Kinematic Templates: Guiding Cursor Movement in End-User Drawing Tools

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Mathematics
in
Computer Science

Waterloo, Ontario, Canada, 2009

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis presents *kinematic templates*, end-user drawing tools that influence the mouse cursor's movement within specific areas of a digital canvas. Two types of kinematic templates influence the cursor's movement: passive and active templates. Passive templates modify existing movement received from a pointing device to change the cursor's speed or direction of one's stroke. Active templates add movement to the cursor without movement from the pointing device. Since templates are provided as user-specified regions, these regions can be associated with areas of detail and they can be overlapped as a means of function composition.

A kinematic template can be configured to improve upon one's freehand output without producing perfect output. Since templates do not necessarily prescribe geometric output, they constitute a visual composition aid that lies between unaided freehand drawing and drawing aids such as snapping constraints and perfect geometric primitives.

Since kinematic templates can improve upon the consistency of one's strokes, it is beneficial for drawing visual styles such as hatching (an artistic effect that adds depth to a drawing with uniform strokes drawn in close proximity) and repetitive patterns. Since kinematic templates do not prescribe a type of output, one can "fight against" a template's preferred path of movement and discover unexpected, serendipitous outcomes.

Acknowledgements

I would like to thank my supervisor Dr. Michael Terry for the inspiration, guidance, and support in this research project. This research project arose from the collaboration between my supervisor and Dr. Edward Lank and Dr. Celine Latulipe: I thank them for their time and contribution to my research. I would like to thank my thesis readers Dr. Craig Kaplan and Dr. Edward Lank for giving valuable feedback to make this thesis better.

Next, I would like to thank my colleagues in the HCI and CGL labs at the University of Waterloo. My colleagues gave me inspiration while I was working, encouraged me to work hard and steadfast, and provided a cordial place to work.

This thesis is an extension of a full paper at UIST 2008:

Richard Fung, Edward Lank, Michael Terry, and Celine Latulipe. Kinematic templates: end-user tools for content-relative cursor manipulations. In *UIST 2008: Proceedings of the Symposium on User Interface Software and Technology*, pages 47–56, New York, NY, USA, 2008. ACM.

I would like to thank my paper reviewers for their insights, which I have incorporated into my thesis; my participants for their time and commitment to testing kinematic templates; and those who encouraged me to pursue my research further.

I would like to acknowledge the Natural Sciences and Engineering Research Council of Canada (NSERC), the David R. Cheriton School of Computer Science, and the University of Waterloo for funding my research.

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Chapter 1

Introduction

Some digital drawing tools transmit freehand input without modification and other digital drawing tools (for example, shape and line tools) produce geometric output. There are cases, however, where one wants to improve upon freehand input without losing qualities of the human hand. This thesis proposes the creation of a new digital drawing aid, *kinematic templates*, to improve upon freehand strokes. Kinematic templates are software drawing tools that influence a cursor's movement by attenuating user input and adding cursor "forces" when drawing in user-defined areas of a canvas.

1.1 Motivation

Painters and illustrators naturally vary the precision with which they manipulate their tools. Fine motor control is used for detailed work while coarse motor control is used for working more broadly in a composition. When greater precision and control is needed than can be achieved using freehand techniques alone, additional instruments can be employed to scaffold movements. For example, physical tools such as rulers, compasses, and French curves can help guide movements.

Digital painters and illustrators vary their precision when drawing, but their ability to vary precision may be limited by the physical input devices that they use. They prefer to use input devices such as graphics tablets and interactive pen displays [29] (for example, Wacom tablets[1] and Tablet PCs) over computer mice, trackpads, and isometric joysticks because they have had significant motor training in handling pencils and similar drawing instruments. Tablet and pen display input devices, however, limit their range of precision to a particular tablet or screen size.

[1] `http://www.wacom.com`

To improve upon one's output precision, a number of digital drawing aids have been created for freehand drawing. Freehand tools such as the pencil and brush tools in Microsoft Paint[2] and GIMP[3] faithfully replicate freehand drawing as they transmit strokes exactly as they are received from the pointing device. Other tools provide geometric and mathematical precision to one's output. For example, vector-based illustration applications such as Adobe Illustrator[4] and Corel DRAW[5] fit mathematical curves to freehand strokes. Precise output tools such as line and shape tools, found in office productivity suites such as Microsoft Office[6] and OpenOffice,[7] produce geometric shapes without any human "sketchy" qualities in the output.

Although some tools produce highly precise output, digital artists may want to retain sketchy qualities of the human hand for aesthetic reasons, and designers may want to retain sketchy qualities of the human hand to receive feedback at the appropriate level of interpretation. To explain the latter, Schumann et al. [31] found that sketches appear hand-drawn received broad design feedback compared to CAD (computer-aided design) diagrams.

To improve upon one's freehand strokes without producing highly precise output, a number of digital drawing aids have been created; this thesis classifies them into beautification techniques and snapping constraints (and is further expanded in Chapter 3). Beautification techniques modify a stroke after it first appears, usually to produce an output that more closely resembles mathematically-defined or geometric output. For example, the freeform tool in Microsoft Visio fits a spline (a type of curve) to selected points along the user's input path and refits the spline as new input is received [6]. The degree to which the output retains qualities of the human hand depends on the beautification's algorithm, for instance, the number of control points added by Microsoft Visio's freeform tool. Alternatively, freehand variation in one's output is reduced by a snapping constraint that makes an object jump to a predefined edge or point. For example, when snapping is activated via the Shift key in Microsoft Paint, the pencil tool constrains the output stroke along predetermined angles.

As this thesis identifies in Chapter 3, freehand input can also be influenced by modifying the cursor's movement, but prior work has not applied this approach in end-user drawing tools. The cursor's movement can be modified in two ways. First, a pointing device's control-display (C-D) ratio, which maps displacement from the pointing device

[2] `http://www.microsoft.com`
[3] `http://www.gimp.org`
[4] `http://www.adobe.com/products/illustrator`
[5] `http://www.corel.com`
[6] `http://office.microsoft.com`
[7] `http://www.openoffice.org`

to the on-screen cursor [28], can be changed. Since C-D ratio modifies the amount of displacement a cursor travels when a pointing device moves, it can make the cursor travel faster or slower. Manipulations to C-D ratio have been researched for improving upon pointing tasks as Balakrishnan [4] and Casiez et al. [13] have surveyed. Second, movement can be added to the cursor independent of user input. Cursor "forces" pull the cursor towards a certain point or place without any user input in that direction [39, 41], which was investigated for target acquisition in menus [1] and user interface widgets [23].

In addition to improving upon pointing tasks, the snap-and-go technique [5] modifies C-D ratio for a visual alignment task. To help select an alignment edge, the snap-and-go technique increases C-D ratio to slow the cursor. It improves upon a regular snapping constraint because a user can still select the areas around an alignment edge. It improves upon freehand movement without producing a precise output. The snap-and-go technique shows how to improve upon freehand output, but it has not been demonstrated in a drawing task.

1.2 Thesis Statement

This thesis introduces *kinematic templates*, end-user drawing tools that alter one's freehand precision by influencing the cursor's movement. Cursor movement can be influenced in both a passive and active manner. *Passive templates* modify displacement received from the pointing device when positioning the on-screen cursor. For example, a user can add a Slow-Down template in areas where fine motor movement is required. *Active templates* add movement to the cursor independent of movement from the pointing device. For instance, an active Orbit template pulls the cursor concentrically about a point when the stylus has contact or a mouse button is pressed. Kinematic templates can guide movement along a prescribed path, attenuate "jitter" (unwanted sideways displacement) in one's movement, change the cursor's speed, and add movement to the cursor.

Kinematic templates are specified in user-definable regions of a drawing. These regions serve as virtual "motor" templates on the canvas that influence cursor movement. Since multiple kinematic template regions can be defined in a composition, they can be layered as a means of function composition.

A kinematic template can vary its influence on freehand input, which allows a template to behave as a soft constraint. For example, a Hatching template guides movement along an axis by attenuating movement along its orthogonal axis. The amount of attenuation along the orthogonal axis can be customized to preserve qualities of the human hand. As a result, movement is guided but not constrained along an axis. This allows kinematic templates to explore a level of refinement to one's output between freehand and highly precise output.

1.3 Contributions

From the design, implementation, and evaluation of kinematic templates, my thesis makes the following contributions:

- I present kinematic templates, end-user drawing tools that influence a cursor's movement. Two major categories of templates are provided to influence cursor movement: passive and active templates. Passive templates guide cursor movement along a path or change the sensitivity of a user's input. Active templates add movement to the cursor independent of movement from the pointing device.

- Kinematic templates are designed to support a continuum of output refinement between unaided and precise output. A number of kinematic template functions improve upon one's output by changing the cursor's speed and guiding cursor movement to specified points and paths. Template functions can be configured to preserve qualities of the human hand.

- Kinematic templates are provided in user-definable regions of a drawing. Since they serve to filter one's input, they can be added and removed without affecting a drawing's prior content. Many functions can be created by overlapping and layering multiple kinematic templates.

- From an initial evaluation of kinematic templates, passive templates allow an artist to be less careful with his or her input and achieve a fairly precise output, which is beneficial when drawing visual styles such as hatching (strokes are placed close together as a means of adding depth to a drawing).

- Although kinematic templates were designed to improve upon one's output, passive templates can also introduce unpredictability. When a user intentionally draws against a template's preferred path of movement (for example, going vertically in a template that guides movement horizontally), small unwanted movements in one's input are extended over a larger distance, thus amplifying variations in one's output. In an evaluation, participants described this as "fighting against" a template.

1.4 Organizational Overview

The remainder of the thesis is organized as follows. Chapter 2 begins with an observation of two working artists. Their use of physical and digital media motivates the design of new digital drawing tools. This thesis focuses specifically on an artist's ability to vary his or her output precision.

Chapter 3 surveys existing digital drawing tools that support varying levels of output precision. There is an opportunity to create a new digital drawing aid that guides cursor movement while drawing, which is accomplished by modifying motor space (that is, the physical space where mouse or stylus movements take place). Prior work in modifying motor space, however, focuses on facilitating pointing tasks. This chapter identifies an opportunity to create a digital drawing aid that explores the continuum of output precision.

Chapter 4 introduces kinematic templates, end-user tools that define cursor manipulation functions within user-specified regions of a canvas. The implementation details of passive and active cursor manipulation functions are presented with example functions. This chapter then describes the user interface that provides cursor manipulation functions as end-user drawing tools.

Chapter 5 evaluates kinematic templates with artistically-talented individuals. Participants were invited to draw compositions using kinematic templates over multiple sessions. This chapter presents the drawings that they produced and describes how participants benefited from using kinematic templates. This chapter also identifies some lessons learned from alternative user interface designs, for instance, when naming templates and tuning an active template's speed.

Chapter 6 concludes this thesis by summarizing the key contributions and identifies areas for further investigation.

Chapter 2

Observation of Artists

This research began by observing two practicing artists working on both physical and digital compositions. These observations were conducted to understand the uses of existing physical and digital drawing tools and to identify areas where digital drawing tools can improve upon freehand drawing. This chapter begins with the observations of two working artists followed by insights into the design of a digital drawing aid that varies precision.

2.1 Observations

Two artists were recruited to demonstrate their work practices in physical and digital compositions. These half-hour on-site interviews were recorded by a collaborating researcher [19]. The first artist worked on a vertical wall-sized charcoal composition. The second artist edited a photograph in Adobe Photoshop and demonstrated drawing with an ink bottle. As part of the interview, both artists talked about their experiences with digital drawing tools.

2.1.1 Attention to Areas of Detail

The first artist worked on a wall-sized charcoal composition, which had already taken form when the interview started. The artist used three tools: charcoal, to add dark tones to the drawing; a chamois (soft cloth), to smudge the charcoal lines and create midtone values; and an eraser, to add highlight tones in the composition.

When working on the composition, it became evident when the artist was working in areas of detail (Figure 2.1). Most of the time, her attention was focused on a partic-

Figure 2.1: An artist drawing with one hand and holding a tool in her other hand.

ular area of the drawing. Her hand and arm movements were slow and refined to avoid changing the surrounding areas. For instance, her elbows were relatively stationary when adding a charcoal line or smudging the charcoal with a chamois. Even though she held different tools in each hand, she worked with only one tool at a time to stay focused in one area. Occasionally, she used both hands together in the same area of detail, for instance, when shading in the background of the charcoal composition (Figure 2.2).

The second artist demonstrated edits to a digital photograph in Adobe Photoshop (Figure 2.3), which she scanned before the interview started. Like the first artist, she demonstrated that some areas of a composition required attention and detail. For instance, when working in areas of high contrast, she exhibited refined hand movements to use the smudge and blur tools.

2.1.2 Intentional Imprecision

Although both artists worked in areas of detail, they were not producing precise output all the time. As an example, both artists used the motor skills of their non-dominant hands to introduce imprecision. Although the first artist could not draw accurately with her left hand (she alluded to this when she said, “I could not do a controlled drawing with my left hand at all”), she did so anyway because “it gives a different line quality.” The second artist intentionally drew with her non-dominant (right) hand when using a graphics tablet because “it lets me be a little freer to come up with something interesting.” When drawing with an ink bottle, she added small tremors to her hand movements to produce “scratchy” lines. Both artists were intentionally introducing imprecision into their strokes.

Figure 2.2: An artist drawing with both hands.

2.1.3 Randomness Added by Physical Media and Tools

There was an element of randomness added when using physical tools. For the case of the ink bottle used by the second artist, many variables affect the output stroke such as an ink's shelf life, the time it takes to smudge the ink, the amount of ink added, and the time taken for the ink to dry. These variables add to the randomness when using the tool, which makes it difficult to reproduce the same output multiple times.

The randomness introduced by the ink allowed the second artist to find a desirable output. For example, the second artist liked brushing and smudging freshly-added ink because she did not have to conceive of where the ink would spread. She compared the experience to using Adobe Photoshop, saying that it could be possible to replicate the same output, but she did not imagine where the fill region should go. That is, she leveraged the properties of the ink, brush, and paper to help define the appearance of the output stroke.

In addition to the ink properties, the ink bottle had extension ink tips to make it longer. The second artist held the ink bottle at the opposite end of the ink tip in order to amplify small variations over the length of the bottle. (The artist could hold the bottle as close as possible to the ink tip if she wanted to be more precise in her movements.)

Digital drawing tools, in contrast, operate without the randomness introduced by physical drawing tools. Digital hand tools such as the blur and smudge tools behave consistently with a given input. As the first artist commented, "That's the hard thing working digitally: I always find that there's no accidents."

2.1.4 Looking for Serendipity

Both artists valued imprecision being introduced into a composition because it could lead to serendipity, as the first artist explained:

> "Any time you are making any piece, you have problems as you are working on it, then you have to figure out how to solve it visually. And to have these problems or accidents are the best things because you'll discover things that you wouldn't be able to make your own brain do."

The first and second artist were adding serendipity when using their non-dominant hands or through the use of tools. When drawing with their non-dominant hands, both artists had less control in their movements, which could lead to accidents and unintentional visual outcomes. The ink bottle's design and ink attributes introduced an element of randomness and, ideally, a serendipitous outcome for the second artist.

2.1.5 Varying Precision in an Input Device

A challenge emerged when working in digital media, which was caused by the size of the input device. The graphics tablet limited the second artist's range of movement to lower arm and hand movements. In contrast, the first artist could make her canvas any size that she wanted such as a wall-sized canvas for her charcoal composition. She could then use her arms, elbows, and standing position to vary her input precision.

Although one's range of movement cannot be changed by the physical limitations of the input device, it is possible to change how movements are mapped from the input device to the digital canvas. For instance, existing drawing software provides a zoom factor when working in a digital composition. It gives an opportunity for the artist to vary his or her hand resolution with respect to drawing content. That is, an artist does not have to be as precise with his or her hand movements when zoomed in. When zooming in, however, fewer areas of the composition are visible.

Although the merits of zooming are evident, the second artist did not change the zoom factor except to have the whole composition fill the screen. She did not zoom into areas of detail because she preferred to see the composition in its entirety. As a result, the artist limited her range of movement to a specific tablet-to-content ratio (or more generally, a control-display ratio as Chapter 3 explains). It may be useful for a digital drawing tool to vary the tablet-to-content ratio when working in different areas of a composition.

Figure 2.3: A digital artist using an external Wacom graphics tablet. The graphics tablet is about the same width as the laptop. Since the artist is left-handed, the graphics tablet is placed slightly left of the computer, which allows her right hand to reach the keyboard.

2.2 Design Insights

The observations presented in this chapter can be used to inform the design of a digital drawing tool:

- Software systems could be designed to predict where detailed areas exist on a composition. In these areas of detail, one's output precision can be varied. For example, one's movements can be slowed down when working in areas that require attention to detail.
- Absolute precision is not always sought. Software drawing tools should allow an artist to target varying levels of output precision, which allows an artist to preserve qualities of the human hand.
- Artists are open to tools that do not behave consistently, which may help explore alternative visual outcomes and introduce serendipity into one's composition.

To vary one's output precision, this chapter identifies that a tablet-to-content ratio can be manipulated by changing a canvas's zoom factor. To extend this notion, a graphics tablet's physical motor space, which is the physical space where a pointing device moves [10], can be dynamically reassigned after a stylus has contact, for instance, to slow down movements within areas of detail. An area that requires fine motor movement can be enlarged in motor space without changing its size on the display. This has the advantage over zooming because every part of the drawing can remain visible.

2.3 Summary

This research identified themes from the observations of two working artists. First, predictable areas of the composition emerged that required fine motor movement for doing detailed work. In areas that did not require attention to detail, an artist's movements were fast and less precise. The ability to vary precision was done solely by an artist's hand and arm movements. Second, in these areas of detail, both artists would sometimes introduce imprecision by drawing with their non-dominant hand or through the use of tools. Third, artists desired imprecision in their drawing because it added serendipity to the composition. In contrast, digital drawing aids were perceived to behave consistently. These findings suggest that digital drawing tools should be able to vary their precision within a continuum between rough and precise output, which was partly addressed by zooming in a digital composition.

Chapter 3

Related Work

From the observations in Chapter 2, artists may want to their drawing precision while preserving qualities of freehand drawing. This chapter surveys digital drawing tools and techniques that modify one's output precision. Existing digital drawing aids restrict one's output to specific locations and/or modify freehand strokes as a post-processing step. Since artists may want to preserve nuances of the human hand in a digital drawing tool, there is an opportunity to create a digital drawing tool to improve upon one's freehand output in real-time while maintaining "sketchy" qualities.

To vary one's output precision in real-time, this chapter surveys techniques that influence cursor movement. Two major approaches are used to influence cursor movement. First, movement can be influenced by modifying existing user input as it is transmitted from the pointing device to the on-screen cursor. Second, movement can be influenced by adding a displacement to the cursor regardless of input received from the pointing device. This chapter identifies that these two approaches have potential to improve upon freehand output while retaining qualities of the human hand.

3.1 Digital Drawing Aids

Many software drawing applications are available to digital artists. Painting applications are provided from the open-source community with GIMP[1] and from commercial developers such as Adobe Photoshop[2] and Corel Painter.[3] Illustrators may prefer using

[1]GNU Image Manipulation program: `http://www.gimp.org`

[2]`http://www.adobe.com`

[3]`http://www.corel.com`

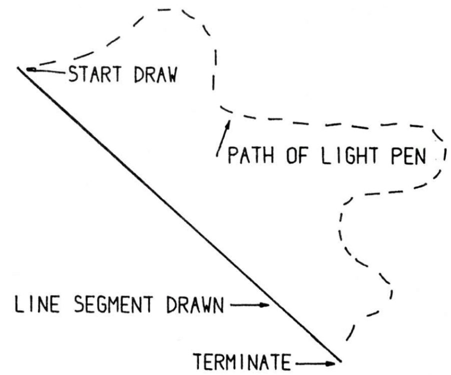

Figure 3.1: Using a line tool, two ends of a line segment are dragged. The stroke path is irrelevant to the drawn line. Image from Ivan Sutherland [36].

vector illustration software such as Inkscape[4] in the open-source community or Adobe Illustrator and CorelDRAW in commercial software. Beyond applications dedicated to painting and illustration, office productivity suites such as Microsoft Office[5] (e.g. Visio) and OpenOffice[6] (e.g. Draw) provide basic drawing capabilities.[7] Operating systems may provide drawing applications with a limited feature set such as Paint in Microsoft Windows.

Software drawing applications provide a number of digital drawing aids, which occupy a continuum of output precision between unaided and precise output. To exemplify this continuum, consider the basic drawing application in Microsoft Windows. Microsoft Paint has hand tools such as the pencil and brush tools, metaphors of their physical drawing equivalents, that draw strokes as they are received from the pointing device. (The difference in input quality, though, is affected by physical limitations of the pointing device.) On the other end, Microsoft Paint has shape and line tools that produce perfect output, which only depends on the start and endpoints. All the movement in between is disregarded in the final output (Figure 3.1).

When drawing strokes with a software drawing tool, some digital drawing aids can improve upon freehand drawing. This thesis classifies these digital drawing aids into two categories, snapping constraints and stroke beautification. Snapping constraints modify freehand strokes while drawing whereas stroke beautification has a visible delay in seeing the final output.

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[4]Inkscape, an open-source vector graphics editor, `http://inkscape.org`, has a feature set similar to Illustrator and CorelDRAW.

[5]`http://office.microsoft.com`

[6]`http://openoffice.org`

[7]Office productivity suites provide tools for word processing, spreadsheets, presentations, and graphics.

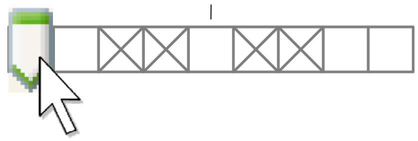


Figure 3.2: Snapping in a horizontal slider. In this example, the two pixels to either side of the snap location cannot be selected.

3.1.1 Snapping Constraints

A snapping constraint limits the possible output locations when drawing a stroke. The position of a stroke or object is defined by the software, for example, along predetermined points, paths, objects, and angles in 2D [8] and 3D [7]. The final output from snapping is visible immediately while drawing.

Since a snapping constraint prevents drawing in an immediate area around the snap edge or point (Figure 3.2), it removes freehand variation in one's output. When a snapping constraint follows evenly spaced grid points, the output stroke cannot be added in between the grid points (for example, in Adobe Illustrator). When a snapping constraint guides output along specific angles (for example, when holding the Shift key and adding a line in Microsoft Paint) or with a ruler added to the canvas [35], the stroke travels along a straight line regardless of where the cursor moves: only the stroke's start and endpoints are specifiable by the user. Snapping movement along a line is extended to drawing perfect arcs [35] and French curves segments [32].

A snapping constraint is beneficial because it reduces unwanted variation in one's stroke. For instance, a snapping constraint allows multiple strokes to appear aligned to each other. Artists, however, may desire small variances off of the snap edge or point in visual compositions. Since a snapping constraint does not allow small variations off of a snap edge or point, it does not satisfy an artist's need in this case.

3.1.2 Stroke Beautification

Stroke beautification techniques modify a freehand stroke as a post-processing step. They do not constrain the placement of freehand strokes during input, but the stroke's appearance can change after a short delay or once it is completed. As an example in Microsoft Visio, the stroke output is fitted to different control points (selected points along the input path) joined by splines and arcs as new input is received [6].

Figure 3.3: A beautification technique morphs a freehand stroke to a straight line, circle, and finally a box. The user sees the output stroke change as new input is received from the pointing device. Image from Arvo and Novins [3].

Current stroke beautification algorithms reduce freehand variation in one's output to produce a particular style of refined output. Strokes may be shifted and scaled to ensure alignment and uniformity in size [46]. The fluid sketching technique morphs a freehand stroke to known geometric shapes [3] (Figure 3.3). In interactive beautification, freehand strokes are replaced with geometric primitives that satisfy geometric properties [24]. When using stroke beautification techniques, artists may find it difficult to draw when their strokes change appearance while drawing.

Rather than changing the appearance of a stroke afterwards, a drawing "nib" may trail the cursor's current position [21, 40]. The nib provides a visual indication that the cursor's location is not directly related to the stroke's output and that a stroke beautification algorithm is in effect. In this case, artists have to form a mental model to understand the effect of the algorithm.

3.1.3 A Non-Constraining Real-Time Drawing Aid

The real-time feedback provided by a snapping constraint allows an artist to see his or her modified output immediately without any delay. Stroke beautification techniques allow one to draw anywhere on a canvas. None of the surveyed digital drawing tools, however, provide real-time output without constraining one's output locations in a single drawing tool. It may be useful to combine these attributes in a single digital drawing aid.

As this section described earlier, these existing digital drawing aids occupy a continuum of output precision between freehand and precise output. The design of snapping constraints, by definition, removes selectable areas of a drawing; thus, it improves upon one's output precision by removing variations in one's output. The design of stroke beautification algorithms also removes variability in one's output strokes, for example, by removing points along a freehand path and replacing them with mathematically-fit curves. A new digital drawing aid can be created to selectively target varying levels of output precision without losing qualities of the human hand, which these existing digital drawing aids have not considered.

3.2 Influencing Cursor Movement

Although digital drawing aids have not considered real-time improvements to freehand drawing, one's freehand input can be improved upon by influencing the cursor's movement. One approach is to modify input received from the pointing device via a control-display (C-D) ratio. A control-display ratio maps displacement from the pointing device in the physical world to displacements of an on-screen cursor [28]. Another approach, which is independent of user input, is to add movement to the cursor regardless of movement received from the pointing device.

Real-time influences to a cursor's movement may be beneficial for a number of reasons. The user will see the influence on the cursor's movement immediately while drawing a stroke. There is a tight feedback loop between moving the pointing device and the corresponding cursor's location. In regards to the stroke's appearance, it will not change appearance unlike stroke beautification techniques. There will be no discrepancy between the cursor and stroke's position (however, there could be a discrepancy between the cursor and an interactive pen display that projects the display).

Despite these potential benefits for influencing cursor movement in drawing, prior work has focused on influencing cursor movement in non-drawing tasks. This section surveys techniques that manipulate control-display ratio and introduce cursor forces. They are investigated mainly for pointing tasks and pseudo-haptic (simulated force feedback) response.

3.2.1 Manipulating Control-Display Ratio

Prior work investigated influencing cursor movement by manipulating a pointing device's control-display ratio. This thesis classifies these applications as pointing tasks, pseudo-haptics, and visual alignment tasks. Of all the techniques, the latter application is most relevant to creating a digital drawing aid.

Pointing Tasks

Previous work in manipulating C-D ratio focuses on facilitating pointing tasks. Since one's precision is limited by the size and resolution of the pointing device, researchers

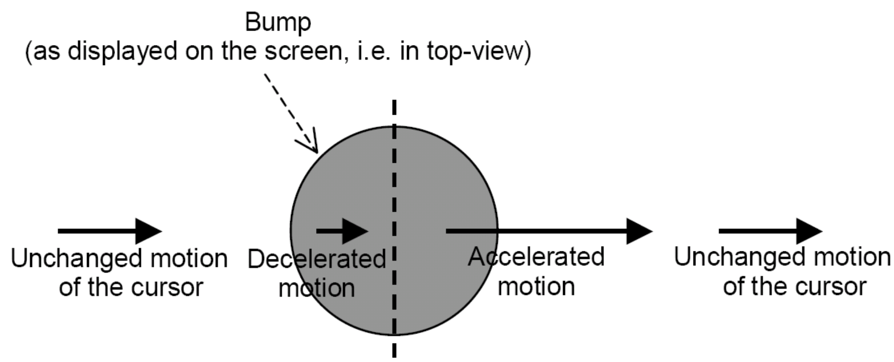


Figure 3.4: The cursor's speed changes based on its position within a virtual "hill" texture. Image from Lecuyer et al. [27].

have sought ways to reduce one's difficulty in selecting a target. Card et al. [11] suggest that targeting tasks can be modelled after Fitts's Law, which describes how a target that is larger or closer is less difficult to select than one that is smaller or further away [17]. Rather than change the size of a target on the display, many techniques manipulate C-D ratio to change a target's size in a pointing device's motor space (that is, the physical space in which a pointing device moves), which is surveyed by Balakrishnan [4] and Casiez et al. [13].

A number of techniques manipulate C-D ratio based on a user's input. Modern operating systems change C-D ratio as a function of one's speed on the pointing device [4]. When the pointing device is moved slowly, C-D ratio is increased so that one's free-hand input can be less precise while maintaining precise cursor movement. Alternatively, Wobbrock et al. [42] suggest using the angle of angular deviation off of a user's general direction of movement to determine when to increase C-D ratio. Instead of examining a user's input motion, a user can explicitly indicate when to slow down the cursor by pressing a modifier key [33]. These techniques do not consider that certain areas require more precision in movement than other areas.

Other work in changing C-D ratio suggests that user interface widgets can be associated with different sizes in motor space. In semantic pointing, Blanch et al. [10] suggest that a widget's motor space size can vary depending on its semantic importance. Worden et al. [43] suggest making a target larger in motor space to help users with motor limitations select a target. Cockburn and Firth [14] suggest enlarging a small target's size in motor space to make it easier to select. Some techniques even remove the motor space surrounding user interface widgets. Upon leaving a target, the object pointing technique [20] makes the cursor enter to another target without having to traverse the space between targets. A similar approach is applied to select an open sub-menu [2]. The goal of

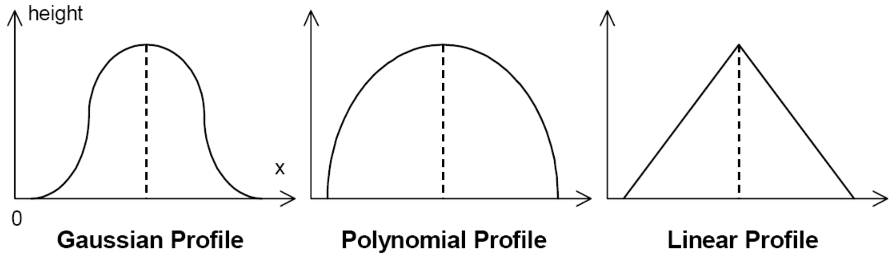


Figure 3.5: Different gradient functions for increasing (or decreasing) the cursor's speed. Image from Lecuyer et al. [27].

these techniques is only to stop the cursor on the target and do not consider the path of movement towards the target.

Pseudo-Haptics

Pesudo-haptic research considers varying C-D ratio depending on the direction of movement. Lecuyer et al. [27] investigate virtual "hole" and "hill" regions on the display, which models the display as if it were a terrain with varying elevation. For a hill texture, the C-D ratio gradually increases when moving towards the region's centre (Figure 3.4). A pseudo-haptic assessment tests how accurately a user can identify different gradient functions (Figure 3.5). A user identifies a gradient change in C-D ratio by moving the pointing device and observing the cursor's corresponding movement. This technique demonstrates that it is possible to simulate physical textures by altering the cursor's movement without physical force feedback, but it does not show how it could be used to improve existing user interface interaction techniques.

Visual Alignment Task

In supporting a visual alignment task, the snap-and-go technique [5] modifies C-D ratio independently on the X and Y axes. As an example in 1D, consider a horizontal slider with a snap location (Figure 3.6). The cursor's X-axis displacement is slowed when crossing over the snap location, which is accomplished by increasing the C-D ratio on the X axis. (The C-D ratio remains unchanged on the Y axis.) It makes it more likely for the user to stop on the snap location, which is enlarged in motor space, while still allowing one to select surrounding areas. The technique also suggests a tall and narrow "bar" widget that slows movement along the X axis in order to guide movement vertically. The technique is better than existing snapping constraints because a user can ignore the

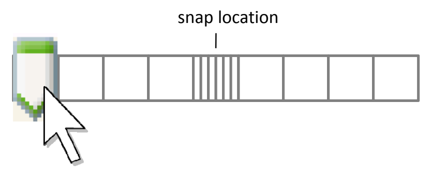


Figure 3.6: Guiding movement in software via motor space. The control-display ratio is increased horizontally at the snap location (boxes represent enlargements in motor space) for a slider in the snap-and-go technique [5].

alignment guide without having to switch modes. This work, however, does not make use of the cursor's path of movement in the final output.

3.2.2 Cursor Forces

As an alternative to modifying existing user input, movement can be added to the cursor without a corresponding movement from the pointing device. They are investigated in both pointing tasks and pseudo-haptics.

Pointing Tasks

Movement is added to the cursor to decrease the distance to acquire a target, which makes a target less difficult to select according to Fitts's Law (a target that is larger or *closer* is less difficult to select). Prior work refers to added cursor movement as "forces" acting on the cursor. Force fields have been added to pull a cursor to an open sub-menu [1] (Figure 3.7(a)). With magnetic mouse dust [23], frequently clicked points on the user interface exhibit a force as if the mouse and clicked points are point charges (Figure 3.7(b)). When working with a trackpad, Yun and Lee [45] suggest adding inertia to the cursor such that after one's finger is released, the cursor continues to travel for some distance in the same direction. These techniques alter the cursor's path to reduce the distance travelled from a pointing device, but they do not use the cursor's path.

Pseudo-Haptics

Pseudo-haptic research also investigates using cursor forces. Simulated force feedback is provided by adding movement to a cursor over particular areas of the display. The Active Cursor system [39] provides user interface elements with metaphors of physical phenomena. For instance, a widget that looks like an oscillating fan spins the cursor

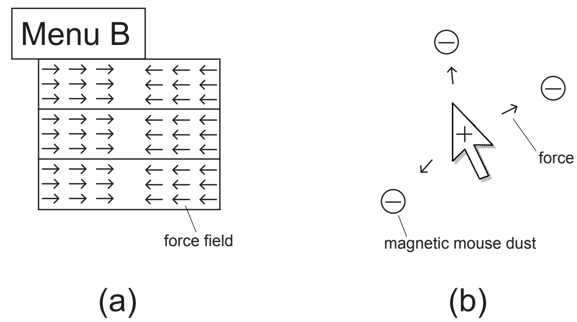


Figure 3.7: Cursor forces are added to (a) an open sub-menu and (b) frequently clicked points in a window.

around. A widget that looks like sand adds random displacement to the cursor's movement. Watanabe and Yasumura [41] suggest adding random displacements to the cursor to experience roughness and resistance when hovering over textures on the display. Although both techniques consider the user's response to these textures, they do not provide these areas as end-user tools nor demonstrate how they improve upon existing interaction techniques.

3.3 Design Insights

The goal of this work is to create a new digital drawing tool that scaffolds an artist's ability to vary his or her output precision. Influencing the cursor's movement is identified as one such avenue for exploration, but how the cursor should be influenced remains an open question.

The design of possible cursor-influencing functions emerges from prior work in manipulating C-D ratio. First, C-D ratio can be changed depending on the user's input or specific to particular regions of the display. Since Chapter 2 identified that artists work in areas of detail, a new digital drawing aid should modify C-D ratio within specific regions of a drawing canvas. More importantly, manipulating C-D ratio can guide movement based upon the direction of movement from a pointing device as suggested in pseudo-haptic research and the snap-and-go technique. The snap-and-go technique [5] provides a specific case where the cursor's movement is guided along an axis, which improves upon one's output precision.

Cursor-influencing functions may also add "forces" to the cursor. Prior research demonstrated adding movement to the cursor for facilitating pointing tasks and to explore pseudo-haptic response. This work, however, has not demonstrated the applicability of cursor forces for a drawing task.

The merit of cursor forces is demonstrated outside of pointing tasks and pseudo-haptics. The Magnetic Curves [44] system, a rendering technique, adds magnetic particles to a canvas. The trajectory of a magnetic particle is then altered by a "magnetic field," which can generate aesthetically-pleasing curves. If the cursor were a magnetic particle, its path could also be altered to help draw curves. The current Magnetic Curves system, however, does not allow a user to interact with a magnetic particle after it is released. Thus, cursor forces may produce a precise output that can be altered by the user, but it has not been provided as an end-user drawing tool.

Although cursor-influencing techniques have not been demonstrated in end-user drawing tools, they deserve exploration in a digital drawing aid. The ideas for further exploration are summarized below:

- C-D ratio, the mapping of displacement on the pointing device from the physical world to on-screen cursor [28], can be increased and decreased to vary a cursor's speed within specific areas of a drawing.
- C-D ratio can be defined *separately* for two orthogonal axes [10], which can guide movement along an axis. For example, movement can be guided along the horizontal axis by attenuating displacements along the vertical axis.
- When the user does not move the pointing device, the cursor's movement can still be influenced. Movement is added to the cursor, referred to as cursor "forces" [1, 23], that guides the cursor towards a point, along a line, or in a specific direction.

3.4 Summary

This chapter identified that a new digital drawing aid can be created to explore the space between freehand and highly precise output. In addition to snapping constraints and stroke beautification techniques, it may be useful to have a non-constraining real-time drawing aid. Influencing the cursor's movement is identified as a potential solution, but prior work focused on facilitating pointing tasks, investigating pseudo-haptic response, and supporting a visual alignment task. The insights from prior work lead to many possibilities for influencing cursor movement in end-user drawing tools. An open opportunity exists in determining what cursor-influencing functions should be provided and how they should be provided as end-user drawing tools.

Chapter 4

Implementation

This chapter introduces kinematic templates, end-user drawing tools that influence the cursor's movement in order to change one's output precision. There are two types of kinematic templates: passive and active templates. Passive templates alter input received from the pointing device in order to change the cursor's speed or guide the cursor along particular paths. For example, a passive Slow-Down template slows cursor movement. Active templates add movement to the cursor independent of user movement. For example, an active Orbit template makes the cursor travel concentrically about a point by simply tapping down with a stylus. One's output precision is determined from the type of kinematic template selected and from customizing a template's parameters.

This chapter begins with the implementation details of cursor manipulation functions. This chapter then discusses how templates are added in user-defined regions of a canvas, how templates can be customized, and how multiple templates can be composed together.

4.1 Influencing Cursor Movement

At the fundamental level, kinematic templates are cursor manipulation functions that influence cursor movement within user-specified areas of a canvas. These cursor manipulation functions receive displacement from a pointing device to position the on-screen cursor.

This section describes a subset of possible cursor manipulations: passive and active templates. Although other templates can be created with a formal definition of a cursor manipulation function (Appendix B), this section presents an equation that explains half of the implemented templates.

Passive templates are functions that alter existing displacement from the pointing device when positioning the on-screen cursor. When the user moves the pointing device, the cursor travels in a path that may be different from a user's expectation.

Active templates are functions that add displacement to the cursor's location. They can be conceptualized as "forces" acting on the cursor. Under the influence of an active template, the user can still move the cursor.

A kinematic template takes effect when drawing (that is, the mouse button is pressed or the tablet stylus has contact) in a template's region. At a timer event, the cursor manipulation function receives a pointing device's displacement (change in position) between the last and current timer event. The cursor manipulation function then computes the displacement of the on-screen cursor.

Let the change in position from the pointing device be a vector $[\Delta m_{x_1}\ \Delta m_{x_2}]^T$ (column vectors in matrix notation) where x_1 and x_2 are axes in a 2-D coordinate system.[1] The cursor's displacement vector is computed by scaling or adding displacement as shown below:

$$\begin{bmatrix} \Delta m'_{x_1} \\ \Delta m'_{x_2} \end{bmatrix} = \begin{bmatrix} s_{x_1} \cdot \Delta m_{x_1} \\ s_{x_2} \cdot \Delta m_{x_2} \end{bmatrix} + \begin{bmatrix} v_{x_1} \\ v_{x_2} \end{bmatrix} \tag{4.1}$$

where the pointing device's change in position Δm_{x_1} and Δm_{x_2} is inputted to the equation and the cursor's displacement vector $[\Delta m'_{x_1}\ \Delta m'_{x_2}]^T$ is computed.

A passive template is created from this equation with *scaling* factors s_{x_1} and s_{x_2} and an active template is created with *additive* factors v_{x_1} and v_{x_2}. If no templates are in effect, $s_{x_1} = s_{x_2} = 1$ and $v_{x_1} = v_{x_2} = 0$. Passive and active templates are not defined concurrently. If this equation defines a passive template, the additive factors are 0. Likewise, if this equation defines an active template, the scaling factors are 1.

In passive templates, scaling factors greater than 1 increase the speed of the cursor's movement. Similarly, scaling factors less than 1 decrease the speed of the cursor's movement. To guide the cursor's movement along an axis, circle, or to a point, the scaling factors are set to constant values in Cartesian and polar coordinate systems as shown in Table 4.1. For a Cartesian coordinate system, $(x_1, x_2) \to (x, y)$. For a polar coordinate system, $(x_1, x_2) \to (r, \theta)$.

The scaling factors along the preferred path of movement (along an axis, a circle, to a point, or along a curve) can be generalized as $s_{\parallel}$ tangent to the path and $s_{\perp}$ orthogonal to the path. For example, in a Cartesian coordinate system, the Hatching template

[1] The transpose function $[M]^T$ switches rows and columns.

Name	Parameters	Effect of Parameters
Passive: guides movement		
Hatching	$s_x = 1, s_y = 0.2$	Attenuates changes in vertical displacement
Grid[1]	$s_x = 1, s_y = 0.2$ or $s_x = 0.2, s_y = 1$	Displacement is partly attenuated on the vertical or horizontal axis depending on the direction of a user's input
Compass	$s_r = 0.2, s_\theta = 1$	Attenuates changes in radius about a point
Radial	$s_r = 1, s_\theta = 0.2$	Attenuates changes in angle about a point
Passive: guides movement along a user-provided path		
Tunnel Line[1]	$s_\parallel = 1, s_\perp = 0.2$	Displacement off of a pre-defined path is partly attenuated
Steady Hand[1]	$s_\parallel = 1$ or 0.2, $s_\perp = 0.2$	Helps to draw curves by predicting the user's preferred path of the stroke
Passive: modifies cursor speed		
Maximum Speed[1]	$s_{x1} = s_{x2} \leq 1$	Imposes an upper bound on the cursor's speed
Minimum Speed[1]	$s_{x1} = s_{x2} \geq 1$	Imposes a lower bound on the cursor's speed
Speed Up	$s_{x1} = s_{x2} = 1.8$	Amplifies displacement from the pointing device
Slow Down	$s_{x1} = s_{x2} = 0.2$	Attenuates displacement
One Way[1]	$s_{x1} = 0.2$ or 1	Slows the cursor when moving left, but allows the cursor to travel right at regular speed
Active: adds movement to the cursor		
Conveyor Belt	$v_x \neq 0$	Introduces displacement parallel to an axis
Orbit	$v_\theta \neq 0$	Introduces concentric displacement about a point
Point Magnet	$v_r \neq 0$	Introduces displacement to and from a point
Magnetic Line	$v_{r\_sum} \neq 0$	Introduces displacement to/from the centre of the path (every point along the path is like a Point Magnet template)
Active: adds movement to the cursor using a history of one's input		
Inertia[1]	v_{x1} α previous Δm_{x1} v_{x2} α previous Δm_{x2}	Introduces displacement in the same direction as previous input from the pointing device

[1] These templates are further explained in Appendix B.

Table 4.1: Passive and active templates created from Equation 4.1. (Passive template scaling factors 0.2 and 1.8 are sample values.)

guides movement along the horizontal axis, its preferred path of movement, by setting $s_x = s_{\|} = 1$ and $s_y = s_{\perp} = 0.2$. If the user was moving the pointing device at 45 degrees to the horizontal axis, the resulting output would be a line moving at 11 degrees to the horizontal axis. The $s_{\|}$ and $s_{\perp}$ notation is useful for describing the Steady Hand and Tunnel Line templates where the preferred path of movement changes as a function of the user's input or cursor location, respectively. The user's input includes the velocity and direction of movement from the pointing device as well as a history of previous input.

In active templates, the additive factors are non-zero to add movement to the cursor. The additive factors work in Cartesian and polar coordinate systems to make the cursor travel in a straight line, in a circle, and to a point (Table 4.1). To maintain a constant velocity, the additive factors are dependent on the timer's period (duration between timer events).

In general, the scaling and additive factors can vary based on the user's input and cursor position. For example, the Inertia template adds previous displacement from the pointing device to v_{x_1} and v_{x_2}. These templates are described in Appendix B.

4.1.1 System Implementation

To provide cursor manipulation functions at the application layer, the system cursor is hidden and an application-rendered cursor is shown using the .NET Framework user interface toolkit [16]. Since only the displacement of the cursor is needed, it should be repositioned on the application window whenever possible; otherwise, it may introduce spurious clicks outside the application window. An application-rendered cursor is drawn inside the canvas viewport to look like the system cursor.

Alternatively, the single groupware (SDG) toolkit [38] provides its own application-rendered cursor and deals with hiding the system cursor. Flash [15] and Java [25] user interface toolkits also provide facilities for hiding and showing application-rendered cursors.

The cursor's current location should be polled regularly by a timer to update the on-screen cursor's position. The timer interval should be set high enough such that jaggedness (visible straight line segments) is not seen in the output strokes. (In the current implementation, the timer frequency is chosen empirically at 16 Hz.) Since delta movements are measured from the displacement of the system cursor, this method works best if all system-defined cursor acceleration functions [13] are turned off (such as the *enhance pointer precision* option in Microsoft Windows).

Name	Effect	Example Usage
Passive: guides movement		
Hatching	Guides movement parallel to an axis	Draw hatching (parallel) lines
Grid	Guides movement along orthogonal axes	Draw rectangles
Compass	Guides movement concent-rically about a point	Draw circles and curved hatching lines
Radial	Guides movement to and from a point	Drawing spokes of a bicycle wheel
Passive: guide movements along a user-provided path		
Tunnel Line	Guides movement along a path drawn by the user. The path can be widened	Draw similar curves or lines
Steady Hand	Guides movement based on the current stroke's direction	Reduce "jitter" in curves or lines
Passive: modifies cursor speed		
Minimum Speed	Enforces a minimum speed on the cursor	Amplifies small movement in user input
Maximum Speed	Enforces a maximum speed on the cursor	Attenuate high-velocity movement
Speed Up	Decreases C-D ratio	Span large distances faster
Slow Down	Increases C-D ratio	Work in a localized area
Active: adds movement to the cursor		
Conveyor Belt	Induces movement parallel to an axis	Create straight lines
Orbit	Introduces angular move-ment about a point	Create circles
Point Magnet	Induces movement towards or away from a point	Repels/attracts the cursor from a point; combine with orbit to create a spiral
Magnetic Line	Pushes the cursor away from the centre of a path	Draw curved lines that are reasonably parallel
Active: adds movement to the cursor using a history of one's input		
Inertia	A history of previous user movement is accumulated and added to the cursor's current movement	Cursor moves in the general direction of previous user input (as if sliding on ice)

Table 4.2: A basic set of kinematic templates provided by the template tool.

4.2 Kinematic Templates User Interface

Before explaining kinematic templates as end-user tools, a scenario of use is provided. Suppose that we wish to draw curved lines in our drawing. We switch to the template tool and position a Compass template, which guides movement concentrically about a point. Although it is added as a circular shape, we change it to an elliptical shape using its handles (Figure 4.1(a)). For the effect we want to produce, we change the template's strength to 100%, which completely constrains movement. We then switch to a pencil tool and start drawing strokes within the template's effect region. As each stroke is drawn, input from the pointing device is modified by the template to position the on-screen cursor (Figure 4.1(b)). The resulting strokes appear better than our hand-drawn strokes, especially if we were not careful with our hand movement.

The scenario of use demonstrates that kinematic templates are end-user tools added to the drawing canvas. The user interface provides the following components to add, edit, and use kinematic templates.

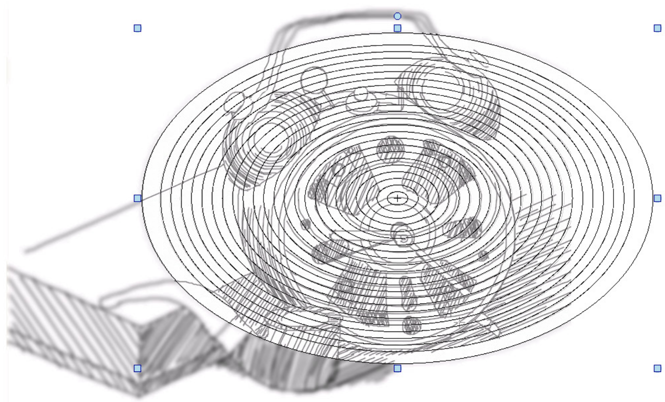
This section presents the following user interface features to work with kinematic templates:

Function name (Section 4.2.1) Since kinematic templates are cursor manipulation functions, they are provided with names and icons to help a user choose between different functions.

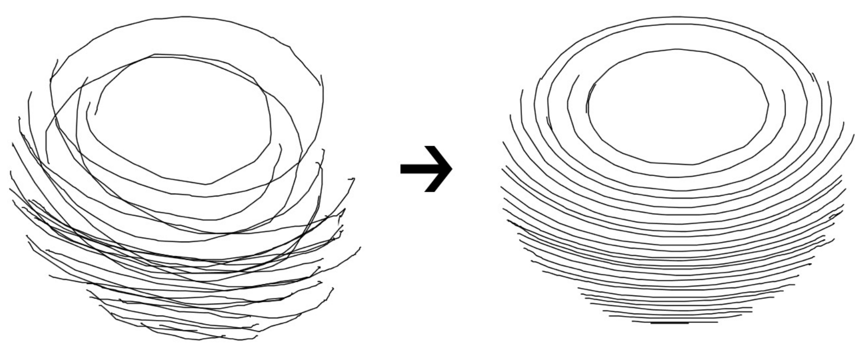
User-definable regions (Section 4.2.2) Motivated by artists working in areas of detail, a kinematic template is added in a user-specified region of a canvas. Kinematic template regions have spatial attributes similar to graphical objects, which include a template's position, size, and rotation angle. Additionally, the template regions provide visual cues to help identify a template's function. Figure 4.2 shows a kinematic template being edited.

User-customizable template settings (Section 4.2.3) Kinematic templates have spatial and non-spatial attributes that affect how a template behaves, which can be configured on the template or in a list of instantiated templates. A strength setting is provided to vary one's output precision when drawing with a template.

Activation on mouse down (Section 4.2.4) Cursor movement is influenced only when drawing within template regions (that is, when the mouse button is pressed down or the stylus has contact).



(a) A Compass template is added to the drawing.



(b) Input recorded from the pointing device (not visible to the user).

(c) The user only sees the modified cursor displacement.

Figure 4.1: A Compass template is added to to help draw curved hatching lines. When drawing strokes (b) in the template, the user sees the cursor (c) guided by the template.

Template composition (Section 4.2.5) Multiple templates can be defined and overlapped on a canvas. Multiple variations of template composition exist.

4.2.1 Choosing a Function

A basic set of template functions, shown in Table 4.2, are provided in the current implementation of the drawing software. Each function has an icon and name to help construct a mental model. Templates can be named after a visual style it creates; for example, a Hatching template helps draw parallel lines for shading. Templates can also be named after physical drawing instruments; for example, the Compass template draws concentric arcs. Active templates can be named after concepts in physics; for example, the Orbit template introduces circular movement and the Point Magnet template introduces movement to or from a point.

The icons are designed such that upon learning the effect of one template, a user can infer the effect of related templates. Passive templates are shown with up to three guide lines. For a passive template that modifies speed, sample inputs and outputs are shown. The Slow Down template is an exception, which shows scattered dots to represent a rough texture. Active templates are represented with arrows to indicate that movement is being added.

4.2.2 Template Regions

In *drawing* mode, a kinematic template influences cursor movement within a specified region of the canvas. These regions are defined by the user and its shape depends on the type of kinematic template. Cartesian-coordinate templates have rectangular or freeform-drawn regions. Polar-coordinate templates have circular or elliptical regions. Path-based templates (that is, Tunnel Line and Magnetic Line templates) are defined as a path with some thickness.

Template regions are similar to vector-based objects in that they can be positioned, sized, and rotated (Table 4.3). In following with conventions for vector-based objects, they provide handles for scaling and rotation (Figure 4.3). Unlike vector-based objects, template regions can only be selected and modified in an *edit* mode (Select or Template tools in Figure 4.2).

In some sense, kinematic templates are related to Magic Lenses [9], spatial regions that temporarily modify visual *output* on the display without affecting underlying content. In contrast, kinematic templates only modify cursor *input*.

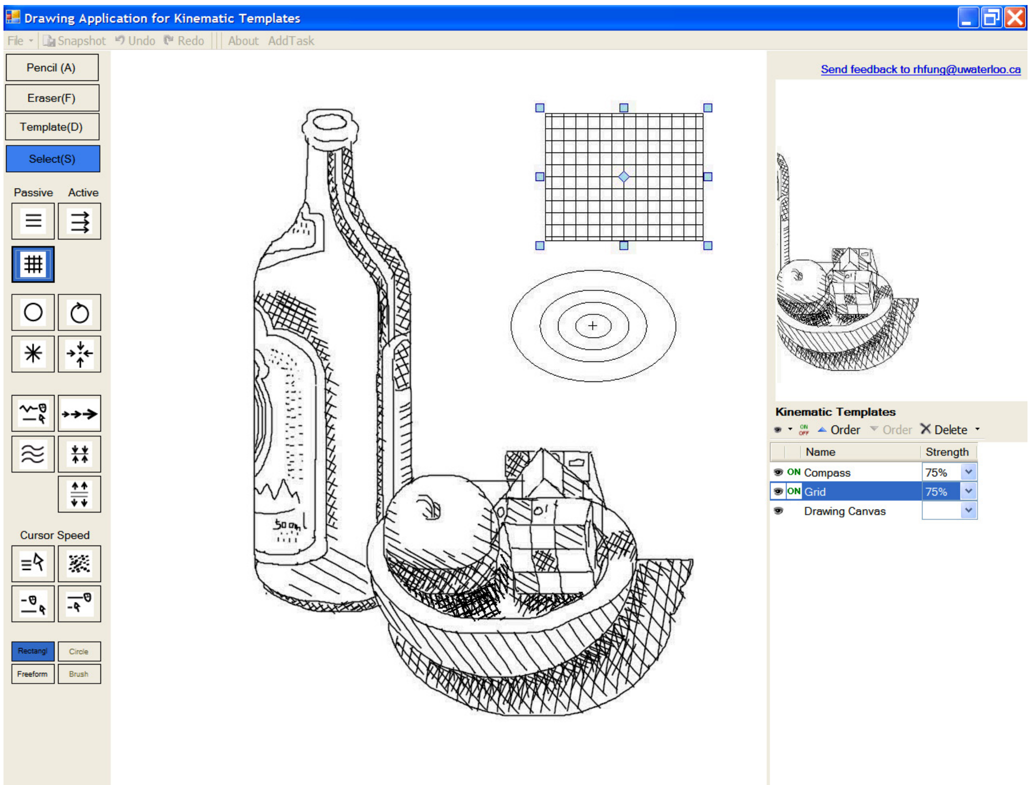
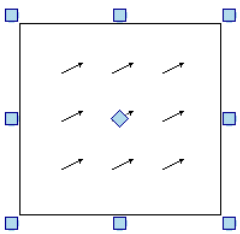


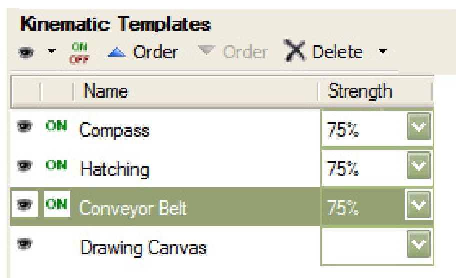
Figure 4.2: A screenshot of the kinematic templates user interface. The middle area is the drawing canvas. The left side of the window has four tools for drawing and editing kinematic templates: the Pencil and Eraser tools are for drawing and the Template and Select tools are for adding and editing kinematic templates. The upper right side of the window is a zoomed out view of the drawing. The lower right side of the window is a list of instantiated templates.

Spatial Attributes	Non-Spatial Attributes
Position of a template	Template strength
Size of a template's effect area	Visibility (if visibility is turned off, the template hides while drawing)
Aspect ratio (polar-coordinate templates)	On/off state (enabled state: if off, the template is removed from the drawing area)
Rotation angle	
Direction of movement added (active templates)	

Table 4.3: Spatial and non-spatial attributes of a kinematic template.



(a) Editing a template region with handles



(b) List of instantiated templates

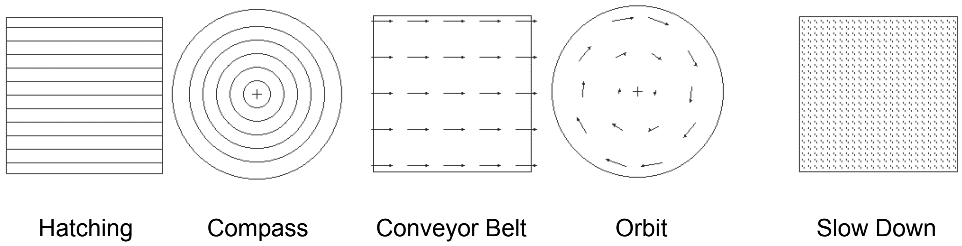
Figure 4.3: User interface elements to modify (a) spatial and (b) non-spatial attributes.

Visual Representation

Without visual cues, a user has to draw inside a template region in order to discover its presence. To make a user aware of a template region, visual cues are provided for each template (Figure 4.4). An outline of the template region is visible on the canvas when it is enabled. Additional visual cues are shown inside a template region, which helps a user identify the type of function in effect. These visual cues are shown and hidden with a two-state "eye" toggle in the right-side list of instantiated templates (Figure 4.3).

The visual cues are specific to the type of kinematic template. Vector plots, grid lines, and patterns are shown for templates as discussed below.

Vector plots (evenly spaced arrows) are shown for active templates that add movement in a predefined direction. The arrows change direction in polar-coordinate (Orbit and Point Magnet) and path-based (Magnetic Line) templates. Other active templates do not show vector plots because the path of added movement changes with new input. For instance, since the Inertia template only adds movement after it receives input from the user, its visual cues would change all the time and distract the user.



(a) Passive templates that guide cursor movement

(b) Active templates that add movement to the cursor

(c) Passive template that modifies cursor speed

Figure 4.4: Visual cues shown in a template's effect area. Visual cues can be shown and hidden by the user.

Passive templates that guide movement along an axis or path show regularly spaced grid lines. An exception is the Steady Hand template: since its guide path changes with user input, it does not show additional visual cues.

Speed-based passive templates do not show visual cues except for the Slow Down template, which shows a dotted pattern using a metaphor of a rough sand texture. (In a previous iteration, the Speed-Up template used the metaphor of an ice sheet, but users perceived it as a visual region and not a kinematic template.)

Bimanual Interaction

In the current implementation of the drawing software, a template can be repositioned with the non-dominant hand while the dominant hand performs the drawing task, which is a form of asymmetric bimanual interaction [22]. Templates can be repositioned using a mouse or the keyboard (both versions are implemented).

4.2.3 User-Customizable Template Settings

Kinematic templates provide customizations to enhance the usability of the end-user tools (Table 4.3). To rotate a template's guide or cursor force, a diamond-shaped handle is provided inside the template's region. A list of instantiated templates (Figure 4.3) allows a user to organize templates by removing a template temporarily and hiding a template's visual cues.

Template Strength

One of the motivations for creating a new digital drawing aid is to vary one's output precision. To allow a user to target specific levels of output precision, each kinematic template has its own strength parameter ranging from 10% to 100%.[2]

The strength of a template is related to the values given by $s_\perp$ and $s_\|$ for passive templates and $[v_{x_1}\ v_{x_2}]^T$ for active templates. Acceptable minimum and maximum values are hand-tuned for each template and assigned a strength σ between 0 and 1, inclusive (the drop-down box shows σ as a percentage). Lower strength is associated with freehand output; higher strength is associated with precise output.

As an example, consider the Hatching, Grid, Compass, and Radial templates, templates that guide movement along a path. Movement off of the preferred path is attenuated via $s_\perp = 1 - \sigma$. The template completely constrains movement when strength $\sigma = 1$ because all movement off the preferred path of movement is attenuated. Likewise, strength $\sigma = 0$ is equivalent to a template with no influence on freehand input.

4.2.4 Activation on Mouse Down

In drawing mode, kinematic templates take effect when the mouse button is pressed down or a tablet stylus has contact. Given that user input is only modified under these conditions, templates work with all pointing devices including trackpads, pointing sticks, mice, and graphics tablets (whether in absolute or relative positioning modes). When the stylus of a graphics tablet has contact, it behaves as a relative positioning device. When the stylus is lifted, the graphics tablet behaves as an absolute pointing device. When using direct pointing devices such as Tablet PCs and interactive pen displays, a correspondence problem can arise between the location of the on-screen cursor and the stylus; otherwise, the technique works identically.

Templates may lock the cursor under certain circumstances such as $s_x = s_y = 0$, but this is not a major issue since cursor movement is affected only when the mouse button is pressed down or the tablet stylus has contact. Users can modify a template's parameters to resolve such situations.

[2]The percentages provided are 10%, 20%, 25%, 50%, 75%, 90%, and 100%.

4.2.5 Template Composition

Multiple templates can be added and overlapped on a canvas. When drawing within these overlapped regions, three different alternatives for template composition exist:

MIMO composition In model-in-model-out (MIMO) composition [9], the output $[\Delta m'_{x_1}\ \Delta m'_{x_2}]^T$ of one template becomes the input $[\Delta m_{x_1}\ \Delta m_{x_2}]^T$ of the next template. The composition of templates is not commutative when mixing active and passive templates, which means that the order of templates is significant. (Mixing like templates—passive with passive or active with active—is commutative when scaling and additive factors are constant values.) For example, consider a situation with overlapping active and passive templates where no movement is received from the pointing device ($[\Delta m_{x_1}\ \Delta m_{x_2}]^T = [0\ 0]^T$). If the passive template is considered first, its $\Delta m'_{x_1}$ and $\Delta m'_{x_2}$ values will both be 0, making the final cursor movement wholly dependent on the active template. If the active template is considered first, however, it is likely to return non-zero values that are modified by a passive template, making the new cursor position a function of both templates.

XOR composition In exclusive OR (XOR) composition, one template or the other takes effect, but both templates are not active at the same time. Consider the Grid template (Table B.1), which is a pre-built combination of two orthogonal Hatching templates. It chooses between one of the guides based on the angle of a user's input displacement. Angles between 0–45 degrees use the horizontal guide and angles between 45–90 degrees use the vertical guide (assuming 0 degrees is horizontal). An indeterminate condition may arise at 45 degrees, but it is unlikely that a user can draw precisely at this angle.

Partitioned composition In partitioned composition, influences from passive and active templates can be computed separately. For instance, templates can be automatically separated such that active templates are added beneath all passive templates. Partitioned composition must be combined with another form of composition for each type of template.

From the user's perspective, MIMO composition is the simplest to understand. The user is expected to learn that the order of templates matters, but this can be supported with training, the user interface, and some experimentation. A user can be instructed that the output of one template becomes the input of the next template in the list of instantiated templates and that the topmost template is first.

XOR composition works for passive templates that show grid lines. The user can be instructed that the template will guide movement along grid lines. Internally, the software can inspect the user's direction of movement and choose the right template to activate. This technique, however, fails for templates that show no grid lines and for active templates. Without a corresponding guide path to match against, there will be ambiguity in choosing which template to activate.

Partitioned composition treats passive templates and active templates as two separate template tools. Users will have to learn that different compositions methods may occur with each of the template types, for instance, MIMO composition for active templates and XOR composition for passive templates. To support this design, two lists of instantiated templates are needed for active and passive templates. Otherwise, this design has the same benefits and drawbacks as the other two composition methods.

Given these alternatives for template composition, the current implementation uses MIMO composition. When templates are overlapped in the current implementation, the output of one template is taken as the input of the next template. Since template order is not commutative in this method of function composition, the template order can be rearranged in a list of instantiated templates (Figure 4.3(b)).

4.3 Summary

This chapter presents kinematic templates, end-user drawing tools that influence cursor movement within user-specified regions of a canvas. Cursor manipulation functions position the cursor based on a user's input and the behaviour of a given function. Passive functions selectively modify movement on the X and Y axes to guide cursor movement. Active functions add movement to the cursor. Multiple kinematic templates can be added to a canvas, each with spatial properties similar to selection regions and graphical objects, but they modify cursor movement and provide behavioural settings that can be customized by the user. Importantly, each template provides a strength setting that allows a template to vary its influence on freehand input within a continuum of output precision. As a result, kinematic templates change the precision of freehand output in real-time while drawing a stroke.

Chapter 5

Evaluation

Kinematic templates are new end-user tools that influence cursor movement, but a question arises: how would artists use kinematic templates? To address this question, artistically-inclined participants were recruited to participate in a study of kinematic templates. The objective of this study was to determine where kinematic templates could be used and how they would be beneficial over existing digital drawing aids. The evaluation provided a task for participants to complete, for instance, to draw a composition. Additionally, participants provided feedback regarding the user interface for kinematic templates. To account for the novelty of the tool, the evaluation provided several sessions for participants to learn kinematic templates. This chapter presents the setup and findings from this evaluation.

5.1 Evaluation Goals

Although digital artists are familiar with conventional software drawing tools, they have not used end-user tools that influence the cursor's movement. An evaluation is needed to understand how kinematic templates can benefit digital artists. An evaluation was conducted to answer the following questions:

- Where and when do artists use kinematic templates? Kinematic templates can guide cursor movement, change a cursor's speed, and add movement to the cursor. Some templates may be used more frequently than others, and other templates might not be used at all.
- What visual styles can be created with kinematic templates? Any type of output

can be produced freehand with sufficient time and attention in one's hand. Kinematic templates may scaffold the creation of certain visual styles such as hatching.

- Do artists target levels of output refinement between freehand and precise output? This work is motivated by creating tools that do not prescribe perfect output and allow for intentional imprecision.

- How should the functionality of kinematic templates be provided in end-user tools? Chapter 4 presents kinematic templates in localized regions of a canvas, which was inspired by artists working in detailed areas of a drawing (Chapter 2). Many decisions were made in the design such as the naming of templates, the visual cues to provide, and the hand-tuned template strength. Its design should be validated with users.

5.2 Evaluation Setup

An exploratory evaluation was conducted to investigate the research questions. The study recruited five participants with the expectation that each participant would use kinematic templates differently depending on his or her artistic skill, drawing style, and experience with digital drawing software. To gauge these differences, participants filled out a questionnaire about their prior experience before starting the evaluation. Participants, though, were not screened for experience with specific digital drawing tools.

The evaluation asked participants to produce visual compositions using kinematic templates. I expected that this goal-driven task would motivate participants to learn and use kinematic templates in a meaningful way. Participants were provided with training to add and remove kinematic templates and to use the software prototype's basic drawing functionality (Appendix C). Since the researchers had no preconceived notion of where the tool would be most beneficial, the evaluation did not require that any particular visual style be produced.

Since human participants were involved in this study, the study received ethics approval from the Office of Research Ethics at the University of Waterloo. Copies of the approved study forms and materials are presented in Appendix C.

This section describes the setup of the exploratory evaluation. After describing the participants, this section explains the drawing tasks that participants were asked to perform. This section then explains the computer environment and data collection methods used in the evaluation.

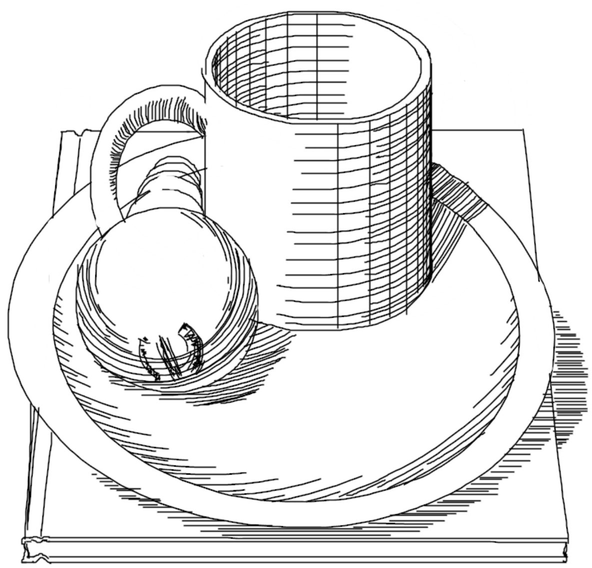


Figure 5.1: Still life of a book, plate, mug, and light bulb. Templates straightened up the edges of the book and improved the hatching lines on the light bulb and mug. The drawing was created mainly with the Compass and Hatching templates. P4 produced this composition.

5.2.1 Participants

Four artistically-inclined volunteers were recruited in second-year digital and fine art classes, and one volunteer was recruited by word of mouth. During the recruitment, participants were given a brief description of the study (Appendix C.1). The recruitment indicated that if they participated, they would be remunerated up to $50 for participation in five sessions ($10 for each session).

Participants ranged in age from early- to mid-twenties and consisted of one male and four females. Four participants were university students and one participant was a professional artist. All four university students had taken art courses in university. Two student participants took digital media classes and the other two student participants were enrolled in a fine arts degree program. The self-taught professional artist reported creating digital art compositions on a regular basis using Adobe Photoshop. All participants drew with their right hand.

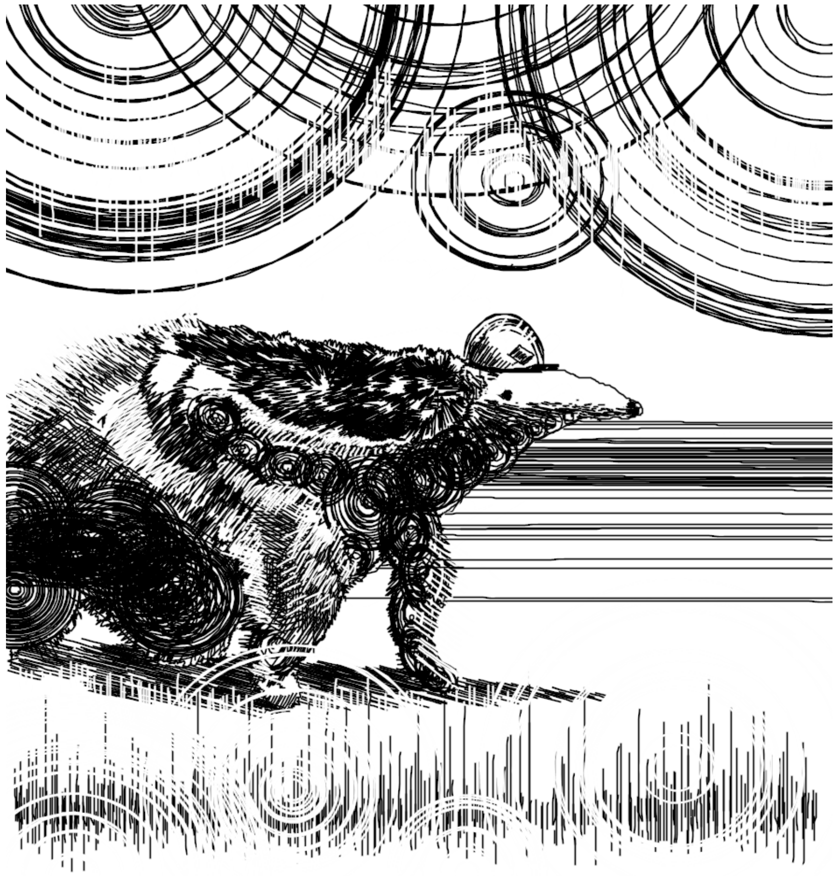


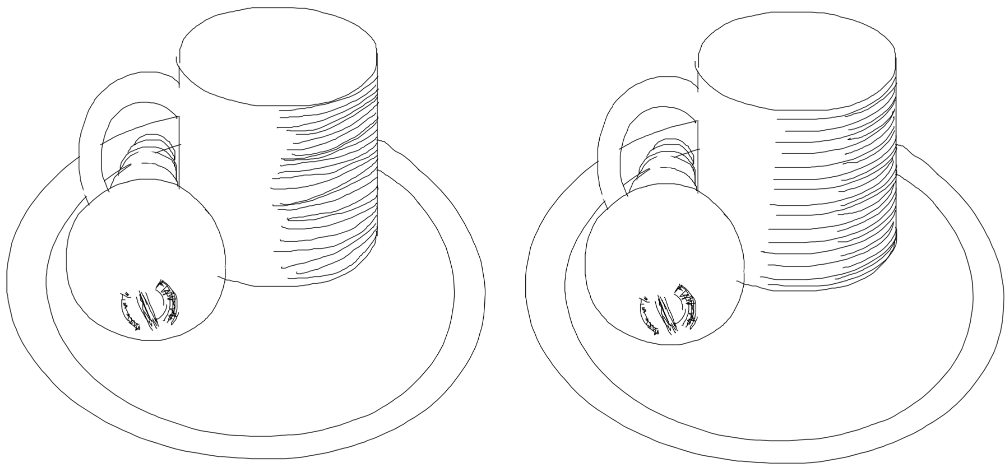
Figure 5.2: Drawing of an anteater wearing a hardhat. The anteater's back is drawn with the Conveyor Belt template (left) and Radial template (middle); the forward and hind legs are drawn with the Orbit template; and the ground and horizon are drawn using the Conveyor Belt and Orbit templates. P3 drew this composition.

5.2.2 Drawing Task

Each participant attended four to five sessions, each lasting between 45 and 75 minutes, over three to twelve weeks. In the first session, participants were given a tutorial to add, edit, and draw in templates (Appendix C.4). The tutorial task did not prime participants to particular visual styles. The tutorial also gave participants practice using a 6×8 inch Wacom[1] graphics tablet. Then, participants produced different visual compositions every session.

To determine what participants should draw, a pilot study was conducted beforehand to test using different source material. When ink drawings and graphic illustrations were provided, pilot participants attempted to copy them as identically as possible. The study,

[1] http://www.wacom.com



(a) (b)

Figure 5.3: A comparison of hatching lines drawn on a mug. A participant drew curved hatching lines on the side of the mug, (a) using only tracing guides and (b) with the Compass template influencing cursor movement.

however, wanted participants to explore any visual style that could be drawn with the aid of kinematic templates.

In still life drawing, an artist replicates a scene comprised of inanimate objects such as a bowl of fruit [30]. Still life drawing was chosen because it allowed a participant flexibility in choosing which details to include and what drawing styles to use. For the evaluation, participants were asked to draw still lifes—which comprised of curved and rectilinear objects such as bottles, light bulbs, mugs, books, and plates—in the first two sessions.

The evaluation encouraged participants to use kinematic templates while creating their composition, but the drawing styles were left to the participant's skill and ability. Participants were told to complete a drawing within a given time, but they were not interrupted until a drawing was completed. Then, participants were asked open-ended questions about their experiences with kinematic templates and issues with the user interface.

5.2.3 Apparatus

The computer setup included a 17-inch LCD monitor, keyboard, and a 6×8 inch Wacom graphics tablet placed in front of the keyboard. The graphics tablet did not show the computer screen. The computer was running Windows XP with a display resolution of

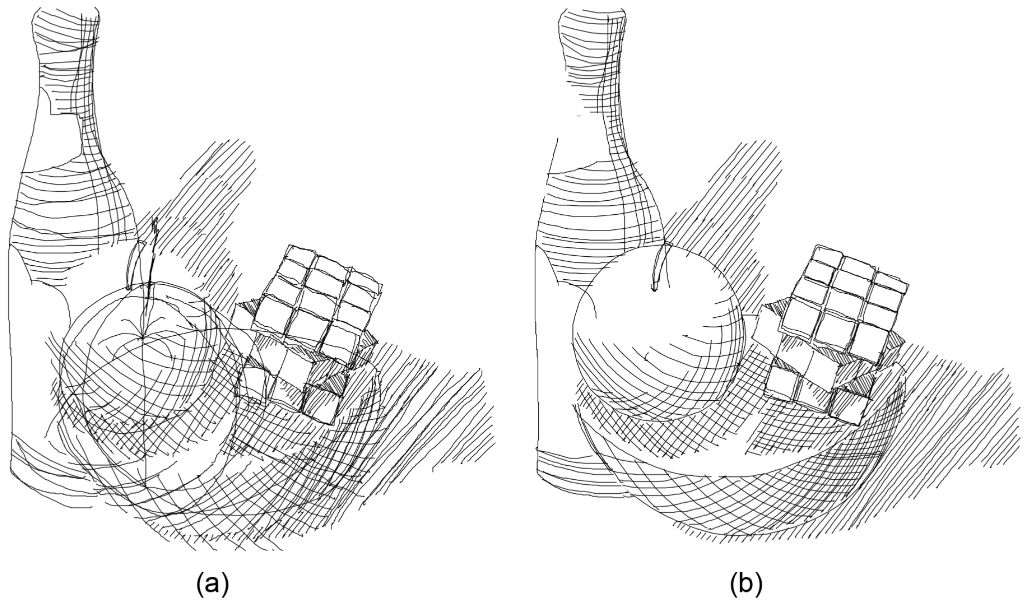
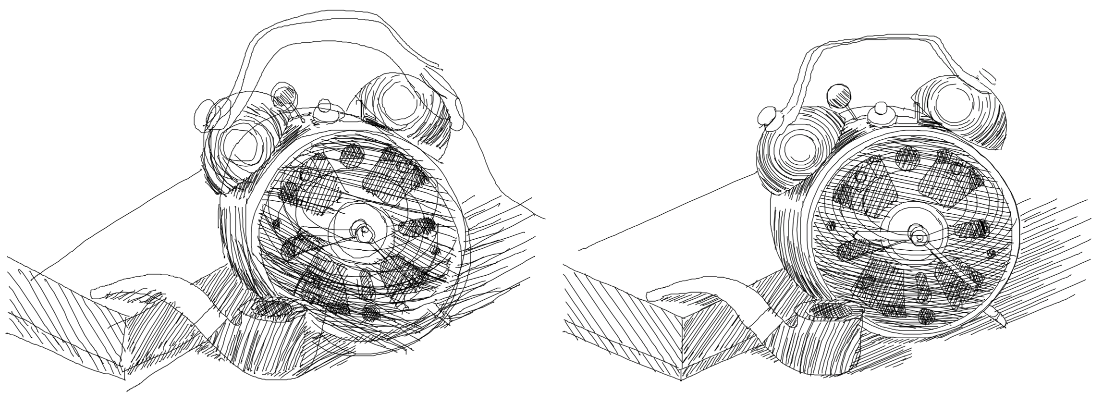


Figure 5.4: Still life of a bottle, fruit, bowl, and Rubik's cube. Passive templates were used to straighten the hatching lines for shading the bowl, apple, and bottle. The input (a) is recorded from the Wacom stylus should not be compared directly to the drawing (b) on the display. The participant never saw the input (a) that was provided on the Wacom stylus. That is, the participant did not intentionally provide such as rough input and could probably draw better by hand. P4 produced this drawing.

1280×1024. The Windows task bar was visible for all participants.

The drawing software changed over the duration of the evaluation as bugs were fixed and different user interface designs were tested. In the early evaluations, the drawing software presented textual labels for the templates whereas graphical icons were presented in later evaluations. The template names also changed during the evaluation based on participants' feedback.

The software restrained some of the visual composition choices. The study wanted participants to focus on using kinematic templates and not existing drawing features such as colour and line thickness. Thus, drawings had to be monochromatic with a single pen thickness; however, different eraser sizes were provided (one participant took advantage of different eraser sizes to create a visual style in Figure 5.6). The drawing canvas was fixed to a single size and they could not resize the drawing, although they could draw in a subset of the available drawing canvas.



(a) (b)

Figure 5.5: Still life of a clock. The input (a) is recorded from the Wacom stylus should not be compared directly to the drawing (b) on the display. The participant never saw the input (a) that was provided on the Wacom stylus. The participant purposely provided rough input and could draw better by hand. Notice how the box and hatching lines are drawn roughly on the Wacom tablet, but appear fairly uniform in the output. P4 produced this drawing.

5.2.4 Data Collection

I was present during each of the drawing sessions to identify issues with the user interface. A question-asking protocol [26] was used in case participants wanted to ask about the user interface. The question-asking protocol gives the participant a *tutor*, an expert who could answer specific questions about an unfamiliar user interface, which helps to reveal user interface issues. Participants could ask about the user interface, for example, "how do I change the angle." On the other hand, participants were not given advice on drawing styles.

Sessions were recorded for further analysis using an audio recording device and CamStudio[2] screen capture software. The software was instrumented to record keyboard input, pointing device input, and strokes that appeared on the display.

5.3 Results Overview

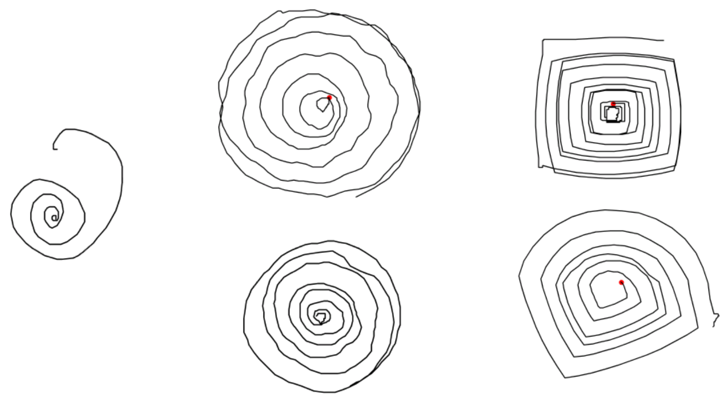
Two participants, the professional artist and an art student, were familiar with producing or editing digital compositions with an external graphics tablet and reported using a

[2] `http://camstudio.org`

Figure 5.6: Drawing of a tree. In the background, the Tunnel Line template was used to draw multiple curves that are similar and parallel to each other; the Orbit template was used to draw spirals; a thick eraser was used with the Orbit template to add concentric circles at top; and the Grid template was used to draw vertical lines. The tree in the foreground was drawn freehand with ink and eraser tools. P3 used a photograph as inspiration.

graphics tablet for at least a year. Although participants were not screened for prior experience with specific software drawing programs, both participants reported using Adobe Photoshop. These two participants found different and interesting uses of kinematic templates. Most drawings presented in this chapter are from these two participants (Table A.1), which Section 5.4 expands in detail. The other three participants had not used a graphics tablet on a regular basis. They used templates primarily as visual guides and proportioning elements (Section 5.4.5). They were learning to use a graphics tablet and draw on a computer.

All participants provided feedback regarding the kinematic templates' user interface. Section 5.5 explores design decisions that improved the user experience and design de-



(a) (b) (c)

Figure 5.7: A spiral drawn by hand (a) is compared to spirals drawn with the Orbit template (b,c), extracted from Figure 5.6. Small variations in input to the Orbit template produce spirals (b) with a particular aesthetic. Spirals are also drawn by combining the Orbit template with the Grid template (c).

cisions that did not work.

5.4 Evaluation Results: Role of Templates

The evaluation observed how kinematic templates are used for different purposes. This section will first consider kinematic templates as a tool that augments freehand drawing to help create patterns quickly with consistency and uniformity. This section then considers how templates were used without a preconceived output in mind: Serendipitous uses of kinematic templates lead to interesting compositions. Afterwards, this section explores the reason why participants felt like they were drawing freehand when using kinematic templates. Lastly, this section identifies that templates also played a role as proportioning elements and tracing guides.

5.4.1 Augmenting Freehand Drawing

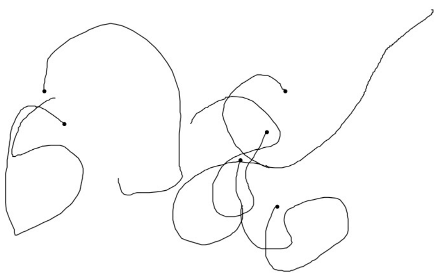
Kinematic templates were used to draw patterns or visual styles that required a degree of consistency and uniformity in one's strokes. Two participants, a student majoring in fine arts and the professional artist, used templates to draw hatching (Figures 5.1, 5.2, and 5.13), circular (Figures 5.2 and 5.6), and a sawtooth pattern (Figure 5.2). Neither the evaluator nor the tutorial primed participants to produce these visual styles; however, participants knew about the hatching style from the name of the Hatching template. For the remaining styles, participants *found* these outcomes on their own as they used kinematic templates.

Hatching is an artistic style where lines are placed close together for shading. Examples of hatching with passive templates are seen with the Hatching template in Figure 5.1, Grid template in Figure 5.13, and Compass template in Figure 5.9. In these templates, the artist had to add the template first and then draw the stroke as if they were drawing freehand. These templates helped improve the consistency of the strokes by ensuring a level of parallelism while retaining slight variations in one's output. An improvement to freehand drawing is seen in Figure 5.3: even with concentric grid lines to trace along, freehand tracing had more variation compared to using a Compass template. Active templates were also used to produce a hatching style. The artist simply had to click and hold inside the Conveyor Belt template to draw straight hatching lines, which is visible in Figure 5.2.

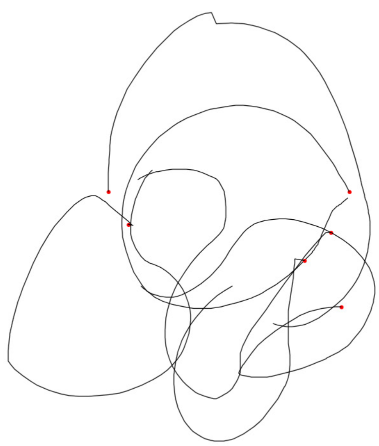
5.4.2 Feeling of Drawing Faster

Participants felt that they could draw faster when using kinematic templates. One participant compared the experience to drawing in an existing software package, "To draw a straight line in Photoshop, you have to take the pen tool and go one by one by one, which is really really really tedious. In this program it's snap—snap as in really fast." To understand the reasons, consider the examples in Figure 5.4 and 5.5. (When comparing the recorded input and visible output, the participant could not see the recorded input. If they could see the input strokes, they would likely have been more careful in their input.) The participant only had to configure a template region once before drawing multiple strokes, which reduced the setup time for each stroke. More importantly, the participant did not have to draw strokes uniformly, as another participant expressed: "I found that even being consistently rough with [the] tools, there is still such a level of force [*sic*] precision." The participant referred to the guiding influence of the template as a force, which straightened the strokes. Since the participant did not have to draw carefully, the participant felt that templates "freed me up to move a lot quicker."

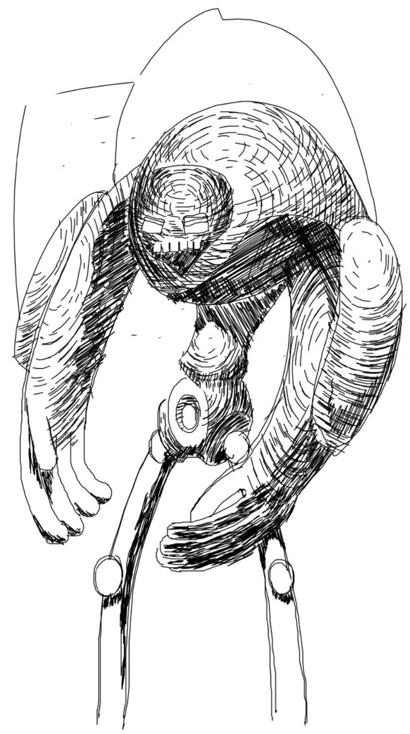
Not only were passive templates beneficial, active templates allowed participants to draw abstract patterns faster while maintaining consistency in strokes. Concentric circles created an interesting abstract pattern in Figures 5.2 and 5.6. The participant agreed that the Orbit template, which adds movement to the cursor, made this pattern faster to



(a) Recorded input



(b) Visible output from the Steady Hand template



(c) Final composition

Figure 5.8: A sci-fi character whose shape was inspired by serendipitous lines drawn in the Steady Hand template. The input recorded by the Wacom stylus (a) and the output from the Steady Hand template (b) shows how working against a template's preferred guide can create interesting shapes. The shapes are used as the outline for a character drawn from imagination (c). P4 drew this composition.

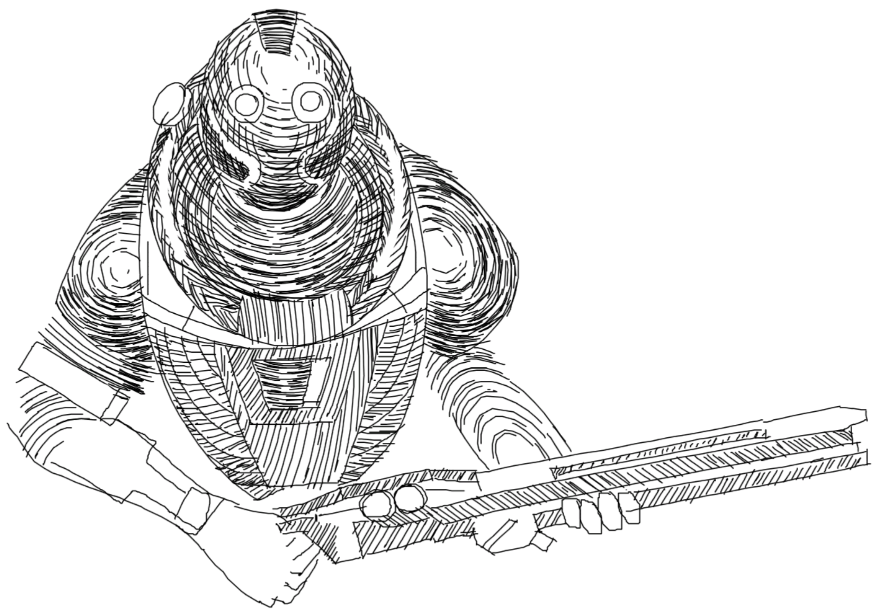


Figure 5.9: Drawing of a sci-fi character using a magazine picture as source material. The Compass, Grid, and Hatching templates were used. P4 created this composition.

draw. These circles could be drawn freehand, but it would take significant attention and precision to achieve the same outcome. These circles could be drawn using an ellipse tool multiple times. In Microsoft Paint and similar drawing applications, however, positioning each ring concentrically would be more difficult since the ellipse tool is dragged from the outer edges.

Another advantage of active templates, which add movement to the cursor, is that a user can still move the cursor. The spirals in Figure 5.6 were created by moving the stylus under the influence of the Orbit template. Since the Orbit template did not constrain one's input, the participant moved the stylus slightly to change the orbit's radius while the cursor moved concentrically. The template improved the consistency of the spirals when compared to a completely freehand spiral in Figure 5.7: each spiral has the same overall visual style, yet each spiral is distinct with hand-drawn qualities. The participant also combined the Orbit template with the Grid template to produce spirals of other shapes.

5.4.3 Introducing Serendipity

Templates also played a role at the early stages of a drawing. Working against a template's preferred path of movement and experimenting with a template resulted in serendipitous compositions.

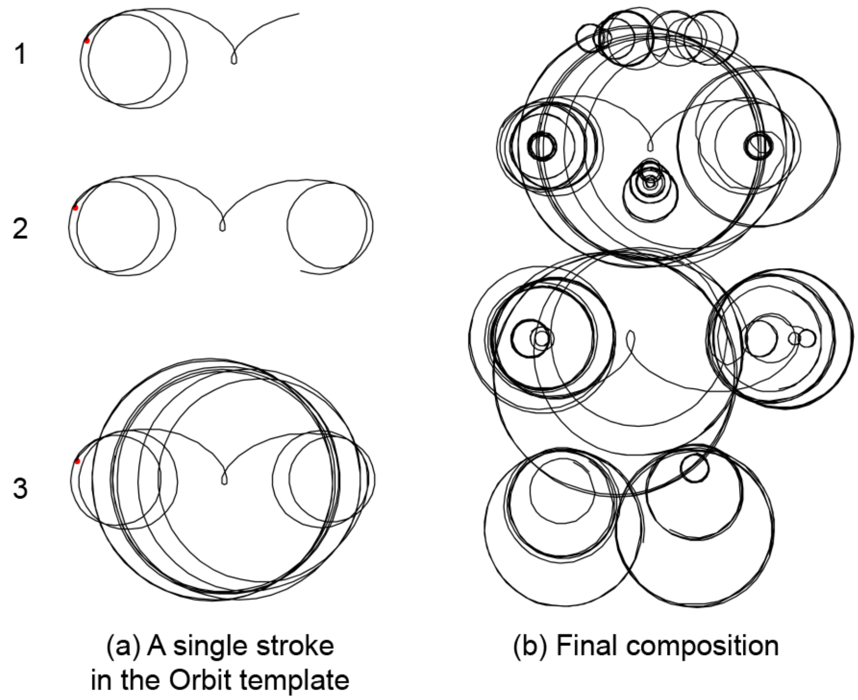


Figure 5.10: A teddy bear drawing. In a formative evaluation prior to the main user study, the Orbit template was repositioned with the non-dominant hand (a) to draw a single stroke. The final result (b) is a teddy bear, produced by F6.

Consider the Steady Hand template. It guides movement in roughly the same direction as previously provided input, and it opposes changes in direction and backtracking along a path. For instance, when drawing a stroke to the right and then turning upwards at 90 degrees, the cursor will not move upwards: rather, the template slows cursor movement. As the user provides more input upwards, a curved corner is effectively drawn, which the user does not expect.

One participant worked against the guide of a Steady Hand template by drawing tight curves (Figure 5.8(a)) and the template produced an output that was significantly different (Figure 5.8(b)). Although the participant expressed difficulty in controlling the cursor, the unexpected output was beneficial. The participant's hand and computer's guiding influence worked together to "get some shapes that I wouldn't naturally draw." The participant viewed the template as a "loss of precision," but it was a good thing. The participant recounted an analogy of drawing with a metre-long pen: "What you lose in precision you gain in gracefulness, especially when you start coming up with shapes in a drawing."

The output created from the Steady Hand template led to serendipity in an imaginative composition. The participant reported seeing a character emerge from the shapes, which resulted in Figure 5.8(c). The participant felt that the template helped to create unique shapes: “Looking at it now, I’m very interested in the composition of the character. The positive and negative space, I didn’t come up with it—I found it. The tools sort of helped me.”

Serendipity in Pilot Studies

A second case of serendipity arose from a pilot study prior to the main evaluation. A participant was experimenting with active templates, which add movement to the cursor, in one of the software prototypes that supported bimanual interaction. In addition to using a mouse, keyboard shortcuts allowed the participant to reposition a template while drawing a stroke.[3] The pilot participant repositioned the Orbit template while drawing a stroke to draw a loop as seen in Figure 5.10(a). In the same stroke and repositioning the template again, an outline of a “head” was formed. After adding other strokes in a similar manner, a teddy bear emerged (Figure 5.10(b)).

For this participant, the *animated* experience in producing the output was enjoyable. The participant had to pay attention to the current position of the cursor and move it at the right instant to increase (or decrease) the radius of concentrically-added movement. Such an output could be drawn by hand or done with an ellipse tool, but the experience would not be the same.

In both cases, serendipity arose from creative uses of a template. A pilot study also demonstrated a niche output when opposing a template’s preferred path. For example, when attempting to draw a circle in the Radial template, a “spiky” circular shape emerged: slight deviations off of a circular path were amplified by the template (Figure 5.11). When moving the cursor in a circular arc, the cursor appears to move slowly so one has to provide a larger input along that arc path. Pilot study participants enjoyed the feeling of resistance when doing this task, described as “fighting the template” by those who tried it. A template’s opposition to intended movement and the resulting output could conceivably lead to a novel visual style.

5.4.4 Feeling of Freehand Control

Passive templates allowed participants to feel as if they were still drawing freehand. The Grid, Hatching, and Compass templates simply guided one’s strokes along a preferable

[3] Two versions of the application were created to reposition templates: one with the keyboard and another with a mouse. This participant used the keyboard version.

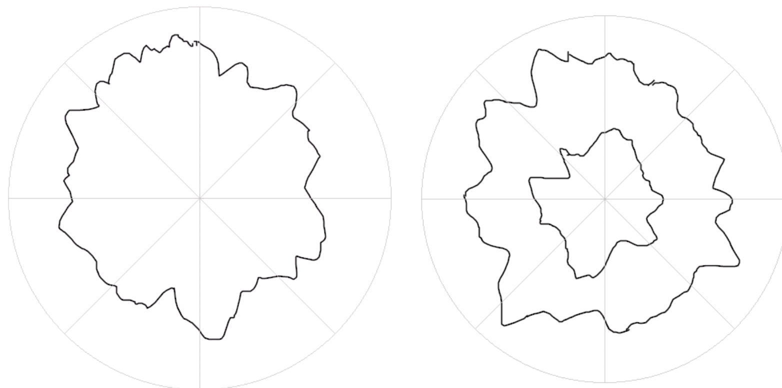


Figure 5.11: Drawing a circle in the Radial template produces a spiky circle. The spiky circle arises from imprecisely tracking a perfect circular path using a trackpad (left) and mouse (right). This example is produced by the author.

path. Participants still had to choose a starting point for a stroke, draw along the stroke, and lift the drawing instrument at its endpoint. Given this type of interaction, "the artist is still doing the majority of [the stroke]" as a participant noted. Participants perceived that strokes remained under the influence of the human hand, as the following comment expresses: "It's kind of nice to have the feel that the artist still has a lot of control, [and] have the template there as a guide." These comments suggest that participants felt ownership of the strokes and that the templates were not an additional burden to the drawing task.

Participants felt that the strokes remained under their influence despite the output appearing significantly better than freehand drawing. As a participant commented on the Grid, Hatching, and Compass templates, "It's kind of fun to have these tools align *your* strokes" (emphasis added). Another participant commented on the feeling of freehand control: "It felt like it was freehand, but looking at it, it definitely has a very accurate, calculated feel to it." The feeling of freehand drawing remained even when template strength was increased from 75% (default setting) to 100%. One participant found that preserving no qualities of the human hand in output was just as acceptable, "I really found myself trusting the 100% setting on many of the tools."

Not all participants shared the same viewpoint. One participant, who was opposed to any template influence, commented: "I like to have the template there as a guideline, but I don't like it to control what I'm doing." This participant used templates only for their visual affordances by setting template strength as low as possible (10% strength was the lowest available setting) and drew everything freehand.

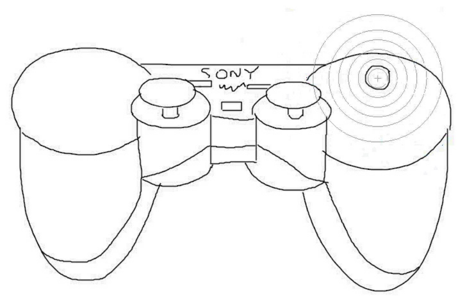


Figure 5.12: A work-in-progress sketch of a game controller. An inner ring of the Compass template is being traced in the upper-right corner. The other features are drawn with the Grid and Compass templates. P1 produced this drawing from a still life.

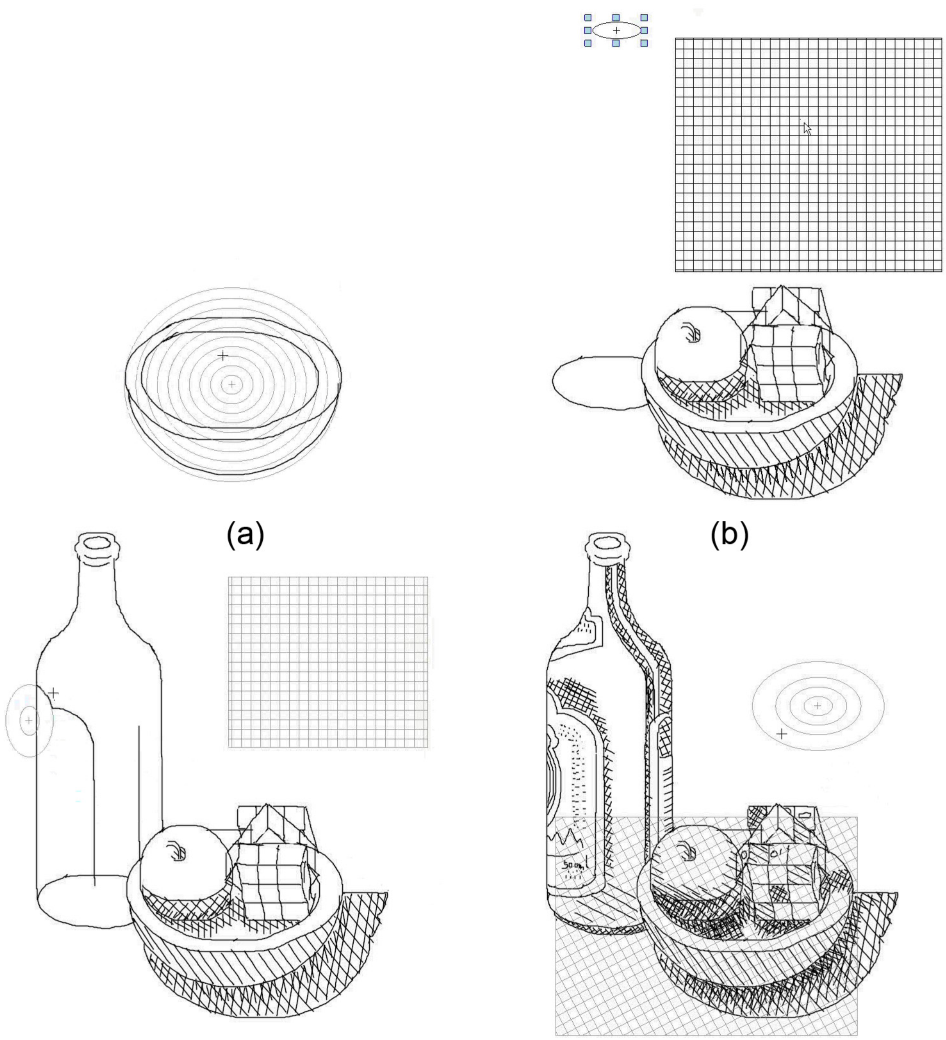
5.4.5 Repurposing Template Affordances

Template regions are identified by visual cues on a composition. An unexpected result emerged when participants repurposed visual representations as proportioning elements and tracing guides.

In freehand sketching, artists may rough out a drawing with light pencil marks. Since templates could be added and removed without affecting existing strokes, they were used as proportioning elements. Templates were placed in approximately the same size and shape of an object or feature. As an example in Figure 5.13, Compass templates are placed where a bowl and bottle's top are drawn.

Visual cues were repurposed as tracing guides. Participants followed along the rings of the Compass template and, to a lesser extent, with the lines of Grid and Hatching templates. Participants positioned the rings and lines of the visual cues to connect to existing strokes. Unfortunately, when tracing along the outer edge of a Compass template (for example, in Figure 5.13(c)), some participants noticed that it would not guide movement outside the template. (The template's effect area only extends a few pixels outside the outer edge). Participants worked around by tracing along a template's inner rings (for example, Figure 5.12). Participants also wanted to change the spacing between the rings and lines, which further suggested their use as tracing guides.

The absence of visual representations in the Compass template demonstrated the need for visual tracing aids. In some prototypes, this template did not show rings to trace along. Since participants could not trace along a curve, participants had to imagine how the guide was influencing the cursor's movement. One participant, for instance, drew against the template's preferred path of movement a few times because she may not have visualized the guide path. The participant had to add a stroke, undo it, and redo it over



(a) (b)

(c) (d)

Figure 5.13: Screenshots of P3 drawing a still life. The Compass template is placed where a bowl will be drawn. Then, the participant traces along the outer edge of the template (a). Later in the drawing, the height of a bottle is proportioned using a Compass template (b). The Compass template (c) is traced along to extend an existing stroke for the bottle's label. The Grid template (d) is used to add hatching strokes to the Rubik's cube.

Functional		Texture	
Hatching	artistic technique where lines are drawn close together for shading	Corduroy	a type of cloth similar to velvet with ridges
One Way	travel only in one direction	Fur	fur is smooth one way but not the other
Radial	radial axis in a polar coordinate template	Dimple Chad	an indentation in paper from a hole punch
Slow Down	cursor moves slower	Sandpaper	sandpaper is rough
Speed Up	cursor moves faster	Ice Sheet	ice is slippery

Table 5.1: Functional and texture metaphors for passive templates.

ten times to get the right curve.

5.5 Evaluation Results: User Interface

The evaluation discovered usability issues in the user interface for kinematic templates. This section discusses how a template's name affected a person's understanding of that template. This section then discusses the results of testing bimanual (two-handed) interaction in the drawing software. Lastly, this section discusses how the hand-tuned speeds of active templates were disliked by some participants and how speed-varying passive templates were used infrequently.

5.5.1 Metaphors Associated with Template Functions

Template names were provided to help form a conceptual understanding of kinematic templates. Two naming schemes were evaluated by participants as shown in Table 5.1. Consider the Hatching/*corduroy* template that draws parallel lines along an axis: in a functional metaphor, it can be used to produce parallel hatching lines; or using a textures metaphor, the pencil follows a groove in corduroy.

People did not associate the textures metaphor with its function.[4] A participant first thought that *ice sheet* was a visual texture, then realized "oh, it's ice like it's slippery." In another instance, the participant asked "what's fur?" and after an explanation, "would it help in drawing fur?" For the Slow-Down/*sandpaper* template, people had opposing

[4]The people that evaluated template names also included formative down-the-hall testing, pilot study participants, and paper reviewers.

views about its purpose: some thought it would add noise (jitter) to one's movement and others thought it made the cursor go faster (sandpaper is an abrasive product to smooth a surface). The actual behaviour slowed down the cursor. These types of responses suggest that texture metaphors can be misleading and that a functional metaphor (for example, a template to slow down the cursor) is better suited.

5.5.2 Bimanual Interaction

When participants were working with templates, it became apparent that template properties were frequently modified when working on a single feature. Shortcut keys, a common convention in existing drawing applications, were provided to quickly switch between tools (`A` for pencil, `S` for select, `D` for template, and `F` for eraser). One participant rotated the angle of the Grid template numerous times to draw a Rubik's cube (Figure 5.4) by switching between the pencil and edit template tools. In another instance, the Compass template was repositioned vertically every three or so hatching lines (Figure 5.1).

To reposition templates without switching modes, a functional prototype was implemented using two-mice bimanual interaction (with the SDG toolkit [38]). One mouse controlled the drawing tools and a second mouse repositioned the most recently edited template. A participant, who liked drawing symmetrical objects on paper with two hands, evaluated this functional prototype with passive templates and said, "it's actually kind of fun"; however, the participant did not reposition the template and draw at the same time. Two other participants, who had previous experience with Photoshop, were asked about using their non-dominant hand for repositioning templates, but they did not like the idea. Despite the evidence suggesting that only a single positional input device is necessary, the teddy bear in Figure 5.10 was drawn by interactively repositioning the Orbit template while changing its radius (in other words, both keyboard and mouse input were provided simultaneously).

5.5.3 Manipulating Cursor Speed

Templates that changed the cursor's speed without influencing movement in a particular direction were rarely used (Table 5.2). The Slow-Down template, for instance, slows the cursor anywhere within its region. A participant commented that Slow-Down and Speed-Up templates serve the same function as zooming in and out, which is already a solved problem in graphical user interfaces. Another participant was prompted to use the Speed-Up template when shading in a region, but the participant said that it made strokes

Frequently Used in a Session	Sometimes Used in a Session	Rarely Used in a Session
Hatching	Tunnel Line	Minimum Speed
Compass	Steady Hand	Maximum Speed
Grid	Orbit	Speed Up
	Conveyor Belt	Slow Down
	Radial	Point Magnet
		Magnetic Line
		Inertia

Table 5.2: Some templates were used more often over the length of the evaluation.

"a little bit too jerky." Participants tested but did not use One-Way and Maximum-Speed templates, which changed the cursor's speed only when certain input conditions were met.

The hand-tuned speeds in active templates did not satisfy all participants. Participants had difficulty stopping a stroke before it intersected an existing stroke, even after lowering the cursor's speed. Participants worked around the issue by erasing parts of the stroke to achieve the desired length. One participant commented specifically on not being able to stop a stroke: "The ones that actually take the pointer and start moving it without me: I really don't like those. Then I have to pay attention to when I have to let go so I don't find those really useful." The participant wanted to stop the stroke at an exact location, which was difficult to do in active templates.

5.6 Discussion

The evaluation results identified how kinematic templates were used and what styles were created from kinematic templates. The evaluation also addressed how to improve the user interface. In considering the results holistically, three questions arise:

- Did participants want to explore the range of output precision or did they want to achieve precise output in an alternative way?
- As a drawing transitions from its initial sketch to its final outcome, did participants use templates at the beginning to outline details or as a tool to finish adding details to a drawing?
- Did participants intentionally introduce imprecision into a drawing?

We discuss each of these points in turn.

5.6.1 Improved Access to Precision versus Selectively Varying Output Preciseness

Modifying the motor space of a pointing device can partially constrain movement along a particular path, thus exploring the continuum of precision between freehand and geometric output. Although the work was motivated by this observation, participants used templates to produce consistent and uniform strokes. Participants, for the most part, left the template strengths at its default setting of 75% or increased strength to 90% and 100% to achieve a "precise, calculated feel to [the strokes]." No participant commented that they produced a composition that looked like a freehand sketch. Further investigation is required to determine if participants will intentionally decrease a template's strength on passive templates to retain sketchy qualities of freehand drawing.

Since participants felt that they could draw faster with kinematic templates, templates may be improving the drawing interaction to achieve precise output. One participant compared to experience in kinematic templates to the experience in Adobe Photoshop, stating that she did not have to switch modes to draw multiple strokes quickly. Participants also felt that drawing in passive templates was similar to drawing by hand because "the artist is still doing the majority of [the stroke]" and "the artist still has a lot of control."

5.6.2 Template Usage in the Drawing Process

In a composition's evolution from its initial outline to its final details, kinematic templates played a significant role in the detailing phase. Kinematic templates were highly beneficial when details were being added to a still life drawing or "rendered" as one participant stated. When shading a composition, passive templates that guided movement allowed participants to produce hatching effects with the Hatching, Compass, and Grid templates. Although a user had to add a template to the canvas, the benefit in producing an output that was better than freehand justified the effort.

Templates were also beneficial when adding detail to a composition that comprised of repetitive patterns. When producing stylistic abstract patterns, the Orbit and Conveyor Belt templates allowed a participant to produce visual output that would be difficult to produce with conventional drawing tools. The effort to tap and hold on the stylus to create these effects (Figures 5.2, 5.6, and 5.10) reduced the effort to add each stroke, which freed the participant to attend to other aspects of the composition such as visual aesthetic.

During the initial stages of a composition where one has a specific shape in mind to draw, templates did not present significant advantages over conventional drawing tools. For instance, the outlines in Figures 5.12 and 5.13(a) were drawn with kinematic templates, but conventional drawing tools could produce a similar output with less steps to setup, position, and remove a template. Nevertheless, templates can help *create* an outline without a preconceived shape in mind. For example, a participant used the Steady Hand template to produce shapes and curves that he would not have imagined on his own.

5.6.3 Potential for Intentional Unpredictability

Templates can introduce *unpredictability* to one's strokes. Except for very few cases such as the spirals in Figure 5.7 and the shapes created with the Steady Hand template, participants did not "fight against" templates. Pilot studies before the main evaluation, however, suggested that templates can introduce unpredictability in one's output. Passive templates such as the Hatching, Grid, Compass, Radial, and Steady Hand templates have a preferred path of movement that one can intentionally work against. When drawing orthogonal to this guide, movements are attenuated, thus small unintended variations along the guide are effectively amplified. The result is a stroke that is not intentionally drawn by the user (Figure 5.11), but it is influenced by the human hand. Artists may see something interesting arise from this output that may lead to an unexpected serendipitous outcome, for instance, the outline of the imaginative character in Figure 5.9 using the Steady Hand template.

5.7 Summary

This chapter presented the results from an initial evaluation of kinematic templates. The evaluation revealed benefits that templates provide when drawing. Preliminary results show that templates are beneficial in drawing patterns that require consistent strokes, maintain the natural feeling of freehand drawing, and help introduce serendipity into a composition. Interestingly, the visual cues provided by kinematic templates were used to identify a region and to trace along. Other design decisions such as naming templates, supporting bimanual interaction, and hand-tuned template parameters affected the usability of the tool. This evaluation demonstrates that kinematic templates are valuable as a new class of digital drawing aids that complement existing digital drawing tools.

Chapter 6

Conclusions and Future Work

This thesis introduced a new software drawing tool, kinematic templates, to vary the precision of freehand input. This chapter begins with a summary of the research approach and thesis contributions before exploring avenues for future work. The future work looks at providing new kinematic templates, improving the end-user interaction of kinematic templates, and exploring the possibilities of kinematic templates with other artists and users.

6.1 Research Approach

This work began by investigating how to improve one's precision when drawing on a computer, which was inspired by artists working in physical and digital media (Chapter 2). When the artists worked in areas of detail, they used fine motor movements. This suggested that digital tools could be developed to inidicate where detailed work was needed. Artists also valued qualities of the human hand; thus, digital drawing aids did not have to produce precise output. Finally, artists wanted to introduce unpredictability into a drawing because it could lead to a serendipitous outcome.

This research was inspired by techniques that demonstrated how freehand qualities could remain in one's output. The snap-and-go technique (Chapter 3) showed that manipulating a pointing device's C-D ratio could guide freehand movement without constraining output. Prior work in manipulating C-D ratio and adding cursor forces showed how the cursor's movement could be influenced in real-time.

6.2 Contributions

Manipulating C-D ratio and adding movement to the cursor were not demonstrated in any existing end-user drawing tools. This thesis contributed a new digital drawing aid, kinematic templates, that can improve upon hand-drawn strokes without being perfect by influencing the cursor's movement. This thesis also contributed a number of passive and active kinematic template functions to demonstrate how to guide movement along a path or axis, change the sensitivity of a cursor's movements, and pull the cursor towards certain points or edges. At the implementation level, this thesis defined a cursor manipulation function, which can create any number of passive and active kinematic templates.

The end-user tools were presented as user-defined regions of a canvas. They provided visible similarities to selection regions, but they influence cursor movement when drawing (that is, when the mouse button is pressed down or the tablet stylus has contact). These regions provided visual affordances, which allowed an artist to identify and learn a template's effect.

Kinematic templates were provided with customizable parameters to vary its influence over freehand input, which explored a continuum of output precision between freehand and highly precise output. Kinematic templates demonstrated that it is possible to improve upon freehand output while retaining sketchy qualities of the human hand.

6.3 Future Work

From the evaluation of kinematic templates, many possibilities for further investigation exist. This section considers creating new kinematic template functions, improving upon the user interface, and assessing kinematic templates in long-term studies and with other user groups.

6.3.1 Investigating Cursor Manipulation Functions

The current implementation of kinematic templates only presents a small set of possible cursor manipulation functions. Some possibilities for new templates are presented below.

Templates as a Function of the Content

The current design of template functions is *independent* of the drawing content. The Hatching template always guides strokes along an axis and the Steady Hand template predicts a path based on prior drawing input. New templates can be designed to influence cursor movement based on the drawing content. Some scenarios are provided to demonstrate this concept.

Consider drawing a closed shape where we want the endpoints to meet. A new template can allow a stroke to be drawn freehand, but as the stroke travels close to the endpoint, it acts as a funnel to guide movement towards that point. (A similar idea is expressed for guiding an object to a snap edge [5].) A hand-drawn quality to the output is maintained while gradually increasing the template's strength to the endpoint.

Consider a case where strokes need to be drawn in roughly the same length. A new template can be created to slow down cursor movement after a given length. Initial movements are drawn freehand and, as the stroke reaches the proper length, the template starts slowing down cursor movement. The user can vary each stroke's length, but the template helps keep a consistent stroke length by attenuating large variations.

Consider a case where a set of strokes needs to be replicated. A new template can be created such that it matches part of a freehand stroke to a set of known strokes. The template starts guiding cursor movement to replicate that stroke. Movement is guided by attenuating movement off of the idealized stroke path, similar to a Tunnel Line template, and the user can add slight variations to each stroke with strengths lower than 100%. Sou et al. [34] and Arvo and Novins [3] proposed systems that match part of a freehand stroke to a set of geometric shapes, but those systems modify the stroke after it first appears and they do not attempt to steer the cursor.

Consider a case where one is tracing over an existing image. A new template can be created to guide movement along edges detected via edge detection algorithms. Since the template allows variations off of the tracing edge, its level of influence over freehand input falls between unaided tracing and vector-based edge tracing tools (for instance, in Adobe Illustrator).

Curved and Distorted Templates

New kinematic templates can be created to help draw curves beyond those suggested in Chapter 4. For example, to draw the side of a cylinder in Figure 5.3 without continually repositioning a Compass template, a single curve can be replicated throughout a template's region in a new template (Figure 6.1).

The design of kinematic templates allows template regions to be translated, scaled, and rotated. Regions can also be manipulated in other ways, but the software drawing prototype has not explored shearing, perspective, and other distortions. The distortions

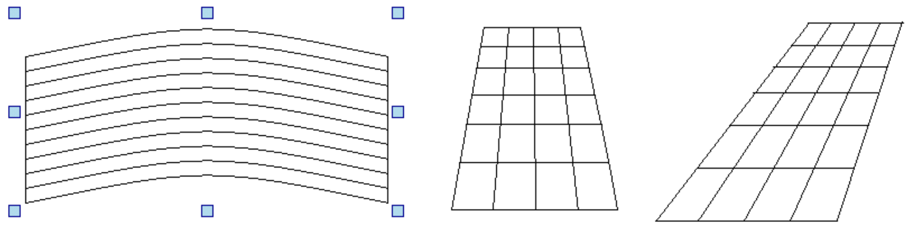


Figure 6.1: New templates for drawing curved hatching lines and perspective drawing.

to templates may help draw certain features such as a book converging to a vanishing point in Figure 5.1.

A Global Template for Perspective

Beyond supporting distortions to template regions, kinematic templates could be designed to support features of the drawing that are present everywhere in a composition. For instance, when producing a perspective drawing, there are one or more vanishing points that apply to the whole drawing (the lines converge at the vanishing points). It is possible to create a Perspective Grid template, applicable everywhere in the composition, that supports drawing to these vanishing points. Fourquet [18], who created a drawing framework to place objects in Renaissance-style perspective, provides a grid that can helps draw in one-point perspective. This perspective-drawing system, however, adds predefined shapes and objects to the grid and it needs to be adapted to support stroke-level drawing.

Remapping X and Y Input for Polar-Coordinate Templates

Currently when drawing in the Orbit template, movements from the pointing device are added to the cursor's current position. When moving towards the top edge in the upper half of the template, the radius is increased. The same movement decreases the radius in the lower half of the template. That is, the conceptual meaning of user input changes depending on the cursor's current location within the Orbit template. A new template can be created that maps user input only to changes in radius. The cursor travels concentrically as in the Orbit template, but movement towards the top edge increases the template's radius and movement towards the bottom edge decreases the template's radius invariant of the cursor's current position. Since movements left and right are unused, a user evaluation is needed to determine if this idea is suitable.

6.3.2 User Interface Design

The current user interface of kinematic templates can be improved upon to help the user interact with kinematic templates and to provide semantically meaningful information as presented below.

Interaction Design

One area for investigation is to reduce the need to switch modes when setting up and editing templates. The current interaction design requires that a user switch tools between drawing, editing, and adding templates, which is a common practice in many commercial drawing applications. Frequently changed template parameters such as a template's angle, strength, and enabled state are currently changed by switching modes or interacting with user interface widgets (Figure 4.3(b)). Some alternative interactions are suggested: a template's angle can be changed with the scroll wheel on an input device; the strength of a template can vary as a function of the pressure exerted on the stylus; and a template may be activated only when a modifier key is pressed down. These design ideas must be prototyped and evaluated to determine their effectiveness. This avenue for investigation already considered using bimanual interaction to reposition templates (Section 5.5.2).

Semantic Meaning from Templates

Users confer a degree of semantic meaning regarding the task and composition itself when adding kinematic templates. Artists add templates roughly in the same size as the feature they will draw and then they remove the template before attending to another area. Although this information is currently unused, it may infer some intent about the task that will be completed.

6.3.3 Follow-on Evaluations

To better understand the possible applications for kinematic templates, the existing evaluation can be improved and kinematic templates can be evaluated with other user groups as described below.

Study Improvements

The evaluation in Chapter 5 can be improved to address study limitations. First, the evaluation could screen participants for prior experience with digital drawing tools. Those who are familiar with the paradigm of digital drawing (that is, use computer drawing software) are better suited to evaluating the tool compared to those without that experience. Second, the evaluation could baseline a user's ability to draw, which can determine if kinematic templates improves an artist's drawing ability or changes how an artist draws. Third, participants could be given more time to learn and explore how to use kinematic templates in their compositions over several months. Fourth, a possible avenue for investigation is to know if kinematic templates support the creative process in drawing [12].

Evaluations with Other User Groups

This thesis referred to anyone drawing on a computer as an artist. Specifically, those who produce digital art include sketchers, illustrators, comic artists, graphic artists, manga artists, and so forth. These groups may find benefits in kinematic templates to produce particular visual styles. Additionally, templates may benefit people other than artists. Engineers and persons with motor control limitations may find benefits with kinematic templates, which we discuss in turn.

Kinematic templates can benefit engineers, although not in technical drawing. Technical drawings, produced by drafting technicians, conform to standards and well-established conventions. Mechanical engineers, however, may need to convey ideas quickly through freehand sketches without the overhead imposed by CAD software (such as AutoCAD[1]). Templates may help in adding consistency to their diagrams without losing "sketchy" qualities.

Manipulating C-D ratio can be used to compensate for motor control limitations. C-D ratio manipulation functions yield benefits in improving target selection in a graphical user interface [37, 42, 43]. In kinematic templates, the Steady Hand template makes a prediction at the user's intended path and then it reduces unintentional sideways displacement (Appendix B). Its algorithm could be further explored in a controlled study to determine its uses.

6.4 Summary

In this thesis, I introduced a new digital drawing aid that influences cursor movement. Kinematic templates are end-user drawing tools that specify regions of a composition where cursor manipulation functions take effect. Cursor manipulation functions are designed to attenuate, guide, and add movement to the cursor. These end-user tools are

[1] `http://www.autodesk.com`

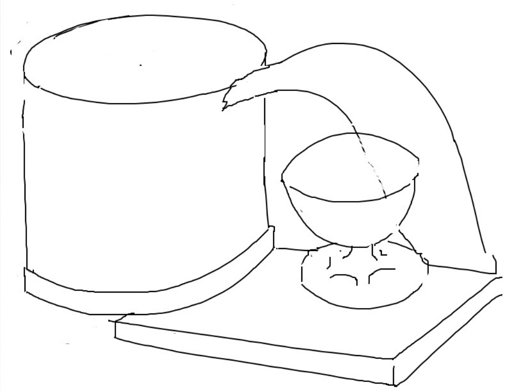
beneficial in maintaining the role of the human in digital drawing. They support drawing certain visual styles in its current instantiation and many avenues for further improvement exist.

Appendix A

Other Evaluation Drawings

Other evaluation drawings are presented in this appendix. These compositions were produced with Hatching, Grid, and Compass kinematic templates. Figure A.1 shows how drawing from a still life allows a participant to selectively omit details. Figures A.2 and A.3 show examples of straight-line hatching to add shadow in a drawing.

(a) A still life



(b) A sketch from a still life

Figure A.1: A still life drawing of a banana, blank CDs, CD case, and ice cream cup. (a) A a still life photograph (digitally edited) is provided for the reader. (b) The participant omitted details when drawing from a still life. P1 drew the sketch using two mice, one to draw strokes and another to reposition a template.

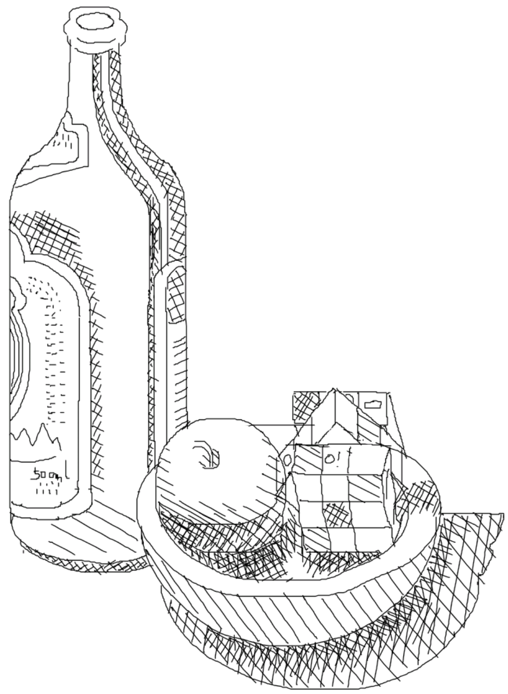


Figure A.2: Still life of a bottle, fruit, bowl, and Rubik's cube. This is the final composition from Figure 5.13.

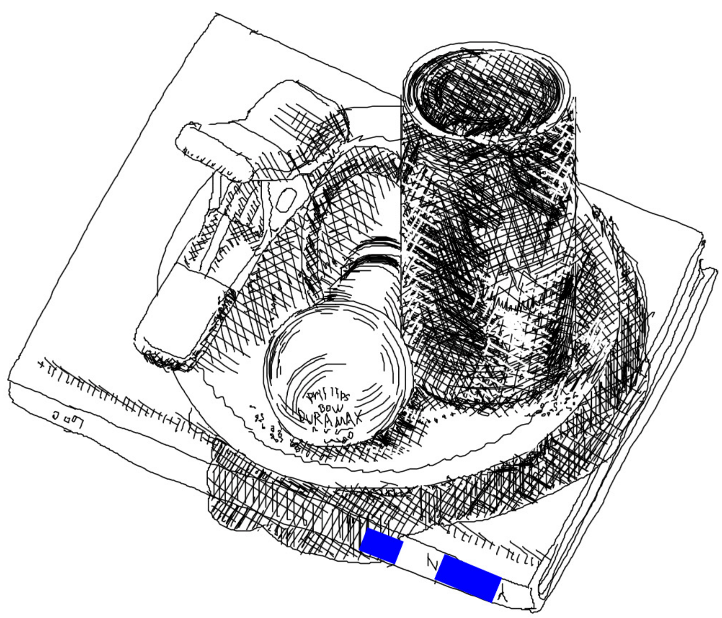


Figure A.3: Still life of a book, plate, mug, and light bulb. P3 created this composition. Two boxes were added to obscure written words.

Figure	**Participant**	**Session**	**Drawing Time** (minutes)
5.1	P4	2nd	35
5.2	P3	3rd & 4th	90
5.4	P4	1st	42
5.5	P4	3rd	53
5.6	P3	5th	57
5.8	P4	5th	42
5.9	P4	4th	50
5.10	F6	pilot	
5.12	P1	1st	17
A.1	P1	4th	35
A.2 / 5.13	P3	1st	37
A.3	P3	2nd	39

Table A.1: The time required by a participant to produce a drawing with kinematic templates.

Appendix B

Template Algorithms

This appendix provides a formal description of a cursor manipulation function, which was introduced in Chapter 4. Note that Chapter 4 used matrix notation and this appendix uses vector notation. The derived scaling and additive factors, however, are equivalent in both versions.

B.1 Cursor Manipulation Function

We use vectors to describe a cursor manipulation function. We represent vectors using uppercase letters ($\mathbf{A}$) or arrows ($\vec{v}$), the components of a vector with $\langle \ldots \rangle$, real-value scalar quantities using lowercase letters (s), and T for an ordinal number. The magnitude of $\mathbf{A}$ is represented as $\|\mathbf{A}\|$. We use set notation when referring to Γ.

When drawing a stroke (that is, the mouse button is pressed down or the stylus has contact), the pointing device's position is polled by a timer to compute the on-screen cursor's position. At the T^{th} timer event, displacement is received from the pointing device, which we define to be $\Delta\mathrm{M}^T = \langle \Delta m_x^T, \Delta m_y^T \rangle$ where $\Delta\mathrm{M}^T$ is a vector in a 2-D Cartesian coordinate system and Δm_x^T and Δm_y^T are in pixel units. (The operating system's control-display ratio [28] converts the pointing device's displacement from physical to pixel units.) The cursor's new location is a position vector $\mathbf{P}^{T+1}$, computed as shown below:

$$\mathbf{P}^{T+1} = \mathbf{P}^T + \mathbf{F}(\mathbf{P}^T, \Delta\mathrm{M}^T, \Delta t^T) \tag{B.1}$$

where $\mathbf{P}^T$ is a position vector representing the cursor's old location and $\mathbf{F}$ is a *cursor manipulation function* that returns a displacement vector. The cursor manipulation function takes the cursor's old position $\mathbf{P}^T$, the displacement from the pointing device $\Delta\mathrm{M}^T$, and duration between timer events Δt^T. Since $\mathbf{P}^{T+1}$'s coordinates are real numbers, the on-screen cursor is placed at the nearest pixel to $\mathbf{P}^{T+1}$.

B.2 Passive and Active Templates

Many cursor manipulation functions can be created from the general definition. This thesis considers a subset of these functions: passive and active templates. Passive templates modify displacement received from the pointing device. Active templates add movement to the cursor. When no kinematic template is in effect, the cursor manipulation function is $\mathbf{F} = \Delta\mathbf{M}^T$.

B.2.1 Passive Templates

Passive templates use the displacement (change in position) received from the pointing device to position the on-screen cursor. When the user moves the pointing device, the cursor may travel slower or faster, or its direction may change.

When increasing or decreasing the speed of the cursor, a passive template is equivalent to manipulating a pointing device's control-display ratio [28] by the same amount on the X and Y axes.

To change the direction of the cursor, passive templates have a *preferred path of movement* (or *guide path*). Some or all movement off of this path is attenuated based on a template's strength (Section 4.2.3). The function $\mathbf{G}(\Gamma)$ returns a non-zero vector that encodes the preferred path of movement. An analogy for $\mathbf{G}(\Gamma)$ is a ruler's edge that a user wants to draw along. Γ represents a subset of the parameters of $\mathbf{F}$.

The user's displacement along $\frac{\mathbf{G}(\Gamma)}{\|\mathbf{G}(\Gamma)\|}$ is separated into tangential $\Delta\mathbf{M}^T_{\|}$ and orthogonal $\Delta\mathbf{M}^T_{\perp}$ components such that:

$$\Delta\mathbf{M}^T = \Delta\mathbf{M}^T_{\|} + \Delta\mathbf{M}^T_{\perp} \tag{B.2}$$

A passive template modifies a user's displacement along the guide path as follows:

$$\mathbf{F}(\mathbf{P}^T, \Delta\mathbf{M}^T, \Delta t^T) = s_{\|}(\Gamma) \cdot \Delta\mathbf{M}^T_{\|} + s_{\perp}(\Gamma) \cdot \Delta\mathbf{M}^T_{\perp} \tag{B.3}$$

where $s_{\|}(\Gamma)$ and $s_{\perp}(\Gamma)$ are functions that return scalar quantities.

B.2.2 Active Templates

Active templates add displacement to the cursor's position. Under the influence of an active template, the user can still move the cursor. The cursor manipulation function for an active template adds a displacement vector $\mathbf{V}$ to the displacement of the pointing device $\Delta\mathbf{M}^T$:

$$\mathbf{F}(\mathbf{P}^T, \Delta\mathbf{M}^T, \Delta t^T) = \Delta\mathbf{M}^T + \mathbf{V}(\Gamma) \tag{B.4}$$

B.3 Basic Passive and Active Templates

Many passive and active cursor manipulation functions can be created with a subset Γ of the input parameters of $\mathbf{F}$. This section describes how these parameters are used for the templates implemented in my work.

This section begins with the guide path $\mathbf{G}(\Gamma)$ for passive templates, which can be constant or depend on the cursor's location. This section then shows how all active templates depend on the time interval Δt^T for the displacement vector $\mathbf{V}(\Gamma)$. Tables B.1 and B.2 summarize the kinematic templates discussed in this section.

B.3.1 Constant and Position-Dependent Guide Paths

Constant Guide Path

When $\Gamma = \emptyset$, $\mathbf{G}$ is constant unit vector that represents an axis. The equation for a passive template becomes:

$$\mathbf{F}(\mathbf{P}^T, \Delta\mathbf{M}^T, \Delta t^T) = \left\langle s_x \cdot \Delta m_x^T, s_y \cdot \Delta m_y^T \right\rangle \tag{B.5}$$

where s_x and s_y are scalar constants. Setting s_x or s_y to values less than 1 attenuate user input; likewise, values greater than 1 amplify user input.

When $s_x = s_y$, the cursor's speed is increased or decreased (for example, the Speed Up and Slow Down templates). When $s_x \neq s_y$, passive templates guide movement along an axis. For example, a passive Hatching template guides movement along a straight line by setting $s_x = 1$ and $s_y = 0.2$. The scaling value 0.2 is an example; in general, scaling factors are specified when setting a template's strength parameter σ as described in Section 4.2.3.

Position-Dependent Guide Path

When $\{\mathbf{P}^T\} \in \Gamma$, a passive template's $\mathbf{G}(\mathbf{P}^T)$ varies according to the cursor's position. For instance, the Tunnel Line template allows a user to draw a freeform path (Section 4.2.2), which the function $\mathbf{G}(\mathbf{P}^T)$ encapsulates. The template guides movement along the path with $s_{\|} = 1$ and $s_{\perp} = 0.2$ to attenuate displacement off of the path.

A special case occurs when $\mathbf{G}(\mathbf{P}^T)$ is always perpendicular to the vector $\mathbf{P}^T - \mathbf{O}$ (that is, the guide path is a circle). The scaling function $s_{\|}(\Gamma)$ becomes $s_\theta(\Gamma)$. Similarly, $s_{\perp}(\Gamma)$ becomes $s_r(\Gamma)$. A passive Compass template guides movement concentrically about a point by setting $s_r = 0.2$ and $s_\theta = 1$. The circular path can be transformed to create an elliptical path, which is the aspect ratio for "polar-coordinate templates" (Figure 4.1 and Table 4.3).

B.3.2 Time-Dependent Displacement Vectors

By design, all active templates add displacement to the cursor at a timer event. The timer interval changes the effect of an active template's displacement vector. That is, in the same amount of time, calling the timer event more frequently would add more displacement to the cursor. To maintain a constant speed, $\mathbf{V}(\Delta t^T)$ is a function of the timer interval. To show an example, a Conveyor Belt template is created with:

$$\mathbf{V}(\Delta t^T) = \left\langle 0, c\left(\Delta t^T\right)\right\rangle \tag{B.6}$$

$$c\left(\Delta t^T\right) = b \cdot \Delta t^T \tag{B.7}$$

where $c\left(\Delta t^T\right)$ is a function that varies in magnitude to maintain a constant speed b (b is hand-tuned). In this example, the cursor has displacement along the Y axis.

When $\mathbf{V}(\mathbf{P}^T, \Delta t^T)$ is dependent on both time and position, movement can be added towards or about a point $\mathbf{O}$. For instance, the Point Magnet template adds movement towards or away from $\mathbf{O}$ with:

$$\mathbf{V}(\mathbf{P}^T, \Delta t^T) = c(\Delta t^T) \cdot \frac{\mathbf{P}^T - \mathbf{O}}{\|\mathbf{P}^T - \mathbf{O}\|} \tag{B.8}$$

B.4 More Passive and Active Templates

A number of direction-, speed-, and history-dependent functions can be created. These templates were not explained in Chapter 4.

Name	$\mathbf{G}(\Gamma)$	Scaling Function	Effect of Function
Passive: guides movement			
Hatching	axis	$s_x = 1$, $s_y = 0.2$	Attenuates changes in vertical displacement
Grid	axis	$s_x = 1$, $s_y = 0.2$ or $s_x = 0.2$, $s_y = 1$	Displacement is partly attenuated on the vertical or horizontal axis depending on the direction of a user's input
Compass	circle	$s_r = 0.2$, $s_\theta = 1$	Attenuates changes in radius about a point
Radial	circle	$s_r = 1$, $s_\theta = 0.2$	Attenuates changes in angle about a point
Passive: guides movement along a user-provided path			
Tunnel Line	freeform	$s_\parallel = 1$, $s_\perp = 0.2$	Displacement off of a pre-defined path is partly attenuated
Steady Hand	computed	$s_\parallel = 1$ or 0.2, $s_\perp = 0.2$	Helps to draw curves by predicting the user's preferred path of the stroke
Passive: modifies cursor speed			
Maximum Speed		$s_x = s_y \leq 1$	Imposes an upper bound on the cursor's speed
Speed Up		$s_x = s_y = 1.8$	Amplifies displacement from the pointing device
Slow Down		$s_x = s_y = 0.2$	Attenuates displacement
One Way	axis	$s_x = 0.2$ or 1	Slows the cursor when moving left, but allows the cursor to travel right at regular speed

Table B.1: Passive templates created from Equation B.3. (Passive template scaling factors 0.2 and 1.8 are sample values.)

B.4.1 Direction-Dependent Functions

Kinematic templates can use the direction of movement received from the pointing device $\Delta\mathbf{M}^T$. The One-Way and Grid templates are provided as examples.

One-Way Template

The One-Way template slows the cursor only when the user is moving in a particular direction along $\mathbf{G}(\Gamma)$:

$$s_{\parallel}(\Delta\mathbf{M}^T) = \begin{cases} 1-\sigma, & \text{if } \Delta m_{\parallel}^T > 0 \\ 1, & \text{otherwise} \end{cases}$$
$$s_{\perp}(\Delta\mathbf{M}^T) = 1 \tag{B.9}$$

where a template's strength parameter $\sigma = [0, 1]$ as described in Section 4.2.3.[1] The current implementation of the One-Way template uses a Cartesian axis ($\mathbf{G}$ is a constant unit vector).

Grid Template

Conceptually, the Grid template is a XOR composition of two orthogonally-aligned Hatching templates. Movement is guided along one axis or the other axis, but not both at the same time. At the implementation level, the cursor manipulation function compares the user's displacement from the pointing device along the X and Y axes. If movement is larger along the X axis than the Y axis, movement is attenuated along the Y axis, and vice versa. An example is shown below:

Case $\Delta m_x^T > \Delta m_y^T$:

$$s_x(\Delta\mathbf{M}^T) = 1$$
$$s_y(\Delta\mathbf{M}^T) = 1 - \sigma \tag{B.10}$$

Case $\Delta m_x^T \leq \Delta m_y^T$:

$$s_x(\Delta\mathbf{M}^T) = 1 - \sigma$$
$$s_y(\Delta\mathbf{M}^T) = 1 \tag{B.11}$$

[1] Using the notation [a, b], the range of σ is from 0 to 1, inclusive.

Name	V(Γ)	Effect of Function
Active: adds movement to the cursor		
Conveyor Belt	constant	Introduces displacement parallel to an axis
Orbit	about a point	Introduces concentric displacement about a point
Point Magnet	to a point	Introduces displacement to and from a point
Magnetic Line	to a weighted sum of points	Introduces displacement to/from the centre of the path (every point along the path is like a Point Magnet template)
Active: adds movement to the cursor using a history of one's input		
Inertia	computed	Introduces displacement in the same direction as previous input from the pointing device

Table B.2: Active templates created from Equation B.4.

B.4.2 Speed-Dependent Functions

Kinematic templates can use the speed from the pointing device $\|\vec{v}^T\|$ where $\vec{v}^T = \frac{\Delta \mathbf{M}^T}{\Delta t^T}$ is the average velocity. For example, the Maximum-Speed template imposes an upper-bound on the cursor's speed as shown below:

$$s_{\|}(\Gamma) = s_{\perp}(\Gamma) = \begin{cases} \frac{b \cdot \Delta t^T}{\|\Delta \mathbf{M}^T\|}, & \text{if } \|\vec{v}^T\| > b \\ 1, & \text{otherwise} \end{cases} \tag{B.12}$$

where $\left\{\vec{v}^T, \Delta \mathbf{M}^T, \Delta t^T\right\} \in \Gamma$ and b is a hand-tuned speed.

B.4.3 History-Dependent Functions

Kinematic templates can use the cursor's previous location and/or previous displacement from the pointing device. The Steady Hand and Inertia templates are provided as examples.

Steady Hand Template

Similar to the Hatching and Compass templates, the Steady Hand template guides movement along a path; however, the path is predicted from a user's displacement from the pointing device. In addition to attenuating sideways displacement off of the path, the template attenuates backtracking.

First, the preferred path of movement $\mathbf{G}^T$ is predicted at the T^{th} timer event. The path combines previous and current displacement from the pointing device as follows:

$$\mathbf{G}^T = \begin{cases} \gamma \cdot \mathbf{G}^{T-1} + (1-\gamma) \cdot \Delta\mathbf{M}^T, & \text{if } \|\Delta\mathbf{M}^T\| > \epsilon \\ \mathbf{G}^{T-1}, & \text{otherwise} \end{cases} \tag{B.13}$$

$$\mathbf{G}^0 = \langle 0, 0 \rangle \tag{B.14}$$

where $\mathbf{G}^{T-1}$ represents the previously predicted path, $\Delta\mathbf{M}^T$ is the user's displacement on the pointing device, ϵ is a minimum-length threshold (so that the estimated path does not become $\langle 0, 0 \rangle$), and $\gamma = [0, 1]$ is a mixture factor of previous and current input. The mixture factor $\gamma = 0.1$ is empirically chosen for a 16 Hz timer. To maintain $O(1)$ time complexity for this function, $\mathbf{G}^{T-1}$ is saved in a variable.

Displacement from the pointing device along the path $\Delta\mathbf{M}^T_{\|}$ is attenuated by $s_{\perp} = 1 - \sigma$ where σ is user-specified strength parameter.

The Steady Hand template attenuates backtracking along the estimated path vector $\mathbf{G}^T$ by changing $s_{\|}$. Backtracking happens when the user's input displacement $\Delta\mathbf{M}^T_{\|}$ is in the opposite direction of the estimated path $\mathbf{G}^T$ as shown below:

$$s_{\|}(\Delta\mathbf{M}^T) = \begin{cases} -(1-\sigma), & \text{if } \frac{\Delta\mathbf{M}^T_{\|}}{\|\Delta\mathbf{M}^T_{\|}\|} \neq \frac{\mathbf{G}^T}{\|\mathbf{G}^T\|} \\ 1, & \text{otherwise} \end{cases} \tag{B.15}$$

Inertia Template

The Inertia template is an active template that keeps the cursor travelling in the same direction without any displacement from the pointing device. Initially, when no movement is provided, the cursor remains still. After a user moves the pointing device, the cursor travels in a straight line for some time until it reaches the edge of the template's region. It is not modelled after inertia in physics—the name is just a metaphor.

The current displacement of the pointing device $\Delta\mathbf{M}^T$ is added to a cursor's previous displacement $(\mathbf{P}^T - \mathbf{P}^{T-1})$ to find the cursor's displacement in the T^{th} timer event:

$$\mathbf{F}(\mathbf{P}^T, \Delta\mathbf{M}^T, \Delta t^T) = \beta \cdot \Delta\mathbf{M}^T + \big(1 - (1-\sigma)^2\big) \cdot (\mathbf{P}^T - \mathbf{P}^{T-1}) \tag{B.16}$$

where $\sigma = [0, 1]$ is a template's strength and $\beta = [0, 1]$ captures a fraction of new user input. When σ is less than 1, the cursor loses its "force" after a while. The β parameter can be thought of as a resistance to make the cursor move, which is empirically chosen to be 0.3 with a 16 Hz timer. To maintain $O(1)$ time complexity for this function, $\mathbf{P}^{T-1}$ is saved in a variable. (According to the definition of an active template in Equation B.4, a user's current input $\Delta\mathbf{M}^T$ should not be scaled by β.)

Appendix C

Study Forms and Materials

The exploratory evaluation conducted for this thesis (Chapter 5) was approved by the Office of Ethics Research at the University of Waterloo. This appendix contains copies of the approved documents.

Recruitment Material Participants were given a general overview of the study via e-mail or in class.

Consent Form Informed consent was obtained from each participant before starting the study.

Initial Questionnaire In the first session, all participants filled in a questionnaire to gauge the participant's artistic experience.

Sample Tutorial All participants were given a tutorial in the first session. Each participant was given a different tutorial because of changes to the software drawing prototype.

C.1 Recruitment Material

Investigators:

Richard Fung, Michael Terry

Experiment Purpose:

This study investigates new digital drawing tools.

Procedure:

The study will provide a brief tutorial on a new drawing tool and then you will preform a drawing task such as to draw a still life. After completing the task, we will ask you questions about the software to improve its usability.

Commitment:

The study consists of up to five separate sessions, each 45–75 minutes in length. Participation is strictly voluntary. For each session completed, you will receive $10, up to a maximum of $50 over the entire study.

C.2 Consent Form

Title: Digital Drawing Aids User Study

M. Math Candidate: Richard Fung
Faculty Supervisor: Dr. Michael Terry

David R. Cheriton School of Computer Science,
University of Waterloo

Overview
You are being asked to volunteer in a study. The purpose of this study is to evaluate and improve new drawing tools that we have developed. Our drawing tools influence the motion of the cursor to help you draw straighter lines and better geometric shapes. They also enable new forms of digital drawing. In this study, we will observe you as you draw with our new digital drawing software.

The study is split up into up to five (5) separate sessions. You are not required to participate in all five sessions.

Study Investigators
This study is being conducted by Richard Fung and Michael Terry in the School of Computer Science at the University of Waterloo. This work is part of Richard Fung's Master's thesis work.

Your Rights as a Participant
Participation in this study is completely voluntary. You may decline to answer questions and you may end participation at any time by advising the researcher.

Study Description
Any user interface can be improved. In this study, we are interested in learning how we can improve our digital drawing tools.

The study is broken up into five separate sessions. In each session, you will be given a short tutorial on the software to use, then the task of drawing a still life and/or a composition of your own choosing. We will ask you to "think out loud" as you draw. Sharing your thoughts will help us better understand how you perceive the software. Following the drawing task, we will ask you questions about the usability of the software and also show you new design ideas to get your feedback. We may also ask you to demonstrate how you draw using existing drawing tools, to help us understand what features of existing software are useful to you. Each session lasts approximately 45-75 minutes.

Since our goal in the study is to improve our software, we encourage you to be forthright with your comments, criticisms, and suggestions.

In the first session, you will also be asked to fill out a questionnaire that will help us better understand your drawing abilities.

With your permission, the sessions will be recorded using audio, video, screen capture, and/or image recording devices. While your image may appear in video and photographs, your identity will be protected by keeping your name confidential in our electronic recordings. At any time, you may ask us to not use any recording device.

Risks
There are no known or anticipated risks to you as a participant in this study other than those associated with the normal use of computers.

Remuneration
You will be remunerated for participation in the study. For each completed session, up to a maximum of five sessions, you will receive $10, for a maximum of $50.

Confidentiality and Data Retention
All information you provide is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …). Data collected during this study will be retained indefinitely in locked cabinets or on password protected desktop computers in a secure location in the School of Computer Science. Electronic data will not include personal identifying information such as names.

You will be explicitly asked for consent for the use of photo/video/audio data, captured from the recordings for the purpose of reporting the study's findings. If consent is granted, these data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers and you will neither be identified by name nor personal details (beyond those discernable from video images, e.g., gender).

Questions
If you have any questions about participation in this study, during or after the study, please contact:

Richard Fung at *rhfung@uwaterloo.ca*
Dr. Michael Terry at (519) 888-4567 ext. 34528

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. In the event you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at
(519) 888-4567 ext. 36005.

Consent Form
I agree to participate in the **Digital Drawing Aids** user study being conducted by Richard Fung, under the supervision of Dr. Terry of the School of Computer Science, University of Waterloo. I have made this decision based on the information I have read in this Information-Consent Letter and have had the opportunity to receive any additional details I wanted about the study. I understand that I may withdraw this consent at any time by telling the researcher.

I am aware that I have the option of allowing the session to be recorded using audio and/or video recording devices to ensure an accurate recording of my responses.

I am aware that excerpts from the session may be included in any public presentation of this research, with the understanding that the quotations will be anonymous.

I am aware that I have the option of allowing pictures to be taken to complement interviews and observations.

I am aware that I can give permission to allow video and/or digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that identifying characteristics will be made anonymous, and I will not be identified by name. I am aware that I may withdraw this consent at any time without penalty.

I was informed that I may withdraw my consent at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at the University of Waterloo at (519) 888-4567 ext. 36005.

With full knowledge of all foregoing, I agree, of my own free will, to participate in the Digital Drawing Aids user study.

___ YES ___ NO

I agree to have the sessions recorded using an *audio* recording device.

___ YES ___ NO

I agree to have the sessions recorded using a *screen capture* recording device.

___ YES ___ NO

I agree to have the sessions recorded using a *video* recording device.

___ YES ___ NO

I agree to the use of anonymous quotations in any presentation or report that comes of this research.

___ YES ___ NO

I agree to allow the pictures taken for use in teaching, scientific presentations and/or publications. I will not be identified by name, only by labels such as P1, in the pictures.

___ YES ___ NO

I agree to allow the screen capture taken for use in teaching, scientific presentations and/or publications. I will not be identified by name, only by labels such as P1, from the screen captures.

___ YES ___ NO

I agree to allow the video taken for use in teaching, scientific presentations and/or publications. I will not be identified by name, only by labels such as P1, in video presentations.

___ YES ___ NO

___________________________	___________________________
Name of participant (please print)	Name of witness (please print)
___________________________	___________________________
Signature of participant	Signature of witness
___________________________	___________________________
Date	Date

C.3 Initial Questionnaire

Title: Digital Drawing Aids User Study

M. Math Candidate: Richard Fung
Faculty Supervisor: Dr. Michael Terry

David R. Cheriton School of Computer Science,
University of Waterloo

Questionnaire

The following questionnaire will ask you some basic questions about your background. You may decline to answer any question.

1. Gender: Male Female

2. Age:

3. How often have you used the listed software packages in the past *year*?

	Never	Infrequently	Sometimes	Frequently	Very Frequently
Photoshop	1	2	3	4	5
Illustrator	1	2	3	4	5
Corel Painter	1	2	3	4	5
GIMP	1	2	3	4	5
Premiere Pro	1	2	3	4	5
Flash	1	2	3	4	5
MS Paint	1	2	3	4	5
Microsoft Office	1	2	3	4	5
InDesign/Pagemaker	1	2	3	4	5
Other drawing tool(s)	1	2	3	4	5

(please specify which: ____)

4. How often have you used the listed software packages in the past *month*?

	Never	Infrequently	Sometimes	Frequently	Very Frequently
Photoshop	1	2	3	4	5
Illustrator	1	2	3	4	5
Corel Painter	1	2	3	4	5
GIMP	1	2	3	4	5
Premiere Pro	1	2	3	4	5
Flash	1	2	3	4	5
MS Paint	1	2	3	4	5
Microsoft Office	1	2	3	4	5
InDesign/Pagemaker	1	2	3	4	5
Other drawing tool(s)	1	2	3	4	5

(please specify which: ____)

5. How often have you used the listed software packages in the past *week*?

	Never	Infrequently	Sometimes	Frequently	Very Frequently
Photoshop	1	2	3	4	5
Illustrator	1	2	3	4	5
Corel Painter	1	2	3	4	5
GIMP	1	2	3	4	5
Premiere Pro	1	2	3	4	5
Flash	1	2	3	4	5
MS Paint	1	2	3	4	5
Microsoft Office	1	2	3	4	5
InDesign/Pagemaker	1	2	3	4	5
Other drawing tool(s)	1	2	3	4	5

(please specify which: ____)

6. What kinds of pointing devices do you use? For each you use, please specify where you use them and how often.

Mouse	yes	no	If yes, where and how often? ________________________
TabletPC	yes	no	If yes, where and how often? ________________________
External tablet	yes	no	If yes, where and how often? ________________________
Trackball	yes	no	If yes, where and how often? ________________________
Track pad	yes	no	If yes, where and how often? ________________________
Track point	yes	no	If yes, where and how often? ________________________

7. How often do you engage in the following activities?

	Never	Infrequently	Sometimes	Frequently	Very Frequently
Painting (water)	1	2	3	4	5
Painting (oil)	1	2	3	4	5
Charcoal drawing	1	2	3	4	5
Pencil/pen drawing	1	2	3	4	5
Sketch/doodle	1	2	3	4	5
Draw comics	1	2	3	4	5
Colouring	1	2	3	4	5

Please provide us with any additional information about the above pursuits to help us better understand your drawing/painting activities:

8. Please tell us about your drawing education.

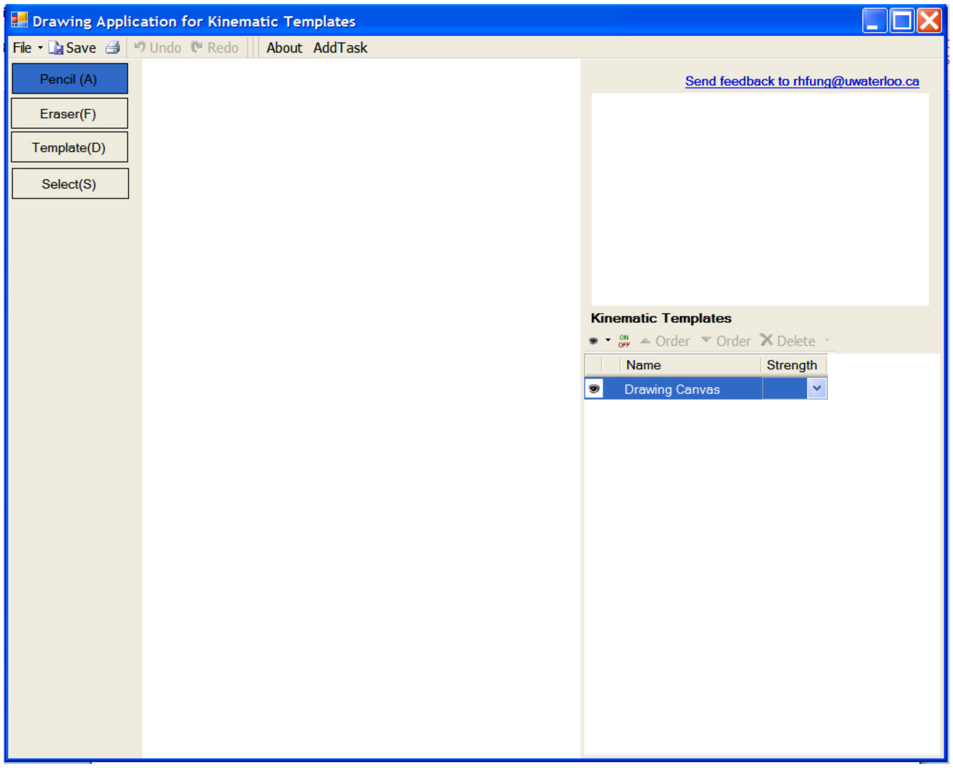
Gr. 1-6 / art class	yes	no	how many years? ________
Gr. 7-9 / art class	yes	no	how many years? ________
Gr. 10-12 / art class	yes	no	how many years? ________
Gr. 1-6 / art school	yes	no	how many years? ________
Gr. 7-9 / art school	yes	no	how many years? ________
Gr. 10-12 / art school	yes	no	how many years? ________
College art class (e.g. Alberta College of Art and Design)	yes	no	how many years? ________
University art class	yes	no	how many years? ________
Architecture drafting	yes	no	how many years? ________
Engineering drafting	yes	no	how many years? ________
CAD drafting	yes	no	how many years? ________
College drafting	yes	no	how many years? ________

Please provide us with any additional information about your education that will help us better understand your drawing capabilities:

C.4 Sample Tutorial

Starting KTPaint

1. You will see some basic commands at the top of the window. To the left is a set of drawing tools.



2. The stylus has two ends, and there are three buttons towards one end. The buttons *do not* provide additional functionality.

3. You should have the Pencil tool selected. Strokes are drawn on the canvas when this tool is selected.

4. Test out drawing strokes on the stylus and tablet to become familiar with it.

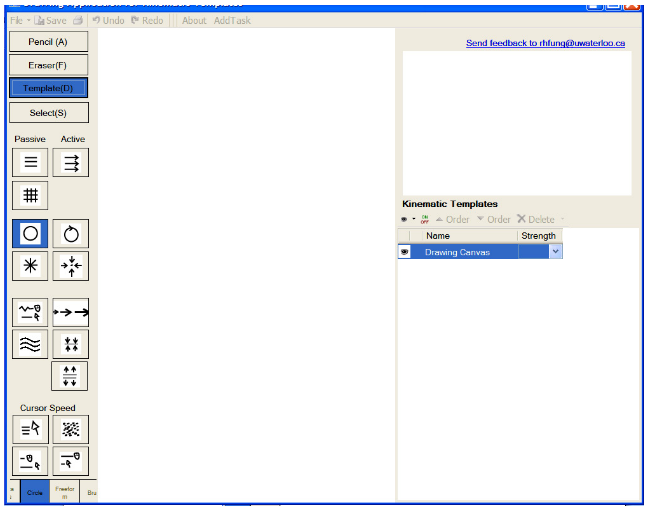
5. Switch to the Eraser tool by pressing the **F** key on the keyboard.

6. To clear the composition, go to “File > New”. When asked, do not save the drawing.

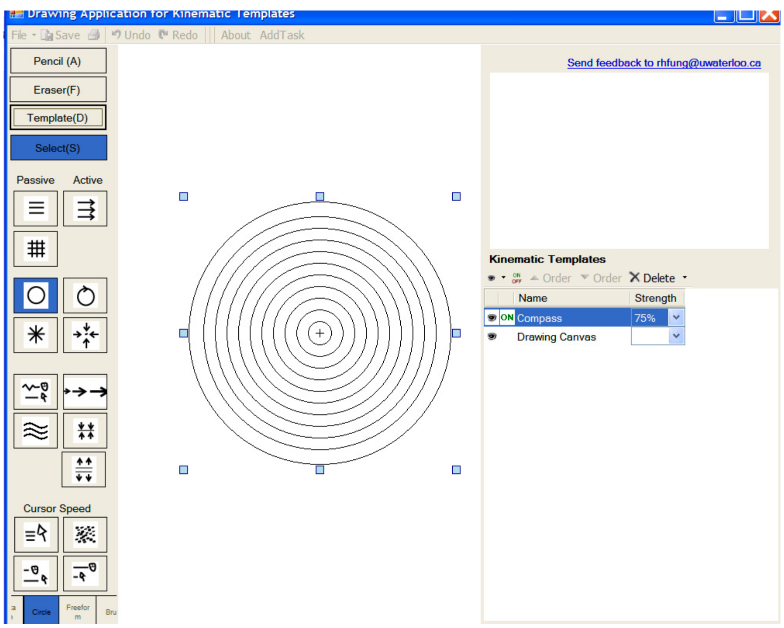
Using a Template

1. To use a kinematic template, choose the Template tool.

2. Select the template with the icon: 



3. Click in the middle of the canvas and pull outwards to add this template. This template area is where the cursor influence will take effect.

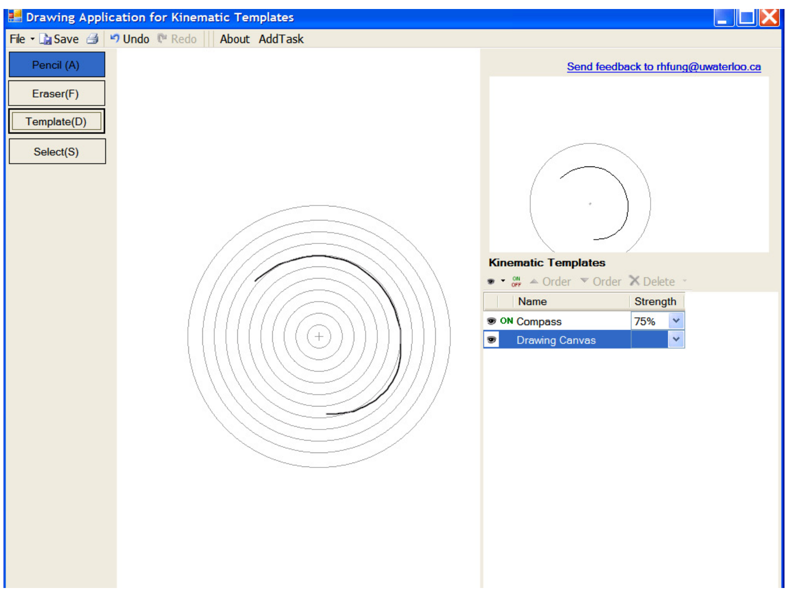


4. Use the handles (blue boxes surrounding the template) to resize the template.

5. To return to the drawing, press **A** on the keyboard.

6. Outside of the circle area, draw some circles, squares, horizontal lines, and vertical lines.

7. Then inside the circle area, draw some circles, squares, horizontal lines, and vertical lines. An example of drawing an arc is shown below.



Moving Templates

1. Select the template by pressing **S** on the keyboard. Then click somewhere on the template.

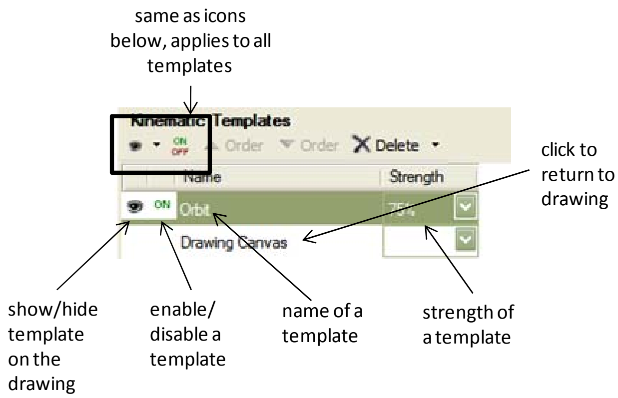
2. Click and drag the template around.

3. Notice how, when moving a template, ink does not follow the template.

4. Press **A** to return to the pencil tool.

5. Another way to select the template is to use the right-side's list and choose "Compass".

6. Press on the Delete button, which is above the list.



7. Notice how the drawn strokes are independent of the template.

Template Strength

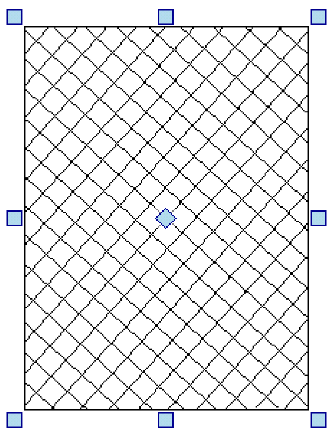
1.Switch to the Template tool and choose a grid template:

2. Click and drag on the composition to add this template.

3. Notice in the right-side pane that the strength for this template is at 75%. This means that 75% of movement is constrained by the computer when drawing inside this template.

4. Find the diamond-shaped blue handle in the middle of the template.

5. Click and drag it to a diagonal, for example, as shown below.



6. Return to the Pencil tool and test out some circles, vertical, and horizontal lines.

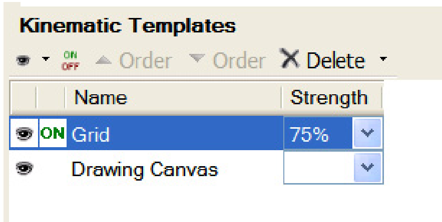
7. Select the grid template and change its strength to 100%.

8. With the Pencil tool, draw some strokes.

9. Select the grid template and change its strength to 50%.

10. With the Pencil tool, draw some strokes.

Template Properties



The eye icon tells if the template should remain visible when you are drawing within the template.

ON The ON/OFF icon tells if the template is active. An inactive template (OFF) will not be visible nor influence drawing.

Removing a Template

1. Templates are not on the undo stack. Press **Ctrl + Z** multiple times to remove all your strokes. Notice how the template remains unaffected.

2. Select the grid template on the right-hand side and press the **Delete** key.

3. The template should be removed.

Short Guide to Templates

The following information tells you how each template may be used. You can test each of these templates in a new drawing.

1. Define the centre point. 2. Drag outwards to define its radius.	**Compass**: prescribes concentric movement **Vanishing point**: prescribes radial movement, opposite to compass
1. Define the top-left corner. 2. Drag out to define the bottom-right corner.	**Hatching**: prescribes movement along an angle that you specify **Grid**: prescribes movement along orthogonal axes >>> **One way:** slows down the cursor if you try to move against the direction shown by the arrow heads
1. Drag a freeform path. 2. Use the diamond-shaped handle to resize templates.	**Tunnel line:** pulls the cursor away from the walls of the path
1. Define the top-left corner. 2. Drag out to define the bottom-right corner.	**Speed up**/**slow down**: increases/decrease the cursor's speed **Minimum**/ **maximum speed:** the software speeds up or slows down the cursor if you move too slow or too quick **Steady hand**: if you try shaking the mouse/pen in this template, those bumps are smoothed out along the general direction of the gesture

Guide to Templates

This page lists all the templates.

1. Define the centre point. 2. Drag outwards to define its radius.	**Compass**: prescribes concentric movement **Vanishing point**: prescribes radial movement, opposite to compass **Orbit**: adds a force clockwise or counterclockwise **Magnet**: pulls or pushes cursor from the centre point
1. Define the top-left corner. 2. Drag out to define the bottom-right corner.	**Hatching**: prescribes movement along an angle that you specify **Grid**: prescribes movement along orthogonal axes >>> **One way:** slows down the cursor if you try to move against the direction shown by the arrow heads **Conveyor belt**: adds a force to the cursor in one direction
1. Drag a freeform path. 2. Use the diamond-shaped handle to resize templates.	**Tunnel line:** pulls the cursor away from the walls of the path **Attraction / Repulsion line:** pulls the cursor to/away from the centre of the path
1. Define the top-left corner. 2. Drag out to define the bottom-right corner.	**Speed up/slow down**: increases/decrease the cursor's speed **Minimum/ maximum speed:** the software speeds up or slows down the cursor if you move too slow or too quick **Steady hand**: if you try shaking the mouse/pen in this template, those bumps are smoothed out along the general direction of the gesture **Inertia**: keeps moving the cursor by itself using previously applied motion (→ → →)

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