INTERACTION DESIGN AND EVALUATION. SESSION 1

Dept. Computer Science – UPC

MOTIVATION

- Interaction Design and Evaluation:
  - Design User Interfaces
  - Measure/Predict performance
  - Design interaction

OBJECTIVES

- Understanding the fundamentals of basic interaction in UI
  - Background (Information Theory)
  - Hick-Hyman Law: Measuring Choice-Reaction Time
  - Fitts' Law: Measuring Pointing Time
    - Typing & Keyboards
    - UI Design
  - Crossing and Steering Laws: Continuous Gestures
  - Guidelines for UI design and evaluation
  - Experiments to assess/evaluate interaction theories

BACKGROUND. BASICS

- **Information Theory**:
  - Due to <u>Claude E. Shannon</u>
    - *A Mathematical Theory of Communication* (1948)
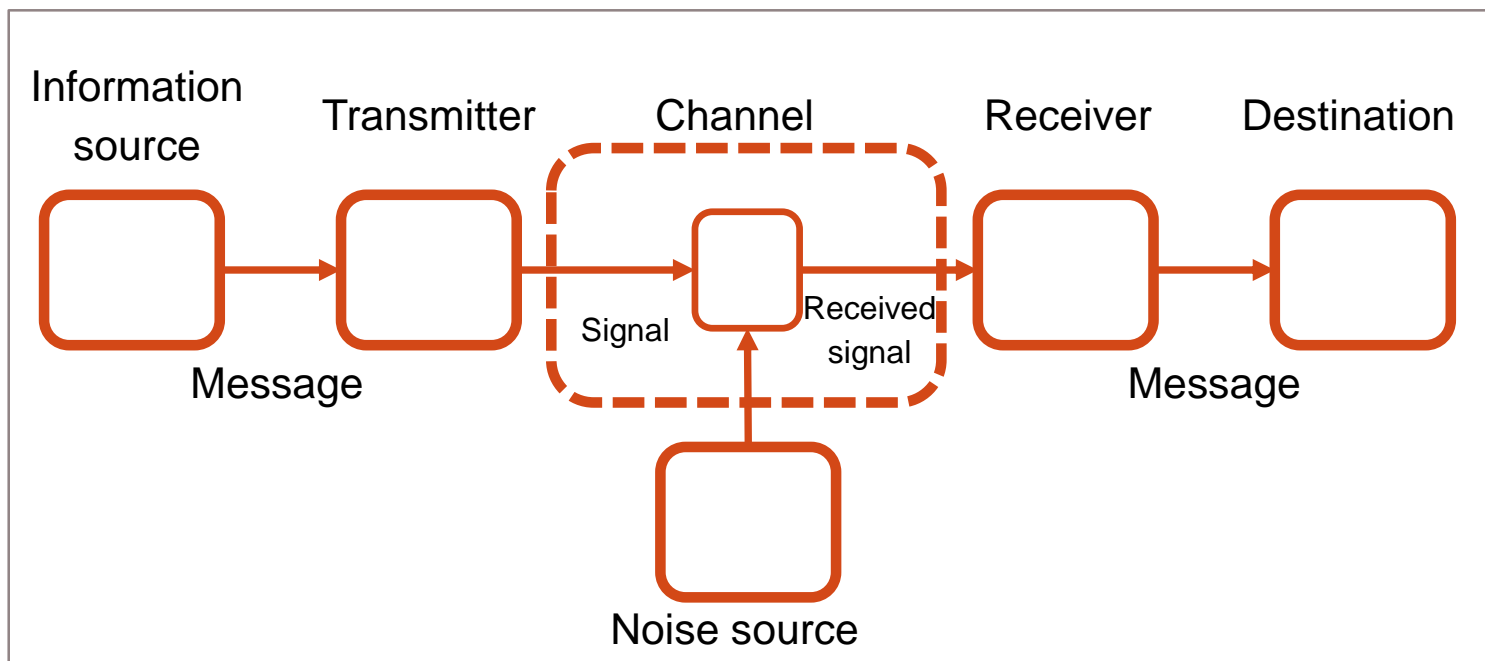 - Based on previous works by Nyquist and Hartley
  - Analysis of transmission of electrical signals for telegraphic communication
  - <u>Shannon Entropy </u>measures:

    The amount of information to be transmitted by a message

BACKGROUND. BASICS

- Information Theory. Elements (telegraph):

Information source — Transmitter — Channel — Receiver — Destination

Message

Signal — Received signal

Message

Noise source

BACKGROUND. BASICS

- Information Theory. Elements (telegraph):
  - **Information source:** The element that produces a message or sequences of message.
  - **Transmitter:** Operates on the message to make it transmissible through a medium.
  - **Channel:** The medium that transmits the message.
  - **Receiver:** The element that reconstruct the message to the destination.

BACKGROUND. INFORMATION MEASURES

- Let d be a device that produces symbols A, B, and C with the same probability
  - M = 3 is the total number of symbols
  - Each time a symbol is produced we are <u>uncertain</u> on which symbol is going to be generated
    - This uncertainty is not so big, since there are only three possibilities
  - The <u>probability of a symbol to appear is 1/M : 1/3</u>
  - The **uncertainty** is measured by $\log_2(3)$

BACKGROUND. INFORMATION MEASURES

- The **uncertainty** we have depends on the number M of symbols $\rightarrow \log_2(M)$.
  - 3 symbols $\rightarrow$ uncertainty of $\log_2(3)$.
  - 2 symbols $\rightarrow$ uncertainty of $\log_2(2)$.

- Logarithms are commonly taken in base 2, and the units are bits.

BACKGROUND. INFORMATION MEASURES

- Let *d* be a device that produces one single symbol: C
  - **M = 1** is the total number of symbols
    - We have **no uncertainty** and $\log_2(1) = 0$
    - The probability of getting the symbol C is 1
    - We previously know which symbol will appear!

BACKGROUND. INFORMATION MEASURES

- We have two devices, one with outputs A, B, C, and the second with outputs 1, 2.

- We combine *words* by concatenating one symbol of device 1 and one with device 2.

- We will have 6 different words: A1, A2, B1, B2, C1, C2
  - 6 symbols $\rightarrow$ uncertainty of $\log_2(6) \rightarrow \log_2(2) + \log_2(3) = \log_2(6)$.

BACKGROUND. INFORMATION MEASURES

- M symbols with equal probability ➜ each symbol has probability P=1/M
  - Rewriting the uncertainty

$$\log_2(M) = \log_2\left(\frac{1}{M}\right)^{-1} = \log_2\left(P^{-1}\right) = -\log_2(P)$$
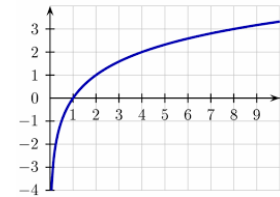
  - **-log_2(P)** is called the **surprise** or *surprisal* of finding a certain symbol
  - We will use p_i from now on for the probability of a symbol i

- For M symbols that have different probabilities, we may have a different p_i for each, provided that

$$\sum_{i=1}^{M} p_i = 1$$

BACKGROUND. INFORMATION MEASURES

- **Information is the reduction of <u>uncertainty</u> or <u>average surprise</u> of a set of symbols**
  - Measuring the surprise for an *infinite* set of symbols (produced by a device) ➜ the frequency of each symbol transforms to the probability.
  - Shannon Entropy measures the amount of information:

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

  - *N* is the number of alternatives
  - p_i is the probability of the *i*th alternative.
  - **H is the entropy of the message that is to be transmitted, the amount of information expected to be received** (no noise).

BACKGROUND. INFORMATION MEASURES

- Information Theory. Shannon entropy:
  - There is interference: Not all information will reach the receiver
  - **Average information faithfully transmitted (R):**

$$R = H(x) - H_y(x)$$

  - **$H_y(x)$ is the equivocation** or conditional entropy of x when y is known

BACKGROUND. INFORMATION MEASURES

- Applications of Shannon entropy:
  - All types of signal transmission and storage:
    - Measuring information
    - Dictionary creation for compression
    - …

OUTLINE

- *Background*

- **Hick-Hyman Law: Measuring choice-reaction time**
  - Hick-Hyman Law
  - Experimental assessment

- Fitts Law: Measuring Pointing Time

- Typing & Keyboards

HICK-HYMAN LAW

- Hick-Hyman Law:
  - Initially stated by William E. Hick (1951)
  - Describes human decision time as a function of the information content conveyed by a visual stimulus
  - It takes longer to respond to a stimulus when it belongs to a large set as opposed to a smaller set of stimuli
  - Extended by Ray Hyman (1952)
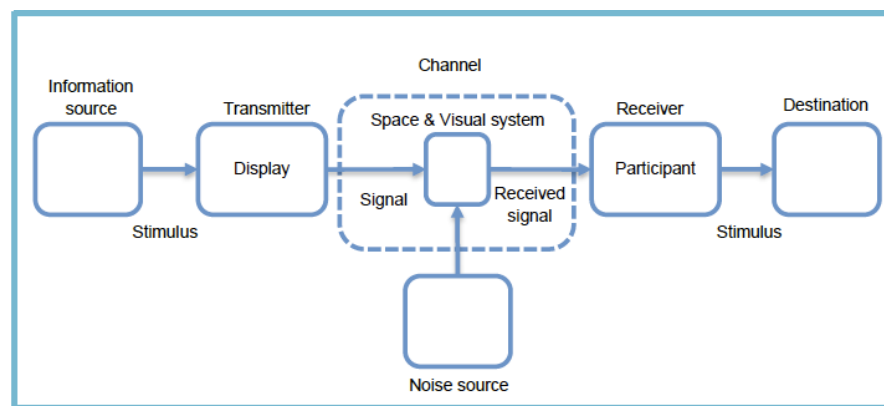
HICK-HYMAN LAW

- **Time to make a decision (Reaction Time):**

$$RT = a + bH_T$$

  - *a*, *b* constants
  - **H_T transmitted information**

HICK-HYMAN LAW

- Hick-Hyman Law:
  - **H_T: Transmitted information:**

$$H_T = \log_2(n+1)$$

  - n are the equiprobable alternatives
  - original formulation did not have the "+1"

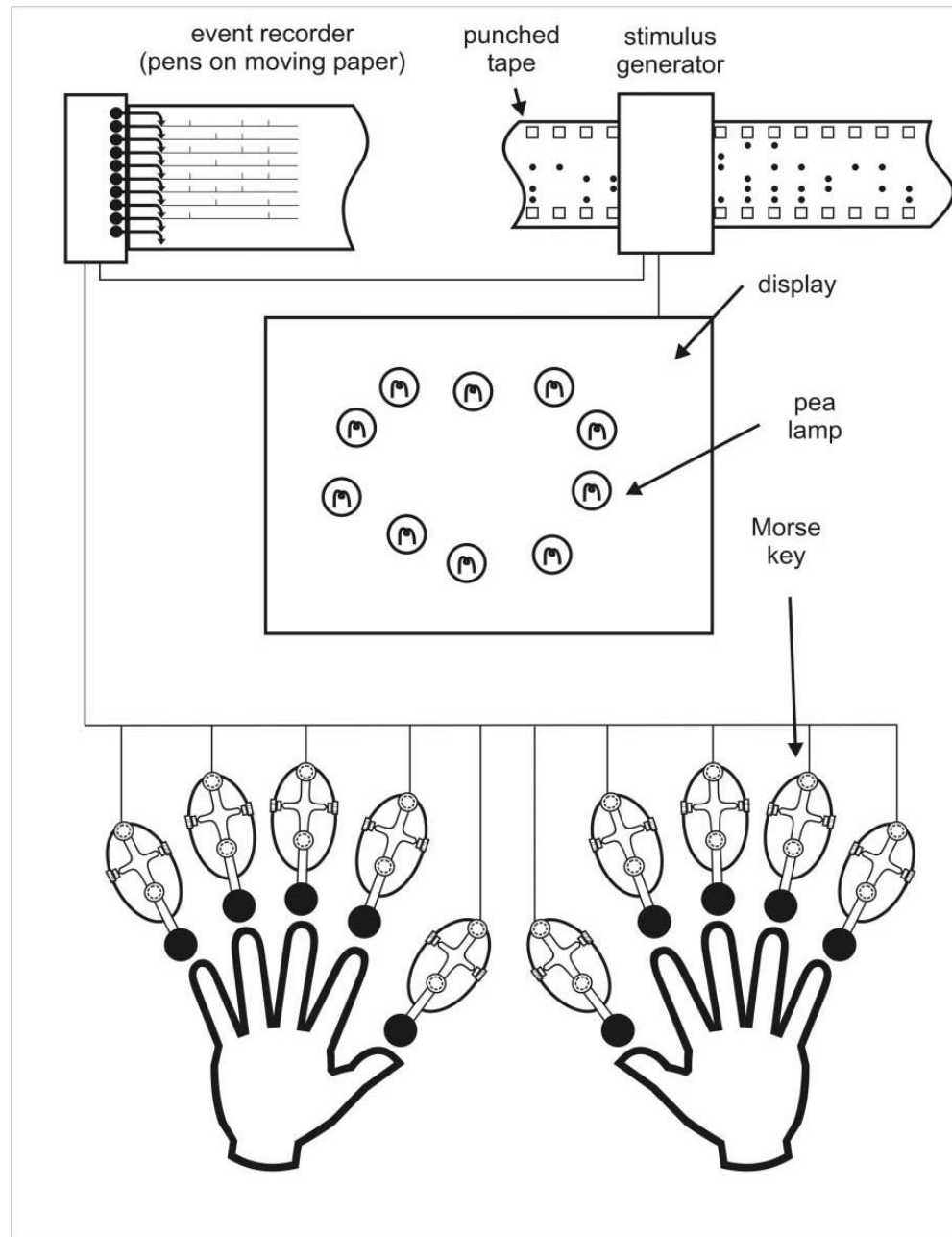   attends for the uncertainty whether to respond or not
  - **Time to answer is the Reaction Time:**

$$RT = a + b\log_2(n+1)$$

HICK-HYMAN LAW. EXPERIMENTAL ASSESSMENT

- Hick's initial experiment:
  - 10 pea lamps are arranged in an irregular circle

  - One random lamp is lit every 5 seconds
  - User has to press the correct key corresponding to the lamp that is lit
  - Stimulus and response encoded in a moving paper in binary code

event recorder
(pens on moving paper)

punched tape

stimulus generator

display

pea lamp

Morse key

HICK-HYMAN LAW. EXPERIMENTAL ASSESSMENT

- Time to answer. Reaction Time:

$$RT = a + b \log_2 (n + 1)$$

  - Reaction Time is a linear function of stimulus information

- Hyman [Hyman53] found that it

  also holds for not equiprobable alternatives

- Experiment:
  - 8 lights (whose names were *Bun, Boo, Bee, Bore, By, Bix, Bev,* and *Bate*)
    - The users had to name the one lit
      - A microphone attached to the throat detected the voice and stopped the timer
    - First with equal probabilities
    - Then, with varying probabilities

HICK-HYMAN LAW. EVIDENCES

- **Evidences of Hick-Hyman Law**
  - Performance in hierarchical full-screen menu selections is well described by Hick-Hyman [Landauer85]
  - *Selection times decay logarithmically with menu length for frequently selected items, but linearly with infrequent ones* [Sears94].
    - Learnt locations (most frequent) fit Hick-Hyman decision times
    - Non-learnt locations fit a linear search
  - Novice users search linearly while experts decide upon item location and fit a Hick-Hyman curve [Cockburn2008]

OUTLINE

- *Background*

- *Hick-Hyman Law: Measuring choice-reaction time*

- **Fitts Law: Measuring Pointing Time**
  - Original formulation
  - Variants
  - Experimental evidences
  - Extensions: 2D and Precision Pointing
  - Discussion
  - Assessed Results

- Typing & Keyboards

FITTS' LAW. ORIGINAL FORMULATION

- States a **linear relationship between task difficulty and movement time (MT)**

- Formulation is also based on Information Theory
  - Amplitude of movement is the *signal*
  - Human motor system is the communication *channel*
  - Target width is the *noise*
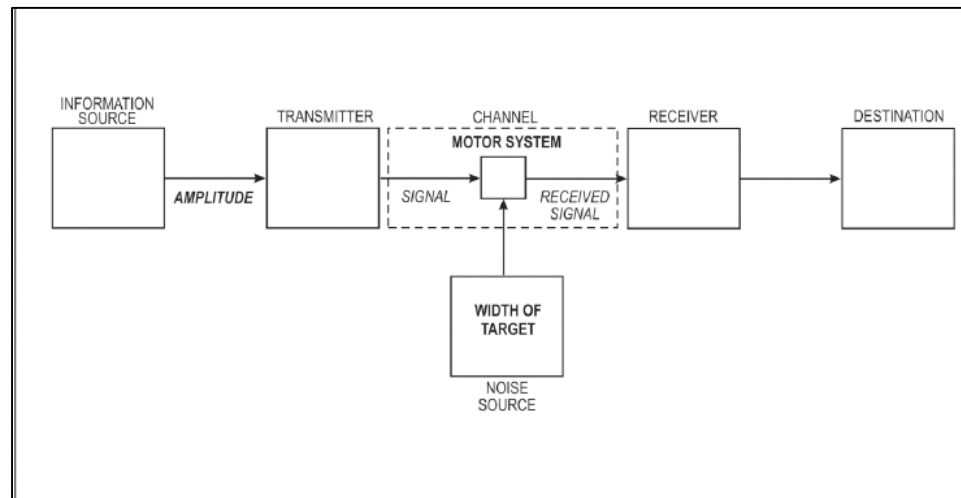
FITTS' LAW. ORIGINAL FORMULATION

- **Task difficulty:**

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

  - *ID:* Index of difficulty
  - *A*: Amplitude of movement
  - *W*: Target width

  - The larger the amplitude the higher the difficulty
  - The larger the target the lower the difficulty

FITTS' LAW. ORIGINAL FORMULATION

- **Movement Time:** Time to point a certain objective (target)

$$MT = a + bID$$

- *a* start/stop times in seconds
- *b* inherent speed of the device

FITTS' LAW. EXPERIMENTAL EVIDENCES

Fitts Law. Original experiments:

- <u>Experiment 1. Reciprocal tapping</u>:
  - Participants used a metal-tipped stylus:
    - Two experiments with two different stylus: ~ 28.35 gr and 453.6 gr
  - Tap two strips of metallic targets of width from ~ 0.635 to 5.08 cm
  - At distance 5.08 to 40.64 cm
    - **Yes, original data is in ounces and inches!!!**
 - Participants instructed to be accurate!

FITTS' LAW. EXPERIMENTAL EVIDENCES

Fitts Law. Original experiments:

- Experiment 2: Disk transfer
  - Participants had to transfer stack round plastic disks (with holes drilled trough the middle) from one pin to another
  - Holes of different sizes and pins of different diameters used

- Experiment 3: Pin transfer
  - Participants had to transfer pins of different diameters from a set of holes to another set of holes

FITTS' LAW. EXPERIMENTAL EVIDENCES

- Fitts Law. Results. Curve fitted: MT = 12.8 + 94.7 ID
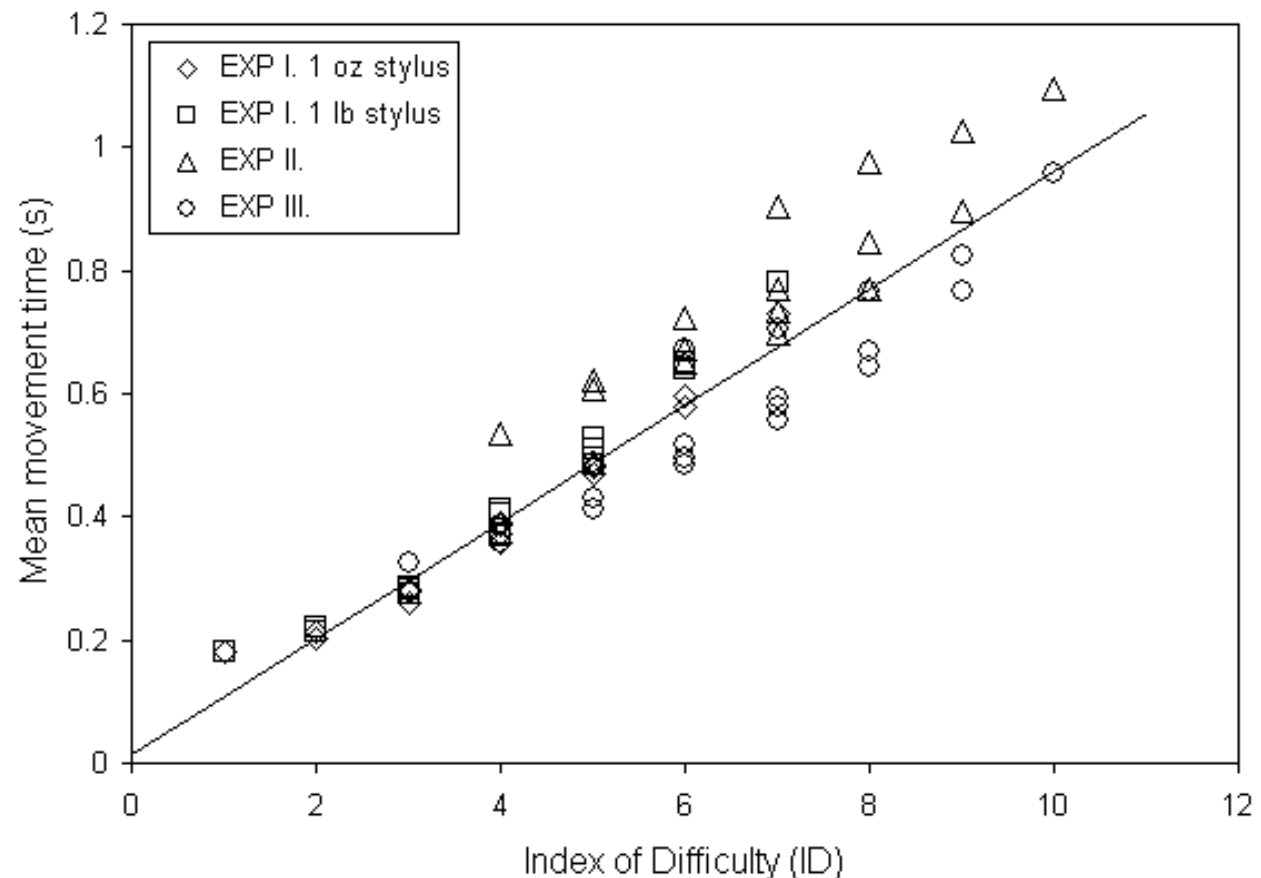
FITTS' LAW. EXPERIMENTAL EVIDENCES

- Fitts Law. Results:
  - Experiment 1:
    - Average error negligible
    - ***Most difficult condition: Smaller W and largest A***
    - Results show that there is a linear relationship between MT and ID

FITTS' LAW. VARIANTS

- Original formulation fits well to the original experiments
  - But it might fit better

- Other researchers have found different formulations that better model the experimental data
  - Including the experimental data by Fitts

- Welford [Welford68]:

$$MT = a + b \log_2 \left(\frac{D + 0.5W}{W} \right)$$

- D is the distance of movement
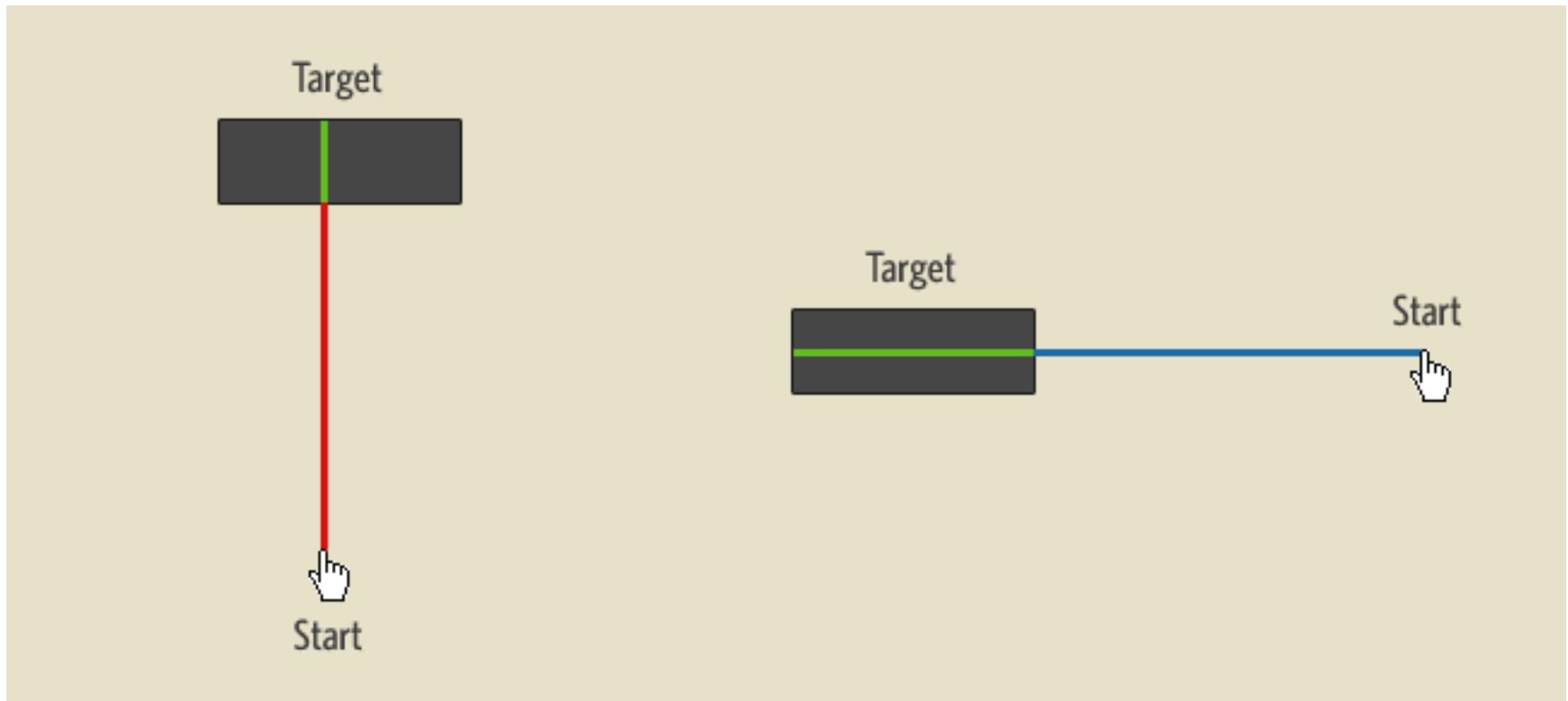- W is the width of the target

FITTS' LAW. VARIANTS

- **MacKenzie's** approach [MacKenzie92] is one of the most accepted:

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

- D is the distance of movement
- W is the width of the target

FITTS' LAW. VARIANTS

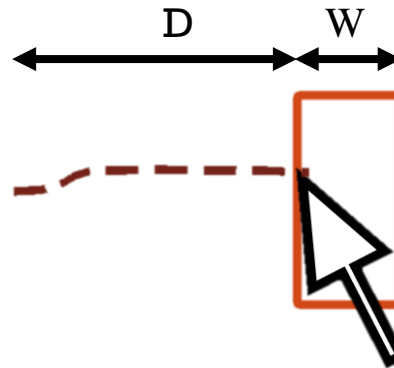- Vertical and horizontal movements can be treated equally

FITTS' LAW. EXTENSIONS

- Main application of Fitts in HCI is evaluation/design of UI and interaction

- Today's interfaces are much more complex
  - Variety of sizes
  - 2D movements
  - Use of fingers
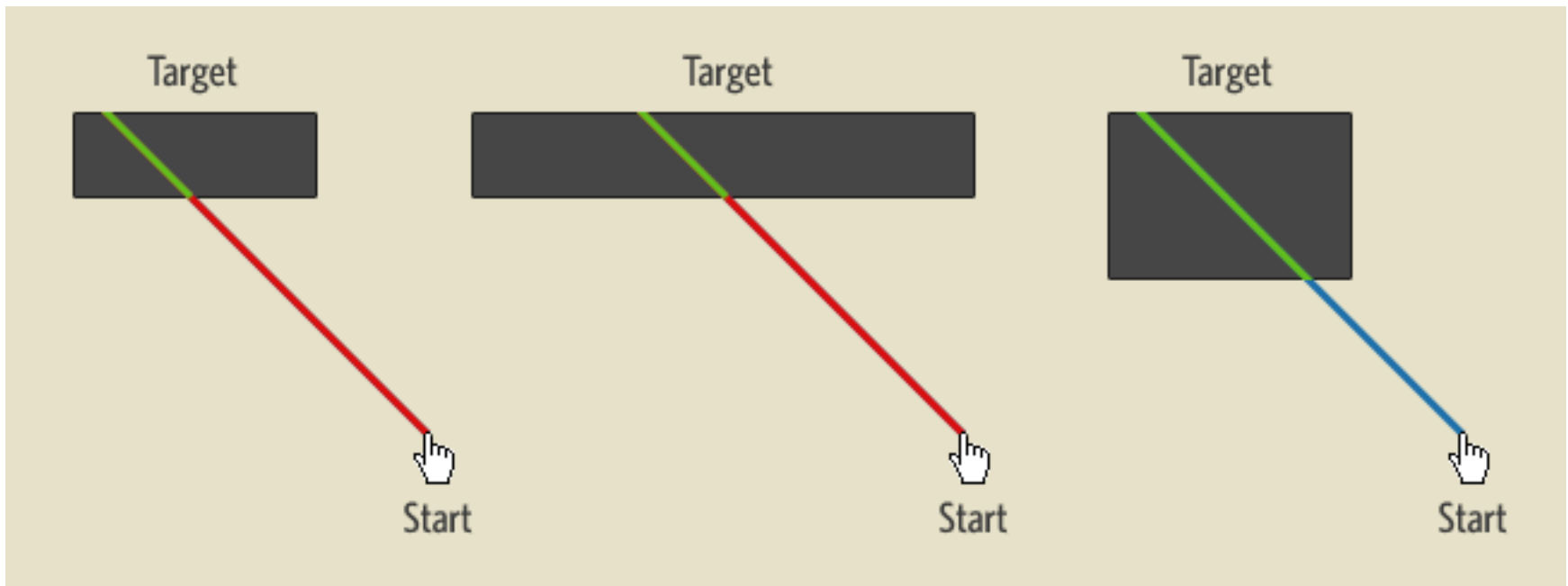
FITTS' LAW. EXTENSIONS

- Use in UI design or evaluation:

- D is the distance the pointer (mouse) covers to reach the target (button)
- W is the width of the target (button)

FITTS' LAW. EXTENSIONS. 2D

- Vertical and horizontal movements can be treated equally… or not!

FITTS' LAW. EXTENSIONS. 2D

- Fitts' Law is designed for 1D movements
  - BUT…most movements in a UI are 2D

- Several extensions deal with 2D movements
  - Mimicking Fitts' Law, but changing some of the parameters
  - [Crossman83]: $MT = a + b\log_2\left(\dfrac{2D}{W}\right) + c\log_2\left(\dfrac{2D}{H}\right)$

  - [Accot97]: $MT = a + b\log_2\left(\sqrt{\left(\dfrac{D}{W}\right)^2 + \eta\left(\dfrac{D}{H}\right)^2} + 1\right)$

FITTS' LAW. EXTENSIONS. PRECISION POINTING

- Fitts Law does not model properly very small targets:
  - Extra time devoted to fine adjustment
  - Increase of errors
  - …

- Very small targets yield a lower fit of the regression curve of the MT function

- Touchscreens also modifies the timing we require to point targets.

FITTS' LAW. EXTENSIONS. PRECISION POINTING

Extension of Fitts' Law by analyzing the behavior both in tactile screens and small targets ([Sears91]):

▪ Named FFitts (**Finger Fitts**), also PPMT (Precision Pointing Movement Time) by some other authors :

$$FFits = a + bID + dID_2$$

$$FFitts = a + b\left[\log_2\left(\frac{cD}{W}\right)\right] + d\left[\log_2\left(\frac{e}{W}\right)\right]$$

FITTS' LAW. EXTENSIONS. PRECISION POINTING

- FFitts:

$$FFitts = a + b\left[\log_2\left(\frac{cD}{W}\right)\right] + d\left[\log_2\left(\frac{e}{W}\right)\right]$$

- the first logarithmic factor measures *the time to place the finger on the screen initially*
- the second factor measures *the time to position the cursor*
- *D* is the distance, measured in three dimensions, from the original hand location to the location of first contact
- If the task consists of iteratively clicking targets: *D* is the distance from one target to the next one
- W is some measurement of target size
- *a*, *b*, *c*, *d*, and *e* must be determined for each specific case

FITTS' LAW. DISCUSSION

Fitting regression curves:

- Validation of Fitts' Law may not extrapolate to outside values
  - Only valid for the experiments carried out
  - Has been demonstrated that **very small values of ID do not fit properly**
  - Limited number of target sizes (four in original Fitts' work)
  - The lack of precise distance measurements (from the user's hand to the target) makes analysis difficult

- The higher number of freedom degrees, the easier to fit in a regression curve
  - Note that this sort of proves are partially done *a posteriori*

- ***Validity Fitts => Experimentation***

FITTS' LAW. DISCUSSION

Speed vs accuracy tradeoff:

- Users can be *guided* through the experimentation:
  - Ask them to be precise
    - Showing error rates enforces correction
  - Ask them to be fast

- We may skew the experiment depending on what we say, e.g.:
  - "This experiment is to demonstrate that larger targets are acquired easier than small targets"
    - Users might want to satisfy you!
    - …Or not!

FITTS' LAW. ASSESSED RESULTS

- **Fitts' Law has shown its validity in multiple setups and devices:**
  - Mouse, joystick, finger, stylus…
  - Different screen types of varying sizes…
  - <u>But the results cannot be extrapolate</u> to data outside the experiment

- **Precued targets lead to more efficient and precise pointing movements than for non-precued targets [Hertzum2013].**
  - Most common case: we know the buttons' positions in advance.
  - The benefit of precuing is larger for the mouse than the touchpad
    - Maybe movement preparation is more effective if the device is more demanding

- **The index finger alone does not perform as well as the wrist or forearm in pointing tasks**
  - But the thumb and index fingers in coordination outperform all above cases [Balakrishnan97]

5. Donades les constants a = 400 ms, b = 200 ms/bit i un objectiu de mida 2.1 cm a una distància de 10.5 cm. Marca la resposta correcta assumint que fem els càlculs amb la versió de McKenzie de la llei de Fitts.
- a. ID ≈ 3.4.
- b. 2 < ID < 3.
- c. ID ≈ 4.3.
- d. MT està entre 1100 i 1200 ms.

6. La llei de Hick-Hyman:
- a. Modela el temps de decisió com una funció de la informació transmesa.
- b. Modela el temps de selecció d'un element com a funció de la distància a recórrer i la mida de l'element.
- c. Modela el temps de decisió com una funció de la distància a recórrer i l'entropia dels elements a seleccionar.
- d. Utilitza l'entropia de Shannon per a mesurar la distància del recorregut mínim.

OUTLINE

- *Background*

- *Hick-Hyman Law: Measuring choice-reaction time*

- *Fitts Law: Measuring Pointing Time*

- **Typing & Keyboards**
  - Layouts
  - Practical Issues
  - Mobile Layouts

FITTS' LAW. EXTENSIONS. PRECISION POINTING

- FFitts:

$$FFitts = a + b\left[\log_2\left(\frac{cD}{W}\right)\right] + d\left[\log_2\left(\frac{e}{W}\right)\right]$$

  - If the task consists of iteratively clicking targets: D is the distance from one target to the next one

INTERACTION DESIGN AND MEASURES

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