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Ecological Work Based Classification Schemes

Abstract: This paper introduces a new approach to the design of classification schemes for complex work domains to help structure the knowledge domains in databases for single users and multiple users in co-operative work. Ecological work based classification schemes are designed on the basis of an empirical analysis of the invariant structures of the work domain and of the information needs of its actors. Invariant structures of a work domain can be explicit or implicit (hidden structures). The invariant structures are identified through empirical analysis of field studies in work domains, guided by the use of a means ends abstraction hierarchy. This hierarchy provides a model for analyzing, organizing and relating different levels of properties within a work domain. The resulting structure is an ecological classification scheme, comprising the different dimensions or categories of domain information that needs to be available for an actor to make a decision. Contrary to traditional classification systems which usually are designed from one particular point of view (a single discipline, paradigm or purpose), ecological classification schemes provide a transparent and structured information environment in which actors can navigate freely according to their current perspectives of work and subjective preferences.

1. Introduction

During the last decade, a number of scientific studies within Information Science, Social Studies of Science and Social Anthropology have explored the construction and use of classification schemes in professional work domains. Information Science studies include Bowker & Star (1999); Davenport (1998); Huber & Gillaspy (1998); Pejtersen & Albrechtsen (2000); Albrechtsen & Jacob (1998). Studies within Social Anthropology and Social Studies of Science comprise i.a. Suchman (1994); Andersen (1994); Cole & Engeström (1993); Star & Griesemer (1989). These studies are important contributions to a cross-disciplinary social theory of classification schemes at work. In addition, a few of these studies have discussed and assessed recent cases of classification schemes developed for specific professions, like nursing and psychiatry (see for instance, McCloskey & Bulechek, 1995; American Psychiatric Organization, 1994; Bowker & Star; 1999; Davenport, 1998; McCarthy & Gerring, 1994). For the medical field, the schemes are found to promote various implicit socio-political agendas within the explicit motivation of “standardization”. Implicit agendas range from managed health care (Davenport, 1998), towards global co-operation and knowledge sharing within medical research (Bowker & Star, 1991) and the development of a new self-understanding within a particular health care profession (Berg, 1999; Davenport, 1998; McCarthy & Gerring, 1994).

These recent studies of work based classification schemes are important for an articulation and broader understanding concerning the diversity of socio-technical functions, intentionalities and constraints of classification schemes within a professional work context. However, so far, no studies have addressed the problem of how to design work based classification schemes that go beyond local work places and/or professions. This paper describes the cognitive systems engineering approach to the design of ecological work based classification schemes based on field studies. The design of such schemes involves a means ends analysis of the work domain and the work content required in decision making during work (Rasmussen, Pejtersen & Goodstein, 1994). Special emphasis is on capturing recurrent themes and topics functioning as invariants (Gibson, 1979) in the domain in order to structure the concepts in such a way that the schemes will function as stable conceptual structures for the actors’ information searching.
1.1. Ecological Work Based Classification Schemes

Ecological work based classification schemes are schemes that are designed on the basis of an empirical analysis of the invariant structures of the work domain and of the information needs of its actors. Invariant structures of a work domain can be explicit or implicit (hidden structures). These invariants can serve as affordances for action. They are identified through the use of the means-ends abstraction hierarchy providing a generic model for analysis and description of work domains and the actors' information needs. This means ends analysis represents the invariants and affordances of work domains as a category separate from the actors, and in addition represents the invariants of the actors' information needs as they are formulated in their decision making during work.

The design of ecological classification schemes is a fundamental problem of structuring knowledge base contents to suit the actors' information needs during their decision making. Thus, ecological schemes require field studies of the search questions and the need formulations as they occur in the actors' work situation. The first step is to make an analysis of the workspace that is studied for the purpose of system design. The next step is to conduct an analysis of the decision situations and the actors' formulations of their information needs during their decision making. These analyses guide the identification of domain knowledge and design of a work based classification system.

This paper explains our approach to the design of ecological work based classification schemes by a conceptual introduction to the means ends model for analysis of a work domain, and by an introduction to J.J. Gibson's theory of direct perception together with implications for scheme design. The two-step approach to scheme design is illustrated by two examples: The design of an ecological classification scheme for the full scale library system called the Book House and by a field study of engineering design. This latter study covers a means ends analysis of the design workspace and the related information needs derived from interviews and questionnaires. In contrast to the library studies, the engineers' search questions during actual decision making were not collected, and therefore, ecological classification schemes have not been developed for this work domain.

2. The Means-Ends Abstraction Hierarchy

The means-ends abstraction hierarchy provides a model for analyzing, organizing and relating the different levels of properties within a work domain. The resulting representation of domain properties is a map of the overall conceptual territory, or in Gibson's terminology (1979), the affordance space within which the actors will navigate. Domain properties are represented in a means-ends structure that relates multiple goals and constraints with a variety of resources. The analysis of domain properties addresses why a work activity exists (goals and constraints), what activities are performed or should take place in the domain, and how these activities can be implemented in tools and work processes (figure 1). The analysis gives further structure through its decomposition into elements along a part-whole dimension and through its identification of the potential means and ends at several levels of functional abstraction. These levels include representations of physical work resources, work processes, general work functions, abstract value functions and, finally, goals and constraints with reference to the environment outside the organization (figure 2). These levels will also guide the identification of domain knowledge and development of a work based classification system. The lowest level of abstraction represents the physical anatomy of the system and the appearance of its elements, that is, its material configuration. The next higher level describes the physical activities and processes of the various elements in a language related to their specific material properties (e.g., physical, mechanical, electrical, or chemical processes). At the level above this, work functions are represented by more general concepts without reference to the physical processes or parts by which the functions are implemented. At the level of abstract function the functional implications are found which are used to set priorities and coordinate resource allocation to the various general work functions and to compare their
### Figure 1. WHY, WHAT and HOW in the Means-Ends Space

<table>
<thead>
<tr>
<th>MEANS-ENDS RELATIONS</th>
<th>PROPERTIES REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals and Constraints</td>
<td>Properties necessary and sufficient to establish relations between the performance of the system and the reasons for its design, i.e., the purposes and constraints of its coupling to the environment. Categories are in terms referring to properties of environment.</td>
</tr>
<tr>
<td>Priority measures</td>
<td>Properties necessary and sufficient to establish priorities according to the intention behind design and operation: Topology of flow and accumulation of mass, energy, information, people, monetary value. Categories in abstract terms, referring neither to system nor environment.</td>
</tr>
<tr>
<td>General Functions</td>
<td>Properties necessary and sufficient to identify the ‘functions’ which are to be coordinated irrespective of their underlying physical processes. Categories according to recurrent, familiar input-output relationships.</td>
</tr>
<tr>
<td>Physical work Processes and Activities</td>
<td>Properties necessary and sufficient for control of physical work activities and use of equipment: To adjust operation to match specifications or limits; to predict response to control actions; to maintain and repair equipment. Categories according to underlying physical processes and equipment.</td>
</tr>
<tr>
<td>Physical resources and Configuration</td>
<td>Properties necessary and sufficient for classification, identification and recognition of particular material objects and their configuration; for navigation in the system. Categories in terms of objects, their appearance and location.</td>
</tr>
</tbody>
</table>

### Figure 2. The Classes and Properties of the Means-Ends Hierarchy

results with the goals and constraints formulated at the upper level. This level of abstract functions represents functionality/intentionality in terms of flow of values for which laws of conservation are valid, such as monetary values, energy, material, people, etc. (For a detailed discussion of the means-ends hierarchy, see e.g., Rasmussen, 1986; Rasmussen et al., 1991; Vicente, 1999). In the work domain analysis, the substance matter of a work domain will be represented at several levels of abstraction which represent goals and constraints, general functions, physical work processes and activities, as well as physical resources and
configuration. The need for human decision making is present only because of the many-to-many mapping among the elements at the various levels. In any work domain, there are many action possibilities and options for choice in the means-ends abstraction hierarchy which have to be eliminated by a decision which is guided by the functional criteria related to the result of a decision as well as subjective preferences concerning the work process.

3. Ecological Scheme Design and Invariants

According to American psychologist J.J. Gibson (1979), our perception and actions are dependent on the invariant properties of our environment (or, in Gibson's terms: ecology). These invariant properties are among the affordances we perceive in the ecology. According to Gibson, our perception is neither mediated (cf. Vygotsky, 1980) nor randomly picked up through our senses and subsequently processed towards "cognitive structures" (cf. eg. Lindsay & Norman, 1977). Gibson formulated an alternative theory of direct perception which is made possible by the affordances, that are the action possibilities of the "real world" (natural or artificial).

Invariant structures constitute a specific form of affordances providing us with a stable context within which we can situate our choices and actions (cf. eg. Gibson, pp. 72-73). Invariant structures can for instance be found as physical objects arranged together in a particular way, such as a block of buildings in a city, labeled with sequential numbers. Invariant structures can also be understood in more abstract terms as classificatory structures of concepts. However, as Gibson points out, "To perceive an affordance is not to classify an object" (1979, p. 134). Gibson's view of classification (invariant structures) is more in alignment with pragmatic epistemologies and philosophies, in particular with Wittgenstein's pragmatic philosophy of language:

The theory of affordances rescues us from the philosophical muddle of assuming fixed classes of objects, each defined by its common features and then given a name. As Ludwig Wittgenstein knew, you cannot specify the necessary and sufficient features of the class of things to which a name is given. They have only "family resemblance". But this does not mean you cannot learn how to use things and perceive their uses. You do not have to classify and label things to see what they afford (Gibson, 1979, p. 134).

While this view by Gibson may seem to exclude the necessity, or even the "epistemological truth" of classification, then the underlying assumption is that invariant structures and objects do exist in the ecology either as "natural" or "artificial" (humanly constructed) structures. However, when we are situated in the ecology, our actions and understandings do not come from the structures per se, but from their perceived usefulness to us, relative to our specific purpose of action and decision in a particular situation. Thus, an ecology can be regarded as having stability and consistency of structure, while at the same time being plastic and changeable according to the perspective from which it is approached by us. Hence, the idea of invariant structures is not equivalent to essentialist, scientific views of a stable and fixed structure of our environment, held by for instance Aristotle and Linnaeus in their theories of natural classification. Rather, following for instance the social theory of classification formulated by Bowker & Star (1999, p 7), they are "spatial, temporal or spatio-temporal segmentations of the world that do some kind of work – bureaucratic or knowledge production."

This latter view by Bowker & Star together with Gibson's view of invariant structures is in line with the underlying rationales for the means-ends approach to work domain analysis. Paraphrasing Bowker & Star's definition of a classification, the means-ends approach promotes a segmentation of the work domain that is intended for a particular form of work: the design and use of an information system.
3. 1. Implications for Ecological Classification Schemes

The challenge of developing a concrete classification for a particular domain is to combine the stability and consistency of the underlying structure of the work context at different levels with the subjective value structures and conceptions of the actors according to their individual and collective purposes for action. Hence, an important challenge for ecological scheme design is to identify and articulate invariant structures of a work domain. These invariant structures must be made visible as affordances in such a way, that they provide the actors' information searching with a context for understanding different levels of possible actions when they use the system. For instance, the identified invariant structures of a work domain can be shown to the actors in the form of metaphorical mappings. These can range from simple representations such as the desktop metaphor, to more abstract representations, like a house with rooms of books (library) as a metaphor for a collection of databases.

Abstract representations can also cover knowledge representations, i.e., representations of deep semantic structures of a work domain, like classification schemes. Such representations can take many forms. The simplest form builds on one basic structure, implementing one single principle for dividing domain knowledge (e.g., part-whole, universal facets etc.), or imposing one single professional point of view on a body of knowledge (e.g., the viewpoint of one single paradigm). Conversely, knowledge representations can build on highly complex and rich structures, implementing a diversity of work constraints and goals, and a diversity of expertise and interests among human collaborators.

According to for instance Svenonius (1992), classification research has so far to a large degree focused on developing principles for scheme design that support ease of design and modification (for instance, universal facets for subdivision of any body of knowledge). As Svenonius points out, such principles are primarily formulated in order to simplify the practice of information retrieval, scheme design and maintenance. In addition to such practical problems is the meta-problem of “what constitutes an appropriate knowledge representation, how is compatibility to be achieved among classifications, how are classifications to be evaluated and what general laws and principles underlie classifications” (Svenonius, 1992, p.17). Because classification schemes are designed to represent and mediate knowledge, an important meta-problem is semantics, i.e. a theory of meaning. Svenonius suggests that future classification research works with the idea of “meaning in use”, i.e. a context-dependent theory of meaning, or a pragmatic philosophy of representation (cf. also Wittgenstein, 1953). This suggested shift of focus in classification research from principles of universality towards principles of use and context-dependency is in line with the ecological approach to scheme design proposed in this paper.

4. Design case 1: Full-Scale Library System

During the 1970s and 80s, the model and method for means-ends analysis were applied for the design and evaluation of the icon-based Book House system for fiction retrieval (Pejtersen, 1994; Rasmussen, Pejtersen & Goodstein, 1994,). The means-ends analysis addressed the workspace of fiction retrieval and the questions and formulation of needs during decision making.

4.1 Means Ends Analysis of the Library Domain

The work domain of a library includes the librarians and the users. The workspace to be addressed is the book stock and multimedia materials. Library users are largely autonomous even if they are somewhat constrained by the materials that are made available under the library laws and policies for library services.

The information seeking task therefore can be described as a multi-level representation of the invariants of users' needs and intentions on one hand, and a similar representation of the invariants of the contents of the available documents on the other hand. Since information
seeking in libraries often takes place in co-operation with intermediaries, local organizational issues and library policies will impact the search process and will have to be taken into account in classification system design. The goals and intentionality of the library may constrain the original goals and intentionality of the users' domain of work or interest. Additional constraints comprise the general administration of the library, for instance, division of labor, acquisition policies, tools etc. Invariants in all these domains are relevant for design of classification schemes, since they will influence the users' perception of affordances, and thus the performance of the decision task.

The field study of the work domain of libraries focused on the retrieval task and the users' query formulations during decision making. Decisions in information seeking are for example analysis of information need, choice of information source, planning a search and evaluation of the relevance of search results. The aim of these field studies was to identify the invariants, or recurrent themes, for the design of a classification scheme that could represent the stock of documents in a way that converged with the invariants of the user needs and with the invariants of the library work domain. In general, the three task domains of the library (documents, users, library) are not formulated in compatible terms. The means ends abstraction hierarchy provides a generic model that makes it possible to map the invariants in these domains.

The means-ends analysis showed that users tend to characterize the contents of documents at different levels of abstraction and from many different perspectives of use. These abstraction levels and perspectives were found to be recurrent themes, or invariants (Gibson, 1979), within the domain. Figure 3 shows the invariants based on the field analysis of libraries: the document content, user needs, and the library, all represented according to the five abstraction levels in the means ends representation (Pejtersen 1980, 1986). This mapping articulates that information retrieval is essentially an activity that attempts to achieve a mapping between three domains: (1) the documents with their goals/values and knowledge domains as expressed by authorships; (2) the user/reader with his/her knowledge domain derived from his/her leisure or work domains; (3) the organizational policies of the library domain. Each of the three domains has five mean-ends levels (figure 3).

For the task domain of documents, the classification scheme identifies the content with respect to the author's goals when writing a document. These also include the authors' constraints from social, cultural, professional contexts, their subscription to and affiliation with paradigms, their choice of specific content, and their ways of composing a document to reach their target reading groups. The left column of the document content in figure 3 refers to the analysis of different invariant perspectives that was adopted during analysis and representation of documents to build a database content supporting multidimensional subject retrieval. The right column shows the invariants of the library domain that are related to the goals of libraries as expressed in laws to promote high quality of information dissemination, education, and culture. Limited budget resources often impacts the tools, resulting in limited information and classification schemes that do not reflect the users' perspectives nor the quality goals of library institutions.

4.2 Invariant Structures and Classification of the Fiction Domain

In order to provide support and guidance for the users' exploration of the Book House, an overall metaphor for ecological interface design was developed around the structure and space of a house of books. This metaphor is a mapping that articulates the invariant structures identified in the work domain analysis. Following Gibson (1979), such a metaphorical mapping constitutes an artificial environment whose invariants, just like the invariants of a natural environment, guide our direct perception and actions. Invariant structures in the Book House are found at different abstraction levels, from the analogy between rooms in a library and information databases to more deep semantic structures like the classification scheme for fiction. The deep semantic structures that are embedded in the constructed classification
scheme are equivalent to the different knowledge levels about fiction within the user community. Each invariant represents one way of organizing and retrieving information in the system, and thus, a specific discourse or knowledge level within the work domain/user community. Together, the invariant structures implemented in the scheme provide the users with a set of decision and action alternatives through its implementation of a dual principle of simultaneous semantic consistency and prediction of possible action. Thus, the design of the scheme is founded on a descriptive approach to complexity and dynamism of domain knowledge, while still implementing a core semantic stability.

<table>
<thead>
<tr>
<th>Document Content</th>
<th>Users' Needs</th>
<th>Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals and Constraints</td>
<td>Author intention, Information, Education, Enjoyable experience</td>
<td>Readers' ultimate goal</td>
</tr>
<tr>
<td>Priority Measures</td>
<td>Literary or professional quality, Paradigm, style, or school</td>
<td>Value criteria related to reading process and product</td>
</tr>
<tr>
<td>General functions</td>
<td>General frame of content, Cultural environment, Historical period, Professional context</td>
<td>General topical interest of historical or social setting.</td>
</tr>
<tr>
<td>Physical work processes</td>
<td>Specific, factual content, Episodic course of events, Factual descriptions</td>
<td>Topical interest in specific content</td>
</tr>
<tr>
<td>And activities</td>
<td>Physical characteristics of document, Form, size, color, typography, source, year of print</td>
<td>Reading ability</td>
</tr>
</tbody>
</table>

Figure 3. The Workspace of the Library Work Domain.
In general, these workspaces are not formulated in compatible terms.

A means/ends analysis of the library work domain and of the users' needs domain has been useful in order to develop a classification scheme for analysis of the document contents at the five different means-ends abstraction levels. In the present case, a means/ends analysis can only be made from the users' problem formulation and query statements in the library retrieval situations. For retrieval in a public library domain analysis beyond this representation of users' work domains will be difficult, but for information systems dedicated the service of
the staff in a particular organization, a more thorough means/ends analysis of users' information needs will be useful and possible.

5 Design case 2: Engineering Design

Increasingly, design work requires a multidisciplinary team of actors, viewing a product as an object belonging to different functional contexts. Multidisciplinary design teams therefore need to seek and integrate information from different domains in order to come to an understanding of how the product being developed will coexist with work activities and patterns of use. The consequence of this development is the need for classification schemes that support decision making during dynamic co-operation among actors with very different expertise and professional backgrounds, concerns and objectives, time horizons, and information needs within and across organizations. Such schemes can serve several different purposes if they provide a compatible and structured information environment for knowledge sharing and collaborative organisation and retrieval of information and knowledge. One purpose is to cope with the complexity of the co-operative decision making in work situations that require complex information with a high amount of abstract attributes from many different domains. Another purpose is to structure and file the heterogeneous information that is produced and retrieved by the team members during a long term product development, which serves to document and reuse work information.

5.1 Means Ends in Engineering Design

The work space of engineering design can be viewed as a means-end hierarchy representing the many to many mappings between the various levels of description bridging the many different work domains to be considered, when solving design problems (Pejtersen, 2000; Pejtersen et al. 1997; Carstensen, 1997). This is illustrated in figure 4, and by the following presentation of a project on the design and planning of the production of an advanced electronic control unit for hydraulic fork-lifts, trucks, and other power tools for construction work. The project lasted four years and the following presentation is a short synthesis based on interviews, questionnaires and studies of project files and work documentation. Our presentation of the engineering design project is structured according to the means ends abstraction levels, starting with the highest abstraction level of goals and constraints for the project and team, and concluding with the concrete physical resources etc. involved.

Goals: The goal of the project was to sell a new technology for electronic control units for hydraulic fork-lifts, trucks, and other power tools for construction work. Another goal was to conduct the work as joint venture and transfer knowledge on hydraulics from another industry to the company. It was important to maintain the image of the company as protective of the environment and of working life qualities.

Constraints: The choice of new materials to be used in the control unit was constrained by market conditions, environmental laws, work regulations and union agreements. The costs caused by a possible new manufacturing method constrained the choice of materials, since a new method could lead to the need for new production tools, reorganisation of work and training of the workers. Another constrain was the company's policies on budgets, time schedules etc.

Priority Measures: Increased profit through a better market share depended on the costs of a new technology and on an improved quality, reliability and safety of the control unit in harsh environments. In addition to the functional specifications, very strict fail-safe characteristics were required due to reported hazards of loosing control with high power tools. Finding a new technical solution at a competitive price that met the required functions in use was given a high priority: a cheap, yet reliable control unit that ensured the end users' safety. Minimum waste disposal of the materials used in the product would protect the environment and reduced use of materials causing disposal problems had a high priority. The product was
to be manufactured through available production tools, or it should be easy to specify and produce in new ways without increasing the production costs. Priorities had to be made among the costs of a new technology, the degree of safety required by the users and the costs of the disposal of the new material. It was obvious that a new and unknown technology had to be invented and therefore the current competence of the design team members and the state of the current technology were other value criteria. In order to increase the speed of the design process and the quality of the product through concurrent engineering, it was important to gain experience in organising the work as concurrent teamwork with a flat management structure.

**General Functions:** In order to achieve the goals of the project, a larger number of functions had to take place. Some of these are architecture design, module component design and implementation, interface design of modules and components, testing and problem diagnosing, production planning, assembling, quality control, waste management documentation, interaction with sub-suppliers, documentation of the project work, information seeking, management, coordination and planning the work.

**Work Processes:** The physical work processes involved in the general work functions and in the use of the physical resources were many-sided, such as: to draw product components, make experiments with hybrid technology such as chip-on-wire bonding and new production materials and methods such as pasting and soldering, seek information about new technologies and materials, write and read specifications, work documentation and reports, prepare meetings with team members, other colleagues and companies, talk to customers and sub-suppliers, lectures and presentations of the work, search for written and oral information, and people with relevant expertise.

**Physical Resources and Configuration:** These include both the manufacturing equipment and other physical entities such as: production tools, automatic assembling equipment, transistor tapes, cad/cam tools, test equipment, databases, engineers, marketing staff, materials, computers, Dialogue databases, Internet, archives, books, manual drawings, specifications, reports, minutes of meetings, release notes, authorizations, test samples, photos, work plans, financial status reports, calculations, overheads, in-coming and out-going mail, and CAD drawings.

This means presentation of the work space of the project is needed to bridge the space between the goals and constraints that the final product should meet and the physical resources of the technologies needed for manufacturing. Information seeking to satisfy information needs and enable decision making during the design process implies iteration between the means ends levels in the abstraction hierarchy in order to find a solution that meets the goals and constraints of the project. It provides the ground for a further analysis of the invariants and affordances of engineering design work that need to be made explicit in work based classification schemes. For example, the organisational work domain invariants such as the company's policy for running development projects, the requirement that the work should be conducted as a joint venture, and that the product should be produced through existing production tools. Other recurrent themes include the environmental laws, the union agreements and work regulations imposed by society.

**5.2. Bridging Means Ends Levels and Domains during Co-operation**

The co-operation in a library is a dynamic, coordinated activity that takes place in a single task situation between an expert and a novice and usually does not continue after the completion of the task. The co-operation in the engineering design team was a dynamic collaboration during weekly meetings among experts on technical design, customers and end users, marketing, manufacturing, and recycling and disposal.

The decisions to be made during the co-operation involved exploration of the role of the product in different domains, analysis of product specifications and test data, generation and evaluation of ideas for error detection, and choice among alternative solutions to safe
materials. These decisions are intertwined with the decisions involved in the information retrieval task similar to those in libraries. For example, analysis of information needs, choice of information source, planning a search and evaluation of the relevance of the results.

In figure 4, the design team members' information needs during their co-operative decision making are viewed as a means-end hierarchy representing the many to many mappings between the various levels of description bridging the many different work domains. It shows that decision making and information seeking during engineering design tasks concurrently iterates among several different work domains: Other companies on the market, marketing and sales, prior products of the company, the customer domain, the manufacturing domain, the sub-supplier domain and the disposal and recycling domain. The vertical bridging between abstraction levels and the horizontal bridging across domains are simultaneously involved in decision taking. For the sake of simplicity, not all levels involved in the co-operative decision making are described within each design domain in figure 4. In what follows, a few examples of co-operative decision taking illustrate the common information needs that occurred during the project.

5.3. Examples of Information Needs

One of the goals of the project was to explore the feasibility of a "joint venture" cooperation with another company with expertise on hydraulics. The technical expertise of hydraulic valves was very likely to be available in another, not rivalling branch. Information was needed about other companies on the market that applied a similar technology. The automobile industry was found to have the necessary expertise on hydraulic valves. Once the industry had been identified, the co-operation and decision making also involved information about the goals of the possible company candidates, their image, size, power, technological strategies, competence, other work functions outside the technical specifications of the project, their technical production conditions etc. The team developed a local classification scheme and classified the competence of possible company candidates for joint ventures (what size? what resources? openness to co-operation? etc). This supported their choice of priorities among company characteristics and helped to cope with complex information involving a high number of abstract attributes.

Another goal was to sell a successful product. Due to customers' complaints about instability of the control unit in extreme environments, it was necessary to improve the safety of the electronic control unit in the existing product. Information was needed about the customers' attitudes to new technical solutions. The marketing and sales domain needed information about the customer domain in order to match the properties of the product to user requirements, including the degree of safety and working quality required by the end users in different workplaces. Information was needed about customers' attitudes to new solutions and the costs that they were willing to pay for a high degree of safety and an improved quality of work. This also involved customer surveys, complaint reports, and materials on competitive products. The technical design solution chosen to fulfil this goal was the implementation of hybrid technology called chip on wire bonding in the electronic control unit. The result of this technical solution and choice of a new material was a change in the manufacturing process, where pasting replaced soldering.

Information about costs, the current capacity, competence of the staff and existing production equipment in the manufacturing domain was used to decide a new manufacturing process, where some components could be produced by the company itself, whereas other components would be purchased from sub suppliers. Sub suppliers contributed with information on the reliability and stability of a new production process using transistor tapes.

Information was needed about sub suppliers and their competence and manufacturing expertise in soldering, pasting and transistor tapes. In order to provide access to information about people's expertise, a local classification scheme is needed that can be used to model and elicit experts' knowledge. The design of such a scheme can be based on the means ends
abstraction hierarchy and the information needs and search questions expressed by design team members in a work situation, when they are looking for people with the expertise that they need to solve their problems. Likewise, the experiences gained from the marketing and purchase departments that have developed good skills in finding the proper expertise by applying a number of different criteria (Pejtersen, 1998, Hertzum and Pejtersen, 2000).

The new materials to be used in the control unit should cause a minimum of disposal problems and therefore it was preferable to choose materials where test data were already available or could be easily gained at a low cost. Thus, in the recycling domain test data were needed about different, optional materials that reduced disposal problems.

As exemplified above, the engineers' collaborative information needs can be organized in a means-end hierarchy reflecting the fact that the product involved can be described at several different levels of abstraction and within several different domains involved in the design work. It follows that in order to be useful in future work situations when the product is redesigned or when similar tasks are conducted, classification schemes for engineering design work should contain information about the product at all these levels and from all the different domain perspectives, as shown in figure 4. In order to address this requirement, it is necessary to identify the invariants of the questions that engineers ask to make decisions during team meetings in an ongoing project over a longer time span. A larger number of need formulations and a higher granularity of the information needs than those identified in this study will be necessary to represent the actors' formulations within the abstraction hierarchy.

6. Conclusion

The approach taken to the design of an ecological work based classification scheme for libraries was based on invariants identified in the policies of the library organisation and in the library users' information needs. If we generalize this approach to the engineering design domain, classification schemes should be based on the invariants found in the company policies (environmental and technical policies), in the laws of society (work regulations, environmental laws), and in the collaborative knowledge sharing and common information needs. Despite these similarities between the library work domain and the engineering design domain, identification of invariants in the design domain is a complex process because of the large number of knowledge domains that are involved. Generic and compatible classification schemes will have to cover the marketing domain, technical domain, the manufacturing domain, the disposal and recycling domain and so on. Further, they should be able to encompass the large-scale diversity of heterogeneous information sources.

An additional problem for the scheme designer is the dynamic and unpredictable nature of the design work. For the scheme designer, this for instance poses the challenge of how to cope with problems like invariant work domain structures versus changing information needs among actors due to changing constraints from the external environment. Another issue related to this problem is compatibility and integration of global schemes and local schemes and maintenance and re-design of schemes. It is likely that the means-ends abstraction hierarchy may serve as a generic, compatible model for analysis of information needs in cooperative work, but it is questionable whether one resulting classification system can encompass the totality of complexity in information searching and knowledge sharing in cooperative work that is distributed in time and space.

Our approach for the design of ecological classification schemes is also intended as a contribution to the general discussion of future classification research. In particular, the ecological approach advocates priority to empirical and situated studies of activities in the work place. Additional sources to capturing domain knowledge are considered, for instance found in related domain studies by social studies of science. The uniqueness of the ecological approach is that it provides the designer with tools to combine conceptual analysis and empirical studies for domain analysis and scheme design.
Acknowledgements: We gratefully acknowledge the support of the Centre for Human-Machine Interaction (CHMI), Risø National Laboratory, Denmark and the Danish National Research Foundation who funded the research presented in this paper. We also want to thank our colleague at CHMI, Hans Andersen, for valuable comments of our presentation of Gibson’s theory of visual perception. We are also grateful to Elaine Svenonius, University of California, Los Angeles, for valuable inspiration on classification philosophy. Finally, we want to thank Danfoss for hosting and participating in our field studies.

References:


Suchman, L. (1994). Do categories have politics? The language/action perspective reconsidered. In: Computer Supported Collaborative Work 2: 177-190


<table>
<thead>
<tr>
<th>Domain Level</th>
<th>Market: other Companies</th>
<th>Marketing &amp; sales</th>
<th>Company's prior products</th>
<th>Customer domain (functions in use)</th>
<th>Manufacturing domain</th>
<th>Sub-Supplier domain</th>
<th>Recycle domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market, goals, agreements, legislation</td>
<td>Product domains, their strategy, joint venture? Company image</td>
<td>Profit, company image, Board policies &amp; commercial agreements</td>
<td>Profit, company image, Working life qualities</td>
<td>Profit, company image, Union agreements, piecework, Working life qualities</td>
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<tr>
<td>Priority measures, Finance, safety, reliability</td>
<td>Technology, Competence, Size, Economy</td>
<td>Profit, market share, produced/purchase Recycling?</td>
<td>Cost, safety, reliability, ease of use</td>
<td>Economy, waste disposal, capacity, safety, competence and production equipment</td>
<td>Reliability, Stability of production</td>
<td></td>
<td></td>
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<tr>
<td>General functions, activities</td>
<td>Functions outside technical specifications</td>
<td>Information seeking, Data collection, Marketing survey</td>
<td>Improved accuracy</td>
<td>Production functions: assembling, testing, quality control, waste management</td>
<td></td>
<td>Recycling of waste and scrapped products</td>
<td></td>
</tr>
<tr>
<td>Physical work processes</td>
<td>Similar production conditions in other domains / companies? Automobiles!</td>
<td>Read reports on failures, complaints</td>
<td>electronic controller fail-safe circuitry</td>
<td>Pasting replaces soldering</td>
<td>Recycling processes for materials applied: - Hydraulic oil/water - Epoxy, solder - Copper, silver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical resources &amp; configuration</td>
<td>Technology applied Hydraulic valve</td>
<td>Knowledge transfer</td>
<td>Hybrid technology chip-on-wire bonding</td>
<td>Automatic assembling equipment, &quot;transistor tapes&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The Co-operative Work Space of Engineering Design