A Case-Based Design Support Method Incorporated with Designer ▪ s Intention Recognition

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Abstract

In creative design processes, the designer may intentionally generate a result which is satisfactory for his/her intention. Accordingly, if a computer system reveals the designer ▪ s intention, and then provides the related information, that might make the design process more efficient. We will propose a framework and an architecture to support intentional design processes, incorporating a case-based intention recognition method with a case-based method to support the design process. A CBR method has possibilities to avoid to prepare fixed and detailed knowledge sources, to output flexible and various information, and to extend knowledge sources step by step. We will also present a prototypical system (YAAD) for electric facilities layout design based on the proposed framework.

Keywords

Interactive system, computer-aided design, intention recognition, collaboration, case-based reasoning, knowledge-based system.

Introduction

One of the reasons why human can communicate efficiently is that they can understand the intentions of each other. In conversations, for instance, one is able to make a better response by understanding the intention. Conversely, one may say «What is the intention of the utterance?» in a conversation, when understanding states of both participants of the conversation may be quite separate. It is a problem in communication not to grasp the intention of the opponent.

Also in collaboration, the lack of mutual understanding of the participants becomes an obstacle both of to efficient communication and efficient problem solving. Therefore, the system ▪ s ability to grasp the intention of users and to use it effectively becomes an important function for effective problem solving in HCI.

Despite the importance of the function to grasp intention, in the design support field, there has been little research which presents such function to put it in a clear range [Tomiyama92]. In this paper, we will discuss a computer support method which incorporates an intention presumption function for design problems.

What is Intention in Design?

The difficulty of a so-called synthetic problem like a design is that there would be two or more candidates of solution to satisfy the input problem and they would cause the explosion of the combination. The basic approach to the synthetic problem is to solve constraints satisfaction, but it is a rare case that a definite solution can be derived from constraints given beforehand. However, since one convincing answer is finally demanded in a design, the designer should give a certain plan to determine a definite solution. That is, the designer has to make decisions of selection from possible solution candidates.

In this paper, we call the designer ▪ s regard which influences the decision making on, «design intention», and call the concrete solution plan selected based on the design intention, «means». So we can say «the intention is achieved by the means».

For instance, when the designer has selected one from two parts, both which met the given specification and offer an equal function, by the reason with a beautiful design, we can say the designer had the intention which s/he wanted to finish the product up beautifully and had taken a concrete means to use the beautiful parts. We also say the design task done in this way, «intentional design». Moreover, we call the structure of the causal relationship between the design intention and the means, «intention structure».

Notice that the design intention is not always the design goal or the functional end the final product to perform, but is a kind of mental state of the designer in the design process. If alternatives to achieve the goal exist, designers could make decisions to choose the preferred means to satisfy the intention.

Intentions of human designers are varied and depend upon the situation especially in creative design, such as in case of a new product development. Therefore it is difficult a priori to describe rules concerning the intention. Even if such rules can be described, flexible processing according to the situation to support creative design is difficult in fixed rules.

Using Case-Based Reasoning

In this paper, we propose a method for computer interactively to presume the design intention and a design support method to provide useful information for design according to the intention presumed, both based on the framework of CBR. CBR methods generally have the following characteristics:

1. to avoid preparing a priori fixed and detailed rules and knowledge sources;
2. to provide flexible and various information through the modification and adap-

tation processes;
3. to extend knowledge sources step by step.

Therefore it is possible to avoid to describe rules concerning the design intention, and the system becomes to have a function to present various information.

We also present an application system of the method to a layout design task. In the early process of most layout design, that is in the conceptual design phase, the designer ▪ s intention would be heavily concerned with the results of the design.

Thinking about the state of the art and the ability of creativity of computer systems so far, it is reasonable to entrust creative judgements to human designers. On the other hand, the computer does not dislike taking pains such as to retrieve necessary data among huge databases, while it may be annoying work for a human. A basic form of the design support of which the method proposed in this paper aims is not design automation by the computer system, but promotion of design activity of human designers by way of computer retrieval and presentation of useful information.

In section 1, we analyze an intentional design process and propose a framework to support the intentional design incorporating an intention recognition method using CBR methodology. In section 2, the method to recognize the design intention using CBR is described in detail. In section 3, a system architecture and a prototype system as an implementation of the method are presented. Then, the system is evaluated in section 4.

In this paper, «design» will be referred to as a creative non-regular design in cases when the new product is developed, and examples have been taken from the electric facilities layout.

1 Case-Based Design Support

1.1 Conventional Design Support

Conventional CAD systems at present, such as graphical drawing tools, can only support lower level operations of the designer or tend to aim at fully automated systems, but cannot sufficiently support creative aspects of design processes. In the field of intelligent CAD, the major aim is to support regular design work as a proxy of the designer by adopting the knowledge engineering approach for each phase of design.

In this sense, expert systems and simulators, which are related to CAD systems, tend to aim partially to automate or support the analysis, the calculation, and the evaluation of complex design tasks. Systems mentioned above seem not to contribute to support flexible decision making in the phase round which the design intention affects directly.

UI research possibly contributes to supplement the part which the CAD systems mentioned above did not directly treat. The purpose of UI research is to pursue the ease of the system to use and understand, such as multi-media systems, and to help human-computer communication lubrication, such as in interactive systems. Media technologies currently play the major role to implement an UI system, but the tendency of current media technologies seems to emphasize only graphic display and/or multi-media presentation. In this sense, the current media technologies seem not to offer a fundamental technology to grasp the intention of the user in communication, which is important to support decision making in conceptual design and collaborate with the human designer.

In this paper, we propose a framework and a method to support the conceptual phases of design through human-computer interaction, by permitting the human designer directly to operate design objects in the UI of the system, by presuming the designer's intention from the sequence of the designer's operations and the design status, and by showing the information related to the intention presumed to the designer.

1.2 Form of Supporting Intentional Design

If the design intention of the designer becomes clear in the design process, support accordingly becomes possible. Situations where the designer regards the design task with the design intention are enumerated as follows:

1. The design intention is clear in the designer, but the concrete means cannot be taken account of.
2. The designer can present a concrete means partially and intuitively, but cannot explain the design intention and the direction well.
3. The designer wants to refer to something for the present, although s/he has various ideas. (The intention is not fully decisive.)

For instance, (1) is a situation which the beginner often encounters. (2) might be a situation where the skilled designer often do. And (3) is where the designer starts a new problem s/he has not ever experienced. In most creative design processes, because the trial and error is repeated, phases shown above often appear one after another. Support forms by computer systems which correspond to the situations above are enumerated as follows:

1. To present concrete means which satisfy the design intention the designer showed.
2. To presume the design intention, then to present the presumed intention and overall means corresponding to the intention.
3. To present examples of intentions and means in various situations.

Anyhow, to achieve the support of such forms, it is necessary for computer systems to have knowledge concerning the relation between the intention and the means. Especially, it is necessary to presume the designer ' s intention from the designer ' s behavior and the design status.

1.3 Design Support Method

Kolodner [Kolodner91] has insisted on the effectiveness of support by CBR to the decision making process in human creative works and artistic judgments. Goel et al. [Goel91] also pointed out that CBR is the right technique for building design systems and better suited for aiding designers in conceptual design. Because the authors grasp the essence of an intentional design as non-regular decision making based on the preference and sensibility of designer, it is good for supporting the intentional design to take an approach based on CBR framework. A main role of the computer in this approach is to accumulate and maintain information and knowledge concerning problem solving, and to present the content according to the situation of the design and the demand and the intention of the designer.

To achieve to support the intentional design by the CBR approach, the following functions in addition to the functions of the standard CBR framework, such as case retrieval, case modification, case memory and so on, are needed:

Reference by the intention: to retrieve and present the case where the design intention is reflected, when the intention is input.

Intention presumption: to presume the intention from conditions which is changing according to the operation of the designer.

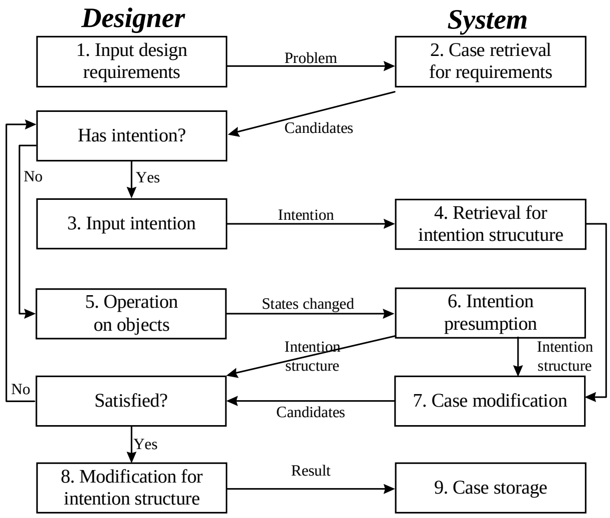

Figure 1. Block diagram of intentional design support

Figure 1 depicts the flow of the processing of the case-based design support method in which the functions mentioned above are used. The input problem includes the goal, objects, constraints, and so on. Step 3 may be performed if the designer explicitly has a particular design intention, otherwise step 5 is performed. Step 6 is achieved by the intention recognition method (see section 2 for details). In step 8, the designer can also modify any symbol of mental statement in the intention structure to reflect his/her design intention. Each step of the system corresponds to a particular phase in a typical CBR process: 2 and 4 to the case retrieval, 7 to the modification, 8 to the adaptation, and 9 to the case storage, respectively.

The design support method described has the following characteristics:

- A flexible design according to the situation becomes possible by permitting the designer free operations for the editing and the modification.
- Mutual understanding of the design intention and good communication is possible between the designer and the system by the intention recognition and the modification.
- There is a possibility that various solution candidates can be synthesized, because the designer can refer to various cases both similar to the intention of the ongoing design, and to the requirements and specifications of the entire design.

2 Case-Based Intention Recognition

2.1 Using Case-Based Reasoning

The problem of conventional techniques to recognize an intention such as the plan recognition technique [Allen80, Johnson90] is that it is assumed that complete knowledge (plan) is given beforehand. It is obviously difficult to describe the intention and belief strictly and to prepare plans beforehand as standard knowledge sources. Moreover, even if such knowledge could be described and the inference could be done well, flexible output according to the situation cannot always be obtained with the conventional rule-based plan recognition. In this paper, we adopt a CBR method in order to avoid the bottleneck of the knowledge description and acquisition, and propose the intention presumption method by which flexible output is possible. The method is good for attacking the conventional problems, mainly because the CBR method generally has the following characteristics and possibilities:

1. to avoid preparing fixed and detailed rules and knowledge sources beforehand;
2. to provide flexible and various information through the modification and adaptation processes;
3. to extend knowledge sources step by step.

2.2 Representation of Intention Structure

We represent an intention structure as a labeled graph. An example of the representation of the electric facilities layout design is shown in figure 2. It consists of four types of nodes, **vocabulary**, **object**, **physical** and **mental node**, and labeled links between them. An object node consists of a set of attributes, where each attributes name is a link label and value is a vocabulary. A physical node consists of a set of objects(the predicate name and arguments), and generally stands for a physical state, such as «left» or «center». A mental node consists of a set of any nodes, and generally stands for a mental state, such as «beautiful» or «compact».

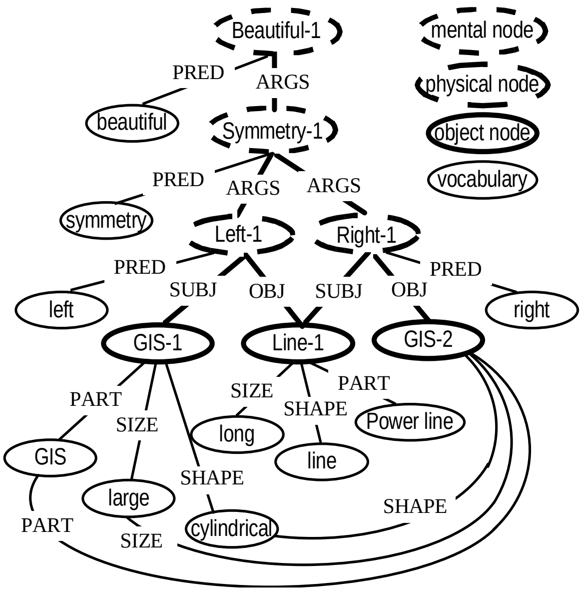

Figure 2. An example of data structure

In this representation, intention in the design is shown mainly by a mental node, and means is shown by sets of physical nodes such as «right» and «left». Moreover, intention structure is a sub-graph which can be traced from a certain mental node. An intention structure which has a mental node in the upper rank will be called a «partial intention structure», such as «symmetry» in figure 2. A certain design case can be represented by the gathering of some partial intention structures. The example in figure 2 is arranged by the design intention that is to be «beautiful» in an electric facilities layout of sub-station.

The main advantage of this representation is to be able to represent both the structure and functions of product at a time. On other hand, the shortcoming is in the data preparation. It is hard to classify and set words into the types, and hard to describe the initial data or copy from real design data, such as drawings. But this shortcoming could apply to a greater or lesser extent of representations for conceptual design support systems.

2.3 Incremental Partial Synthesis and Interactive Modification of Intention

Intention recognition based on CBR will be achieved by recognizing the states which were done by the operations of the designer as the input and by retrieving the similar case for the case base of intention structures. However, the intention presumed by simple application of this method might not show the intention of the designer adequately. The one due to case shortage and the one due to the individual variation are thought the reason. In this paper, we will propose a more adequate method of grasping intention by incrementally synthesizing partial structures and by modifying an intention structure through the interaction, to confirm the intention to the designer.

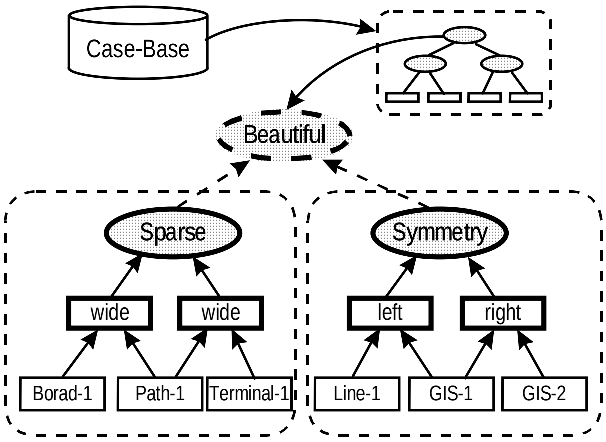

Figure 3. Synthesis of intention structures

The incremental partial synthesis is a process which gradually catches states which were changed by the operation of the designer, at any time, to presume a partial intention by case retrieval, and to synthesize the partial structure retrieved and the intention structure that the system has already presumed and maintained. Generally, the goal of the entire design can be achieved by synthesizing the divided sub-goal. Similarly, it seems that the intention of the entire design is composed of the synthesis of the intention to a partial object. If it is assumed for the designer to concentrate on the achievement of a partial intention at a time, it is appropriate to pay attention only to the means done in a certain phase in the design, then to presume the intention of the phase, and finally to presume the entire intention by syntheses of the parts.

The basis of the synthesis is to retrieve an upper intention which includes these partial structures. Figure 3 is an example of synthesizing partial intention structures. This example shows that «beautiful» was retrieved and presumed as an upper intention by the synthesis, a partial intention «symmetry» is presumed in this phase with a partial intention of «sparse» presumed before. This is achieved by retrieving an intention structure which contains nodes similar to two partial intentions from the case which became a retrieval result before or the case base. At this time, the means of each intention need not be always necessarily similar, because the design of a concrete means and the design in the conceptual level can be separated to some degree.

The modification of the intention structure is to permit the designer interactively to modify the intention structure presumed to the current intention in any phase of the design. The designer can change the name of an arbitrary mental node. As a result, the separation between the intention presumed and the intention which the designer actually imagines can be corrected.

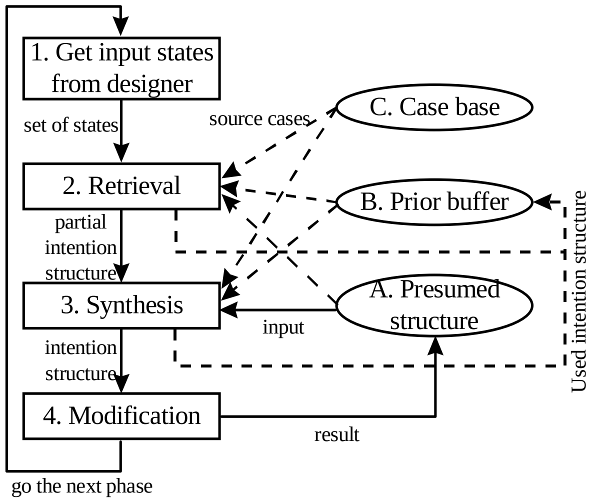

Figure 4. Block diagram of intention recognition

The case modified by the designer is stored to the case base and becomes new knowledge. Moreover, because a lot of various cases will be used through the incremental partial synthesis and a new structure will be produced dynamically crossing while designing, the separation of mutual understanding due to case shortage will be decreased. On the other hand, the problem of the individual variation, which seems to depend mainly upon the difference of the vocabulary used and the difference by the situation, will be corrected only through the interactive modification function by the designer at present. However, we guess that there are few obstacles to proceed the entire design by the intervention of such an interactive processing in an interactive support system.

Figure 4 shows the flow of the intention recognition process explained above. The solid line in the figure shows the flow of the data to be processed, and the dashed line shows the flow of intention structures or cases which are the sources for the retrieval.

2.4 Case Retrieval and Similarity Measurement

In the retrieval of figure 4, several partial intention structures similar to the input are retrieved from intention structures used before or source cases in order of A, B and C. In the synthesis, several partial intention structures which mainly consist of mental nodes, are retrieved from the sources in order of B and C, then those are tried to synthesize with the input structure presumed before (A. in figure 4).

The presumed (intention) structure and the prior buffer are empty at the start of the design. The prior buffer is a push-down stack which maintains the cases which contain intention structures which the system judged to be similar in processes 2 and 3. Using this buffer, the source case which became a retrieved source recently can be retrieved at first, and efficiency improvement of the retrieval processing can be expected.

The similarity measurement of the cases is done by a graph matching method and a distance measurement using a vocabulary database. The vocabulary database is a database which defines vocabularies used in the system and the distance degree between them.

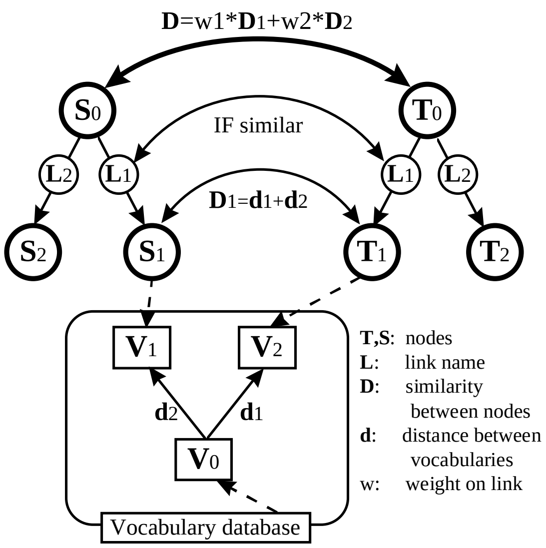

Figure 5. Similarity measurement

The similarity between two arbitrary data structures (graph) can be defined as follows:

1. The similarity between vocabularies is a distance degree obtained from the vocabulary database.
2. The similarity between data structures other than the vocabulary is a minimum sum total in the similarity combination between the subordinate nodes.
3. A stable penalty is added to the similarity of the upper node for the remaining node not combined, when the number of subordinate nodes is different. This must be done only in the target(input) side.

The image of this similarity measurement processing is shown in figure 5.

The check for the similarity combination in the above graph matching (2.) needs the exponential amount of the calculation. Then, it runs by the following rules:

1. The combination of the subordinate nodes between physical nodes takes corre-

spondence only by the link name of the argument.

2. The order of processing the combination of the subordinate nodes of mental nodes follows the temporal reverse order of the order operated by the designer for the input side.

3 System

In this section, a system architecture and a prototype system which achieves the described design support method with the intention recognition function are described.

3.1 System architecture

The system architecture is shown in figure 6.

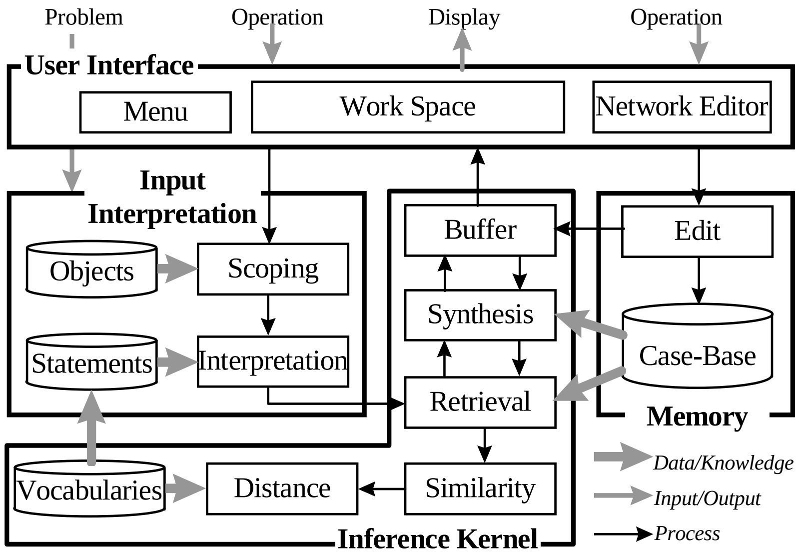

Figure 6. System Architecture

The UI is a graphical one in which a user can directly manipulate design materials and edit graph structures which represent the causal structure of the design intention and the means (figure 7). The input interpretation part interprets operations and states in the UI and transfers them to the internal data structures (graph), using the objects and statements KB.

The inference kernel is the main part of CBR, including the retrieval and synthesis programs and the prior buffer described in section 3. The memory part maintains cases as intention structures and provides an editing facility to change structures for users to modify and adapt them to reflect the design intention.

3.2 YAAD: Layout Design Support Prototype System

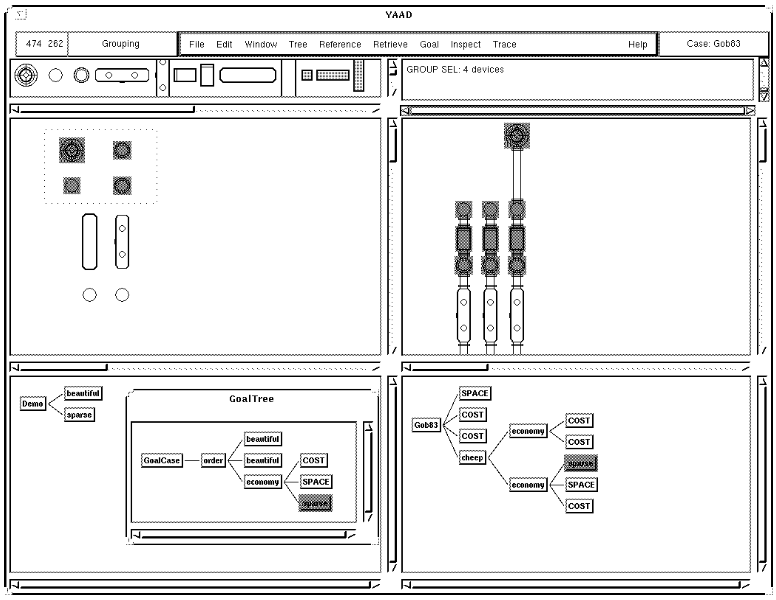

Figure 7. Screen Copy of YAAD

We implemented a prototype « Yet Another CAD system » (YAAD) for electric facilities layout design using C and Motif on a UNIX workstation. A screen copy of YAAD is shown in figure 7. This figure is a snapshot of Gas Insulated Substation (GIS) layout design. Designers can do some layout operations on objects and edit the intention structures in the left hand window (the working area), while a retrieved layout example and its intention structures are shown in the right hand window (the case area). Most operations in YAAD can be done only by mouse operations.

To support a more detailed information reference, the following data reference functions among each window were achieved in YAAD:

1. Reference from arbitrary node in the intention structure to the correspondent object or the set of objects in the working area.
2. Reference from arbitrary object or state in the working area to the correspondent one in the case area.
3. Reference from arbitrary node of the presumed intention structure to the correspondent state of the retrieved case in the case area.

These reference functions can be achieved by leaving correspondence information in the matching process of the similarity measurement. Such reference functions contribute to the ease of the designer ▪ s understanding of the behavior of the system.

3.3 Design Example by YAAD

The electric facilities layout design in the sub-station is generally done considering particular conditions of the location and the required specifications, such as the power output degree. To match the requirements from the customer in addition to these conditions and realize the characteristic of the design, the design group examined design policy from various aspects. Especially in the equipment layout, the designer often considers an abstract policy «fine sight», «economy», or «maintenance and extendibility», etc.

Moreover, the designer has used a CAD tool in the actual drawing and referred to drawings accumulated in the past design. However, to what example the designer refers and what example existed in the past have not been well supported and have been retrieved by the experience of the designer so far. In this way, the embodiment of the examined design policy is rich depending on the experience of the designer.

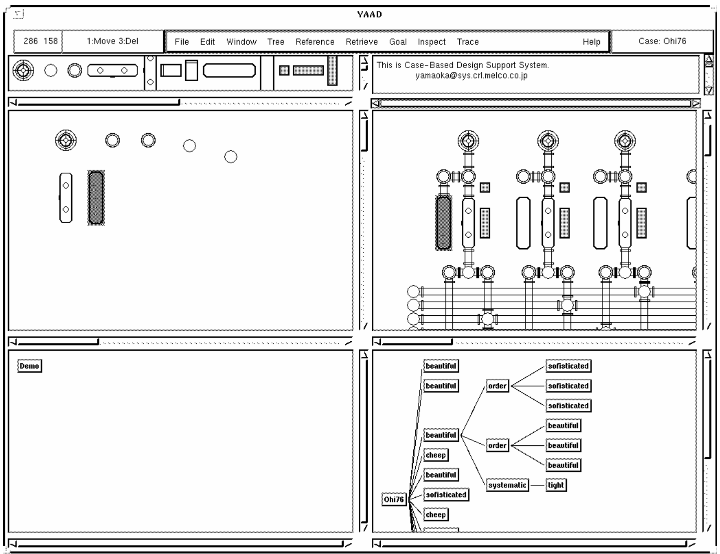

Figure 8. Retrieving parts

We made YAAD prototype a tool which supported such a layout design. In the prototype, total 132 vocabularies, 12 parts data and 6 physical statements, all related to the electric facilities, are registered as the databases. The vocabulary database is a thesaurus form which is extracted from a Japanese synonym dictionary. Four past design examples were input as initial cases, and divided into 54 intention structures in total concerning the GIS layout by the authors referring to actual design documents.

In the following, an example use of the prototype is explained. Figure 8 indicates a result of retrieving from the whole input parts. The reversing parts indicate the reference linked by the similarity measurement process.

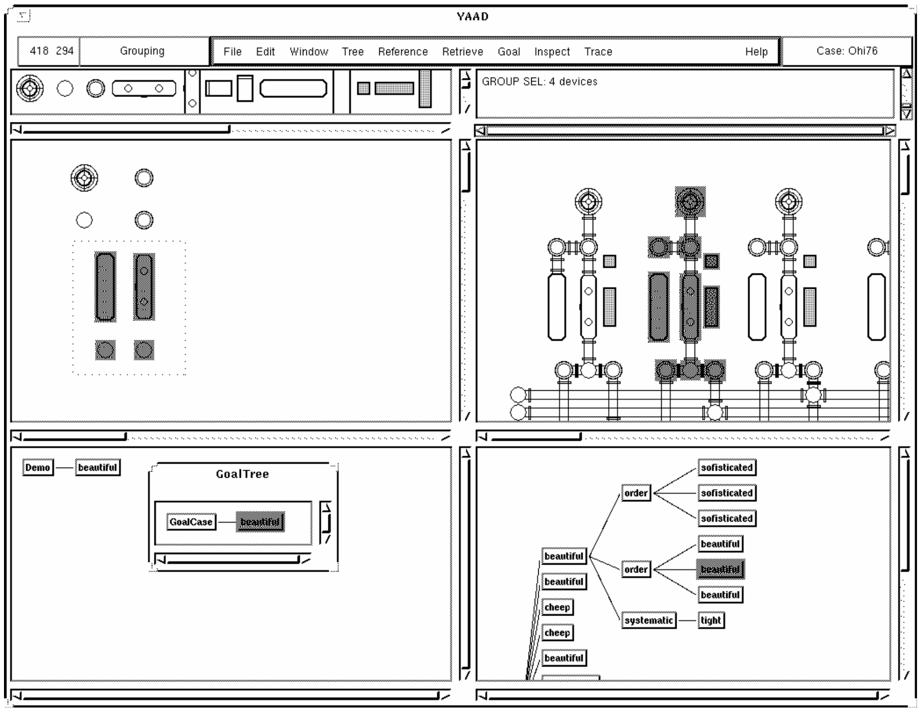

Figure 9. Retrieving results

Figure 9 is a result of retrieving from the scope specified by the designer, after he did a rough layout in the working area. A similar intention structure case in which «beautiful» is the intention was found here. In the case area, parts in the intention structure corresponding to the scope are displayed in reverse.

Moreover, the intention is copied to the presumed intention window (a pop-up window) and the working intention window. In this way, the designer can refer to past examples and the intention similar to the condition now.

Figure 10 is a result of retrieving from another scope and presuming the upper intention by synthesizing the intention structures. It is indicated that a partial intention structure labeled «sparse» is first retrieved (shown in the case intention area), then it is synthesized with «economy» to the upper intention «order»(shown in the presumed intention area).

In figure 11, the means of intention «economy» presumed and synthesized in figure 10 is flushed in the case area, then referring to it the designer can modify the layout in the working area. In addition, the name of the first intention structure «beautiful» is changed to «COST» and «economy» is added to the upper intention in the work intention area. In this way, the designer can produce the layout and its intention structure which satisfies his intention by referring to various information. Also, it can be memorized as a case, and can be used in the future.

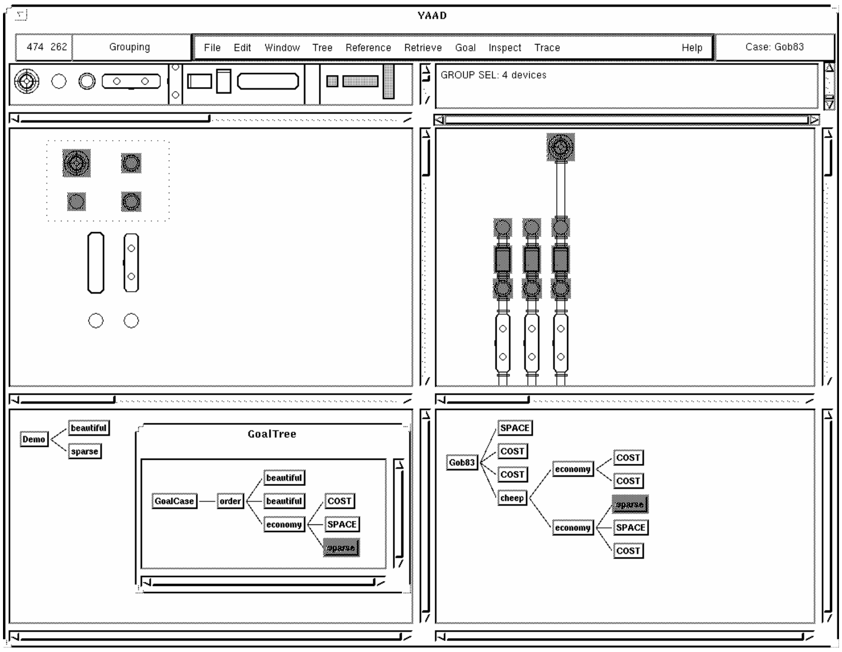

Figure 10. Alternative retrieving results

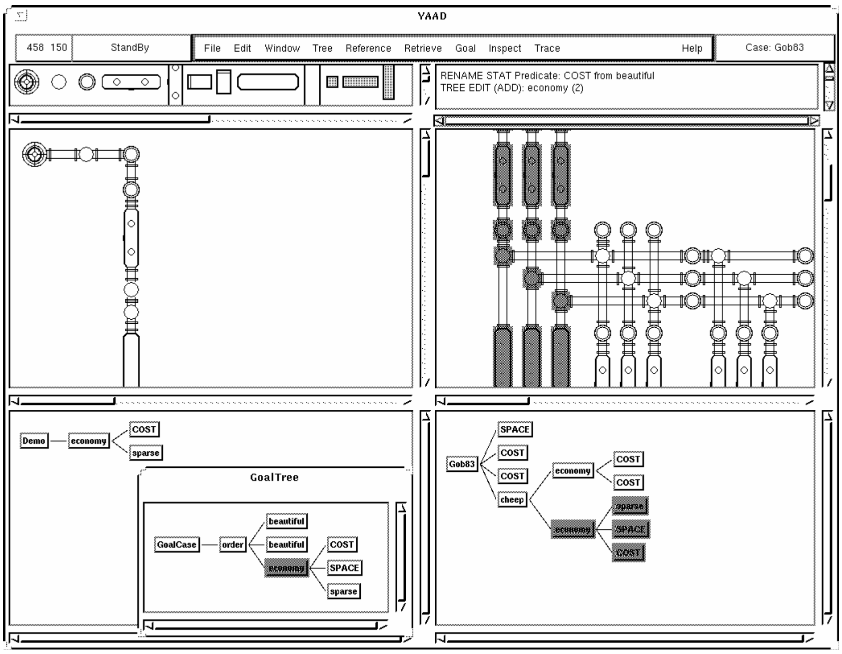

Figure 11. Applying "economy" intention

4 Evaluation

At present, though the information offer function and the intention presumption function with this system are under evaluation through a prototype trial, the following subjective opinions were obtained from several design engineers:

- **Satisfactory points:**
  - The possibility of referring to various ideas for a new problem is effective.
  - The idea was able to enhance starting with a certain intention expression presumed from operations and save the time finding out the related information in the conventional way.
  - It is good to be able to examine the case where the means is different even if the intention is the same closely and to be able to take a partially different idea according to situation of the problem.
  - The intention structure of a past case explained what I want to do.
- **Dissatisfied points:**
  - It is annoying to specify the scope of objects in a phase frequently. Such a part should be automated because there is a part where the layout can be done regularly.
  - It is hesitant to modify the intention structure, because the name thought of at first is influenced by the vocabulary of a past example.

5 Future problems

Though the support function of presuming and using the design intention, which is the main purpose of this research, has been almost achieved in YAAD, it is necessary to clear the following problems for feature improvement.

- **Vocabulary setting**. In general, the output of CBR system is largely controlled by the similarity measurement. The similarity depends on the distance degree between vocabularies, and, the change of the degree largely influences the result of both the layout and the intention presumption processing. On the other hand, there are individual and situational variations of the expression of intention, so that it would be a problem to reflect these variations to the result. Thus, a vocabulary edit function by which the designer can easily change the settings to reflect the individual preference will be necessary in the future. Moreover, it is vital to add an automatic modification function by an induction learning technique.

- **Integration with conventional design support**. The main purpose of YAAD is supporting a creative design in the scene that the preference of the designer is valued. However, considering the support of the entire design task, including regular design tasks, it is necessary to unite approaches in which conventional approaches, such as using design object models, qualitative models of the do-main, simulations, rule-based automation, and so on, and the case-based approach are well integrated.

- **Explosion of the retrieval calculation**. In CBR systems, the explosion of the amount of the case retrieval calculation cannot be avoided, especially when the amount of stored cases and/or the number of input objects become large. So, developing an efficient method to retrieve cases from the case-base, including parallel and/or intelligent search algorithms, and an effective mechanism to maintain the case-base are future goals.

Conclusion

A case-based method to support intentional design incorporating the intention recognition ability was proposed and a prototype system YAAD based on the method was described. In creative design tasks, the intention of the designer is largely reflected in the final result. Therefore, in order to support the creative design effectively, it is important to grasp the design intention according to the situation.

The proposed case-based method provides the supporting information related to the design intention by presuming and using the intention situationally and interactively. Moreover, the load of knowledge description concerning the intention is evaded by incremental case storing which is an original characteristic of CBR. We explained a design example using YAAD prototype for electric facilities layout, and verified the effectiveness of some functions through the trial use.

It is important to devise the evaluation method concerning the effect of the design support. In the future, at the same time as groping for the evaluation technique, we want to confirm the effectiveness of the method described in this paper by using it in other application fields.

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