Fitts' Law: Modeling Movement Time in HCI

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Overview

What is Fitts' Law?

Fitts' law is a model of human psychomotor behavior developed in 1954 [6]. Extending Shannon's theorem 17 in information theory (a formulation of effective information capacity of a communication channel), Fitts discovered a formal relationship that models speed/accuracy tradeoffs in *rapid*, *aimed* movement (not drawing or writing). According to Fitts' Law, the time to move and point to a target of width W at a distance A is a logarithmic function of the spatial relative error (A/W), that is [11]:

$$MT = a + b \log_2(2A/W + c)$$

where

- MT is the movement time
- a and b are empirically determined constants, that are device dependent.
- c is a constant of 0, 0.5 or 1 (refer to [11] for details)
- A is the distance (or amplitude) of movement from start to target center
- W is the width of the target, which corresponds to "accuracy"

The term $\log_2(2A/W + c)$ is called the index of difficulty (ID). It describes the difficulty of the motor tasks. 1/b is also called the index of performance (IP), and measures the information capacity of the human motor system.

Mathematically interpreted, Fitts' Law is a linear regression model [13]. The regression coefficients are (see figure 1):

- a : intercept
- b : slope (1/b is index of performance (IP))

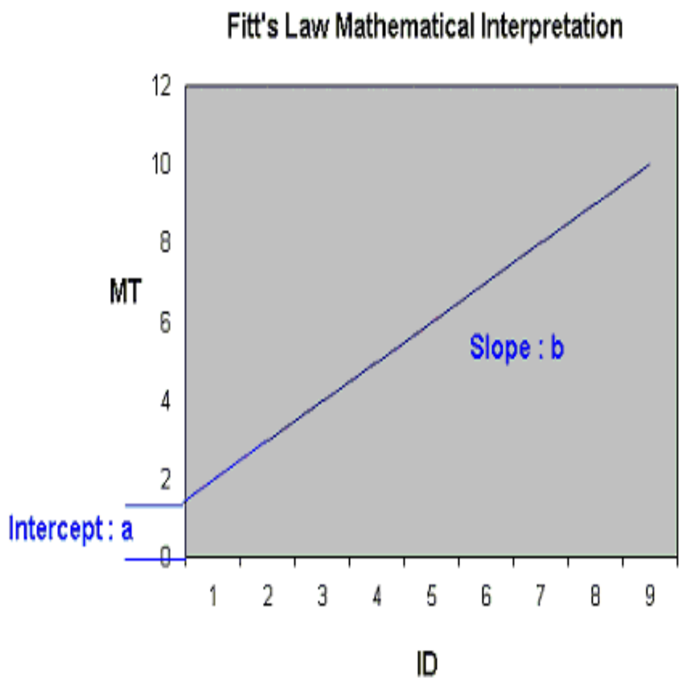

Figure 1: Fitts' Law is a linear regression model

Physically interpreted, Fitts' Law states the following [2]:

- Big targets at close distance are acquired faster than small targets at long range;

- ID provides a single combined measure of two main physical properties of movement tasks;

- ID increases by one unit for each doubling of amplitude and halving of width;

- Positive intercept indicates additive factors unrelated to ID. It can be related to mechanism of movement and/or selection (mouse, button, etc)

Dimensional Extension of Fitts' Law

Fitts' law is inherently one-dimensional since target amplitude (A) and width (W) are measured along the same axis in Fitts' original experiments (reciprocal tapping, disk transfer, and pin transfer). When dealing with two-dimensional target acquisition tasks, new interpretations of "target width" must be considered. MacKenzie & Buxton (1992) compared five width interpretation models regarding 2-dimensional targets [11] [10]:

- *Status QUO model*. It simply discards the height and only considers the horizontal extent.
- *Sum model*. It simply takes the width to be the sum of the height and the width of the target.
- *Area model*. It takes the product of the width and height and uses it as the width in the index of difficulty. This model can be used for targets with shapes other than rectangles.
- *"Smaller of" model*. It picks the smaller of the height and width. Intuitively it may produce accurate results, because the smallest dimension of the object will be the most restricting when attempting to move a cursor inside it. This model is only useful for rectangles.
- *W' model*. It uses the length of the line between the center point of the target object and the object boundary along the approach angle. This is appealing because it is a 1-D interpretation of a 2-D task. But it is more difficult to calculate because the angle between the starting point and the target object must be known. This model is good for circles, rectangles and others.

Scope and Application

Fitts' law is an effective quantitative method of modeling user performance in rapid, aimed movements, where one appendage (like a hand) starts at rest at a specific start position, and moves to rest within a target area. The law can be used to assist in the design of user interfaces and evaluation of alternative task methods in Graphical User Interface (GUI). It can also be used to predict the performance of operators in a user-adaptive system, assist in allocating tasks to operators, and predict movement times for assembly line work [13].

Principles

Theoretically, the following principles exist when applying Fitts' Law to interface designs:

- Things done more often should be assigned a larger button. This seems an intuitive principle, but it needs to be used very carefully, since it harms the consistency of the interface.
- Things done more often should be closer to the average position of the user's cursor. The amplitude (A) of a widget allows more control from interface designers compared to the width (W). Again, this needs to be used with caution, since frequency-based widget arrangements may slow down the user from finding things compared to logic-based arrangements.
- The top, bottom, and sides of the screen are infinitely targetable because of the boundary created by the edges of the screen (unless a virtual screen exists) [3]. They should be fully utilized.

There are tradeoffs when applying Fitts' Law to interface designs. Fitts' Law suggests that interface components should be made larger and positioned closer to the average cursor position. These suggestions may act in opposition to other factors that make an efficient interface, such as organization and use of available screen space.

Example

As an example of using Fitts’ Law to assist user interface design, consider the invention of interface widgets such as pop-up menus. Given a large, 1600 x 1200 screen, where should a target be placed so that the user can access it fastest no matter where the user is originally located? Fitts’ Law says that for a fixed-sized target, the acquisition time decreases when the amplitude of movement decreases. So the fastest pixel is located right at the current location of the mouse pointer. Popup menus make use of this “magic pixel” [3], showing up relative to the mouse pointer, no matter where the user may have moved it (see figure 2). The pixel requires zero travel and is, in effect, an infinitely large target – it just cannot be missed.

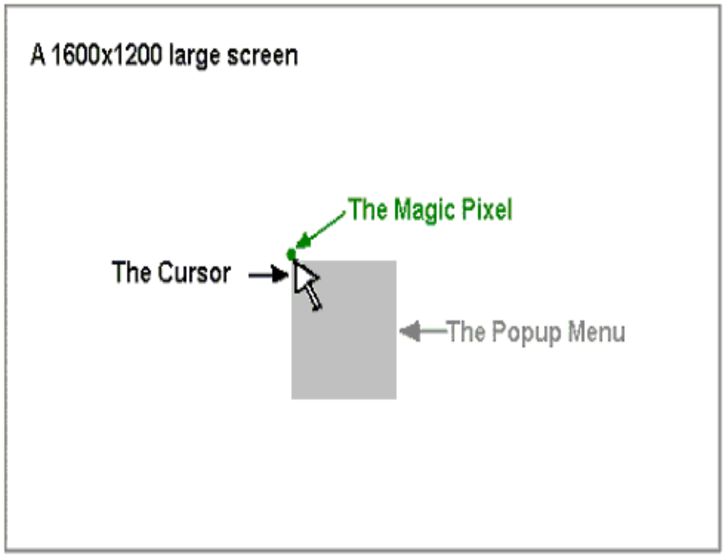

Figure 2: The popup menu and the magic pixel

Applicability to HCI and Discussions

Fitts' Law is an intensively used theory in Human-Computer Interaction. It can be used in assisting interface designs (the invention of pop-up menus) and in interface evaluation (e.g., "embedded model" in [13]).

Another prevalent use of Fitts' Law is to help study and compare input devices. It has been verified to be able to predict user performance in some common tasks (such as point-select and point-drag tasks) using common input devices, such as mouse, trackball, or stylus [5] [12] [7]. A study of hand and head movements in two dimensions by Jagacinski and Monk found out that Fitts' Law also described head movement, and it worked for 2-D with angular uncertainty [8].

However, there is a lack of consensus in the IP measures found in across-study comparisons of input devices, mainly due to the absence of a sound and consistent technique for dealing with errors [13]. As a result, incorporating Fitts' law prediction equations into design tools still remains just a thought until research can validate the measures.

Furthermore, there are some cases that Fitts' law failed to predict correctly. E.g., some input devices are not suited to Fitts' Law, such as isometric joysticks that are force sensing and undergo negligible human limb motion [13]. Extensions and changes to Fitts' Law have been proposed for some of those cases, such as Touchscreens [14], and standard GUI with lots of small target areas (such as radio button, combo buttons, and buttons on toolbars) [14].

Fitts’ Law is valid but limited. First of all, it does not address numerous factors other than target amplitude and width that affect user input performance. While there is evidence that task completion times are reduced when a task is split over two hands [4], Fitts Law does not address the effect of parallel strategies of delegating positioning and selecting to separate limbs. Fitts Law also does not address the effect of human body asymmetry on performance, such as the performance difference between preferred and non-preferred hands [9], and the observation that subjects were uniformly more accurate in terminating flexor (arm motions towards the body) than extensor (away from the body) movements [6]. Secondly, Fitts’ Law is a prediction model for rapid, aimed movements for pointing (target acquisition). So it does not work for trajectory-based user input activities such as drawing, writing, and steering, which are becoming common tasks in modern computer interfaces. Researchers are looking for new laws for this type of movements [1][15]. Thirdly, the focus of Fitts’ law is to model low-level tasks of pointing and moving. It does not consider numerous other parameters, such as system response time, mental preparation time for the user, home timing, selection rules for alternative methods, etc. [13]. These intermediate and high-level activities have been addressed in the Keystroke-Level model and GOMS model (refer to the corresponding articles in this Web site.).

The use of Fitts’ Law in some complex situations still needs to be studied. For example, moving targets exist in real interfaces (e.g., when choosing a font from a scrollable list, the list may scroll before the font of interest is reached.), can Fitts’ Law be modified to address this case? When it comes to 3-D movements and Virtual Reality environment, a lot of things need to be reconsidered, both regarding Fitts’ Law itself and its application in Human Computer Interaction. For example, can Fitts’ law describe user performance of pointing in Virtual Reality? How should the 3-D amplitude be measured for the formula? Fitts’ Law suggests bigger size widgets for frequent tasks and place those widgets closer to the average position of the user's cursor. The suggestion is likely to have negative effects on the layout in 2-D. In 3-D, can the tradeoff be lessen between organization/layout optimization and Fitts' Law optimization?

References

[1] Accot, J., Zhai, S. (1997). Beyond Fitts' Law: Models for Trajectory-Based HCI Tasks. *Proceedings of CHI '97*, Atlanta, Georgia, ACM Press.

[2] Amento, B., Brooks, P., Harley, H., McGee, M., (1996), Performance Models: Fitts’ Law. http://ei.cs.vt.edu/~cs5724/resources.html. Accessed on September 24, 2002.

[3] AskTOG, A Quiz Designed to Give You Fitts, http://www.asktog.com/columns/022DesignedToGiveFitts.html. Accessed on September 24, 2002.

[4] Buxton, W., & Myers, B. A. (1986). A study in two-handed input. *Proceedings of the CHI '86 Conference on Human Factors in Computing Systems*, 321-326. New York: ACM.

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

[6] Fitts,P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*, 381-391.

[7] Gillan, D.J., Holden, K., Adam, S., Rudisill, M., and Magee, L. (1990). How does Fitts' Law fit pointing and dragging? *Proceedings of CHI '90* (pp. 227-234). Seattle, WA: ACM Press.

[8] Jagacinski, R. J., & Monk, D. L. (1985). Fitts' law in two dimensions with hand and head movements. *Journal of Motor Behavior, 17*, 77-95.

[9] Kabbash, P., MacKenzie I.S. and Buxton W. (1993). Human Performance Using Computer Input Devices in the Preferred and Non-Preferred Hands, *Proceedings of CHI'93 Human Factors in Computing Systems*, 474-481.

[10] MacKenzie,I.S. (1992). Movement time prediction in human-computer interfaces. *Proceedings of Graphics Interface '92*, 140-150. Toronto:CIPS.

[11] MacKenzie,I.S., and Buxton,W. (1992). Extending Fitts' law to two dimensional tasks. *Proceedings of the CHI '92 Conference on Human Factors in Computing Systems*. New York:ACM.

[12] MacKenzie, I.S., Sellen,A., and Buxton,W. (1991). A comparison of input devices in elemental pointing and dragging tasks. *Proceedings of the CHI '91 Conference on Human Factors in Computing Systems*, 161-166. New York:ACM.

[13] MacKenzie, I. S., Fitts' Law as a Performance Model in Human-Computer Interaction, Ph.D. thesis, http://www.yorku.ca/mack/phd.html. Accessed on September 24, 2002.

[14]Sears A. and Shneiderman B. (1991), High Precision Touchscreens: Design Strategies and Comparisons with a Mouse, *International Journal of Man-Machine Studies*, 34 (4), 1991, pp. 593-613.

[15] Viviani, P., and Terzuolo, C.A. (1982). Trajectory Determines Movement Dynamics. *Neuroscience*, 7, 431-437.