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Selexels: a Conceptual Framework for Pointing Devices with Low Expressiveness

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Abstract. As human–computer interaction extends beyond the desktop, the need emerges for new input devices and interaction techniques. However, many novel interaction techniques must be prototyped in a proof-of-concept form, and can suffer from low *expressiveness*: their ability to convey the intended meaning is limited. We present a new conceptual framework based on *selexels* that allows application designers to match the expressiveness of the user interface to that of the input device. This allows the user interface to provide a fluid user experience despite the limitations of the input device. A user study validates the framework, shows that selexel-based pointing tasks can be modeled using Fitts' Law, and provides insights for structuring evaluations of prototype input devices.

1 Introduction

With the era of ubiquitous computing emerging, computing resources are moving off the desktop and extending into our private and public spaces. One research question is how we will physically interact with these computing systems: Will there be a standard equivalent of mouse and keyboard in the post-desktop world? To answer this question, researchers have been developing new applications, devices, and interaction techniques for situated displays [OPC04]. New input device technologies, such as those integrated with mobile phones, can suffer from low expressiveness. Currently, we are lacking the conceptual frameworks to accommodate input devices with low expressiveness.

In this paper, we present a conceptual framework that clearly characterizes the *expressiveness* of relative pointing devices. With this definition, designers will be able to structure user interfaces to match the expressiveness of the input device by limiting the selection resolution of the display, where the selection resolution is independent from the display resolution. To this end, we will introduce the notion of *selexels* that are (to put it simply) "pixels in selection space."

2 Motivation

The inspiration behind this work is the *Sweep* technique [BRSB05] that uses the camera on a mobile phone to detect motion of the handset in several dimensions. This technique enables many direct manipulation interactions with large public displays, including cursor control. Currently, the technique suffers from low sampling rates and resolution because of the limitations of current mobile processors and cameras. With future improvements in mobile processing capabilities, the resolution and sampling rate will improve. However, we want to develop applications that can be used today that still provide a fluid user experience. (Note that this problem also occurs when someone uses standard desktop input devices with a very high resolution display.)

3 Background

The expressiveness of input devices was first defined by Card et al. [CMR91] as an evaluation criterion capturing how well the input conveys the intended meaning. Without explicit guards, a mismatch of expressiveness can cause problems in the user interface. These problems were formally described by Card et al. using parameters of input devices. The **In** parameter represents the input domain, which describes the physical properties of the world. The **Out** parameter represents the output domain set of the input device, which describes the values that an input device can produce.

> "In the design of input devices, an expressiveness problem arises when the number of elements in the **Out** set does not match the number of elements in the **In** set to which it is connected. If the projection of the **Out** set includes elements that are not in the **In** set, the user can specify illegal values; and if the **In** set includes values that are not in the projection, the user cannot specify legal values." [CMR91]

For an example of an expressiveness problem, consider a touch panel overlaying a display where the resolution of the touch panel (where transducer values form the **Out** set) is much less than the resolution of the display (where pixels form the **In** domain). If a user wanted to select an individual pixel, he would not be able to express that request exactly.

The expressiveness problem is closely related to the problem of device precision. Pointing precision characterizes how small of a target can be conveniently selected with the device. Quantifying the pointing precision of absolute input devices in terms of screen area is relatively straightforward. However, quantifying the precision of relative pointing devices is more difficult. Card et al. [CMR91] quantify precision of input devices in terms of bits using insights from subjective ratings of the difficulty of pointing tasks using the mouse in text editing applications, where the threshold between easy and hard tasks lies between selecting a word and selecting a character; selecting a word is the *hardest easy task*, and selecting a character is the *easiest hard task*. Thus device precision is defined by Card et al. as follows:

> "We characterize the precision of a device as the *ID* that requires the same amount of time as the easiest hard task of the mouse." [CMR91]

Here, *ID* is the Fitts' law index of difficulty of the pointing task measured in bits. The problem with this definition is that it requires empirical testing to determine the precision of the device, limiting its utility as a design tool. In this paper, we propose a new definition to quantify the precision of relative input devices based on device parameters, and show how this definition can be used to predict changes in precision without empirical testing.

4 The Selexel Approach

Our approach is to match the selection resolution of the user interface to the expressiveness of the input device. This is accomplished by dividing the screen into atomic selectable elements, or *selexels*, with a resolution that is independent of the pixel resolution of the screen (see Fig. 1). By separating selexels from pixels, we adjust the range of motion in the interface to support a smooth and fluid user experience for the input device in use, while preserving the screen resolution and information capacity of the display.

The traditional conceptual framework for analyzing pointing tasks separates the task into two spaces: motor space and display (or visual) space. This is reflected by the frequent use of the control–display (C–D) ratio to describe the relationship between motion distance in the physical world (meters) and motion distance on the screen (pixels). Our new conceptual framework adds selection space as a level of indirection between motor space and display space. Using this framework, a traditional desktop interface is a special case where the selection space is identical to the display space. We note that since the motor space is mapped to selection space and not display space, the concept of C–D ratio is replaced by the notions of Control-Selection (C–S) ratio for the relationship between motor and selection space, and Selection-Display (S–D) ratio for the relationship between selection and display space.

Expressiveness is easily confused with the notion of device resolution. Resolution of an input device, usually measured in dpi (dots per inch), describes precision in motor space; how small of a movement, in motor space, can be distinguished by the transducer. Expressiveness, characterized by selexels (unitless), describes precision in selection space; how many distinct positions, in selection space, can one express, or "reach", using this input device in a given timeframe. The length of this timeframe will be discussed below.

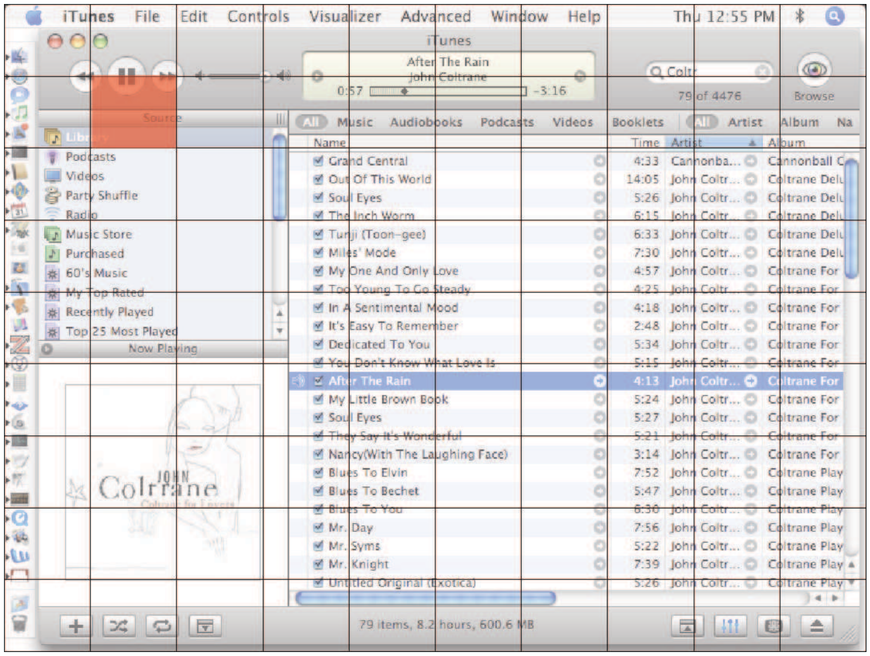

Fig. 1. A sample selexels screen division over a typical desktop interface. It indicates that existing desktop interfaces may need to be modified to disambiguate selection with low precision pointing devices.

5 Related Work

There are many approaches to improving selection performance in pointing tasks that increase the size of the cursor. The *area cursor* has an active selection region that spans a screen area, rather than a single point. Kabbash and Buxton [KB95] show that selection of a point-sized target can be accurately modeled using Fitts' law by setting W to the cursor width, reducing the index of difficulty for small targets. However, area cursors can overlap multiple targets, making user selection ambiguous. Worden et al. [WWBH97] propose an improved area cursor with an additional hot spot at its center to disambiguate between multiple closely-spaced targets within the cursor area. This cursor performs better than the standard point cursor when targets are far apart, and identically to point cursors when targets are closer together. The Bubble cursor [GB05] dynamically resizes the active cursor region to always encompass exactly one selectable object that is nearest to the center position of the cursor. This effectively changes the width of the target to the size of the Voronoi region surrounding the target, maximizing its size in motor space. This technique is superior to previous techniques in that it also demonstrates benefits over the point cursor for densely packed targets. However, for each of these solutions, cursor motion is governed by pixels, making them unsuitable for tasks for input devices with low expressiveness.

A cursor in the selexel domain is similar to these techniques in that it has an active region that spans a screen area, rather than a single pixel. However, a cursor highlighting a single selexel is actually a point cursor in selection space, even though the active region may span a screen region in display space. Thus, the techniques proposed above should result in the same performance improvements if applied to targets in selection space, but we leave the experimental validation of this theory to future work.

Several selection techniques have been shown to increase pointing performance by dynamically adjusting the control–display (C–D) ratio [BGBL04, BCHE05], sometimes referred to as cursor acceleration. Pointing performance can be improved by increasing the control–display ratio while approaching the target (and thereby decreasing the distance traveled in motor space), or by decreasing the control–display ratio while inside the target (and thereby increasing the target size in motor space). In this paper, we focus on a static C–S ratio. However, these adaptive techniques should still be applicable in the selexels domain by replacing the C–D ratio with the C–S ratio, but again we leave the validation of this theory to future work.

6 The Selexels Framework

A selexel cursor has the same ambiguity problem as the area cursor when covering multiple targets, as demonstrated in Fig. 1. There are several options to eliminate this ambiguity:

- The input device could be restricted to one that supports the minimum selexel resolution required for the interface to have no cursor overlap of multiple targets. In this way, the selexels framework allows us to define device criteria for interacting with existing applications. However, most desktop applications are not compatible with a grid selection scheme, requiring the standard "one selexel per pixel" scenario.
- Alternatively, if a situation requires the use of a low precision pointing device (e.g., in the aforementioned case of large public display interactions using the Sweep technique), the layout of the interface could be altered to be compatible with the selexel resolution of the input device. This can be accomplished through manual rearrangement, or through automatic layout of user interfaces as in [GW04]. In this way, the selexels framework allows us to define graphical layout constraints for applications designed for low-expressiveness pointing techniques. (See Future Work for more discussion on this topic.)
- Lastly, drawing inspiration from the Bubble Cursor [GB05], the size of the selexel in pixels (the S–D ratio) can be dynamically varied to always contain one and only one selectable target, essentially mapping each selexel to the Voronoi regions of the targets on the display, and thereby minimizing the number of selexels in an interface. A simplified 1D version of this approach is embodied by the tabbed interface, where a user can cycle the selection focus through the selectable items in an interface, often by pressing the tab key. The problem with this approach is that the resulting C–D ratio (a combination of C–S and S–D ratios) might be unpredictable for users, preventing them from accurately planning their movements. In this paper, we focus on the case of a constant S–D ratio.

6.1 Expressiveness of Relative Pointing Devices

We characterize the expressiveness of a relative pointing device using the precision of the input technique based on models of human motor performance including Fitts' law [Fit54, Mac92], and the linear speed-accuracy tradeoff [SZH+79]. The reasoning behind our definition can be best explained using the conceptual framework presented by Meyer et al. [MSK+90], which was used to create the stochastic optimized submovement model. This model attempts to reconcile the strengths of Fitts' Law (better suited to model spatially constrained tasks, such as cursor positioning using a mouse), and the linear speed-accuracy tradeoff [SZH+79] (better suited to model temporally constrained tasks, such as cursor positioning using a joystick to control cursor velocity) into a unified model capable of expressing a wider range of movement tasks. The stochastic optimized submovement model is based on the assumption that the subject attempts to hit the center of the target region with their first submovement (see Fig. 2). If the primary submovement successfully acquires the target, then the action terminates. The model anticipates noise in the motor system to affect the primary submovement, causing a slight variation from the intended movement and the actual result. If a miss occurs, then a secondary corrective submovement will be used, and so on. Thus for a pointing task to be valid for this model, the input device must theoretically allow a subject to reach a target in the primary submovement, even though noise in the motor system may require additional submovements before the target is successfully acquired.

> We define the *expressiveness* of a relative pointing device as the number of distinct positions a user can express in a single submovement.

The duration of a submovement is defined by the basic human reaction time. Using Card, Moran, and Newell's human processor model [CNM83], the basic reaction time is approximated by $T_{sub} = \tau_p + \tau_c + \tau_m$, or one cycle for each of the perceptual, cognitive, and

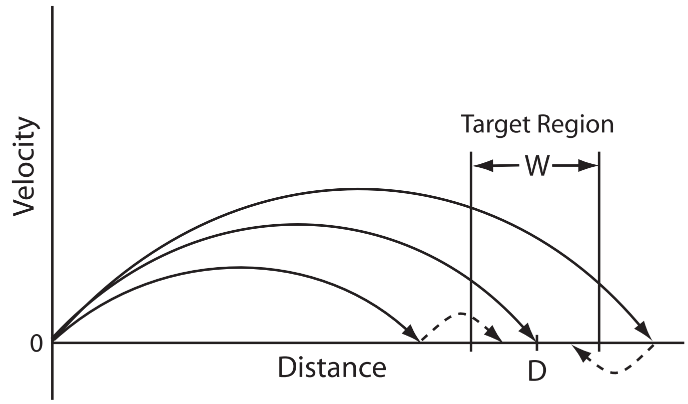

Fig. 2. The optimized dual-submovement model is a variation of the optimized submovement model with two submovements. Hypothetical primary submovements are marked with a solid line, secondary submovements with a dashed line. (based on Figure 6.8 from [MSK$^+$90].)

motor processors. This equation approximates the time for the user to observe the motion progress (τ_p), decide on a correction (τ_c), and perform the correction (τ_m). For the average user ("middleman" in [CNM83]), this sum would result in an approximate submovement duration of 240ms.

We define the expressiveness of a relative input device in terms of the motion throughput of the transducer (D in dots per sec.), and the psychological limits of human information processing in terms of the submovement duration (T_{sub} in sec.). Motion throughput describes the rate at which motion information can be processed by the input device. Industry typically reports the device specifications in terms of device resolution (N_{dev} in dots per inch) and maximum supported rate of motion (v_{motion} in inches per sec.). We can use these parameters to define motion throughput as follows:

$$D := N_{dev} * v_{motion}$$

Alternatively, the motion throughput can be defined using the transducer resolution (N_{trans} in dots per sample) and sampling frequency (f_{sample} in samples per sec.), assuming a single transducer per axis of motion. To simplify the definition, we first define the notion of sample reach ($Reach_{sample}$ in dots) as the maximum selexel distance that can be reached in a single sample.

$$Reach_{sample} := .5 * (N_{trans} - 1)$$

The scaling factor (.5) is necessary because the transducer resolution is split into positive and negative values along the motion axis. One sample is removed to account for the zero value which has no motion. If positive and negative measurements are separated into multiple transducers, this equation may require slight adjustments. The motion throughput can then be alternatively formulated as,

$$\begin{aligned} v_{motion} &:= f_{sample} * Reach_{sample}/N_{dev} \\ D &= N_{dev} * f_{sample} * Reach_{sample}/N_{dev} \\ D &= f_{sample} * Reach_{sample}. \end{aligned}$$

We further define the submovement reach ($Reach_{sub}$ in dots) as the maximum selexel distance that can be reached during a single submovement (T_{sub}).

$$Reach_{sub} := D * T_{sub}$$

We note that $Reach_{sub}$ is measured in dots, which is a unitless quantity relating to the number of distinct values that can be expressed during a submovement.
Expressiveness can then be defined as the set of points ($\mathbb{E}$) that a user can express in a single submovement. For a one-dimensional input device, assuming a C–S gain function of $S(t)$ (i.e. cursor acceleration), we can define expressiveness as follows:

$$\mathbb{E} := \{S(x) \text{ :where } 0 < x < Reach_{sub} \text{ and } x \in \mathbb{Z}\},$$

where $\mathbb{Z}$ is the set of all integers. We note that in the case of no C–S gain ($S(t) = t$), this reduces to the set of integers between 0 and $Reach_{sub}$, and the cardinality of the expressiveness set ($|\mathbb{E}|$) is $Reach_{sub} + 1$.
An input device is said to have higher expressiveness when the cardinality of the expressiveness set ($|\mathbb{E}|$) is greater than that of another device. We also note that changing the C–S gain function from $S(t) = t$ cannot increase the cardinality of the expressiveness set; instead, it may create unreachable gaps or even decrease expressiveness if multiple transducer values map to the same cursor displacement in selexel space. This theoretical observation fits with the findings of Jellinek et al. [JC90] who explored second order cursor acceleration using several different C–D ratios on a mouse, but found no performance improvements.

6.2 Examples

A case study of specific input devices should serve to illustrate the theoretical definition with practical examples. They show how expressiveness can be used as a design metric to gauge the suitability of a relative input device for a particular interaction scenario.

Opto-Mechanical Mouse Figure 3 shows the inner workings of an optical-mechanical mouse. The resolution (dpi) of the mouse is determined by the ratios of the physical dimensions of the ball, the grips, and the discs. The current industry standard for device resolution (N_{dev}) of these mice ranges from 400 to 800 dpi. For this example, assume that the pulse accumulator is capable of storing 8 bits of information for each dimension of motion, resulting in a transducer resolution (N_{trans}) of 256 possible outputs per sample.
For traditional PS/2 mice, common in the 1990s, the default sampling rate under Windows 95 / 98 was 40 Hz. Thus, their throughput can be calculated as follows:

$$\begin{aligned} D &= (N_{trans} - 1) * .5 * f_{sample} \\ &= (256 - 1) * .5 * 40 \\ &= 5120 \end{aligned}$$

Then their $Reach_{sub}$ follows as:

$$\begin{aligned} Reach_{sub} &= D * T_{sub} \\ &= 5100 * .240 \\ &= 1224 \end{aligned}$$

Thus a user would start to have problems with expressiveness using this device with a screen resolution of 1225 or higher in any dimension.

Optical Mouse As another example, consider the Agilent Technologies ADNS2610 optical mouse sensor [Agi04]. It supports a resolution of 400 dpi, and rates of motion up to 12 inches per second. Thus, its throughput can be calculated as follows:

$$\begin{aligned} D &= N_{dev} * v_{motion} \\ &= 400 * 12 \\ &= 4800 \end{aligned}$$

Fig. 3. An optical-mechanical mouse: (1) Motion across the desktop surface moves the ball. (2) Grips transfer the ball movement to turn (3) optical encoding disks. (4) Infrared LEDs shine through the holes. (5) Infrared sensors accumulates light pulses and converts them into X, Y motion. (Source: Wikipedia)

Then its $Reach_{sub}$ follows as:

$$\begin{aligned} Reach_{sub} &= D * T_{sub} \\ &= 4800 * .240 \\ &= 1152 \end{aligned}$$

Thus a user would start to have problems with expressiveness using this device with a screen resolution higher than 1152 in any dimension. Note that if the resolution of the sensor was bumped to 800 dpi, then the $Reach_{sub}$ also doubles supporting resolutions much higher than 2000 pixels in either dimension.

Analog Joystick Consider a USB analog joystick (shown in Figure 4) that has a resolution N_{trans} of 256 positions on each axis after digital conversion. The joystick measures absolute tilt in the (*rX*, *rY*) dimensions, but is used as a relative positioning device by mapping tilt to control the velocity of cursor movement. Positioning a cursor with velocity control is a temporally constrained task. Modern operating systems support sampling such USB devices at a rate of 125 Hz. Thus the rate of motion D can be expressed as follows:

$$\begin{aligned} D &= (N_{trans} - 1) * .5 * f_s \\ &= (256 - 1) * .5 * 125 \\ &= 15937.5 \end{aligned}$$

Then the resulting $Reach_{sub}$ follows as:

$$\begin{aligned} Reach_{sub} &= D * T_{sub} \\ &= 15937.5 * .240 \\ &= 3825 \end{aligned}$$

This indicates that this particular joystick has a very high expressiveness, notably higher than the mice examined above. It should be noted that expressiveness does not necessarily indicate that a device can be used with a higher felicity [CMR91]. To draw conclusions about the pointing speed (or device bandwidth), it is still necessary to compare the devices using an ISO 9241-9 [ISO00] standard empirical evaluation. However, the expressiveness reveals which pointing tasks are possible for the input device in a single submovement.

Fig. 4. An analog joystick measures absolute tilt of the stick in the *rX*, *rY* dimensions.

Sweep Sweep [BRSB05] is an experimental input technique that uses the camera on a mobile phone to detect relative motion of the phone. The interaction is intended to support novel interactive applications for large public displays. The current implementation of this technique detects relative motion in the (X, Y) dimensions with a sample frequency (f_s) of 12.5 Hz and a transducer resolution (N_{trans}) capable of detecting 9 distinct dots (displacements) per sample. The actual physical sensor in this example is the camera which has a relatively high resolution. However, for the purposes of expressiveness we consider the output of the motion detection algorithm to be the transducer output since those are the actual values that can affect the cursor. Thus,

$$\begin{aligned} D &= (N_{trans} - 1) * .5 * f_s \\ &= (9 - 1) * .5 * 12.5 \\ &= 50 \end{aligned}$$

Then the $Reach_{sub}$ follows as:

$$\begin{aligned} Reach_{sub} &= D * T_{sub} \\ &= 50 * .240 \\ &= 12 \end{aligned}$$

Thus the largest resolution that would not result in expressiveness problems would be 13×13. This means that the use of this input device with standard desktop resolution will result in difficulties because of the severe mismatch in expressiveness. This matches the difficulties expressed in a previous evaluation of the Sweep technique [BRSB05].

6.3 Expressiveness of Absolute Pointing Devices

For direct surface interaction, such as a touch screen, the expressiveness $|\mathbb{E}|$ simply maps to the resolution of the input surface (dpi) multiplied by its size. The $Reach_{sub}$, however, can be limited by the physical characteristics of the relevant parts of the human body, such as arm length.

7 Practical Application of Selexels

Mismatches in expressiveness can disrupt the user exprience. This new method of characterizing expressiveness allows us to identify and resolve these mismatches to provide a more fluid experience. Selexels provide a level of abstraction that allows us to reduce the selection resolution of the display to match the expressiveness of the input device, without sacrificing valuable display resolution.

7.1 Usage Scenario

We may apply these concepts to interactions in the domain of large public displays, as illlustrated in the following scenario.

> While Hans is waiting for his train to Berlin, he notices a large public display on the platform displaying advertisements and community news. He recognizes the style of a 2D bar code next to the display. He has previously used a similar barcode to initiate interaction with a demo display in the T-Mobile showroom. He takes a picture of the code (just as he had done in the showroom), and his phone automatically connects wirelessly to the display via Bluetooth and transfers information characterizing its input expressiveness. The advertisement transforms into an interactive menu with a selexel resolution matched to his input device, allowing Hans to select from several options including: browsing the news, checking the weather, or even contributing to an interactive community bulletin board where people post images, video, and text. Hans waves his phone through the air using the Sweep technique to select the weather option. A map of Germany appears and as he navigates the cursor over different regions, the current conditions and forecast are displayed to the right of the map. It looks like the previously forecast afternoon showers are no longer a threat in Berlin. Hans then calls his wife to invite her to go to their favorite restaurant for dinner on the quaint cobblestone patio.
>
> Shortly after Hans leaves, Maria wants to check up on her bulletin board post from last week about the proposed new theatre to be built next to the train station. Her phone is much older than Hans's and the expressiveness of the Sweep technique is much lower. As she connects to the display, the cursor grows and the menu options move further apart to adapt the selexel resolution of the interface to match that of her phone. Now she is able to use her more limited phone as a pointing device, yet the system still provides a fluid experience.

This scenario shows how expressiveness can be used to tailor a user interface on the fly to the capabilities of the input devices that are used in a particular interaction. These concepts may also be useful for scenarios using very high resolution displays such as those described in [CRM$^+$06].

8 Evaluation

Card, English, and Burr's [CEB78] seminal work showed that the *efficiency* of pointing devices can be analyzed using Fitts' law [Fit54, Mac92], which models human motor performance by predicting movement time in a pointing task as follows:

$$MT = a + b * ID$$
$$ID = \log_2(\frac{D}{W} + 1),$$

where D is the target distance, W is the target width, and ID is the index of difficulty of the pointing task. a and b are empirically determined constants that vary with the characteristics of the input device. These empirically determined constants are affected by a wide variety of input device characteristics including mass, friction, resolution, sampling rate, lag, and C–D gain [Mac92]. Changes in any of these parameters will also change the result of the regression analysis.

In a series of experiments, we attempt to characterize how pointing tasks are affected by the relationship between the expressiveness of the input device and the selexel resolution of the display. A custom test program allows us to vary the selexel resolution of the display, and vary the expressiveness of input devices by artificially limiting the resolution and sampling rate. The test application hides the system cursor and displays a point cursor in selexel space (an area cursor in pixel space) that moves selexel-wise, appearing to jump from one selexel position to the next. The application was implemented in Objective-C under Mac OS X.

C-S ($Reach_{sample}$)	Selexels	Pixels	S-D	C-D
1280	1280	1280	1	1280
256	256	1280	0.2	1280
40	40	1280	0.03125	1280
20	20	1280	0.01563	1280

Table 1. By matching the selexel resolution to the C–S ratio ($Reach_{sample}$) we maintain a constant C–D ratio across the test conditions.

9 Experiment 1

Given that the selexel cursor represents a point cursor in selexel space, Fitts' Law [Fit54] should be a suitable model for predicting target aquisition time in pointing tasks. However, the selexel cursor is an area cursor in pixel space. Previous studies of area cursors have demonstrated that selection using area cursors lowers the index of difficulty for smaller targets [KB95, WWBH97]. Also, as users have come to expect pixel-wise cursor motion, the selexel-wise motion may impede or annoy the user. Thus, it is important to examine whether pointing in the selexel paradigm can be modeled by Fitts' Law. This experiment is specifically designed to examine if the input device expressiveness affects the empirically determined constants of the input device (a and b).

9.1 User Study Design

Using a within-groups design, users were asked to complete a horizontal tapping test based in part on ISO 9241-9 [ISO00]. For each test condition, the same range of target distances ($D =$ 256, 640, and 1024 pixels) and target widths ($W =$ 64 and 128 pixels) were used.
To simulate input devices of varying expressiveness, the sampling period of the mouse was artificially increased to 20ms to guarantee a constant sampling rate for all test conditions. The transducer resolution (N_{trans}) of the input device was varied to have a $Reach_{sample}$ of 1280, 256, 40, and 20 dots per sample. The selexel resolution of the test UI was designed to match the $Reach_{sample}$ of the input devices with selexel resolutions of 1280×800, 256×160, 40×25, and 20×13 selexels respectively (selexel sizes of 1×1, 5×5, 32×32, and 64×64 pixels). By matching the selexel resolution of the UI (S–D ratio) to the transducer resolution of the input device (C–S ratio), the resulting C–D ratio remains effectively constant (see Table 1) across the different conditions.
The cursors were all displayed as point cursors in selexel space, except for the one selexel per pixel condition. In this condition, a 5×5 pixel area cursor was used instead of a 1×1 pixel point cursor for visibility. This particular cursor still maintained the other properties of a point cursor in pixel space in that it had an active region of 1×1 pixel at the center of the cursor, and its motion was pixel-wise.
The pixel placement for target pairs remained constant across test conditions. However, the pairs of targets were placed such that some were aligned to the selexel boundaries and some weren't (depending on the selexel condition). When a target is not aligned to selexel boundaries, its width may span over several selexels even if its size in pixels is much less than a single selexel.
Both the ordering for the different expressiveness conditions, and the ordering for the different IDs were varied to reduce learning effects in a within-groups study. A fully crossed design resulted in a total of 24 combinations of D, W, and matched $N_{trans}+$ selexel resolution pairs. For each combination, 25 target selections were required.

9.2 Participants

10 volunteers (4 females, 6 males) ranging in age from 22 to 27 participated in the study. All of the participants were students (8 computer science, and 2 political science) from a local university.

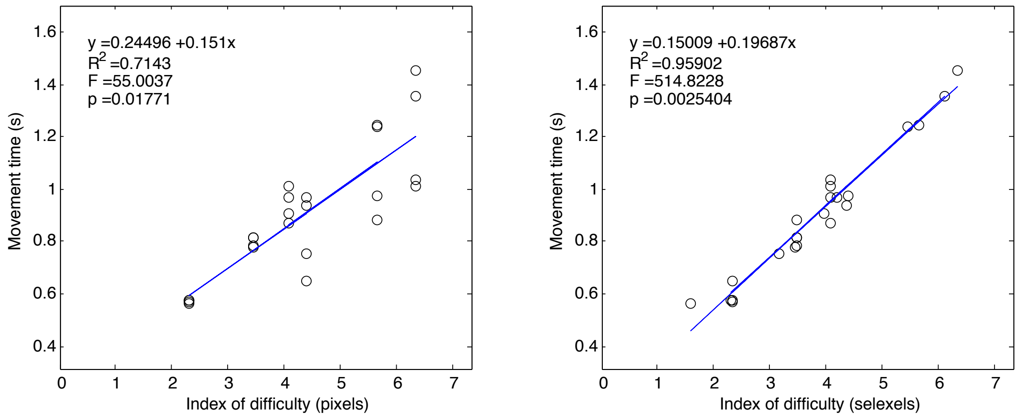

Fig. 5. (Left) Index of difficulty calculations in terms of display pixels are not well suited for selexel pointing tasks. (Right) The same data reinterpreted with index of difficulty in terms of selexels provides a strong correlation. The correlation is strong despite the fact that this data is mixed across selexel conditions, demonstrating that selexel resolution has no impact on device performance as long as the C–D ratio is preserved. Here the C–D ratio is preserved by matching the expressiveness of the UI to the expressiveness of the input device by changing the selexel resolution.

9.3 Equipment

The tapping test was performed using a Logitech M-BJ58 (800 dpi) USB optical mouse, an Apple 23" Cinema LCD monitor with the display resolution set to 1280×800, and a PowerMac Dual 2.0 GHz G5 processor.

9.4 Results

The results from this experiment are shown in Figure 5. The graphs indicate that using the distance and width in units of pixels results in a valid ($p < 0.05$), but poor model ($R^2 = 0.71$) for selexel pointing tasks. If the same data is reinterpreted using target distance (D) and target width (W) in units of selexels, the model becomes much improved ($p < 0.005$, $R^2 = 0.959$). An analysis of variance (ANOVA) shows a significant effect for index of difficulty [$F(15, 23) = 42.99$, $p < 0.0003$], and no significant effect for the expressiveness conditions [$F(2, 23) = 1.64$, $p < 0.28$].

9.5 Discussion

These results confirm previous findings [KB95] that show that area cursors lower the index of difficulty for small targets, but these results further show that movement time for targets larger than one pixel can be accurately predicted using units of selexels to calculate the ID for selexel pointing tasks.

Another result of this experiment is that selexel-wise motion had no effect on task completion time. This is demonstrated by the fact that the mixed results can be modeled very well ($R^2 = 0.959$) using a single linear regression.

A more significant result from this experiment is that, contrary to what one might expect, transducer resolution (N_{trans} in dots per sample) has no effect on task completion time, as long as the C–D ratio is preserved across test conditions. This result has important implications for evaluating prototype input techniques with low transducer resolution, such as the Sweep technique. As mobile processors and cameras continue to improve, motion detection will become more powerful, and the resulting transducer resolution will improve. Using this study as a model, an evaluation can be structured such that conclusions can be made about pointing performance of future mobile phones as the transducer resolution

(dots per sample) continues to rise (assuming all other parameters, such as C–D ratio, remain the same).
The error rates for pointing under selexels were lower than pointing under pixels. This can be explained using the speed-accuracy trade-off since the target widths effectively expand to the selexel span of the target, reducing the physical accuracy required for the pointing task.

10 Experiment 2

To further validate our conceptual framework, it is necessary to experimentally verify the notion of $Reach_{sub}$, the maximum distance that can be reached in the first submovement. Based on the conceptual framework, the selexel resolution should match $Reach_{sub}$ preventing any target distances from exceeding the maximum distance. This experiment examines the effect of target distances exceeding $Reach_{sub}$.

10.1 User Study Design

This experiment was structured as a horizontal tapping test, very similar to Experiment 1. It used a within-groups design, and reused the parameters for target distance (D), target width (W), and target placement. However, in this experiment we maintained the transducer resolution (N_{trans}) to have a constant $Reach_{sample}$ of 20 dots per sample. With a sample period of 20 ms, the $Reach_{sub}$ can be calculated as follows:

$$Reach_{sub} = f_{sample} * Reach_{sample} * T_{sub}$$
$$Reach_{sub} = (1/.020) * (20) * .240$$
$$Reach_{sub} = 240$$

This $Reach_{sub}$ of 240 selexels per submovement was maintained across all conditions.
The selexel resolution of the display (and resulting pixel size) was varied as in Experiment 1. As a result the C–S ratio remained constant, while the S–D ratio varied, resulting in a range of C–D ratios.
The ordering for the different selexel resolutions, and the ordering for the different IDs were varied to reduce learning effects in a within-groups study. A fully crossed design resulted in a total of 24 combinations of D, W, and selexel resolution. For each combination, 25 target selections were required.

10.2 Participants

11 volunteers (2 females and 9 males) ranging in age from 22 to 29 participated in the study. All of the participants were students (8 computer science, 1 political science, and 2 undisclosed) from a local university.

10.3 Equipment

The equipment used was the same as Experiment 1.

10.4 Results

The results from this experiment are shown in Figure 6. In the first graph, all of the conditions are mixed, resulting in data that is unable to be modeled using Fitts' Law ($p = 0.61$). In the second graph, the same data from the first graph is reinterpreted by removing conditions (marked with an "x") where the target distance (D) exceeds the submovement reach ($Reach_{sub}$) to allow comparison with the original data. The second graph results in a data set that can be modeled by Fitts' Law ($p < 0.05$). Using an analysis of variance (ANOVA), a binary "reach exceeded" variable has a significant effect [F(1,23)=28.79, p¡0.00003] showing that target distances exceeding submovement reach ($Reach_{sub}$) increase task completion time.

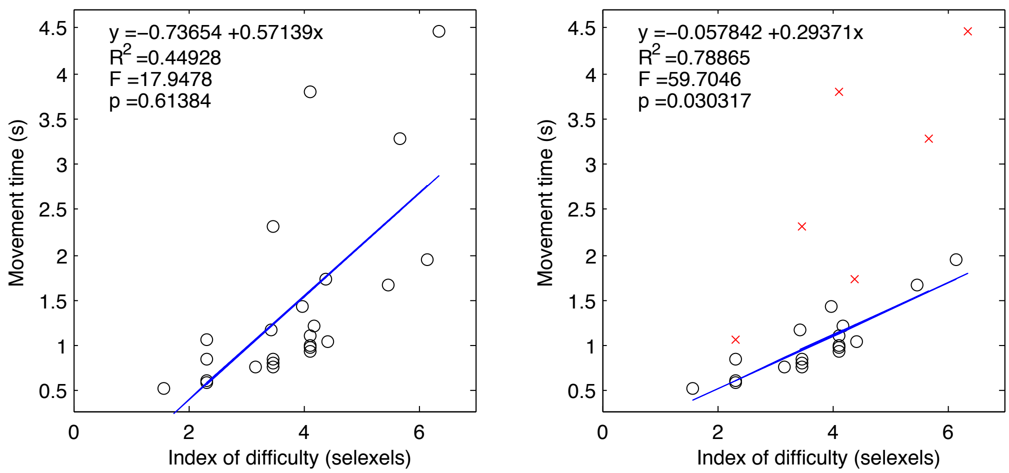

Fig. 6. (Left) In this experiment, contrary to the previous experiment, the mixed results across experimental conditions cannot be modeled with Fitts' Law. (Right) The same data is shown with target distances greater than $Reach_{sub}$ removed (marked as "x"). The conditions where the targets were placed only slightly further (256 selexels) than the submovement reach (240 selexels) are still relatively close to the model, indicating that slight mismatches in expressiveness are only a minor issue. However, the extreme mismatches in expressiveness with target distances of (512, 1024) are extreme outliers in terms of target acquisition time. With these points removed, the data can be modeled by Fitts' Law ($p < 0.05$). These graphs combined indicate that an upper bound to the validity of Fitts' Law can be predicted.

10.5 Discussion

In the second graph of Figure 6, the conditions where the targets were placed only slightly further (256 selexels) than the submovement reach (240 selexels) are still relatively close to the other samples, indicating that slight mismatches in expressiveness are only a minor issue. However, the extreme mismatches in expressiveness with target distances of (512, 1024) are extreme outliers in terms of target acquisition time. This indicates that target distances exceeding $Reach_{sub}$ disrupt the user experience and increase task performance time.

The reader may have noticed that the quality of the input device model ($R^2 = 0.788$) is much lower than that of the previous experiment. This is due to the fact that the data has mixed C–D ratios across the different experimental conditions. As mentioned before, the C–D ratio is one of the input device parameters that is captured by the Fitts' law coefficients (a and b). Separating the different C–D ratio conditions, as in Figure 7, should result in models that account for much more of the variance in the data (a higher R^2). Figure 7 demonstrates that this is true except for the condition with a selexel size of 1×1, which contains only target distances greater than $Reach_{sub}$. This further indicates that an upper bound to the validity of Fitts' Law can be predicted using $Reach_{sub}$.

11 Conclusions

Previous characterizations of the expressiveness of relative input devices required empirical testing, limiting their utility as a design tool. We have presented a conceptual framework to characterize the expressiveness of input devices based on the physical properties of the hardware, allowing its appropriateness for a particular interaction scenario to be more easily assessed. Our selexel framework allows the user interface to be tailored (even adapted at run-time) to match the expressiveness of the input device without sacrificing the screen resolution, which is important to preserve the information capacity of the display.

Our experiments have shown that pointing under selexels can be modeled by Fitts' Law, demonstrating that selexel-based motion has no effect on task performance time. Experi-

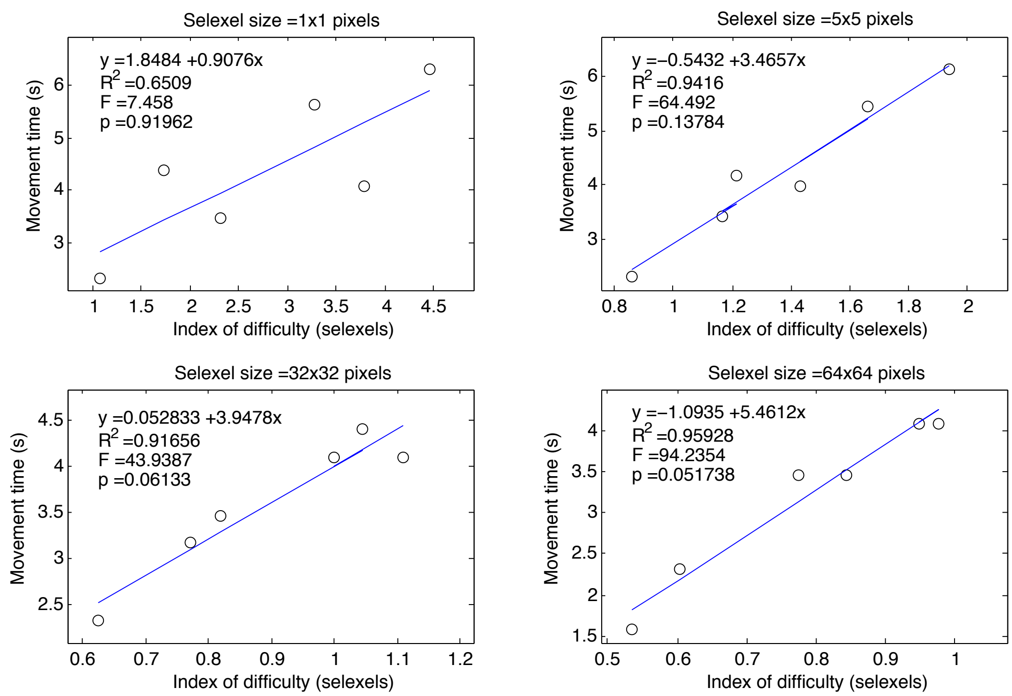

Fig. 7. This figure demonstrates that separating the data from Figure 6 into separate charts based on C–D ratio results in more accurate models (a higher R^2) for conditions where the targets were within $Reach_{sub}$. Note that the condition with target distances greater than $Reach_{sub}$ (selexel size of 1×1) still poorly correlates with the model despite separation, further indicating that an upper bound to the validity of Fitts' Law can be predicted.

ment 1 further demonstrates that transducer resolution has no effect on task performance time as long as the C–D ratio of the UI is preserved.

In experiment 2, our conceptual framework was validated by experimentally verifying the notion of $Reach_{sub}$. These results demonstrate that the upper bound for the validity of the Fitts' Law model can be predicted based on the physical properties of the input device. This new conceptual model can help structure the evaluation of input devices with low expressiveness.

12 Future work

We are currently working on toolkit support of the selexel framework, allowing applications to dynamically adjust their selexel resolution based on the input device used.

This work has focused on cases where the expressiveness of input devices is much lower than that of the display. However if the expressiveness of the input device is much higher than the display, sub-pixel selection is possible, but other feedback mechanisms (external to the display) are needed to indicate which selexel is selected.

The selexels framework has the potential to improve the accessibility of user interfaces by simplifying pointing tasks for people who have normal visual capabilities, but suffer from motor impairments.

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References

[Agi04] Agilent Technologies. ADNS-2610 Optical Mouse Sensor. *(http://cp.literature.agilent.com/litweb/pdf/ 5988-9774EN.pdf)*, Retrieved 2006-08-16 2004.

[BCHE05] Patrick Baudisch, Edward Cutrell, Ken Hinckley, and Adam Eversole. Snap-and-go: helping users align objects without the modality of traditional snapping. In *CHI '05: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 301–310, New York, NY, USA, 2005. ACM Press.

[BGBL04] Renaud Blanch, Yves Guiard, and Michel Beaudouin-Lafon. Semantic pointing: improving target acquisition with control-display ratio adaptation. In *CHI '04: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 519–526, New York, NY, USA, 2004. ACM Press.

[BRSB05] Rafael Ballagas, Michael Rohs, Jennifer G. Sheridan, and Jan Borchers. Sweep and Point & Shoot: Phonecam-based interactions for large public displays. In *CHI '05: Extended abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1200–1203, New York, NY, USA, 2005. ACM Press.

[CEB78] S. K. Card, W. K. English, and B. J. Burr. Evaluation of mouse, rate controlled isometric joystick, step keys and text keys for text selection on a CRT. *Ergonomics*, 21:601–613, 1978.

[CMR91] Stuart K. Card, Jock D. Mackinlay, and George G. Robertson. A morphological analysis of the design space of input devices. *ACM Trans. Inf. Syst.*, 9(2):99–122, 1991.

[CNM83] Stuart K. Card, Allen Newell, and Thomas P. Moran. *The Psychology of Human-Computer Interaction*. Lawrence Erlbaum Associates, Inc., 1983.

[CRM+06] Mary Czerwinski, George Robertson, Brian Meyers, Greg Smith, Daniel Robbins, and Desney Tan. Large display research overview. In *CHI '06: CHI '06 extended abstracts on Human Factors in Computing Systems*, pages 69–74, New York, NY, USA, 2006. ACM Press.

[Fit54] P. M. Fitts. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47:381–391, 1954.

[GB05] Tovi Grossman and Ravin Balakrishnan. The bubble cursor: enhancing target acquisition by dynamic resizing of the cursor's activation area. In *CHI '05: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 281–290, New York, NY, USA, 2005. ACM Press.

[GW04] Krzysztof Gajos and Daniel S. Weld. Supple: automatically generating user interfaces. In *IUI '04: Proceedings of the 9th international Conference on Intelligent user interface*, pages 93–100, New York, NY, USA, 2004. ACM Press.

[ISO00] ISO. Ergonomic requirements for office work with visual display terminals (VDTs) - Requirements for non-keyboard input devices. *ISO 9241-9*, 2000.

[JC90] Herbert D. Jellinek and Stuart K. Card. Powermice and user performance. In *CHI '90: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 213–220, New York, NY, USA, 1990. ACM Press.

[KB95] Paul Kabbash and William A. S. Buxton. The "Prince" technique: Fitts' law and selection using area cursors. In *CHI '95: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 273–279, New York, NY, USA, 1995. ACM Press/Addison-Wesley Publishing Co.

[Mac92] I. Scott MacKenzie. Fitts' law as a research and design tool in human-computer interaction. *Human-Computer Interaction*, 7:91–139, 1992.

[MSK+90] David E. Meyer, J. E. Keith Smith, Sylvan Kornblum, Richard Abrams, and Charles E. Wright. Speed-accuracy tradeoffs in aimed movements: Toward a theory of rapid voluntary action. In M. Jeannerod, editor, *Attention and Performance XIII*, pages 173–226. Lawrence Erlbaum, Hillsdale, N.J., 1990.

[OPC04] Kenton O'Hara, Mark Perry, and Elizabeth Churchill. *Public and Situated Displays: Social and Interactional Aspects of Shared Display Technologies (Cooperative Work, 2)*. Kluwer Academic Publishers, Norwell, MA, USA, 2004.

[SZH+79] R. A. Schmidt, H. N. Zelaznik, B. Hawkins, J. S. Frank, and J. T. Quinn. Motor-output variability: A theory for the accuracy of rapid motor acts. *Psychological Review*, (86):415–451, 1979.

[WWBH97] Aileen Worden, Nef Walker, Krishna Bharat, and Scott Hudson. Making computers easier for older adults to use: area cursors and sticky icons. In *CHI '97: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 266–271, New York, NY, USA, 1997. ACM Press.

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