Chapter 5:

Models: Predictive Models for Interaction

Overview

Fitts' Law:

→ Psychomotor behaviours.

Introduction

Predict movement time for rapid & aimed pointing.

tech Motor abilities

Fitts' law is a robust model of human psychomotor behaviour. Paul Fitts was working at the intersection between technology and the motor abilities of humans. So, he was an early expert on human-machine interaction.

We are using Fitts' law when we want to predict the movement time for rapid and aimed pointing tasks, like clicking on buttons or touching icons. This model was developed in 1954 by Paul Fitts, and it describes the movement time in terms of distance and size of a target and a device. Generally said, this law predicts how long it takes us to interact with a specific interface and a particular device. While not described for Human-Computer Interaction in the first place, it was rediscovered in 1978 in this field. It "*was a major factor leading to the mouse's commercial introduction by Xerox*" (Stuart Card). One of the reasons was that with this law, a precise optimisation of current solutions could be shown, so people were eager to find out more about the computer mouse and use it for their work. Subsequently, the potential and benefits of this model were getting more transparent, and today, it is widely spread and often discussed in the literature.

Derivation from Signal Transmission

Fitts' law is derived from a formula well known in signal transmission; the Shannon-Hartley theorem. This theorem describes the maximum rate at which information can be transmitted over a communications channel with a certain bandwidth and the presence of noise:

$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

Max information transmission rate.

C: channel capacity (bits / second)
B: bandwidth of the channel (Hertz)
S: total signal power over the bandwidth (Volt) → signal power (Volt)
N: total noise power over the bandwidth (Volt)
S/N: signal-to-noise ratio (SNR) of the communication signal to the Gaussian noise interference
(as linear power ratio – SNR (dB)=10 $\log_{10}$(S/N))

Paul Fitts was well educated in electrical engineering. He knew this theorem very well, so that's how he came up with the idea to use it to model his specific problem of analysing the time it takes to acquire a particular target when your pointing system (this can be anything) is currently not on the target.

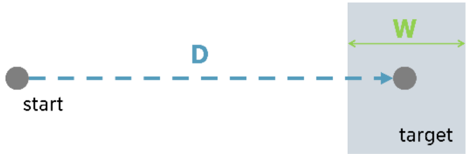
time = acquire target when pointing.

Fitts' law – Equation

As you will notice, the formula of Fitts' law looks quite similar to the one of the Shannon-Harley theorem. The time to acquire a target is a function of the **distance to** and the **size of the target**, and it depends on the **particular pointing system**.

time to acquire a target.

$$MT = a + b\log_2\left(1 + \frac{D}{W}\right)$$



MT: Movement time
a, b: constants dependent on the pointing system (pointing system)
D: distance to the target area → distance.
W: width of the target → width.

Fitts' law – Index of difficulty (ID)

difficulty irrespective of device or method.

One part of Fitts' law equation represents the Index of Difficulty (ID). It describes how difficult a task is independent of the device used or the method used to reach the target.

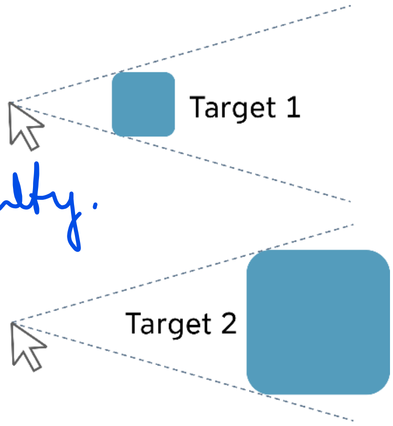
$$MT = a + b * ID$$

MT = a + b* ID

$$\rightarrow ID = \log_2\left(1 + \frac{\boldsymbol{D}}{\boldsymbol{W}}\right)$$

small close ≙ large far. ≙ same difficulty.

Taking a closer look at this equation shows that a small but close target is equally difficult to reach as a large target that is far away. This is also shown in the image on the right: for the targets applies:



$$ID_{target1} = ID_{target2}$$

Fitts' law – Throughput

One additional aspect you can derive from the formula: The throughput in the context of Fitts' law is also known as the index of performance or bandwidth. Two definitions can be found in the literature:

Averages of ID & Avg. of MT used.

$$TP = \frac{ID}{MT} \qquad or \qquad TP = \frac{1}{b}$$

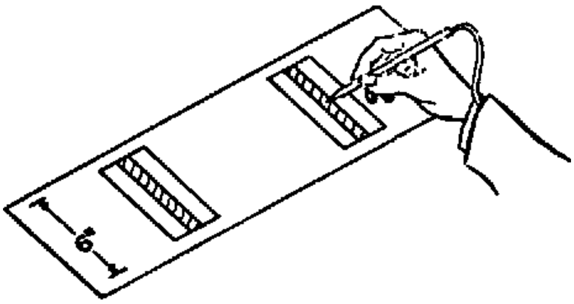
Given input only one metric

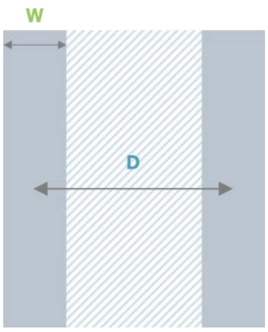
In the original Fitts' law, you need two parameters (a, b) as metrics for the input systems. Whereas the throughput represents a given input device through a single metric. To calculate it, average values for ID and MT are used. However, probably the best approach to describe your pointing device is to perform a regression analysis to compute a and b.

For further discussion points on the throughput:
Zhai, S. 2004. Characterizing computer input with Fitts' law parameters: the information and non-information aspects of pointing.
Int. J. Hum.-Comput. Stud. 61, 6 (Dec. 2004), 791-809

Fitts' law – Experiment

The original experiment of Paul Fitts was a 1-dimensional problem. Below you can see the reciprocal tapping apparatus. The task in the original experiment was to hit the centre plate in each group alternatively without touching either side plate (this would have counted as an error).





The question is now: **can we easily use the 1-D problem in a 2-D case?** When we look at graphical user interfaces: they are not one-dimensional, so we need to extend the problem to two dimensions. Different solutions exist to perform this transfer:

- "Status Quo": W = horizontal width (Most accepted one!)
- "Sum Model": W = width + height of the target
- "Area Model": W = width * height
- "Smaller of": W = min (width, height)
- "W' Model": width in the movement direction

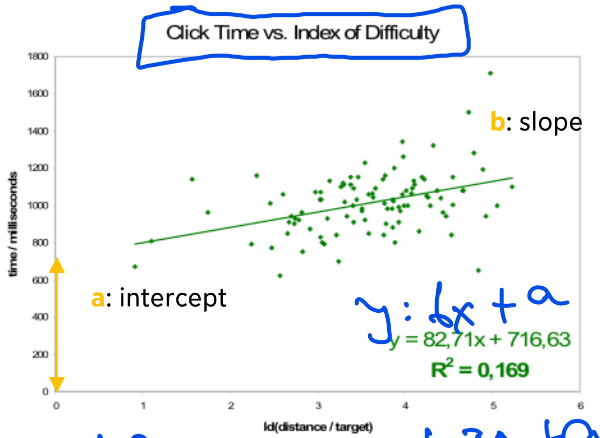
Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement.
Journal of Experimental Psychology, 47, 381-391
MacKenzie, I. S. and Buxton, W. 1992. Extending Fitts' law to two-dimensional tasks. In Proceedings CHI '92. 219-226.
Zhai, S., Accot, J., and Woltjer, R. 2004. Human action laws in electronic virtual worlds: an empirical study of path steering performance in VR.
Presence: Teleoper. Virtual Environ. 13, 2 (Apr. 2004), 113-127.

Finally, let's have a look at the last part of the equation we did not talk about yet: **a and b**

As mentioned above, these two constants are different, depending on the pointing device that is used. When we want to use a specific computer mouse, for example, we can have a look in the literature and find the values for a and b. But when we have a new device, we need to set up an experiment to determine both values.

hit target when distance & size of target are varying.

Therefore, we create a task for the users in our experiment, where they need to hit the target with our new device several times, while the distance and the size of our target are varying.



For each step we measure the time (MT) it took the user to hit the target. With that we get to this graph on the right, showing the index of difficulty and the movement time in milliseconds. Through a simple linear regression we then obtain a: the intercept, and b: the slope.

time = b.x + a

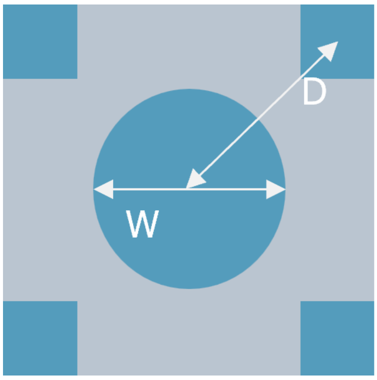
(MT) y = b ID + a

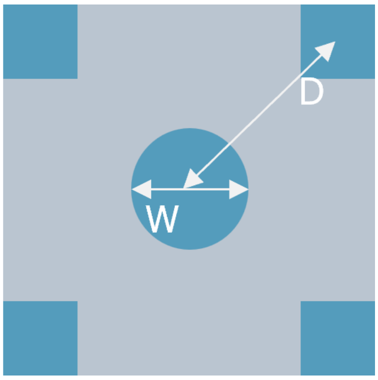
Movement time.

Heiko Drewes. 2010. Only one Fitts' law formula please!. In CHI '10 Extended Abstracts on Human Factors in Computing Systems (CHI EA '10). ACM, New York, NY, USA, 2813-2822.

Fitts' law – Example

Imagine you have some kind of device as shown on the left in the following sketch:





This device has four small buttons and one big circular centre button. Now, the design team comes to you and tells you, that this centre button should be smaller, as the image on the right shows. The following values are given:

Current version:	New design:
D = 42 mm	D = 42 mm
W = 14 mm	W = 6 mm

Use the Fitts' law formula to calculate: How big is the difference of the movement time for the user between the two designs when b = 150 ms/bit?

You can find the solution at the end of this handout.

Fitts' law – Implications for HCI

Finally, we need to ask: **Where and how can we use this law in HCI?**

Create larger targets:

A bigger target size facilitates the interaction.

bigger size = better.

Login   Login

Choose a size proportional to amount of use:

Usage more (bigger more

But keep in mind the principles (consistency)!

bigger size.

Minimize movement:

The distance to your target should be minimal. Targets should be placed near to the expected position of the cursor.

Copy   Paste   Delete

Use edges and corners:

The edges of your screen might seem as a limit, but your mouse can move infinitely out. So targets at these edges are equally infinitely wide.

Fitts' law – Additional Literature

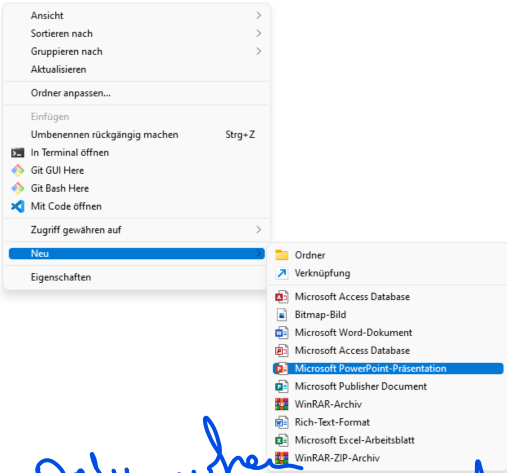
A Cybernetic Understanding of Fitts' Law:
http://www.hcibook.com/e3/online/fitts-cybernetic/

Bibliography of Fitts' Law Research
(to get an impression about research in the HCI community):
http://www.yorku.ca/mack/RN-Fitts_bib.htm

Fitts' Law on interaction-design.org:
http://www.interaction-design.org/encyclopedia/fitts_law.html

Steering Law

Introduction



The steering law was discovered in 1959 by Nicolas Rashevsky. It was long forgotten about, when in 1997 it was rediscovered by Accot and Zhai, when they wrote a publication about it.

The steering law models movement time of a pointer through a 2D tunnel and it can be seen as an extension to Fitts' law. It applies to many different interaction scenarios, for example when you navigate through menus such as the ones shown in this image.

→ 2 level menus

When using this law, always keep in mind, that it only models the interaction time when your task is successful. It doesn't consider errors; the consequences when you leave the tunnel

Only when task is successful. Not when errors.

Steering Law – Equation

The formula of the steering law is quite similar to Fitts' law, but it is easier to model. It states that the time to acquire a target through a tunnel is a function of the length and width of the tunnel and depends on the particular pointing system.

$$MT = a + b\,\frac{D}{W}$$

"Tunnel"

MT: movement time
a, b: constants depending on the pointing system
D: distance, i.e., length of the tunnel
W: width of the tunnel

Steering Law – Index of Difficulty

Similar to Fitts' law also one part of the equation describes the index of difficulty:

$$MT = a + b\,\frac{D}{W} \quad \rightarrow \quad ID = \frac{D}{W}$$

As you can see, the ID is now **linear** and not anymore logarithmic. This means, steering through a tunnel is way more difficult than just pointing a target. Especially long and narrow tunnels have a high ID.

Steering through tunnel > more difficult than pointing a target.

Steering Law – Extension to Arbitrary Tunnels

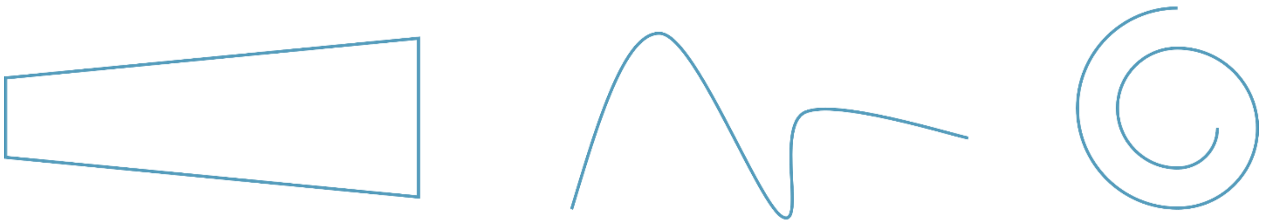
As you may have noticed, the presented formula of the steering law assumes that the width of the tunnel is constant. When our tunnel is shaped differently, maybe even arbitrary, we need to adapt our formula to:

$$MT = a + b \int_C \frac{ds}{W\ (s)}$$

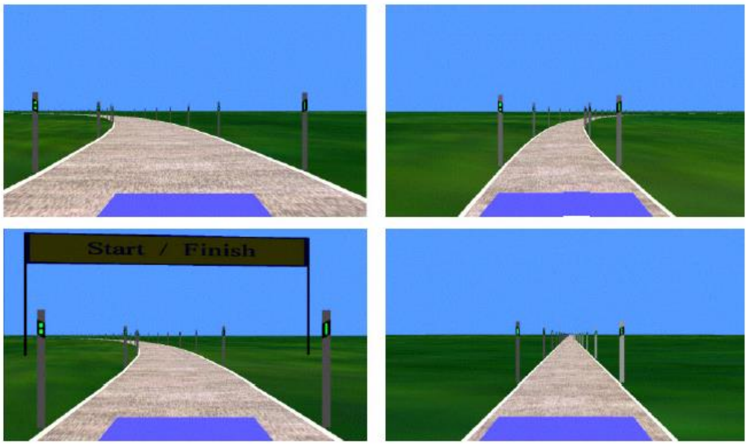
C: path characterised by s
W(s): width dependent on s

Steering Law – Application

The early work regarding the steering law were focusing on car driving scenarios and models with straight tunnels. Since then, various shapes of tunnels have been explored.



This is of course not limited to two dimensions. For example, an extension to 3D can be performed in virtual reality applications.



Zhai, S., Accot, J., and Woltjer, R. 2004. Human action laws in electronic virtual worlds: an empirical study of path steering performance in VR.
Presence: Teleoper. Virtual Environments 13, 2. 113-127.

Hick's law

More # possibilities
↳ More time to decide.

Another law relevant for UI design is Hick's law. Originally, this law came into the HCI domain from psychology. In Hick's law it is all about decisions; the larger the number of possibilities you have when making a decision, the more time you need for it. The logarithmic form is based on the categorizing of possibilities humans perform automatically; we do not make a decision for each individual option, rather we decide on categories of options. Just imagine yourself in a restaurant, you decide whether you take a dessert additionally or not, you do not make a decision for each dessert, that is on the menu.

$$T = b\log_2(n+1)$$

⇒ Decide not based on indv. but on category of decisions

T: time required to decide
b: empirically determined constant for the system that is used
n: equally probable choices

In case the probability of the choice of the options is unequal, the law can be generalized to:

$$T = bH$$

H here represents the entropy of decisions coming from information theory. This can be calculated as follows, with p_i representing the probability of an alternative i:

Entropy.

$$H = \sum_{i}^{n} p_i \log_2\left(\frac{1}{p_i+1}\right)$$

Divisions & not random ordering.

Important to note is that Hick's law can be only applied if the user can search by sub-division, so the list of possibilities must not be randomly ordered.

What exactly does this imply for HCI?

Categorization: (Bunches)
Contents in a menu for example, that are related to each other should be placed near to each other.

Necessity:
Reduce the number of decisions your users have to make.

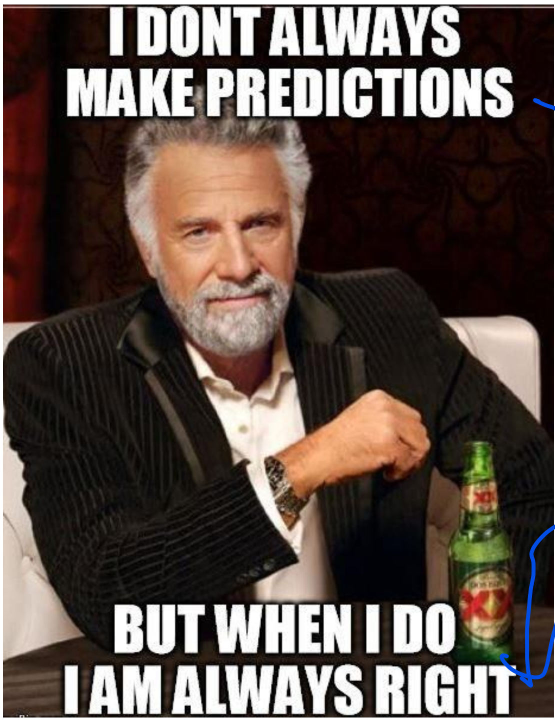
Focus:
Avoid overwhelming and reduce the cognitive load, by recommendations or highlighting

If you are interested in finding out more about Hick's law:
https://uxplanet.org/design-principles-hicks-law-quick-decision-making-3dcc1b1a0632

https://www.fyresite.com/hicks-law-the-psychology-behind-faster-ux/

References

1. Image of Paul Fitts: https://aresluna.org/fitts/pics/paulfitts.jpg
2. B. Shneiderman. Designing the User Interface: Strategies for Effective Human-Computer Interaction , 5th Edition. 2009. ISBN: 978-0321537355
3. Alan Dix, Janet Finlay, Gregory Abowd and Russell Beale. (2003) Human Computer, Interaction (3rd edition), Prentice
4. L. Suchman, Plans and Situated Action:- The Problem of Human-Machine Communication. 1987, ISBN 978-0521337397



Solution to Mini-Exercise:

$$\Delta MT = a + b\log_2\left(1 + \frac{D_2}{W_2}\right)) - (a + b\log_2\left(1 + \frac{D_1}{W_1}\right))$$

a - cancel's out

$$\Delta MT = MT_2 - MT_1 = 450\,ms - 300\,ms = 150\,ms$$