiquitous learning service model that reuses and extends the content of unified knowledge bases to achieve the goals of the knowledge-based digital museum. The ontological knowledge base layer of the KBDM framework can further be constructed by applying ontology to represent the unified knowledge bases in addition to user context and usage. Not only does it cover ubiquitous, proactive, adaptive, and collaborative properties, but this application can also efficiently reuse and diffuse large quantities of knowledge content. Consequently, the adaptive service agent layer and ubiquitous digital museum service layer in the KBDM framework are constructed in a manner that does not include the knowledge discovery module. The details are presented below.

Museums attempt to create a learning environment by using digital technologies to produce and deliver knowledge. The resulting learning environment exists both onsite as digital interactive content, and online on Web sites [33, 35]. The rapid evolution of information and communication technologies encourages museums worldwide to develop mobile learning solutions by creating extra channels for users with mobile handheld devices to supplement conventional docent and audio guides, and current digital technologies [29, 52, 64]. Many studies have indicated that mobile learning presents a chance to revolutionize the way that museums interact with visitors. Some applications designed for mobile devices can enhance visitor experience in museums [28, 41, 56, 67, 86, 87]. However, most mobile learning projects for museums, particularly in Taiwan, have not successfully developed of onsite tour guide applications for exhibitions. A friendly interface, attractive application [64, 87], multimedia presentation [86], and interactive accessibility [49, 56] are major concerns in such projects. Very few projects combine museum-wide content and services with related domains, applications and projects to create a ubiquitous, proactive and adaptive learning service. Therefore, most relevant knowledge cannot be integrated and reused; the learning content is uniform and constrained to particular domains; the learning environment is restricted in locations of museums, and services cannot be adapted to individual learners.

This study addresses some major factors in addition to these general design factors. Major factors include the type and subject of a museum (art, history or science), audience types and their requirements (student, teacher, general public or expert), integration of related content resources (collection, exhibition, education and entertainment) and the integration of service and business models with the physical museum (inside and outside the museum). This study proposes a model of ontological knowledge-based mobile learning with ubiquitous, context-aware and personalization services to fulfill these key factors. A ubiquitous learning service [28] enables learners to undertake learning activities covering the pre-visit, onsite-visit and post-visit stages. A context-aware system serves people intelligently and interactively using users' contextual information, such as temporal and spatial information, in the museum around them [15, 51]. A personalization service provides a new communication strategy based on a continuous process of collaboration, learning and adaptation between a museum and its visitors during all learning stages [45].

Ontology defines the characteristics of a formal, explicit specification for a shared and common understanding of various domains [89]. A unified knowledge base developed in a digital archiving project for the NMNS acts as the kernel component to integrate content from exhibition, education and collection resources in a museum. Ontology acts as a common, sharable knowledge concept for communication between learners and the unified knowledge base. The learners' learning records can be represented by an ontological usage profile aggregated from the content profiles at a conceptual rather than titular level. These usage profiles identify useful usage patterns of individuals, groups and global learners. These patterns are used to recommend content for active learners.

A practical mobile learning project based on the proposed model was implemented and opened in July 2005 at the life science hall of the NMNS. This model is likely to be extended to the entire museum before the end of 2006.

This remainder of this chapter is structured as follows. Section 4.2 describes the learning service evolution from e-learning, m-learning, to u-learning. Section 4.3 describes a mobile learning scenario in a user-centered ubiquitous, context-aware and personalized learning environment. Section 4.4 presents a model that is modularized into three layers, ubiquitous learning service layer, adaptive application layer and ontological knowledge base layer, to realize the design issues. Section 4.5 describes an ontology-based model, which is designed to denote and combine learning content for collection, exhibition and education, as well as user context and usage. Section 4.6 describes a personalization service to carry out recommendations adaptively and proactively during the pre-visit, onsite-visit, and post-visit stages for each active learner.

4.2 Learning scenario

The following scenario shows how a student learns in a ubiquitous, context-aware, personalized environment with a knowledge-based mobile learning service. The scenario is described with the division of pre-visit, onsite-visit, and post-visit stages (see Figure 4.1).

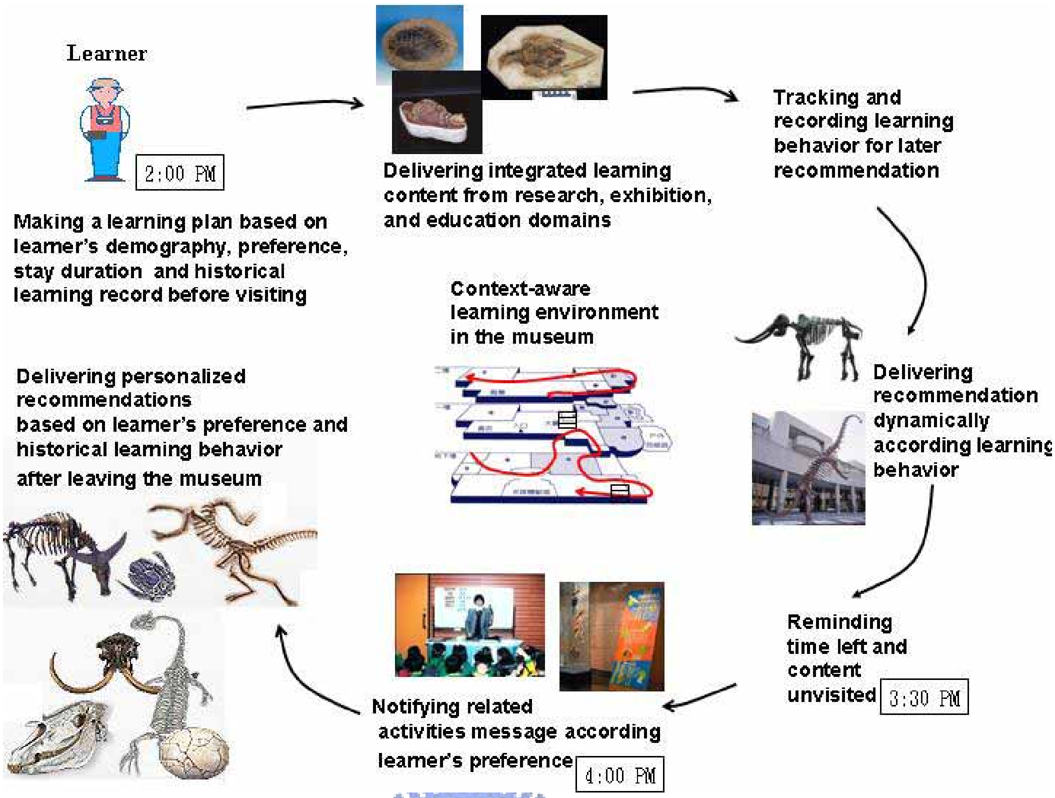


Figure 4.1 Learning scenario during pre-visit, onsite-visit, and post-visit stages

4.2.1 The pre-visit learning stage

Assume that a student wishes to visit a natural science museum for two hours, concentrating on exhibitions about fossils. Before visiting the museum, the student creates a learning plan at home using the Internet by specifying his subjects of interest, visit date, and stay duration. The system recommends all relevant learning content from a global perspective of the museum based on his demography and preference for fossils. The student then determines his final learning plan according to the recommendation, and registers for his planned visit.

4.2.2 The onsite-visit learning stage

When the student visits the museum, he downloads his previously created learning plan and conducts his learning activity by a handheld device. If the student does not wish to learn by planning, then he can learn by following some learning packages prepared by the museum, or learn freely without constraints. All three learning modes are served in a context-aware environment, and the system automatically pushes relevant guiding maps, learning content and messages based on his location and related context. The student may, while learning, follow the original visiting plan about fossils, or he may be interested in another exhibition about dinosaurs, which is not in the original plan. In this case, some exhibition items and messages of science educational activities about dinosaurs are also delivered to the student. All learning behavior is tracked and analyzed to provide further intelligent and proactive recommendation services to the student.

4.2.3 The post-visit learning stage

The student can continue learning via the Internet at any place and time after leaving the museum. The learning service recommends additional content to the student based on his preference and learning records tracked by the system during his onsite visit. The recommendation includes extra exhibition content that interests the student, but which he has not yet appreciated during his onsite visit. Other related content in collection and education knowledge bases are also recommended to the student. The system tracks and analyzes the student's learning behavior from his rating and navigation. Hence, the automatic recommendation service for the student's next pre-visit plan or post-visit learning is close to his requirements.

4.3 Learning service model

A knowledge-based ubiquitous learning service model in a museum (see Figure 4.2) can be sketched out according to the learning scenario in Section 4.3, and modularized into three layers, namely the *ontological knowledge base layer*, *adaptive application layer* and *ubiquitous learning service layer*.

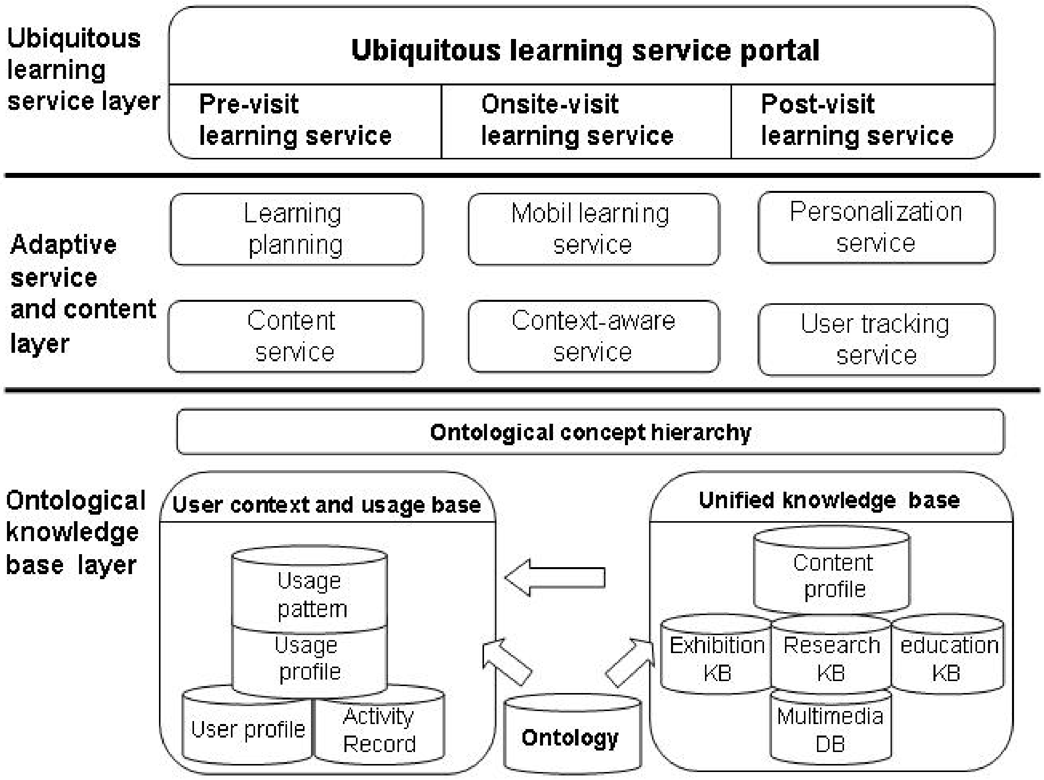


Figure 4.2 Knowledge-based mobile learning service model

4.3.1 The ubiquitous learning service layer

The ubiquitous learning service layer provides pre-visit, onsite-visit and post-visit learning via a single service portal. The pre-visit learning service provides an ontological interface to determine the learning content chosen by a user or recommended by the system. The learner can arrange a visiting plan, and register it before visiting. The learner can download a registered learning plan to choose package learning or free learning when visiting the museum. Our implementation discards infrared, ultrasound, WiFi (**Wi**reless **Fi**delity) and RFID (Radio Frequency Identification) solutions, due to their problems with operating efficiency, roaming and usability in exhibitions. Instead, a context-aware system based on ZigBee/IEEE 802.15.4 technology [48] was developed to serve learners by determining their demography, preferences, interests, locations, stay duration and visiting behavior. The post-learning service allows learners to continue learning from more recommended content related to past onsite visits.

4.3.2 The adaptive service and content layer

The adaptive service and content layer provides several services for learners in the pre-visit, onsite-visit, and post-visit stages. The *learning planning service* provides an ontology-based interface allowing a learner to create a learning plan during the pre-visit stage. The *mobile learning service* provides plan-learning, package-leaning and free-learning modes for a learner to proceed with his learning activity during the onsite visit. The service collaborates with the context-aware service to transmit requests to the content service during the onsite visit, and reminds the learner of his time spent and his current learning status. The *context-aware service* senses the learner's temporal and spatial context, and notifies the content service to deliver the appropriate guide maps, learning content and related activity messages to the learner. The *user tracking service* tracks the learning behavior of a learner during the onsite visit to capture the preference information for the personalization service. The learner's learning activities are dynamically tracked and recorded to refresh his learning preference of each learner. The *personalization service* adaptively and proactively recommends learning content to the learner in every stage. The *content service* delivers relevant content from requests of the learning planning service, the mobile learning service and the personalization service.

4.3.3 Ontological knowledge base layer

The ontological knowledge base layer generates and manages learning content, and maintains user context information and learning records for all learners. This layer consists of three components: ontology, unified knowledge base and user context & usage base. The *ontology* provides common and sharable concepts to denote the unified knowledge base and the user context & usage base. The *unified knowledge base* comprises a multimedia database and an integrated knowledge base in research, exhibition and education, and is created under an ontology-based concept hierarchy for content creation, management and publication. The *user context and usage base* includes user profiles, learning records, usage profiles and usage patterns. Section 4.5 describes in detail the unified knowledge base and the user context & usage base.

4.4 Ontology-Based content and user context modeling

Ontology has been applied in the past to digital archives, digital museums and museum-related e-learning projects to provide shared and reusable knowledge standards from user and system perspectives. The HowNet approach [23] is adopted herein to build a unified natural and cultural ontology for NMNS (see Figure 4.3). This study adopts the unified classification hierarchy from our previous work, and extends knowledge concepts about exhibition and education topics in natural science to establish the ontology. This ontology plays several significant roles in this study. First, this ontology serves as a sharable thesaurus describing entities, attributes, relationships and events for the unified knowledge base and user context. Second, the ontology maps content onto a simplified and standard specification, and processes it consistently for the learning service. Third, the concept tree of the ontology can be naturally employed to design access interface and calculate the similarity of concept definitions from the user context and the unified knowledge base in the personalization service.

Figure 4.3 A unified natural and cultural ontology

4.4.1 Modeling of Knowledge-based Learning Content

A global knowledge system with an ontology-based concept hierarchy and relationships in a domain or between domains was previously built in the Chapter 3. In order to support a mobile learning service, we extend the conceptual modeling of enterprise domain knowledge system and multi-layer reusable knowledge content structures in section 3.6 by applying ontology to connect the knowledge entity and user context entity. Figure 4.4 illustrates the conceptualization of knowledge elements in the unified knowledge base and the user context based on the shared ontology.

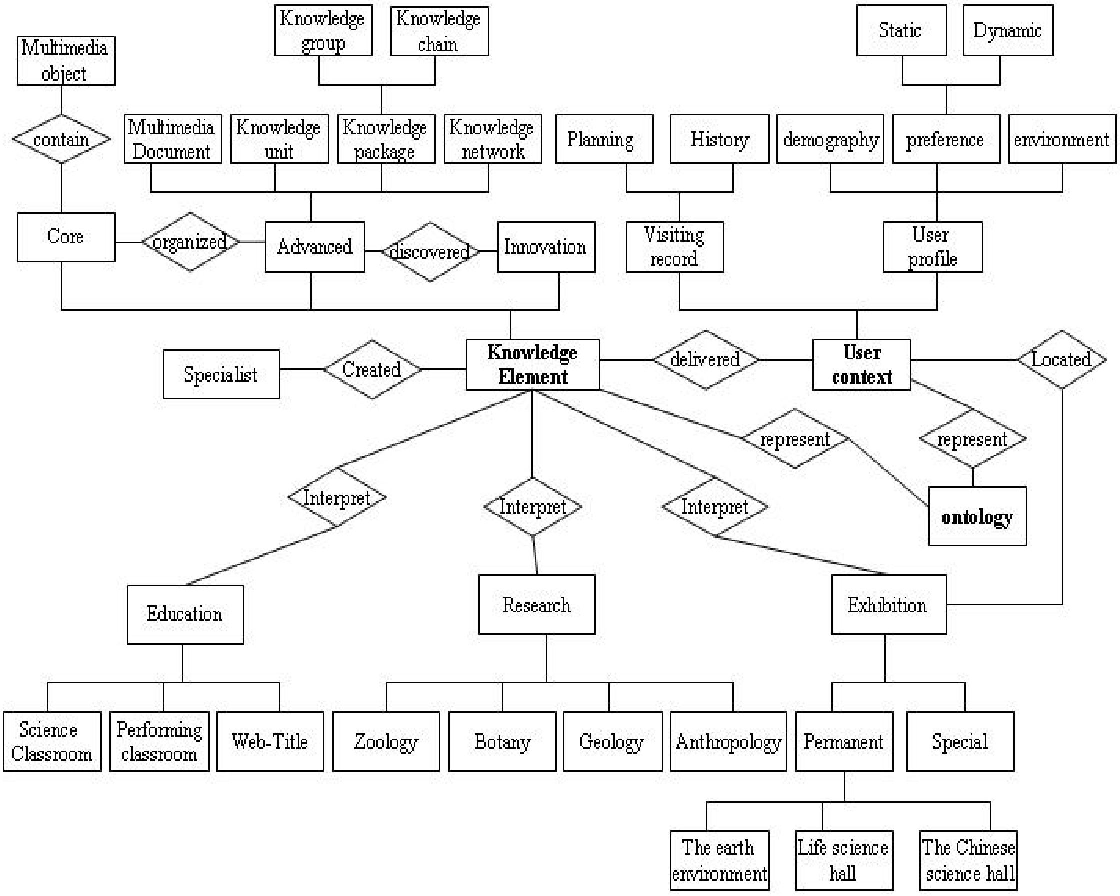


Figure 4.4 Ontological content and user context modeling

The multi-layer reusable content structures defined previously in Section 3.4 can express and organize many classes of content. An entity called *knowledge element* represents the superclass of all content, and consists of *core knowledge elements*, *advanced knowledge elements* and *innovative knowledge elements*. A core knowledge element is the basis of knowledge content, and consists of a multimedia object and its semantic metadata. An advanced knowledge element is further structured from a set of core knowledge elements, and can be a *multimedia document*, a *knowledge unit*, a *knowledge group* or a *knowledge network*. A multimedia document integrates several core knowledge elements to describe an item related to an object of nature or culture (one species of bird or plant, or an artifact), or an exhibition and education topic. A knowledge unit possesses a hierarchical structure, and is adopted to structure all related multimedia documents to interpret a particular object or topic. All knowledge units can be categorized into three subclasses, namely the *collection knowledge unit*, *exhibition knowledge unit* and *education knowledge unit*.

A new entity, *knowledge package*, is defined to support the package-learning mode. This entity comprises a set of knowledge units with the same properties to present a research, education or exhibition topic. The *knowledge package* consists of two subclasses, the original *knowledge group* entity and a newly defined entity, *knowledge chain*. A knowledge group is a set of learning content items, and a knowledge chain denotes a sequence of knowledge units in a learning path. The knowledge chain entity can be applied to design learning packages for the package-learning mode. Specialists in content domains can define the cross-relationships between any pair of the above various elements, whether from within the same domain or different domains, to form a knowledge network.

Each knowledge element is converted to a content profile according to the shared ontology. All knowledge elements can thus be converted to content profiles with a consistent specification and process for the personalization service. Section 4.6 describes the process for creating content profiles.

4.4.2 User context and usage information modeling

Context-awareness is a key issue in the area of mobile and ubiquitous computing. Mobile users often require information depending on their current context, e.g. their location, their environment or available resources. For a mobile information system, several aspects of context can be considered, such as the characteristics of the particular mobile *device* (storage and screen size) and *network* (bandwidth and peers), context of the *application* (requirements in storage, download and display capability), context of the *user* of the system (e.g., time, location, interests), context of *information objects* (e.g., location). The handling of the concept data depends on the intended usage: information about the mobile device could be used to adapt the networking mode (to gain efficiency in the system communication) or to adapt the information display (to gain effectiveness in the user communication) [37].

People interact with a rich and stimulating environment like a museum for intellectual and aesthetic pleasure. This activity is not structured: adapting choices to the contingent situations, visitors move in the physical space guided by their interests or stimulated by the context. In order to avoid breakdowns in the flow of the activity, the boundary between the physical space and the information space should .be seamless

Information on the user context of a learner is vital to provide intelligent and proactive services to support context-aware and personalized mobile learning. Each registered user has a user context, which includes the *user profile* and *learning records*. As well as demographic information such as ID, age, education, sex, address and e-mail, a user profile also includes *static and dynamic preferences* and *environment context*. The static preference includes interesting domains specified by a user, and the dynamic preference is updated from the historical learning records tracked by the system. The environment context contains a learner's location, time used and time left, which are identified and measured by the system. The learning records contain the *learning plan* and *historical learning records*, and are denoted by a *usage profile* with a set of concept definitions aggregated from the content profiles. Usage patterns of individuals, groups and global learners are further discovered from usage profiles and used by the personalization service.

This work models user context and usage information using ontology. This method has two major advantages. First, the recommendation results based on content accessed can be assured to be accurate if the concepts are consistently represented in learners' usage profiles as knowledge bases. Second, learners can easily inquire about concepts when they do not precisely understand topics or know the titles of all learning content items.

4.5 Ubiquitous personalization service

In this section, we aim to develop a personalization technique to support ubiquitous learning during pre-visit, onsite-visit, and post-visit stages. Several techniques applied in personalization service are the following: content-based filtering, collaborative filtering, rule-based filtering and Web usage mining. More advanced data mining methods and algorithms for use in the Web domain include *association rules* (a technique for finding frequent patterns, associations and correlations among sets of items), sequential *pattern discovery* (an extension of associated rule mining in that it reveals patterns of co-occurrence incorporating the notion of time sequence), *clustering* (used to group together pages or users that have similar characteristics) and *classification* (a process that maps items into various classes such as different types of user profile) to discover interesting and valuable patterns [45].

We adopt Dai's [17] web usage mining approach to design a personalization service for ubiquitous mobile learning. This approach can be split into three phases, *semantic preprocessing*, *pattern discovery* and *online recommendation*. The first two phases can be processed off-line, while the third must be processed on-line. Figure 4.5 shows the personalization learning service model that we modify from Dai's to fit personalization service for a knowledge-based digital museum in our study.

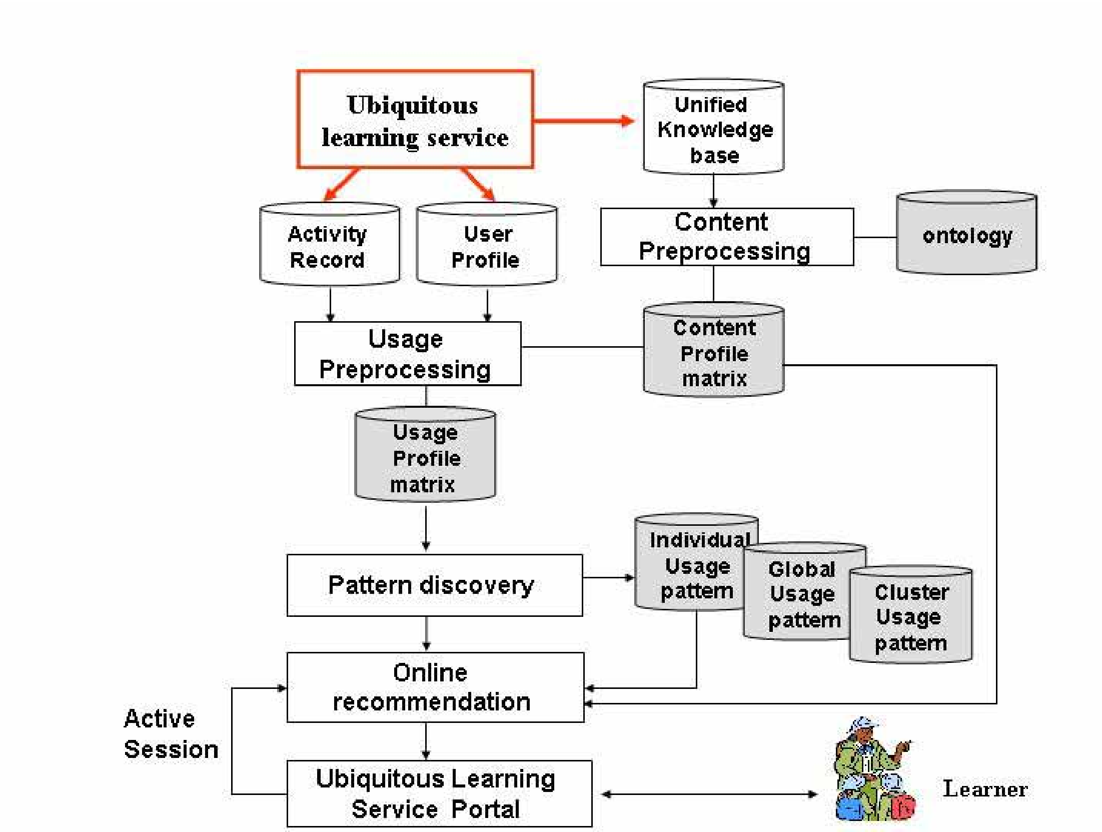


Figure 4.5 Personalization learning service model (adapted from Dai's)

4.5.1 Preprocessing phase

The preprocessing phase consists of two stages, *content preprocessing* and *usage preprocessing*. In the content preprocessing stage, the system generates a content profile for each knowledge element. A content profile consists of content ID, knowledge class, type and a set of concept definitions. For instance, two exhibition topics "Flying reptiles" and "Digging dinosaur fossils" belong to the exhibition area entitled "The age of dinosaurs." The "Flying reptiles" can be represented by dinosaur, reptile, extinguish, and fly while the "Digging dinosaur fossils" can represented by dinosaur, fossil, and dig.

The content profiles of the highest N-frequent concept items in a learning activity are aggregated in the usage preprocessing stage to form a usage profile. A usage profile includes the learner ID, learning activity ID and preferred concept definition. The dynamic preference is then updated according to the usage profile. For instance, if both "Flying reptiles" and

“Digging dinosaur fossils” appear in a learner’s learning activity, then the preference concept definition comprises dinosaur, reptile, fossil, extinguish, fly, and dig. The usage profiles of all learners can be aggregated to generate a usage profile matrix, which is utilized to discover useful patterns, as discussed in the next section.

4.5.2 Pattern discovery phase

The pattern discovery phase discovers useful usage patterns utilized by the online recommendation phase. One content pattern and three learner usage patterns, namely individual usage pattern, group usage pattern, and global usage pattern, can be discovered in this phase. In this study, these patterns were discovered using association mining algorithms [34] based on usage profiles.

In the individual usage pattern discovering process, an N-frequent itemset is determined from the concept definitions of each learner’s historical learning records to represent his preference. In the group pattern discovering process, all learners are divided into groups according to their demography and static preferences. N-frequent itemsets are obtained from the learning records of all learners in the same group. In the global pattern discovering process, all N-frequent itemsets are found according to all users’ usage profiles to represent a set of popular learning content groups among all learners.

In order to recommend and deliver content efficiently, all content items are grouped into clusters based on their similarity in their content profiles. Each cluster can be represented by a cluster content pattern with an aggregated concept definition from all content items in the cluster using clustering algorithms [34].

4.5.3 Online recommendation phase

The online recommendation phase provides an intelligent and proactive learning service during the pre-visit, onsite-visit, and post-visit stages. The recommendation service has two modes, user specification and system recommendation. The user specification mode makes recommendations by matching the learner’s static preferences and cluster content patterns.

The system recommendation mode makes recommendations by matching the individual usage pattern (dynamic preference), group usage patterns and global usage patterns with cluster content patterns. The similarity between the usage patterns and the cluster content patterns is measured by calculating the distribution of concept definitions in the concept tree according to the shared ontology. The algorithm for measuring the similarity between a usage pattern and content pattern is shown below:

U1, U2 represent the preference concept definition list specified by a learner and concept definition list specified by content experts

U1i，U2j are two nodes in the same concept tree

A(U1i,U2j) is U1i & U2j's co-ancestor

If U1i=U2j then

Score(A(U1i,U2j)) = High/(High+1)

Else

Score(A(U1i,U2j))=level(A(U1i,U2j))/(High+1)

(Get the maximum Score from the Definition pairs in the same tree)

Distribution(U1,U2)=(Tree{Def(U1)∩Tree{Def(U2)})/
(Tree{Def(U1)} U Tree{Def(U2)})

α= Distribution(U1,U2)

Sim(U1,U2) = (α *(AVG(Score())) + (Distribution (U1, U2))

During the pre-visit stage, a learner can specify topics from the recommendation list, and arrange a plan to meet his requirements for both modes. The recommended content focuses on exhibition items and education activities that the learner plans to see. During the onsite-visit learning stage, the learner can choose the plan-learning mode by downloading a registered plan, or choose the package-learning or free-learning mode. The extended content is proposed dynamically, while the refreshed individual usage pattern is similar to cluster content patterns.

The recommended content focuses on collection knowledge units, exhibition units and messages of education activities according to the up-to-date individual usage pattern. After visiting the museum, the learner can obtain further recommendations from the system based on the last learning activity or matching individual, group or global usage pattern with the cluster content patterns. The recommendations are extended to relevant areas in collection, exhibition and education, and are categorized according to content type in the multi-layer reusable content structures defined in Section 4.5.1. Figure 4.6 shows an example of the personalization service during the pre-visit, onsite-visit and post-visit stages. Figure 4.7 shows the implementation system to fulfill this ubiquitous personalization service model.

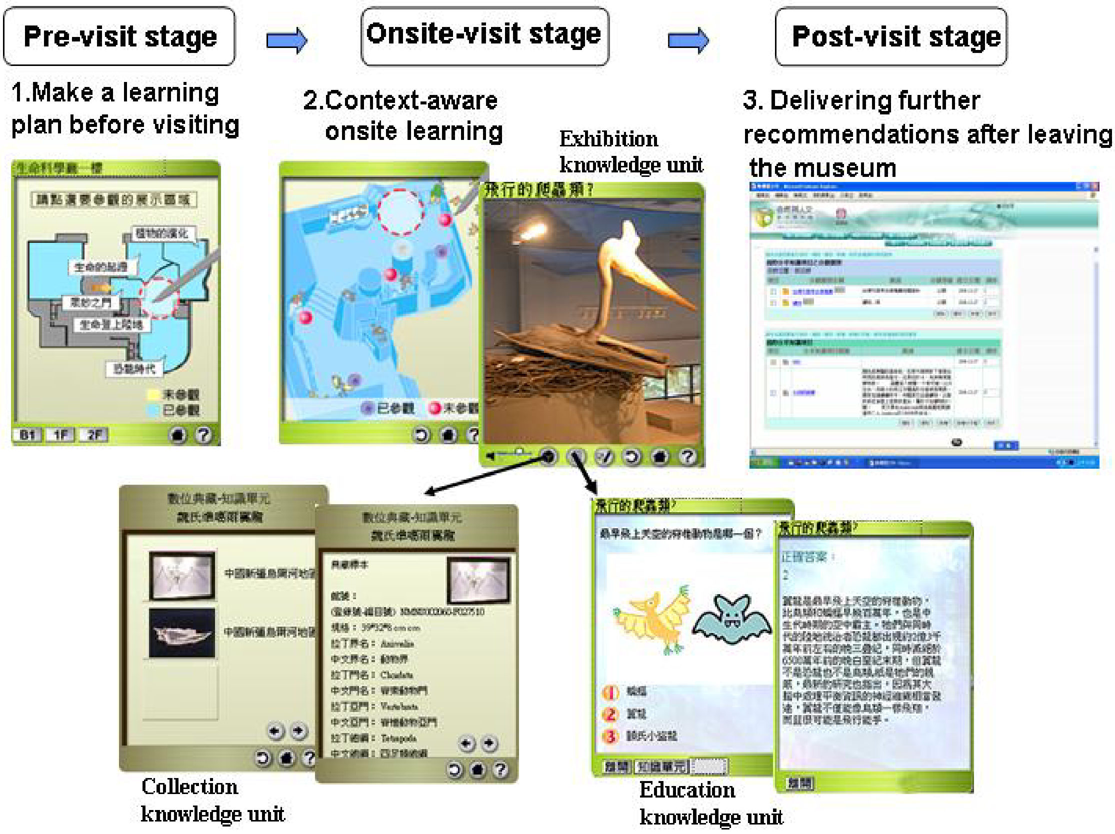


Figure 4.6 Example of ubiquitous personalization service

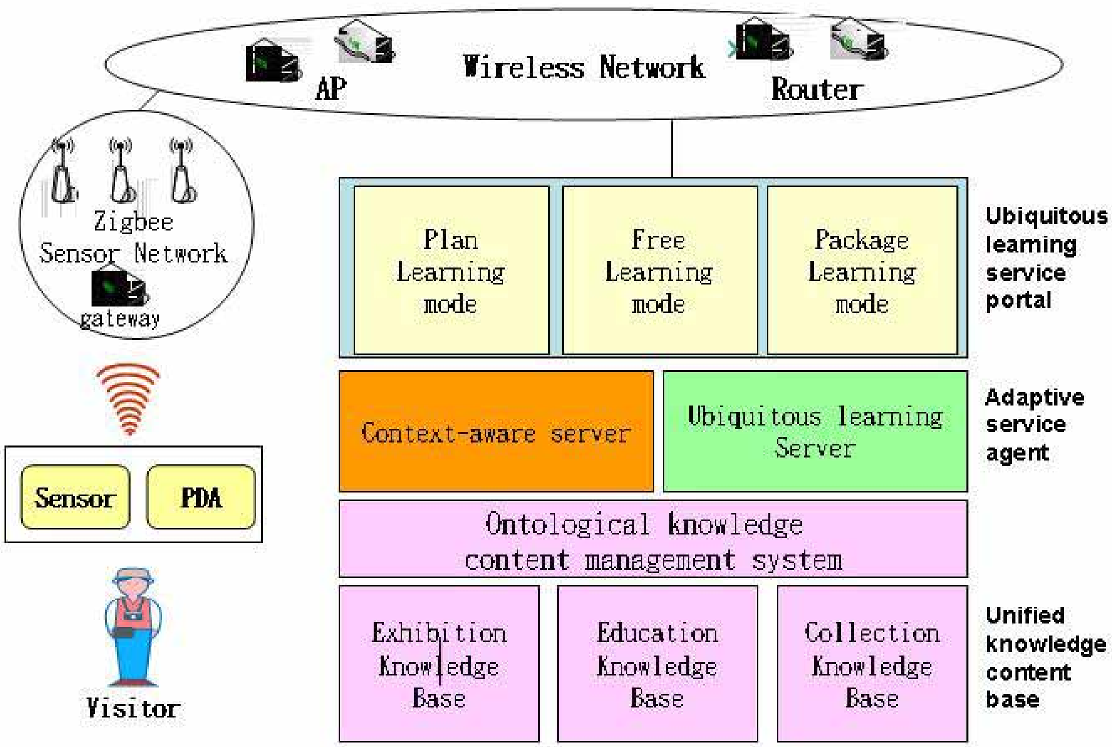


Figure 4.7 The implementation system for ubiquitous personalization service

Chapter 5

Ontological techniques for reuse and sharing knowledge

5.1 Background and Purpose

In the previous two chapters, the KBDM framework was constructed through the UCKM model and the knowledge-based ubiquitous learning service model. A unified knowledge system is created by integrating knowledge bases from various individuals, domains, projects, and applications. A knowledge-based digital museum is created by reusing the unified knowledge content; these contents and applications are diffused to various users proactively, adaptively and ubiquitously based on common and sharable ontological knowledge concepts. However, knowledge bases should be reused and shared as broadly as possible among communities and institutes using common knowledge acquisition and representation tools. Furthermore, implicit and innovative knowledge should further be automatically discovered and generated based on these knowledge bases. Consequently, knowledge sharing and discovery services can be incorporate into the KBDM framework to achieve these objectives.

Like most digital museums, NMNS aims to construct a virtual museum for the public by utilizing various information technologies. Though the content can be manually represented via query or through metadata schemas or hyperlinks, this study argues that the digital archive represents a promising model for providing "knowledge." Restated, the usability of current NMNS only focuses on providing explicit and static information. The current systems thus are insufficient for supporting advanced knowledge engineering, for example knowledge inference processes. To make provision for the future knowledge era, NMNS has surveyed ontological technologies for strengthening the current system. This study develops a pioneered project based on ontological techniques for restructuring current digital contents into corresponding knowledge bases. Three main tasks involved in this project are:

(1) Constructing a vascular plant ontology which represents a prototype of the knowledge base of NMNS,

(2) constructing an herbal drug ontology which pretends another knowledge base from outside communities, and

(3) developing a knowledge system for verifying the usability of correlative knowledge bases.

5.2 XML-based and Ontological techniques

Various studies have utilized KBSs in various fields, including expert systems, artificial intelligence, and decision support systems. Additionally, various approaches and tools have been used over the years to develop KBSs. However, many studies have noted challenges of sharing and reuse among KBSs [12, 31, 81]. Swartout [76] have concluded that KBSs are generally based on embedded systems and utilize their own special terminology system. Consequently, traditional knowledge technology and engineering restrict interoperable abilities among KBSs. Recently; XML technology has been introduced for data exchange and integration purposes in various application areas. Moreover, the XML-based plus ontological technique is an emerging technology that has been considered as an important solution for addressing the problem of reuse and sharing in KBSs.

The ontologies have long been used to express a shared understanding of information by human beings. Gruber [30] defined ontology as *"a specification of a conceptualization."* A conceptualization is an abstract, simplified view of the world that is used for representational purposes. That is, the ontology is a formal description of the concepts, attributes, and relationships involved in constructing common understanding for cognitions of real world events. A conceptualization is an abstract, simplified view of the world that is used for representational purposes. 'Explicit' means that the type of concepts used and the constraints on their use are explicitly defined. The ontology is a formal description of the concepts, attributes, and relationships involved and should be machine-readable. The 'shared' means ontology is used in constructing common understanding of a domain that can be communicated across several parties and application systems. For museums, ontology acts as the common understanding concept between knowledge specialists as well as the communication agent between knowledge specialists and users.

In the KBSs community, ontological techniques are used by defining a set of terminologies, the universe of discourses, and axioms. Consequently, as Gruninger [31] noted, ontology is useful for defining the common vocabulary used for representing shared knowledge. Since the advantages of XML are obvious, for example machine readability, automated parsing, and self-descriptive ability, there has been strong development of the XML-based ontological languages including RDF, DAML+OIL, and OWL.

Resource Document Framework (RDF) and RDF Schema (RDF-S) are the first solution from the World Wide Web Consortium (W3C) that provides a way for defining structured sets of terms involving class hierarchies and constraints [19]. RDF is a format for making descriptive assertions and statements by using two roots: metadata and representation. In library communities, electronic catalogs have been improved via the RDF-based Dublin Core format. For example, Amann [4] utilized RDF and RDFS to integrate ontologies and thesauri that can be used to query metadata. Additional background on RDF and RDF-S can be found in (http://www.w3c.org/RDF).

Because RDF/RDF-S has a limited ability to describe relationships with respect to objects, the method is currently being improved. Since 2000, DAML (DARPA Agent Markup

Language) has been developed as an extension to XML and RDF. The recent release of DAML plus Ontology Interchange Language (OIL) provides a rich set of constructs for creating ontologies and marking up information to make it machine readable and understandable [21, 73]. More details of DAML+OIL can be found in the Web site (http://www.daml.org).

Ontology Web Language (OWL) is the newest XML-based ontological language to be developed by the W3C. OWL inherits most features from DAML+OIL and has now become the recommended version (official and formal standard). According to the OWL specifications, the standard has three increasingly expressive sublanguages for different levels of usability: OWL-Lite is designed for a classification hierarchy and simple constraint features; OWL-DL supports those users who want the maximum expressiveness while retaining computational completeness and decidability; and OWL-Full has useful computational properties for reasoning systems with maximum expressiveness, but without computational guarantees. Because of the need to take advantage of the inference process, this study chooses OWL-DL as the ontology language. Further background of OWL and relative specifications can be found in the Web site (http://www.w3c.org/2004/owl).

5.3 Develop Ontological KBSs

To demonstrate the scope of KBS, this study creates the vascular plant ontology that belongs to the botany domain. Additionally, herbal drug ontology is created as a correlative domain. In practice, both ontologies are created using the OWL-DL format and are published on the Web. The herbal drug ontology integrates the vascular ontology during the execution. A developed application system then implements user requests to retrieve knowledge contents by implementing inference process.

Figure 5.1 illustrates the design architecture used in this study. The right block of the figure shows the multi layer reusable content architecture in the NMNS digital museum and the corresponding vascular plant ontology. Meanwhile, the left part of the figure illustrates an herbal drug ontology that is logically located outside NMNS. Both ontologies will be implemented in this study. Knowledge engineering procedures have been proposed for constructing ontological KBSs. Since there is different scope and content of various knowledge engineering procedures, this study has surveyed other research for further clarification [58, 62, 74, 75]. This study concludes and redefines knowledge engineering procedures for constructing ontological KBSs as follows:

- Knowledge acquisition deals with how knowledge engineers gather expertise from experts.
- Knowledge representation involves how knowledge engineers formalize expertise into a knowledge base format.
- Knowledge retrieval involves the query process between applications and knowledge bases.

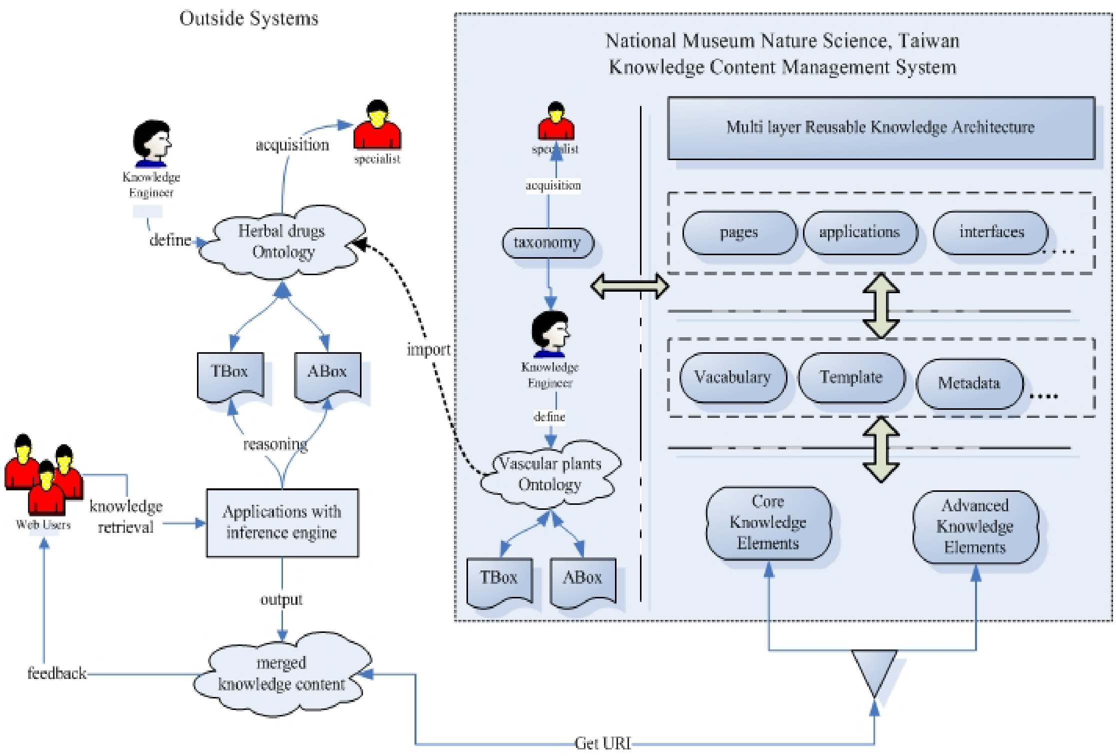


Figure 5.1 Overview of ontological architecture design

As Devanbu and Jones [20] and Baader and Nutt [6] observed, a KBS can be denoted as $K=(T, A)$. The expression represents that a knowledge base (K=) can be derived from TBox (T) and ABox (A). The TBox contains intentional knowledge in the form of a terminology, and the ABox contains extensional knowledge or so called assertional knowledge. The key role in both the TBox and the ABox is description logic that offers inference capability based on terminology and assertions. Figure 5.1 shows that both TBox and ABox are the outcomes of constructing ontologies. The figure also stresses that both ontologies are logically divided into TBox and ABox respectively. Additional studies of KBS can be found in the research [6].

5.4 Knowledge Acquisition

Knowledge acquisition is the first phase in the development of a KBS. The main task involves how to gather cognized concepts from domain knowledge. This study invited botanists and herbal pharmacologists as knowledge sources attempted to both vascular plant and herbal drug ontologies. The concept structure of vascular plant ontology utilizes the taxonomy of NMNS, which utilizes the specification of biological taxonomy (sometimes termed the Linnaean taxonomy due to its invention by Carl Linnaeus in 1735 [22].

On the other hand, pharmacologists have accumulated various resources such as literatures, herbal drug dictionaries, specifications, textbooks, and so on, to identify concepts related to herbal drugs. Figure 5.2 shows that knowledge acquisition involves gathering non-ordered and unstructured cognition into an identical ordered and structured concept. In the conceptual process, knowledge engineers must identify each concept that is comprised of a terminology, attributes, and relationships among terminologies. Numerous concepts can then be structured as taxonomy and become domain ontology.

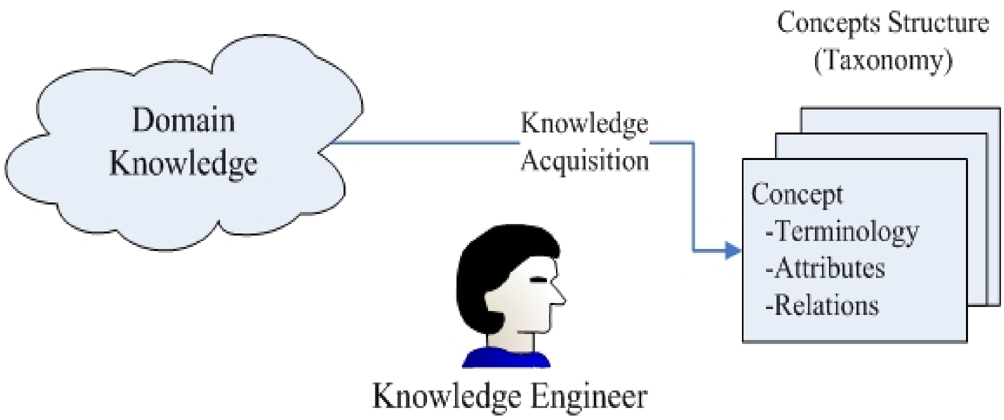


Figure 5.2 Knowledge acquisition and concepts

To efficiently elicit concepts from knowledge and create ontology structure, this study trained both knowledge engineers and experts to utilize the formal concept analysis (FCA) method and supporting tools to facilitate acquisition. FCA is a mathematical approach that analyzes relationships among components and calculates their dependency [27]. First, this study constructed a formal context of a concept within a lattice to express the components of the knowledge domain, including objects, attributes, and their relations. The components can be justified during the analysis. Second, mathematic algorithms, such as the Duquenne-Guigues algorithm, are used to calculate dependency rates and derive implications regarding their relations. Finally, a terminology hierarchy is proposed and a concepts hierarchy can be considered. Consequently, this phase provides a knowledge analysis mechanism for gathering common concepts and their attributes of domain ontologies. As knowledge scientists agree, FCA is a mature theory and tools exist for supporting concept analysis. Additional details of FCA have been provided [27]. Some useful FCA tools include the following: Vogt [79] and http://sourceforge.net/projects/conexp. To extract ontological concepts from real world, the formal concept analysis (FCA) [27] was adopted. FCA has been borrowed from lattice theory and mainly used for the analysis of data for filtering explicitly given information and the detail definition for formal contexts and concept lattices is defined as follows [27]:

1. A triple *(G, M, I)* is called a formal context if *G* is a set of objects, *M* is a set of attributes, and *I* is binary relations between *G* and *M*.
2. Let *g* be an object and *m* be an attribute. For deriving $A \subseteq B$ and $B \subseteq G$,

   $A' := \{m \in M \mid (g,m) \in I \ for \ all \ g \in A\}$

   $B' := \{g \in G \mid (g,m) \in I \ for \ all \ m \in B\}$ is then defined.

3. A pair of *(A, B)*: $A \subseteq G$, $B \subseteq M$, $A'=B$, and $B'=A$ is then called a formal concept.

The idea of FCA lattices comprises objects, attributes and the incidence relations into a table. The lattices can be represented by a line diagram to help designers to classify objects in different categories. To get ontological concepts precisely, the analysts can divide objects independently by adding more attributes in a lattice. For example, a simple set of vascular plants include objects, such as Pinacene, Thelypteridaceae, Aceraceae, and Araceae. The domain expert initially noted several attributes, such as seed, fern seed, herb, and arborous tree. Figure 5.3 illustrates objects in the left side and attributes in the top. The cross symbol indicates that the specific plant have the corresponding attribute. All empty cells indicate both plants and attributes don't have any relations.

As shown in Figure 5.3, the object Thelypteridaceae and Pinacene have same attributes that will further grouped in the same category. To identify unique object, domain expert may give more attributes to separate them. For examples, the attribute seed can be further divided into Angiospermae and Gymnospermae. The expert then assigns Angiospermae into Thelypteridaceae and Gymnospermae into Pinacene respectively. The updated lattice context can also be represented by a line diagram for better visual verification.

A	B	C	D	E
	Seed	Fern Seed	Herb	Arborous
Pinacene	X			X
Thelypteridace...	X			X
Aceraceae		X	X	
Araceae	X		X	

Figure 5.3 An example of vascular plants in lattice context

Generating implicit concepts is an important feature of formal concept analysis [44]. We adopt Ganter's definition of formal concept analysis to explain this feature. Let *A* and *B* be two objects, then $A \rightarrow B$ *for* $A, B \subseteq M$ *holds if* $A' \subseteq B'$, that is all attributes from *A* also has all attributes from *B*. Many FCA tools embed above attribute exploration mechanisms to facilitate object-attribute verification and consistency. As illustrated in Figure 5.4, the added attributes contribute each object independent. Consequently, FCA is useful for analyzing and extracting the ontological concepts.

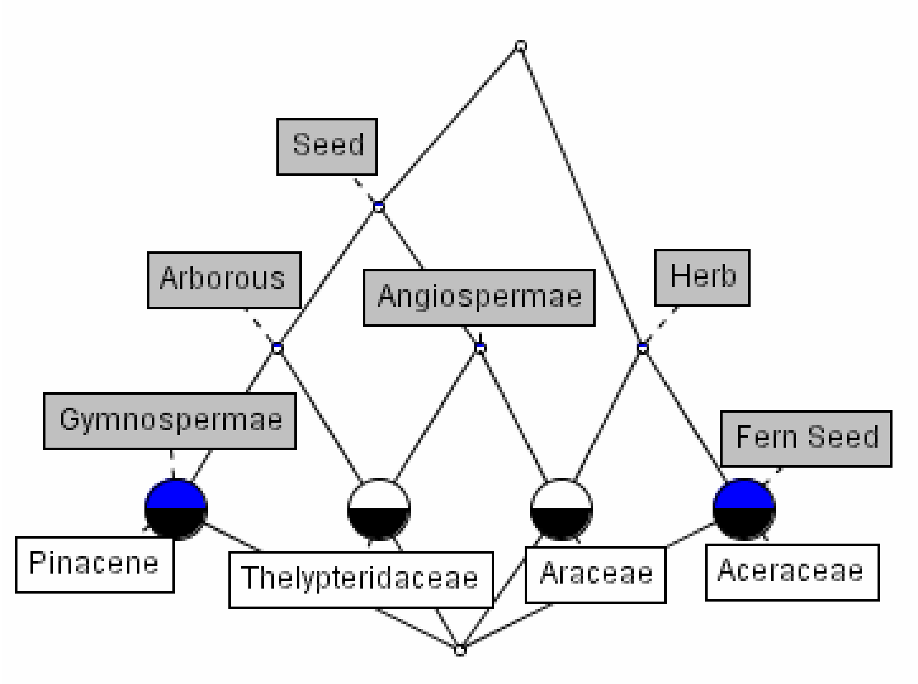


Figure 5.4 An example of vascular plants in line diagram

5.5 Knowledge Representation

Knowledge representation involves representing expertise (i.e. concepts) into information systems with specific formats. This study utilizes OWL-DL as the format for representing ontologies that are further considered as knowledge bases. Ontology normally comprises three components including classes (concepts), properties (attributes), and individuals (instances). The description logic (DL) is a describable fragment comprising classes, properties, and logic notations that express attribute or class relations [6]. OWL-DL supports automated reasoning by calculating logical relations and classifying ontology hierarchy.

In this study, the vascular plant ontology begins from establishing its concepts hierarchy, which is identical to a pyramid or tree with seven levels: species, genus, family, order, class, phylum, and kingdom. Each level has a specific description based on using the DL. For example, the plant "Gardenia Jasminoides Ellis", must be identified and located based on its corresponding levels, starting from Plantae, Angiospermae, Dicotyledoneae, Rubiales, Rubiaceae, to Gardenia. As object technology discipline, the child object inherits all features defined in its super objects. The following DL expressions are partial samples of the vascular plant which comprises Spermatophyte and Pteridophyta, and then the Spermatophyte comprises Angiospermae and Dicotyledons, and so on. The expressions can be represented using OWL-DL and are listed in Table 5.1.

Table 5.1 Partial expressions of the vascular plant using OWL-DL

```
- <owl:Class rdf:ID="Vascular_Plant">
  - <rdfs:subClassOf>
    - <owl:Restriction>
      - <owl:someValuesFrom>
        - <owl:Class>
          - <owl:unionOf rdf:parseType="Collection">
               <owl:Class rdf:ID="Spermatophyte">
               <owl:Class rdf:ID="Pteridophyta" />
            </owl:unionOf>
          </owl:Class>
        </owl:someValuesFrom>
      - <owl:onProperty>
          <owl:ObjectProperty rdf:ID="hasVascular" />
        </owl:onProperty>
      </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing />
  </owl:Class>
```

This study defines and represents 65 diagnostic term concepts in the herbal drug ontology and defines 266 named plant concepts in the vascular plant ontology. Some 313 herbal drug assertions and 722 vascular plant assertions are constructed respectively to provide facts. The ontologies described in this study have been published on the Web. The ontologies also can be reused and shared with other ontological knowledge bases. The establishing tasks are extremely time-consuming and require heavy loading; thus, the use of assisting tools is recommended. Some useful tools are available online, including Protégé (http://protege.stanford.edu/) and OilED (http://oiled.man.ac.uk/).

This study utilizes Protégé 2.1.2, OWL plugin, and Racer to establish ontological knowledge bases in vascular plants. Protégé is an integrate development environment (IDE) tools for building XML-based knowledge base systems. It provides simple and customizable editor and implementation functions. Protégé acts as a common architecture that allows extensible applications plug-in and provides add-on functionalities [50, 66]. The OWL plugin provides developers edit and visualize OWL classes and their properties. Moreover, OWL DL enables the definitions of description logic. Racer is a reasoner engine for developing inference capability. The Racer is especially designs for description logic computation based on TBox and ABox of knowledge base architecture. Consequently, the synergy of these supporting tools is helpful for creating ontological knowledge base.

To demonstrate the scope of ontological knowledge bases, this study creates the vascular plant ontology that belongs to the botany domain. In practice, ontologies are created using the Protégé and OWL plug-in editor and are published on the Web. A developed application system then implements user requests to retrieve knowledge contents by implementing inference process. To efficiently elicit concepts from knowledge and create ontology structure, this study trained both knowledge engineers and experts to utilize the formal concept analysis method and supporting tools to facilitate extracting concept structures. The conceptual structures further provide the inputs of establishing ontologies. As shown in the left window of Figure 5.5, the conceptual tree view represents ontology class structure. When classes and properties of the ontology are established, the last step is giving formal definitions to describe each component. As shown in the middle bottom of Figure 5.5, for example, the asserted conditions window is the description of the "Rhododendron."

Each DL expressions can be associated with several items including notations, properties, and fillers. The filler can be a class, a set of classes, or a combination of another DL expression. For example, if the "Rhododendron" had a feature of the erect steam, we describe the expression using an existential notation (∃), a property (*hasStem*), and the filler (erectStem). The DL expression therefore be defined as $\$\ \mathit{hasStem}\ (\mathit{erectStem})$. The asserted conditions have two different categories: necessary (ô) and necessary & sufficient (≡). The necessary expressions represent a subsumption relationship and the necessary & sufficient expressions represent a bidirectional equivalent relationship. In this example, the "Rhododendron" only demonstrates necessary expressions.

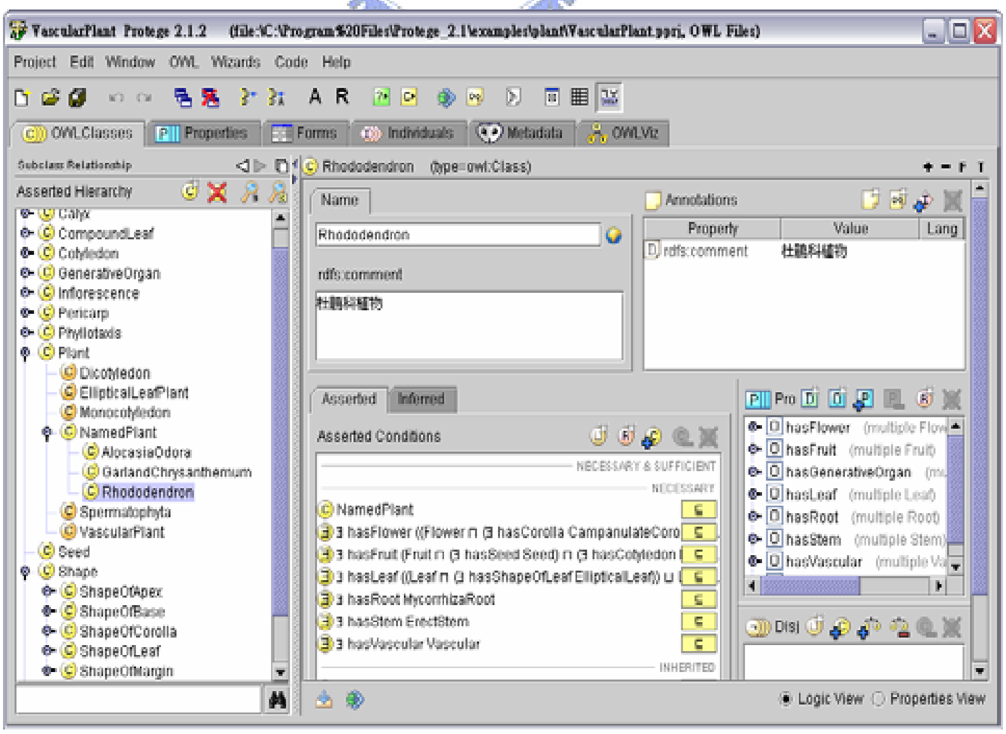


Figure 5.5. A Screen shot of using Protégé OWL plugin

5.6 Knowledge Inference and Retrieval

The protégé platform provides capabilities to integrate description logic reasoner engine, such as Jess, Clips, Racer, and so on. This study utilizes the Racer as a DL reasoner. The Racer provides several functionalities, such as consistency checking and taxonomy classifying for basic inference process. The consistency checking validates each class definition. If any inconsistent situation happened, the ontology has logic issue and can not be classified correctly. Designers are required to modify definitions of the ontology, such as asserted conditions. The taxonomy classifying is according to asserted conditions to generate an inferred hierarchy. In this hierarchy, it includes both asserted and inferred classes.

To retrieval knowledge from the developed ontologies, Protégé provides built-in knowledge acquisition (KA) functions by defining criteria in run time. Users also can develop their specific inference application by using related API, such as Jena API.

As illustrated in Figure 5.6, this study utilized Protégé query and KA functions to retrieval knowledge. The criteria are restricting in Rhododendron that had pink flowers, and erect steam. The response demonstrates that Dendrocharis is one of the qualified instances. Since Protégé also can associate the digital contents in the Web, the related contents are also retrieved as illustrated in the bottom of Figure 5.6. The Web based knowledge retrieval system presented in this study was developed by Jena APIs (http://jena.sourceforge.net/) and is used as a knowledge reasoner. The reasoner loads both TBox and ABox when an inference process is triggered. Since the TBox contains terminological axioms (definitions), the reasoner confirms the consistency of assertions using corresponding definitions and calculates relations among assertions in the KBS Abox.

For example, in the knowledge retrieval process a user makes an inquiry regarding a diagnostic description, such as a fever symptom. The system takes two treatment features of fever symptoms from the herbal drug ontology, "clearing away heat" and "purging intense heat", and generates a recommended herbal drug list. Figure 5.6 shows the outcome of the user selecting one of the herbal drugs. In this figure, the results of the first three sections are inference results that are implemented through the integration of both herbal drug and vascular plant ontologies. The first section provides general information regarding treatments and related herbal drugs. Meanwhile, the second section is abstract descriptions of the selected herbal drug. Moreover, the third section deals with the plant and its corresponding biological hierarchy tree. The herbal drug is generally represented using a common name rather than a scientific name. In this example, "Gardeniae Fructus" and "Gardenia Jasminoides Ellis" are the common and scientific names, respectively. The last section presents more descriptions of this plant, which are gathered from the NMNS content management system.

Figure 5.6 A knowledge retrieval example

It is important to stress the key points in the inference process (see the expressions below this section). In herbal drug ontology, "Gardeniae Fructus" is used for the treatment "clearing away heat", that can be further inferred to be an appropriate corresponding herbal drug for treating fever symptoms. In the vascular plant ontology, "Gardenia Jasminoides Ellis" is a child of "Gardenia", and inherits the characteristic "clearing away heat" from "Gardenia." Furthermore, the common name "Gardeniae Fructus" of the plant is "same as" the scientific name "Gardenia Jasminoides Ellis" in the logical manner. The process can be concluded based on the treatment details of fever symptom to find the logical "same as" relation between "Gardeniae Fructus" and "Gardenia." Based on subsumption and "same as" relations "Gardenia Jasminoides Ellis" can be identified as an appropriate plant for treating a fever symptom. All expressions are indirect relations between the symptoms of fever and "Gardenia Jasminoides Ellis." The power of the process is the inference capability that uses the implicit information to produce explicit knowledge.

5.7 Discussions and limitations

Figure 5.6 may look like a conventional Web page that can be published by any author who fills out proper data. However, the value of this study lies in demonstrating that the digital contents of NMNS can be promoted as knowledge sources, and can be reused by the public in the future. For example, suppose that if some parties have KBSs and wish to share their professional knowledge with others. Traditional techniques may only provide system integration rather than infer their contents in knowledge layers. That is, knowledge sharing involves not only system connection but also the participation of knowledge inference mechanisms. Particularly, this study has demonstrated that the OWL-DL can be used to construct an ontological KB. The OWL-DL supports describing concepts, attributes, and instances which contain a hierarchical description and logical relationship. Additionally, the

OWL is a machine readable language, which can automatically parse and share a knowledge base.

Jacob [43] has noted the difference between categorization and classification, which can be used to verify this study, particularly in creating an ontological KBS. Based on his explanation, categorization involves the process of dividing the world into groups of entities whose members share certain similarities. In the knowledge acquisition and representation phases of this study, FCA is used to collect common understandings of terminologies and their supporting attributes and relations as concepts. The OWL-DL then conducts detailed descriptions of each terminology that can be considered as categories (concepts). On the other hand, classification involves the orderly and systematic assignment of each entity to a single class within a system of mutually exclusive and non-overlapping classes. In the knowledge retrieval phase, the inference process analyzes terminology definition and then appropriately categorizes assertions.

The main limitations in this study are that the development of ontological KB is time-consuming and requires seamless collaboration among specialists, knowledge engineers, and information systems. Building an ontological KB is an art more than a technical skill. Furthermore, a well-defined ontology requires long-term and constant maintenance. Therefore, this study proposes making ontologies smaller.

Chapter 6

Conclusion and future research

This study specifies various problems, including content silo trap problem among projects, content lost during activities, weakness throughout the entire knowledge management process, and poor provision of integrated services, existing in digital museum projects worldwide. A knowledge-based digital museum with curatorial, social, professional, administrative and promotional goals that uses unified knowledge content to provide proactive, adaptive, ubiquitous and collaborative services for various types of users through global knowledge management processes in actual and virtual accessible spaces is specified as the goal of the next generation digital museums.

To solve these problems and achieve the goal of creating a knowledge-based digital museum, this study proposes a knowledge-based digital museum framework and designs a practical system for application to the National Museum of Natural Science, Taiwan. The proposed framework attempts to solve overall knowledge management issues, including creation and management; reuse and diffusion; and sharing and exploration that can be fulfilled for a museum from both global and long-term perspectives. This framework is realized via the three real research approaches to demonstrate its practicability and benefits. The details are discussed in Chapters 3, 4, and 5. This study yields three important results:

(1) Unified knowledge content management (UKCM) model

This model unifies abundant and growing knowledge content acquisition, representation, creation, organization, and publication for all specialists, departments, projects, applications, communities and domains based on common and standard workflow and multi-layer reusable knowledge content structures from both global and long-term perspectives.

(2) Ontological knowledge-based learning service model

This model reuses unified knowledge content to develop various value-added applications, particularly for learning services; and diffuses these contents and applications to various users proactively, adaptively and ubiquitously based common and sharable ontological knowledge concept.

(3) Ontological knowledge reuse and sharing approach

This approach shares knowledge content among domains, communities, and institutes and explores implicit and innovative knowledge in knowledge bases to expand coverage of knowledge domains using sharable and standard ontological techniques.

The above findings are in accord with the goals of the KBDM framework and satisfy the practical knowledge management requirements for NMNS. This study wishes to highlight some unique advantages of the proposed KBDM framework that are overlooked in global digital museum projects. These advantages, which are summarized as follows:

(1) Knowledge-based digital museum

This study constructs a knowledge-based digital museum to reveal the overall knowledge creation and management; knowledge reuse and diffusion; and knowledge sharing and exploration capabilities and impacts that most projects do not fulfill. First, knowledge workers create the contents and there is an authoritative basis for assuming them to be true. Second, the various contents are interpreted using metadata with semantic annotation created by knowledge workers. Third, ontological techniques represent all knowledge contents via a common knowledge concept.

(2) Unified knowledge content management approach

Some digital museum projects have applied knowledge management approaches but these projects have only considered dealing with problems involving partial contents created by partial knowledge specialists in a museum. This study demonstrates the unified approach that knowledge management process is applied from the perspective of a global museum. Accordingly, the entire knowledge management process can be supported in issues involving creation and management, reuse and diffusion, and sharing and exploration

(3) Multi-layer reusable knowledge content structures

Most digital museum projects are focused on multimedia content or some other particular complex type of content, and thus their projects suffer from two major drawbacks. First, the limited content structure cannot fully support the contribution of domain know-how by knowledge workers. Second, the contents cannot efficiently support reuse in various services and applications. This study proposes multi-layer reusable knowledge content structures that knowledge workers can follow these structures to fully express their knowledge concept into systematic structures for users to capture them charily. The various content types can be flexibly organized and reused by various services and applications.

(4) Ubiquitous knowledge-based learning service model souvenirs

Museums are considered one the most important learning faculties in modern society. Numerous learning services focus on designing interactive user interfaces and multimedia presentations for specific applications with limited learning content. Based on the unified knowledge bases, this study provides a learning service with abundant research, exhibition, and education knowledge content and integrated services, including support for ubiquitous, context-aware, personalized services.

(5) Ontological approach for entire knowledge management process

Numerous digital museum projects are aware that ontology is an effective tool for creating common and sharable knowledge concepts among domains, communities, and institutes. Few of these projects can apply ontological techniques covering knowledge creation, management, reuse, diffusion, sharing, and exploration process to support applications such as this study.

Although this study's findings have theoretical and practical implementations for constructing KBDM framework, this study is not problematic free. Some of the limitations of this study are highlighted below.

(1) Flexibility of knowledge content structures

It is uncertain whether the proposed multi-layer reusable knowledge content structures fully support the expression and organization of content for all possible applications. The problem is that it is difficult to predict what kind of structures will be needed in advance for a particular application. To date, we are certain that it is enough for expressing and organizing knowledge content for NMNS's current applications. In the event of a future need to create new structures for certain applications, we believe that it will be easy to include them in the multi-layer structures.

(2) Completeness of sharable ontology

Designing ontology is tedious and time consuming. Building an ontological KB is more of an art than a technical skill. The greatest challenge is the process of obtaining consensus among individuals, domains, and communities. Therefore, this study simply presents the methodology for constructing ontologies via an example involving two related domains. This approach enables the gradual construction of the ontologies among correlated domains and communities.

(3) Development of user segmentation content

Content creation is costly in terms of time and money as well as being labor intensive. It is not practical to create different content for different groups of users. It is better to create content for the major user groups and applications within limited resources. Currently, this study simply focuses on creating content for major groups of users, such as domain experts, K12 students and the general public.

(4) Balance between systematic generation and art design content

The system generates a vast amount of knowledge content. This significantly reduces the burden faced by system engineers in converting this content into web pages. However, the visual quality and art creativity are constrained due to the limited presentation templates used. Accordingly, it is necessary to compromise between efficiency and visual quality for individual applications. If visual presentation is emphasized, supplemental art design is necessary following system generation processing.

(5) Decision maker support

Although this study proposes an entire knowledge management framework and realizes it via practical approaches, the content must still be created by knowledge specialists. Considerable knowledge content must also be delivered through various applications and promoted through various intelligent services. Besides enormous resource support, particularly in terms of techniques, manpower and funds, the main success factor is support from decision makers with global and long-term vision. Consequently, numerous contents, applications and services can be created continuously without barriers via top-down strategy.

Future research is clearly required, but this study is a crucial step. Among the numerous topics to be investigated in future researches, some important ones are as follows:

(1) Intelligent knowledge discovery and exploration mechanism

Research on knowledge discovery, classification, and organization is underway. Currently, a classification hierarchy is being used; a partial ontologies via an example involving two related domains is constructed, and in the future this hierarchy will be developed into a fully-fledged ontology among domains. The innovative implicit knowledge amassed in core and advanced knowledge elements will be generated and inferred inside the same domain or among related domains automatically. Moreover, the ontology will be dynamically extended, maintained, and mapped between specialists and users during content creation. Figure 6.1 illustrates the ontological knowledge discovery framework.

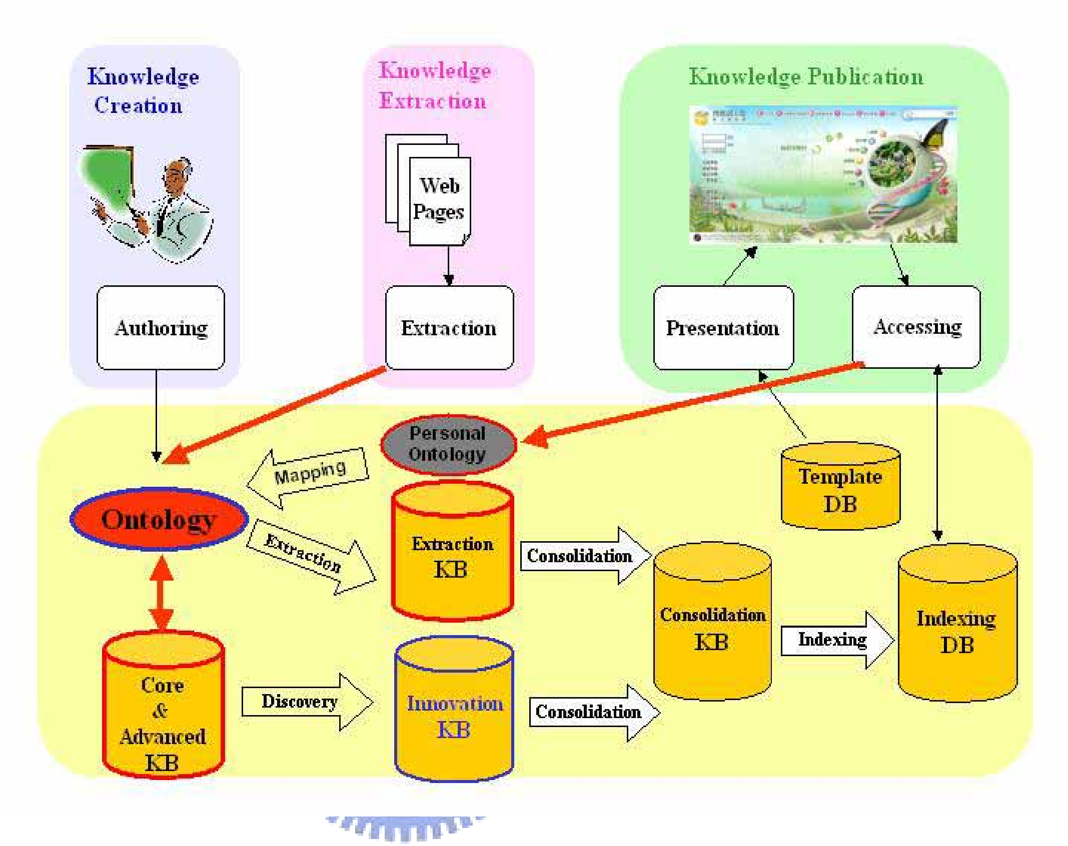


Figure 6.1 Ontological knowledge discovery framework

(2) Ontology-based personalized service model

The ubiquitous learning service model will be extended to all applications to construct a ubiquitous knowledge-based digital museum portal. An advanced personalization service for serving various users and applications will shortly be created. A more intelligent web mining personalization service that includes a personal ontology and natural language query will be created based on the improvement of ontology and data mining techniques. Figure 6.2 shows the personalization service model to support all applications and every individual user for the entire ubiquitous knowledge-based digital museum portal.

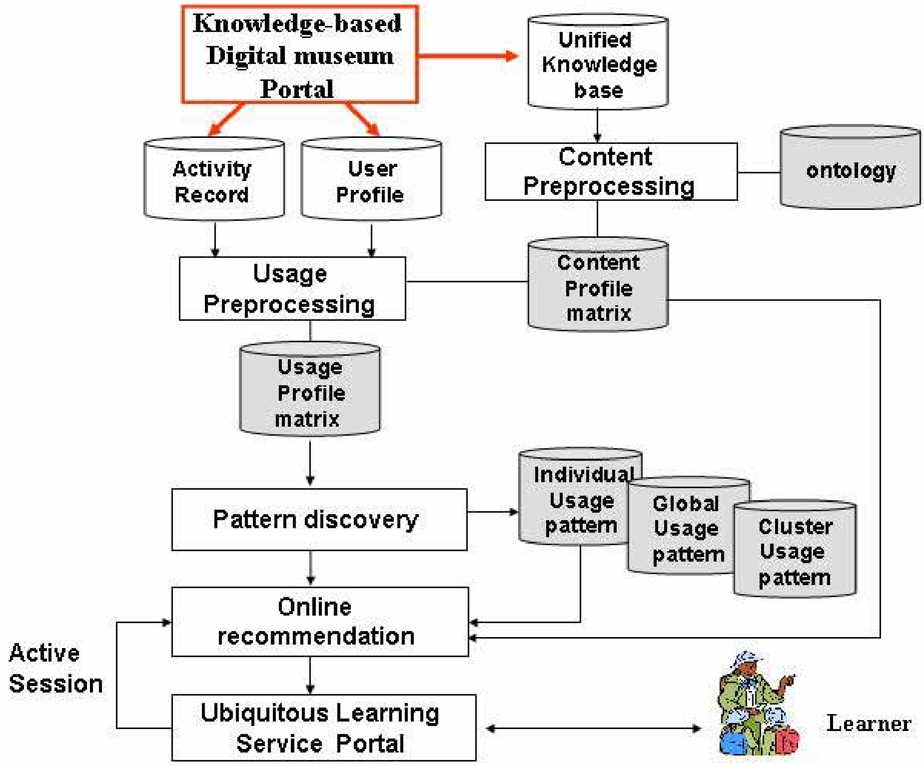


Figure 6.2 Personalization service for ubiquitous knowledge-based digital museum

(3) User behavior and satisfaction evaluation

This study creates extensive unified knowledge content based on multi-layer reusable knowledge content structures, and used these structures to develop ubiquitous, context-aware, and personalized learning services for users. However, this study further needs to know whether the contents and services can meet user requirements and whether the proposed system can achieve good performance for each service. Therefore, it is necessary to design evaluation methods by monitoring service response from the system and relevance feedback from users. Such evaluations can help us to improve and adjust content quantity and quality and service accuracy and efficiency.

(4) Advanced online authoring tool for designing applications

The proposed system provides multi-layer reusable knowledge content structures with systematic authoring tools for organizing various types of contents for various applications. These authoring tools can easily construct knowledge elements using predefined structures. However, more visual and flexible systematic authoring tools are required to support curators and teachers to design digital exhibition or educational material online by utilizing the vast existing knowledge bases.

(5) Knowledge-based digital museum business model

The KBDM framework has significantly extended the curatorial, social, professional, administrative and promotional goals of physical museums. This study hopes that this framework can incorporate with e-commerce model to serve knowledge consumers and digital industry. Therefore, the current framework should be extended to support commercial operation and promotion for both domestic and international considerations. This new generation digital museum business model can support museums not only for fulfilling original functions but also for creating revenue in the current knowledge economy era. Figure 6.3 illustrates the ubiquitous knowledge-based digital museum business model.

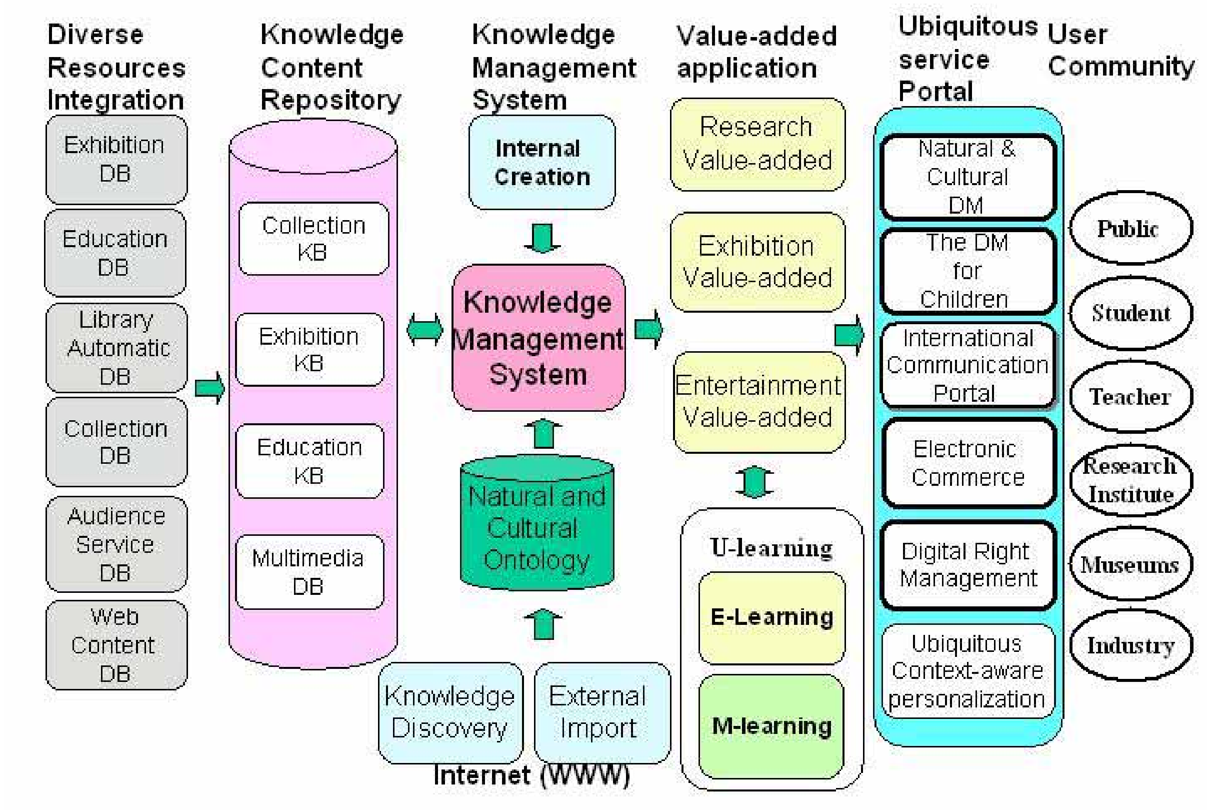


Figure. 6.3 Ubiquitous knowledge-based digital museum business model

Finally, this study stresses again that its objective is not to solve all knowledge management issues for all museums. On the other hand, this study tries to develop a knowledge management methodology that can provide a worthy reference for museums that possess vast quantities of knowledge. This framework can not only achieve unified knowledge management problems but also create unlimited opportunities and competition based on the vast knowledge content and numerous innovative services possessed by museums.

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