Design Considerations for Composite Physical Visualizations

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Abstract

While physical visualizations have existed for many years, most of them remain monolithic and static. We identify a promising category of physical visualizations we call composite physical visualizations. Composite physical visualizations are combinations of multiple physical objects and can be designed to better leverage both human and technological capabilities. We show that two important properties have to be considered when designing such visualizations: their level of actuation and their manipulability. Through examples, we illustrate the tradeoffs between these two dimensions, and identify the need for more research in this particular area.

Author Keywords

Physical Visualizations

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction

Physical visualization has existed for thousands of years, yet the Information Visualization community is just starting to study it [9]. Many current physical visualizations (e.g., [3]) are monolithic, static, and not interactive. Some of them are made of multiple individual

Figure 1: Visualization using colored wooden tiles

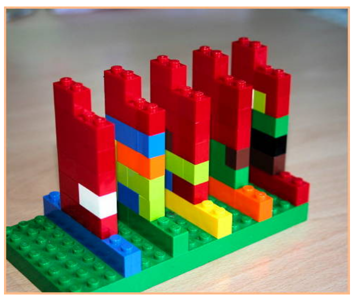

Figure 2: Activity logging visualization built by Michael Hunger out of LEGO bricks

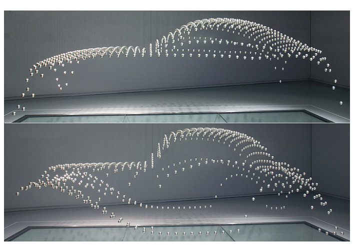

Figure 3: BMW Kinetic sculpture

objects that can be rearranged in order to represent a variety of informative configurations. We call them *composite physical visualizations*. A major benefit of such visualizations is that they support modularity and updatability, but their design space is not well understood.

In this paper, we show that composite physical visualizations can be classified according to two orthogonal dimensions: *i) their level of actuation* and *ii) their manipulability*. Among existing systems, some have a high manipulability but no support for actuation (e.g. [8]), while others are fully actuated but not manipulable (e.g. [1]). Only a few systems are combining both qualities and none supports both full manipulability and full actuation. We discuss the tradeoffs between these two dimensions, and identify the opportunities and challenges for future research and design.

Manually arranged visualizations

An easy way to build a composite physical visualization is to arrange multiple objects manually in order to create visual patterns representing data. This type of composite physical visualization is fully manipulable, but not actuated at all. Such visualizations have been studied by, e.g., Huron et al. [8]. In their study, users were asked using square wooden tiles of various colors (see figure 1) to build representations of a given dataset.

Other examples include an activity logging visualization built by Michael Hunger [7] which uses stacks of LEGO bricks of different colors to represent activities carried on during each day (see figure 2), and Jacques Bertin's physical matrices [4].

Such manually arranged physical visualizations provide the benefits of being highly flexible and requiring little expertise [8]. However, constructing and updating them can be tedious and time consuming when manipulated objects are numerous.

Actuated visualizations

By introducing automatic actuation and computation, it is possible to make composite physical visualizations dynamic. It is then possible to automatically rearrange the objects to reflect changes in data. For example, ART+COM built a series of kinetic sculptures made of objects attached to winch-controlled wires [1]. The height of each object can be accurately controlled (see figure 3). Even though this allows visual representations to be updated dynamically, users are not able to manipulate the objects directly. This limitation is due to the wires used to control the objects and preventing them from being manipulated.

Some actuated composite physical visualizations can be manipulable but the level of actuation is limited. For instance, Durrell Bishop's Marble Answering Machine [2] uses physical tokens to represent incoming voice messages. For each new message, a new token rolls down automatically from a storage container to a presentation container (see figure 4). To listen to the message, the user places the token in a specific spot. However, the system cannot be considered as fully actuated. For example, once heard, a message token has to be repositioned in the storage container.

More recently, Follmer et al. [5] developed inFORM, a dynamic shape display which, using a large collection of moving vertical bars, can change shape (see figure 5). This device is fully actuated in the sense that each of its objects (i.e., the vertical bars) can be moved computationally. It is also manipulable as each object can react to users' gestures. However, each object cannot be

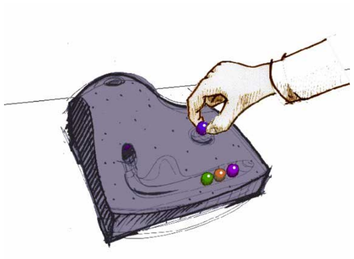

Figure 4: Durrell Bishop Marble Answer Machine

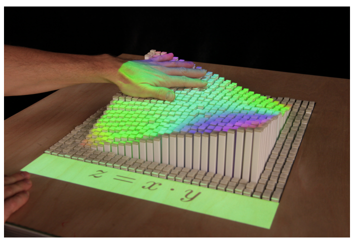

Figure 5: inFORM, a Dynamic Shape Display

considered fully mobile as it can move in only one dimension. Moreover, many of the supported gestures are not direct-manipulation gestures. Thus, this system is not fully manipulable.

Challenges

As we can see through the previous examples selected among many others, many different types of composite physical visualizations exist. However, none of them is yet able to combine two properties that we consider important for an ideal composite physical visualization: *full actuation* and *full manipulability*.

Technological considerations
One technological challenge is to support full actuation while ensuring the full mobility of objects. As demonstrated by the kinetic sculpture (figure 3) and the inFORM system (figure 5), one cannot fully manipulate objects that are physically constrained. By contrast, Durrell Bishop's marbles are not constrained in any way, allowing users to grasp marbles and manipulate several of them at the same time. However, supporting full object mobility will in many cases make the design more complex if computation or actuation features have to be embedded in the objects. Different approaches are possible [9] and can be classified into extrinsic (e.g., magnetic fields [10]) and intrinsic actuation (e.g., self-propulsion [6]). Intrinsic approaches seem more realistic as they scale up to arbitrary numbers of objects and they do not require a controlled environment to operate.

Assuming that technology will soon make it to possible to build composite physical visualizations providing these two properties, designing them will remain a challenge. Designers will need to consider many aspects to build effective and usable composite physical visualizations.

Physical Object Design
One aspect to consider is physical object design. To encourage users to take advantage of manipulation, the design of the objects is crucial as it will constrain the possible interactions. Even for visualizations that are dynamic and updatable, objects have to be carefully designed. The choice of the form factor will impact possible manipulations such as grouping, stacking or assembling. For instance, square objects like LEGO bricks can be assembled and stacked easily while round objects cannot. The right form factor is highly context dependent, for example it is often desirable to have objects with a flat base to insure stability, but the roundness of objects can be also be exploited to ease actuation like in figure 4. The size and the material will also affect manipulation. Medium sized objects are easy to handle but users cannot manipulate many (dozens) at a time. Furthermore, low friction can make objects slippery and difficult to control, while heavy material can make manipulation tiresome.

Conclusion

While many current physical visualizations are monolithic and static, we believe that physical visualizations made of multiple objects can better leverage both human and technological capabilities. We called such visualizations *composite physical visualizations* and showed that they can be usefully classified according to two dimensions, their level of actuation and their manipulability. Only a few systems are combining both characteristics and none supports both full manipulability and full actuation. Through examples, we illustrated the tradeoffs between these two dimensions, and identified opportunities and challenges for future research and design in this domain. We are aware that this position paper rises more questions than solutions, but we hope it will lead to interesting debates and discussions during this workshop.

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