The Globalization of Manufacturing in the Digital Communications Era of the 21st Century: Innovation, Agility and the Virtual Enterprise

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Collaborative Development and Use of Ontologies for Design

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Abstract

In this paper, we introduce ontology-centric knowledge organization approach to realize design knowledge base system for sharing and reuse of knowledge. Since ontology is used here as an intermediate level of information representation between the model and media level of information, it can work to bridge multiple models and multiple users. DesignersAmplifier is a workbench for designers where they can store, organize their information resources, and also can communicate to other designers based on the ontology-centric knowledge organization. DesignersAmplifier helps designers to organize documents with ontology. For example, it can re-build documents as hypertexts of which hyper-links are linked to concepts in ontology. It can help designers to expand search words by ontology or by collocation data in documents. DesignersAmplifier can help communication among designers by exchanging ontologies. We realized exchanging ontologies by mobile agent architecture.

Keywords
ontology, cooperative design, mobile agent, information organizing

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1   INTRODUCTION

Rapid growth and spread of information technology especially network technology enables people to use computers more naturally and easily and as a result, their working style is changing, i.e., style of designers' work is also changing. It is especially significant on information gathering. Once main information sources for designers were their experience that was stored as drawing and documents written on paper, or human communication among colleagues, manufacturers, and customers. Now they can access not only their past documents and drawings by computers but also various kind of related information on the network. They can communicate with other people more rapidly and frequently by computer. Capability of information gathering is significantly increased. It is good news for designers to have good facilities for information access, because design is getting so complicated that more various information should be taken into account.

But such information flood can make designers confused, because they do not know how to use such enormous information effectively for their designing work. It does not denote incapability of designers but incapability of the current information technology. The current information technology like information gathering (for example, Knoblock and Levy (1995)) and information extracting (Cowie and Lehnert, 1996) mainly concerns how to obtain condensed information from broad information sources objectively. It is suitable for search problems for public information sources like newspapers. But design is more intensive and constructive work. We need a new technology to handle intensive and structurized information.

In the following sections, we will show our attempt for the above purpose, which is called DesignersAmplifier. DesignersAmplifier is a workbench for designers where they can store, organize their information resources and also can communicate to other designers.

2   DESIGN AS KNOWLEDGE ORGANIZATION

Design is a process of creating new artifacts, more precisely creation of specifications of new artifacts for manufacture from given requirements (Takeda et al., 1990). Although it is a visible and apparent process in design, there is another, usually invisible but also important process in design, namely, re-organization of knowledge. When a new requirement is given to designers, they sometimes survey their internal knowledge like experience and expertise, and sometimes collect external knowledge like books and catalogs in order to solve the given requirement. Such introduction of new knowledge and re-interpretation of existing knowledge cause designers' knowledge to re-organize in order to adapt current and future design tasks.

For example, suppose that a designer is given a required specification of product of which one of performance is greater than those he has designed. He would examine his past cases to check whether they could satisfy the requirement, find how to improve the performance somehow, and design a new product by modifying one of past cases. This example does not seem creative in ordinary sense, but even it contains re-organization of knowledge. He learned how the

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performance is achieved and reached a new conceptual configuration or structure for the product that could lead a new product satisfying the requirement.

Design is not always done by a single designer, rather team or group design is common activity. In such case, since knowledge is sharing among designers, re-organization of knowledge should also be shared, i.e., re-organization of knowledge is done in communication among designers. For example, suppose that a designer could form a new concept. It should be transferred to other designers, examined and sometimes modified by them, then finally shared.

In this paper, we do not seek theory or formalization for re-organization of knowledge itself, rather seek how to support such activity. The key issue is how to support designers' conceptualization process and exchange of concepts among them.

3 ONTOLOGY-CENTRIC KNOWLEDGE ORGANIZATION

In this section, we discuss how designers organize heterogeneous information and show an architecture for such knowledge organization.

3.1 Information Levels

Most crucial part of information organization is not in well-structured information but in unstructured one. Designers use various kind of information from physical models to natural languages. We have usually paid attention to so-called ``models'', e.g., 2/3D model and some mathematical model like thermodynamics and kinematics. Since models are well investigated and understood, there are many books and studies to handle them. But models are not sources but results of knowledge organizing formed after much engineering and scientific effort. Individual designers have tried to capture unstructured information, and some excellent and common organization of information could become models.

In design process, required specifications are normally given as human oriented or human understanding media such as natural languages. On the other hand, product specifications as results of design are in many cases given as machine oriented media or machine understanding or mathematically formalized media like geometric models, because current manufacturing methods are governed by computers. Focusing on representation media, design is a process that translates descriptions by human-oriented media to those by machine-oriented media (see Figure 1). Although it is a big gap, designers can somehow find the way to bridge them using their knowledge on objects and models and experience on design.

The same situation happens on communication among designers. Designers sometimes exchange information through human-oriented media and sometimes through machine-oriented media. We need systematical way to bridge both media. In this paper, we propose an intermediate media level between human-oriented and machine-oriented media. Function of this level is to provide fundamental relations between what both types of media. In our approach, it is a level in which only syntax is provided, and called "formalization level". Syntax is used to explicate structures in human-oriented media and it can also have some relations to structures in machine-oriented media. Structure in the formalization level is thus understandable both for human and machines.

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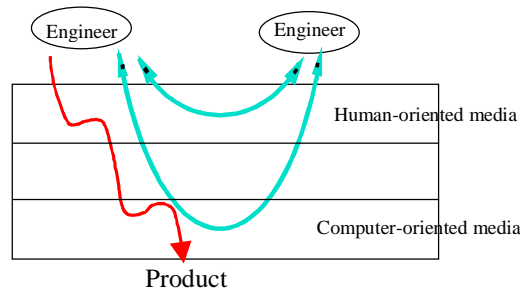
Figure 1 Levels of Information

3.2 Roles of Ontology in Cooperative Knowledge Organization

We adopt the formalization level as ``ontology'' in this paper. Although ontology cannot capture all functions of the formalization level, it can offer indispensable connection between the media and model levels.

Ontology is a term in philosophy and defined as ``the branch of metaphysical enquiry concerned with the study of existence itself'' (Flew1979). In AI community, an ontology is defined as ``an explicit specification of conceptualization''(Gruber 1993) that is intended to use as base for knowledge representation. Ontology is represented as systems of symbols in computers, i.e., symbols and their relations that represent concepts and their relations. Ontology commits only declarative nature of systems of concepts because its purpose is to provide consent for knowledge representation, e.g., identification of concepts. Therefore ontology is adequate as representation for the formalization level.

We here propose a new approach for knowledge based systems called *ontology-centric knowledge organization*. In this approach, roles of ontology are two-holds. One is as method of organizing knowledge that is further categorized as follows;

1. Ontology is used to structurize information from various sources by using its structure.
2. Ontology is used to bridge between the human-oriented and the computer-oriented level representation.
3. Ontology is used to bridge between multiple designers.

The other is as a kind of knowledge which itself should be acquired and organized. Ontology also should be accumulated, refined, and organized in the system. In order to include incoherent and simultaneous information activities, ontology should be multiple. Then it is important how to deal with relations among multiple ontologies. We have proposed formalization of multiple ontologies by modal logic in Takeda et al. (1995) and shown practical methods of integrating multiple ontologies in Takaai et al. (1997). In this paper, we focus on the former aspect of ontology.
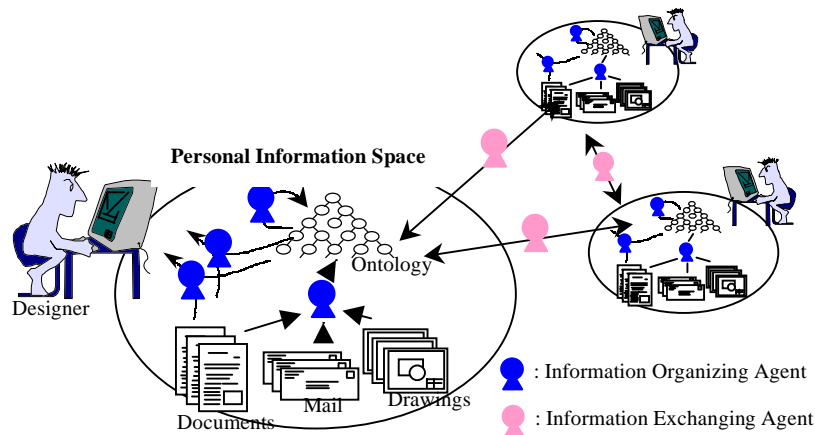
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Figure 2 Architecture of DesignersAmplifier

4   CONCEPT OF DESIGNERSAMPLIFIER

DesignersAmplifier is our current prototype system to support designers continuously from the human-oriented level to the computer-oriented level, which is based on ontology-centric knowledge organization approach. The basic idea of this system is to provide a information space for each designer where agents assist designers' access to information sources, organization of acquired information, and communication to other designers (see Figure 2). Designers can access information sources with support of DesignersAmplifier, e.g., by adding related information, at the same time DesignersAmplifier can collect designers' behavior by monitoring their information access. Information access and communication is sometimes purely in media level, sometimes in both media and formalization levels, and sometimes in media, formalization, and model levels. DesignersAmplifier mainly supports media and formalization levels, and can connect model-centered systems. Each designer can do his information activities through DesignersAmplifier so that DesignersAmplifier can maintain his personal information space. DesignersAmplifier also assist him to compose his ontology by providing various information organizing facilities like statistical analysis and ontology-based information classification. Thus he can evolve ontology more which can in turn strengthen information organizing facilities of DesignersAmplifier. This cycle can realize autonomous development of knowledge organization.

5   D/AMP 1.0: IMPLEMENTATION OF DESIGNERSAMPLIFIER

We have implemented prototype of DesignersAmplifier called D/AMP 1.0 that is based on agent architecture. There are personal information spaces provided for individual designers, and agents to process specific tasks on them. There are documents, ontologies, and agents on personal information spaces. Agents can read information on spaces and produce and put new information on them. They can also move other personal information spaces to find and retrieve information. Designers can order some tasks to agents or manipulate documents and ontologies by referring results from agent execution (see Figure 2).

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D/AMP is implemented as server (personal information space) and client (interface), and server is realized by Scheme and Java on workstation, and client is by Java on WWW browser.

5.1 Representation of ontology

We adopt frame ontology (Gruber 1993) as basis of representation of ontology, i.e., ontology is is-a hierarchy of concepts. A class represents a concept. Each class has its name, expressions, and slots. An expression is description how the concept is appeared in media like documents. A slot represents an attribute of the concept, and is described as a slot name, a class for attribute value, and an attribute value.

Super-sub relation represents a relation that implies inheritance. Connective relation represents other relation

5.2 Information Organizing

Our policy for ontology construction is not automatic ontology generation but computer-aided ontology building, i.e., the system supports designers to build ontology by showing related information. Basically only designers can develop concepts on ontology but they can use various analyzed or organized information which information organizing agents can present designers by using ontology on the environment.

Document-structurizing agent modifies documents so that words in documents can refer corresponding concepts in ontology. Collocation-computing agent computes collocation of words in document sets. Word-weight-computing agent computes the word weight by keyword vector method (Salton and McGill, 1983). Document-search agent searches documents with the collocation data and the word weight. Word-similarity-computing agent computes the word similarity from collocation data and other information. Information such as search result, collocation data, word weight and word similarity, is presented and used by designers to make design documents and ontologies.

5.3 Exchanges of ontologies among designers

In DesignersAmplifier, designers can collect concepts in other designers' ontologies. It is realized by mobile agent architecture. A mobile agent sent on a mission can visit other personal spaces, extract related concepts on them, and bring them back to the original personal space.

A serious problem with distributed information resources is how to find mutual relations among them. There are two ways to achieve interaction among distributed information resources. One is to provide special agents or facilities that can advice appropriate resources for given problems. Such facility is realized as information broker (Fikes et al., 1996) or mediator (Wiederhold 1992)(Takeda et al., 1995). The advantage is that no new mechanism is needed for information resources. The disadvantage is that broker or mediator should know contents of information resources in advance. On the other hand, mobile agent architecture can adapt
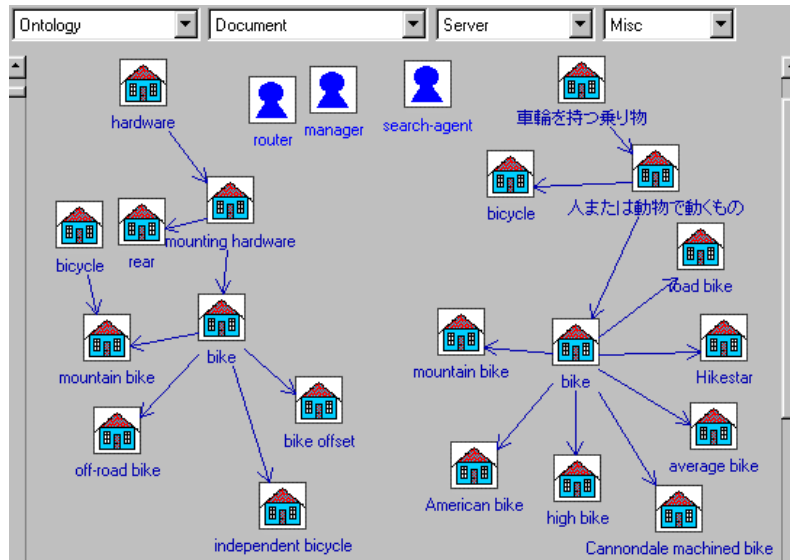
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Figure 3 Collected concpets by mobile agents

dynamically changing information resources although it requires new mechanism embedded in information resources. Since personal information spaces for designers change their contents dynamically, we adopt the latter approach.

We introduced a mobile agent mechanism in DesignersAmplifier and provided ontology-collecting agent.

5.3.1 A mobile agent mechanism

Agents and their information environments or places are basic components of mobile agent architecture (White 1996)(Rothrmel and Popescu-Zeletin 1997). An agent works with information on information environment where it resides or with communication with other agents. There can be multiple environments so those agents can move from one environment to another.

In D/AMP, an environment corresponds to a personal information space, and agent to either an information organizing module or an information-exchanging module between personal information spaces. As implementation, a mobile agent is defined as function in Scheme, and Scheme processes exchanges function codes through TCP/IP.

Since it is not secure that mobile agents can do as same as other static agents in personal information agents, we provide *manger agents* that control access from mobile agents to personal information space, i.e., every access is done through manager agents. We also provide *router agents* that assist mobile agents to determine which space they should go. A mobile agent can prepare which space it would go around in advance or determine it depending on spaces that it would visit. In the latter cases, router agent can suggest spaces related to the current space. There are manger and router agents in each personal information space.
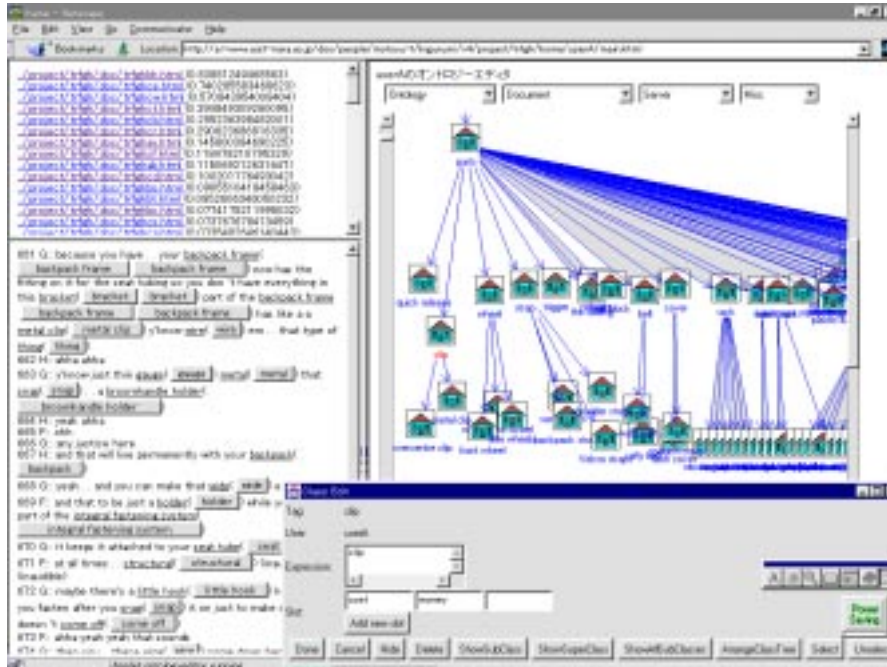
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Figure 4 Outlook of DesignersAmplifier (1.0)

5.3.2   *Ontology-collecting agent*

Using the mobile agent mechanism, we provide ontology-collecting agent that search and bring back systems of concepts in ontologies on other personal information spaces.

Ontology-collecting agent first receives a keyword list from a designer. It obtains a space to visit next by asking router agent on the current space, and then moves to the specified space. It then searches related concepts in the ontology on the personal information space, and stores a copy of the concepts and their relations. Then the ontology-collecting agent again tries to move next space that the router agent on the space that knows relevant spaces to the current space. Finally, the ontology-collecting agent goes back to the initial personal information space, and put the all stored concepts and their relations. Figure 3 shows that the ontology-collecting agent put concepts and their relations related to keyword "bike". "House" icon stands for concept in ontology and "Figure" icon for agent. The agent visited two other personal information spaces, and captured "bike" concepts and some related concepts to it. Since it found "bike" concepts in both two spaces, there are two concepts named "bike". Although names are the same, we can understand that hey have different sub and super concepts by referring other concepts collected together.

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6 EXAMPLES OF USE OF DESIGNERSAMPLIFIER (D/AMP 1.0)

Here we show how DesignersAmplifier (D/AMP 1.0) works by using the protocol data in a bicycle rack design (Cross et al., 1996). The protocol is a text data of conversations so that it is poorly organized.

The aim of this experimental use is to examine (1) organizing of protocol data, (2) design knowledge extraction from protocol data, and (3) re-usability of protocol data with search mechanism.

6.1 The protocol data in a bicycle rack design

The theme of the protocol is the design of rack to fix backpack to mountain bike easily. Three designers, who did not know the bicycle design so much, discussed the theme with some materials and data. The protocol data (about 1500 lines) is made by conversations of discussion. In this experiment, we divided the protocol into small text segments by twenty lines to compose a document set. And we picked out 240 concepts from the protocol and built ontology with them and the super-sub class relations.

6.2 Editing ontology

Figure 4 is a screen shot of the browser of DesignersAmplifier (D/AMP 1.0). The right part of window is ontology window in which designers can browse and edit ontology on his personal information space. Icons stand for class concepts, and blue arrows for super-sub class relations and green arrows (not appear here) for other relations. Right bottom pop-up window shows the concept edit window. Designers can look at definitions of concepts and edit them in this window. Here, the window shows the concept of clip. It has an expression 'clip' and a slot 'cost' that belongs to money class.

6.3 Browsing and search design documents

Figure 4 also shows the search result. When designer checks reference concept "clip" in right ontology browsing window, the system puts the search result in left window. Left top window shows a document list ordered by evaluation value of search result. Left bottom frame shows the content of a document that is selected from the above the document list by designer. This document is structurized one, i.e., some words are hyper-linked with concepts on ontology. Designer can retrieve a part of ontology related to the document by clicking these hyper-links. For example, the word "clip" is linked to the concept "clip" on ontology. Collocation-based search method is chosen in this example.

6.4 Collocation computing

Table 1 is a part of collocation data calculated with the protocol. Each pair of a word and a number indicates a word and its collocation value. The table shows top 10 words for "clip". Most of these words actually have some relations with clip in the protocol. For example, the words "wire" and "strap" are fixing devices as same as clip.

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Table1 Collocation of word "clip"

word	value	word	value
frame	10.9	wire	2.6
bag	10.0	outside	2.4
pack	5.6	strap	2.4
thing	5.0	back	2.4
bike	5.0	slip	2.3

6.5 Re-usability experiment

We performed a simple experiment to evaluate our system. The purpose of the experiment is how users can re-use protocol data by using our information organizing methods. We prepared the scenario that a user searches and investigates the parts of protocol in which designers discussed fixing methods of backpack on bicycle. We prepared subjects who have not seen this protocol. We compared performance with our system and with the Unix command "less". Time limit is an hour for each subject. Each subject is requested to search six or seven locations in which designers discussed fixing methods either by our system or "less" command. The correct answer we prepared is three locations.

With "less" command, the only one location that user answered is a correct answer, but with our system, the user detected all three correct answers. Mainly, the user found them with the following ways.

1. The user obtained the collocation words of some fixing method words (e.g., "strap").
2. The user obtained the related words on ontology.
3. The user searched the documents with these reference words and read the top three or four documents.

The experiments show that information-organizing facilities that we provide are useful to understand documents rapidly. Understanding documents in design is not achieved by simply searching documents, because specifications for search themselves are not well defined. When we want to search information for design, it often happen there are only vague or incomplete specifications for search, for example, only some of keywords are remembered and others not. In order to make specifications more complete and concrete, we should sometimes expand them and sometimes squeeze them. Information organizing facilities can help such processes. For example, referring to ontology helps users to expand their specification for search based on background knowledge, consulting collocation data is to help users based on features of the given document set, and reading some structurized documents assists users to refine specifications by understanding individual relations among concepts.

7 DISCUSSION AND CONCLUSION

Most relevant approach is work by Dong and Agogino (1997). We agree with them that unstructured information is crucial for design and that we should pursue to develop to process such information.

But difference is the basic assumptions for unstructured information, and therefore methods to deal with it are different. As we mentioned Section 3, we

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assume three layers for design information. Our claim is that unstructured information should have relations to more structured information like ontology. We have provided methods based on ontology. As we have shown in network-based information gathering, ontology-based search is reliable and effective in pruning unintended information (Iwazume et al., 1996).

But as Dong and Agogino mentioned, pre-defined ontology is not useful because of dynamics of design. The important feature of our approach is that unlike other ontology-based approaches (e.g., Gruber et al. (1992)) ontology itself should be developed during design. Dynamics of design should be captured as ontology development. Some of information organizing facilities can contribute ontology development.

Another important feature of our approach is that our system is highly interactive. We did not introduce any techniques like machine learning, because they are not mature enough to apply highly conceptual process like ontology development. Instead, we provide various presentations for users and communication methods to others for ontology integration. Ontology integration is another problem to solve. We have proposed some methods (Takaai et al., 1997), but more work should be done for this problem.

Although the current implementation is not sufficient and not well tested, we believe that we arose a new aspect for integration of design information and showed a solution for it.

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