INFORMATION RETRIEVAL IN INTEGRATED WORK STATIONS

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INTRODUCTION.

Modern information technology is now introduced in many work places and an important trend is the development of integrated 'work stations' which can serve the requirements of an entire job. In the future, office workers will perform a complex set of operations from one work terminal related to text editing, document handling and filing, communication, purchasing transactions, etc. Designers are supported in modelling parts, laying out wiring and piping, running process simulations and doing economical calculations from a cad/cam station.

The user of such systems will have to access information from several different databases. The sources of information to the various databases will be very different, data will come from several different professional areas, they will be indexed and stored by professionals having a background and outlook different from the user, and the actual needs of a user in a particular task will not be known by the information indexer. Co-ordination of databases for integrated work stations, therefore, is not a question of communication protocols and proper interface design, but a question of developing a framework for information indexing and retrieval which makes it possible for a database designer to select the search attributes which are task and situation-independent but, nevertheless, related to invariants of the work domain and can give users access to the different databases in query terms coming natural during work.

In the following sections, the structure of the work domains to be represented in work stations is discussed, and it is concluded that several different work domains have similar characteristics with respect to this structure. Next, some general aspects of users' task when navigating through a multi-dimensional data base are discussed and, finally, some specific conclusions are drawn with respect to design of an icon-based interface. For this particular discussion, an example from information retrieval in libraries is used because a data base designed from analysis of users' needs is available.

REPRESENTATION OF THE WORK DOMAIN.

A key problem in organising information for data bases of integrated work stations is the development of a useful representation of the particular work domain. In advanced systems, most routine tasks will be automated and the task of the user will predominantly be co-ordination of the automatic functions and planning of functions for new, unfamiliar work conditions. Goal oriented planning means exploration of means and ends together with selection of adequate resources according to the relevant, often subjective, process criteria.

Accordingly, analyses of decision making in different domains have shown that a representation in terms of a means-end/part-whole problem space is useful to identify the information need of decision makers. In order to support problem solving in advanced systems, it is not possible to base system design on normative procedures, and the analyses of actual performance show clearly that frequent shifts of strategies and concurrent shifts in the level of mental representation are necessary during the course of work (Pejtersen, 1979 for library work, Rasmussen and Jensen, 1974, for electronic trouble shooting). This in turn leads to the conclusion that a system user should be able to select information at several levels of abstraction and decomposition according the the immediate needs.

In any planning task involving exploration of a means-ends network, and for which no normative work procedure can be given, it is important that the user can navigate freely in the means-ends network. Any potentially useful function or item in a work context is located in a means-end network and, consequently, can be characterised in terms of 'what' it is, 'why' it can be useful, and 'how' can be used or implemented irrespective of the actual situation. This in turns implies that its representation in a data base for an integrated work station should include these features in a way that the items can be retrieved by means of these different questions.

In order to illustrate the generality of the representation problem, examples from a number work of domains are briefly reviewed in the following sections:

Engineering design Engineering design is an area for which information technology is introduced in the work interface in the form of systems for computer aided design (CAD) and computer integrated manufacturing (CIM).

Figure 1, illustrating the work environment of an engineering designer, shows clearly that a designer needs to have access to data bases representing different problem domains. The first problem domain is a means- end hierarchy representing the many-to-many mapping between the various levels of description bridging the space between the purpose and constraints the final system should meet, and the physical resources of the technology considered for the system implementation. Another domain will be considered for manufacturing, representing the means-end relations of the available manufacturing resources in terms of processes and machinery. In addition, since components designed previously for other applications may be available on stock and useful for the new design, access will be needed to information about such items in a data base with retrieval attributes related to the various levels of the design hierarchy. The design process will imply an iteration between the levels in the functional hierarchy in order to identify the acceptable functional properties of a component but, at the same time, iteration across the manufacturing

PROBLEM DOMAIN IN COMPUTER-AIDED DESIGN

MANUFACTURING ENVIRONMENT		FUNCTIONAL SYSTEM ENVIRONMENT	ATTRIBUTES OF COMPONENTS ON STOCK
MANUFACTORING GOALS AND CONSTRAINTS		FUNCTIONAL SYSTEM GOALS AND CONSTRAINTS	FUNCTIONAL GOALS AND CONSTRAINTS OF PREVIOUS APPLICATIONS
MANUFACTURER'S PRIORITY SETTING; FLOW OF ENERGY, MATERIAL, AND MONETARY VALUES, MANPOWER, ETC.		CUSTOMER'S PRIORITY SETTING; FLOW OF ENERGY' MATERIAL, AND MONETARY VALUES, MANPOWER, ETC.	PRICE, RELIABILITY AND OTHER HIGHER ORDER SPEC'S
GENERAL MANUFACTURING SYSTEMS AVAILABLE: CASTING, FORGING, ASSEMBLING, CUTTING, ETC.		GENERAL FUNCTION TO BE PERFORMED IN TARGET SYSTEM: BEARING; SUPPORT; CONDUCT;TRANSFER;	INTENDED FUNCTIONAL CONTEXT OF INITIAL DESIGN
PHYSICAL FORMING PROCESSES AVAILABLE		ACCEPTABLE PHYSICAL FUNCTIONS OF SEPARATE PART	PHYSICAL FUNCTIONING SPEC'S
AVAILABLE TOOLS AND MACHINERY	PART TO BE MANUFACTURED.	RELATED FUNCTIONAL COMPONENTS	SHAPE, SIZE MATERIAL
GEOMETRICAL FORM, MATERIAL, SURFACE FINISH.			

The figure illustrates the different problem domains relevant for design: the manufacturing environment, the ultimate functional context, and the stock of available previous solutions to similar design problems.

FIGURE 1

hierarchy together with consultation of the properties of the designs already in stock should be supported. For easy shifts between these hierarchies during the design process, consistent search attributes should be used for the different databases.

Emergency management. An area for which the application of modern information technology is considered for decision support, is the general emergency management related to protection of the public against effects from events like major fires, flooding, chemical accidents, etc. (Rasmussen et al., 1986). The task domain of general accident and emergency management has a very unstructured nature because it does not exist until an accident has happened and, consequently, can only be described in terms of sets of unrelated elements that will be activated and structured during an accident and the following efforts for control. In fact, two domains can be identified and represented in separate means-end/part-whole domains, see Figure 2.

One domain will represent the risk potential in terms of the properties of the potential sources of accidents together with the environments through which they may propagate: At the lowest level is found information on geographic and topographic features of potential risk sources and their environment in terms of maps of installations, likely routes of propagation and of access, etc. At functional levels are specified the physical processes involved in normal and accidental chains of events, and in the propagation of consequences as well as the consequences of such events on the general public, in more general terms comparable with the acceptance limits specified in laws and regulations which are represented at the highest level.

Another domain represents the properties of resources available for counteraction in terms of fire brigades, hospitals, transport facilities, etc. in terms of geography, anatomy and physical functioning at the lower levels, through more general functions to the policies and general goals of society at the highest.

The information retrieval aspect of the decision task appears to be particularly important for systems to support emergency management. Large amount of information about very different aspects such as geographical features, meteorological data, road conditions and traffic data, physical and chemical properties of plants and substances, resources of medical centres, may be needed for advice by an accident manager. This information will be supplied by many different sources and, typically, not in formats suited for a stressed decision maker needing procedural advice on short notice. Database formats and retrieval tools therefore become a central issue of system design.

Information retrieval in libraries. Library systems are interesting in the present context because the information retrieval task is generally becoming increasingly important in the user-system interaction of decision tasks in many other domains. For decision support in any domain, it is necessary that the user can identify, retrieve and comprehend information from the database by queries that comes naturally in the work context, and database design and information retrieval has long been the core of library and information science. There is a long tradition in

PROBLEM DOMAIN IN EMERGENCY MANAGEMENT

RISK DOMAIN	RESOURCE DOMAIN
GOALS, VALUES, AND CONSTRAINTS; LAWS, REGULATIONS AND PUBLIC OPPINION	
CRITERIA FOR SETTING PRIORITY: RISK, ECONOMIC AND SOCIAL EFFECTS	CRITERIA FOR SETTING PRIORITY: FLOW OF MONETARY VALUES, AND MANPOWER
GENERAL ACCIDENT CATEGORIES: FIRE, FLOODING, EXPLOSIONS, ETC.	GENERAL RESOURCES: MEDICAL CARE, EVACUATION, FIREFIGHTING, ETC.
PHYSICAL PROCESSES IN POTENTIAL ACCIDENTS AS SPECI-FIED BY ANALYSIS OR PRIOR EVENTS	PHYSICAL FUNCTIONING OF TOOLS AND EQUIPMENT; INTERACTION WITH TARGET
TOPOGRAPHICAL, DEMOGRAPHICAL CHARACTERISTICS OF POTENTIAL DANGER SOURCES AND LOCALITIES	APPEARANCE, LOCATION, AND CONFIGURATION OF MATERIAL TOOLS AND RESOURCES

The problem space of emergency management will not be defined until an emergency is present. For a general description serving system design, therefore, it will be useful to consider a representation of the potential risk and the resources for accident control separately. The figure show a common goal representation for the two aspects, because political and public attitudes are the basis for requirements to industry as well as for the resources made available for control of emergencies.

FIGURE 2

this domain for developing linguistic and classificatory methods for analysis, organisation, representation, display and retrieval of information across different knowledge domains- all facilities of relevance to design of any integrated work station.

Field studies by Pejtersen (1980, 1984, 1986) have led to a formulation of a search space which have features similar to the problem space discussed in the previous sections. Analyses of end user-intermediary searches in libraries have shown that users express their reading needs in a way which can best be represented in a multi-faceted or multidimensional classification system.

The content of the various facets were: 1. Author's intention with the document such as to give the user emotional experience, information, education, etc. or to promote ideas, e.g., social criticism, philosophical attitudes etc. 2. Frame or setting of the subject matter content in terms of time and place, i.e., the geographical, historical, social, or professional environment, etc. 3. Subject matter of a document, in terms of action and course of events ('plot'), psychological development/description, social relationships. 4. Accessibility, the physical characteristics of a document, readability, printing, physical format, publisher, etc.

In order to support user access to literature in a database system, it should be possible to identify and locate items by search terms in any of these facets of the user demand or in combinations of them. In consequence, the information retrieval task in libraries will involve a mapping between two separate multi-level problem spaces, the user need and the contents of available bibliographical references, see figure 3.

Thus, design of computer supported retrieval systems requires development of a classification system and a database in terms compatible with facets of user needs. This involves database requirements similar to those of engineering design and emergency management.

The problem space of the retrieval task can be described as a multi-level representation of the user needs on one hand, and a similar representation of the contents of the available documents on the other. Two decision makers are typically involved in the task, the user who may only know the reading needs in implicit terms, and an intermediary who may know only part of the content of the individual databases and of their knowledge domain. The joint decision task during a search then will be to **analyse/determine** a user's need in terms compatible with the database structure, **select** documents and **compare** their match with the need. In order to make it feasible for the end user to access the data bases directly, interfaces are necessary which are able to guide the users' navigation in the complex data bases.

By analysis of actual user behaviour in libraries, several different strategies for identification of documents to match user needs have been identified (Pejtersen, 1979). Some of these are:

* Analytical Search. The intermediary is in control, explores systematically the dimensions of the user's needs, retrieve documents, compares aspects of needs with aspects of documents, suggests titles for the user's consideration and approval. This

strategy is the rational, problem solving strategy.

* Search by Analogy. The intermediary is in control and explores the user's need by asking for information about the user's previous reading, to be able to find 'something similar'. Prototypes thus identified are then analysed to identify search terms for new documents.

* Browsing Strategy. Finally, an information seeker in a library may have a need which is so ambiguous that specification of a search template is evaded and, instead, the content of a shelf or a database is scanned to explore a match with the intuitively present need and the available items.

Comparing with the mental strategies discussed for supervisory process control, it will be seen that these strategies are formulated at the same level of generality and can be used to specify the mental model and the categories of information which should be considered for the design of support systems and their interfaces.

These search strategies are discussed in a subsequent section with reference to experiments with users' navigation in bibliographic data bases.

Conclusion. The examples serve to illustrate the great variety of data sources which can be involved in integrated work stations. Several aspects of information retrieval are important for design of databases. One is, that to be of use in a situation when a user seeks advice in relation to a specific task, it should be possible to retrieve the information from questions related to the means-ends relations of that specific problem domain. This implies that data bases for integrated work stations cannot be created by merging existing data bases and create a proper interface. The information should be indexed and formatted in a way compatible with the relational structure of the users' domain. It should also be noticed that frequently, information in databases is dominantly descriptive, declarative information whereas the user will need operational, procedural guidance. This in turn makes it more difficult to index information when the user problems are not known explicitly. In this area, the tools and techniques of artificial intelligence may bring useful solutions. The application, however, will depend on extensive studies in actual work situations in order to be able to formulate user strategies and subjective preferences.

The conclusion of this discussion is that careful studies of the actual needs of the decision makers for which integrated work stations are designed are necessary, together with experiments based on generalisations from such field studies. One major problem is, that experiments with new system concepts presuppose the existence of data bases which are designed from analysis of actual users' needs. In the following, design and experiments with data bases and user interfaces for information retrieval in libraries are described.

PROBLEM DOMAIN OF LIBRARY SYSTEMS

DOCUMENT CONTENT	USER NEEDS
AUTHOR INTENTION; INFORMATION; EDUCATION; ENJOYABLE EXPERIENCE.	READERS ULTIMATE GOAL
LITERARY OR PROFESSIONAL QUALITY; PARADIGM, STYLE, OR SCHOOL.	VALUE CRITERIA RELATED TO READING PROCESS AND PRODUCT
GENERAL FRAME OF CONTENT; CULTURAL ENVIRONMENT, HISTORICAL PERIODE, PROFESSIONAL CONTEXT.	GENERAL TOPICAL INTEREST OF HISTORICAL OR SOCIAL SETTING
SPECIFIC, FACTUAL CONTENT. EPISODIC COURSE OF EVENTS; FACTUAL DESCRIPTIONS.	TOPICAL INTEREST IN SPECIFIC CONTENT
PHYSICAL CHARACTER-ISTICS OF DOCUMENT. FORM, SIZE, COLOR, TYPOGRAPHY, SOURCE, YEAR OF PRINT.	READING ABILITY

The figure illustrates the levels of representation implied in the analysis of features of a document and of a user's needs for library information retrieval.

FIGURE 3

SYSTEM DESIGN, AN EXAMPLE.

In this section, different aspects of design of data base systems, information retrieval strategies and user interfaces will be discussed with reference to information retrieval in libraries. This domain is chosen because a data base designed from user studies is available for experiments.

The discussion in the previous sections clearly shows that a multi-dimensional, relational database is necessary in which items can be identified rapidly and with good resolution by their match to users' queries. The structure used for data base design in the present experiments is developed from the empirical investigation of user behaviour in libraries, discussed in a previous section, and illustrated in Figure 4.

Navigation in Data Bases. It is important for the design of information systems for the casual users (such as library systems) and for users in unpredictable situations (such as emergency managers) that navigation in data bases can be based on task independent rules. The hypothesis of the experiments discussed in the following sections is that efficient navigation in a database will be possible only if the data base structure can be embedded in a context which can be represented on the display interface in a way making it possible for a user to develop efficient sensory-motor manipulation skills. This in turn, will be possible if the abstract attributes of the items of the database are consistently recoded to positions in a spatial representation, because manual skills are typically concerned with the spatial-temporal characteristics of the environment (cf. the direct manipulation paradigm).

The sensory-motor control patterns at the automated level of behaviour is concerned only with the interface manipulation task itself, i.e., manipulation of items on the visible surface. The advantage of a mouse-based system is that the communication of spatial - temporal aspects in the loop perception-action are intact. The commands to send the computer are selected from a repertoire presented on the screen. They can be identified by means of their physical position, and pointed at by the mouse before the selection order is transmitted by a 'click' sign. This implies a direct relationship between the movement pattern and the perceptual control, see figure 5. Very efficient navigation in a database, consequently, would be possible if the abstract attributes of the items of the database could be consistently recoded to positions in a spatial representation, and its location identified perceptually while navigation in the space is analogically controlled by patterns of movements.

For library systems, as for most professional data bases, it is a problem that the number of abstract dimensions of the database is rather high; that the number of items in the base is large and, in particular, that the attributes for search are not typically formulated explicitly by the users. In general, therefore, an intermediary (computer or librarian)is necessary to translate to user terms or to conduct the search on behalf of the user.

CLASSIFICATION SYSTEM FOR LIBRARY DATABASES

1. **Author's Intention**

   * Emotional Experience;
   * Information,
   * Education,
   * Promotion of Ideas, e.g., Social Criticism, Philosophical Attitudes etc.

2. **Frame** or setting of the subject matter content

   * Time and Place,
   * Geographical, Historical, Social, or Professional Environment,

3. **Subject Matter** of a book,

   * Action and Course of Events ('Plot'),
   * Psychological Development or Description,
   * Social Relationships.

4. **Accessibility**,

   * Physical Characteristics of a Book or Document,
   * Readability,
   * Printing Characteristics,
   * Book Format,
   * Publisher.

The figure illustrates the dimensions of users' needs as identified by field studies in libraries.

FIGURE 4.

In the present experiments, an attempt is made to exploit the capabilities of computers for flexible presentation by relating the information items to their location in a virtual space, a store house, in which three dimensions of the multidimensional attribute space is represented by the location in a room, while the remaining, relevant dimensions are taken care of by arranging for several rooms and departments in the store. In this way, it will be possible to transfer the Simonides (500 BC) mnemotechnic trick (to imagine the items to remember to be located along a familiar street or in a familiar room, see e.g., Fuller, 1898) to a multi-dimensional representation or, in other words, to use the idea of George Miller (1968): Information is a question of 'where'.

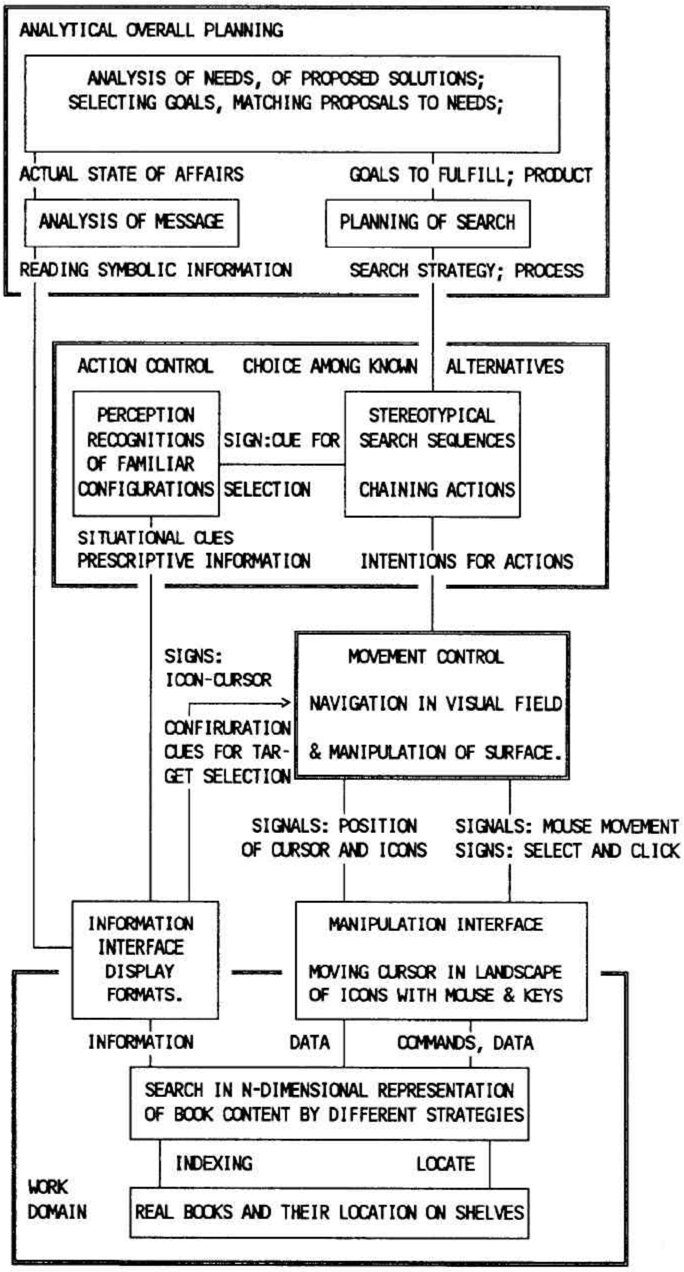
This representation will make it possible for a user to search the spatial analogy of the data base by mental strategies similar to those mentioned in the discussion of library systems in a previous section. Computers have the advantage compared to a physical collection of items: The same information item can be located in several different places and, therefore, a data space with more than three dimensions can be represented by a number of rooms. In this way, a user can **'browse'** according to location, if the rooms representing the most relevant dimensions are visited.

Other strategies mentioned, depend on specification of the search attributes, either directly, the **analytical search**, or in terms of a model example, **search by analogy**. Since the needs are only implicitly formulated by the user, it is generally necessary to show the possible dimensions for user's choice (recognition is easier than recall).

In this spatial or topographic metaphor, an analytical search is a kind of selective 'addressed' search in a domain selected by from a display of a 'work-room' showing the landscape of topical items which can be selected. In the analogy of a city map, you have an indication at least of the street you want to visit together with a helicopter which will bring you there directly. Being there, you will look at the houses. In the 'browsing strategy', you don't know the address, but you will recognise what you are looking for, when you see it. This means, you have to pass through the streets of the city until you recognise an item. In a library this implies scanning the physical books on the shelf. In a computerised system, however, you can choose a sub-space of, or a 'channel' through the multi-dimensional space by specifying some aspects of the target, which are known (to be what you want or do not want). In this way, the difference between analytical search and browsing in a computerised system is a question of degree, not of categories.

In this type of interface, manipulation is not directly connected to the information content, but to general interface manipulation skills in terms of reading signs for selection, giving signs in terms of commands, etc. In any highly familiar environment, actions are activated by cues or signs which are only related to the actions by conventions, not by their symbolic meaning. The

COGNITIVE CONTROL OF SEARCH



The figure illystrates the different levels of cognitive control of the manipulations of the interface to a library system. Distinction is made between control of physical movements, intentional actions, and planning of the activity.

FIGURE 5.

choice of interface messages for control of search activities, therefore, is rather free. This freedom can be used in 'iconic' interfaces to guide the user. For this purpose it is important to consider the possibility of using a form of signs which are clearly related to the actions to make or alternatives to choose among but, at the same time, can be interpreted symbolically with reference to the substance matter of the users' domain. In terms of figure 5, this implies that display icons are chosen, which simultaneously present a close mapping onto effective cues at the levels of movement and action control (their sign function) and onto the semantic content of the data base which is relevant to the user's planning level (their symbolic meaning). The use of pictures with different referents to guide the user in the present experiments is illustrated in Figure 7,8 and 9.

Iconic Interfaces. For the design of the iconic displays shown in the figures, a simple taxonomy of icons and other pictorial action signs was suggested. As mentioned, in a sensory-motor task, actions are released by cues which are related to actions by mere convention or empirical correlation. This gives the designer a freedom to chose the pictorial content of the action cues. For information retrieval in work stations, iconic cues for action can be used to map the actual information content onto a general interface structure and to 'customise' it to a particular application. The idea here is that the data base irrespective of the subject matter content is viewed as a multi-dimensional store-house of information items. A standardised, generalised display interface is then developed, which has a structure and sign function of icons closely related to the topography of the store house and rules for navigation, whereas the symbolic reference of the icons are tailored to subject matter of a particular application. This approach is in contrast to the 'desk top metaphor' for office systems by which the reference of icons is to the appearance of tools in a previous familiar technology, not a symbolic reference to the actual work content.

Icons are, typically, pictograms which are intended to function as 'signs', i.e., in addition to the particular function as cues for action, the graphic pattern has some 'similarity' with the content of action. In general, this similarity is referring to the physical appearance (Eco, 1979). In the present context, however, similarity to representation in the interface of higher level structures also justify the term 'icon'. By definition, signs (and icons in their action cueing function) refer to the action by mere convention. The connection may be formally instructed or discovered by the actor empirically. However, different principles can be used for selection of the icons to serve as signs, and a taxonomy of signs from this point of view may be useful for design.

The form of signs may be related to any of the items in the sequence of the action scenario, see figure 6, and a taxonomy will be related to the different sign references given in the figure. In some cases, icons refer to the context of action, to the actors conception of the situation. In this case, icons can get the

SCENARIO FOR DEFINITION OF SIGN REFERENCE.

1.) IF <STATE> --> 2.) THEN <ACTOR> --> 3.) DO <ACT> --> 4.) WITH <OBJECT> -->

5.) IN-ORDER-TO <GOAL, TARGET>

Design of signs and icons can be based on reference to any item in the action scenario:

1. The state of affairs needing attention.
   Traffic signs: A 'steam engine' signals crossing trains; be careful;

2. The actors who should care.
   Lady's and gents on restroom doors;

3. Action to perform.
   Sign with man walking on stairs;

4. Object to use.
   Garbage can icon;

   Object not to use.
   'Deleted' cigarette;

5. State to reach.
   'Light-on' icon

   State to avoid.
   'Flame' signalling no-open-fire;

6. Symbolic reference.
   Reference to the meaning of information items;

*. Nothing. Pure convention.
   'Red light' at street crossing;

The figure illustrates the different references to the action scenario that can be chosen for design of icons.

FIGURE 6.

character of symbols. In the information retrieval context, symbolic reference to the meaning of information items, without reference to the direct search activity, may by very helpful for an experienced user. In general, the choice of significance for signs can be based on different criteria such as, for instance, easy remembering, easy guessing by novice; relation to population stereotypes. Given the many degrees of freedom underlying the design of iconic signs, a general principle should probably be adapted for design guide in order to have an intuitive context for guidance of users. Different mnemo-technical principles can be used, relating signs to all of the different elements of the cue-agent-action scenario, as discussed in the figure.

CONCLUSION.

The conclusions of the discussion in the paper is that the design of data bases for advanced integrated work stations is not a problem of compatibility of computer systems and communication protocols together with design of proper user interfaces. First of all, it is necessary that information is indexed with reference to user questions which come naturally in the actual work context. In this respect, it is frequently a problem that the different relevant data have very different sources and are stored for other purposes than faced by the work station user. The use of the means-end framework as a general basis for information indexing seems to be advantageous. Furthermore, the classical approach to support information retrieval by using the spatial 'storehouse' metaphor for a database appear promising. Whether this is actually the case will be the topic for experiments in libraries.

ACKNOWLEDGEMENT

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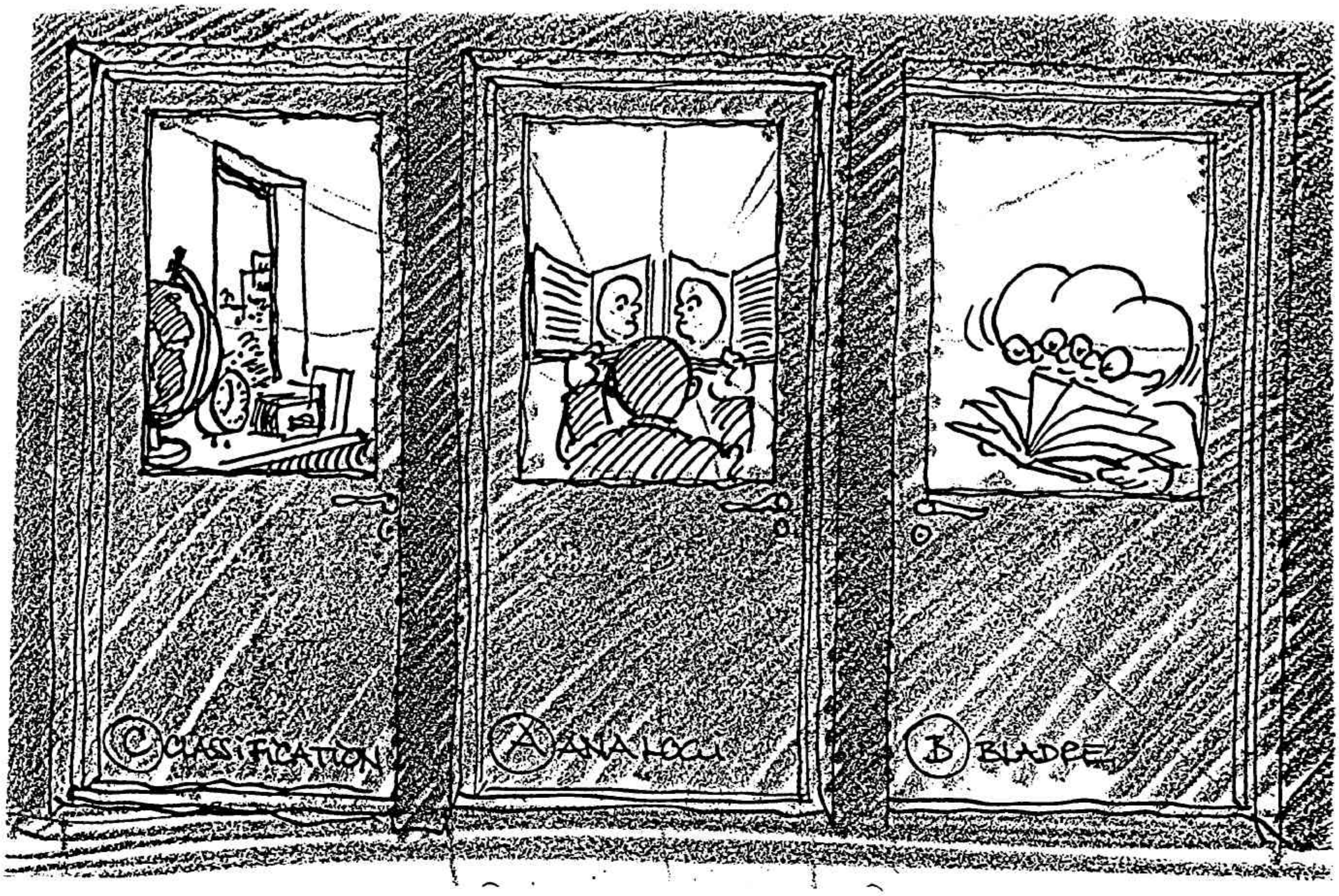
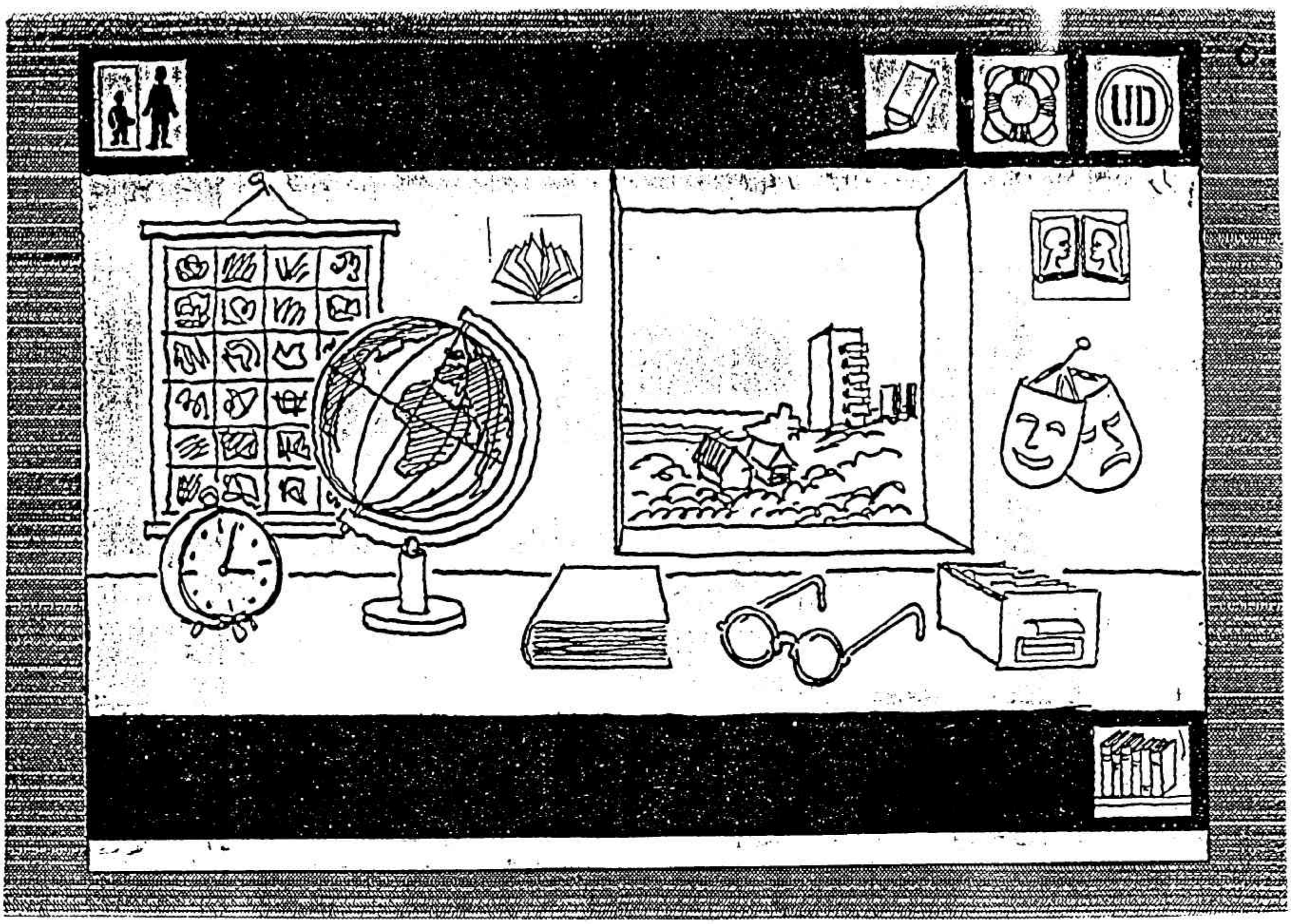


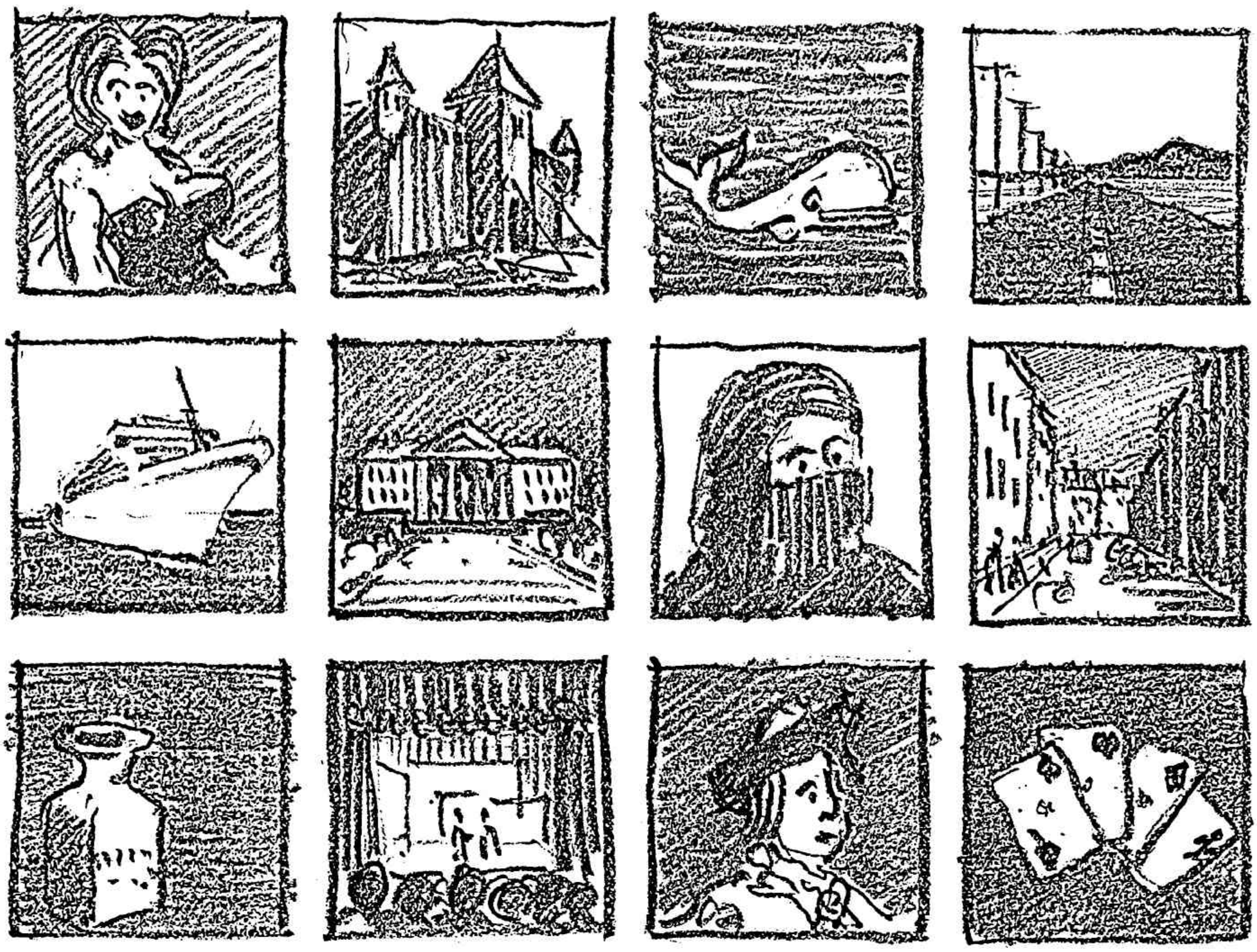
The figure presents the display asking a user to chose between a strategy of analytical specification of needs in terms of the classification system of figure 4, the browsing strategy, and the strategy of search by analogy. The choice is made simply by pointing with a mouse.

FIGURE 7.



This figure shows the work room for choice according to the analytical strategy supported by the classification scheme. The globe signifies geographic frame, the clock temporal frame. The glasses represent accessibility and the masks emotional experiences, and so forth. Choice is made with a mouse.

FIGURE 8.



This display is intended for browsing in subject matter contents. Icons support the user's intuitive exploration of the semantic contents of the data base and provide aid in the formulation of information needs.

FIGURE 9.

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FIGURE 9.