Exploring Effectiveness of Physical Metaphor in Interaction Design

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Abstract
One direction of the emerging paradigm of interface design is the use of physical metaphors, the adoption of physical phenomenon from the real world with physical principles such as gravity or inertia. To explore effectiveness of physical metaphors in interaction design, we conducted an exploratory study by selecting one specific task where a physical metaphor was applied with physics: searching for a phone number in a contact list using an inertial scroll method with a mouse and touch screen interface environment. The result from this initial study showed that employing a physical metaphor does not always guarantee an improvement of performance; a different effect can be drawn according to the interaction style.

Keywords
Physical metaphor, interaction design, interface design, interaction styles, inertial scroll

ACM Classification Keywords
H5.2. [Information interfaces and presentation]: User Interfaces

figure 1. Apple iPhone uses inertial scroll as a physical metaphor with physics [3]

Introduction

The forms of interfaces have evolved though the work done by HCI researchers over the past few decades. One direction of the emerging paradigm of interface design is the use of physical metaphors, the adoption of physical phenomenon from real-world with physical principles such as gravity or inertia. When Jacob, et al. introduced the reality-based interaction framework [3], they described this as a 'naïve physics', involving a type of informal human perception of basic physical principles such as gravity, friction or velocity. According to their study, pre-existing real world knowledge and skills such as physics in the real world may reduce the mental effort required to operate a system. This reduction of overhead effort may improve human performance. Agarawala and Balakrishnan [1] noted that their virtual desktop, called bump-top, behave in a more realistic manner by adding physics simulation. Moreover, a physical metaphor with physics in the form of inertia and springiness is found across nearly all the Apple iPhone applications [4].

Although many researches show the strength of using physical metaphors with physics, we want to know whether a physical metaphor is always effective in human-computer interaction designs. Understanding the detailed effects of employing physical metaphors in physics to certain task in interface design and knowing how these influences can be differentiated according to different interaction styles can have viable implications on practical interface design and on further research.

We conducted an initial experiment by creating prototypes of scroll task that uses mass and inertia in two different types of interaction styles: a mouse interface and a touch screen interface.

Experiment Design

Our overall goal is to explore the effectiveness of physical metaphors in interface design. We attempted to start with a simple exploratory study by selecting one specific task that applied a physical metaphor with physics and two different interaction styles. To start with more objective experimental data, we focused on measuring and analyzing efficiency of task performance efficiency rather than emotional influences.

Contact list with inertial scroll: We selected 'searching for a phone number in a contact list using an inertial scroll' as an appropriate task. Scroll tasks are among the most important tasks when using digital devices practically. Unlike the actual physical paper, all of the information should be expressed in a limited size of the display area and the user needs to scroll the contents to see the other parts [6]. For a long time, scroll tasks were done using a 'scroll bar'; but recently however the inertia as a physical metaphor, which makes virtual objects have their own momentum, is becoming common with scroll tasks especially in small devices. For example, in Apple iPhone, a user can scroll by directly dragging the list rather than using the scroll bar. When flicking through the contact list via an inertial scroll, the list continues to scroll after the user's input is removed, as if the list itself had mass and inertia (Figure 1). We thought that an inertial scroll task is a feasible example that can represent the type of physical metaphor we want to explore.

Mouse and touch screen interface: We needed to select certain interaction styles to conduct this experiment. From a keyboard or mouse to the gesture interface, there are many types of interaction styles that have been developed through technology. We wanted to use

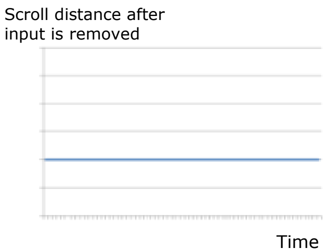

figure 2. Scroll behavior with no inertial effect

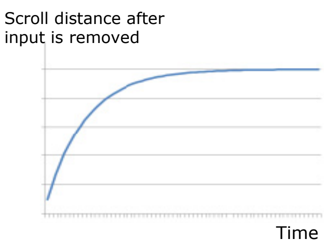

figure 3. Scroll behavior with proper inertial effect (coefficient of friction=0.08)

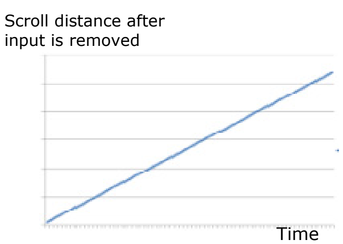

figure 4. Scroll behavior with exaggerated inertial effect (coefficient of friction=0.005)

two interfaces that satisfy several criteria: 1) They must be familiar to people and should not be a novel, such as a gesture interface. We want to avoid obtaining a result from its novelty but instead aim at a result that stems from the characteristics of the interaction style. 2) The selected interfaces must have distinct characteristics with respect to each other. 3) Both selected interfaces should be well adapted to the chosen task of searching for an address in the contact list using an inertial scroll. Through these criteria, a mouse and a touch screen interface are selected. The mouse interface is one of the most typical means of classic human-computer interaction. The touch screen interface is type of emerging interface that can interact most directly with information displayed on a screen [2], in contrary to a mouse interface. However, it is not too new to evoke in users much of a novelty effect these days. In both interfaces, searching for something from long list is frequently performed; therefore, both can be well adapted to our inertial scroll task.

Experiment Setup

To understand the effects of applying inertia as a physical metaphor, we needed to set proper levels of the inertial degree that will be applied to our prototype. We made an initial prototype of a contact list that can be scrolled with different instances of the inertial effect. From a technical point of view, an inertial scroll is implemented by giving a certain value of mass to the list (as a real paper) to be scrolled, and the coefficient of friction (expressed as 'μ') between the list and the floor on which the list is scrolling so that the list has its momentum. We made seven prototypes that applied different extent of inertial strength by giving different

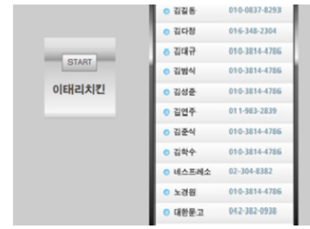

figure 5. We made prototypes of a contact list using different levels of inertial effect. User's task completion time is logged automatically by computer

values of the coefficient of friction (μ = 0.02, 0.04, 0.06, 0.08, 0.1, 0.15, 0.3). The virtual value of the mass for a 'scrolling list' kept constant (100 g). We conducted pilot study with these initial prototypes and selected the one that gave the best usability and emotional feeling for both the mouse and the touch screen interface (μ = 0.08). Add to this, two more prototypes were selected to compare the effect according to whether physical metaphor is applied or not; one is prototype with no inertial effect, another is with exaggerated inertial effect (μ = 0.005). These three different inertial effects are termed 'no inertia', 'proper inertia', and 'exaggerated inertia', respectively (Figure 2,3 and 4).

We added 100 arbitrary phone numbers to our inertial scroll prototypes and programmed that the prototype suggests one target contact randomly to user when the user select 'start' button (Figure 5). The user can select any phone number in the list. The task completion time, that is from the time new target is suggested until the user finds and selects a target from among 100 phone numbers in the contact list, is logged automatically by computer.

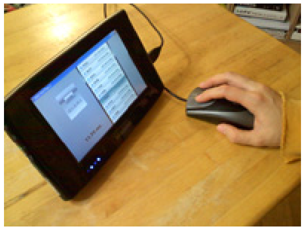

figure 6. Experiment with prototype in the mouse interface

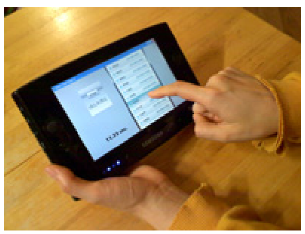

figure 7. Experiment with prototype in the touch screen interface

Finally, we created real working prototypes of the contact list with three different extent of the inertial scroll effect. All of the prototypes used in the main study were made using Adobe Flash ™ with Actionscript. The study was conducted using an ultra-mobile PC (UMPC, Samsung Q1) that support both a mouse and a touch screen interface. This offered the same condition for study with prototypes in different interaction environments.

We recruited 19 participants of which nine were males and ten were females. In order to minimize bias comes from different familiarity about interaction style, we recruited participants who are very familiar with both mouse and touch screen interface. Their ages ranged from 23 to 39 years old, with an average of 27.2 (N=19, SD=3.78). All of them were university students.

For three prototypes and two interaction types, respectively, each participant was asked to try ten scrolling and searching tasks (Figure 6, 7). A total of 60 data were collected from one participant. To minimize the effect from the order of prototypes or interaction types, we conducted an experiment in a randomized order. Five minutes were given whenever the prototype or interaction type is changed to user can take a rest and get familiar with new prototype and interaction style.

Results and Discussion

We analyzed the data using a two-way ANOVA test, as we wanted to understand the influence of the extent of the inertial effect, the type of interaction, and a combination of both.

Interaction Style	Extent of inertial effect	Average task completion time (second)
Mouse	No inertia	4.679 (SD=2.18)
	Proper inertia	5.163 (SD=2.53)
	Exaggerated inertia	4.914 (SD=2.77)
Touch	No inertia	5.171 (SD=2.25)
	Proper inertia	4.247 (SD=1.70)
	Exaggerated inertia	4.890 (SD=2.01)

figure 8. Results from the experiment

The results are shown in Figure 8 and 9. It was found that there were no main effects of interaction style or physical metaphor. But there was a significant interaction between the physical metaphor and the interaction style. ($F_{(2,84)} = 4.979$, $p < 0.008$). For exaggerated inertial scroll, task performance is not distinguished between mouse and touch screen interface. But for scroll task without inertial effect, there was a significant difference between two interaction types ($p < 0.001$). Especially, there was remarkable difference when proper inertia is applied ($p < 0.001$). For proper inertial scroll task (which we selected at the study setup phrase), 5.16 seconds was elapsed under the mouse interface while 4.25 seconds was elapsed under the touch screen interface.

We could see the inertial effect and interaction type affect efficiency of task performance interactively. The most interesting thing in our study results was that neither inertia effect nor interaction type makes significant as a main effect; the influence of the inertial effect to mouse and touch screen interface was in sharp contrast (Figure 9). When no inertial effect is applied, task performance was the best in mouse interface,

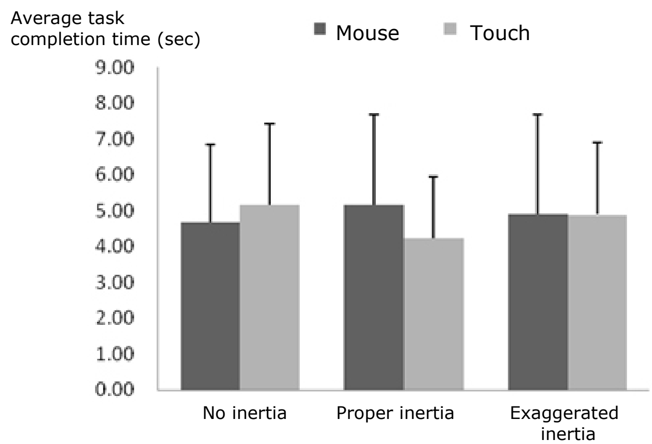

figure 9. Results from the study: Different effect is drawn from same physical metaphor according to the interaction style. (higher bar means lower performance)

while it was the worst in touch screen interface. In contrast, proper inertial effect leads to the worst task performance in mouse interface, while it leads to the best in touch screen interface. Meanwhile, task performance is converging at the 'exaggerated inertial scroll' task.

The results of this study show that employing the physical metaphor as adopted from real-world physical phenomenon does not always guarantee the improvement of performance. In other words, a different effect can occur according to the interaction style, even if exactly the same physical metaphor is applied to the task. This indicates that the characteristics of the interaction style and physical metaphor should be considered when designing interactions.

We discussed the reason why the touch screen interface is better matched with physical metaphor, the proper inertial scroll in this case, in terms of task performance. In contrast with the mouse interface, task performance with the touch screen interface was improved when a physical metaphor was applied. With the touch screen interface, the user can interact directly with information displayed on the screen. The zero displacement between input and output, control and feedback, hand action and eye gaze, makes touch screens very intuitive to use [2]. From this characteristic of the touch screen interface, user can manipulate graphic objects on the screen more naturally than a mouse interface, especially when they have to manipulate graphic object which is moving. Thus, physical metaphors related with movement of object, such as inertial effect which we used in our experiment, are more natural with touch screen interface. Therefore users could control inertia naturally as needed in touch screen interface. In addition, selecting target, which is our given task, is a kind of pointing task; users have to point target in a contact list. According to MacKenzie, et al. [5], index performance in the stylus (we can regard it similar with touch screen interface, in terms of direct pointing) is higher than in the mouse in pointing task. These can explain why there was difference in performance between two interfaces. As the results show, as the interaction style has more affinity with physical metaphor, performance can be improved. Otherwise, it brings a negative result; in the mouse interface, an inertial effect degraded task performance.

In order to understand the detailed characteristics and the relationship between physical metaphors and interaction styles, we need further study with a more structured framework. One factor, however, that we can clearly agree upon is that a physical metaphor has a notable effect on task performance with certain interaction styles. For a touch screen interface, a physical metaphor causes a 17.9% improvement in task performance, while it causes 9.4% degrading for the mouse interface. We thought these changes are remarkable. Therefore, task performance can be improved by employing proper physical metaphors based on understanding both physical metaphors and interaction style.

Conclusion and Future Work

To explore the effectiveness of using physical metaphor in interface design, we conducted an exploratory study by selecting one specific task in which a physical metaphor was applied with physics. The task was searching phone number in a contact list using an inertial scroll with a mouse and touch screen interface environment. The key implication of this study is that the nature of the interaction style should be considered when designing interaction using a physical metaphor. From the results of this study, employing the physical metaphor does not always guarantee an improvement of performance. A different effect can result according to the interaction style. When we see a notable improvement in the performance with the touch screen interface in contrary to mouse, we can conclude that performance can be improved by employing proper physical metaphors through understanding both physical metaphors and the interaction style.

Although we could determine the importance of understanding more about physical metaphors and interaction styles from this study, the results were came from small specific situation. To explore the effectiveness of physical metaphors in general, we will conduct study that covers a wide range of physical metaphors with various physical phenomena such as gravity, collisions or magnetism along with many different interaction styles. In addition, we need to the effects of each physical metaphor with each interaction style on the user generally including user's emotion or attitude as well as time or accuracy. With these further studies, we can obtain valuable implications for future interaction designs.

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