# Position-Paper for
# Future_Workspaces

# Hyper-Bonds
## – Multimodal Interfaces for Collaborative Workspaces of the Future -

F. Wilhelm Bruns, D. Müller
Bremen University, Germany
Research Center for Work, Environment and Technology (artec)
19. 9. 2002

Multimodal Man-Machine Interfaces for learning and working are getting more and more important if we foresee, as we do, a closer integration of different real and virtual realities, mixed realities. To make these multimodal interfaces, based on mechatronic principles easy to use as a developer and user, we need more general theoretical concepts and practical modules. A generalized concept to blend physical systems with their virtual counterparts, being their computer-internal representation or a functional continuation will be introduced. *Hyper-Bonds* combine the unified abstract systems representation of bond graphs with their concrete implementation in a "hyper-connection" between physical phenomena of the computer-external environment and the logical structure of computer-internal representations in a vivid way. The theory is laid down and a first application in a learning and working environment for automation technologa, allowing a free determination of boundaries, is shown. Further applications and extensions are highlighted.

## 1. Introduction

Mixed realities are becoming more and more popular and have some interesting perspectives for tele-service and tele-learning. They represent a kind of coupling of real world phenomena to various information, represented within a computer. This might take place in the sense that information is displayed and overlaid to real phenomena (see Augmented Reality research: Weiser 1993, Wellner 1993), in the sense that real phenomena are used as handles to manipulate information (see Graspable User Interface research: Fitzmaurice et al 1995) or in the sense that both worlds are bi-directional tight together (Ishii & Ullmer 1997, Brave et al 1998). The focus of this paper is the later approach.

In some previous work, we introduced the concept of complex objects (Bruns 2000) being objects with a real concrete part coupled to various virtual representations by means of grasp- or image-recognition, Fig. 1. The fruitful application of this concept in several environments for learning and systems design has been demonstrated (Grund & Grote 2000).

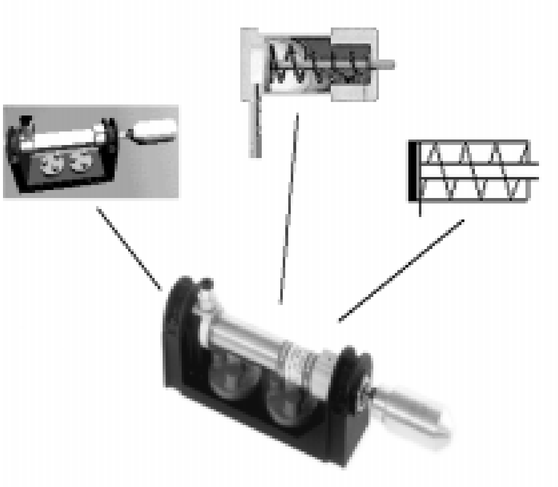


Fig. 1: Complex Object

This coupling introduces the possibility to build and change real systems and synchronously generate their functional representatives. Simulation may be carried out with the virtual model and compared with the behavior of the real system. It is then possible, to download the controlling algorithm, driving the virtual model, also to a Programmable Logic Controller (PLC) and drive the physical system by means of sensors and actors, Fig. 2. We extended this concept by a bi-directional link between the virtual and the real model, being able to sense and generate various relevant physical effort and flow phenomena via a universal connection system first realized for pneumatics (Bruns&Gathmann 1999), Fig. 3.

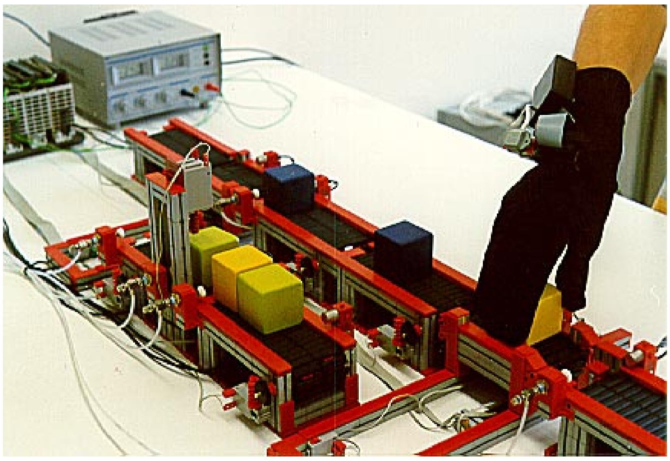


Fig. 2: Driving a real Model with a PLC

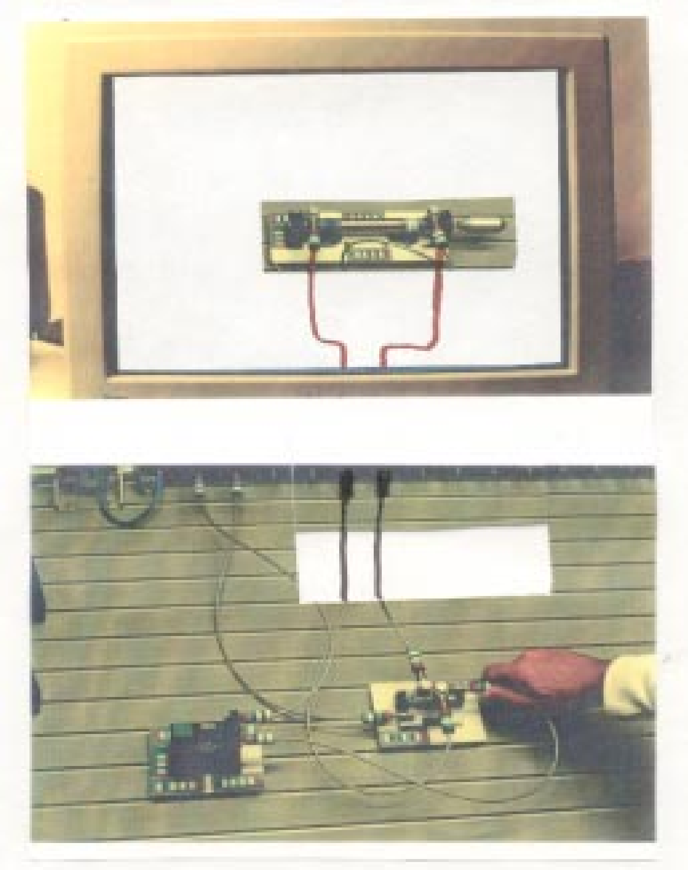


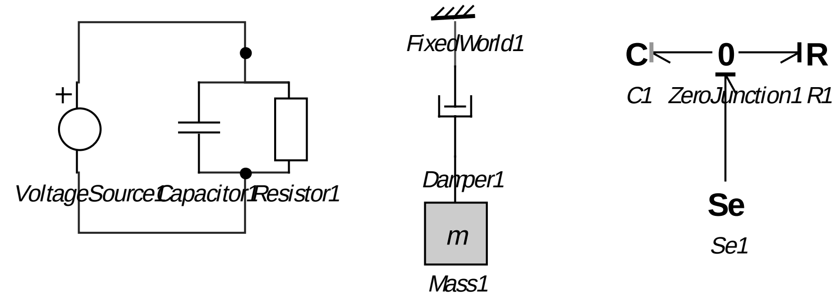
Fig. 3: Reality with a hole

The unifying concept allowing this approach is the Theory of bond graphs (Paynter 1961, Karnopp 1995). Its implementation is done by PLC-technology.

At first, a short recall of bond graphs is given and their usefulness for this approach shown. A short motivation for Hyper-Bonds from a system dynamics point of view follows. In section 3 the detailed concept of *Hyper-Bonds* is introduced. Some applications and perspectives finish this contribution.

## 2. Usefulness of Bond Graphs

Paynter introduced the theory of bond graphs as a unifying view on physical phenomena from a continuity of power-flow perspective. Power flows through system components and connections by way that the product of effort and flow is continuous, following typical laws of energy conservation and power-flow continuity. Effort (e) is the driving force for flow and can be a pressure difference, force and torque, electrical potential difference, temperature difference etc. Flow (f) can be a flow of material, momentum, electric current, entropy. Bond graphs are networks with edges of (e,f)-connection and nodes with constant e (0-node) or f (1-node). Bond graphs can be used to describe dynamic behaviors of different physical domains with one formalism (Fig. 4-5), similar the way we use differential equations for all kinds of physical phenomena. In fact, for calculation means, bond graphs are transferred to systems of differential equations and then integrated (symbolic or numerical). For engineering purposes bond graphs have several advantages as they are vivid and preserve important constraints (Cellier et al 1995). One important feature of bond graphs is the input-output relation of effort and flow, seen from a physical component perspective. Components are always connected by bonds having the value pair e and f where one of them can be seen as input the other as output from a cause-reaction point of view. However, which one is input and which one output can only be determined from an overall systems view by causal reasoning. Knowing e and f at one connection, resulting from calculation or measurement, allows a cutting of the system in two parts and a separate investigation.



*20-sim3.1 demo (c) CLP 2000*

Fig. 4: Bond graph for equivalent mechanical and electrical systems

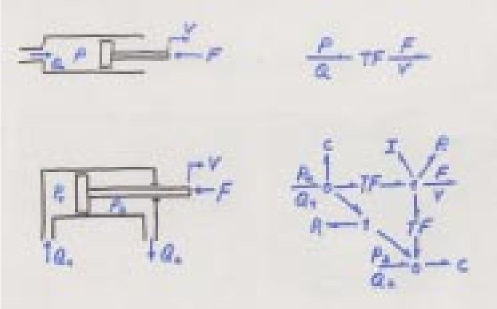


Fig. 5: Bond graph for a pneumatic cylinder with different levels of abstraction

Bond graphs are especially useful for the description of mechatronic systems, where powerflow is transformed and exchanged between different forms of energy, Fig. 6. Several simulators now support the notation of bond graphs.

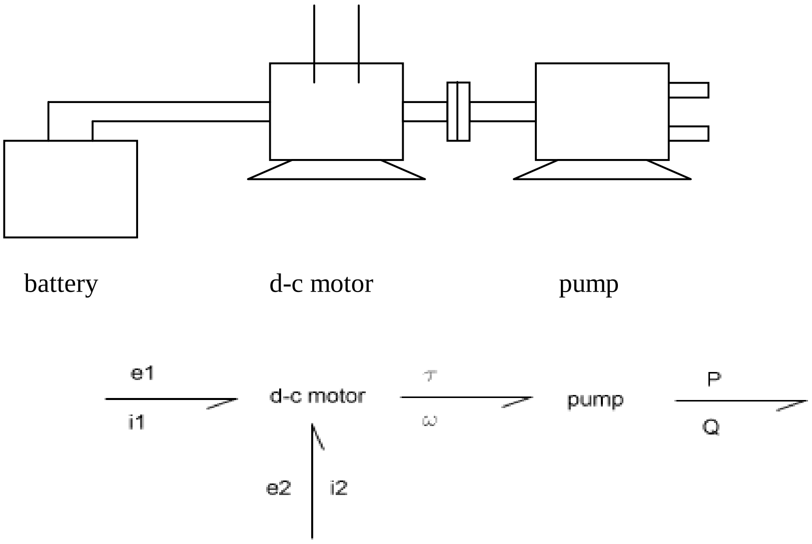


Fig. 6: Mechatronic System described by bond graph

The feature of effort and flow, determining a systems behavior can be used fruitfully, to implement arbitrary cuts in an overall system, realizing one part in reality, the other one in virtuality and provide a mechanism to sense and generate arbitrary efforts and flows. This will be demonstrated.

## 3. Systems and Boundaries

In physical science, and not only there, we learn the principle of cutting a system at well defined boundaries and replacing the external influences by some observable and measurable relevant variables, reducing the investigation to the internal dynamics of the rest. In laboratory work we use this principle to construct reproducible experiments, but also mentally we use it to think about systems in hypothesis and mental experiments (consider the principle of virtual work applied by d'Alembert). For future laboratories, being more and more penetrated by computers, a free and easy distribution of a system between reality and virtuality seems to have some advantages (Fig. 7). Certain well known aspects of a system can be represented in a formal way by algorithms in the computer, others to be investigated in more detail and uncertainty are represented in reality, but coupled to a dynamic surrounding. This would allow completely new forms of easy experimental work and learning.

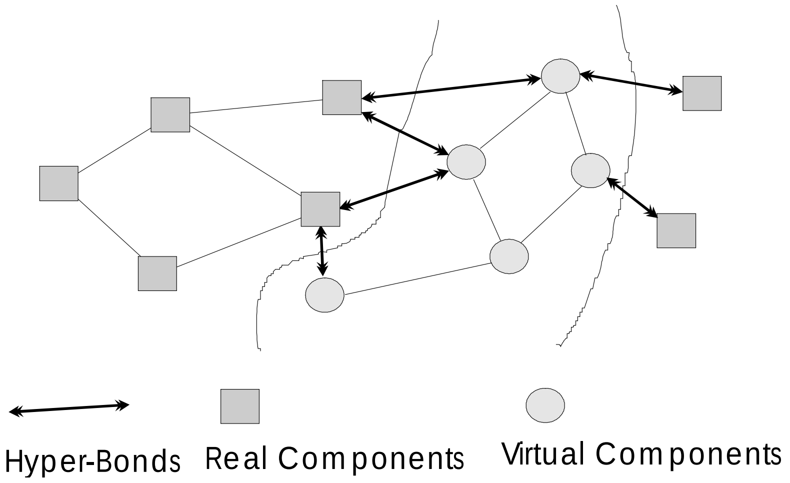


Fig. 7: Boundaries cutting a system

## 4. Hyper-Bonds: a sensing and generating Mechanism

In order to provide arbitrary boundary conditions, we must have a mechanism to switch between source and sink and to generate one phenomenon and sense the other. We chose to generate the effort and sense the flow, because this has the broadest application area, as we will see. The alternative would yield some different implementation. The implementation for electrics (voltage and current) and pneumatics (pressure and volume-flow) is given in Fig. 8, together with its abstract bond graph representation.

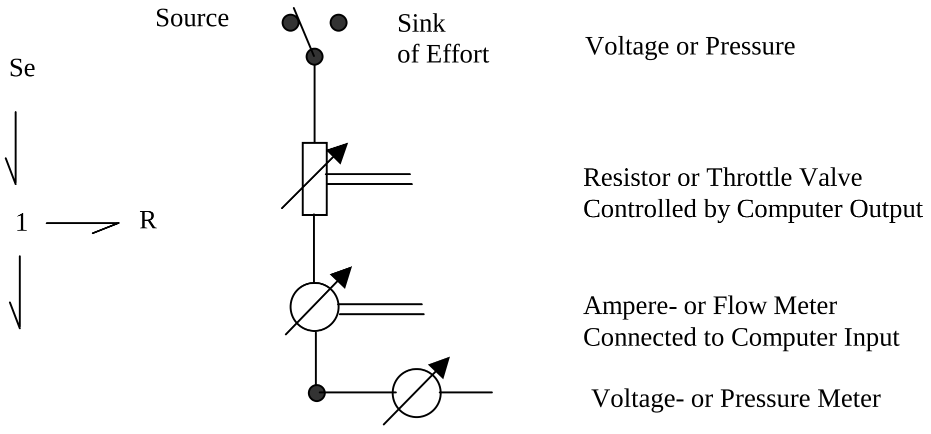


Fig. 8: Hyper-Bond for Voltage/Current- or Pressure/Volume-Flow

As all necessary components are available in a standard mechatronics construction kit, we built a reduced version of a prototype (Fig. 9) and then multiplied and miniaturized it.

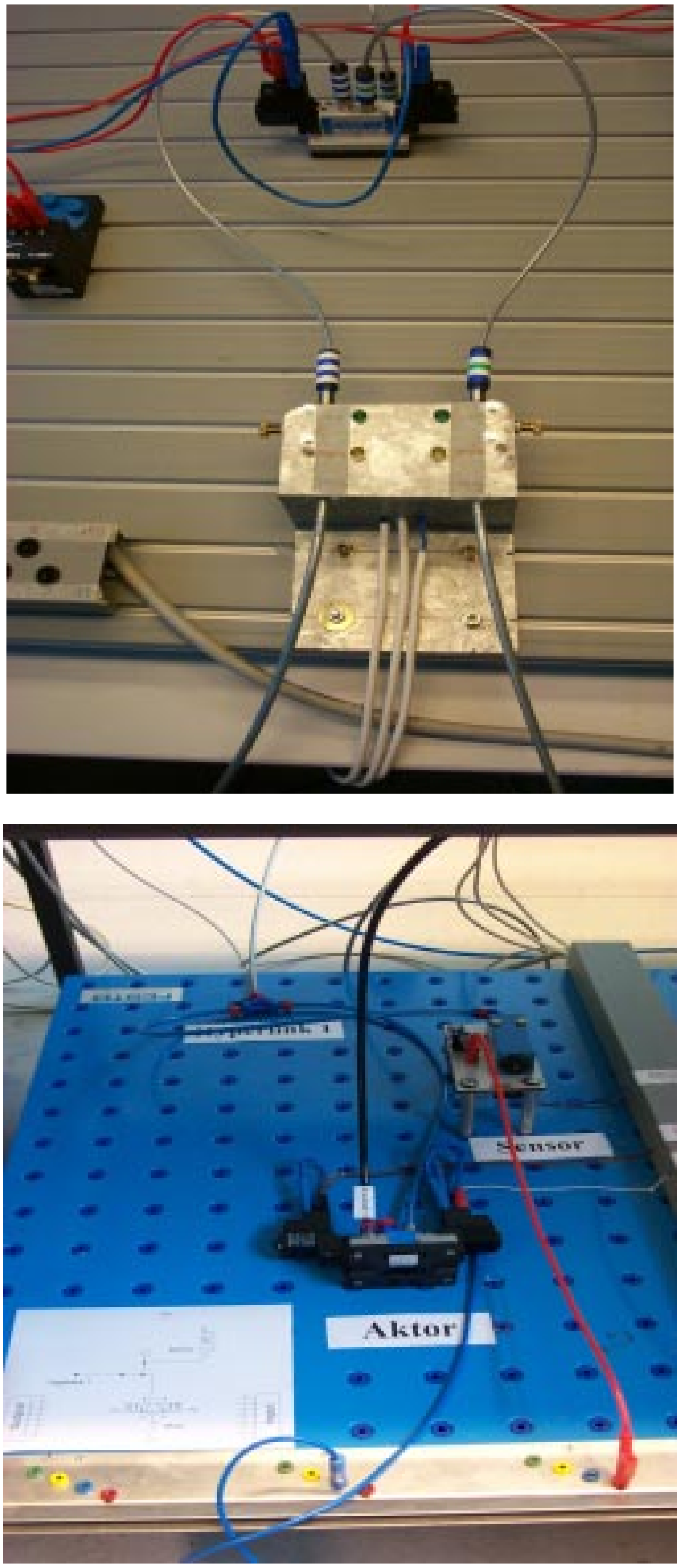


Fig. 9: Implementation of a Pneumatics Hyper-Bond
(lower picture shows implementation, upper picture application side)

The integration into a virtual construction and simulation environment has been done by some parallel digital and analog I/O ports, Fig. 10. To be more flexible, the I/O can be handled by a separate box or PLC, connected to the PC via bus or serial interface.

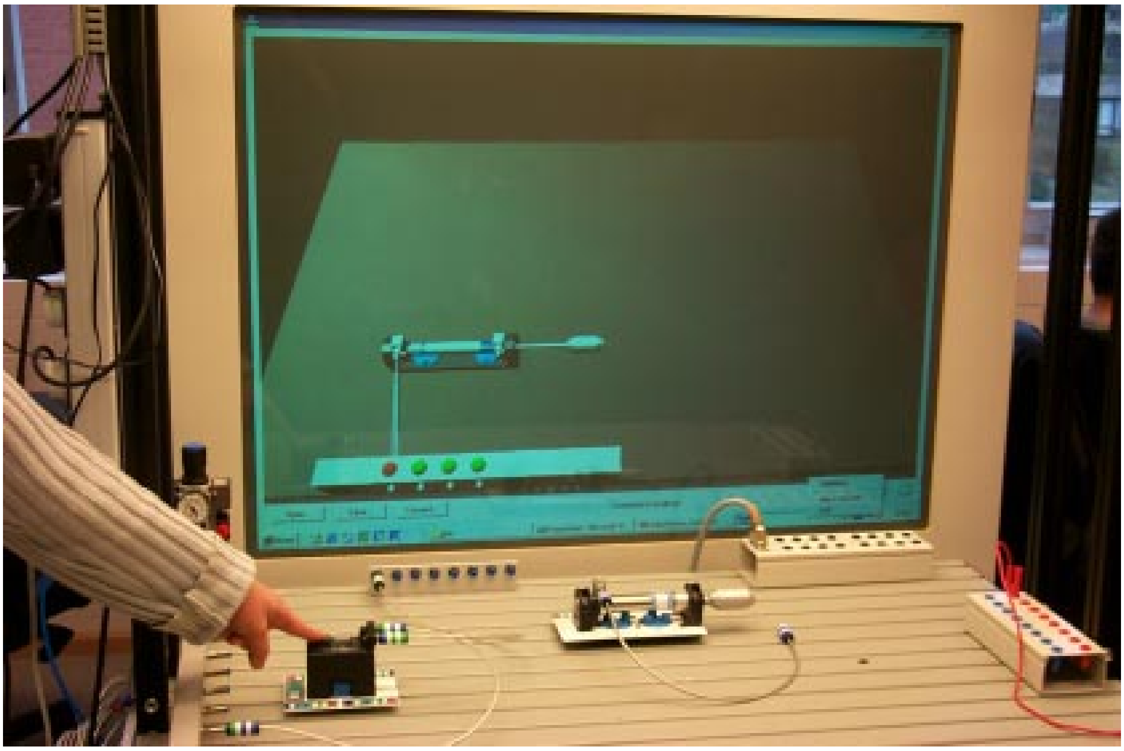


Fig. 10: Integration of Hyper-Bonds in some application

## 5. Applications and further Perspectives

The new concept of Hyper-Bonds is being applied in a learning environment for electro-pneumatics (Fig. 11), where students can work on complex systems, freely switching between virtuality and reality[1]. Especially if one is interested in a work-process-oriented learning, using authentic situations and always wants to see the complex context, it is of high value, to be able to select certain interesting aspects of a system, put them as real components on ones desk, but still have them connected to and integrated in the overall system. As the virtual model can easily be distributed over different locations (only with some restrictions in time behavior), one has the possibility to have one complex virtual system materialized in parts at one location and in parts at other locations. This opens completely new perspectives for distributed task oriented learning and working in a co-operating group.

For **systems development** our concept may support an incremental implementation and testing of complex devices. For service and maintenance it would support the stepwise investigation and repair of disintegrated parts.
We have shown so far how to implement *Hyper-Bonds* in the domains of electrics and pneumatics, the implementation for hydraulics, thermodynamics and mechanics should follow.

---

[1] EU-IST Project DERIVE (Distributed Real and Virtual Learning Environment for Mechatronics and Tele-Service

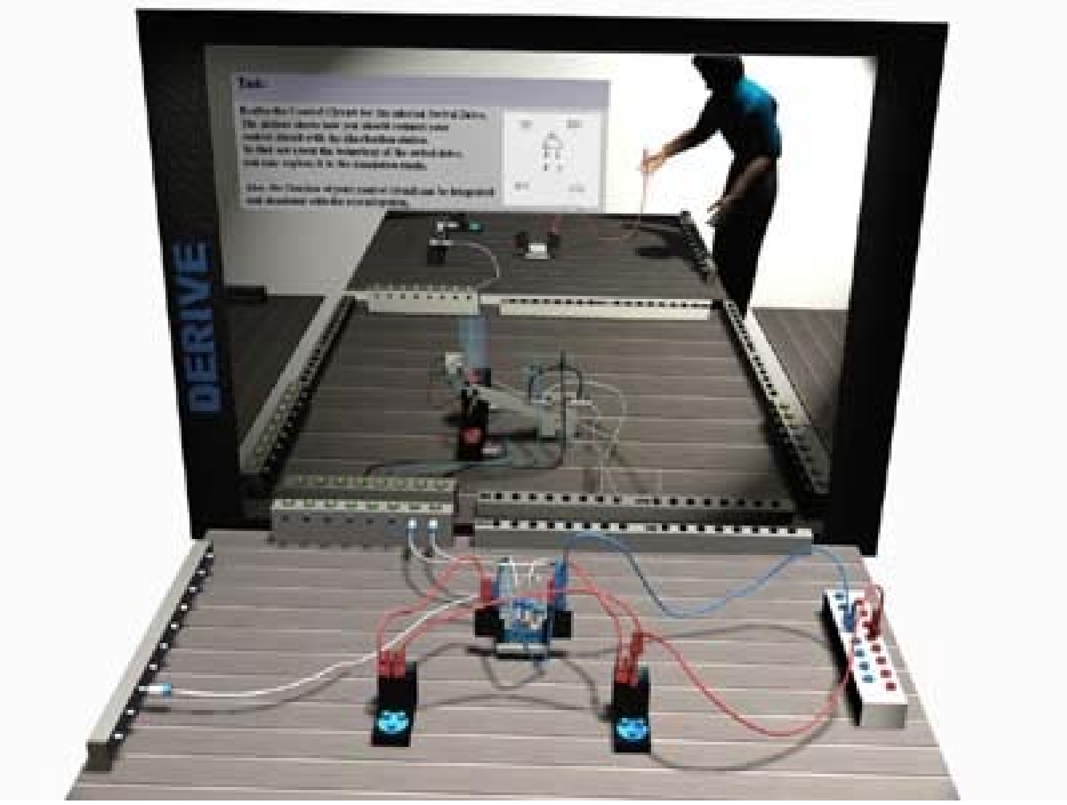


Fig 11: DERIVE Learning Environment

## References

Brauer, Volker. Simulation Model Design in Physical Environments. Computer Graphics ACM Siggraph vol 30, no. 4, pp. 55-56, 1996

Brave, S., Ishii, H., Dahley, A.: Tangible Interfaces for remote Collaboration and Communication. Proc. Of CSCW ’98, Nov. 14-18, 1998

Breretron, M., McGarry, B.: An Observational Study of How Objects Support Engineering Design Thinking and Communication: Implications for the design of tangible media. CHI 2000 Conf. Proceedings, acm press, pp. 217-224, 2000

Bruns, F. W.: Zur Rückgewinnung von Sinnlichkeit - Eine neue Form des Umgangs mit Rechnern, Technische Rundschau, 29/30, 1993, pp. 14-18

Bruns, F. W.: Complex Construction Kits for Coupled Real and Virtual Engineering Workspaces. CoBuild `99

Bruns, F. W., Gathmann, H.: Auto-erecting Agents for a collaborative Learning Environment. Proc. of 8th IEEE Int. Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises, June 16-18, Stanford, 1999, 287-288

Cellier, E. F., Elmqvist, H., Otter, M.: Modeling from Physical Principle. In W. S. Levine (Ed): The Control Handbook, CRC Press, Boca Raton, 1995, pp 99-108

Fitzmaurice, G. W., H.. Ishii, W. Buxton. Bricks: Laying the Foundations for Graspable User Interfaces. CHI’95 Mosaic of Creativity, 1995, pp. 442-449

Ishii, H., B. Ullmer, B. Tangible Bits: Toward Seamless Interfaces between People, Bits and Atoms. CHI´97, Atlanta, Georgia, 1997

Karnopp, D. C., Margolis, D. L., Rosenberg, R. C.: System Dynamics – A unified Approach. John Wiley, New York, 1990

Paynter, H. M.: Analysis and Design of Engineering Systems, MIT Press, Cambridge, MA, 1961

Weiser, M.: Some Computer Science Issues in Ubiquitous Computing. In: Communications of the ACM, 36/7, July 1993

Wellner, P.: Interacting with Paper on the DigitalDesk. In: Communications of the ACM, 36/7, July 1993

## Acknowledgement

I would like to thank my colleagues contributing to this concept in theory and practice: Herman Gathmann, Hauke Ernst, Jürgen Huyer, Kai Schmudlach, Rainer Pundt, Dieter Müller.
Our research is being supported by the Deutsche Forschungsgemeinschaft DFG (G-Nr. Br 1556/2-3, G-Nr. Br1556/3-3) and the EU (MM1002 and IST2031).