Comparing Multi-Touch Interaction Techniques for Manipulation of an Abstract Parameter Space

Sashikanth Damaraju
Interface Ecology Lab,
Texas A&M University

Andruid Kerne
Interface Ecology Lab,
Texas A&M University

ABSTRACT

The adjustment of multidimensional abstract parameter spaces, used in human-in-the-loop systems such as simulations and visualizations, plays an important role for multi-touch interaction. We investigate new natural forms of interaction to manipulate such parameter spaces. We develop separable multi-touch interaction techniques for abstract parameter space manipulation. We investigate using the index and thumb to perform the often-repeated sub-task of switching between parameters. A user study compares these multi-touch techniques with mouse-based interaction, for the task of color selection, measuring performance and efficiency. Our findings indicate that multi-touch interaction techniques are faster than mouse based interaction.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors, Measurement, Performance, Experimentation.

Keywords: input separability, multi-touch, multi-touch, abstract parameter spaces

INTRODUCTION

We investigate multi-touch techniques to develop new natural forms of interaction for the multidimensional abstract parameter spaces that affect human-in-the-loop systems such as simulations and visualizations. While many current generation devices come equipped with multi-touch input sensing, utilization of this medium of interaction is still limited. Multi-touch researchers have developed techniques for manipulating objects in literal 2- and 3-D spaces, such as maps. For direct spatial manipulation, mappings for actions such as rotate, translate and scale to finger movements are easily understood. The dexterous operations we regularly perform with our fingers in the real world are used to manipulate virtual objects.

In contrast to manipulations in physical spaces, we consider manipulations in multidimensional abstract parameter spaces that lack a literal spatial representation. A range of significant interaction tasks require users to work with multi-dimensional abstract parameter spaces. Application areas include visual analytics, data mining, aircraft flight operations, power station and manufacturing system operations, and image, video and audio editing. Multi-touch manipulation of abstract parameter spaces will enable continuous adjustment of multiple values, for example replacing banks of sliders, each with separate mouse activations. For example, the Photoshop “film grain” filter has 3 numerical parameters: grain, highlight area, and intensity. The user must separately click each slider. To isolate the effect of interaction technique, in the present research, we use a simple task, color matching. The dimensions of this abstract parameter space are hue, saturation and value.

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This research studies the ability of people to manipulate an abstract parametric space through fine motor control of multi-finger movement, as represented by the functional usability of a set of multi-touch interaction techniques that were designed in consideration of physical properties of the hand and problems that people have separating and coordinating movements of individual fingers.

With embodied interaction media, such as multi-touch and haptics, relevant physical properties expand to emphasize the tactile and corporeal. We hypothesize that operative aspects of good affordance design include minimizing physical effort and efficient adjustment of parameters.

In this paper, we develop a user study comparing multi-finger and mouse-based interaction for selecting a color. Our principal hypothesis is that multi-dimensional manipulations through movements of fingers of a single hand are faster than mouse-based interaction.

RELATED WORK

Multi-touch interaction use cases have focused on literal spatial manipulations of rotation, scaling and translation of elements in two [10, 12] or three dimensions [15]. Literal spatial multi-touch direct manipulation has also been applied to deformable shapes for animation [8], and physics for natural interaction [18]. Nacenta et al [17] have developed techniques to improve the separability of multi-finger input for literal spatial manipulations.

The notion of input separability for interactive systems was introduced by Jacobs et al for analysis of the perceptual structures of multidimensional parameter spaces and input devices [9]. They describe two ways of perceiving parameter spaces: *integral* (e.g.: x, y and z to define position) and *separable* (such as size and color) that can prescribe design decisions regarding the choice of input device or widget.

Malik designed widgets that use bi-digit input, using the thumb and the index finger, for cursor control and single parameter adjustment [13]. Recent research shows multi-finger chords can be used for discrete selection of mode or menu items [1, 11]. The present complementary research investigates the use of multi-finger input to adjust multiple parameters in continuous multi-dimensional abstract spaces, instead of discrete item selection.

There has been considerable research detailing the benefits of bimanual over single-handed interaction, with various input modalities [1, 3, 7]. For the purpose of this study, we do not aim to build the ideal interaction for color selection, but are using the dimensions of color as an example abstract parameter space in which to investigate the level of control exhibited by fingers of the same hand across interaction techniques.

Moscovich et al studied differences in performance while using (a) the index and thumb of one hand, and (b) the index fingers of the left and right hands [13]. They articulated a notion of direct manipulation dependent on the fingers directly touching the object they manipulate. Forlines et al [5] recommend the mouse over single finger interaction due to a lack of accuracy and occlusion problems while using the finger. The present research investigates the design space of indirect interaction, wherein the fingers do not touch the object of interest. Wu and Balakrishnan took a similar approach, but with the usual operation of scaling [19]. Indirection helps reduce issues for touch-based direct manipulation, such as occlusion of the target by the hand, and the target being out of reach.

EXPERIMENT DESIGN

We conduct a within-subjects study to compare the efficacy of techniques that map movement of fingers of a single hand to the adjustment of multiple parametric dimensions. The independent variable is the interaction technique used. The dependent variable measured is the time taken to complete the task. We focus our attention primarily on the index finger and thumb, because they are motorically characterized by highly independent degrees of freedom. The independent variable has five conditions, described below. The participant performs multiple trials (a trial is selection of a single color) with each condition.

Apparatus

We fabricated an FTIR based configurable multi-touch device [6]. The screen has a diagonal of 35” (88.9cm) with a rear projected display at 1920×1080 resolution, with an input rate of 60Hz (latency of 17ms). The surface of interaction is a Rosco Grey projection screen.

The multi-touch device enables configuration of height and tilt of the interactive surface, from a vertical wall, through an inclined easel, to a horizontal tabletop. For this study, the inclination of the surface was fixed at an angle of 23° from the horizontal, with the closest edge of the screen at a height of 28” (a standard work desk is 30” high). The inclined surface enables participants to maintain a comfortable upright posture, without having to strain their neck to lean forward during use, as they would with a horizontal tabletop configuration. A support was provided for participants to rest an elbow on during interaction.

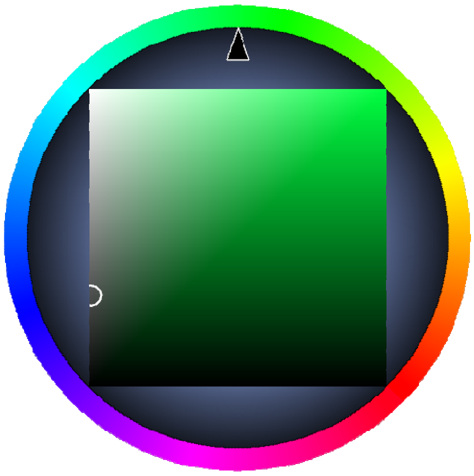

Figure 1: The interface widget for color selection.

Interface Design

The interface widget for color selection is shown in Figure 1. In a square at the center of the widget, we represent the saturation-value varying subset of the HSV color space for a given hue. A ring around this square visualizes the range of hue. The thumb is differentiated from the index finger by being closer to the user (lower on the screen). The motor space for the hue is the same as that of saturation and value, i.e., to move from one end of the range to the other, the participant moves the same distance for each of the HSV dimensions of color. The multi-finger conditions described below (**C1, C2**) have a common mapping for hue variation – the horizontal movement of the index finger is mapped to change in hue, while the thumb is used as a pivot.

Participants

There were 18 participants between the ages of 21 to 26. Each participant received a $5 gift card. All of the participants were right handed, except one.

Study Task

For our study, participants are asked to select a target color, starting from a given initial color, each characterized by the three parametric dimensions of hue, saturation, and value. They are asked to perform a set of 12 trials for each of three interaction technique conditions. Each trial requires adjusting all three dimensions. Of the three conditions, 2 involve multi-finger interaction with different mappings. The remaining condition is mouse-based interaction. The study lasted half an hour.

Interaction Technique Conditions

The multi-touch technique conditions develop variations on the mappings of finger/thumb movement to color dimension. We design interaction techniques to enable the user to effectively manipulate the abstract parameter space of color. The interface widget in Figure 1 helps reinforce the mappings from the movements of the fingers to the adjustment of a specific parameter – hue, saturation or value.

In each multi-touch technique, interaction begins when the user places two fingers anywhere on the screen, without depending on touching a widget in a certain place, and ends at the last adjustment made by the user before touching the 'done' button.

C1. Constrained Manipulation: The mappings are as follows: as follows: horizontal movement of the index finger, with the thumb as pivot, is mapped to change in hue. Horizontal and vertical movements of the thumb, with the index finger as pivot, are mapped to changes in saturation and value, respectively; however only one of saturation or value can be manipulated at a given time. The components of the velocity vector of the thumb movement select the parameter to be manipulated.

C2. Index+Middle: Again, horizontal movement of the index finger pivoting from the thumb controls hue. But in this condition, the index and middle finger together are dragged horizontally to adjust saturation, and vertically for value. We hypothesize that by shifting the fingers in contact with the screen, the effort for selection of parameters will be reduced.

C3. Mouse Interaction: This is a control condition that enables practical comparison with the multi-touch conditions. The circular marker in the saturation-value swatch moves by clicking at a specific point on the square. Participants click directly on the desired value, either on the 2 dimensional saturation-value color square or on the hue ring, which is not possible with the previous conditions. We hypothesize that users will be slower in this one parameter at a time manipulation condition than in the multi-finger conditions. We use the mouse condition as a baseline to compare the effects of the multi-touch interaction techniques on task performance time.

Study Procedure

The participant is presented with the initial and final colors as two squares above the color picker widget, with numerical values shown below each square. For each trial, the participant uses one of the interaction techniques to manipulate the initial color to match the target color. The current color is continuously updated to match the values adjusted by the user. The participant is asked to click the 'done' button to signify the end of each trial.

Each set of trials is constructed by selecting 12 initial and target color tuples. They are held constant across all conditions and participants. The order of the trials is randomized for each condition. The order of conditions is randomized for each participant by selection from a Latin square.

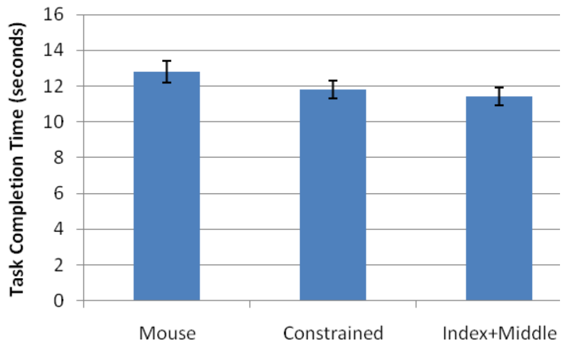

Figure 2: Time for multi-touch interaction technique conditions; error bars show 95% confidence.

Each new interaction technique condition begins, for each participant, with a tutorial screen. The experimenter accompanies this with a short demonstration of the interaction technique. The participant is allowed to practice with each interaction technique at the start of each trial set until s/he is ready to begin the set. The participant is encouraged to rest between trial sets.

We log the movement of each finger for each trial for all of the study conditions. Color matching is a cognitively demanding task, with considerable variation across users and trials. To avoid errors resulting from the user's perceived level of accuracy, a fixed accuracy measure is used for all trials. When the participant sets a parameter within range of the target value, a mark is shown next to it. Once all the parameters are within range, the next trial begins.

HYPOTHESES

H1. Multi-finger manipulations will be faster than the mouse condition for color selection.

H2. The efficiency of the multi-finger conditions (**C1-C2**) will be comparable to that of the mouse (**C3**).

We will verify **H1** by comparing completion times for trials against the mouse condition. Since we use a fixed accuracy measure for all trials, the traditional metric of error is not applicable. Instead, to test **H2**, we use Zhai and Milgram's measure of *inefficiency* [21]. Inefficiency is defined as $(d - s) / s$ where d is the distance traversed by the user through the parameter space, and s is the shortest path from initial position in the parameter space to the target. This measures the level of control the user exhibits during the task.

RESULTS

Each trial is performed by all participants in all 3 conditions. Figure 2 graphs task completion times across conditions. In the following analysis, we normalize the time taken for each trial, with the equivalent time taken to perform the same trial by that participant with the mouse.

The following results are produced using a Welch two sample t-test. Participants performed 9.25% faster with the constrained multi-finger condition (**C1**) than with the mouse condition. The result was statistically significant ($t = 2.951$, $df = 17$, $p < 0.005$). They performed even faster (11.12%) with the index+middle finger condition (**C2**) than with mouse, and again this was significant ($t = 2.71$, $df = 17$, $p < 0.008$). The results validate our first hypothesis **H1**.

We also found from the results that the efficiencies of the multi-finger conditions (**C1, C2**) as good as the mouse condition ($p = 0.48$, 0.43 respectively), proving our second hypothesis (**H2)**.

CONCLUSION

We began addressing the crucial problem of how-to use multi-touch as an input modality for users working with abstract parameter spaces. We developed multi-touch interaction techniques for manipulation of values in these spaces. A user study compared performance of the constrained manipulation and index+middle techniques with mouse-based interaction. Our results show that multi-touch manipulation is faster than with the mouse, and no less efficient. Constraining manipulation along a single dimension contributes to the efficiency of manipulation by increasing the separability between parameters. Future research will work to combine the techniques, letting users select among ensembles of affordances to accomplish different parts of a task. Operation selection techniques, such as multi-finger chorded marking menus [11], can be used in conjunction with abstract parameter space manipulation techniques, to fluidly connect menu operation with dexterous parameterization of selected operations.

To extend the utility of multi-touch beyond literal parameter spaces, such as maps, is a key problem for natural user interaction. The value of multidimensional visualizations and simulations will be synergized with new interaction techniques that facilitate exploration of high dimensional data spaces. We have begun to explore this design space with multi-touch interaction techniques that employ separability. We find evidence that participants quickly learn to adjust multiple parameters of an abstract parameter space through single-handed, multi-finger movement, outperforming mouse based interaction. Future research will investigate the impact of multi-touch interaction techniques for manipulation of abstract parameter spaces in contexts such as design and information-based ideation.

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