Human-Computer Interaction: 3B. Input Models

23 October 2025

Previously: Human Movement and Fitts' Law

- Fitts' Law
- Factors in Movement Performance
- Speed-Accuracy Trade-off
- Index of Difficulty (ID)
- Building a Fitts' Law Model
- Throughput of Input Devices

Throughput

- Throughput is the amount of data that can pass through a system in a given amount of time
  - In communication systems, throughput depends on bandwidth (speed) and signal-to-noise ratio (accuracy)
  - It provides a single metric of a system's efficiency, that combines speed and accuracy, measured in bit/s
- One of the key ideas underlying Fitts’ Law is that we can adopt throughput as a single measure of human performance with an input device, for the transfer of information to a computer

Throughput in Fitts' Law

- Fitts' Law defines throughput *TP* as a measure of input efficiency

$$TP = \frac{ID}{MT} \qquad \text{[in bit/s]}$$

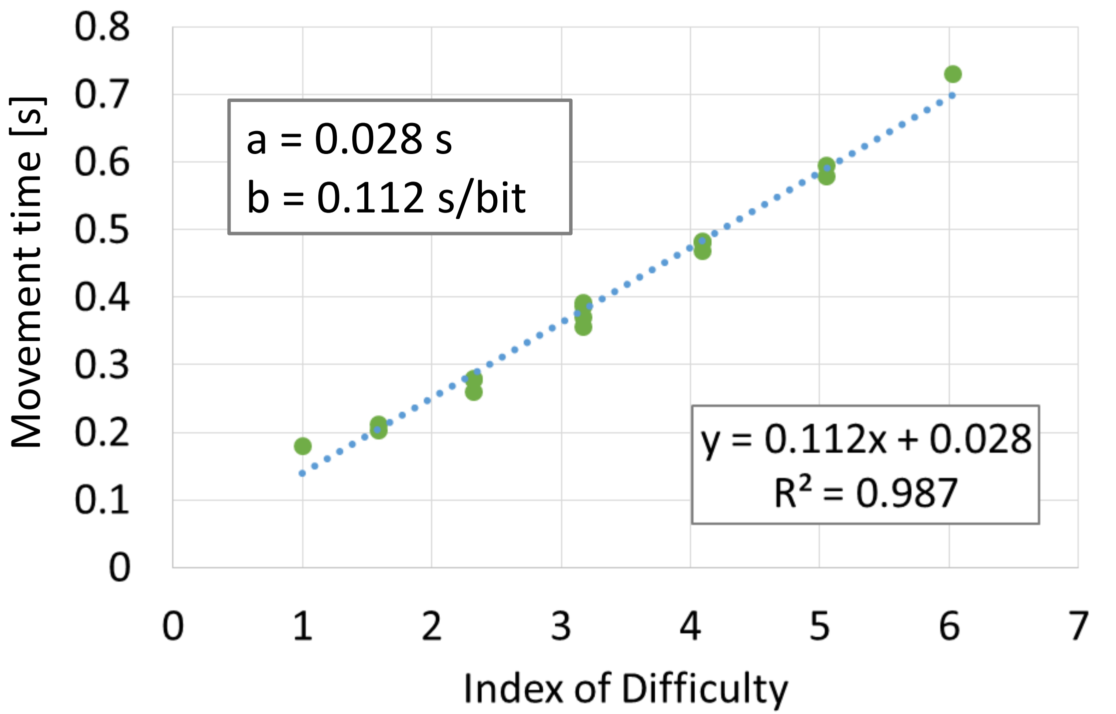
- Throughput (ID/MT) increases …
    - When we can complete more difficult tasks (higher ID) within a given time (fixed MT)
    - When we need less time (lower MT) for a task of given difficulty (fixed ID)
- Throughput combines speed and accuracy into a single metric of performance, of a user with an input device

Throughput – Fitts' Law Visualisation

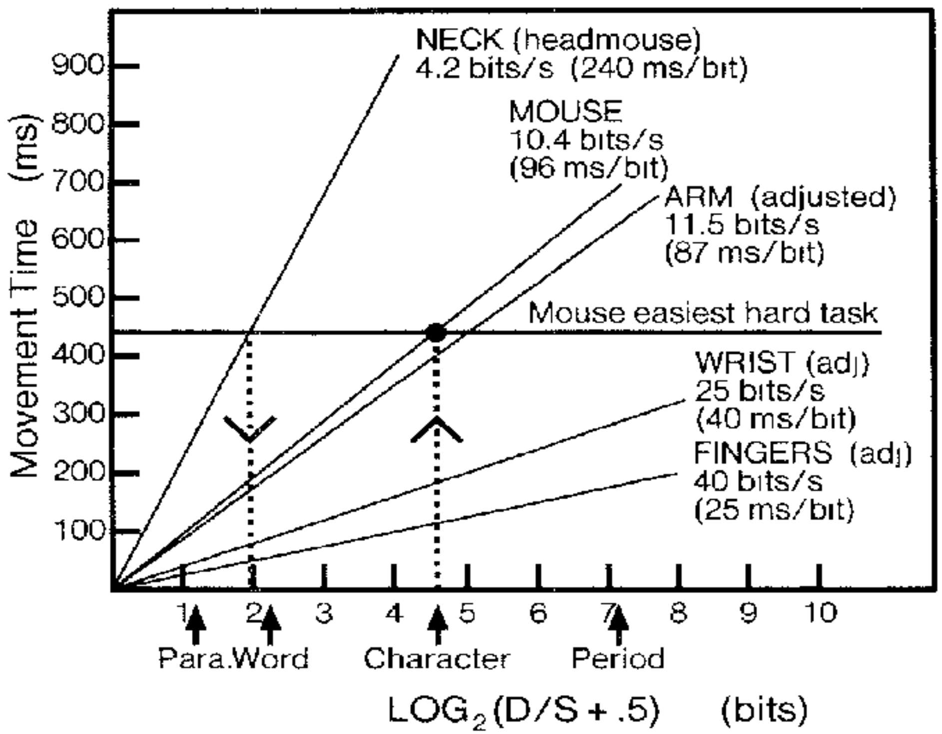
- $MT = a + b * ID$
- $TP = \frac{ID}{MT}$
- We can approximate throughput as the inverse of the slope

$$TP = \frac{1}{b}$$

- The <u>flatter</u> the slope, the higher the throughput



Throughput of devices / muscle groups



- Mouse tasks, perceived difficulty:
  - Select a word: “hardest easy task”
  - Select a char.: “easiest hard task”
- Mouse throughput 10.4 bit/s
  - 1991 data! Further optimization since
- Fingers have higher throughput, 40 bit/s
  - For adjacent buttons, not in general
- Head pointing is less efficient, 4.2 bit/s
  - Select a word in the time mouse pointing can select a character

Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991). A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems 9(2 April): 99-122. https://dl.acm.org/doi/pdf/10.1145/123078.128726

Movement and Fitts' Law – Key Points

- Movement and input are subject to a speed-accuracy trade-off
- Most input in HCI is based on *aimed* movements
  - Reaching for controls, pointing with a mouse, typing on keyboard, …
- Aimed movements can be modelled using Fitts' Law
  - Modelling the difficulty of input tasks
  - Modelling the performance with different devices
- Throughput is a measure of input performance that takes both speed and accuracy into account

Input Models

- Application of Fitts' Law
- Pointing and Crossing
- Steering Law
- Keystroke-Level Model (KLM)

Learning Objectives: be able to …

- Describe performance models for different types of input task
- Choose the right model and interpret its parameters correctly for modelling and prediction of task completion time
- Identify movement tasks in user interfaces that are difficult and consider how they can be made easier

What are Models good for? What is Fitts' Law good for?

- Models are representations of phenomena that help us understand how something works (or how it will work)
  - As simple as possible
  - As complex as necessary
- Models are never perfect
- Models are based on assumptions
- Models are useful for specific phenomena, and not useful for other

- Fitts' Law models performance of <u>aimed</u> movement
- Assumptions
  - Target is known in advance (no search time)
  - Reachable in uninterrupted movement (no steps)
- Fitts' Law holds for pointing
  - Direct and indirect
- But does not hold for (e.g.) drawing

1D Fitts' Law Recap

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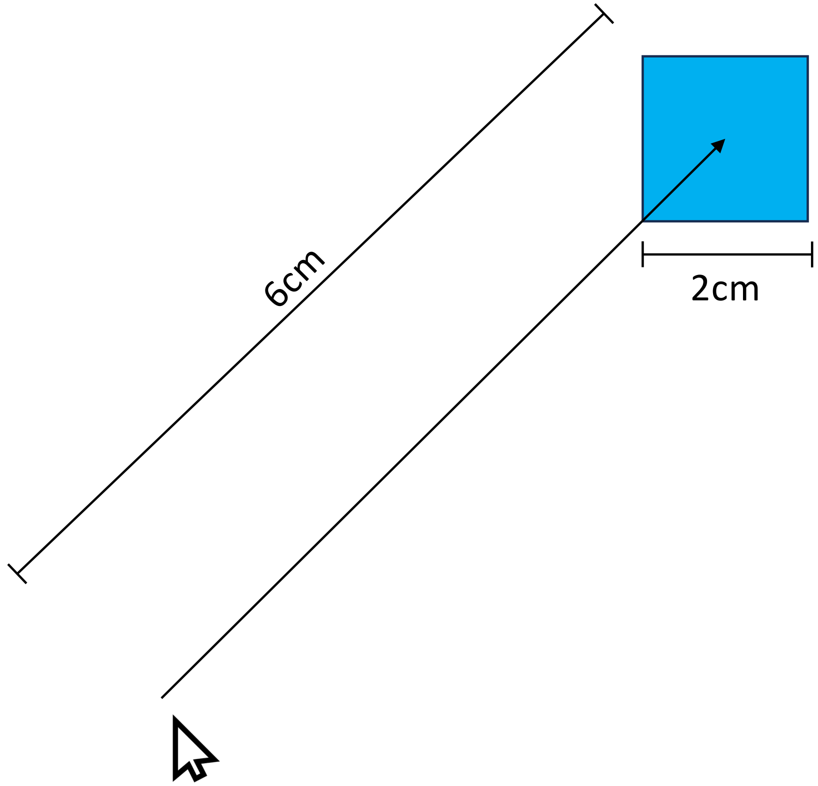
- $MT = a + b * log_2\left(\frac{D}{W} + 1\right)$
    - $\mathrm{a} = 50\ \mathrm{ms}$
    - $\mathrm{b} = 100\ \mathrm{ms/bit}$
- $MT = 50 + 100 * log_2\left(\frac{6}{2} + 1\right)$
- $MT = ?\ \mathrm{ms}$

n	1	2	4	8	16	32	64	128
$Log_2(n)$	0	1	2	3	4	5	6	7

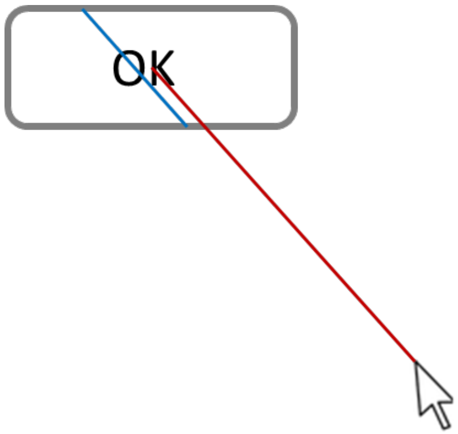
2D Fitts's Law

- Now we are moving in x and y
- What happens to MT?



Fitts' Law applied to 2D Pointing

- $MT = a + b * log_2\left(\frac{D}{W} + 1\right)$
- Task: move pointer onto the target as quickly as possible



Distance

- from current cursor position to center of target

Width

- across target, in the direction of movement

I. Scott MacKenzie and William Buxton. 1992. Extending Fitts' law to two-dimensional tasks. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '92). Association for Computing Machinery, New York, NY, USA, 219–226. https://doi.org/10.1145/142750.142794

Which menu design is most efficient?

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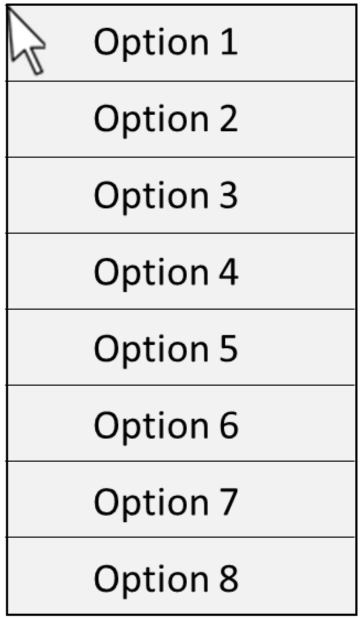
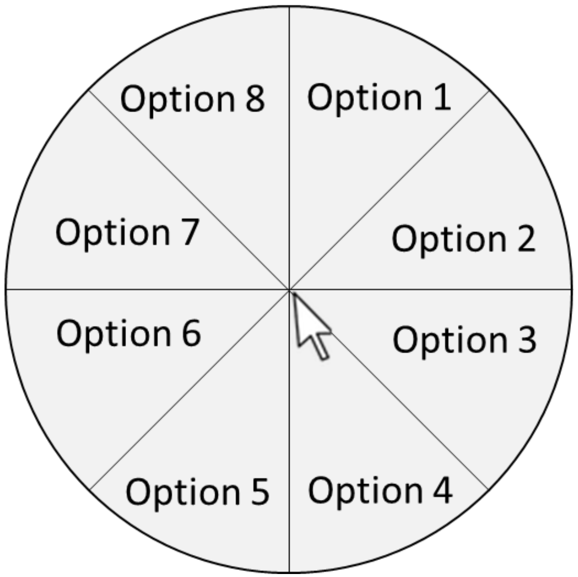
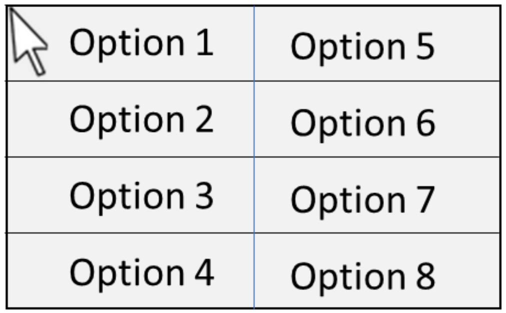


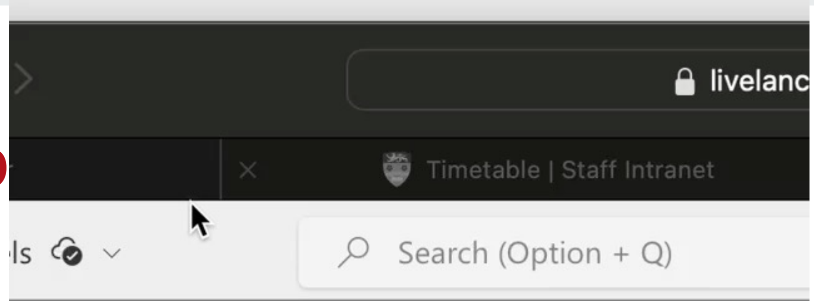




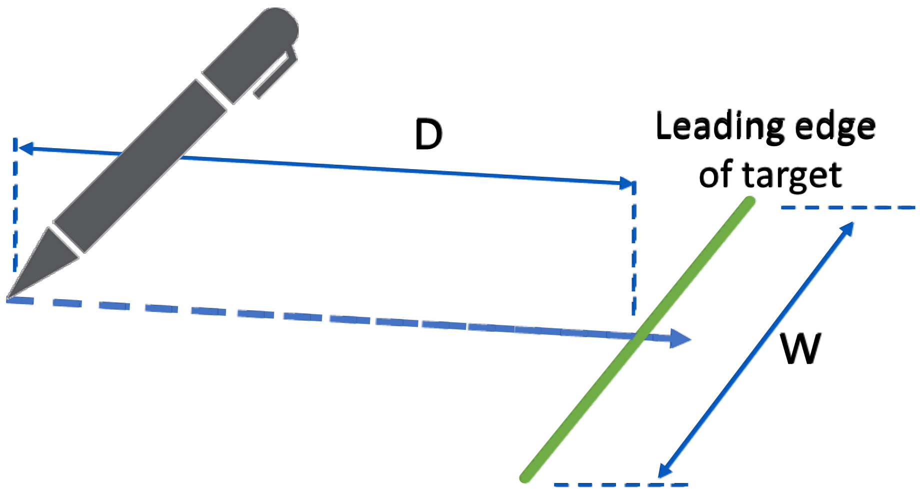
Input Models 3

- Models
- Application of Fitts' Law
- **Pointing and Crossing**
- Steering Law
- Keystroke-Level Model (KLM)

Goal-Crossing (or just: Crossing) Mo



- Emerges in the Pen/Stylus era of interfaces
- Instigated by “no-click” interaction studies with buttons by Ren & Moriya
- Goal-crossing is a common interaction style

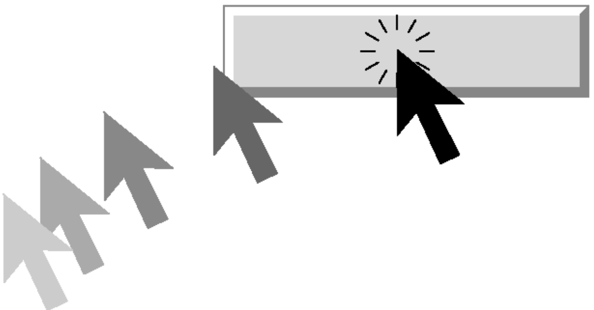


X. Ren and S. Moriya. Improving selection performance on pen-based systems: a study of pen-based interaction for selection tasks. ACM Transactions on Computer-Human Interaction, 7(3):384–416, 2000

Goal-Crossing (differences)

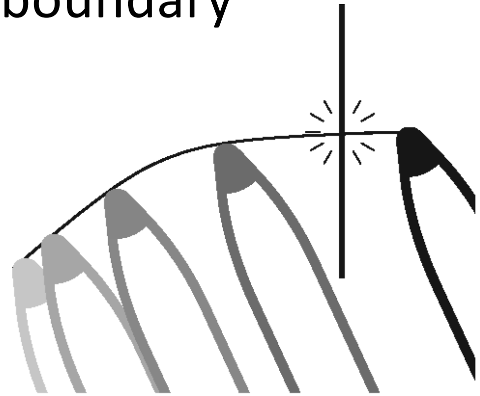
Pointing

- Control and correction at end of movement only
- Crossing object boundary and stopping on object



Crossing

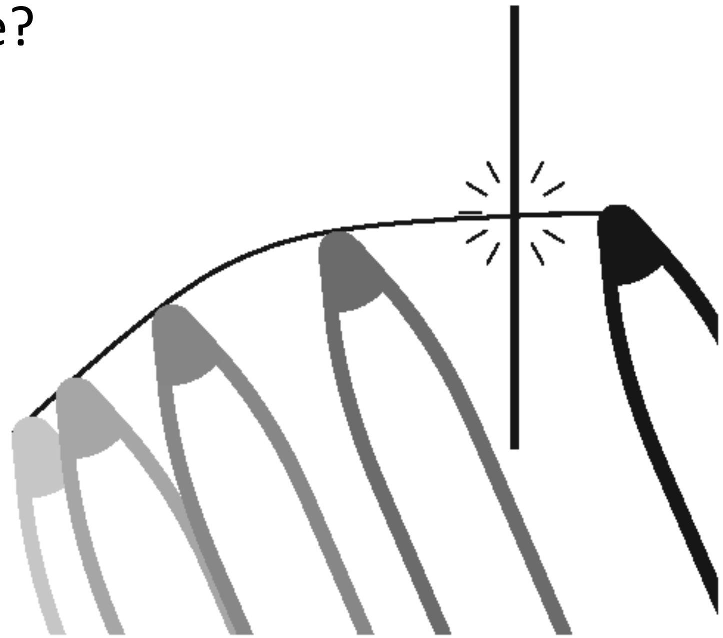
- Control and correct all the way towards the goal
- Crossing through an object for selection, no need to stop within object boundary



Fitts's Law Model for Crossing

- What part of the formula might change?
- $MT = a + b * log_2\left(\frac{D}{W} + 1\right)$

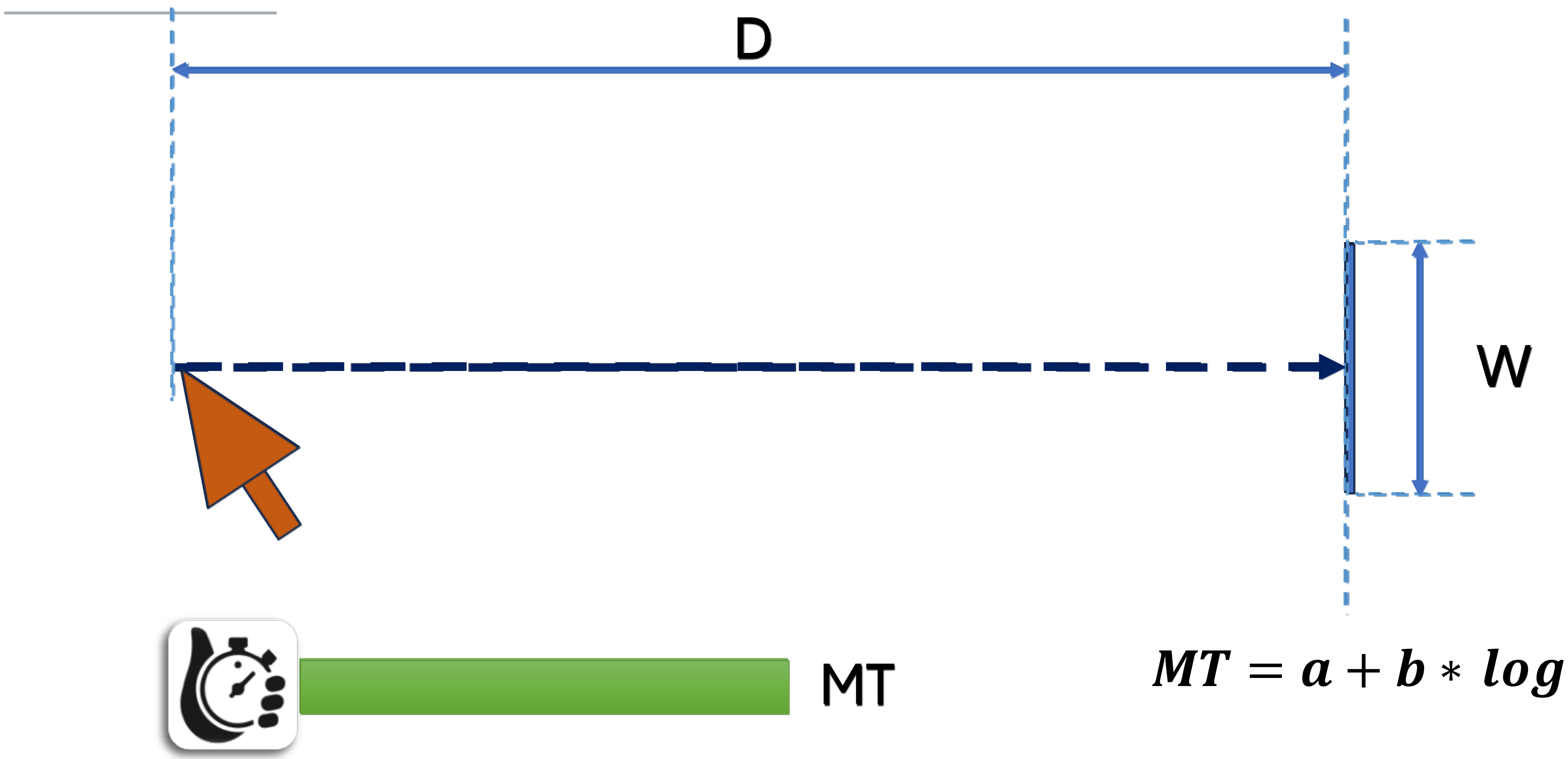
A B C



D = Everything

E = Nothing

Goal-Crossing Model

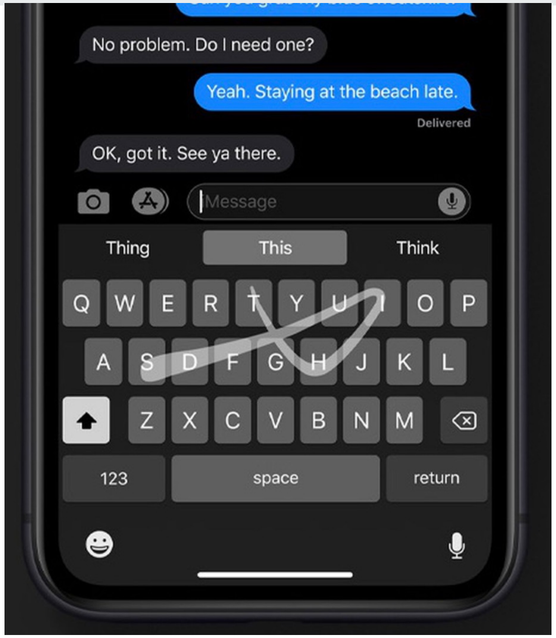


$$MT = a + b * log_2\left(\frac{D}{W} + 1\right)$$

Johnny Accot and Shumin Zhai. 1997. Beyond Fitts' law: models for trajectory-based HCI tasks.
In ACM CHI '97. 295–302. https://doi.org/10.1145/258549.258760

Advantages of Crossing-based Selection

- Selection of objects that are "thin"
- Multi-selection: move across multiple objects to select
  - e.g. swiping across keys on a keyboard
- Good with input devices that have no button to click
  - Mid-air pointing (Kinect etc); Head pointing in 3D world
- Pen/stylus: crossing with pen on surface; don't need to lift pen to tap
- Good when movement is jittery, or tracking noisy
  - e.g. hand tremor in mid-air pointing, controllers with low precision



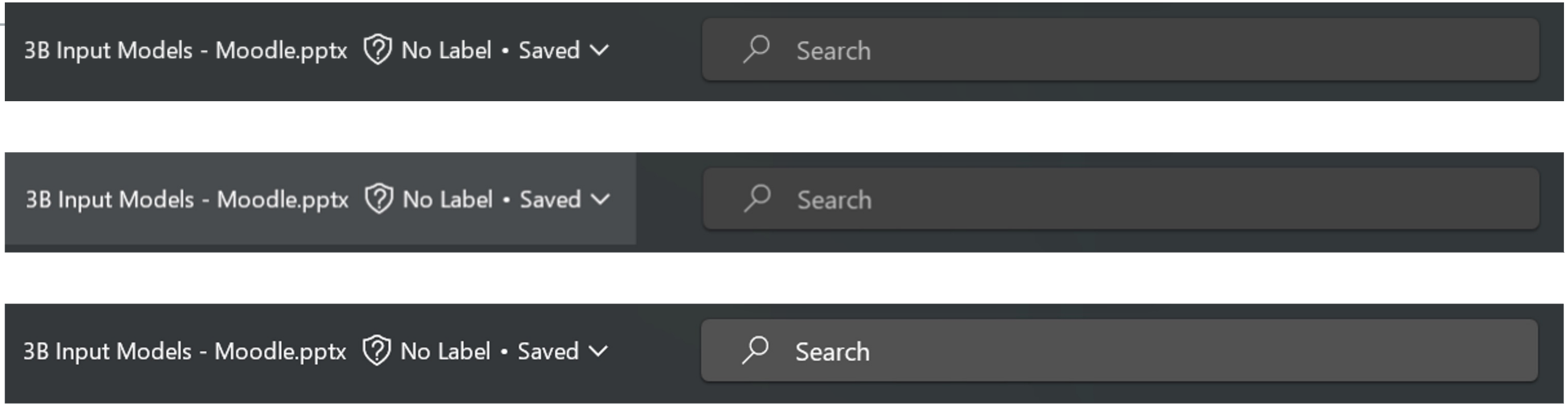
Apple QuickPath

Edge cases (side-by-side)

A

B

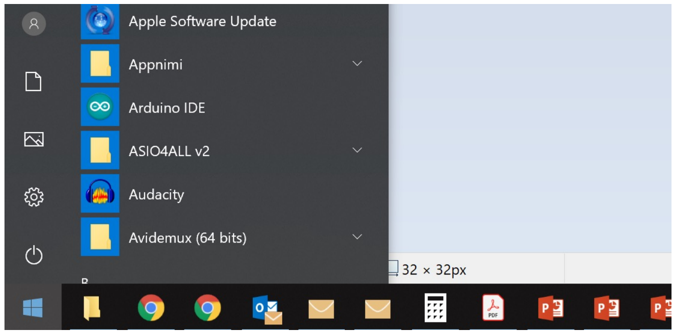
C

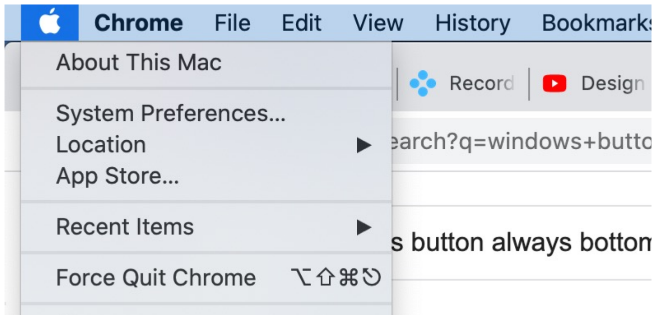


- The left-hand side selection is crossing-based making it easier to reach
- The right-hand side “Search” bar is pointing-based and makes it hard to hit as compared to crossing.

Fastest accessible points: Corners and Edges

- Application menu bar: in window or at top of screen?
- Access to key controls and menus in display corners
- Corners of the display are fastest to access from anywhere on screen



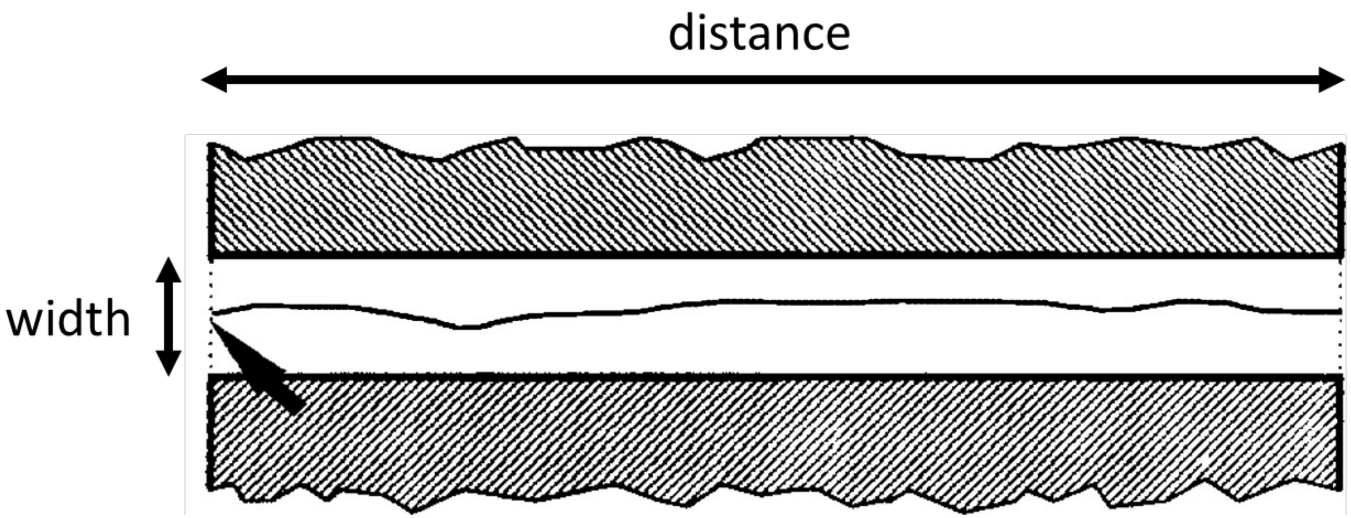


Input Models

- Models
- Application of Fitts' Law
- Pointing and Crossing
- **Steering Law**
- Keystroke-Level Model (KLM)

Steering a Mouse through a Tunnel

- A straight road … with distance D and width W



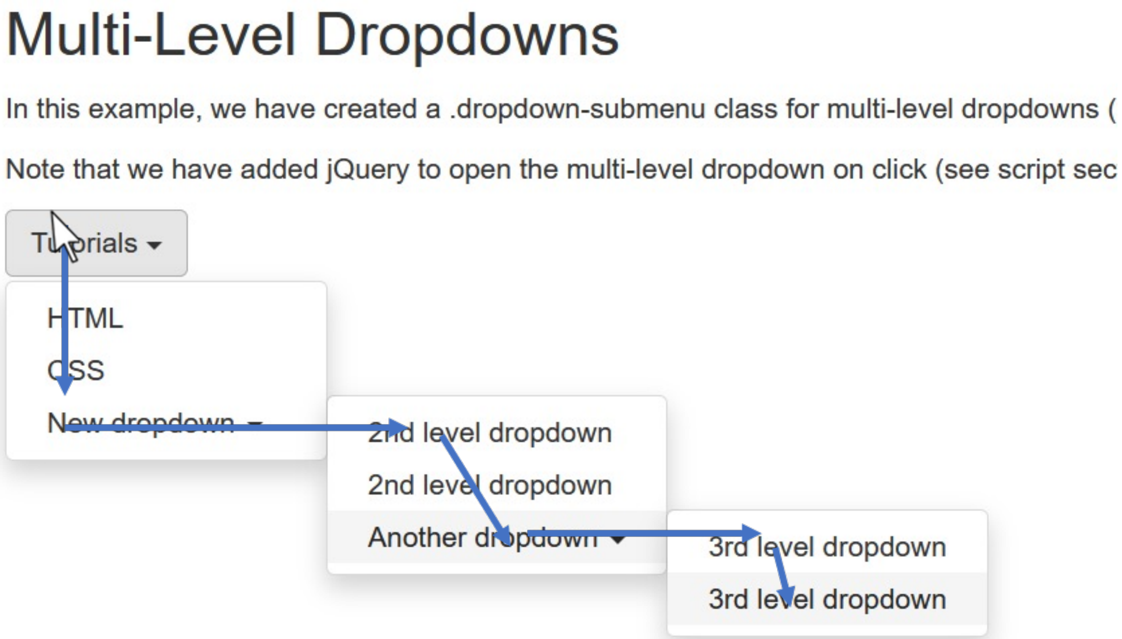
Johnny Accot and Shumin Zhai. 1997. Beyond Fitts' law: models for trajectory-based HCI tasks.
In ACM CHI ’97. 295–302. https://doi.org/10.1145/258549.258760

Steering Law (Accot-Zhai)

$$MT = a + b * \frac{D}{W} \qquad ID = \frac{D}{W}$$

- The movement time (MT) to acquire a target through a tunnel is a function of the length (D) and width (W) of the tunnel
  - MT: movement time
  - a and b: constants dependent on the pointing system
  - D: distance, i.e. length of the tunnel
  - W: width of the tunnel

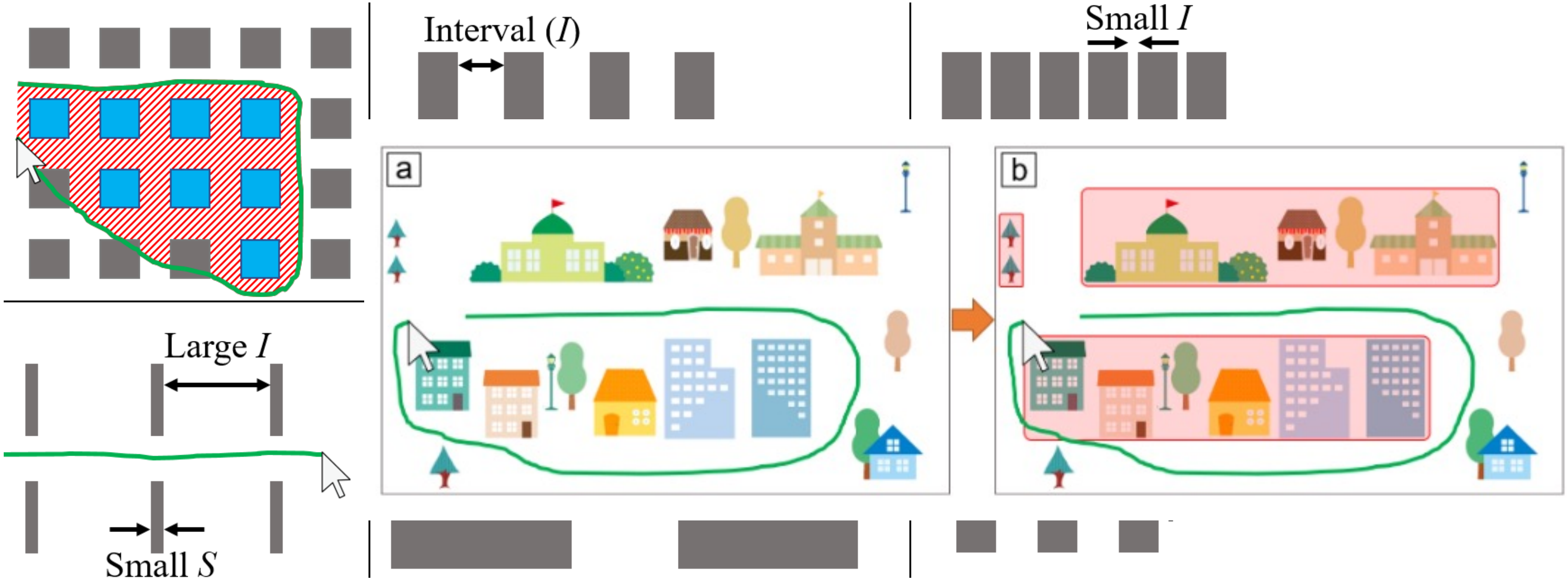
Tunnels in the User Interface



- Pointing to ‘Find’
  - ID=log2(D/W)
- Steering through tunnel to submenu
  - ID=D/W
- Pointing in submenu

Steering between objects

Shota Yamanaka, Wolfgang Stuerzlinger, and Homei Miyashita. 2018. Steering through Successive Objects. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, Paper 603, 1–13. https://doi.org/10.1145/3173574.3174177

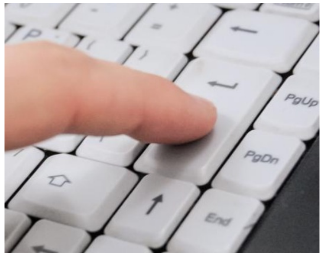


Pointing and Keystroke-Level Input

- Application of Fitts' Law
- Pointing and Crossing
- Steering Law
- **Keystroke-Level Model (KLM)**

Keystroke-Level Model (KLM)

- KLM defines a set of basic input operators with time estimates for their execution
- Physical motor operators
  - Pressing a key, Pointing with the mouse, Draw a line
  - Move hand from one device to another

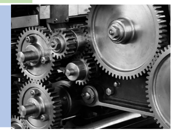


- Mental operator
  - Mental preparation of a motor action
  - Also to model time to make a decision, or to look for something

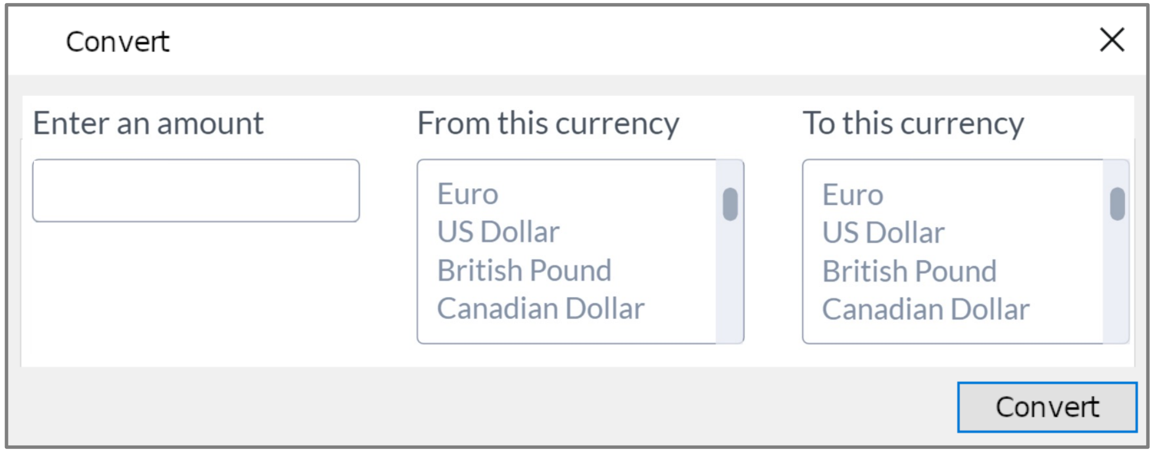
- System response
  - Time the user must wait for a response

KLM

Operator	Description	Associated Time
K	Keystroke, typing one letter, number, etc. or function key such as ‘CRTL’ or ‘SHIFT’	Expert (90 wpm): 0.12s Average non-skilled (40 wpm): 0.28s unfamiliar with keyboard: 1.2s
H	‘Homing’, moving the hand between mouse and keyboard	0.4s
B/BB	Pressing or releasing a button (B) Clicking a button(BB)	0.1s 2*0.1s
P	Pointing with a mouse to a target	1.1s
D(n_D, l_D)	Drawing n_D straight line segments of length l_D	$0.9s*n_D + 0.16*l_D$
M	Subsumed time for mental acts; sometimes used as ‘look-at’	1.35s
R(t)	System response time, time during which the user cannot act	Dependent on the system



Example



- Task: Convert 12 Euro to US Dollar

select text field

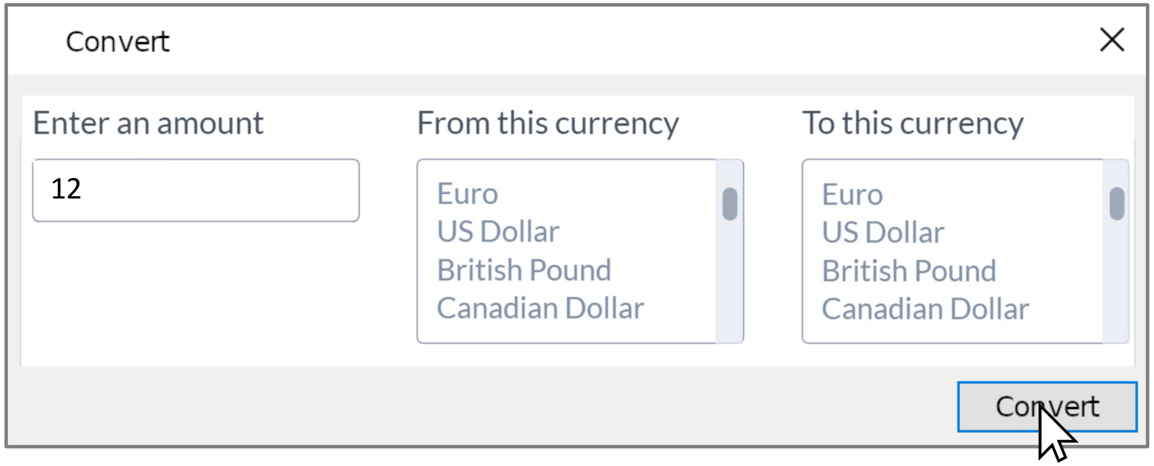
enter value

select Euro

select Dollar

select Convert

Example – Predict Task Time



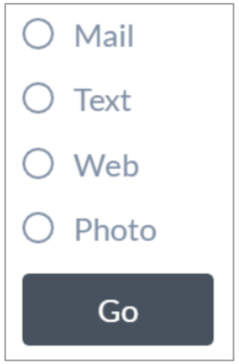
select text field	**P,B,B**	1.3
enter value	**H,M,K,K**	2.31
select Euro	**H,M,P,B,B**	3.05
select Dollar	**M,P,B,B**	2.65
select Convert	**P,B,B**	1.3
		10.61 s

Operator	Description	Time
K	Keystroke	0.28
H	‘Homing’	0.4
B	Pressing or releasing a button (B)	0.1
P	Pointing with a mouse to a target	1.1
M	Mental acts	1.35

KLM – Comparing Methods

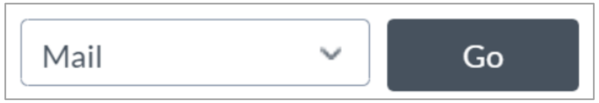
- Task: go to ‘Photo’
- Hand on mouse, nothing selected, mouse pointer at top-left edge of UI element
- Go button is the same as Return key

Version 1



Version 2

Version 3



Version 4

Operator	Description	Time
K	Keystroke	0.28
H	‘Homing’	0.4
B	Pressing or releasing a button (B)	0.1
P	Pointing with a mouse to a target	1.1
M	Mental acts	1.35

Mentimeter

Version 1

- Mail
- Text
- Web
- Photo

Go

Version 2

Mail

Text

Web

Photo

Version 3

Mail

Go

Version 4

|

Go

Utility of KLM

Advantages

- Simplicity of the model: easy to apply
- Can be done from just sketches of an interface
- Surprisingly accurate
- Appropriate for routine tasks
- Especially useful to compare alternatives
- Testing designs for frequently and repetitively used interfaces

- Limitations

- Assumes that the user is expert and the task well-rehearsed
- Assumes error-free operation
- Not appropriate for tasks that involve exploration or reasoning

Input Models – Key Points

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- Input is based on movement, and we can model movement time for different types of task – pointing, crossing, moving through tunnels
- Fitts' Law applies in many ways in UI design
  - Careful how to interpret W depending on task: tolerance in the movement
- Steering Law applies when movement is continuously constrained, by object boundaries or obstacles
- KLM can be used to model input time for composite tasks using keystrokes, device switches, pointing, and clicks as primitives