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A METHOD FOR SUPPORTING CONCEPTUAL DESIGN PROCESS USING QUALITATIVE REPRESENTATION OF TEMPORAL AND SPATIAL RELATIONS

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1 Introduction

Cooperative design among designers is widely executed in product design these days. For the cooperative design by a design team, it is important how to precisely understand the design information. Many researches have been done and proposed methods that help designers to communicate each other and share various types of design information in real time. For example, Tomiyama proposed the framework of integrated CAD system with a mechanism of data compatibility between different CAD system by using systematized knowledge [1]. Brissaud proposed the concept of an indicator of machinability for supporting discussion between designers [2]. Taura proposed the active chain model to handle evolution histories of design product information and design rationale by using record of design processes [3].

Nevertheless, the real design activities done by a design team are not often being done actually in the same time [4]. Such a case, a designer usually wrote some comments with the design drawing to transmit his/her thought about design to other designers. However, such kind of communication has problems. For other designers, to search or pick up related information they need from whole comments is laborious work, and the obtained information from the found out comment sometimes far from the information they really want. To understand decision-making and plans by other designers, a designer needs design information not only geometrical data but also the information about mechanisms and behaviors [5]. Therefore, the method to handle various types of design information in integration is needed for description of designed object.

On the other hand, engineering design consists of some design processes. Usually, a designer executes a conceptual design process first, then detailed product in a detailed design process. In the conceptual design process, a designer derives the concept of a designed object from the initial required functions [6]. Since the determined concept by the conceptual design process becomes the based idea in following design processes, it has large influence on quality of designed object. If the conceptual design process can be modeled and supported by a computer, it is possible to reduce development cost and lead time. It is the reason that the development of the supporting system to support a conceptual design process is one of the most important issues on engineering design process.

In this research, we focus on this process and propose a representation method in consideration of the design process, designers' reasoning process, and qualitative functional and spatial relation between rough imaged parts of the product

2 Representation of conceptual design information that treat relation between the function and the entity

To transmit description about designed object among designers, the description must include the information about "how the idea comes from where" In this section, we introduce representation method for conceptual designed object that include such kind of information.

Generally, it is assumed that the product design is proceeded as follows [e.g. 6].

1. Clarification of the required function to a designed object.
2. Decomposition of the required function to the detailed behaviors for searching design solution.
3. Derivation of the mechanism corresponds to detailed behaviors with considering constraints.
4. Combination of the mechanism to the whole entity.

Conversely, when the designer wants to understand the design from final product, one of the effective methods is to decompose the product and derive the function from decomposed parts. Thus, the derivation relation between the required function and entity that satisfied required function, and/or those between the entity and the functions that the entity roles, are represent in the processes of the circumstantiation by analysis, and combination integration by synthesis [7]. That is to say, a designer designs product using the hierarchy of a function, and the hierarchy of substance. Especially, on the conceptual design stage, function decomposition processes are done by using both a functional hierarchy and a structural hierarchy is known by the observation of designer's activities [8]. Therefore, a method of representing of functions, conceptual entities, and their relation is proposed.

2.1 Representation of function

From physical point of view, the function has a role that has some influence on a specific object. On the other hand, the function can explain that it has the role to achieve the designer's intention. Therefore, it is very important to understand a "function of designed object" which represents a role of designed object and designers' intentions of it [9]. In this research, the function is defined as the role that has some influence on a fixed object according to designer's intention.

The function defined above is expressible in the conceptual mechanism corresponding to the function as temporal and spatial behavior. Thus, to show the relation between the function and entity and to handle them at the same time, it is necessary to represent the conceptual entity that the designer imagines. Therefore, we introduce abstract building block named functional block as conceptual entity that has at least one function. The functional block is defined as follows.

- The functional block is a representation of conceptual entity that has one or some function(s).
- The functional block is expressed in the hexahedron that all faces are vertical to one of coordinate axis of the three-dimensional orthogonal coordinate system.

- The function that the functional block has is described as an influence given to other function block by “Verb + Object” form.
- The relation between function and conceptual entity is represented by combination of functional block and “Verb + Object” formed description.

By using this description, the conceptual entities and their functional and spatial relation including designers’ intention can be represented. The device that affects the physical object is represented by one functional block. And a mechanism, which a designer has derived from a function, is represented by changing the size of these blocks and/or arranging them.

2.2 Description of Spatial Relation about Conceptual Entities

When the mechanisms are composed based on the required functions, it is necessary to consider the spatial problems such as how to arrange each mechanism, and how to avoid interference by operation. These problems were not explicitly handled on the conceptual design stage so far because most of quantitative information concerning the mechanism has not been decided yet. By providing the information even if it is qualitative level information, the evaluation of the mechanism on the initial designing stage can be enabled. Moreover, it makes easy for other designers to understand the spatial relation of the mechanism assumed by the designer on the conceptual design stage. Therefore, we propose description method of qualitative spatial relation between functional blocks.

Here, we introduce 13 qualitative relations between two intervals shown in Fig.1 proposed by Allen [10]. These relations, which are originally used for represent temporal intervals, indicate all relative position between two intervals. In this research, these 13 qualitative relations are applied to describe spatial position between two functional blocks.

Relation	Pictorial example
A before B	
A meets B	
A overlaps B	
A equal B	
A overlapped-by B	
A met-by B	
A after B	
A finished-by B	
A contains B	
A started-by B	
A starts B	
A during B	
A finishes B	

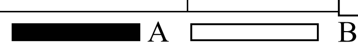


Figure 1. The thirteen possible relations between an ordered pair of intervals.

Because the functional block is on the three-dimensional orthogonal coordinate system, and all faces are vertical to one of coordinate axis, the relation between two objects on one axis can be expanded to three dimensions. Consequently, when functional block A and B are assumed, a qualitative space relation between functional block A and functional block B is described as the following expression.

$$SR(A, B) = (R_x, R_y, R_z) \tag{1}$$

Here, R_x, R_y, and R_z are a qualitative spatial relation between functional block A and functional block B of x, y, and z axis, respectively. For example, when two functional blocks are arranged as shown in Fig. 2, the qualitative spatial relation is described as follows.

$$SR(A, B) = (\text{during, meets, starts}) \tag{2}$$

By representing a qualitative spacial relation using proposed description, arrangement and interference check of blocks becomes possible on the conceptual design stage. This description is also possible to use as a constraint on the following process. This characteristic is effective to the transmission of the designers' intention.

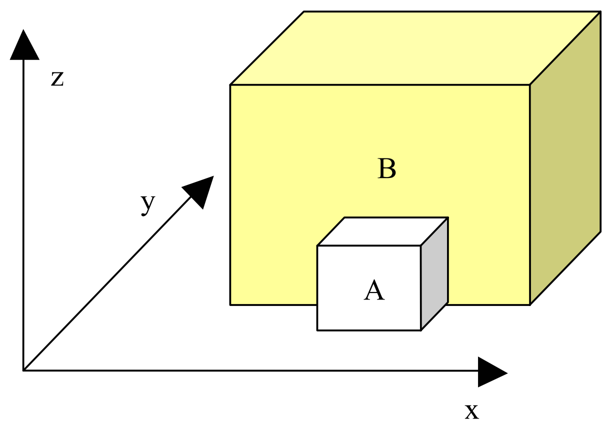


Figure 2. The representation of spatial relation between two object.

2.3 Description of the function execution time sequence

Considering about combination of two or more mechanisms, the order of the functional operation greatly influences the behavior of the entire product. Therefore, the method of representing the function execution time sequence of the conceptual entities is described as follows.

A basic unit of the expression of time information is roughly divided into two. One is "point" that focuses on the event, and the other is "interval" that focuses on the state [11]. Here, if starting time and finishing time of state is decided, the interval can be expressed from these two points. Oppositely, from interval, time point that causes the state change can be represented. Therefore, in this research, the description of the functional operation uses the point expression that catches easily as an event, and time order management is done by intervals derived from these points.

Since the relation between two points of time can be described as a relative position of the two points, the relations between two points is represented by one of seven relations shown in Table 1.

Table 1. The relations between two points.

Relation	Description
A before B	Point A is earlier than point B.
A equal B	Point A and point B is the same time.
A after B	Point A is later than B.
A equal B or A after B	Point A is not earlier than point B.
A after B or A before B	Point A and point B is not the same time.
A before B or A equal B	Point A is not later than B
A before B or A equal B or A after B	No relations between point A and point B.

When the description of qualitative relations of the points, the relation of the time interval can be expressed. Finally, the relative relations between functions can be described by the time interval relation expression derived from Table 2.

Although the relation handled by this description method is qualitative, the designer can check the correspondence of their assumed function execution time sequence by using the qualitative relation transition law. Consequently, the designer can decrease misunderstandings and/or overlooking. Moreover, because these information can be transmitted to the following designing processes as the designer's intention concerning the functional operation, the failure of the design by miscommunications can be decreased.

Table 2. Derivation of the relation between intervals from the relations between two points.

Relation between starting points	Relation between finishing points	Relation between intervals
A_{start} before B_{start}	A_{end} before B_{end}	A before B
		A overlaps B
		A meets B
A_{start} before B_{start}	A_{end} equal B_{end}	A finished-by B
A_{start} before B_{start}	A_{end} after B_{end}	A contains B
A_{start} equal B_{start}	A_{end} before B_{end}	A starts B
A_{start} equal B_{start}	A_{end} equal B_{end}	A equal B
A_{start} equal B_{start}	A_{end} after B_{end}	A started-by B
A_{start} after B_{start}	A_{end} before B_{end}	A during B
A_{start} after B_{start}	A_{end} equal B_{end}	A finishes B
A_{start} after B_{start}	A_{end} after B_{end}	A after B
		A overlapped B
		A met-by B

2.4 Uniting temporal and spatial relations

The description methods of the qualitative spatial relations between conceptual entities and function execution time sequence are described above. When the mechanism represented as conceptual entity carries out some behavior according to its function, the spatial relations between the conceptual entities are changed. Besides, whether the product can execute the function in the order intended by the designer depends on realizability in the state of the substance that changes by the functional operation. These facts show the necessity for integrated handling of the relation concerning the time of the operation that originates in the function and the relation concerning the space of the operation that originates in entities.

According to designer's thought process, he/she searches for the mechanism that was the corresponding entity from the detailed function. Here, a detailed function is described similar to the operation that makes behavior or behavior that represents the state change in entity. Moreover, the function execution time sequence is made detailed during the function decomposition processes.

Thus, on the detailed function level, the expression method related to the function execution time sequence can be extended also to the expression related to the behavior operation order. And, although behavior is represented as movement of the functional block, representing only temporal axis is enough to consider with functional aspect. Therefore, on the detailed function level, relation of functional block movement and function execution time sequence can be represented by same description. Consequently, the relation of the function execution time sequence and the movement order of the functional block can be treated integratedly.

On the other hand, since behavior is defined as a temporal change of state of entity, the spatial relations between entities also change according to behavior. That is to say, the spatial relation also changes in the scene from which the relation of the time sequence of behavior is described. Therefore, movement direction information on the functional block is added to the spatial relation description according to the operation order description of behavior.

Thus, the temporal and spatial relations about behavior are described integratedly. Finally, it is possible to handle by integrating the relation of the function execution time sequence and the spatial relation between the conceptual entities through temporal and spatial descriptions of behavior.

3 Implementation of the conceptual design support system

3.1 Composition and implementation of the system

A pilot system that realizes the proposed description method is developed. This system aims to support design activities on the conceptual design stage and support transmitting and sharing of design information.

The system is composed of conceptual entity modeling system, which is including user interface, and three other subsystems. Fig. 3 shows the structure of the system. Each subsystem is described as follows.

- The conceptual entity modeling system

  This subsystem has aimed to represent the entity image that the designer is assuming. This system can do the following operations; those are addition, delete, division, changing size, and changing arrangement position of functional block. By these operations, the designer's entity image can be made an embodiment as conceptual entity. In addition, when the designer operates to the functional block, the function description window concerning operated functional block is opened, and the description of the related object and given influence to the object is pressed.

- The spatial relations management system

This system stores the qualitative spatial relation description between functional blocks, does the interference check when the functional block operates, and retrieves the position in which the block can be arranged. The qualitative spatial relation description between functional blocks is automatically generated from the arrangement position in the concept substance modeling system. The condition of not permitting the interference between functional blocks can be defined not to permit the plural functional blocks to have a common partial space. Therefore, interference can be checked by using the following condition; i.e. at least one axis of qualitative spatial relation between two entities is one of before, meet, met-by or after. The retrieval of the position in which the functional block can be arranged has been achieved by using the method of checking interference.

- The time sequence management system

This system supports to input starting and finishing time of the function, the behavior, and the operation, stores function execution time sequence, and checks the correspondence of function execution time sequence by using the qualitative relation transition law. When the function is described on the conceptual entity modeling system, starting and finishing time of the function are also input. When the designer closes the function description window, the system automatically checks the consistence of function execution time sequence. And when contradiction or lack of condition is found, the system warns the designer.

- The design activities management system

This system handles operations in the conceptual entity modeling system by the designer(s). The aims of the system are sharing and understanding design information. The function information and the relations of various information stored in each subsystem is managed. These information are retrieved and presented by the user request.

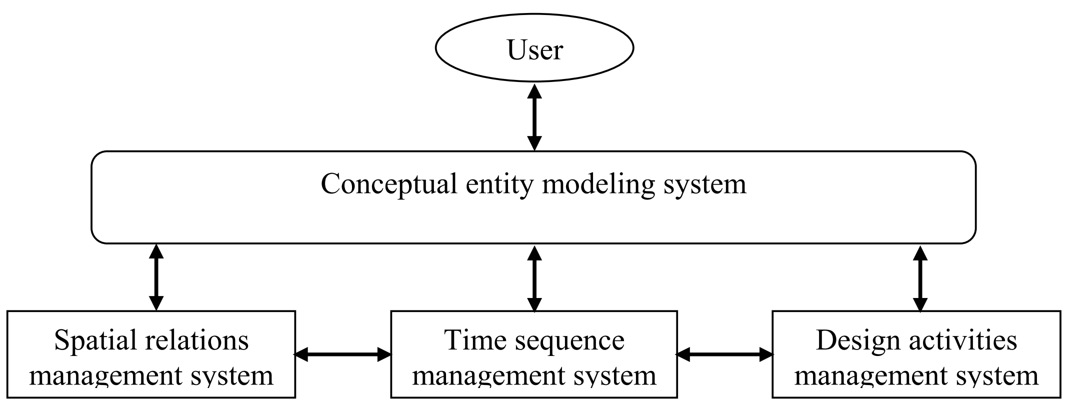
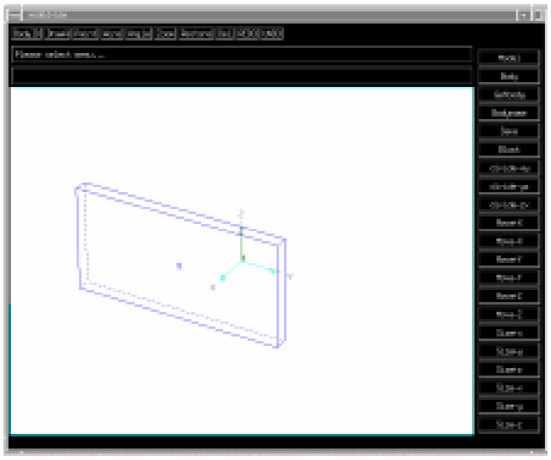


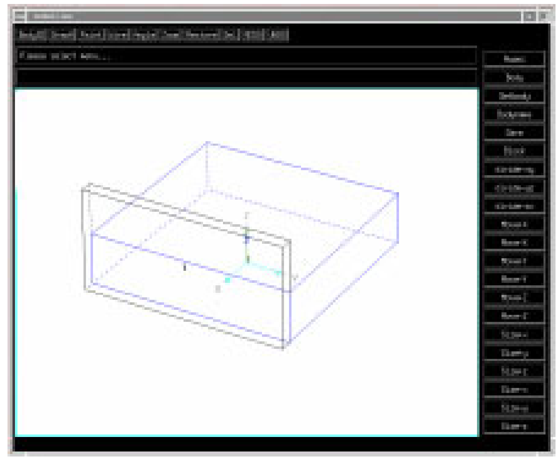
Figure 3. Composition of the system.

3.2 Case study

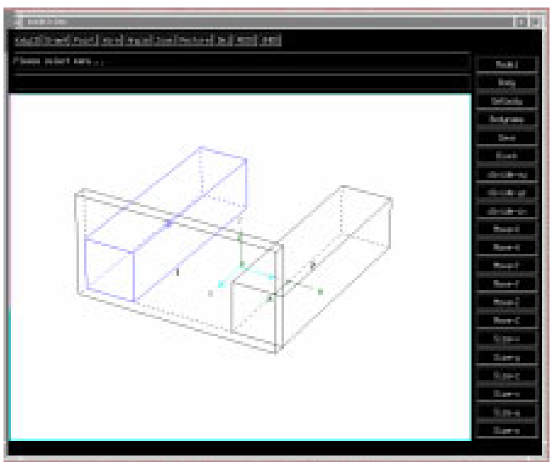
The conceptual design of the product that satisfied the required function “transport earth and sand” was done by using a pilot system. Figure 4 shows snapshot of the progress of the design.



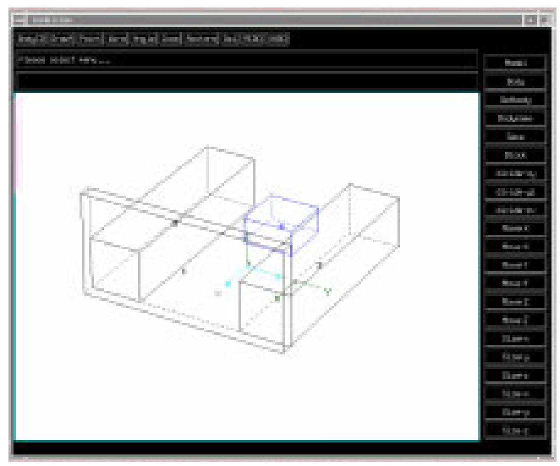
(a) Create functional block 1.



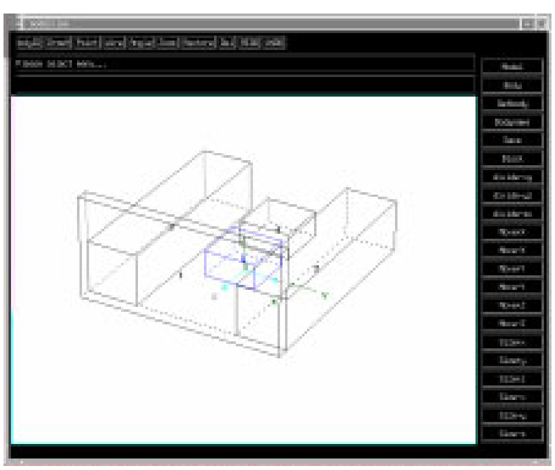
(b) Create and arrange functional block 2.



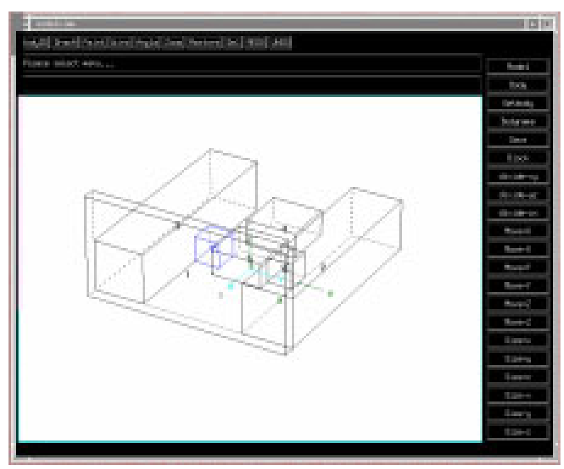
(c) Divide functional block 2 to two blocks.



(d) Create and arrange functional block 3.



(e) Create and arrange functional block 4.



(f) Create and arrange functional block 5 and 6.

Figure 4. Snapshot of the creating and arranging functional block processes.

On this case, the design is proceeded as follows.

(a) Functional block 1 is created as the object that pushes earth and sand.

(b) Functional block 2 with the advancing function is created. This block is arranged just behind functional block 1 to push it directly.

(c) Functional block 2 is divided into two functional block 2-1 and 2-2 from the idea that the moving direction is changed by pushing only the one side of functional block 1.

(d) Functional block 3 that generates driving power is created and arranged.

(e) Functional block 4 that recieve driving power from functional block 3 and transmits other mechanism is created and arranged.

(f) Functional block 5 and 6 which transmit driving power to functional block 2-1 and 2-2 is created and arranged.

By using the functional block, the system can record design processes including the reason of derivation of the mechanism. Function execution time sequence and qualitative spatial relation are managed by the system. Moreover, we confirmed that checking contradiction and interference system was working by inputting function information. These result shows it is possible for designers to describe conceptual design image including design intention with our proposed method. Furthermore, the stored information with proposed method become possible to transfer the design information to other designers.

4 Conclusion

In this research, the conceptual design stage where it had a large influence on the quality of the designed object was paid to attention, and was discussed to express the relation between the function and the conceptual entity of the product. As a result, we propose the relation description between function and conceptual entity by functional blocks we also propose temporal and spatial relations between functional blocks by qualitative relations. Using these proposed description methods, designer's intention, such as arrangement of entities, functional operation timing, and so on, can be described explicitly. We also develop the pilot system for supporting the conceptual design process with proposed description methods, and show that the system can support the designers by representing designers' intention.

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