Mixed Reality with Hyper-Bonds

F. Wilhelm Bruns
University of Bremen
bruns@artec.uni-bremen.de

Abstract

A unified concept to mix real and virtual objects will be introduced. Hyper-Bonds are connections between external physical phenomena and internal logical structures of a computer based on the Theory of Bond-graphs, a unified and vivid way to describe systems dynamics. The theory is laid down and applications in learning environments are shown.

1. Introduction

Mixed realities are becoming a significant scientific and technological domain. First envisioned by Sutherland [16] they represent a bi-directional coupling of real and virtual world phenomena. The virtual world is in a broad sense projected into the real world and vice versa. Weiser [17] and Wellner [18] applied this principle in an *Augmented Reality* by displaying and overlaying computer- images to real phenomena. This approach has experienced considerable acceleration since the pioneering work of Rekimoto [14,15] by [ ]. Fitzmaurice et al [7] used real phenomena as handles to manipulate information (see Tangible User Interface research) and Ishii & Ullmer [8] and Brave et al [2] coupled both worlds tightly in a bi-directional way. We will focus on this branch of mixed reality.

In some previous work, we introduced the concept of complex objects [4] being objects with one real concrete part coupled to various virtual representations by means of grasp- or image-recognition [1], figure 1. Markers on both ends of connecting tubes allowed us to recognize connections between objects, thus identifying the topology of a system, figure 2. The fruitful application of this concept in several learning environments has been demonstrated and evaluated at four European schools on 12 prototype systems with some 90 Students in 16-hour-courses of Pneumatics [8]. There are some indications, that learning with mixed reality environments based on concrete and abstract objects has many advantages [3]. If one considers the manifold of different learning styles known to pedagogues (linguistic, logical-mathematical, bodily-kinesthetic, visual-spatial, musical, interpersonal, intra-personal) this is not surprising.

This coupling so far has been only unidirectional, giving the possibility to build and change real systems and synchronously generate their functional representation in terms of Petri-Nets or a special simulation language for pneumatics. Simulation could then be carried out with the virtual model and compared with the behaviour of the real system, but no interactive bi-directional connection was realized. However in a systems design application it was possible, to download the controlling algorithm driving the virtual model as a PLC-Program to an industrial Programmable Logic Controller and drive the physical system by means of real sensors and actors, Figure 2.

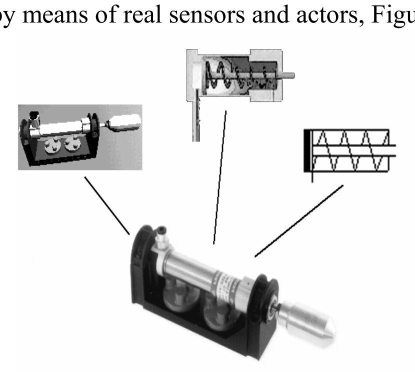

Figure 1: Complex Pneumatic Object

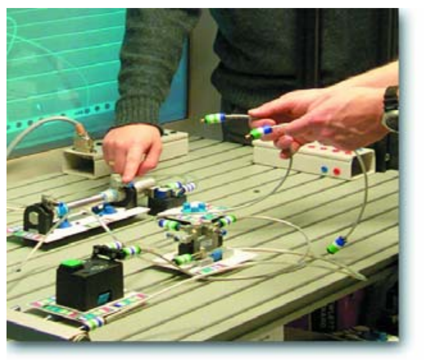

Figure 2: Tube recognition by end-markers

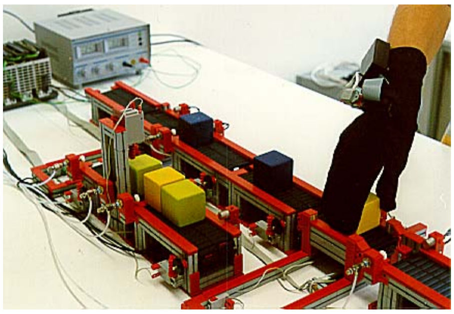

Figure 3. Specifying a real Model.

Our theoretical concept has then been generalized towards further physical phenomena from the areas of pneumatics, hydraulics, electrics, mechanics, thermodynamics. The unifying concept allowing this approach was the Theory of Bond-Graphs developed at the MIT [10].
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 and pedagogical point of view follows. In section 3 the detailed concept of *Hyper-Bonds* is introduced. Some applications and perspectives finish this paper.

2. Usefulness of Bond-Graphs

Paynter [13] introduced his 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 [4]. 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.

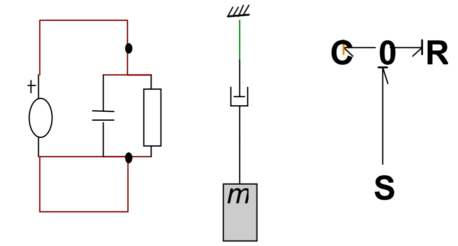

Figure 4. Bond graph for equivalent mechanical and electrical systems.

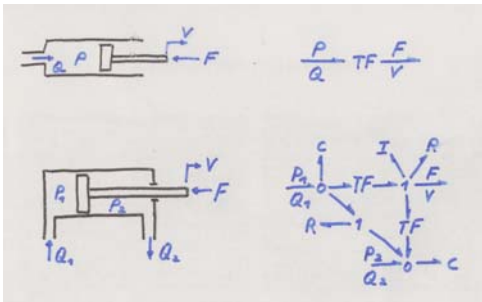

Figure 5. Bond graph for a pneumatic cylinder with different levels of abstraction

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

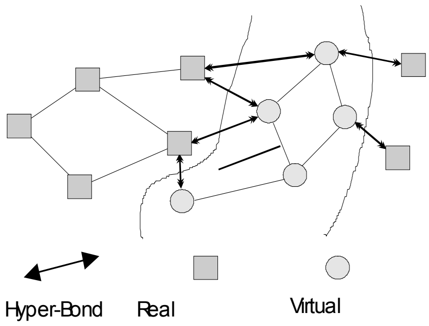

Figure 6. Boundaries cutting a system.

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 sense and generate a phenomenon. We chose to generate the effort and sense the flow, because this has the broadest application area. The alternative would yield some different implementation we are not considering here. The abstract bond graph representation for an implementation of electrics (voltage and current) and pneumatics (pressure and volume-flow) is given in figure 7.

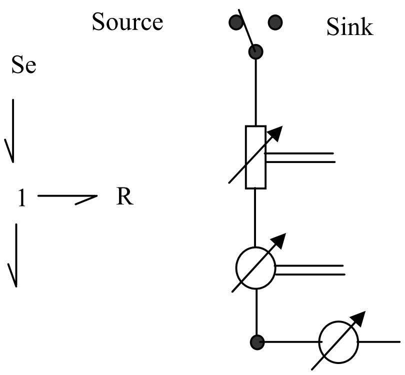

Figure 7. Hyper-Bond for Voltage/Current- or Pressure/Volume-Flow

As all necessary components are available in a standard mechatronics construction kit, we built a simplified prototype (Fig. 8).

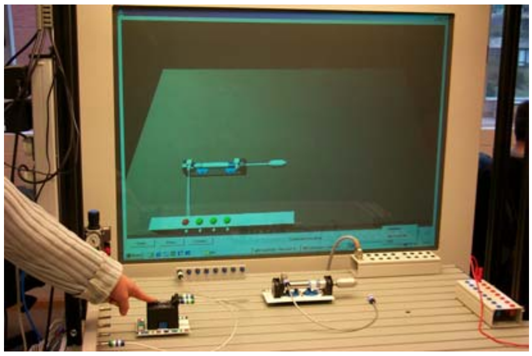

Figure 8. Integration of Hyper-Bonds in a pneumatics application

5. Applications and further Perspectives

Our concept of Hyper-Bonds was applied in a learning environment for electro-pneumatics (figure 8), 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 one's desk, but still have them connected to and integrated in the overall system. As the virtual model can 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, figure 9. This opens up completely new perspectives for distributed task oriented learning in a co-operating group. For systems development our concept would support an incremental implementation and testing of complex devices. For service and maintenance it would support the stepwise investigation and repair of dis-integrated parts. In an ongoing European project Lab@Future we demonstrate this concept as an open laboratory for distributed internet based mixed reality, figure 10 [].

We have shown so far how to implement *Hyper-Bonds* in domains of electrics and pneumatics, the implementation for hydraulics, thermodynamics and mechanics will follow.

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

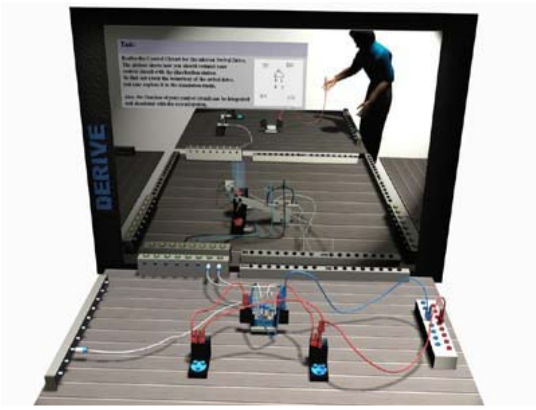

Figure 9. DERIVE Learning Environment.

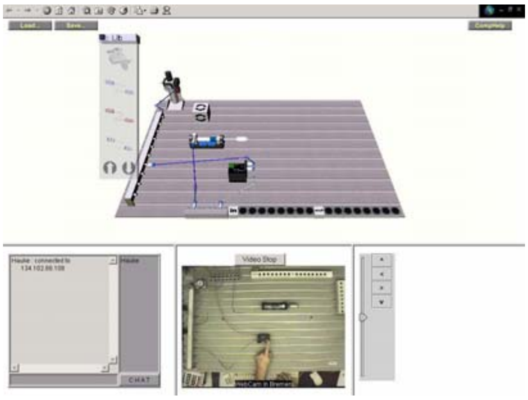

Figure 10. Distributed Mixed Reality Laboratory [19].

6. References

[1] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, B. MacIntyre, „Recent Advances in Augmented Reality“, *IEEE Computer Graphics and Applications*, Nov/Dec, 2001

[2] V. Brauer, „Simulation Model Design in Physical Environments”, *Computer Graphics ACM Siggraph* vol 30, no. 4, 1996, pp. 55-56.

[3] S. Brave, H. Ishii, A. Dahley, “Tangible Interfaces for remote Collaboration and Communication”, *Proc. of CSCW ’98*, 1998.

[4] M. Breretron, B. McGarry, “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, 2000, pp. 217-224.

[5] F.W. Bruns, “Complex Construction Kits for Coupled Real and Virtual Engineering Workspaces”, *CoBuild `99, Lecture Notes in Computer Science*, Springer, New York, 1999

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

[7] S. Feiner, B. MacIntyre, T. Höllerer, A. Webster, „A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment”, Proc ISWC ’97, Cambridge, 1997, pp 74-81

[8] S. Feiner, B. MacIntyre, T. Höllerer, T., “Wear It Out: First Steps Toward Mobile Augmented Reality Systems.” In: Y. Ohta, H. Tamura (Ed): Mixed Reality, pp 363-378

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

[10] S. Grund & G. Grote, „Integrating Real and Virtual Training Tools via a Graspable Interface in Vocational Training: The Evaluation of a New Training Tool“, In M. J. Smith & G. Salvendy (Ed.): System, Social and Internationalization Design Aspects of Human Computer Interaction, Lawrence Erlbaum Association, London, 2001, pp. 819-823

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

[12] D.C. Karnopp, D.L. Margolis, R.C. Rosenberg, R., “System Dynamics – A unified Approach”, John Wiley, New York, 1990

[13] G. Klinker, D. Stricker, D. Reiners, „Augmented Reality: A Balance Act between High Quality and Real-Time Constraints“, Proc 1. Int. Symp. on Mixed Reality (ISMR ’99), Y. Ohta and H. Tamura (eds.), “Mixed Reality – Merging Real and Virtual Worlds”, March 9-11, 1999, pp. 325-346

[14] Y. Ohta, H. Tamura, „Mixed Reality – Merging Real and Virtual Worlds, NY, 1999

[15] H.M. Paynter, “Analysis and Design of Engineering Systems”, MIT Press, Cambridge, MA, 1961

[16] G. Raitmayr, D. Schmalstieg, „A Platform for location based Augmented Reality Applications“, ÖGAI Journal 21/1, 2002, pp. 1-5.

[17] J. Rekimoto, J. “Matrix: A realtime object identification and regstration method for augmented reality”, Proc. Asia Pacific Computer Human Interaction 1998, Japan

[18] J. Rekimoto and K. Nagao, “The world through the computer: Computer augmented interaction with real world environments. In Proc. UIST ’95, 1995, pp. 29-36

[19] I.E. Sutherland, „The ultimate Display“,

[20] M. Weiser, “Some Computer Science Issues in Ubiquitous Computing”, In: *Communications of the ACM*, 36/7, July 1993

[21] P. Wellner, “Interacting with Paper on the DigitalDesk”, *Communications of the ACM*, 36/7, July 1993

Distributed Mixed Reality Lab http://lab.artec.uni-bremen.de

7. 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.

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).