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Bridging the Gap between Real and Virtual Modeling
- A New Approach to Human-Computer Interaction -

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Abstract
Three-dimensional computer-aided modeling of dynamic processes supported by virtual reality techniques such as 3D-stereo viewing and nD manipulation devices does not reach the usability (ease, concreteness, intuitiveness, directness) that we experience in modeling with real physical objects. Pure virtual prototyping may reduce cognition and communication. To solve this problem we introduce the concept of a *Graspable Real Reality User Interface* which bridges two modeling worlds: the real world of physical objects and the virtual world of signs and images. Sensorized user hands will couple

physical objects of the real world to virtual objects, thus allowing fairly unrestricted manipulation and expression. In this way modeling with real physical objects can create an abstract virtual model. Some applications of this concept will be presented here.

Introduction

Several simulation projects in the area of production and logistics indicated that, in spite of sophisticated input and output features of computer supported modeling systems, physical models still play an important role for cognition and communication. We therefore introduce the concept of a Graspable User Interface that aims at combining two model worlds, the one inside the computer and a corresponding physical one in the real environment. Sensorized user hands will couple physical objects of the real world with virtual objects, thus allowing fairly unrestricted manipulation and expression. In this way modeling with physical objects can create an abstract virtual model. This can be used for systems analysis and control optimization. Some applications of this concept will be presented here.

Our concept of human-computer interaction aims at overcoming some frequently encountered disadvantages of computerbased work: isolation, sensomotorical deprivation and reality loss.

Vividness has been an old aim in computer simulation. Since the early days of Computerized Numerical Control (CNC) for turning, milling and robotics the simulation and visualization of these processes have been impressively improved.

In industrial simulation studies, however, where we had to model complex production- and transportation-systems, we still appreciated the possibility to discuss and manipulate the planned system on the basis of mock-ups, physical models of paper or plastic bricks (Bruns, Heimbucher & Busekros 1995). Nevertheless there is little doubt about the value of abstract formal models that can systematically be studied in a numerical way. Therefore we prefer both models: the physical and the virtual one. The question arises, should we not couple these model worlds tightly, in order to work synchronously in reality and virtuality? From this desire rose the idea to use a data glove not for its original purpose to manipulate virtual objects but for acting on physical objects, building physical models and teaching their behavior by demonstration (Bruns 1993). In Bruns, Heimbucher & Müller (1993) we laid the foundations for a new class of user interfaces in shop floor and handicraft working in opposition to the wide spread desktop metaphor. This approach is also in contrast to some other concepts of combining real and virtual objects.

Concept of a Graspable Real Reality User Interface

The concept of a Real Reality User Interface, as we call it, is based upon the idea that most of our manipulations of virtual and real objects originate from our hands. Therefore sensoring our hands allows to recognize our actions on virtual as well as on real objects with the same interface. By using appropriate interfaces, the activities on concrete objects are recognized by the computer which changes its internal model. The advantages of computerized calculation and variation are preserved, and the creative act, the multiperspective view, the communication of users, and the percedption of material resistance are strengthened.

For a flexible manipulation of real objects with the aim of modeling, there are challenging requirements to be met by the interface. A data glove, which is tightly attached to a users hand, is continuously sending its position, orientation and bending values of the fingers to the computer. This stream of data is used to recognize grasp-patterns and gesture commands. At first, geometrical objects corresponding to the physical objects have to be constructed with a conventional geometrical modeler. Then, for each class of objects a class of grasps has to be taught. At the beginning of a session, the internal and external components of modeling have to be instantiated and assigned. All following glove data are then used to recognize if a valid grasp-pattern occurs within a close vicinity of an object. If this happens, the object is moved corresponding to the movement of the sensorized hand. Opening the grasp yields a separation of hand and object. For complex modeling, which goes beyond geometrical shaping, further requirements have to be met. Various attributes which specify their dynamic behavior and their relations among each other have to be assigned to the objects. A numerical calculation of simulation scenarios should be initiatable by a hand sign, and their results should be displayed by various output channels.

Prototype Implementation
First prototypes of this concept have been developed and will be further improved in a current project called *Computer supported Crossing between concrete and abstract Models of Production Systems*[1]. With a simple data glove and feature based versions of grasp recognition a „brick world“ and a virtual world can be geometrically manipulated as shown in fig. 1 (Bruns et al 1993, Brauer 1994).

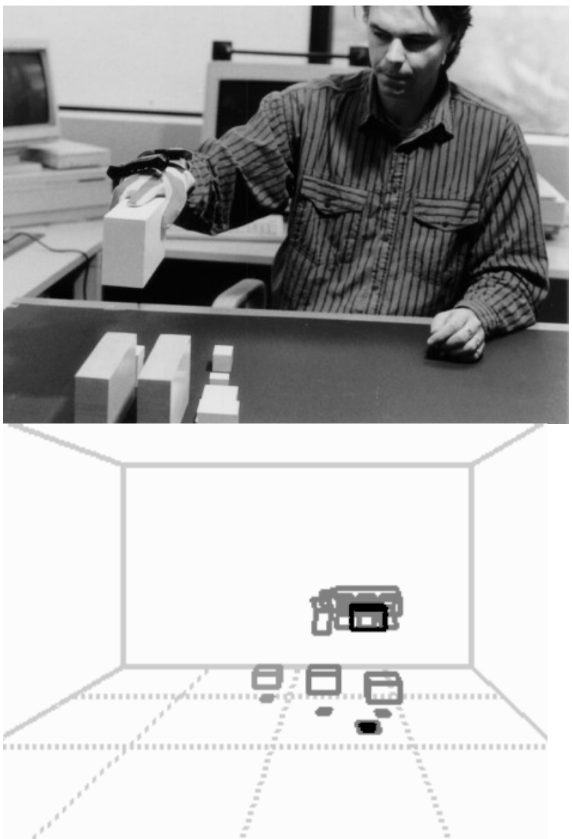

Fig. 1: Synchronous Modeling in Real und Virtual Reality

[1] this project is granted by the DFG (German Research Community)

In addition to geometrical modeling it is now possible to teach dynamic behavior and decision rules by concrete demonstration. Individually taught behavior patterns are abstracted and then used to create machine control programs. The prototype has been demonstrated for a Conveyor System (fig 2).

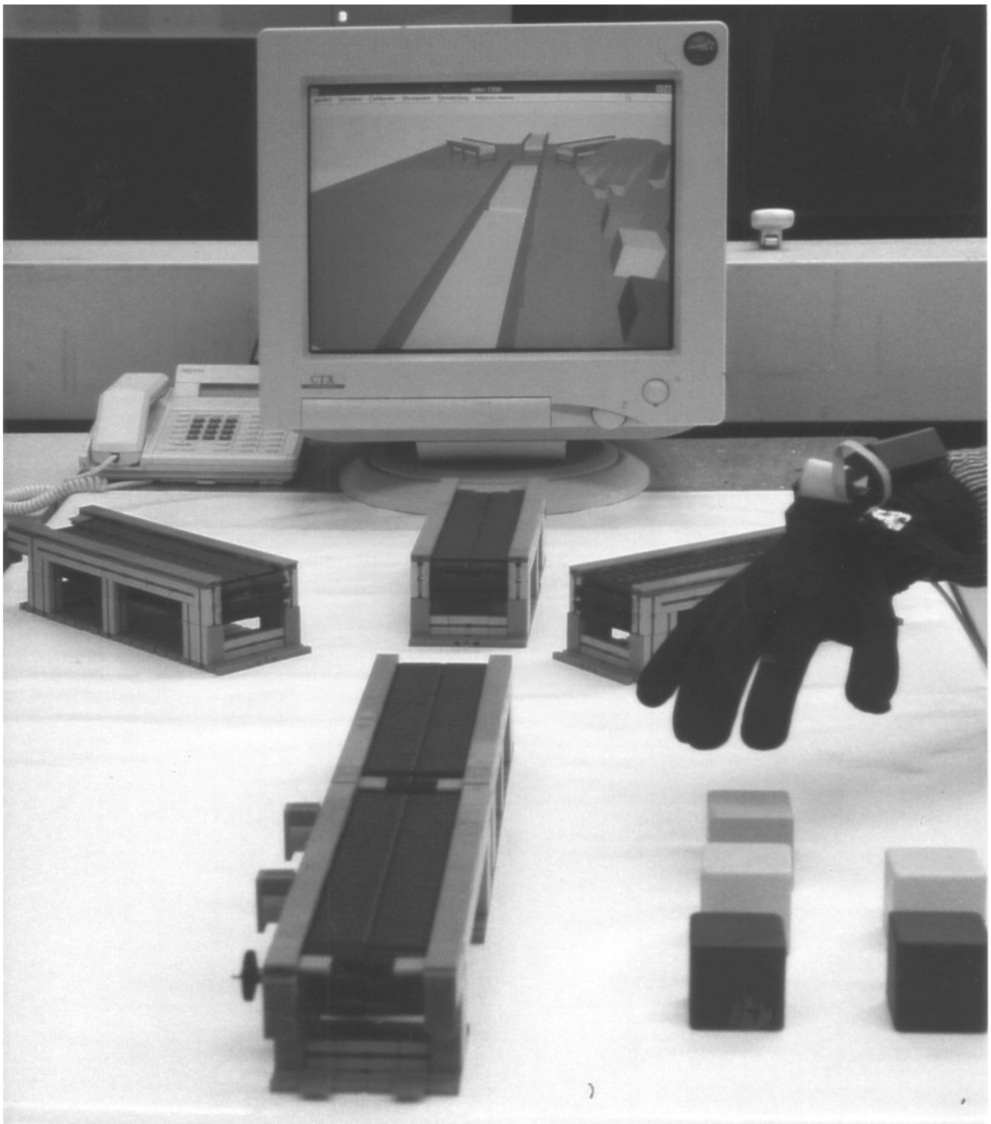

Fig. 2: Concrete Modeling of a Conveyor System

The following hardware and software are used for the implementation:

Computer:	Pentium PC, 100 MHz
Tracking System:	Polhemus 3Space IsoTrak II
Data Glove:	Fifth Dimension, 5th Glove 95
3-D Graphics Tool:	Sense8 World Tool Kit for Windows
Operating System:	Microsoft Windows 32s
Language:	Borland C++

Conveyor Bricks: Fischer Technik Conveyor System

At first, for each conveyor type we construct a geometrical and graphical virtual representation with conventional modeling tools such as AutoCAD. These virtual building blocks are then imported into the Real Reality modeler. The initial state of the real conveyors (position and orientation) is measured with a tracking system. This can be done individually for each scenario or once for the starting position of a reusable box of building blocks. The same is repeated for different types of containers. Using the data glove, the user then teaches his kind of grasping real objects. He thus attaches an associated grasp pattern to each type of object. After that, the user places the conveyors on the model ground, thus building a conveyor system. Conveyors may be connected or gaps between them may be bridged by a robot system. Now, different types of containers can be taken out of their starting position and moved through the system of conveyors on individual paths. These paths are recorded and abstracted to a parametric representation which then can be interactively edited in the virtual scenario. From this internal representation we are able to generate program code for the control of industrial robots. The virtual model is now used for systems analysis. Randomly created containers enter the system and pass their way through it, activating the relevant robot programs according to the taught set of ramification rules and pathways.
With this prototype we could demonstrate some major advantages of our Real Reality concept:

- The similarity between real and virtual objects supports the spatial and dynamic orientation in complex systems. Physical laws and constraints such as spatial extension of bodies, steadiness of motion, friction, acceleration, and synchronization are carefully respected.
- The physical model can be viewed from different viewpoints, always preserving the whole context. Additional technical devices like head mounted displays are not necessary.
- The modeling user senses the hardness and heaviness of physical objects and uses them intuitively.
- Modeling with real objects supports a cooperative and communicative work in teams.
- By sensorizing the users hand it is possible to use familiar objects of the environment for modeling purposes. Just an appropriate grasp pattern has to be taught.

Related Work

Several efforts are being undertaken to improve the concreteness of modeling. One main stream is Virtual Reality where the aim is to enhance the perception of virtual objects by using interfaces like data gloves and data helmets (Isdale 1993). The improvement of pure virtual environments is not our aim.
Mirakami & Nakajima (1994), and Fitzmaurice et al (1995) differ from our concept in a crucial aspect. They propose a new interface for direct and intuitive 3-D geometric shape manipulation. Their interface consists of a sensorized real elastic object which can be deformed with bare hands, thus deforming a 3-D shape model displayed on a computer screen.
Fitzmaurice et al propose a Graspable User Interface which allows direct control of electronic or virtual objects through sensorized physical artifacts (bricks) which act as

handles for control. These sensorized bricks can be logically attached to virtual objects such as the vertices of a geometrical structure in a drawing application.
The concepts of ubiquitous computing (Weiser 1991) are far-reaching. Here computational properties are embedded in many physical artifacts that are spread out in our environment. A behavior construction kit (Resnick 1993) allows to build models which consist of computerized LEGO pieces with electronic sensors which can be programmed using LEGO/Logo.
All these approaches have a sensorization of physical objects in common. The implementation must provide a model of how to react on the changes that these bricks experience from their environment. This is different from our approach, in which the hands of a user are sensorized and where a model of how we modify the environment is implemented.
Kang & Ickeuchi (1994) propose a concept of programming robots by concrete teaching. From the recording of hand poses and gestures they generate a program for automated assembly. This concept has the same technological basis and difficulties as our concept, but it does not show a perspective to support modeling processes in general nor does it define a new user interface for human-computer interaction which improves cognition and communication.

Future Research and Applications

The applicability of the Real Reality concept is manifold. An example for the domain of control systems demonstrates this. Constructing and operating complex wired systems requires a deep understanding and training with the used elements. Our approach allows the construction of concrete positioning and wiring of electric and pneumatic elements and a synchronous generation of a virtual model (fig. 3). In later phases of system design and building this model can be used for various purposes, for example to search errors, to identify confused component connections, or to optimize the system as a whole. A direct combination of real experiments with computer models may help to recognize and to enlighten errors like wrong polarity, mixed up input and output or mixed up components. The computer model can be used to view the model in different levels of abstraction and for simulation purposes. For industrial production we think of tools for quality control which compare the assembly of parts with construction plans.

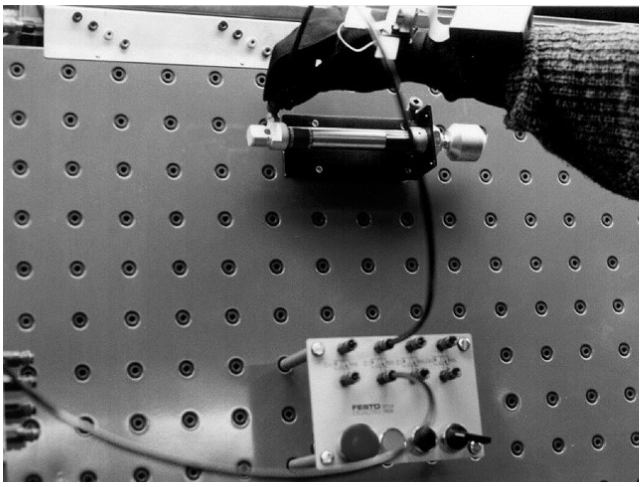

Fig. 3: Concrete Modeling of a pneumatic Control System

By using direct manipulations of real objects as a computer interface and by integrating this principle into the learning process, as we do, a new approach to human-computer interaction is created. It supports the process of concrete modeling and it constitutes a basis for cognitive abstractions, thinking, and the formation of concepts[2]. Our approach raises questions of cognition and system theory. How do we grasp tools and parts? In which way are mental models effected by the acts of grasping and concrete manipulation?

MacKenzie & Iberall (1994) analyze the task oriented grasping of objects with the hand, and follow the question of how our brain controls our hands. Their research aims at a deeper understanding of the relation between functions of the central nervous system and the grasping hand. They identify different phases of prehension[3]: 1. planning an opposition space (perceive task specific object properties, select a grasp strategy, plan a location and orientation of the hand), 2. setting up an opposition space (preshape fingers, orient palm, drive fingers guarded), 3. using an opposition space (capture, lift, manipulate, replace), 4. releasing an opposition space (release stable grasp, open hand into rest position or open posture, transport hand away from object). They discuss various constraints which become effective on different levels in these phases: social/cultural, motivational, functional, physical, neural, perceptual, anatomical/physiological, evolutionary/developmental. Their results are helpful for modeling natural and artificial hands and prehension systematically. The complementary question, however, is: „How do our hands influence our concepts?“.
Gentner & Stevens (1983) turn to a question that is relevant for our research: „Which kind of formal representation of physical phenomena is useful for a stepwise differentiable system of conceptual and mental models usable from novice to expert stage of learning?“ They emphasize requirements like: manipulation of uncomplete, unstable, fuzzy, „nonscientific“ models. This motivates us to integrate concepts of „Naive Physics“ and Qualitative Process Theory (Kuipers 1994, Iwasaki et al 1994) into our work. For our future research we see several areas of investigation:

- The improvement of pattern recognition algorithms for grasps. It seems to be promising not to use general pattern recognition methods but to adopt specialties of the grasping hand as they have been investigated by MacKenzie & Iberall (1994).
- The problem of object manipulation and transportation. We need better models of the hand, to extrapolate from glove data to changes of the physical environment.
- The problem of grasp release. How do we make sure that the grasp release is instantaneous?
- The problem of abstraction from recorded activities and events to rules and computer programs.

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[2] in german this is expressed by the terms greifen (grasping) and begreifen (understanding)

[3] prehension means the task oriented movement of the hand(s)

- The interactive variation of the virtual model.
- The generation of complex virtual behavior on the basis of taught prototypes.
- The generation of complex real behavior on the basis of a backward bridge between the virtual model and a motorized and sensorized reality.

Conclusions

In this paper we introduced our concept of Real Reality modeling which is linked to virtual modeling by the sensorization of our hands. Compared with conventional Graphical User Interfaces the power of this concept lies in its orientation towards a variety of our senses during the modeling process, especially to the haptic one.

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