Grasping, Communicating, Understanding: Connecting Reality and Virtuality

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Abstract
Several simulation projects in the area of production and logistics indicated that, although we have sophisticated input and output devices for computer supported modeling, 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 outside world. Sensored 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 real physical objects can create an abstract virtual model. Some applications of this concept are presented. A further perspective for a new action oriented communication and learning with artifacts is envisioned.

Keywords
action learning, graspable user interfaces, handicraft metaphor, real reality, bridging modelworlds

Introduction

A new concept of human-computer-interaction is proposed, that aims at overcoming some often encountered disadvantages of computerbased learning and working: isolation, sensomotorical deprivation and reality loss of the learner.
At first, with some hints about the empirical basis, we justify our motivation for better user interfaces in simulation practice. Secondly, the aim of an improved reality orientation of user interfaces is highlighted and a brief survey of this new emerging field is given. Then I present our new concept, describe the prototype and argue for its potentiality and advantages. A discussion of emerging consequences for the process of learning and working follows.

Motivation for a reality oriented graspable user interface

Vividness has been an old aim in computersimulation as a means of teaching skills and knowledge. Since the early days of Computer Numerical Control (CNC) for turning and milling and its simulation for training purposes there has been a scientific debate about how much could be learned with an isolated, protected, abstract virtual model and what remains an unreplaceable domain of learning in direct contact with real physical processes and the work situation. Böhle & Milkau (1988) and Böhle (1995) empirically enlightened the problem of diminishing concreteness for a skillful control of machines and the accumulation of experience.
In several industrial simulation studies where we had to model complex production- and transportsystems, we appreciated the possibility to discuss about and manipulate the planned system on the basis of mock-ups, physical models of paper or plastic bricks

(Bruns, Heimbucher & Busekros 1995). However, we always felt uncomfortable when we had to rebuild the model in an abstract mathematical way to systematically investigate its dynamic behavior. Why could we not couple the two modeling worlds in a tighter way, so that we could synchronously model 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 tightly coupling between real and virtual objects.

Related Work

Several efforts are being undertaken to improve the concreteness of modeling. One main stream is 'virtual reality' where the aim is to get a better view and feeling of virtual objects by the use of interfaces like data gloves and data helmets (Isdale 1993). This improvement of appearances of the virtual is not our aim.

Mirakami & Nakajima (1994) and Fitzmaurice et al (1995) come close to our idea but differ under a crucial aspect. Murakami & Nakajima propose a new interface for direct and intuitive 3-D geometric shape manipulation. Their interface consists of a real elastic object that 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 that allows direct control of electronic or virtual objects through sensorised physical artifacts (bricks) which act as handles for control. These sensorised bricks can be tightly 'attached' to virtual objects like the vertices of geometric structures in drawing programs.

Further reaching are concepts of ubiquitous computing (Weiser 1991). Computation is embedded in many physical artifacts and spread throughout our environment. A behavior construction kit (Resnick 1993) allows building models out of computerized LEGO pieces with electronic sensors that can be programmed using LEGO/Logo and then spread throughout the environment to interact with users or physical objects.

All these approaches have in common a sensorization of physical objects and a model about how to react on changes of the environment coupled to these bricks. This is in contrast to our approach where the hands of a user are sensorized and the model is about how to change the environment. The consequences on learning with these artifacts will be discussed below.

Kang & Ickeuchi (1994) proposed a concept of robot programming by concrete teaching. From the recording of hand poses and gestures they generate a program for automated assembly. Although this concept has the same technological basis and difficulties as our concept, it does not have the intention to support the modeling process in general nor does it define a new user interface for human-computer interaction improving the process of understanding and communication like our approach (Bruns/Müller/Heimbucher 1993).

Concept of a Graspable User Interface

Basic idea of this concept is, to record and process the manipulation of real concrete objects and use the real world as a user interface. A desktop should then be usable as a real desktop and not metaphorical as a virtual desktop, which is accessible only via two-dimensional input/output devices like mouse and screen, and disappears into the computer. In shop floors and offices it will be possible, to model with real material, shaping and teaching functional and behavioral structures. Using appropriate interfaces, the activities on concrete objects are recognized and used for changing computers internal model of the outer world. The advantages of machined calculation and variation are preserved, but the creative act, the multiperspective viewing, the communication of users with others and with the material is 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 user's hand, is continuously sending its position, orientation and bending values of the fingers. This stream of data can be used to recognize grasp-patterns and gestures for commands. At first, geometrical objects corresponding to the real objects have to be constructed with a conventional geometrical modeller. 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. Variable attributes have to be assigned to the objects, that specify their dynamic behavior and their relations among each other. Numerical calculation of simulation scenarios should be initiated by a handsign and their results should be published by various output channels.

First prototypes of this concept have been developed and are now improved in a project *Computer supported Crossing between concrete and abstract Models of Production Systems*[1]. With a simple data glove[2] and a first version of grasp recognition a „brick world“ and a virtual world can be manipulated as shown in Fig. 1 (Bruns et al 1993, Brauer 1994). An object oriented software toolkit (Müller 1993) offers an open environment for simulation functionality.

The application of this concept is manifold. An example for the domain of control systems should demonstrate this. Construction and operation of control systems require the understanding of complex wiring. In related vocational training, a teaching of theoretical fundamentals is usually accompanied by laboratory exercises and tests and can be supported by computerized means. Our approach will allow the construction of

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

[2]better ones are expected soon

concrete positioning and wiring of electric and pneumatic elements (Fig. 2) and the synchronous generation of a virtual model (Fig. 3). This latter model can be used for various purposes in later phases of the learning process, i.e. to search errors, to optimize, to identify confused component connections. A direct connection of the real experiment with a computer model could help to recognize and enlighten errors (wrong polarity, mixing up input and output, mixing up components). The computer model can be used to view the model on different levels of abstraction and under different perspectives.
Using direct manipulations of real objects as a computer interface and integrating this working method into the learning process is new. It supports the process of concrete modeling and constitutes a basis for cognitive abstractions, thinking and formation of concepts[3]. This approach raises questions of cognition and system theory. How do we grasp tools and parts? What contribution to the generation of mental models is attributed to grasping and concrete manipulation? What kind of knowledge representation in computer models supports the development of mental models?

MacKenzie & Iberall (1994) analyze the task oriented grasping of objects, »Our working definition of prehension is the application of functionally effective forces by the hand to an object for a task, given numerous constraints«(p. 6) and follow the question, how our brain is controlling our hands. Their research aims a deeper understanding of the relation between functions of the central nervous system and the grasping hand. They identify different phases of prehension: 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 that are effective on different levels in these phases: social/cultural, motivational, functional, physical, neural, perceptual, anatomical/physiological, evolutionary/developmental. Their results are very helpful for a systematic modeling of natural and artificial hands and prehension, but they do not contribute to the question ‘How do our hands influence our concepts?’.
Gentner & Stevens (1983) turn to a question that is relevant for our research: what 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 uncompleted, unstable, fuzzy, ‘unscientific’ models. This motivates us to aim at the integration of concepts of ‘Naive Physics’ and Qualitative Process Theory (Kuipers 1994, Iwasaki et al. 1994) into our work.

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

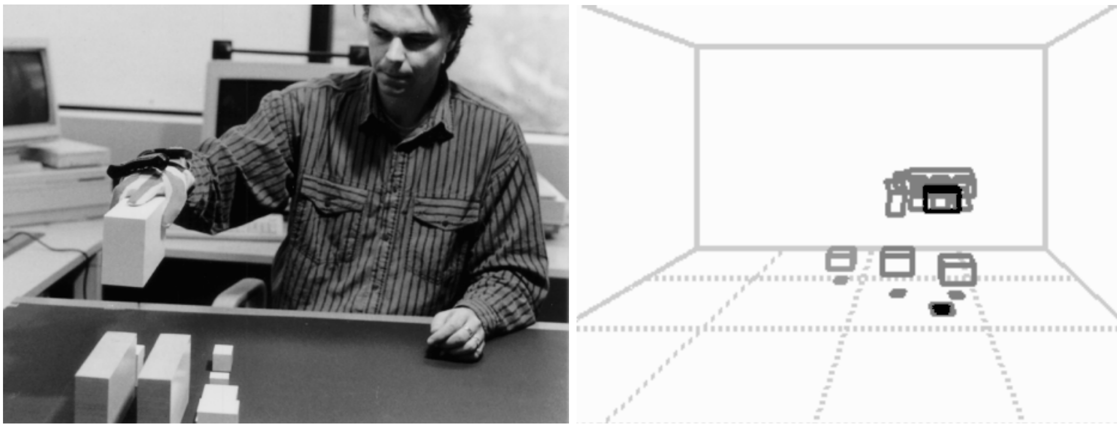

Fig. 1: Synchronous Modeling in Real und Virtual Reality

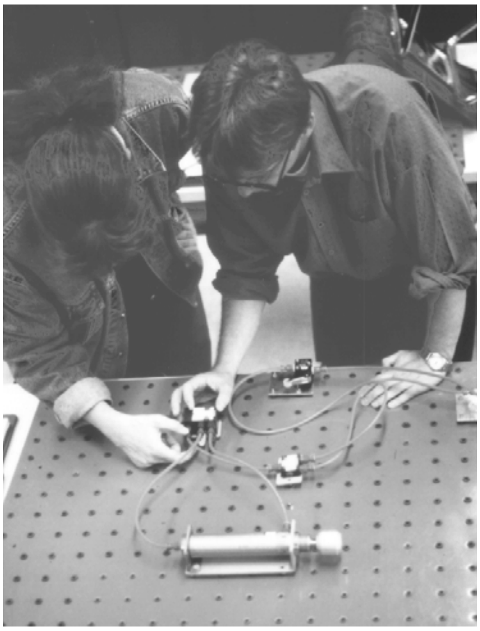

Fig. 2: Concrete Modeling of a Control System

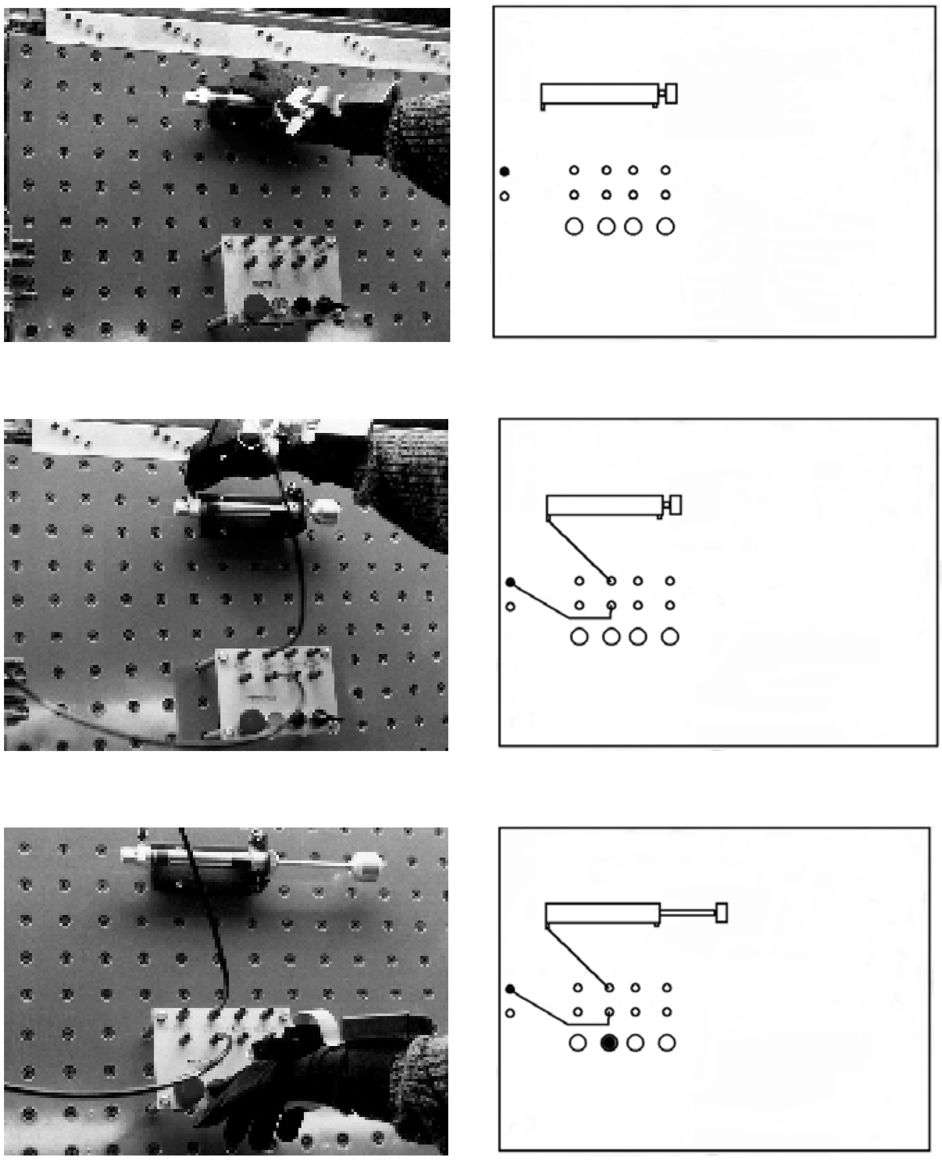

Fig. 3: Synchronous Real and Virtual Modeling of a Control System

Consequences for action oriented learning

The following discussion aims at elucidating perspectives of learning with our concept. Of course, we can not answer the question, how exactly our hands are influencing our mental models, but we are quite sure, that there is a difference for our understanding of complex systems, if we are working in a concrete way with those elements (Fig. 2) or only at an abstract level (Fig. 3, right). The real experiences of single physical phenomena are helpful, if not necessary, prerequisites for the understanding of compound models. We do not argue, that a coupling to real phenomena is equally important for each learner, but we want to open the possibility for a bridge between concrete and abstract models (Fig. 3). The role of grasping for our understanding also depends on the kind of physical reality we investigate or build. We experienced the advantage of gesturing and grasping mainly at the work with mechanical systems (cranes, bridges, conveyors, vehicles, robots, pneumatic switches).

At a first glance it does not seem to make a difference if we sensorize the objects of the real world, or if we sensorize our hands. In both cases, there has to be some explicit formal model implemented in some sort of computing machinery about how changes of the real world are mapped to the virtual world. The difference is, that in the first case, we have to model every possible user action or we have it explicitly constrained to a certain handle. Take for example the mouse, you cannot use it otherwise than rolling the ball in a feedback way, so that the cursor stays within the screen of your computer and has a certain contextual relation to other virtual objects. This is true for mice, bricks, cubes. We could say that the objects, the electronic and the virtual objects, determine our actions on them. In this sense the word *object orientation* gets another connotation.

On the other side, if we sensorize our hands, we are very flexible and independent. Changes of the real world are now measured in terms of the source of action, our hands. It can be up to us, how we want our actions to influence the real or virtual world. We just have to teach the system our way to handle things. For example, if we want to grasp a certain class of cylinders (Fig. 3) or pencils (or mice for those who are already tightly attached to this technology, although this could be a dummy mouse, a mock-up, just a piece of comfortable wood), we just have to teach the system, how we want our actions to be interpreted by the machinery. We are very flexible. This anthropocentric technical solution allows much more freedom for the integration of computers in our learning and working environment.

Of course, we do still have to model all desirable actions of our hands on real and virtual objects, but this can be very broad class algorithms and we can always verify the conformity of the implemented model with reality. Take geometric modeling: you form a 3D-Shape in reality with a material as clay or plasticine and your sensed hand and finger movements generate a shell for the virtual 3-D object. Then you teach some handles, the way you want to grasp the real and the virtual object. Then you teach some dynamics, the ways you want the object to dynamically react on certain external or internal events, and so on. The central point is, that much programming of the system is done by our hands, be it geometrical, dynamic or complex behavioral. Of course, there are interrelations that we can not specify by hand and finger movement and they can not be replaced by our concept, but from studies of the design process we know, that many things are specified by gestures and poses.

The hand has been attributed by many authors as a central organ for the evolution of man as a species (Popitz 1989, MacKenzie & Iberall 1994). The hand is an organ for distant pointing and signaling, for direct social contact by touching the other's body and for object manipulation (touching, grasping, shaping, beating, throwing). There is much evidence that all understanding starts with the grasping of concrete things. The shaping of things is mostly conducted by imagination and conception, it is based already on mental models and aims. Shaping and beating are close connected to the origin of tool engineering. Popitz (1989, p. 62) points out, that the decisive evolutionary phase was, when man learned to differentiate between the hardness of materials and used one against the other (stone against wood, harder against softer stone). »Diese List der Hand, mit der sie überlegene Härte der Dingwelt gegen diese Dingwelt selbst wendet, ist der erste Akt technischer Intelligenz« (Popitz 1989, p. 65). The principle of tool engineering emerged: the preparation of one thing to use it for the work on others. Since then, tool production has proven to be a very productive detour, leading to ever increasing diversity of tools and longer chains of means and purpose. This lengthening of means-purpose chain also caused a lengthening of the organic-technical feedback loop between hand, tool, brain and eye and received a qualitative thrust with modern interactive graphical user interfaces, which now constitute a feedback loop of hand, computer, brain, eye. Principally there is not much difference to the feedback loop practiced in car driving or crane operation: our hands manipulate a control stick and the remote action of our machinery on the environment is perceived by our eyes. The only difference is, that we do not operate on real things but on virtual ones. The long term consequences of this shift with respect to our learning performances are unclear. We do not know how this dematerialization of our actions will influence our mind. One important thing has changed: the hardness of material is no longer a restriction and motivation.

The hand has lost its dominance, but Popitz points out, that when we want to produce something original, creative, like painting, cooking, potting, then we still rely upon our hands. As learning processes are always new and creative for the learner, do we not depend on the grasping of our hands, on the real grasping?

»Auch die Vorstellungsfähigkeit - die Entwicklung vorstellungsgeleiteten Handelns - und das explorierende Handeln, das Erkunden der Dinge, lassen sich in einer einsichtigen Konsequenz ableiten aus der Wiederholung bestimmter Erfahrungen in der Manipulation der Dinge, aus technischen Handlungserfahrungen mit der Hand. Das kann ich hier nur behaupten« Popitz (p. 69). The connection between manipulation and imagination has intensively been investigated and confirmed by Piaget (1959). He brings another important category to our attention: the role of dreams.

Bion (1992) bases his theory of thinking on the ability to convert undigested emotional experiences into dreamthoughts and then into thoughts. According to Bion’s *Learning from Experience*, ideas and models about reality arise from the absence or malfunction of real objects. The idea of the feeding breast or bottle comes into mind as a substitute for their frustrating absence. This process of digesting new experiences in terms of the old, according to Bion, takes place at a deeply personal level, at the level of dream processes. And this process of learning is a continual oscillation between creating and destroying models of the inner and outer worlds (Skelton 1995, p. 389). Probably every engaged scientist and problem solver has experienced the situation, where he found the solution of a problem at night, sleeping and dreaming. This raises the question of our emotional participation in virtual modeling. My impression is, that learning by experience depends on hard digestible things, which are less possible in an isolated and virtualized model world than in the real world. Transformation of experience into symbols depends on social and bodily contact. This depends upon face to face and hand to hand communication. The hardness of material or the absence of the feeding breast is motivating and yields models about reality. Working with virtuality yields models about models. If we work with real objects having virtual objects coupled to them our primary focus is the behavior of real things. Only as a second thought do we validate the conformance of the virtual model with reality. My final thesis is, that dreamthoughts are initiated by concrete and social working conditions but less in isolated or technical mediated cooperation and action.

Conclusion

Learning by experience in a real and social context is more and more restricted in computerized virtual environments. We introduced a new concept of computer usage by manipulating real objects with our sensorized hands, which supports direct communication and action between actors and objects, displacing the computer into the background. Our concept will be helpful in vocational training in the areas of computer supported geometric modeling, layout and process planing for production systems, configuration of flexible manufacturing, assembly and disassembly systems.

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