Towards a Unified Model of Simple Physical and Virtual Environments

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Abstract

This paper presents a general modeling approach intended to facilitate design of physical-virtual environments. Although the model is based on elements found in typical office environments, certain care has been taken to open for the modeling of more diverse settings with minimal ontological changes. The design approach finds inspiration in the technology-driven areas of Ubiquitous/Pervasive Computing (Weiser, 1991) and Graspable/Tangible User Interfaces (Fitzmaurice, Ishii & Buxton, 1995) as well as more empirical and theoretical research on Knowledge Work (Drucker, 1973; Kidd, 1994), office organisation (Malone, 1983), and Distributed Cognition (Hollan, Hutchins & Kirsh, 2000).

1 Motivation

The purpose of our work is to investigate the possibilities of modeling physical and virtual environments as one environment, centered around a specific human activity. This idea is motivated by the observation that physical environments (e.g. an office, a shop floor, a sports stadium, or a house) and virtual environments (e.g. the desktop environments offered by personal computers (PCs), digital assistants (PDAs), and cellular phones) are not viewed as completely separate entities by human agents themselves when performing modern information technology-supported activities because objects and processes tend to have representations in both worlds. The hypothesis is that by taking on a joint physical-virtual design perspective, it would be possible to design physical-virtual environments that better support these increasingly common, increasingly intertwined, physical- virtual human activities. Specifically, we believe that objects that have representations in many locations (including physical and virtual places) would be more easily handled taking on this stance. The work presented in this paper is an attempt to move towards a greater understanding of the possibilities and challenges involved in bridging the physical and the virtual worlds.

2 Modeling Approach

The fundamental differences between the physical and virtual worlds forces any unifying modeling effort such as the one briefly described in this paper into a series of challenging design trade-offs between the preservation of typical characteristics of one of the worlds at the cost of losing modeling power when describing the other. The modeling approach described in this paper is centred around the concept of *containment* in the physical and the virtual world and the related concepts of human *intra*- and *extra-manipulation* of objects related to each other through containment relationships.

3 Modeling Focus: Manipulation and Organisation of Objects

In order to keep our model simple, we limit ourselves to activities that, more or less, a) have a clear meaning, b) are observable by a human agent, and c) are observable by an artificial agent. Although this narrows the scope of the model significantly (it leaves out for instance pure cognitive or social processes) we believe that for our purposes, the gain in modeling power compensates for it. A distinction is made between physical, virtual, and physical-virtual activities. The notion of activity is furthermore divided into operations, actions and activities based on what abstraction level the phenomena takes place. ("Activity" is used whenever no distinction is necessary.) The model leaves for the designer to categorise the studied activity and sub-activities along these dimensions although agent domain knowledge and potential breakdowns (Bødker, 1989) should influence the decision.

Objects are categorised by the analyst/designer as belonging to the group of domain objects, tools, containers, or agents. (see table 1 for an example categorisation) in a given activity context. It is important to note that the same physical or virtual object can be viewed as for instance a domain object in one situation and as a container in another, depending on the activity and on the interest of the analyst/designer. E.g. an office room might be viewed as a container when a person is performing a knowledge work activity in it and as a domain object in the context of constructing a building.

Container objects play an important structural role. The proposed framework tries to capture two important activity-supporting functions of containers: 1) to provide more or less structured space for long-term storage of "cold" objects, and 2) to provide a) space, and b) tools for manipulation of "warm" domain objects. The notion of "warm" and "cold" objects is borrowed from the empirical work of Sellen & Harper (2002) used by them to distinguish between objects assumed to be relevant for a currently ongoing activity, and those not. Although some container objects frequently play both roles, some are more tuned towards the storage function and others towards supporting the manipulation of domain objects. Whenever a distinction is needed, we denote them "storage objects" and "workshop objects" respectively.

The (re-)organisation of objects is an important part of Knowledge Work activities (Malone, 1983; Kirsh, 1995; Sellen & Harper, 2002). If we concentrate on the physical and virtual organisation activities, they are both possible to observe and have a relatively clear purpose and thus qualify as activities suitable for modeling using our framework.

Table 1: An example categorisation of objects in the physical and virtual worlds

		physical	virtual
domain objects		a book on a bookshelf in an office	a web page in the context of a search on the Internet
tools		a screwdriver when mending a car	a clipboard
containers	**workshop**	a desktop on which you can find pens, a stapler, etc.	a word processor application window
	storage	a refrigerator	a folder in a file hierarchy
agents		a human	a reminder-application

4 Containment Hierarchies

Both physical and virtual environments can be modeled as hierarchies based on the objects situated in them and containment relationships between those objects. Because the physical and virtual worlds typically differ in their structure, “containment” cannot mean exactly the same thing in both worlds. Furthermore, structural constraints ensures a very regular tree structure for the physical world while in the virtual world, cheap “cloning” of objects on the one hand, and independency from laws of nature such as having only three spatial dimensions on the other, opens up for a more irregular structure in the virtual world where for instance the same object can appear at more than one place. Thus, virtual containment hierarchies belong to the class of hierarchies called semi-lattices (Hirtle, 1995). The actual definitions of physical and virtual containment has been omitted here for space reasons but examples can be inferred from table 2.

4.1 Intra- and Extra-Manipulation

The effects of manipulating an object is propagated upwards and downwards in containment hierarchies according to mechanisms decribed as intra- and extra-manipulation. An extra-manipulation of an object on one hierarchical level is identical to an intra-manipulation of that object’s parent-object one level above. Further, a container object’s internal state is equal to the set of external and internal states of that object’s children who in turn depend on the states of their children and so on. Since practically all objects can act as containers (e.g. when interested in the spatial relationship between fibers in an apple, the apple can act as container) and thus nesting is unavoidable, one object has to be chosen to act as a reference object (RO) whenever an analysis is to be done, to avoid confusion. Extra-manipulation of a RO changes the relationship between the RO and its surroundings (technically, its sibling and parent objects in the containment hierarchy). An intra-manipulation of a RO changes the internal structure of the RO itself (technically, the relationship inbetween RO’s children as well as the relationship between them and RO).

4.2 Short- and Long-Term Manipulation

While it is sometimes hard in the physical-world to clearly distinguish between short-term and long-term lasting object manipulations, such a difference is more evident in the virtual environment offered by the WIMP paradigm: Extra-manipulation of containers of the type “window” (see table 2) do seldom last for long and are seldom part of the result of the activity but instead motivated by the temporary management of screen real-estate. We denote such manipulations short-term manipulations. Long-term manipulation of objects are manipulations that have a long-term effect.

4.3 Conditions for Object Manipulation in the Physical and Virtual Worlds

Table 2 illustrates the differences between physical and virtual objects with regard to how they afford short- and long-term intra- and extra-manipulation operations. For reasons of space, only domain and workshop objects (see table 1) are included. Furthermore, the virtual environment modeled in table 2 is the one presented by the widely spread WIMP (Windows, Icons, Menus and Pointing device) interaction paradigm currently dominating the area of personal computers. Virtual environments offered by other interaction paradigms would look different. The WIMP paradigm allows the manifestation of virtual objects in three distinct forms which complicates the modeling since each object form allows for different manipulation opportunities, in contrast to for instance the physical world whose objects rarely take on dramatically different shapes.

Table 2: Examples of intra- and extra-manipulation afforded by physical and virtual objects[1]

			short-term		long-term	
			intra-manipulation	**extra-manipulation**	**intra-manipulation**	**extra-manipulation**
Virtual World (WIMP environment)	**Window RO**	workshop	- DM-spatial translation of children objectsW (domain objects, tools) within the spatial boundaries of RO - to include an object as a child ("open"-menu item, "show tool x"-menu item)	- DM-spatial translation of RO within the spatial boundaries of the parent (the desktop) - DM-spatial resizing of RO - hide RO ("minimize"-button) - de-activate RO ("close"-button)	- to adjust workshop preferences settings such as simple/ advanced menus; picas or points, etc.	- ?
		domain object	- DM-spatial translation of children objects (text etc.) within the spatial boundaries of RO (e.g. scrollbar, PgUp/Dn, zoom)	- DM-spatial translation of RO within the spatial boundaries of the parent (the workshop object) - DM-spatial resizing of RO - transform RO from W to Wm ("minimize"-button) - de-activate RO ("close"-button)	- to change the content (the children) of a domain object (e.g. the text in a document) or the content structure (e.g. the location of files in a file system)	- ?
	Icon RO		- ?	- to select/deselect RO (by clicking (DM)) - to rename RO	- to change file properties (pop-up menu)	- DM-cross-storage-container translation (or duplication) of RO
	Minimized Window RO	workshop	- ?	- hide W clone of RO ("minimize"-item in pop-up menu) - show W clone of RO (single-click on RO) - de-activate RO ("close"-item in pop-up menu)	- ?	- ?
		domain object	- ?	- DM-spatial translation of RO within the spatial boundaries of the parent - transform RO from Wm to W ("restore"/"maximize"-button) - deactivate RO ("close"-button)	- ?	- ?
Physical World	**Any RO**	workshop	- DM-spatial translation of children objects within the spatial boundaries of the RO (e.g. to move a bottle of wine across the dining table) - to include an object as a RO child (e.g. to put a book on the desktop)	- DM-spatial translation of RO (e.g. to put your work bag (the RO) containing pens, papers and laptop on the seat beside you on the morning train)	- to repaint the walls of a living room (the RO)	- to move a desk (the RO) from one room to another
		domain object	- DM-spatial translation of children objects (e.g. book pages) within the spatial boundaries of RO (e.g. to turn the pages) - to write things on a blackboard (the RO)	- DM-spatial translation of RO within the spatial boundaries of the parent (e.g. to move a pawn (the RO) forward in chess) - DM-spatial resizing of RO (e.g. to roll-up the blinds of a window)	- to overline lines of text in a text document using a highlighter pen	- DM-translation of RO to a storage container .(e.g. to move a book from a bag to a shelf) - DM-spatial resizing of RO (e.g. to crumple up a piece of paper)

[1] Legend: RO = Reference Object; DM = Direct Manipulation; object postfixes W, I, Wm = Window, Icon and Minimized Window manifestation respectively.

5 Conclusions & Future Work

Although space restrictions has limited the presentation to only the corner stones of the framework, we believe to have shown that the proposed unified terminology and the selected structural characteristics of physical and virtual environments together has the potential to enable the modeling of simple physical and virtual environments as joint single environments. The presented concepts have been proven useful in the design and analysis of the physical-virtual prototype system Magic Touch (Pederson, 2001).

Future work includes application of the model onto common physical-virtual environments such as offices, industrial shopfloors, building construction sets, home environments and entertainment settings. The result of each application effort is expected to become a mix of mutually connected, containment-based, physical and virtual hierarchies that together represent structural affordances & constraints within the specific physical-virtual environment in the light of specific activities.

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