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Using Causality to Close the Physical-Virtual Gap

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1 Introduction

In the ideal case of human computer-supported activity, there should be no user interface factors distracting human agents from the interesting and important parts of their activities. This is a widely shared view among HCI designers. "The aim of invisible, ambient and transparent interfaces is to reduce the cognitive burden on the user by offering interface features that are adaptive, proactive, automatic and understandable." (Quoted from the call for papers of this workshop.) Although the ideal situation is not likely to arrive ever, designing environments towards that end is beneficial.

Of the four complementary focus areas mentioned in the quote above (adaptive; proactive; automatic; understandable) the work presented in this short paper takes the *automatisation* approach. Specifically, the goal is to decrease overhead costs currently present when performing physical-virtual activities [2], i.e. activities that involve frequent switching between physical and virtual environments. The approach is object-centric and based on an unbiased perspective on the physical and the virtual world: the two worlds are regarded as equally important for human computer-supported activity.[1]

1.1 Synchronizing the Two Worlds

The proposed approach for bridging the physical-virtual environment gap follows two complementary paths: 1) maximising redundancy so that activity-relevant object attributes in the two worlds are presented and preferably also manipulable in both worlds, 2) keeping these redundant attributes synchronised with minimal human attention. One path cannot be successfully followed without the other.

It is reasonable to believe that physical-virtual systems that push in these two directions will offer a better environment for physical-virtual activities for two reasons: 1) they will reduce the number of forced physical-virtual environment switches since some of the actions that motivated them before are not necessary any more; 2) they will make some of the still necessary physical-virtual switches less expensive for human agents performing them, since some of the update-related actions connected to the world switch are now performed automatically in a proactive fashion.

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[1] The general physical-virtual design framework [2] of which the work presented here is part, challenges the common view of Human-Computer Interaction as a research discipline mainly dealing with the design of "user interfaces" by proposing an alternative and complementary view, abstracting away the user interface, leaving only physical and virtual objects.

2 Physical-Virtual Artefacts

Pragmatically one can say that physical (real-world) objects and virtual (presented through various kinds of digital displays) play the same role, or correspond to each other if they are used to facilitate the same kind of human action (tool similarity) and/ or if they represent the same abstract entity (information correspondence) within a specific human activity. Table 1 shows some examples. The proposed approach is to

	physical	virtual
tool similarity	pen & eraser	word processor
tool similarity and information correspondence	paper document	web page
information correspondence	a specific car A	the manual to car A

Table. 1. Examples of objects that play similar roles and/or correspond to each other although they are situated in different worlds [2]

reduce the physical-virtual environment gap by complementing similarity- and correspondence-relationships between physical and virtual objects with *causal* relationships. The concept of Physical-Virtual Artefact (PVA) [2] serves as an analysis and design tool for this purpose (see Def. 1).

> **DEFINITION 1:** A *physical-virtual artefact* is an abstract artefact that (1) is manifested in both the physical and the virtual environment, where (2) these manifestations to a large extent utilise the unique affordances and constraints (Norman, 1988) that the two different environments facilitate, and finally (3) where one manifestation of a specific physical-virtual artefact is easily identified if a corresponding manifestation in the other environment is known. [2]

Figure 2 on next page illustrates a hypothetical situation where a human agent decides to switch from a physical environment to a virtual in order to more efficiently perform the next manipulation action on a specific PVA. At command, the corresponding PVA is retrieved into the virtual environment. The virtual manipulation action is then performed on the PVA (the virtual manifestation) by the human agent and the resulting state changes of shared attributes is automatically propagated to the PVA (the physical manifestation) by the physical-virtual infrastructure. The human agent is free to choose in what world (the physical or virtual) the activity involving the PVA is to proceed as long as the activity is about manipulating attributes shared by both PVA manifestations. Figure 1 illustrates the vision of PVAs as conceptually situated somewhere inbetween the physical and the virtual worlds, facilitating physical-virtual activities..

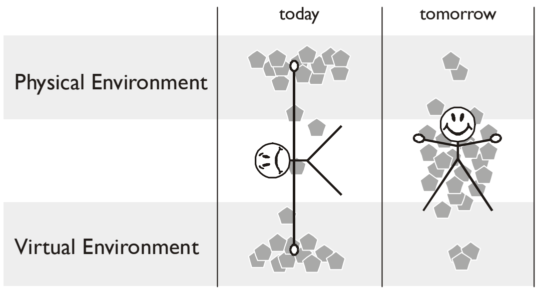

Fig. 1. Illustrating how Physical-Virtual Artefacts are envisioned to facilitate physical-virtual activities by (almost) always being accessible by the human agent, no matter if she or he happens to be acting in a physical or virtual environment.

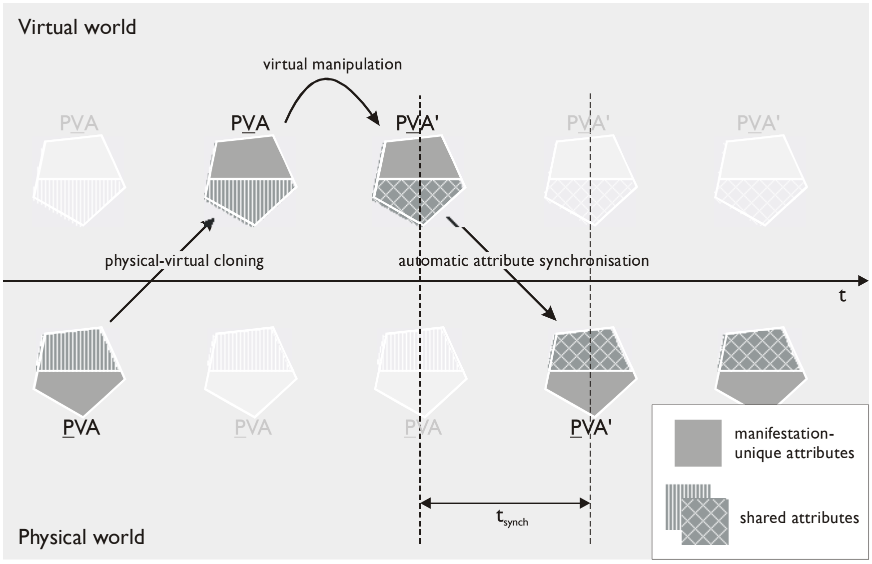

Fig. 2. A hypothetical case illustrating how synchronized physical-virtual artefacts could decrease world-dependency in human activity [2]

3 The Physical-Virtual Environment Gap

The physical-virtual environment gap creates a tension that in one way or the other has to be overcome when performing physical-virtual activities. Either the human agent takes extra steps in order to bridge the gap (e.g. retypes the text when paper-based information is to be transformed into digital form), or there is an underlying computer infrastructure that automatically reduces the “width” of the gap (e.g. the paper containing the information is automatically identified as available in electronic form on Internet, and the system immediately retrieves and displays it in the virtual world when the human agent switches from the physical to the virtual world). The first solution is the standard today, while the second situation is something that has emerged as a possible alternative (or perhaps more realistically speaking, a complement) only recently.

3.1 Gap Dimensions

When studied more closely, the physical-virtual environment gap can be viewed as a collection of differences between the physical and the virtual world, differences that in the light of a given physical-virtual activity are obstacles that have a negative effect on the performance. Each “difference category” or *gap dimension* measures the gap from a particular perspective and the idea is that by evaluating a specific physical-virtual environment along each gap dimension (assigning a value in the range from “very similar” to “very different” to the physical-virtual environment based on the different properties of the physical and virtual world in the specific setting and along the specific dimension), we get a reasonably good estimate of how big the physical-virtual environment gap is in a specific physical-virtual environment for performing a specific physical-virtual activity. Four important gap dimensions are:

- *Presentation:* The degree of difference between how corresponding physical and virtual objects/event are presented.
- *Manipulation affordance:* The degree of difference in what properties of objects that can be manipulated by human agents, and in how the manipulation is done.
- *Organisation/navigation:* The degree of difference in how collections of objects are organised in places and how you navigate the space.
- *Causal dependency:* The degree to which activity-relevant state changes in one world automatically has effect in the other, i.e. how strong the causal dependencies between objects and events in the two worlds are.

Table 2 shows the four gap dimensions along with consequences of the physical-virtual differences we can identify within each. Column three and four in the table show some approaches to reduce or “bridge” the differences.

gap dimension	**resulting in**	**human agent’s way of coping with the gap**	**designer’s potential way of decreasing gap**
physical-virtual **presentation differences** of objects or events although they play similar roles within a PV activity	things look, feel and behave different	general cognitive work, trial-and-error, learning	streamlining PV perceptional design if not interfering with function, strengthen PV identity by increasing causal dependencies
difference between what **properties of objects that can be manipulated** by human agents in each world	certain actions have to/are preferred to be performed in one of the worlds instead of the other	world switch	expand PV manipulation affordances as much as possible in both worlds, let manipulation affordances in one world inspire design in the other
organisation/navigation differences between how physical and virtual space is organised	different navigation methods	general cognitive work (incl. use of spatial memory), learning	PVA infrastructure, “intelligent” physical-virtual place synchronisation, the use of spatial metaphors
weak **causal dependencies** between physical and virtual PVA manifestations	physical and virtual objects “live separate lives” although they represent the same thing	manual synchronisation (incl. general cognitive work, extra physical or virtual actions), cognitive overhead for maintaining a coherent cognitive model of corresponding objects in the two worlds	adopting a physical-virtual design perspective, more collaboration between software engineers and physical designers, more use of sensors and actuators, better user modelling

Table. 2. Four dimensions of the physical-virtual environment gap and examples of approaches for minimising it in each particular dimension [2]

3.2 The Origin Of, and Cause For, The Gap

The physical-virtual environment gap finds its roots in a relatively stable set of fundamental differences in how objects can be presented, organised, manipulated, communicated, transformed and stored under influence of constraints from the laws of nature in the case of the physical world, and theories of computation in the case of the virtual world. But there are also other causes:

- *The mere existence of physical-virtual activities:* If people would use the two worlds for completely different and independent things, there would not be any gap. Or at least, it would not really matter.
- *The dominating single-world design perspective:* Although the HCI research community often suggests to incorporate many aspects of human activity in system designs, including physical world considerations, physical aspects of the environment (in particular the roles of physical tools and physical work objects) are rarely part of the design.
- *The general problem of designing for flexibility:* Even for intra-world activities it is hard to design environments that support "ill-defined" activities since deciding a way to perform it is part of the activity itself. There is a general trade-off between strong automation (resulting in a limited set of possible ways of doing things) and weak automation (giving potentially endless, but not efficient, ways of performing an activity). The trick is to allow for flexibility on the right level of abstraction for the human agent performing the activity.
- *Technological sensing and actuation problems:* For integration to take place, objects and events have to be transformed from phenomena in one world to phenomena in the other. Although sensor and actuation technology has advanced in recent years there are still many phenomena that simply cannot survive a physical-virtual trip (from the physical world to the virtual or vice versa).
- *User modelling/AI problems:* In order to automate some of the actions that human agents have to do manually in order to bridge the gap, computer systems would have to watch and interpret human activities "always", and without asking or being asked. Such background processes often generate an immense amount of data that has to be fed into models of humans behaviour for interpretation and potential system reaction. These models are not easy to design without restricting the human agent to a very limited set of "allowed" actions.

4 Magic Touch — A Gap-Bridging Prototype System

In an attempt to explore the possibility of automating synchronisation of the two worlds, a physical-virtual prototype system has been developed [3]. The system is primarily focused on enabling the definition of PVAs and to mediate basic manipulation of physical PVA manifestations (e.g. paper documents) to their virtual counterparts (e.g. web pages). Fig. 3 shows the conceptual system architecture, Fig. 4 shows the wearable object identification and location tracking unit, and Fig. 5 shows a visualisation based on containment relationships between physical objects in the real-world office environment in which the system is installed.

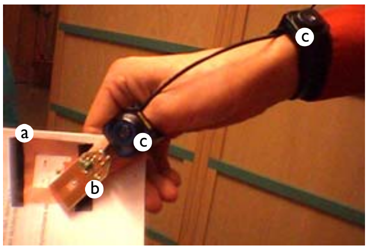

Fig. 4. Magic Touch PVA Manipulation Tracker v.0.51 in action. The photo shows (a) an RF/ID tag attached to a paper document, (b) a stiff antenna, and (c) position transmitters [2]

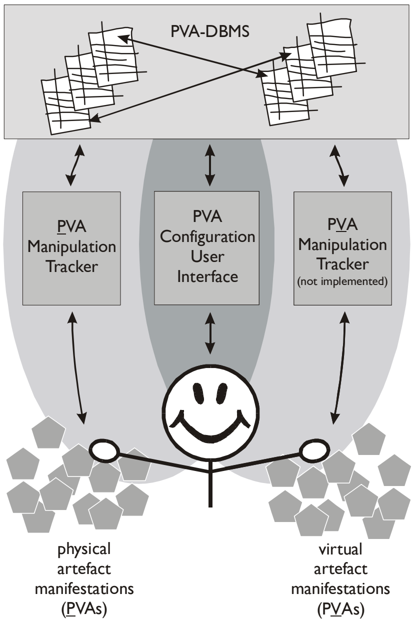

Fig. 3. Magic Touch conceptual system architecture. The PVA-DBMS linking the physical (left) and virtual (right) environments together by keeping track of artefact manifestation changes done by the human agent in any of the two environments [2]

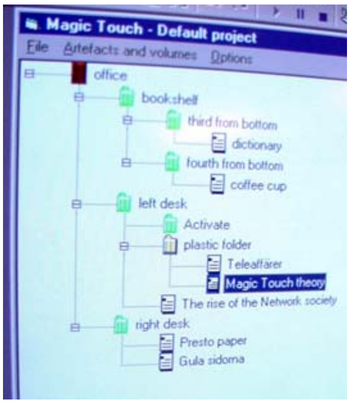

Fig. 5. Parts of the PVA Configuration UI of Magic Touch 1.0 showing a hierarchical virtual representation of objects in a physical environment based on containment relationships [2]

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