Towards a Natural User Interface for Comprehensive Support of Conceptual Shape Design

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ABSTRACT

The lack of possibility of creative communication in the conceptualization phase of the design process significantly decreases the effectiveness. The aim of this research is to find effective non-traditional shape conceptualization techniques.

The paper presents an analysis of the activities in the conceptualization process and the man–machine communication. It also shows how to evaluate and select the most efficient shape conceptualization techniques.

1. INTRODUCTION

1.1. Problem statement

It is known for long time that the lack of creative communication between humans and CAD systems is one of the most significant problems that are hindering efficiency. An adequate interface should allow designers to concentrate only on their specific design task, without paying attention to how communicate with the computer. There exist solutions supporting specific activities of native human communication, but we cannot find any system on the market yet, which wraps up all issues relating the conceptualization design tasks.

1.2. Hypothesis

In our opinion, the ideal computer aided conceptual design (CACD) system would be similar to the one bounded by the dashed rectangle in Figure 1. The ideal

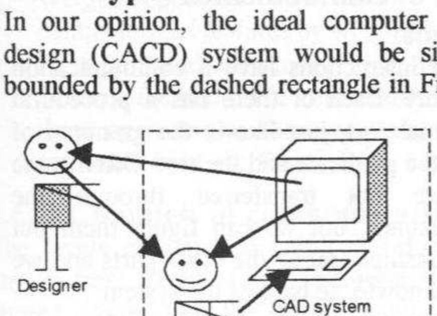

Figure 1 The ideal CACD system should behave like a smart drafts-man and one of the recent CAD software together

system should have an intelligent user interface, which understands the high level natural communication of the human being, corrects the small mistakes without notifying the user, and advises and proposes solutions.

1.3. Aims of the research

Our long-term aim is to create a design system, which supports the complete shape conceptualization process by integrating technologies based on the specific needs of the application field.

The objective of the paper is to (a) analyze the shape conceptualization process, (b) discover the significant elements and influencing factors of the communication in the conceptualization process, and (c) show how can we arrive at more effective shape communication techniques.

1.4. Research methodology

Research into creative communication needs a specific methodology. This paper covers those steps that are indicated in italic of our research methodology described below.

- *Definition of application field*
- *Analysis of the activities of computer aided conceptualization*
- *Characterization of the input*
  - *Contents of communication*
  - *Channels of communication*
  - *Level of abstraction in communication*
- *Selection of appropriate techniques for user interface in particular application field*
  - *Elaboration of the aspects of evaluation*
  - Evaluation/ranking of the categories of techniques
  - Selection of the techniques from the top-ranked categories
- Composing a framework of an effective system interface for a particular application field by integrating the top-ranked technologies.
  - Proposing algorithms for the selected technologies
- Implementing the technologies
- Evaluation and testing

2. INVESTIGATION OF THE CONCEPTUALIZATION PROCESS

As a starting point of the analysis of the activities related to the application field, we investigate the conceptualization process in general. Afterwards, we look at the specific activities of shape exteriorization.

2.1. The spiral of the conceptualization process

The conceptualization process is a loop formed by steps for creation/modification and evaluation of concepts. In the case of computer supported conceptualization, we can describe the loop by three partial models:

- the mental model of design concepts,
- the computer model of design concepts, and
- the mental model of the model of the computer (we might call it the designer's view on the computer model).

These three models crate a kind of loop based on their contextual dependencies. By introducing one more dimension of investigation for the conceptualization loop, we can represent the evolution of concepts and models as a spiral (Figure 2). The diameter of the spiral shows how close the three models are to each other semantically. During the conceptualization process, each model usually changes and gets closer to the others. When a given computer model resembles the design concept so much that the designer is satisfied with it, the process is finished.

Let us have a closer look at the steps of a general conceptualization process. Consider the following scenario:

1. The three models are given. (The computer model may be an empty model at the beginning.)
2. The designer evaluates the models and the design concept:
    - He compares his view about the computer model to the original mental model to judge how accurately is the concept represented by the computer.
    - Based on his view about the computer model, he investigates the design concept, whether the concept really fulfills the requirements.
3. The designer communicates the needed changes to the computer.
4. The computer modifies its digital model.
5. The computer communicates the modified model to the designer. (The loop continuos with the step 2.)

2.2. Activities of the conceptualization process

There are three activities in this scenario mentioned above, where the computer has important role. Although it needs much deeper investigation to see how can we speed up the conceptualization process, in this subchapter we limit ourselves to the essence of the activities.

The first activity is when the designer communicates the required changes of the model to the computer. The computer must interpret and react on the communicated contents. We will go into a more detailed analysis of it in the next chapter.

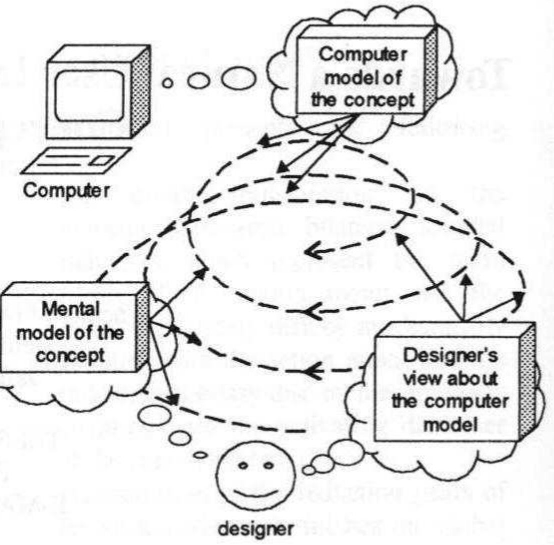

Figure 2 Evolution of models in the conceptualization process

The second activity is modification of the computer model. The effectiveness and opportunities of modification are determined mainly by the applied representation. The computer has to be capable to handle the incomplete and vague concepts, which is one of the most dominant characters of conceptualization. We have decided to use discrete model representation. The paper of Rusák et al [1] discusses it in detail.

The third activity is communication of the computer model to the designer. There are several existing output systems on the market. We can find numerous solutions in the field of scientific visualization, for example, displaying the model in virtual reality, producing photo-realistic pictures etc. According to our observations, the output systems tend not to be the bottleneck of the computer support of the conceptualization process.

3. INVESTIGATION OF THE INPUT COMMUNICATION

3.1. Structure of communicated instructions

The communicated instructions have a communication independent structure. Each of them has a procedural part, and a contextual part, just like in the grammar of natural languages: the predicate and the rest. Often some of the parts are not transferred through the communication channels, but we can figure them out based on the relationships among the other parts and we need to rely on the knowledge base of the system.

Each procedural operator can be classified as set, get, create, or destroy types. The contextual part depends largely on the procedural part. Since our aim is to create a shape model, the classification of elements of the contextual part of communication is exactly the same as with the regular geometric models of CAD systems. We distinguish geometry (morphology and scale), topology, identification information, location, and attributes. Depending on the category of a particular element of a user instruction, it may have a most effective device to communicate it.

3.2. Dependence of the aspects of communication

Referring to the first activity in the earlier mentioned scenario, if the designer is not satisfied with the digital shape model, he wants to change it by communicating one or more instructions to the computer. He can do it in several ways. He may choose from the available modeling operators, communicate his choice on different abstraction levels, and select different kinds of communication channels. We can conclude that the three aspects of communication, i.e. (a) content of communication, (b) the channel of the communication, and (c) the level of abstraction, are independent from each other.

3.3. Contents of communication

In order to describe a domain of the desired shape or modify its attributes, location etc., we use operators. The operators are determined by the their types (procedural part) and parameters (contextual part). We have operators to create, modify, destroy, or get any of the parts of the geometric model. The most influencing operators are the shape modification operators, therefore we present the categories of them based on the theory they apply.

- The create operator is very simple. It does not determine the boundary of the object on a procedural way, but with a large set of discrete points. E.g. this can be applied by using data gloves or 3D scanner.
- The copy operator makes a copy of the boundary or a part of the boundary of a particular object. It facilitates not only the regular copy/paste type of operations, but to apply metaphors, as well.
- We have a number of volumetric operators, which use the set theory, e.g., the "mix" operator [3] uses the union. They are used by all cutting type of modifications.
- Weight operators can modify the shape like parameterized features by weight functions.
- Physical based operators [3] use the theory of finite element methods. We can modify our shapes with these operators as they were physical objects, we can bend, twist etc. them.

3.4. Channels of communication

The levels of communication of information are well known from the literature. The number of levels is still argued issue, but the main points are established. Weaver [2] discusses three aspects of communication that are related to the syntax, semantics, and effects. In our opinion, the selected channel and coding of the communication concerns the physical, statistical, and syntactical levels of communication. The channel can be voice, keyboard, mouse, hand gesture etc., which form the physical layer of communication. We can apply different coding, e.g., in the case of voice based information transfer, we can use natural languages. The coding covers the statistical and the syntactical levels. What we get at the end of the processing of this input is supposed to be syntactically correct information. No matter what sort of channel or coding we choose, the same semantic elements (the type and parameters of the modeling operators) have to be transferred through. Therefore, it has to be possible to convert the input to a channel independent syntax. We can express exactly the same by hand gestures through a sign language as by talking, although both the channel and the coding are different.

3.5. Level of abstraction

We can express the same intent on the same channel several different ways. The basic difference appears in the level of abstraction. This has also something to do with the levels of information communication.

For instance, we can use the lowest syntactic level. In this case, the syntactic description that we get from the processing the input signals is executable without interpretation. This means that the user must follow a prescribed syntax, and each syntactically complete instruction can directly be connected to a modeling operator.

A more advanced level is the semantic level, where we can attach semantic meanings to the content. In our case, the semantics refer to the modeling operators. This level of the communication also allows the user to apply casual syntax, for instance, he may even skip the required parameters. However, the semantic meaning of the communication must be unambiguous. The reason of it is that the computer has to figure out, which modeling operator was intended to be used. Applying the semantic level of communication may make the use of the shape conceptualization system more understandable for the user.

The third level of abstraction is the pragmatic level, when the user does not need to specify at all, the appropriate modeling operator to achieve the desired shape. He can declare requirements for the concept, and the computer has to come up with proposals, how to fulfill. For instance, the user can declare that he wants a more streamlined shape, and the computer is supposed to propose changing the curvatures of specific regions of the shape.

The fourth level is the apobetical level. It relates much more to the human being than to the shape conceptualization. We consider here feelings, motivations, jokes, etc.

4. SELECTION OF INPUT TECHNIQUES

A particular combination of the communication channel, level of communication, and a clearly defined set of modeling methods is called here shape conceptualization

Table 1 The needed knowledge categories for a given communication level

Level	Knowledge required
Physical	Nothing
Statistical	Coding rules
Syntactical	Type information of the categories of the elements of the geometric models Type information and algorithm of operators Relationships between the types of operators and categories of elements
Semantic	Predefined objects, including semantic parts of the objects (e.g.,front, top), what the user can refer to Operators with predefined conditions, which has pictorial meaning for the user Predefined constant attributes, e.g., "red" instead of numbers
Pragmatic	Relationships between the functional requirements and theories of shape modifications
Apobetical	Human feelings, motivations, intentions

technique. The primary issue is to find the most efficient input techniques for our shape conceptualization system. In order to achieve our goal, we can create a three-dimensional matrix, one aspect of communication represented on each axis. We can indicate several techniques at each cells of the matrix. Obviously the techniques that we put the same cell of the matrix, use the same theory of their operators, the same channel and the same level of communication. (For instance, saying "Take the intersection of the two objects" or "Take the union of the two objects".) There can also be minor differences, e.g., in the expression mode, or some operators may require different number of parameters etc. Although, this may influence the efficiency, we can assume that the efficiency of the techniques that share a cell is nearly the same. Therefore, we can conclude that it is not necessary to name and define all the techniques before evaluating them. It is sufficient to evaluate only the cells of the matrix, and we can define the actual techniques later.

The evaluation procedure is twofold. On the one hand, the theory of the operators and the level of the abstraction determine the actual syntax to be transferred. On the other hand, a particular channel of the communication can be more suitable for transferring the given syntax than other channels. Let us elaborate more about the two issues:

In Chapter 3.3., we have introduced the five theories of shape definition/modification that we want to use. Therefore, we have to choose, which level of abstraction is the most appropriate for the particular theories. Although, we have to send significantly less data to the system by increasing the level of communication, it is not always the case that the higher level we communicate the faster the result is achieved. We have to consider that using high level communication accompanied by uncertainty. The level of communication is proportional the knowledge the system requires (Table 1). If the knowledge of the system about a particular task is not exactly the same as the knowledge of the user then the result can be different that the user expects. We can conclude that the higher level of abstraction we choose to communicate, the less data we have to transfer, and the less predictable the result is.

The evaluation of possible channels of communication (i.e. the device and the coding the channel uses) for transferring a particular syntax can include many aspects e.g., device costs, or the needed time and effort learning how to use the device etc. However, the main point of the efficiency of the transfer is the speed.

5. FURTHER RESEARCH

The research will go on by a comprehensive evaluation of the categories of the shape conceptualization techniques. We are going to use the abstract prototyping tool of Opiyo [4]. Based on the ranked categories, we will define the actual techniques to use. Since our aim is not to produce a fully functioning software prototype but only a proof of idea implementation, we will filter out several techniques, which is not necessary for the proofing and takes too much effort to implement.

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