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PHYSICAL-VIRTUAL KNOWLEDGE WORK ENVIRONMENTS — FIRST STEPS

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ABSTRACT

By examining the common distinction between “physical” and “virtual”, from different viewpoints such as users’ view and designers’ view, and by briefly discussing some development of theoretical and practical tools for integrating the physical with the virtual, this paper presents our first steps towards the goal of designing better knowledge work environments where physical and virtual activities could be performed jointly and with minimal overhead with regard to the gap between the two worlds. Some general problem areas, to be included in the future research agenda, are also identified and briefly discussed.

1. THE PHYSICAL-VIRTUAL ENVIRONMENT GAP

Knowledge work (Drucker, 1973; Kidd, 1994) environments equipped with personal computers tend to create a significant gap between the virtual environment offered by the computer system(s) on the one hand, and the surrounding physical environment on the other (Pederson, 1999). A field study involving 81 professionals categorised as knowledge workers with the aim of investigating the effects of alternating between physical and virtual environments has been performed during 1999. Early analysis supports the belief that the gap is a common and noticeable obstacle in everyday knowledge work (see figure 1 and 2 below) although further empirical investigation is necessary.

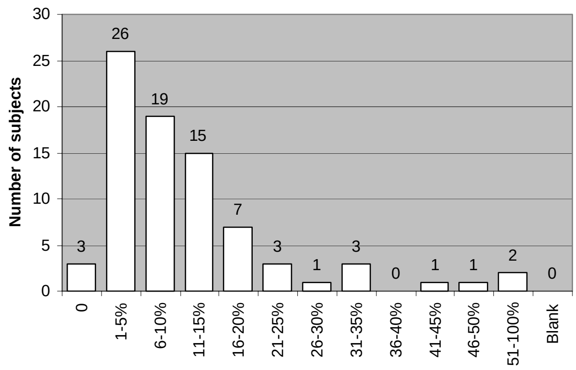

Figure 1: *Perceived proportion of working hours spent on bridging the physical-virtual environment gap.*

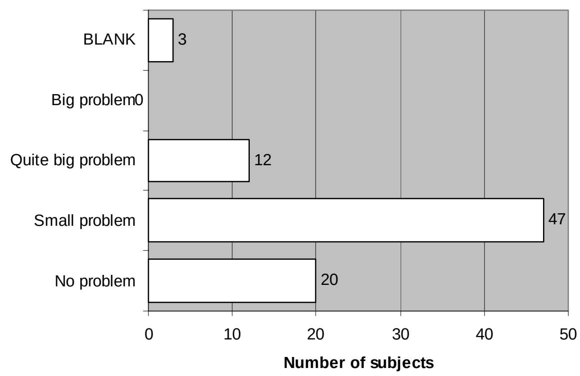

Figure 2: *Perceived magnitude of the problem of manually bridging the physical-virtual environment gap.*

2. THE PHYSICAL-VIRTUAL DESIGN PERSPECTIVE

Based on analysis of differences and similarities between physical and virtual environments (e.g., Arias, Eden, & Fischer, 1997; Pederson, 1999), a perspective for design and analysis of integrated physical-virtual environments is derived. The physical-virtual design perspective emphasises a holistic view on the design of knowledge work environments and the objects within them, in order to break loose from traditional distinctions made by designers of software, electronics hardware and architecture (Pederson, 1999). In practice, the physical-virtual design perspective is about categorising physical and virtual objects with the aim to find ways to conceptually and technically link objects

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Objects		Physical Environment	Virtual Environment
working objects	raw and refined material building blocks	the wheel of a car, a car itself	embedded software for controlling engine performance of a car
	work process related information entities	paper description how to adjust the breaks on a car	car spare part supplier's contact details on a web page
tools	mechanical	hammer, hydraulics system	resize-box in drawing program (direct manipulation), word processor
	cognitive	pen, paper	calendar with reminder functionality
agents		car mechanic, client	Internet agent searching for best-buy parts on the web
work processes and routines		designed by agents within ("users") and/or outside (organisation managers, *site architects*, other agents)	designed by agents within ("users") and outside (organisation managers, *software designers*, other agents)

Table 1: *An example categorisation of a fictitious environment, a car engineering workshop.*

residing in both worlds to each other. As an illustration, table 1 shows a simple categorisation of objects in a fictitious car engineering workshop. The linking process will not be discussed here, except for the idea itself (see Physical-Virtual Artefacts below), but has been performed rather successfully in the Magic Touch project where objects in a physical office have been linked to virtual objects.

Examining objects within physical and virtual environments, we find that many differences are products of human design activity and not laws of nature. The two environments are usually pure artefacts themselves, designed independently from each other and for different purposes. Thus we assume in our work that most of the differences we identify by observing physical and virtual environments today can be eliminated or synergetically utilised by additional human design activities. It is our belief that this design approach not only has the potential of creating environments in which knowledge workers can act without caring about the physical-virtual environment gap, but that it also leads to the development of new cognitive tools that makes knowledge work more focused, fun and creative.

3. PHYSICAL-VIRTUAL ARTEFACTS (PVAS)

Definition: A *physical-virtual artefact* is an abstract artefact that (1) is instantiated in both the physical and virtual environment, where (2) these instantiations to a large extent utilize the unique affordances and constraints that the two different environments facilitate, and finally (3) where one instantiation of a specific physical-virtual artefact is easily identified if an equivalent instantiation in the other environment is known.

Notation: While PVA refers to both instantiations of a PVA (that is, the PVA as whole), P̲VA refers to the physical instantiation of a specific PVA and PV̲A refers to the virtual instantiation of a specific PVA.

An important point is that corresponding P̲VA and PV̲A instantiations do not necessarily have to look or behave in a similar fashion. On the contrary, to fully take advantage of the unique affordances and constraints (Norman, 1988) within the physical and virtual environments respectively, they are by necessity different. We believe that the most important characteristic of corresponding PVA instantiations is that they are tightly linked to each other, and that visual and behavioural characteristics similarity is of secondary importance (Pederson, 1999).

3.1 Technological challenges posed by PVAs

3.1.1 Automatic update of P̲VA when a PV̲A has been altered

Laws of physics constrain the possibilities for a computer system to modify physical artefacts. "Unlike GUI icons, phicons cannot spontaneously disappear or 'dematerialize,' cannot instantly change position or instantly morph into different physical forms..." (Ullmer, 1997). However, some recent research show promising results for particular kinds of physical objects. Certain materials can be reshaped (MEMS, 2000), and paper-like displays painted with ink made up of special chemical substances can change content (EINK, 2000), if suitable electronic signals are sent to them.

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3.1.2 Automatic update of PVA when a PVA has been altered

The challenge lies in recognising and digitising the alterations made on the PVA. Also here there is promising development, regarding certain kinds of alterations. Specifically pen-based activities can be tracked using touch sensitive surfaces (e.g. the Crossboard from IBM), or by tracking the movements of the pen itself, e.g. ANOTO (2000).

3.1.3 Automatic revision control as PVAs become consecutively altered

Revision Control is a research area on its own. The only additional challenge is the recognition of PVA alterations and update of PVAs which are problems already mentioned above.

3.2 Theoretical challenges for the Physical-Virtual Design Perspective

3.2.1 Automatic physical-virtual user modelling

In large a classical Artificial Intelligence problem, although interaction viewed from the physical-virtual design perspective has the potential to model “cross-environment” activities without particular attention or bias towards neither environment.

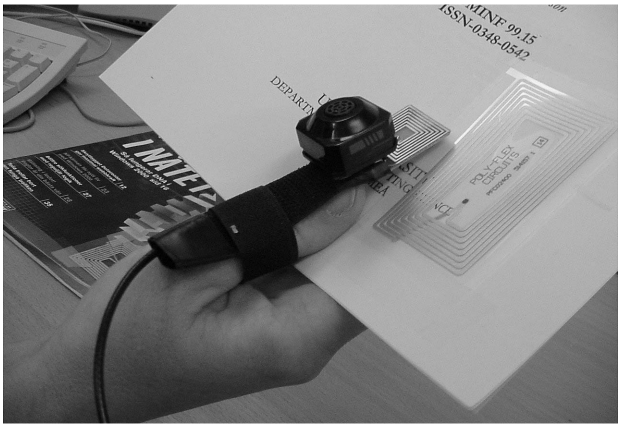

Figure 3: *One of the user’s hand holding a paper document.*

3.2.2 Painting the physical-virtual border

As a perspective encouraging designers to forget about the differences between physical and virtual environments, probably one of it’s most important contributions is to give a clear picture of the border which it is trying to erase. What physical phenomena can’t be usefully virtualised? What virtual phenomena cannot be given a useful physical representation?

3.2.3 The meaning of physical spaces

As indicated by empirical studies in office environments (e.g., Malone, 1983), and as a well-established fact in the area of architecture, much human activity is expressed by moving objects from one place to another. To acknowledge and interpret these “space semantics” (Harrison, & Dourish, 1996) has to be part of the design perspective.

4. THE MAGIC TOUCH PROTOTYPE ENVIRONMENT

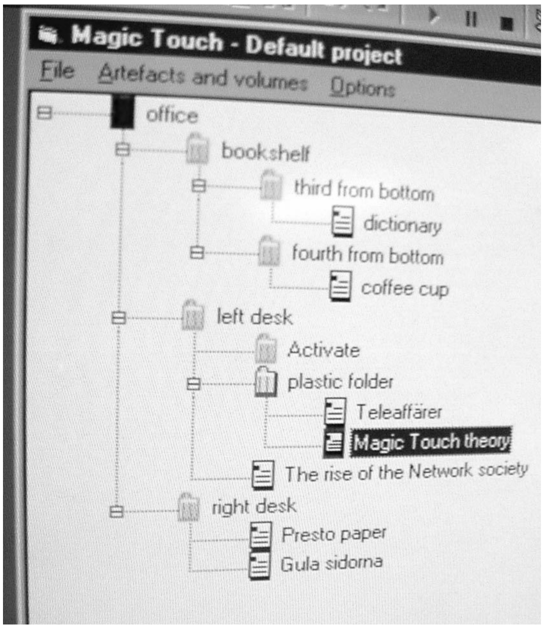

Figure 4: *Spatial relationships between physical spaces and objects visualised as a dynamic hierarchical structure.*

The system keeps track of objects based on a wearable, position-tracked RF/ID reader placed on a finger (Pederson, 2000, 2001) (Figure 3). The user of the system can easily assign names and functionality to physical objects and spaces, as well as create PVAs, e.g. link paper documents to Internet URLs. The system maintains a hierarchical representation of the physical environment where each physical space (e.g. book shelf) and object (e.g. coffee cup) is represented digitally (Figure 4). As soon as the user moves a PVA from one place to another, the hierarchical representation is immediately updated. By keeping information about all PVAs in a database, the system fulfils requirement 3 of the PVA definition since this allows users to search for PVA instantiations both in physical and virtual space and inspect them at wish.

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4.1 Architecture

A single-user version of the system was first demonstrated in June 2000. At the time of writing, a more flexible client-server based solution is under development. Based on the architecture shown in figure 5, it separates the PVA database from the user interface allowing for a multiplicity of special-purpose user interfaces (of which the hierarchical tree viewer in figure 4 is one), system independency of position tracking and sensor technology, as well as the sharing of PVAs and active volumes among geographically dispersed users.

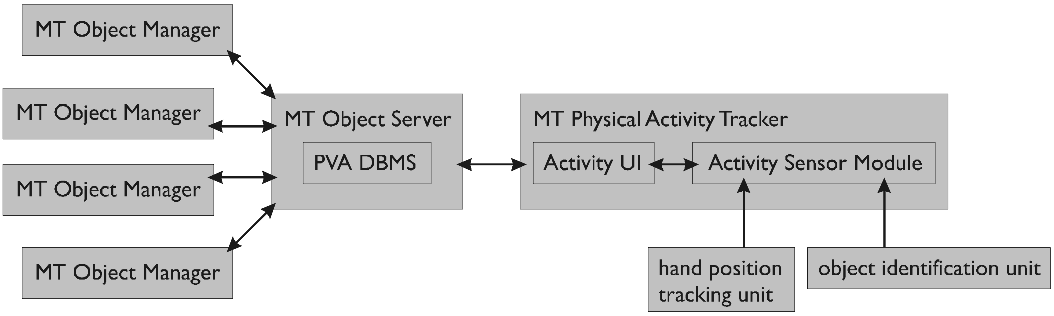

Figure 5: *The basic Magic Touch system architecture consisting of (1) object managers providing special-purpose GUIs, (2) physical activity tracker clients handling input from sensors in a specifical physical environment, and (3) an object server that keeps all authorised clients up-to-date with information about any alteration on Physical-Virtual Artefacts performed by users.*

4.2 Shared active volumes

Within a physical environment facilitated with a Magic Touch system, users can define three-dimensional “active volumes”, $\underline{P}VA_{AV}$, in the physical environment that automatically is given a representation $P\underline{V}A_{AV}$ (a folder in the hierarchical structure shown in figure 4). If a specific $\underline{P}VA$ is placed within the $\underline{P}VA_{AV}$, the corresponding $P\underline{V}A$ immediately shows up within the $P\underline{V}A_{AV}$ in the hierarchy. Suppose now that two or more persons have defined identically large active volumes on different geographical locations and that these locations are facilitated with a system such as Magic Touch. Assuming that the system has support for the sharing of active volumes and that the systems have a common database containing information about PVAs (currently under development), as soon as any of the persons would put a $\underline{P}VA$ into “her/his” $\underline{P}VA_{AVshared}$, a corresponding $P\underline{V}A$ would show up in all other instantiations of $P\underline{V}A_{AVshared}$. Interconnected physical-virtual environments allow for more physical interaction among distributed knowledge workers and increases “workspace awareness” (Gutwin, Greenberg, & Roseman, 1996).

5. MULTI-ENVIRONMENT THINGS (METHINGS)

Space-sharing scenarios such as the active volume-based above has inspired to consider geographically distributed and shared PVAs. Indications suggest that the concept of PVA needs to be generalised in order to encompass the new complexity of these multi-environment things (mEthings).
Networked physical environments has similarities with the concept of ubiquitous computing (Weiser, 1991). However, while ubiquitous computing is something like “access to the virtual world from anywhere in the physical world“, networked physical environments is in its extreme “access to the physical world from anywhere in the virtual world“.

5.1 General questions regarding mEthings

If the physical-virtual world becomes a giant switchboard of interconnected geographically distributed mEthings sharing complex causal relationships, how do we dare to touch anything? Obviously, it is necessary to make the switchboard transparent in the senses that it should be possible to inspect and “program” by end-users. There might be a trade-off between on the one hand making symbolic manipulation more physical (e.g., Fitzmaurice, & Buxton, 1997; Ishii, & Ullmer, 1997), thereby allowing us to utilise more of our human senses and trained spatial capabilities, and on the other making well-known physical causal relationships less predictable by digitally augmenting things. Another general question regards the problem of privacy and security (Levine, 2000).

6. FUTURE WORK

- To extend and formalise the physical-virtual design perspective into a stable framework for analysis and design of physical-virtual knowledge work environments.
- To finalise the implementation of the client-server based version of Magic Touch and to evaluate the system in general. The Computer-Supported Cooperative Work and Telepresence functions that this version will support, by allowing for the sharing of PVAs and PVA_{AV}, are of specific interest.
- To further optimize the Magic Touch wearable device for better ergonomy, as well as more robust identification and positioning mechanisms.

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