Human-Computer Interaction: 3A. Movement and Fitts’ Law

22 October 2024

Human Movement and Fitts’ Law

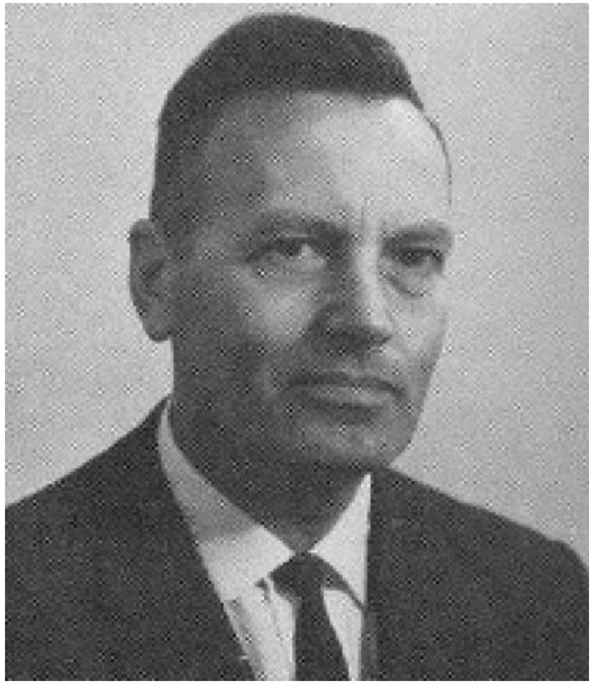
- Fitts’ Law
- Index of Difficulty (ID)
- Building a Fitts’ Law Model
- Speed-Accuracy Trade-off
- Throughput in HCI

Learning Objectives: be able to …

- Identify factors in human performance of input
- Calculate the ID of a pointing task
- Build a Fitts’ Law model of the performance with an input device
- Explain how speed-accuracy trade-off and throughput apply to input

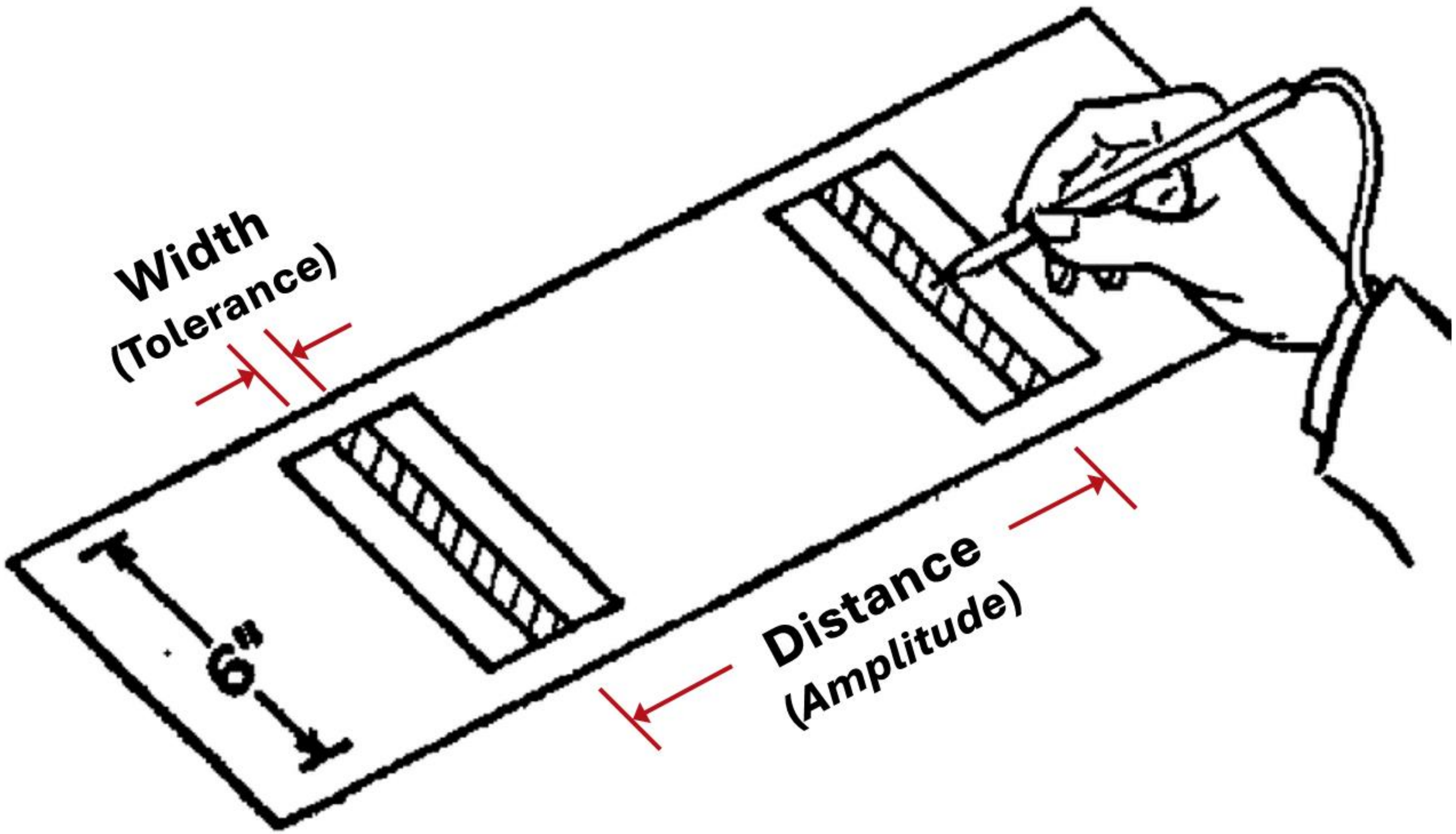
Fitts’ Law

- Paul Fitts (1912-1965)
  - Psychologist
  - Pioneer in Human Factors
- Fitts’ Law is a model of human performance
  - How long does it take to make a movement to a known target?
  - How does this depend on properties of the movement task?
    - Distance and size (width) of the target

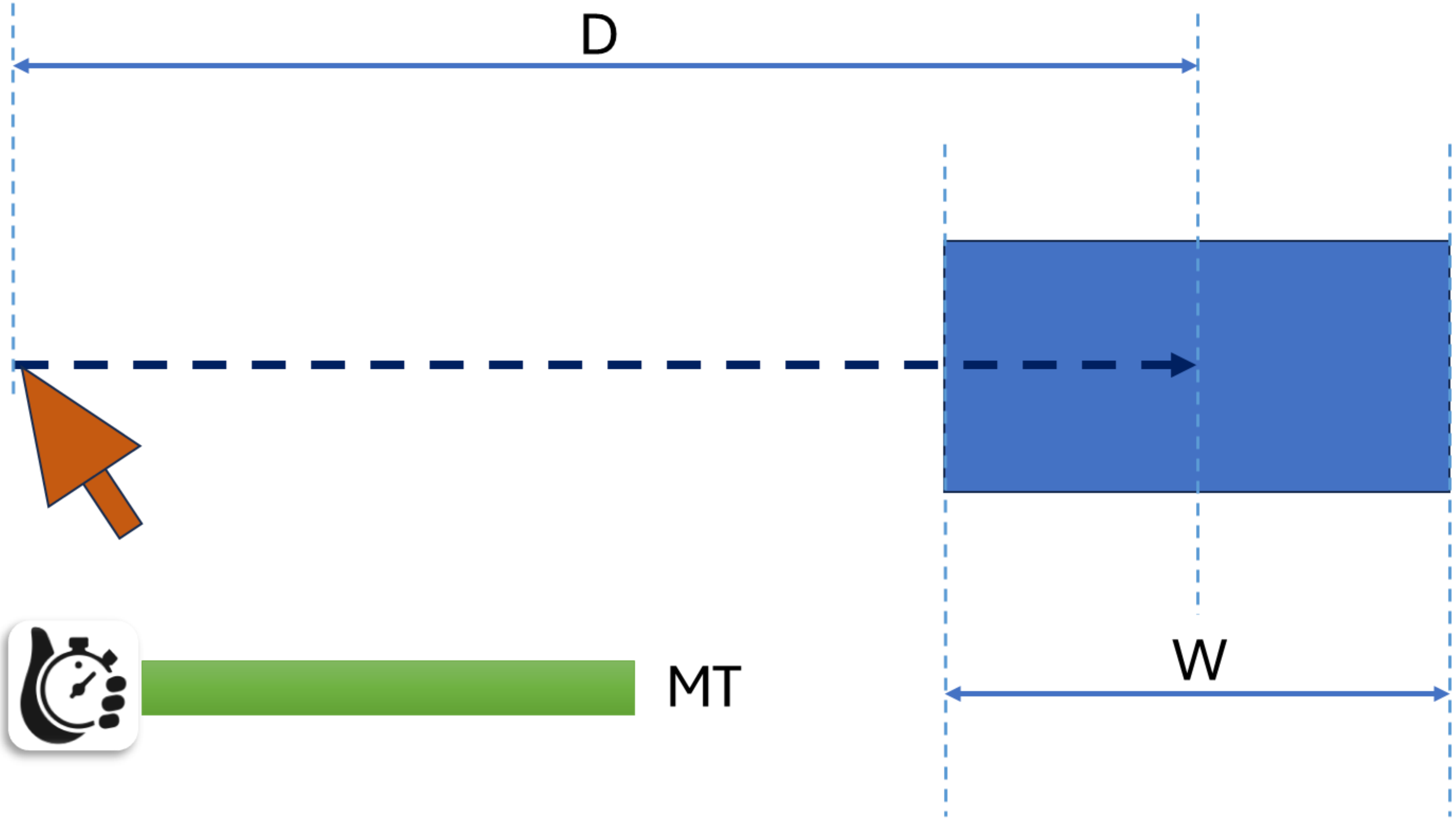


Fitts' Experiment – Apparatus

- Four distances (D): 2, 4, 8, 16 inch
- Four widths (W): 0.25, 0.5, 1, 2 inch
- 16 combinations



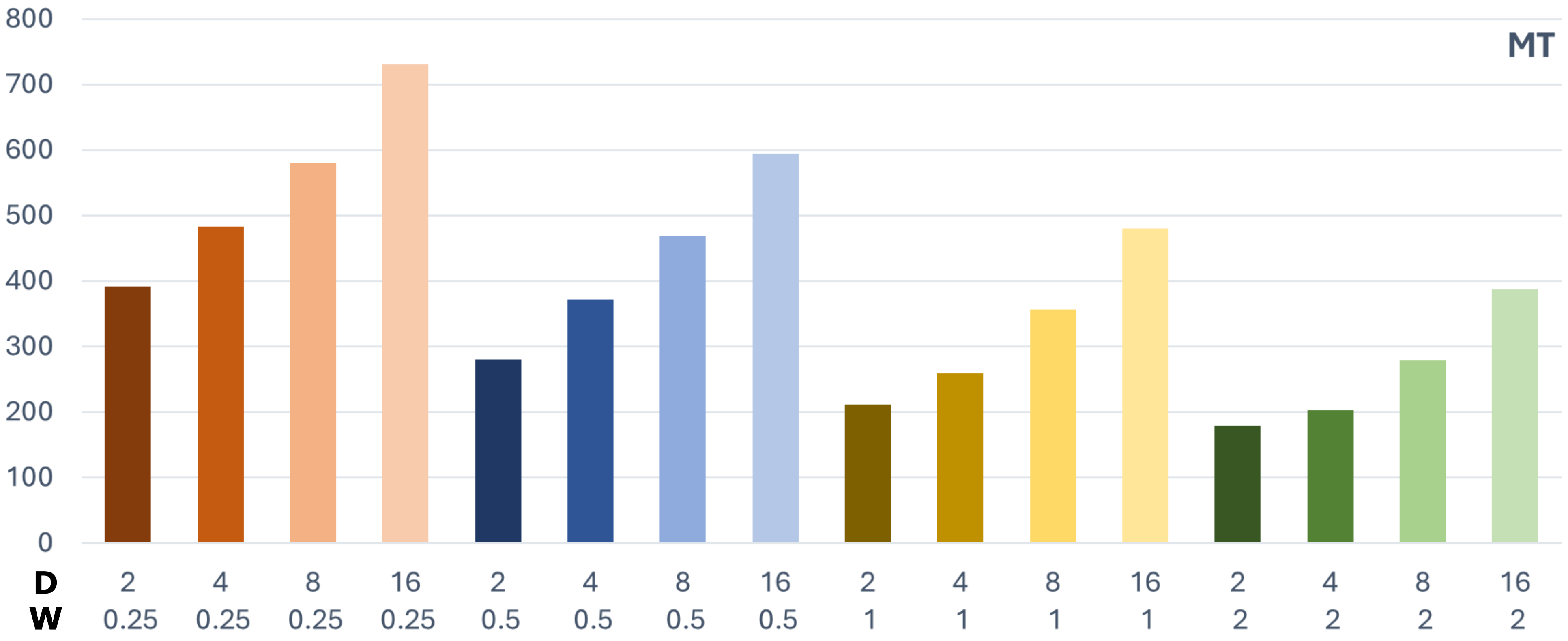
Fitts' Experiment – W and D in 1D Task



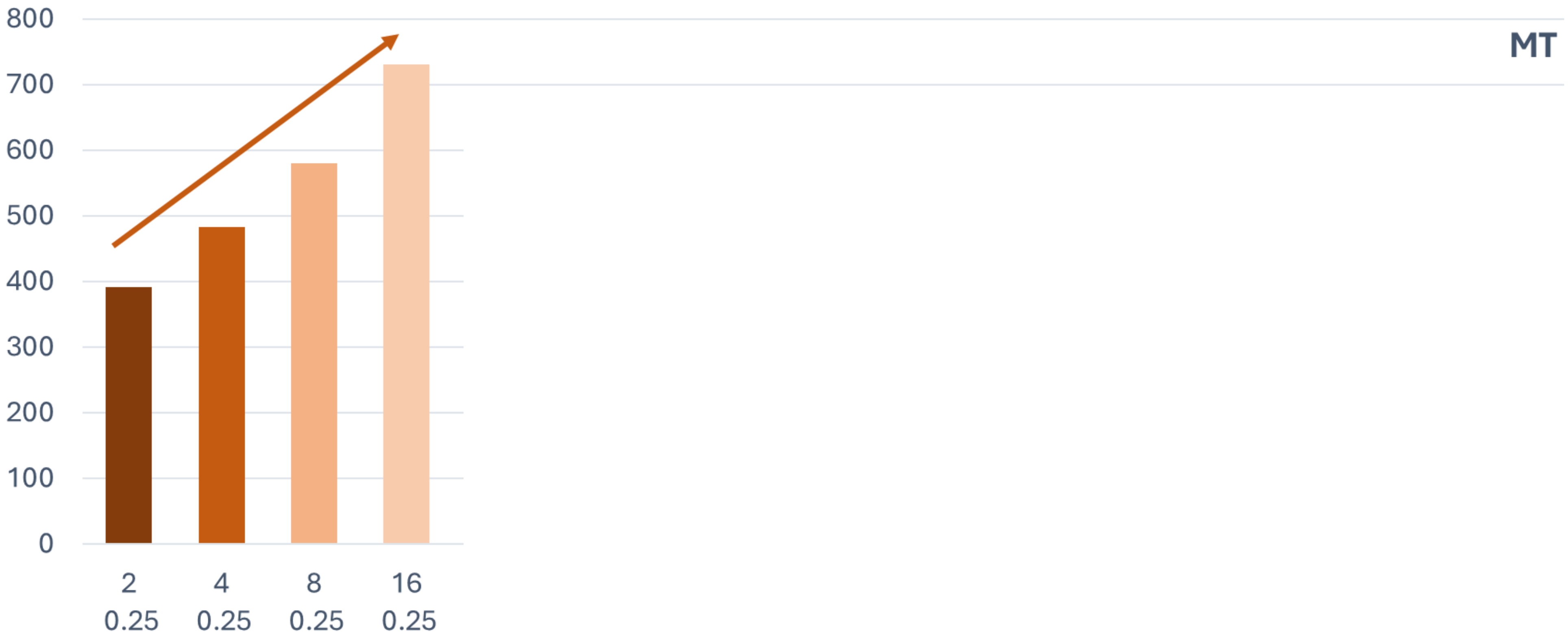
Fitts' Experiment – Dataset

Amplitude	Width	MT
2	0.25	392
2	0.5	281
2	1	212
2	2	180
4	0.25	484
4	0.5	372
4	1	260
4	2	203
8	0.25	580
8	0.5	469
8	1	357
8	2	279
16	0.25	731
16	0.5	595
16	1	481
16	2	388
	Mean	**391.5**
	SD	**157.3**

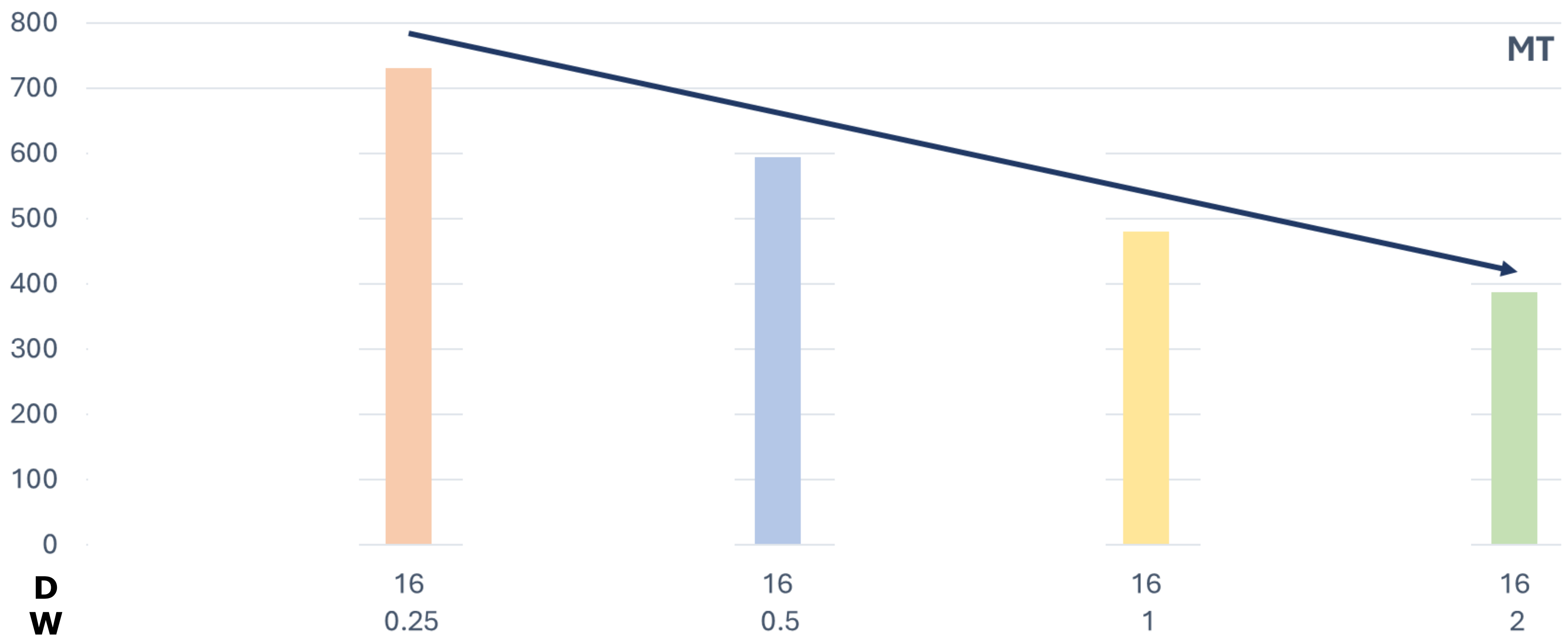
Fitts' Experiment – Initial Analysis



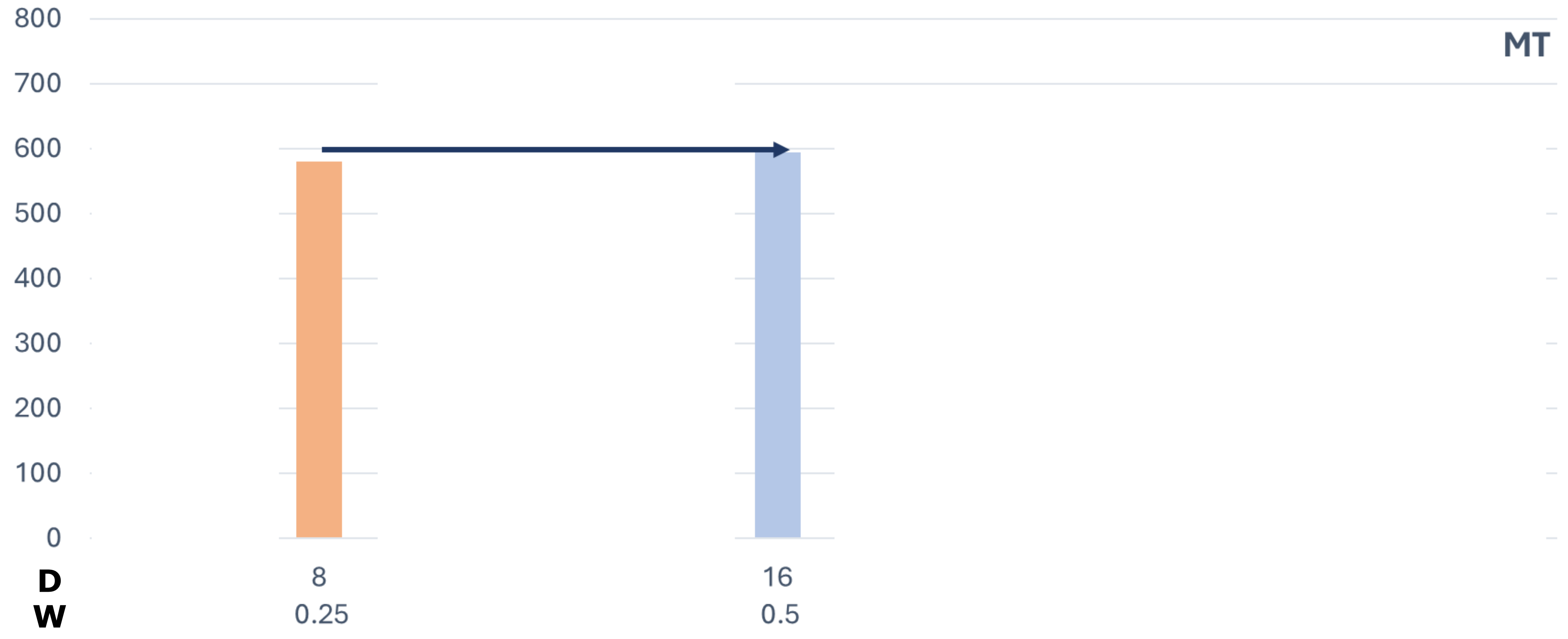
Fitts' Experiment – Factor of Distance



Fitts' Experiment – Factor of Size



Fitts' Experiment – Interactions (Size x Distance)



Fitts' Experiment – Interactions (Effects - Inverse)


```
Data point 1:   D:8   W:0.25
Data point 2:   D:16  W:0.5
“Mid-point”:    D:8   W:0.5
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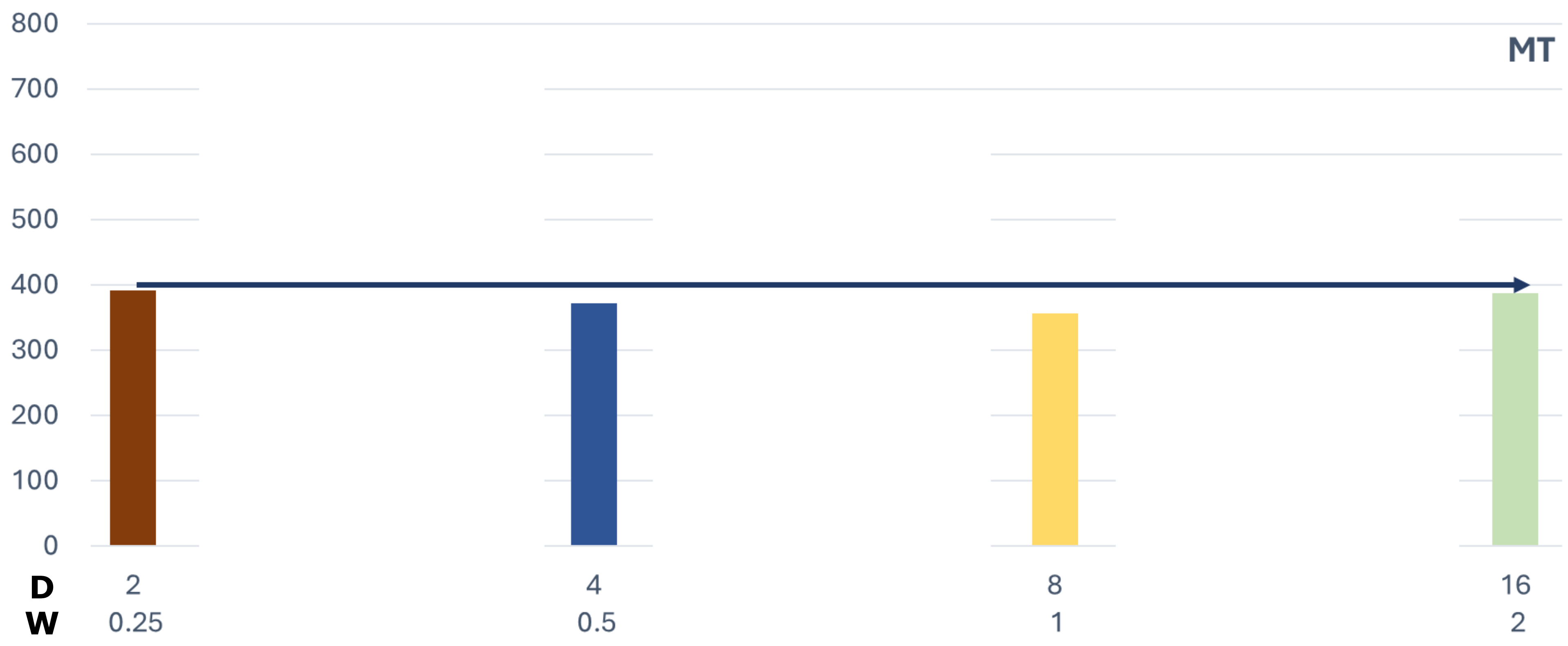
Fitts' Experiment – Interactions (Effects - Direct)



Fitt’s Experiment – Conclusions

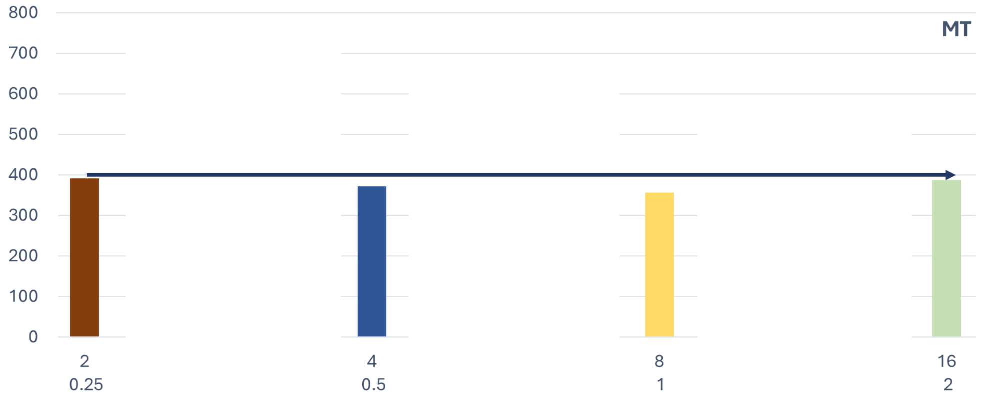
- Movement time depends on the task
- A pointing task has two properties that affect performance
  - Target distance (= Amplitude of the movement)
  - Target width (= Tolerance for landing on the target)
- When a target is nearer, we can reach it faster
- When a target is smaller, we have to slow down to land on it

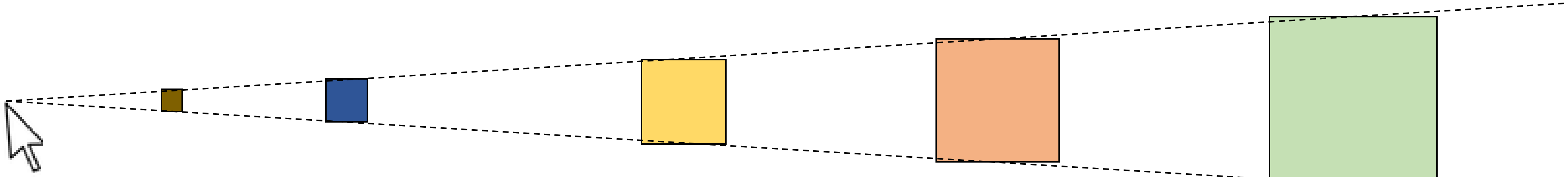
Human Movement and Fitts' Law

- Fitts' Law
- **Index of Difficulty (ID)**
- **Building a Fitts' Law Model**
- Speed-Accuracy Trade-off
- Throughput in HCI

Task Difficulty

- Some tasks take the same time to complete
- They have the same *difficulty*
- We can model task difficulty based on distance and width





Index of Difficulty (ID)

- Paul Fitts proposed to combine distance and width into a single *index of difficulty*, measured in bits
- The formulation has become refined through later research, and in HCI we now use:

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

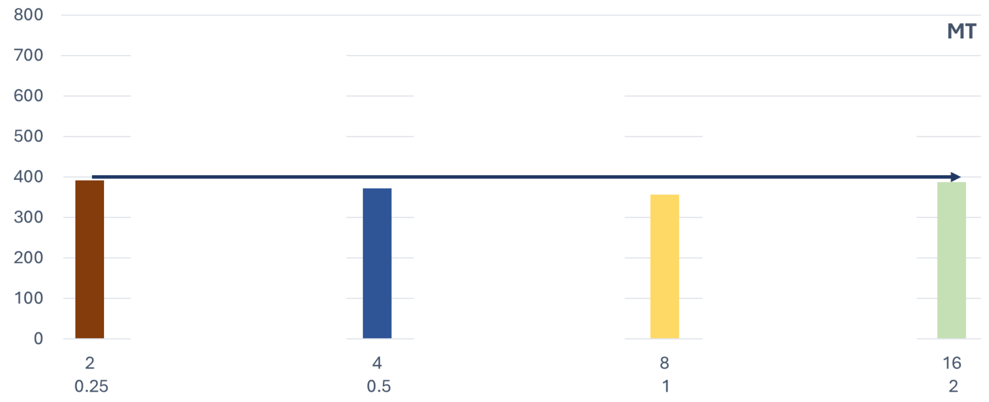
$$ID = log_2\left(\frac{2D}{W}\right)$$

Original formulation proposed by Paul Fitts

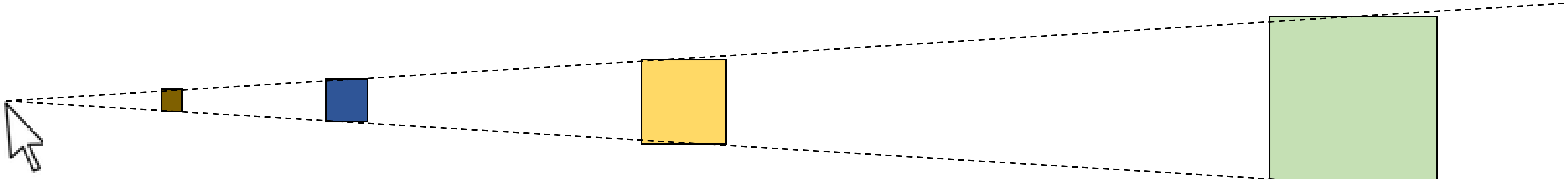
Index of Difficulty (ID) – Example 1

- These four tasks have the same D/W ratio

$$\frac{D}{W} = 8$$



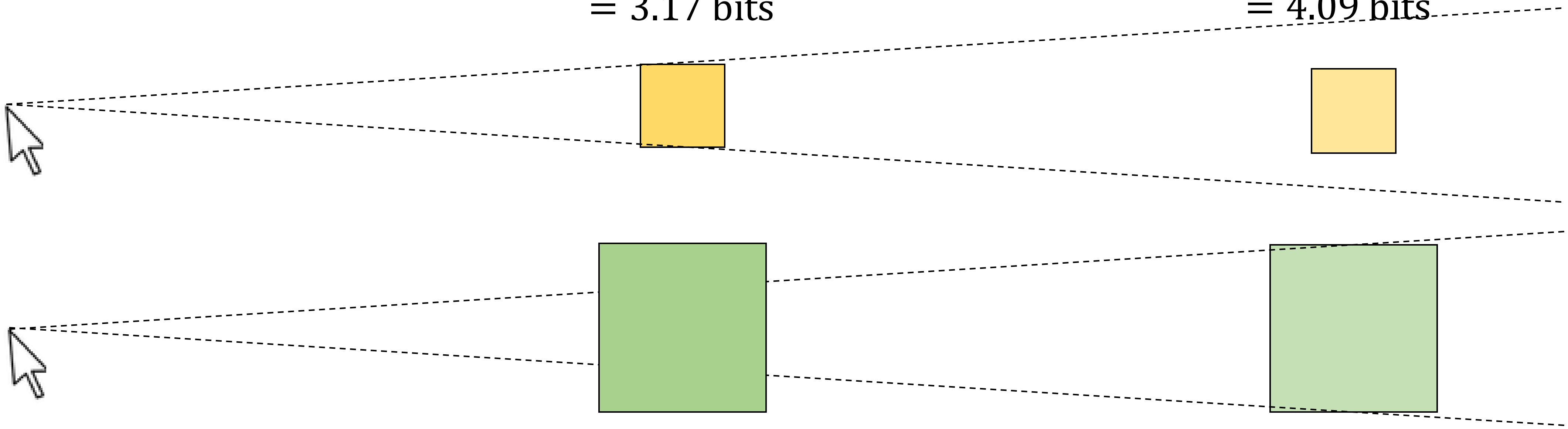
- $ID = log_2(8+1) = 3.17$ bits



Index of Difficulty (ID) – Example 2

$ID = \ log_2(8+1)$
$= 3.17$ bits

$ID = \ log_2(16+1)$
$= 4.09$ bits



$ID = \ log_2(4+1)$
$= 2.32$ bits

$ID = \ log_2(8+1)$
$= 3.17$ bits

Index of Difficulty (ID) – Example 2

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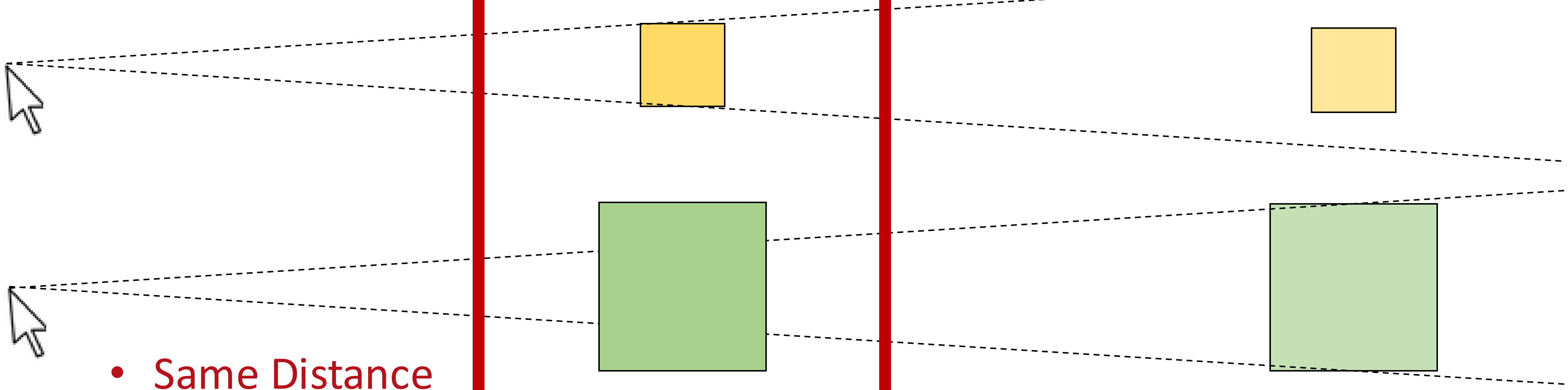


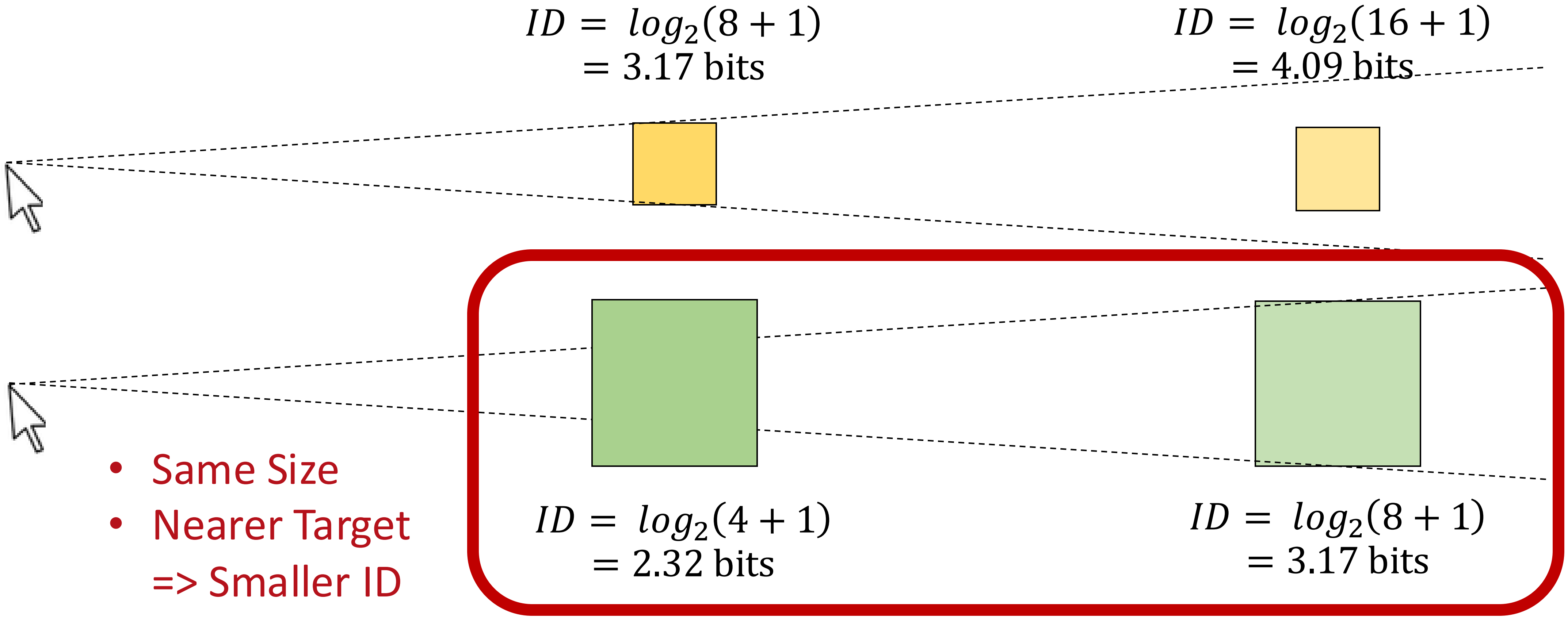
$$ID = \ log_2(4+1)$$
$$= 2.32 \text{ bits}$$

$$ID = \ log_2(8+1)$$
$$= 3.17 \text{ bits}$$

- Same Distance
- Larger Target

  => Smaller ID

Index of Difficulty (ID) – Example 2



- Same Size
- Nearer Target

=> Smaller ID

Building a Fitts’ Law Model

Amplitude	Width	ID	MT
2	0.25	3.17	392
2	0.5	2.32	281
2	1	1.58	212
2	2	1	180
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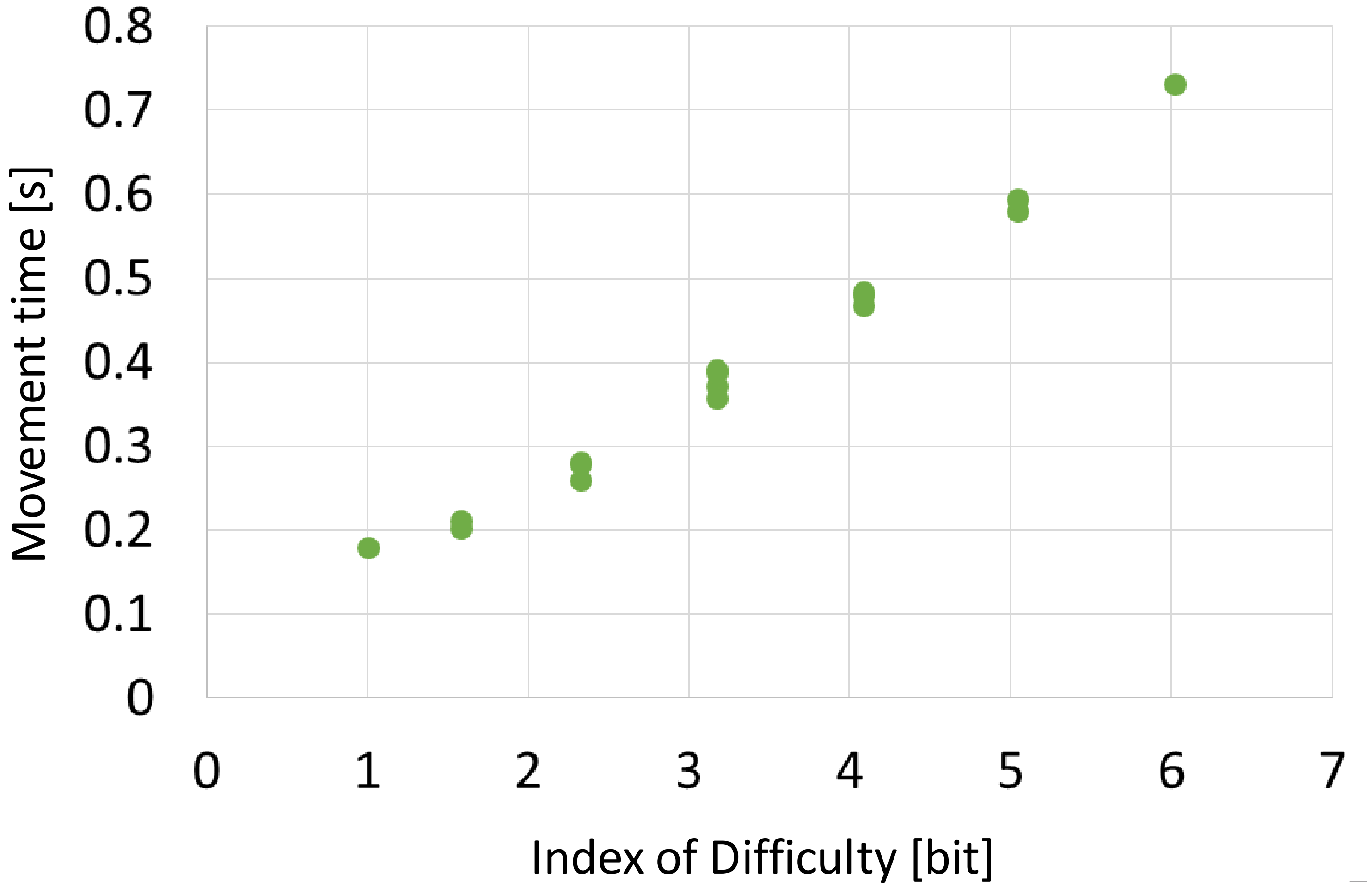
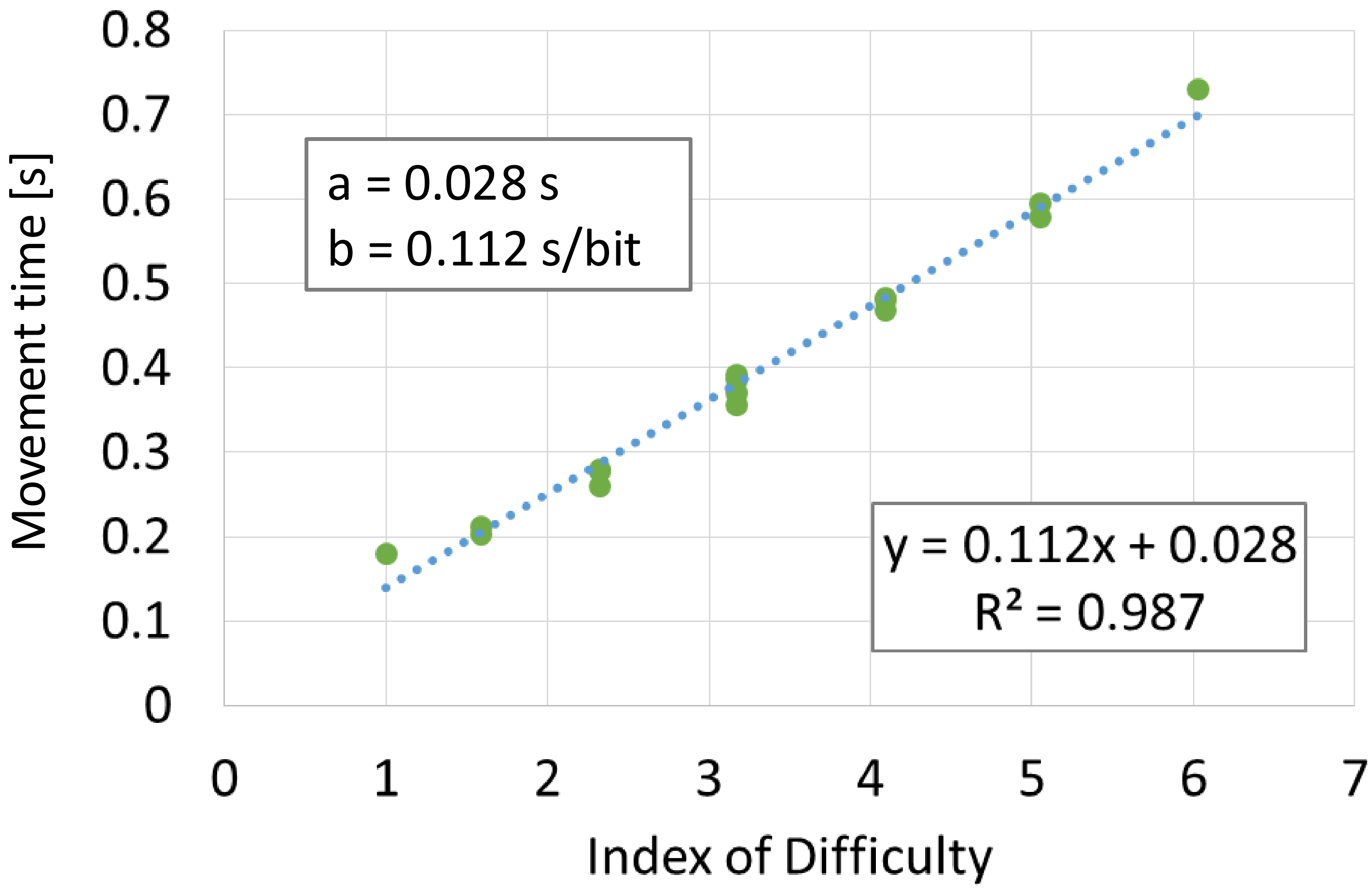


Building a Fitts' Law Model - Formulation

- Movement time depends on task difficulty
- The relationship is linear
- Fitts' Law:
  $MT = a + b * ID$
- The values for a and b are specific to the apparatus / device



Fitts' Law – Generalisation

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

- Distance (D): Distance of the target
- Width (W): width of the target in the direction of the movement
- ID: index of difficulty of the task, in *bits*
- b: rate at which time increases with task difficulty, in *seconds/bit*
- a is a time constant, in *seconds*

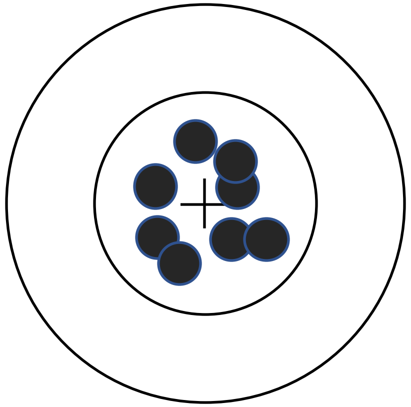
- D, W and ID are properties of the movement task
  - **independent** of the device used for the movement
- a and b are **device-dependent**, on the device and body part used to perform the movement

Human Movement and Fitts’ Law

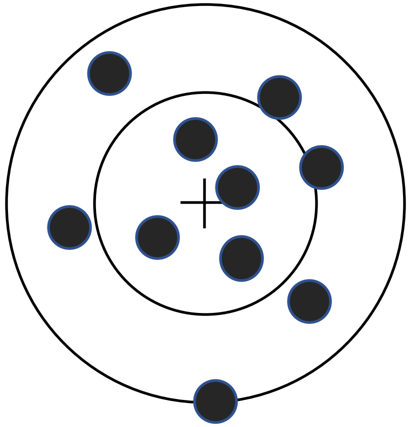
- Fitts’ Law
- Index of Difficulty (ID)
- Building a Fitts’ Law Model
- **Speed-Accuracy Trade-off**
- **Throughput in HCI**

Speed-Accuracy Trade-off

- Fitts' Law captures the *speed-accuracy trade-off* in movement
  - We move faster, when we don't have to be accurate
  - We can be more accurate, when we move more slowly



- The speed-accuracy trade-off is a fundamental property of input in user interfaces
  - When we move faster, we make more errors
  - Pointing with less precision
  - Typing errors



Factor of Device

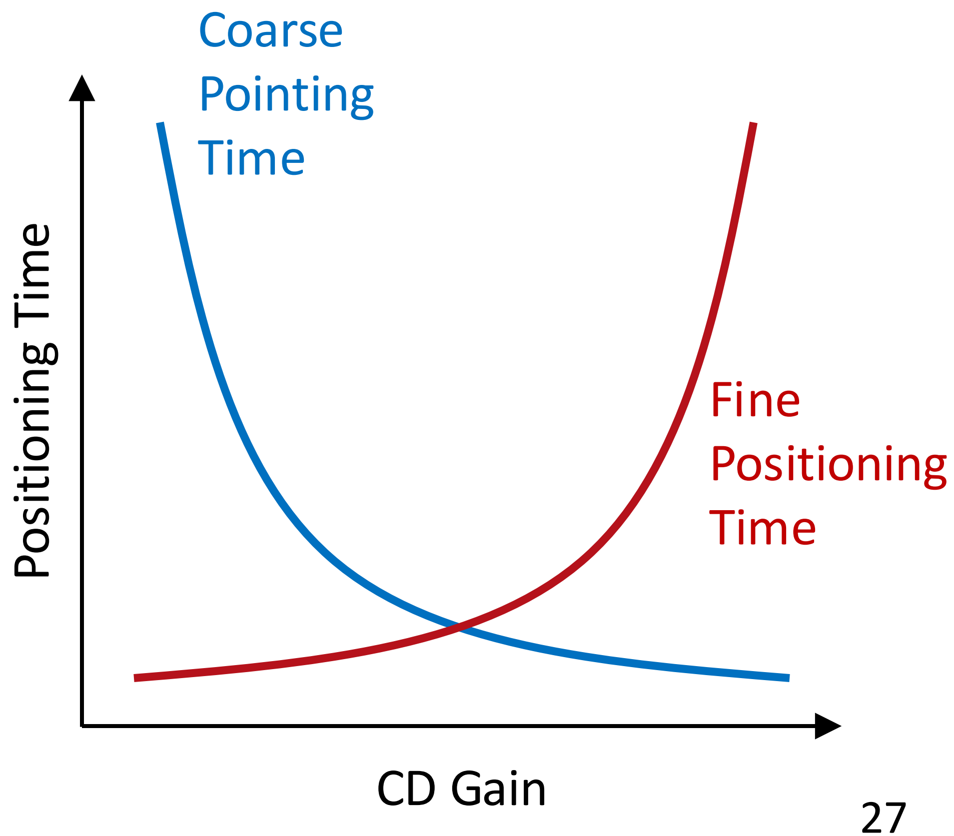
- Speed and accuracy of input depend on the input method
- There are many factors that can influence speed and accuracy
  - The movement of the user that is sensed in *motor space* (eyes, head, hands)
  - Input devices and trackers used (mouse, trackpad, joystick, …)
  - The mapping of input from motor space to display space (control-display gain, transfer function)
- Collectively we refer to these as *Factor of Device*

Example: Control-Display Gain (CD Gain)

- CD gain is a scale factor in mapping input from a device to a cursor on the display:

$$CD_{gain} = \frac{V_{display}}{V_{control}}$$

- CD gain > 1: less movement of the input device needed, for faster cursor movement on the display (coarse pointing)
- CD gain <1: cursor moves more slowly than the input device, for precise input (fine positioning)



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

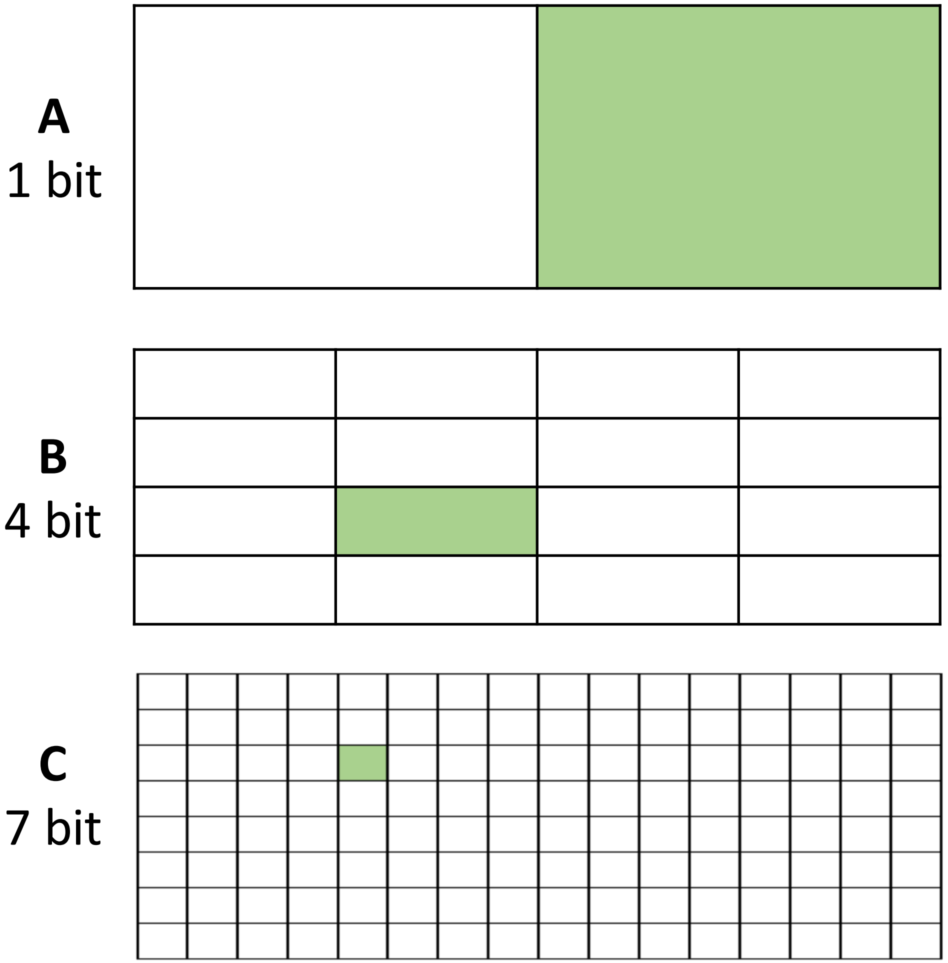
- Fitts' Law defines throughput *TP* as a measure of input efficiency

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

- 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 – Thought Experiment

- Think of information transfer as selection of 1 from N options
- If we divide the screen into two large buttons (A) then we can select 1 of 2
  - Transferring 1 bit/selection
- If we divide the screen into more buttons, then every selection transfers more information
  - B: 1 of 16 => 4 bit/selection
  - C: 1 of 128 => 7 bit/selection

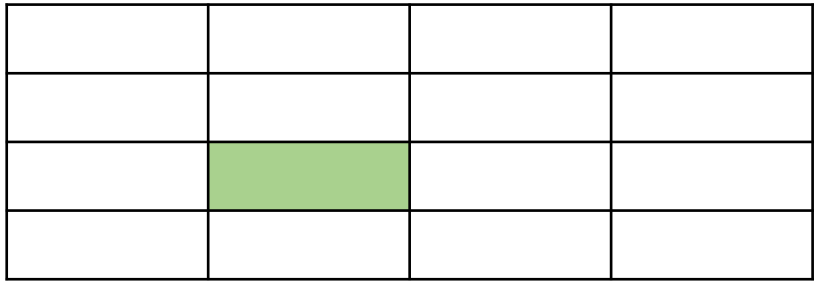


Throughput – Thought Experiment
Scenario 1: No errors

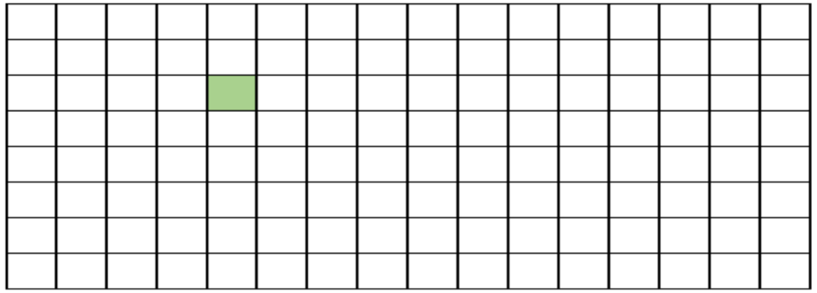
- Scenario 1: we are very careful to avoid any input error
- The time for a selection depends on the button size, say
  - A: MT = 250ms -> 4 selections/s
  - B: MT = 666ms -> 1.5 selections/s
  - C: MT = 1000ms -> 1 selection/s
- Which interface has the highest throughput?

A
1 bit

B
4 bit

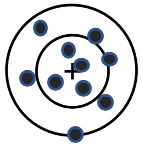


C
7 bit



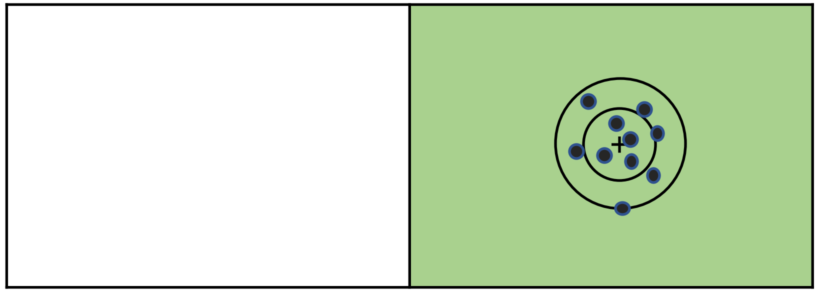
Throughput – Thought Experiment
Scenario 2: High-speed input

- Scenario 2: we risk error and make all selections at high speed
  - MT = 250ms -> 4 selections/s
- Fast movement means that we will not be precise. Our input will be noisy:
  - A: no errors
  - B: 40% error rate
  - C: 80% error rate

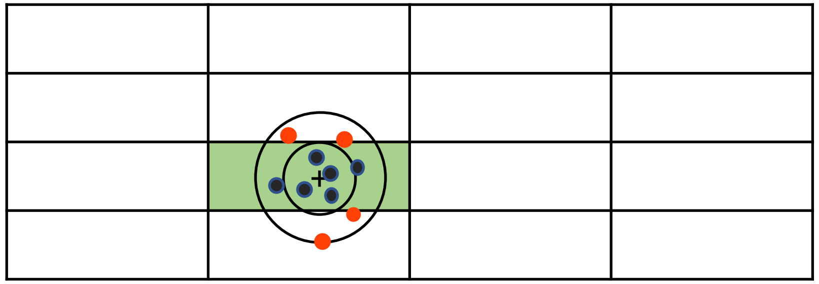


- Which interface has the highest throughput?

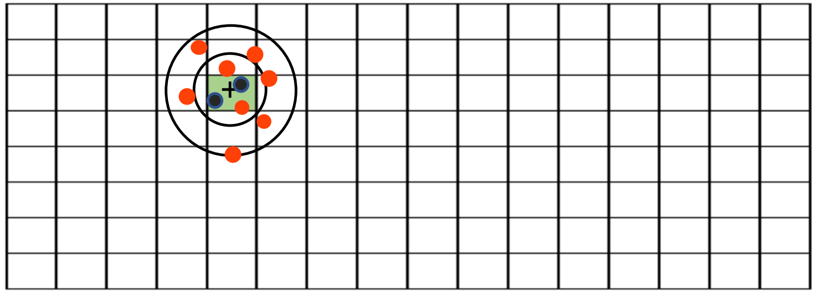
A
1 bit



B
4 bit



C
7 bit

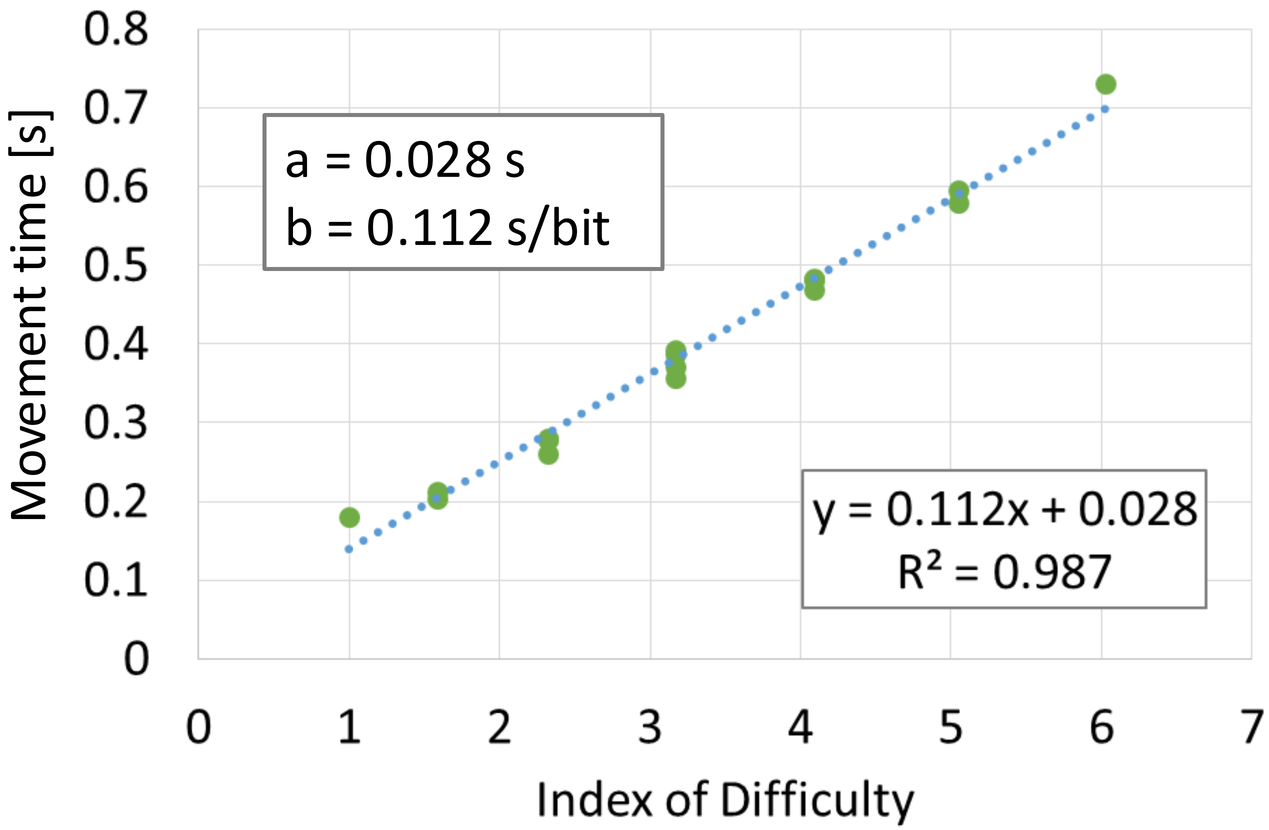


Throughput – Fitts' Law Visualisation

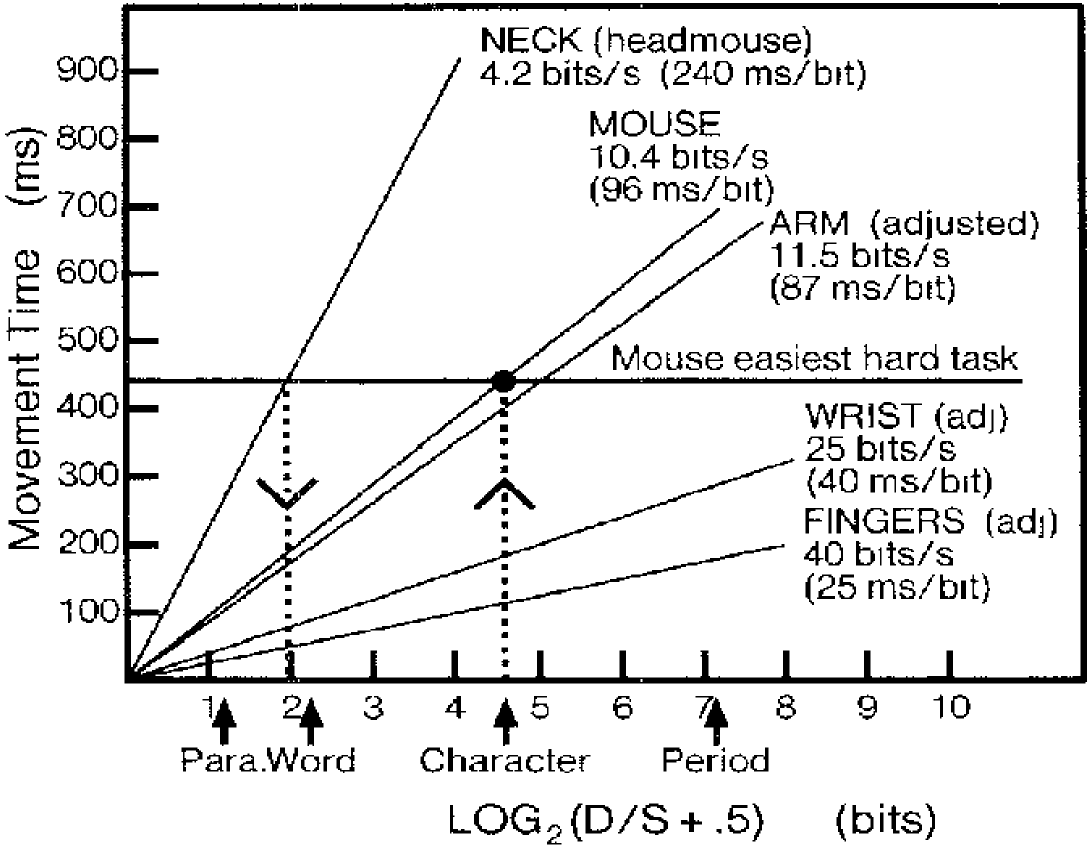
- $MT = a + b * ID$
- $TP = \frac{ID}{MT}$
- We can approximate throughput as the inverse of the slope

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

- 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

Next Lecture

- Input models
- Fitts' Law Application
- Pointing and Crossing
- Steering Law
- Keystroke-level Model (KLM)