Multi-Tap Sliders: Advancing Touch Interaction for Parameter Adjustment

Sashikanth Damaraju
Department of CSE
Texas A&M University
College Station
sashi@cse.tamu.edu

Jinsil Hwaryoung Seo
Department of Visualization
Texas A&M University
College Station
hwaryoung@tamu.edu

Tracy Hammond
Department of CSE
Texas A&M University,
College Station
hammond@cse.tamu.edu

Andruid Kerne
Interface Ecology Lab
Texas A&M University
College Station
andruid@ecologylab.net

ABSTRACT

Research in multi-touch interaction has typically been focused on direct spatial manipulation; techniques have been create to result in the most intuitive mapping between the movement of the hand and the resultant change in the virtual object. However, as we attempt to design for more complex operations, the expectation of spatial manipulation becomes infeasible.

We introduce Multi-tap Sliders for operation in what we call abstract parametric spaces that do not have an obvious literal spatial representation, such as exposure, brightness, contrast and saturation for image editing. This new widget design promotes multi-touch interaction for prolonged use in scenarios that require adjustment of multiple parameters as part of an operation. The multi-tap sliders encourage the user to keep her visual focus on the target, instead of the requiring to look back at the interface.

Our research emphasizes ergonomics, clear visual design, and fluid transition between the selection of parameters and their subsequent adjustment for a given operation. We demonstrate a new technique for quickly selecting and adjusting multiple numerical parameters. A preliminary user study points out improvements over the traditional sliders.

Author Keywords

multi-touch; parametric spaces; exploratory interfaces;

ACM Classification Keywords

H.5.2. User Interfaces: Ergonomics, Graphical User Interfaces (GUI), and Interaction Styles.

INTRODUCTION

This research promotes the use of multi-touch as a modality for supporting creative design tools. We describe a motivation from an analysis on what the operation requires. A new interaction technique is presented that merges the operations of selection and adjustment of numerical parameters.

Historically, *command line interfaces* (CLIs) constituted the first modality of human computer interaction. The user had to memorize commands acceptable to the computer. Commands were designed with ease of repetition by expert users as a priority. Shortened textual notations of described actions was the norm: *ls* for list, and *rm* for removing files. As computing resources improved, displays allowed the visual representation of complex content on the screen.

Graphical user interfaces (GUIs) adopted the paradigm of Windows, Icons, Menu, and Pointer (WIMP) for presenting and interacting with content. The *menu* emphasized recognition of operations from a visible set of menu items, over the recall of how to invoke a command from a vast number of options, as was the case in CLIs.

In 1983, Shneiderman [30] introduced the term *direct manipulation* to mean interaction with elements of the GUI using a pointer. The pointer, controlled by the physical movement of a mouse by the human, operated on visual targets such as buttons or menu items.

However, with multi-touch, the human can now interact with a computer by directly placing her hands on the visual. The pointer is no longer a required part of the interaction between the human and the computer.

This research investigates the design space of multi-touch interaction beyond direct spatial manipulation. Inspired by the use of multiple fingers of a single hand for quick command selection in keyboard shortcuts, we demonstrate how numerical parameters can be quickly selected and adjusted.

The summarized contributions of this paper are:

- Motivating the new design space of parameter adjustment.
- Demonstrating a new technique for merging selection and adjustment of a small sets of parameters with touch interfaces.
- Initial studies showing drawbacks and benefits of using touch for relative parameter adjustment.

MOTIVATION

Engaging in visual design tasks often requires users to adjust multiple parameters for an associated action. These are typically presented to the user as a set of sliders. Parameter adjustment requires the user to shift visual focus away from the target to acquire the thumb of the slider. Design often requires iterations of the following sequence of subtasks: parameter selection, adjustment, and observing the effect on the target. The duration of each iteration is further extended when the user needs to switch between different parameters. This leads to to-and-fro visual saccading between an interactive component and the target object, even if the interface is located close to the target.

Jacob [17] presents a dual classification of how humans perceive combinations of attributes: *integral* or *separable*. Attributes such as the x and y points of a location are perceived as an integral whole. Manipulation of location includes both the parameters. However, the tuple of attributes size and saturation are not perceived together, but are separable. We attempt to bring the user an experience that allows the integration of the multiple parameters of an operation as close at hand as possible.

These distractions of repeated saccading during tasks with high cognitive loads, such as visual design, lead to break downs in the user experience. This context is similar to that of visual analytics, wherein the visual is not a design, but a visualization of large sets of data. The problems describe above apply to interactions that require problem-solving and analysis of data. Our research attempts to develop new forms of interaction for manipulation in such multi-dimensional abstract parameter spaces that do not have an obvious 2D or 3D spatial representation.

Photo Editing

Creative fields such as post-processing of a photograph taken by a digital camera is a delicate balancing act. The photographers take great care in making minute adjustment of a large number of parameters available to them. Figure 1 shows a set of four parameters that manipulate the tone curve. The values of each of such parameters are used to perform a complex set of mathematical calculations to alter the pixel color values.

Even though photographers may not fully comprehend the details of the implementation, they understand the resultant visual change. As their expertise with the software grows, their knowledge of the relationship between the several groups of parameters increases. However, this does not imply

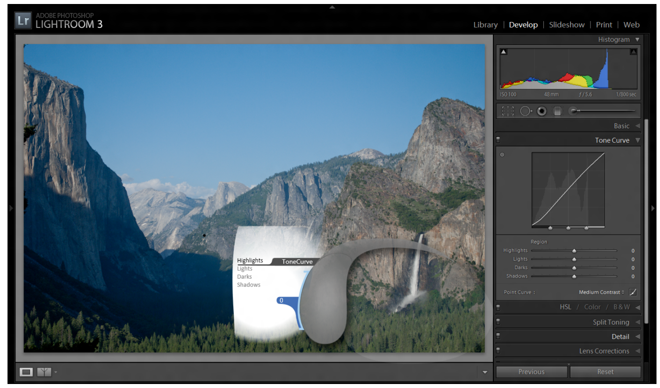

Figure 1. The Multi-tap slider seen overlayed in context with Adobe Photoshop Lightroom 3®.

that given a photograph, an expert photographer can uniquely identify the desired parameter values without interaction.

There is no correct answer. The user interface exposes a set of knobs that feed into complicated algorithms that ultimately change pixels. Details are abstracted away from the user to simplify the experience, while delivering as much power from the algorithms as possible. Providing more knobs would overwhelm the user, where as providing fewer might take away control. The software attempts to find a balance between the two.

The operation demands play. There is a constant exploration of what the photograph could look like with different values. Each parameter is constrained to a fixed range. However, even with just four parameters, under the menu Tone Curve, the possible combinations are in the millions. The operation is purely subjective. The experience and design sense of the photographer can aid in identifying a satisfactory combination of the parameter values. This selection is the primary purpose of the interaction. Devoting more visual and cognitive faculties of the brain, will aid the user in making a qualitatively improved product.

INTERACTION DESIGN

We use this defined motivation and context to establish the goals for our design.

- Promote integrated selection and manipulation of parameters. A group of parameters are considered *integrated* for an operation, the interaction should emphasize this integrality.
- Optimize visual cognition: Use the tactility of touch to leverage selection, instead of requiring targeting a slider thumb.
- Ergonomics: Long term use, relaxed hand posture. Minimizing muscle movement during use.
- Supporting expert users for complex tasks: Utilizing manual dexterity as a learned skill.

This research utilizes indirect interaction via a visual. The visual described is an intermediary between the target of the interaction (a photograph) and the human hand, providing

Figure 2. On the left is the relaxed hand posture that is used during operation. The functional components of the Multi-tap Slider are emphasized on the right: the *index slider* for adjustment, and the *finger pad* for selection.

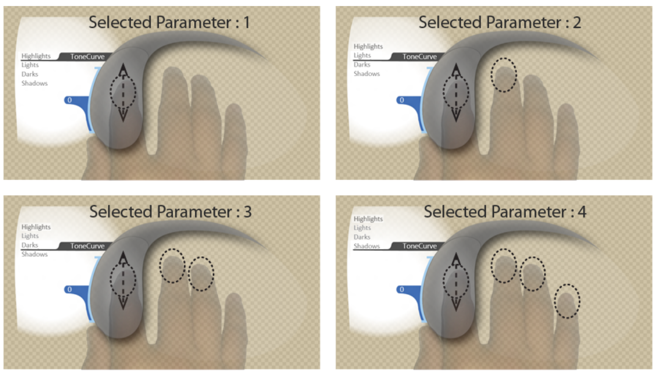

Figure 3. Illustration of parameter selection. The dashed ellipses indicate fingers making contact with the screen. The index finger performs the adjustment through forward and backward movements. When a parameter is selected, the index finger can be raised, re-positioned and lowered as needed. On the left, the selected parameter is underlined.

feedback on two states, that of the interaction, and that of the system. This interface has been designed for use with the wrist being rested on the screen, and the hand in a relaxed posture, as it were clutching a mouse. For increased comfort, the angle of the touch screen is raised to 30°, like an architects drafting table.

The Multi-tap Slider consists of two functional subcomponents: the *index pad*, which behaves as a relative slider for the selected parameter, and a *finger pad* that determines the currently selected parameter based on the number of fingers making contact with it. Figure 2 shows an annotated view of the Multi-tap Slider.

This design operates in two modes, the parameter *adjustment* mode and the parameter *set selection* mode. Each set of parameters is considered as a unique operation that requires frequent repetitions of selection and adjustment of the contained parameters.

Adjustment Mode

We use contact of fingers with the screen (specifically the finger pad) as a quasi-mode selection. The ring, middle and little fingers only perform the function of modifiers. The degrees of freedom of these fingers are limited, only the index finger is used for all adjustment.

For selection, fingers are raised and lowered onto the screen. With no fingers on the finger pad, the first parameter (Highlights) is selected, one finger on the finger pad selects the second parameter (Lights), two selects the third (Darks) and three fingers on the finger pad selects the third parameter (Shadows).

To adjust values, the index finger performs a forwards-backwards movement. This is similar to the operation of a scroll wheel on a mouse. Upward and downward movements can be precisely performed with little or no training. The resulting interaction with this widget requires limited muscle movement.

The user receives immediate tactile feedback as to which parameter is currently selected. The visual optimizes the utility of screen space that is usually occluded by the hand. The large target areas for the index pad and the finger pad allows the user to use the slider without visually focusing on the presented interface, even though their hand occludes most of the visual. Visual feedback of the current state of the interface is provided with a representation of the mapping between number of fingers and the parameter. The slider visualizes the maximum and minimum permissible values, while showing the current value of the parameter.

Resting the wrist on the screen increases the comfort of operation, and increases the precision of the interaction with individual fingers. Without this rest, the weight of the hand is supported by the arm, and the single finger in contact with the screen. Prolonged use on a multi-touch screen without adequate wrist support is likely to build up fatigue in the arm.

Set Selection Mode

Although the sliders can operate on a small set of four parameters, we broaden the scope by providing an upper level menu. This is accessible by performing a double tap with the index finger over the *index slider*. Figure 4 shows the presentation of the upper level menu. By moving the index finger along the index slider, the selection can be changed in the same way the parameter is adjusted. Performing a single

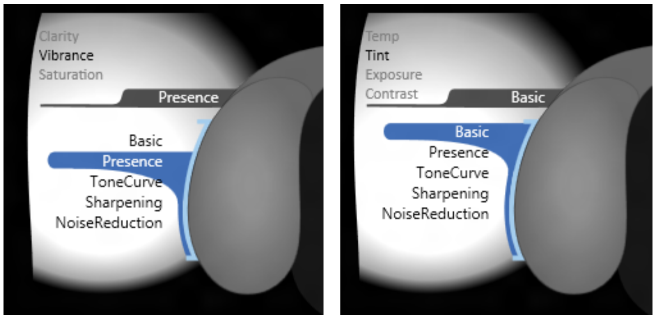

Figure 4. On performing a double tap of the index slider, the set selection mode is presented. Shown here are two selected sets, with the parameters within displayed on the top left of each. A single tap selects the parameter set.

tap will select the set, and the Multi-tap Slider will go back into the parameter adjustment mode.

We provide visual feedback for different states of interaction, as it allows the user to uniquely identify erroneous interaction (as described in [33]). The index slider has a blue glow when it is being operated on. The entire slider can be translated and scaled using the top portion (the gray above the finger pad in Figure 2). A blue glow along the entire shape represents that the translation is being performed. The selection of parameters is also visualized by change in text color and position. As shown in Figure 2, the currently selected parameter black, with other parameter names in gray.

COMPARATIVE USER STUDY

With an earlier prototype of this design (then called the SliderPad), we performed a comparative user study. The differences between the presented version and the study are: 1) No menus in the first prototype, and 2) The visual was modified with improved aesthetics. This is not of concern to the results, as they only performed tasks with a single set of four parameters. These changes are purely cosmetic and have no impact on the applicability of the results.

Figure 5 shows the two configurations of the Multi-touch SliderPad, single handed and bimanual.

We conducted a within-subjects experiment to investigate whether finger count can be used as a parameter selection mechanism, compared to the traditional interfaces of sliders. The task is to select and adjust a parameter to a target value. We designed the experiment with three conditions, the single handed and bimanual configurations of Multi-touch SliderPad and the traditional slider interface. We noted that the two Multi-touch SliderPad conditions and the relative sliders require a relative adjustment of values, whereas the traditional slider interface requires an absolute adjustment of values. To measure the differences in relative and absolute adjustments, we added a fourth condition of relative sliders. The relative sliders (shown in right of Figure 6) are four rectangles of fixed size, placed vertically, and adjacent to each other. The user selects a parameter by placing their finger on one of these rectangles, and could adjust the corresponding target parameter.

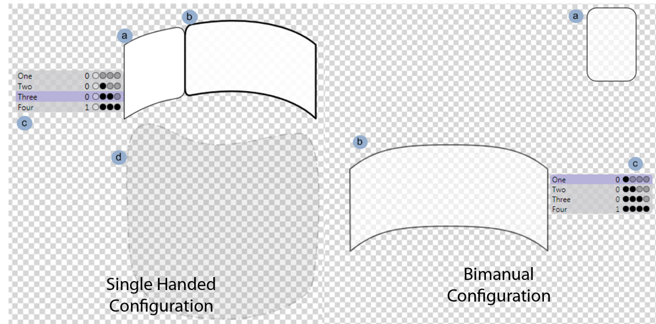

Figure 5. Previous iteration of the Multi-tap slider for a comparative study. The two configurations considered are the for one and two handed use of the Multi-touch SliderPad showing a) the index pad for parameter adjustment, b) the finger pad for parameter selection c) visual feedback of selected parameter and current values and d) for the single handed configuration, a region for palm support

Task and Procedure

The task presented the user with four parameters, visualized as bars in the center of the screen, with the height of each bar mapped to the corresponding parameter value. The target parameter is visualized with a mark at the target value. The sliders in all conditions are towards the user on the bottom of the screen. The user selects the appropriate parameter and adjusts it until the target rectangle's height matches the mark on screen. The parameters have a range from zero to one, and the task is considered complete when the parameter value matches the target with .01 accuracy.

We measured two dependent variables, one being the time to select a parameter for adjustment, and the other the time to reach the target value. Time to adjust the parameter begins when the previous parameter reaches the target value, and ends when the correct parameter is adjusted. The completion time begins on adjustment of the parameter, and ends when the user lifts off their finger at the correct target value. The two Multi-touch SliderPad conditions and the relative sliders adjust the parameter based on the acceleration of the finger over the interface, allowing for more precise adjustments to use finger rolls and coarser adjustments to use flicks of the finger.

We had a total of 13 participants, 1 female and 12 male, all right handed. Each of them performed 24 trials with each of the 4 conditions resulting in a total of 13 participants $\times$ 24 trials $\times$ 4 conditions = 1,248 total trials. The order of conditions was counter-balanced across participants. Each of the conditions used a fixed set of parameter values presented in random order. Participants were given a short demonstration before each condition, and had a few minutes of practice trials to accustom themselves to the interface.

Results

Participants reported that they had no problems learning the two Multi-touch SliderPad conditions. After initial practice, multiple subjects reported that they were more comfortable than the relative sliders and traditional sliders. A repeated-measures analysis of variance (ANOVA) run showed a significant effect on technique for parameter

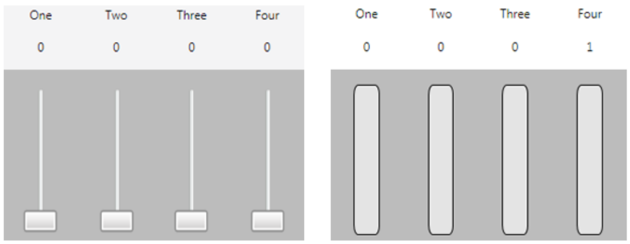

Figure 6. Control conditions with the traditional sliders on the left and the relative sliders on the right

selection time ($F_{3,30} = 3.8$, $p < 0.02$). Participants were faster at switching between parameters for the three conditions using relative parameter adjustment (Multi-touch SliderPad Single Handed = 1.43s, Bimanual = 1.54s, Relative Sliders = 1.28s) than the traditional sliders (1.85s), with no significant difference between the first three. This shows that acquiring the slider thumb affects the parameter selection time. An ANOVA on the completion time shows no significant difference between the conditions ($F_{3,36} = 2.7, p = 0.054$) with a Fischer's Least Significance Difference of 0.72 seconds. This result shows that after a short practice, participants are faster at switching parameters with the SliderPad than the traditional sliders.

However, the SliderPad conditions were not faster than relative sliders. We observed that the presented target has a strong visual correspondence with the sliders in both the relative and traditional conditions. This gave relative sliders a visual advantage over the SliderPad conditions, as the selection of parameters is aided by the presented target. This will not be the case while working on design tasks because there is no fixed target spatially configured like the sliders.

The comparable results for the single handed and bimanual conditions are interesting. On the one hand, the bimanual condition can be seen as a kind of kinematic chain in which the parameter selection by the non-dominant hand is framing the precise value adjustment by the dominant hand. At the same time, the mapping individual fingers to parameters in the multi-touch condition results in a form of direct embodiment. More situated research will be required to discover if there are context in which the kinematic chain or the direct multi-touch embodiment is more valuable.

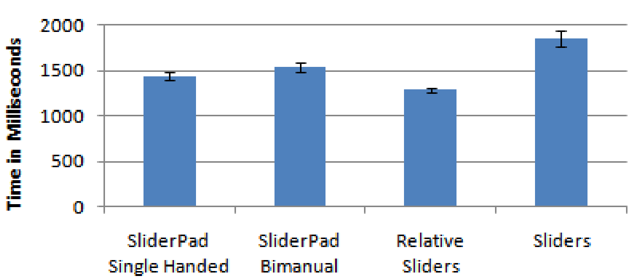

Figure 7. Time to select between parameters for each of the conditions. Bars indicate standard error.

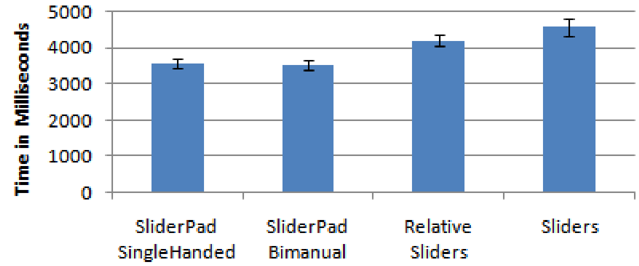

Figure 8. Time to complete the parameter adjustment for each of the conditions. Bars indicate standard error.

For our user study, we did not specify exactly how participants should place their hand and perform the task: where exactly their hand should be placed, whether their wrist or arms should be rested. They used it as they found comfortable.

While operating the relative sliders, we observed that participants rarely rested their palms on the table, as targeting different sliders required repositioning of the hand. We observed participants were quickly fatigued and tended to rest between tasks. This was not a problem with the single handed and bimanual Multi-touch SliderPad conditions, as the palm can rest on the screen without moving throughout the operation.

RELATED WORK

Our research draws from several related fields in touch interaction. Recent interest in the field has increased considerably due ubiquity of input devices, and the low cost for entry to do-it-yourself multi-touch screens. To frame our research, we consider below the breadth of research in touch interaction.

Legacy interfaces

Initial touch research focuses on overcoming the initial obstacle of precise selection. Early research by Schneiderman et al [29] raise the issue and present *take-off* as a promising technique, wherein a cursor is presented to the user with an fixed offset to their finger. Zoom-pointing [6] is developed using graphical scaling of the target area, increasing the motor control space available to the user. Albisson and Zhai [2] develop multiple techniques to improve the precision of the finger on a screen, using 2D levers, an interface that allows precise manipulation of the cursor position.

In the interest of supporting general purpose use of computer using the touch modality, researchers developed techniques to emulate the mouse, and its buttons. The fluid DTMouse [11] describes a mapping using multiple fingers to emulate mouse move while avoiding occlusion (mouse cursor is moved at the mid point of two fingers) and mouse drag (a third finger toggles drag mode). Benko et al, [7] introduce a menu for a bimanual operation that facilitates magnification, controlling speed of cursor movement (indirect manipulation of the cursor) and snapping the cursor to items. Matejka et al [24] develop a new design (SDMouse) for multi-finger chorded mouse emulation.

Direct Spatial Manipulation

Following the paradigm of direct manipulation, research on multi-touch interaction emphasizes focus on altering the spatial attributes of elements. Traditionally, the term direct manipulation was used for graphical buttons that could be clicked to perform a command. With touch, manipulation is more direct.

We use the term *direct spatial manipulation* to specifically identify techniques that alter spatial appearance of a visual. Direct spatial manipulation makes the selection of commands of rotation, translation and scaling *implicit*. These commands are selected through the use of *mappings*, a relationship between the movement of the human hand across the surface to a command or operation executed on an item on screen. The result of these manipulations is the adjustment of visual parameters of items, namely their X,Y location, their angle of orientation, and their scale.

Research has developed interaction techniques for translation of virtual items [36], using two fingers for rotation for 2D[18, 19] and 3D[15, 28]. Additional attributes of pressure for layering of multiple elements on a touch screen [10]. When multiple simultaneous activities are performed with a single movement, there is an inevitable loss of accuracy. Martinet et. al.,[23] raise issues of coordination, and find that simple techniques of differentiating actions with number of fingers helps specify intent.

Gestural Interaction

Research in human-computer interaction deals with the unambiguous understanding and processing of human intent. A goal of *natural user interface* [1, 34] is to the human to express their intent comfortably, using actions we commonly use in the world. The mappings to non-spatial operations are not self evident. Sensing technologies additionally can sense different parts of the hand that make contact with the screen, such as palms, or the side of the hand.

Wu et al [**?**], use the DiamondTouch table to explore possible mappings of the hand for activities beyond the literal. Their implementation, a photo browser application, enables annotation, wiping (erasing), cut/copy-pasting, and the expansion and collapse of piles.

Advances in hardware has allowed recognition of more qualities of touch, such as detecting the palm, side of the hand and close fist. ShadowGuides [12] introduces a new feedforward visualization that is aimed at teaching such gestures. Using play to alter the perceived cost of learning, Gesture Play [8] describes a physical simulation with springs, dials, and props to teach specific gestures to the user.

Changes to spatial attributes are a great fit for direct spatial manipulation techniques. The mappings from body movements to changes in the visual are clear and explicit. The resulting experience can be considered natural to the user.

However, the question of what mappings are obvious is not easy to answer. Although mappings can be made, there isn't a clear objective design process that allows for the development of gestural mappings to an arbitrary set of commands. What may be considered natural or intuitive for one person, may not be for another. The context of the mappings may have a similar effect, the gesture may be more natural when mapped to a different operation in a different context. This leads to an ambiguity in selecting the most obvious gesture. This subjective variance in human opinions makes designing a vocabulary of gestures for complex actions a difficult problem.

Considering that most commands lack a literal obvious real-world counterpart, their association to a hand movement is an important interaction design topic. One process of development of this mapping is described by Wobbrock, Morris and Wilson [26, 35]. They use a *participatory design* approach to elicit a gesture vocabulary from the users, without first imposing a rigid set of pre-defined gestures. We find that this approach has a demonstrable benefit to designing gesture sets, especially if the participants in the process match the intended demographic for the resultant product.

Multi-touch Menus

The cognitive overhead of memorizing a large set gestures increases. Taking a clue that signified the paradigm shift from CLIs to GUIs, this overhead can be reduced by encouraging recognition over recall: visualize possible commands in a clear and consistent manner to the human.

We call this form of command selection *explicit*. The user must be able to *navigate* to a commands from within a menu, making available commands *visible*. Traditional menus are functional, and can be operated by touch interfaces. The need new fluid multi-touch techniques for command selection is evident.

The introduction of a visualization of the menu in some form at the finger contact. We describe two categories of menus, 1) stroke-based marking menus, that may or may not have a visual representation of operations at all times, and 2) visual menus that emphasize a consistent visual representation during their operation.

Lepinski, Grossman and Fitzmaurice [21] translate work on marking menus[20] from the domain of stylus / pen based interaction to multi-touch. While regular marking menus use directional strokes for each menu level, they explore the use of hand chords for the top level menu selection. A chord is identified by a detecting which combination of fingers make contact with the screen. These techniques are aimed at facilitating a smooth learning curve for a novice user to become an expert.

However, from personal experience, attempting to quickly alter between the chords repeatedly is physically difficult, and induces undue stress in the hand. Their evaluation neglects to raise these experiential issues that are extremely relevant to their techniques adoption in the real-world.

Bailly et al [3, 4] extend the marking menus to bimanual interaction. Instead of using hand chords, they use only the number of fingers to encode the selection of the first level. The use of the second hand allows for a larger selection. For selection at the next menu level, they use two techniques, directional strokes and simple multi-finger tapping. The motivation behind this set of techniques is that with some training, a human can remember spatially, and kinaesthetically (with muscle memory) the mappings between a hand movement and a command. However, the also implement the finger count method for at-a-distance interaction.

Considering the pace of adoption of the multi-touch modality in research, it is surprising that, to our knowledge, there have only been a handful of publications that develop novel techniques for presenting visual menus to the user.

Stacked Half Pie menus [16] use a single touch to navigate a hierarchy, visualized as a semi-circle. A goal of the design is to reduce the distance that the hand must traverse to access items of the menu. Banovic et al.,[5] present a menu activated by the thumb, the menu can be accessed using the little, ring, middle or index fingers. Attribute gates [31] allow the user to set multiple attributes of an element (given a discrete set of options for each) using a single stroke with co-location tabletop collaboration as the context. In his dissertation, Malik [22] describes an exploration of single-handed multi-finger interaction. He introduces the use of natural movement of the thumb as it spans an arc to select from a discrete set of items, and also manipulate a slider over a continuous range of values.

Parameter Adjustment

Techniques for the selection and subsequent adjustment of numerical parameters have been designed for other interaction modalities. Pook et al introduce *control menus* [27] for the mouse or stylus. A radial pie menu presents available options, on moving a threshold distance away from the center selects an action, and subsequent movement of the cursor or mouse performs adjustment of that menu. In the same year Guimbretière et al., present *flow menus* [14] that allow chaining of operations by re-entering the center of the menu. A single fluid stroke of the stylus can perform several operations. Results from a laboratory study by Guimbretière et al. showed that techniques which merge selection of the command with adjustment of the parameter outperformed the other techniques [13].

FaST Sliders [25] again use marking menus for selection of parameters, but have an improved adjustment stage. The cursor is 'captured', and adjustments do not require dragging of the cursor. A mouse-click completes the adjustment. The in-context slider [32] is a mouse based technique that can be raised and adjusted without a click. Hovering over a circular affordance raises a single slider, whose value can be set with a single click.

These techniques emphasize the fluid selection and adjustment of a *single* parameter with a mouse or stylus. The parameters may be nested in a hierarchical menu. To operate on several parameters within a certain menu would require additional steps. Damaraju and Kerne[9] describe a multi-touch technique for adjusting a small set parameters without navigating a menu. They present findings on a user study to manipulate parameters of color (hue, saturation and value) using single handed multi-finger mappings. Their technique shows an improvement over a base line of traditional menu. The multi-touch technique uses number of fingers and simple finger disambiguation to allow quick repeated selection and adjustment of one of the three parameters.

DISCUSSION

Within the current state of the art in multi-touch research, we frame this research as introducing a new design space. From our results, we find that improving ergonomics and designing for expert use. Our user study shows that traditional sliders can be outperformed by a simple rectangular relative slider. The advantage of not grabbing the thumb of the slider improves selection time. However, we show that our design for parameter selection could improve over this relative slider. The index finger is consistently used for adjustment regardless of which parameter is selected.

FUTURE WORK

To understand the impact of this technique for subjective tasks, it is important to perform evaluations in context. We are working with a Digital Photography course, being taught at an undergraduate level, to conduct studies over multiple sessions to evaluate the long term affects on the ergonomics and comfort. We acknowledge that the novelty of the interaction requires a certain amount of learning, it is unclear as to exactly how long it would take. From our user studies, we found that from a 5-10 minute training phase, users were able to outperform the baseline of traditional sliders.

From preliminary pilot studies, we found that more features could complement the interaction without increasing complexity. One such feature that would immediately impact the utility over the keyboard/mouse combination is using the thumb for the Undo operation. A simple tap to undo and a swipe to re-do from the thumb will allow simple, quick adjustments. The Multi-tap Slider has been initially designed for manipulation of numerical values, however, discrete item selection can also be easily performed.

Although the technique is designed for non-spatial parameters, it could be integrated with spatial tools. For example a simple brush tool in Adobe Photoshop has associated parameters such as size, brush head, opacity, flow. These parameters could be adjusted with the hand, while the use of a single finger could use the brush itself. Alternatively, the non-dominant hand could operate the tool parameters while the dominant hand uses a stylus for operation. Other contexts such as music and video production, digital painting have similar integration of parameters that will benefit from using the Multi-tap Slider.

REFERENCES

1. Abowd, G. D., and Mynatt, E. D. Charting past, present, and future research in ubiquitous computing. *ACM Transactions on Computer-Human Interaction 7*, 1 (Mar. 2000), 29–58.
2. Albinsson, P.-A., and Zhai, S. High precision touch screen interaction. In *Proceedings of the conference on Human factors in computing systems - CHI '03*, ACM Press (New York, New York, USA, Apr. 2003), 105.

3. Bailly, G., Lecolinet, E., and Guiard, Y. Finger-count & radial-stroke shortcuts: 2 techniques for augmenting linear menus on multi-touch surfaces. In *Proceedings of the 28th international conference on Human factors in computing systems*, CHI '10, ACM (New York, NY, USA, 2010), 591–594.
4. Bailly, G., Müller, J., and Lecolinet, E. Design and evaluation of finger-count interaction: Combining multitouch gestures and menus. *International Journal of Human-Computer Studies 70*, 10 (Oct. 2012), 673–689.
5. Banovic, N., Li, F. C. Y., Dearman, D., Yatani, K., and Truong, K. N. Design of unimanual multi-finger pie menu interaction. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces - ITS '11*, ACM Press (New York, New York, USA, Nov. 2011), 120.
6. Bederson, B. B., and Hollan, J. D. Pad++. In *Proceedings of the 7th annual ACM symposium on User interface software and technology - UIST '94*, ACM Press (New York, New York, USA, Nov. 1994), 17–26.
7. Benko, H., Wilson, A. D., and Baudisch, P. Precise selection techniques for multi-touch screens. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, CHI '06, ACM (New York, NY, USA, 2006), 1263–1272.
8. Bragdon, A., Uguray, A., Wigdor, D., Anagnostopoulos, S., Zeleznik, R., and Feman, R. Gesture play. In *ACM International Conference on Interactive Tabletops and Surfaces - ITS '10*, ACM Press (New York, New York, USA, Nov. 2010), 39.
9. Damaraju, S., and Kerne, A. Comparing multi-touch interaction techniques for manipulation of an abstract parameter space. In *Proceedings of the 13th international conference on multimodal interfaces - ICMI '11*, ACM Press (New York, New York, USA, Nov. 2011), 221.
10. Davidson, P. L., and Han, J. Y. Extending 2D object arrangement with pressure-sensitive layering cues. In *Proceedings of the 21st annual ACM symposium on User interface software and technology*, UIST '08, ACM (New York, NY, USA, 2008), 87–90.
11. Esenther, A., and Ryall, K. Fluid DTMouse: better mouse support for touch-based interactions. In *Proceedings of the working conference on Advanced visual interfaces*, AVI '06, ACM (New York, NY, USA, May 2006), 112–115.
12. Freeman, D., Benko, H., Morris, M. R., and Wigdor, D. ShadowGuides: visualizations for in-situ learning of multi-touch and whole-hand gestures. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces - ITS '09*, ITS '09, ACM Press (New York, New York, USA, Nov. 2009), 165–172.
13. Guimbretière, F., Martin, A., Winograd, T., and Ere, O. I. S. G. Benefits of Merging Command Selection and Direct Manipulation. *ACM Transactions on Computer-Human Interaction 12*, 3 (Sept. 2005), 460–476.
14. Guimbretiére, F., and Winograd, T. FlowMenu: combining command, text, and data entry. In *Proceedings of the 13th annual ACM symposium on User interface software and technology*, UIST '00, ACM (New York, NY, USA, 2000), 213–216.
15. Hancock, M., Carpendale, S., and Cockburn, A. Shallow-depth 3d interaction. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07*, ACM Press (New York, New York, USA, Apr. 2007), 1147.
16. Hesselmann, T., Flöring, S., and Schmitt, M. Stacked Half-Pie menus: navigating nested menus on interactive tabletops. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ITS '09, ACM (New York, NY, USA, 2009), 173–180.
17. Jacob, R. J. K., Sibert, L. E., McFarlane, D. C., and Mullen Jr., M. P. Integrality and separability of input devices. *ACM Trans. Comput.-Hum. Interact. 1*, 1 (Mar. 1994), 3–26.
18. Kruger, R., Carpendale, S., Scott, S. D., and Greenberg, S. Roles of Orientation in Tabletop Collaboration: Comprehension, Coordination and Communication. *Computer Supported Cooperative Work (CSCW) 13*, 5-6 (Dec. 2004), 501–537.
19. Kruger, R., Carpendale, S., Scott, S. D., and Tang, A. Fluid integration of rotation and translation. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '05*, ACM Press (New York, New York, USA, Apr. 2005), 601.
20. Kurtenbach, G., and Buxton, W. The limits of expert performance using hierarchic marking menus. In *Proceedings of the INTERACT '93 and CHI '93 conference on Human factors in computing systems*, CHI '93, ACM (New York, NY, USA, 1993), 482–487.
21. Lepinski, G. J., Grossman, T., and Fitzmaurice, G. The design and evaluation of multitouch marking menus. In *Proceedings of the 28th international conference on Human factors in computing systems*, CHI '10, ACM (New York, NY, USA, 2010), 2233–2242.
22. Malik, S. *An exploration of multi-finger interaction on multi-touch surfaces*. PhD thesis, Toronto, Ont., Canada, Canada, 2007.
23. Martinet, A., Casiez, G., and Grisoni, L. The effect of DOF separation in 3D manipulation tasks with multi-touch displays. In *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology - VRST '10*, ACM Press (New York, New York, USA, Nov. 2010), 111.
24. Matejka, J., Grossman, T., Lo, J., and Fitzmaurice, G. The design and evaluation of multi-finger mouse emulation techniques. In *Proceedings of the 27th international conference on Human factors in computing systems*, CHI '09, ACM (New York, NY, USA, 2009), 1073–1082.
25. Mcguffin, M., Burtnyk, N., Kurtenbach, G., and Street, K. FaST Sliders: Integrating marking menus and the adjustment of continuous values. Graphics Interface (2002). 35–42.
26. Morris, M. R., Wobbrock, J. O., and Wilson, A. D. Understanding users' preferences for surface gestures. In *Proceedings of Graphics Interface 2010*, GI '10, Canadian Information Processing Society (Toronto, Ont., Canada, Canada, 2010), 261–268.
27. Pook, S., Lecolinet, E., Vaysseix, G., and Barillot, E. Control menus. In *CHI '00 extended abstracts on Human factors in computing systems - CHI '00*, ACM Press (New York, New York, USA, Apr. 2000), 263.
28. Reisman, J. L., Davidson, P. L., and Han, J. Y. A screen-space formulation for 2D and 3D direct manipulation. In *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, UIST '09, ACM (New York, NY, USA, 2009), 69–78.
29. Sears, A., and Shneiderman, B. High precision touchscreens: design strategies and comparisons with a mouse. *International Journal of Man-Machine Studies 34*, 4 (Apr. 1991), 593–613.
30. Shneiderman, B. Direct Manipulation: A Step Beyond Programming Languages. *Computer 16*, 8 (Aug. 1983), 57–69.
31. Sulaiman, A. N., and Olivier, P. Attribute gates. In *Proceedings of the 21st annual ACM symposium on User interface software and technology*, UIST '08, ACM (New York, NY, USA, 2008), 57–66.
32. Webb, A., and Kerne, A. The in-context slider: a fluid interface component for visualization and adjustment of values while authoring. In *Proceedings of the working conference on Advanced visual interfaces*, AVI '08, ACM (New York, NY, USA, 2008), 91–99.
33. Wigdor, D., Williams, S., Cronin, M., Levy, R., White, K., Mazeev, M., and Benko, H. Ripples: utilizing per-contact visualizations to improve user interaction with touch displays. In *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, UIST '09, ACM (New York, NY, USA, 2009), 3–12.
34. Wigdor, D., and Wixon, D. *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*. Morgan Kaufmann, 2011.
35. Wobbrock, J. O., Morris, M. R., and Wilson, A. D. User-defined gestures for surface computing. In *Proceedings of the 27th international conference on Human factors in computing systems*, CHI '09, ACM (New York, NY, USA, 2009), 1083–1092.
36. Wu, M., and Balakrishnan, R. Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In *Proceedings of the 16th annual ACM symposium on User interface software and technology*, UIST '03, ACM (New York, NY, USA, 2003), 193–202.