A Dimension Space for Designing Richly Interactive Systems: a Perspective on the MagicBoards

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ABSTRACT

This paper introduces a Dimension Space describing the entities making up richly interactive systems. The Dimension Space is intended to help designers understand both the physical and virtual entities from which their systems are built, and the tradeoffs involved in both the design of the entities themselves and of the combination of these entities in a physical space. Entities are described from the point of view of a person carrying out a task at a particular time, in terms of their attention received, role, manifestation, input and output capacity and informational density. The Dimension Space is applied to two new systems developed at Grenoble, exposing design tradeoffs and design rules for richly interactive systems.

INTRODUCTION

Recent years have seen technological advances allowing the exploration of exciting new interaction paradigms that involve, for example, augmented reality and cooperative work. These advances have included the development of inexpensive and novel I/O devices such as cameras, digital sensors, data projectors and immersive displays, the creation of portable devices such as personal digital assistants and portable telephones, and the proliferation of high-speed networks. Examples of richly interactive applications based on these novel technologies include augmented reality flight strips supporting the work of air traffic controllers [17], Ishii's tangible bits [16], embodied interfaces [11], the INFOTABLE and INFOWALL "spatially continuous" workspaces [23] and the CASPER computer aided surgery system [10,7]. The Magic Board augmented reality whiteboard falls into the same bracket, as a 'richly interactive' system, by virtue of its design principles having included the corporeal interaction of user and device, in relation to alternative and physical media for production and reflection [9,2,25].

All these applications owe their richness, to a greater or lesser extent, to the fact that they blur the line between the computer and the physical world and pay heed to the embodiedness of the human operator [1]. The design of such systems cannot be limited to the design of a user interface, but extends to the design of how physical and virtual entities are to be combined into a complete system. For example, the design of Mackay's flight strips was informed by ethnographic studies of air traffic controllers, including extensive considerations of how these controllers cooperate amongst themselves, and of the physical design of their workstations.

Up to now, little methodical support has been provided for the design of systems involving multiple actors interacting with both physical and virtual entities in order to carry out some task. Based on the experience at Grenoble in the design and implementation of the CASPER and Magic Board systems, we propose a Dimension Space to aid in the design of complete interactive systems. We consider interactive systems to be made up of entities, both physical and virtual, which may be objects of some task, instruments used in carrying out the task, collaborating actors, or adapters between the physical and virtual worlds [10].

The Dimension Space sets out to identify the properties of these entities, illustrating and contrasting the points of view of actors using the system to carry out a task. Its primary role is to serve as a descriptive and exploratory tool for designers and to communicate and record their reasoning about potential interactive systems. The Dimension Space presupposes an existing and detailed analysis of the content and context of the work domain from which evaluation criteria may be drawn [4,22]. It is capable of describing the interactive properties of combinations of entities, properties that may be of value or disruptive depending on the system of work concerned. The Dimension Space thus belongs to a family of approaches that have been described as *Design Space Analysis* [19], by elaborating possible designs against a determined set of requirements.

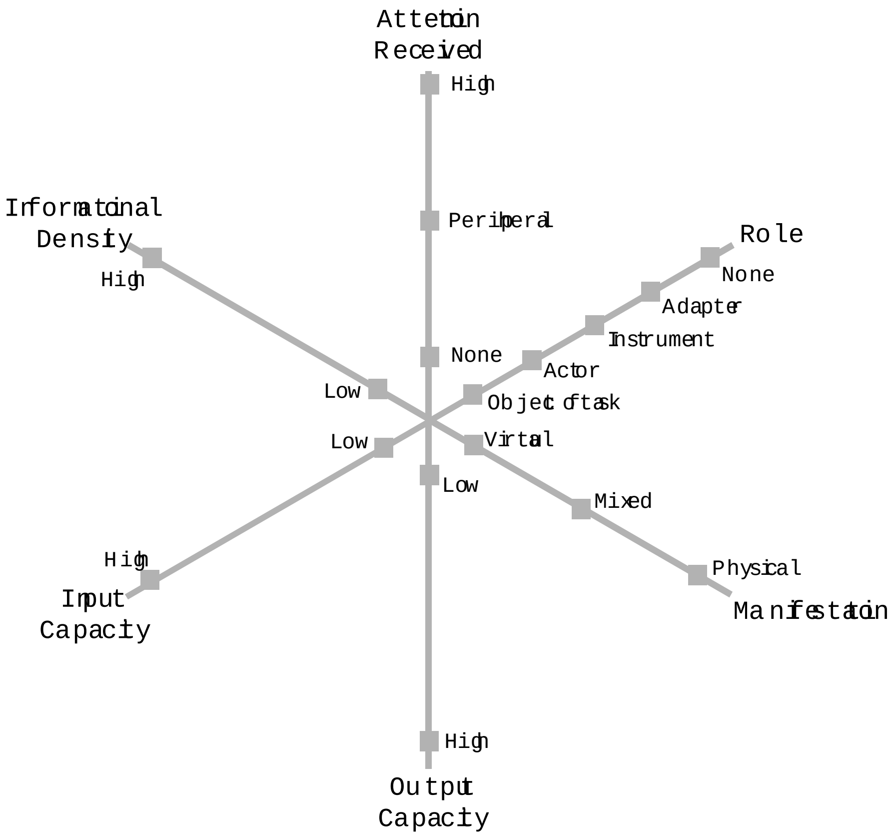

Figure 1: A Dimension Space for describing entities in the context of th
In this space, an entity is described as a plot, from the perspective o
out a particular task at some time

The Dimension Space characterizes entities in terms of their attention received, role, manifestation, I/O capacities and informational density. Using the axes of the Dimension Space, we can ask questions such as, what is the purpose of the entity (from the point of view of a user carrying out some task); how does the entity combine physical and virtual attributes, and how does the entity constrain the use of other entities? As is shown in the final section of the paper, the Dimension Space allows us to propose examples of general design rules for richly interactive systems, and helps in evaluating such rules.

The *Magic Board* provides a realistic example of a modern interactive system involving group cooperation and rich interaction between the physical and virtual worlds. For the Dimension Space, its salient characteristics are:

- users may create and manipulate text and graphics that are either physical (using standard dry-ink pens) or virtual (projected via a data projector)
- the contents of the Magic Board are digitized via a camera.

- users may perform operations such as copy/pasting, moving or deleting the virtual contents of the whiteboard
- users may also use familiar pens and eraser brushes on the physical content of the board.

For example [25], to move a region of the Magic Board, a user performs a sequence of gestures to select a region with his/her finger, and then drags the selection to a new location. The camera is used to track the user's finger. The effect of user actions on the Magic Board depends on whether the content is physical or virtual. For example, this move operation moves virtual drawings but copies physical drawings. Similarly, erasing with a physical brush affects only physical drawings.

RATIONALE

Systems such as the Magic Board involve multiple people collaborating to perform a task, using both physical and virtual artifacts. Traditional interactive systems have been designed as isolated software components, in the context of supporting a single user carrying out some task. Even the designs of applications supporting collaboration often abstract the notion of collaboration away from its physical context, while attempting to preserve its social and organizational setting. In contrast, richly interactive applications must be designed as complete systems involving the mutual interaction of people, software, and physical entities. That is, they must recognize the physical context of collaboration as an active constituent of interactive processes.

Considering the system as a whole exposes problems in both the *static* design of the system, and in the analysis of its *runtime* implications. As we shall see in the next section, the Dimension Space is proposed to expose a broad set of design issues in both the static and runtime design of interactive systems.

Static design issues for systems involving multiple users in a physical setting include:

- *Identifying relevant entities:* A first step in designing an interactive system is to identify the entities from which the system is composed. The entities making up the Magic Board include a camera, a finger, a tracker, physical ink marks, virtual ink marks and the surface upon which the marks are created and modified.
- *Identifying how entities are used:* Just as it is important to design how software entities are used by people in carrying out their tasks, such analysis must extend to physical entities implicated in interactions.
- *Identifying tradeoffs in entity choice:* Some entities involved in an interaction are *fixed*, in the sense that they cannot be replaced. (e.g. as a design decision, the physical surface and conventional markers are fixed.) Other entities are *replaceable* (e.g., the tracker and the means of rendering the virtual ink), and can be chosen or designed following analysis of their existing or desired properties. For example, different means of tracking the finger and different technologies are available for digitizing drawings (such as computer vision or tactile input devices.) It is important to identify what tradeoffs are involved in the choice of which replaceable entities to include in the system.

In addition to these static design concerns, design issues arise in the runtime use of the system, both in determining the system's intended use and in identifying problem areas in this use:

- *Use over time:* The attributes of entities within an interaction change over time. This allows the recording of high-level scenarios of work using a mixed physical/ virtual system.
- *Point of view:* Different actors collaborating to perform a task will view the entities making up the system in different ways, depending on their role in the task, their focus of attention, and even on the physical layout of their workspace. The appropriateness of a given entity depends on its multiple-role potential within the "cognitive system" network [15].

- *Identifying discontinuity:* Temporal views of systems help in identifying discontinuities in interaction with the system. Such discontinuities may occur when, for example, different entities compete for an actor's attention, or the attributes of an entity abruptly change as an actor moves from one task to another.

Once relevant tasks and actors have been identified, the Dimension Space helps to identify how these actors carry out tasks in the context of a system mixing physical and virtual entities.

THE DIMENSION SPACE

The Dimension Space helps designers better understand the properties of and relationships between entities. To explore these questions, designers *plot* the significant entities composing their system, both physical and virtual, in the Dimension Space. These plots are made from the point of view of a specific user of the system, carrying out a specific task at a particular time.

By constructing and viewing these plots, the system designer elaborates the implementation design space. By contrasting the properties of alternative entities on the dimensions, design issues can be exposed, and different design options can be examined. As our examples will show, the Dimension Space is not itself sufficiently rich to resolve all of these design issues. However, by exposing design issues and showing a range of design choices, the Dimension Space complements other tools that permit more detailed analysis of specific design problems.

The Dimension Space is a six-dimensional space capturing properties of the physical and virtual entities that make up an interactive system. By plotting positions on each of six axes, an entity can be described by a point in the Dimension Space. Therefore, different people may view the same entity as having different attributes, and these attributes may change over time, or as the task at hand changes.

Figure 1 shows the axes from which the Dimension Space is constructed:

- The *attention received* axis specifies how much attention the actor is currently paying to the entity. For example, if a person is writing on the Magic Board, his/her attention may be centred on the pen and whiteboard; a radio playing music may receive peripheral attention, while the desks and chairs in the room receive no attention at all.
- The *role* axis captures the purpose of the entity, from the point of view of the actor carrying out the task. For example, when erasing the content of the Magic Board, the whiteboard is the object of the task, while the brush in an instrument used in carrying out the task. Similarly, for people brainstorming using the Magic Board, the object of the task is the content of whiteboard, while the whiteboard and pens are instruments.
- The *manifestation* axis positions the entity within the physical and virtual worlds. Some entities, such as the whiteboard contents of the Magic Board, may contain both physical and virtual elements.
- The *input/output capacity* axes specify the capabilities of the entity in the acquisition and rendering of information. For example, the PalmPilot® organizer is capable of presenting less visual information than a full-size colour display. A mouse may be capable of capturing finer resolution input than a vision-based finger tracker.
- The *informational density* axis expresses the relevance of the information presented by the entity. Information may be dense, implying all presented information is relevant to the task, or diffuse, implying that much of the entity's information is irrelevant, or that relevant information is hard to find.

CONCLUSION

The Dimension Space may expose design issues in the physical and virtual entities making up interactive systems. Its six dimensions can be used to plot entities from the point of view of an actor carrying out a task, and that these plots can expose interesting design issues for interactive systems involving multiple components and a mix of physical and virtual artifacts. We propose that the Dimension Space can be used in conjunction with design rules for systems involving multiple users and both physical and virtual artifacts. This represents the early stages of work as to how the Dimension Space might fit within a method for physical/virtual interactive system design. To continue this work, we propose to:

- Investigate more deeply what forms of supplemental analysis might help in pursuing problems motivated by Dimension Space analysis.
- Following the philosophy of Cockton and Clarke [8], find systematic methods for creating links between Dimension Space plots and supplemental analyses.
- Extend the list of design rules for richly interactive systems.

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