Informing design by recording tangible interaction

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Abstract
Evaluating tangible user interfaces is challenging. Despite the wealth of research describing the design of tangible systems, there is little empirical evidence highlighting the benefits they can confer. This paper presents a toolkit that logs the manipulation of tangible objects as a step towards creating specific empirical methods for the study of tangible systems. The paper argues that the data derived from toolkit can be used in three ways. Firstly: to compare tangible interaction with other interaction paradigms. Secondly: to compare among different tangible interfaces performing the same tasks. Thirdly: via integration into a structured design process. This paper focuses on this last topic and discusses how detailed data regarding object use the data could be integrated into classifications and frameworks such as the Shaer's et al's TAC paradigm.

Keywords
Tangible interaction, toolkit.

ACM Classification Keywords
H5.2. User Interfaces

Introduction
Tangible interaction is a rapidly growing research area in the field of HCI. It is maturing fast, with early

commercial applications of research prototypes such as the ReacTable [10] and Siftables [4] beginning to appear. However, there has been only limited progress in the development of evaluation methods appropriate to tangible interaction [12]. This lack has led to difficulties in robustly demonstrating the value of incorporating tangible interaction techniques into a system design. These challenges affect situations when tangible interaction is compared to other interaction paradigms [9] or when the comparison is between two different tangible systems. This paper argues that a toolkit for recording users' manipulations of tangible interactions is a first step to develop a mature methodology to quantify and evaluate a tangible application. It proposes that such a toolkit be embedded into the development cycle via extensions to the TAC paradigm, while inherently supporting current classifications for tangibles (e.g. Holmquist *et al.* [6]). The contribution of this paper is the design and development of such a toolkit. Its integration into the TAC paradigm [11] is explored via an example application in the form of a tabletop game.

The rest of the paper is organized as follows: (1) a brief literature review covering evaluation of tangible interaction; (2) the toolkit description and a discussion of how it can be integrated with the TAC paradigm; (3) the design of a simple tangible game that generates data for the toolkit; (4) speculations as to future work.

Related work

The toolkit presented in this paper aims to help researchers build better tangible systems by allowing them to understand the benefits of using tangible interaction over other interaction paradigms in specific applications. It also serves as a tool to methodically compare tangible systems and make informed design decisions while using existing frameworks. These topics are review in turn below.

Comparing tangible interaction to other paradigms

Past work has compared tangible interfaces to other forms of interaction, such as keyboard/mouse or multi-touch input (e.g. [8]). Typically, these studies are hard to generalize or require users to perform tasks that highly simplistic [9]. Furthermore, they often report findings that study participants feel more satisfied using tangible interaction [e.g. 8] or find it easier to control and manipulate digital information [e.g. 9]. Such studies are typically well documented, and the findings appear solid and replicable. However, it is clear that such data can only support very general claims and has limited applicability. In particular, it is hard for researchers to build upon each other's results as they develop new applications, tasks or interfaces. There is also no way for researchers to coherently export and communicate data from their experiments, nor easily interpret such data generated by other researchers.

Selecting tangible interaction design candidates

Tangible systems can be found in a wide range of domains such as learning, planning, information visualization, entertainment, or social communication [12]. However, few system descriptions provide clear documentation and design rationale. Such decisions are important and nuanced, covering aspects such as the size, shape, or color of tokens or the fundamental mechanisms underlying the interaction. Although it is safe to assume that these questions are considered during the design process of a tangible application, they are rarely reported by researchers, and have been the focus of little dedicated research. This paper argues that having a systematic way to communicate such design decisions would facilitate future work on similar applications, contributing to the creation of meta-knowledge regarding the design of tangible systems that enable greater levels of consistency to emerge.

Frameworks for the development of tangible interaction
There are already a number of frameworks and classifications, such as the TAC paradigm [11], intended for researchers developing tangible systems. Typically, they provide explanatory power and system documentation through notation tools that emphasize the abstract, logical structure of the problem domain, design solution or application [12]. These frameworks say little in regard to particular design decisions, such as: what is the best physical token for a particular action; or where a particular constraint should be located, and what form should it have.

Such choices are a key part of tangible interaction design, but current tools and dissemination methods (e.g. visualization tools such as VisTACO [1]) fail to support the documentation of these processes resulting in the lack of propagation of this design know-how. This paper argues that tools to support elaboration of design decisions would help address this issue and that this could be achieved via extensions to the TAC paradigm. Ultimately, it suggests that such activities can lead to the generalization of new knowledge pertaining to tangible interaction in the form of concrete new design guidelines.

Toolkit to record tangible interaction

The toolkit presented on this paper was motivated by the desire to effectively compare two different versions of a tangible interface using more than qualitative metrics or subjective ratings. The ultimate goal of the work is to provide an open, coherent and practical way to record the manipulation of tangible artifacts in order to infer qualities of tangible interaction so that meaningful comparisons can made in the following ways: between tangible systems and other interface forms; between different versions of a tangible system; and between different sets of tangible tokens and constraints. Additionally, we suggest that the data generated by the toolkit will facilitate the interpretation and sharing of empirical usage data between researchers in the field of tangible interaction.

The toolkit was developed as a library for the Processing programming language. It records information into a SQLite database. Processing was selected as it is a cross-platform, open-source programming language that supports rich visual interfaces and integrates well with common tangible systems, such as tabletops. SQLite is a simple, common self-contained transactional database that can be easily installed on a range of computers and operating systems. The toolkit itself was developed using SQLJet, an Open Source Java API for SQLite. The toolkit is able to represent and record:

- Every *token* in a tangible system. Each token is associated with one of Holmquist *et al.*'s [6] classifications for physical objects (containers, tokens, and tools).
- Every other *constraint* in a tangible system. Two key two types of constraints are modeled: token present/absent constrains and spatial constraints (e.g. on tabletops) where X and Y position information extends basic presence information.

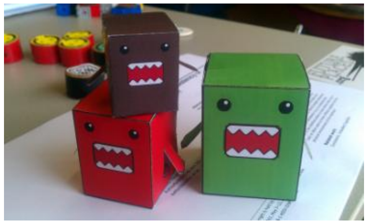


Figure 1. Three of the tokens used in Monsters vs. Samurai

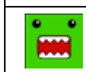
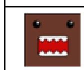
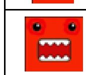
Manipulation		
Action	Token	User response
Move		12%
		17%
		11%
		19%
		**21%**
		8%
		5%
		5%
		2%

Figure 2. Possible addition to the *TAC palette* of Monsters vs. Samurai. For the *Action Move*, it is possible to see which of the tokens was most used in a user study.

- Time-logged *events* such as: pickups, drop downs, hovers, slides, rotations, flips, stacks, alignments, assemblies, and groupings. It is the responsibility of developers to identify such events, since automatically detecting them for all systems would be unfeasible.

Applicability with current frameworks and classifications
Logging usage data of sort described above natively allows the system to compare among design alternatives, for instance by highlighting the different usage patterns they evoke. The toolkit can also be deployed in the iterative development of a tangible system by linking it to current methodologies and frameworks for tangible interaction. Due to the events it records, the system supports all three of Ullmer *et al.*'s [3] classifications for tangibles (interactive surfaces, constructive assemblies, and tokens + constraints), and also Holmquist *et al.*'s [6] classifications for objects (containers, tokens, and tools). The toolkit can also be expanded in the future to record *dynamic bindings* of digital information to individual tokens (e.g. [2]). We explored how the data can be integrated into the TAC paradigm, a tool developed to ease the specification and comparison of tangible interaction designs, by incorporating data from user studies and evaluations. We argue such extensions will increase the usefulness of the tool. Examples of techniques we considered include: the animation the *dialogue diagram*; the creation of different *interaction diagrams* for each of the tokens belonging to a single *TAC*, highlighting the *manipulations* that occur in each one; or the addition a new column to the *TAC palette*, in which every token pertaining to a *TAC* will have information associated with the *manipulations* that actually occur during a user study. This way, the TAC paradigm would keep its descriptive power as well as stay a relevant piece of documentation through all stages of the development.

Example Application: Monsters vs. Samurai
A simple tangible tabletop game was developed to demonstrate how the TAC paradigm could be adapted to work with usage data reported from the toolkit. Monsters vs. Samurai is based on fiducial marker tracking technology and involves players moving physical objects that represent monsters (see Figure 1) in order to keep an ever-growing army of Samurai at bay. There are nine different tokens that can be combined – three different sizes and three different colors (green, brown and red). The weakest monster is the smallest green token, while the strongest is largest red token. As time goes by, the samurai army gets bigger and stronger and becomes capable of defeating more and more of the monsters. Users earn points when the samurai are in pursuit of a monster (or a group of monsters), and lose points if the samurai are intimidated and running from the monsters. Users also lose points when they are moving the tokens or when all tokens off the tabletop. The game ends when the samurai army reaches a monster.

TAC	Representation			Association	Manipulation	
	Variable	Token	Constraints	TAC Graphics	Action	Response
1	Monster	Monster object	Tabletop surface Other monsters		Add	Checks for monsters' clusters Recalculates the samurai goal
					Move	Checks for monsters' clusters Recalculates the samurai goal
					Remove	Updates the monsters' clusters if necessary Recalculates the samurai goal

Figure 3. The *TAC palette* for Monsters vs. Samurai

Monsters vs. Samurai was developed using the Processing language and uses the Trackmate software from the Tangible Media Group [7]. It was modeled

Manipulation	
Action	User response
Add	33%
Move	**42%**
Remove	25%

Figure 4. Possible addition to the *TAC palette* of Monsters vs. Samurai, in which it is shown the most performed *Actions* by users

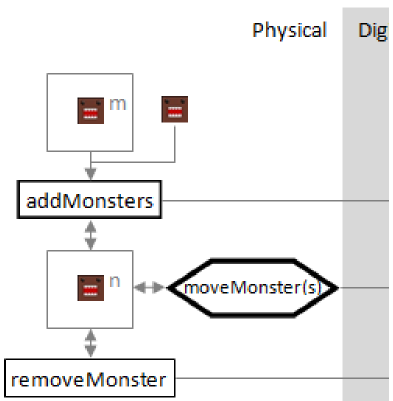


Figure 5. Possible *interaction diagram* for Monsters vs. Samurai, where thicker borders on the geometric shapes represent actions that were repeated more times

using the TAC paradigm (see Figure 3). User studies are currently underway and possible visualizations for integrated usage data from the system into the TAC paradigm have been created. Figure 2 shows an addition to the *Manipulation* column of the *TAC palette*, in which usage data has been associated with the move event for each token in the system. In Figure 4 another possible addition to the *Manipulation* column is shown, in which it is possible to understand which *Actions* were performed more frequently. A last example is found in Figure 5, where in an *interaction diagram* the weight of the rectangles' and hexagons' border (representing actions and manipulations) is directly connected to the number of times those were performed in an evaluation session. We suggest that this information could be used to shed light on the different affordances of a tangible object, the overall interface dynamics or user comprehension of a task, problem space or system.

Future Work

Much further work is required to fully develop and validate this concept. This includes work on the following broad topics and specific areas:

Development

- Open the development to the community, in order to encourage the widest deployment, customization and collection of data.
- Develop compatible versions of the system for common platforms such as the Microsoft Surface.
- Expand the representation format beyond purely token-based systems to include events from pointing and multi-touch systems. Retain a unified format.
- Integrate more emerging classifications for tangible interaction, such as those modeling dynamic bindings between tokens and digital information (see [2]).

Recording

The current system records events based on the interaction between trackable tokens and constraints they operate under. If the toolkit is to be part of a tangible interaction evaluation suite, it should also focus on the users, by:

- Identifying which user are performing system manipulations such as grouping, assembly, alignment, or stacking of tokens. Tracking techniques to support user identification are currently emerging [e.g. 5].
- Identifying users passing tokens between one another.
- Recording dialog for subsequent analysis of manipulations and events. With such an enhancement, the toolkit can shed light on the context in which users perform actions. For example, by identifying occurrences of *verbal shadowing* it may be possible to infer whether bodily interaction is sufficient to indicate each user intention during particular actions.
- Accounting for the positioning of users around the application's interaction area.

The TAC paradigm

- The toolkit should map the data it records to a specific TAC paradigm.
- Researchers should be able to easily define specific metrics so as to create different visualizations from the same data and the same TAC paradigm (e.g. highlight data such as the most frequently used tokens).

Conclusion

This paper presented the motivations for, and design and development of, a toolkit that to standardize data recording in order to support the evaluation of tangible systems. It records a range of manipulations and events, from object pickups to the grouping of tokens. The goal of this tool is threefold. First, it should facilitate the comparison of a tangible system with a system built on another interaction paradigm. Second, it should help researchers make design decisions based on evaluations with users. These decisions include choosing an appropriate token, constraint or interface for a specific application or task. Lastly, it should build upon and complement current frameworks and classifications for tangibles, such as the TAC paradigm. Embedding the toolkit in this process would provide researchers with a structured comparative tool based on objective data from empirical studies. This paper illustrated how this integration could take place by proving illustrative examples of embedding usage data with TAC paradigm models. Future work focuses on how to automate the process of feeding data from evaluations into the TAC paradigm and on broadening the functionality and scope of the system in order to encompass a full range of tangible approaches and platforms. Achieving these goals will represent firm steps towards a systematic, rigorous tool for effectively evaluating tangible interaction.

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