# 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
  - Hick-Hyman Law: Choice-Reaction Time
  - Fitts' Law: Pointing Time
  - Crossing and Steering Laws: Continuous Gestures
  - Guidelines for UI design and evaluation
  - Experiments to assess/evaluate interaction theories



# OUTLINE – SESSION 1

- Background
- Hick-Hyman Law: Measuring choice-reaction time
- Fitts Law: Measuring Pointing Time

# OUTLINE – SESSION 1

- **Background:**
  - Basics
  - Information Measures
- Hick-Hyman Law: Measuring choice-reaction time
- Fitts Law: Measuring Pointing Time



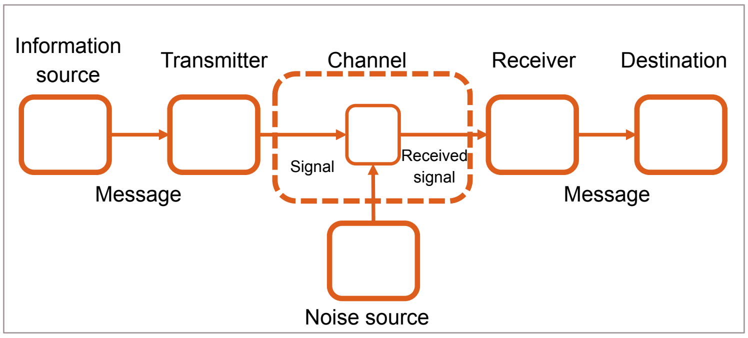
# BACKGROUND. BASICS

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

    *The amount of information to be transmitted by a message*

# BACKGROUND. BASICS

- Information Theory. Elements (telegraph):






# 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 uncertain on which symbol is going to be generated
    - This uncertainty is not so big, since there are only three possibilities
  - The probability of a symbol to appear is 1/M : 1/3
  - The **uncertainty** is measured by $\mathbf{log_2(3)}$



# BACKGROUND. INFORMATION MEASURES

- The **uncertainty** we have depends on the number M of symbols → $\log_2(M)$.
  - 3 symbols → uncertainty of $\log_2(3)$.
  - 2 symbols → 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 → uncertainty of $\log_2(6)$ → $\log_2(2) + \log_2(3) = \log_2(6)$.

# BACKGROUND. INFORMATION MEASURES

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

$$\log_2(M) = \log_2\left(\left(\frac{1}{M}\right)^{-1}\right) = \log_2\left(P^{-1}\right) = -\log_2(P)$$

  - ***$-log_2(P)$*** 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 uncertainty or average surprise 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:

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

    - *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):**

$$R = \mathrm{H}(x)\text{-}\mathrm{H}_y(x)$$

  - **$H_y(x)$ 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
    - …

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# OUTLINE

- *Background*
- **Hick-Hyman Law: Measuring choice-reaction time**
  - Hick-Hyman Law
  - Experimental assessment
- Fitts Law: Measuring Pointing Time
- Typing & Keyboards

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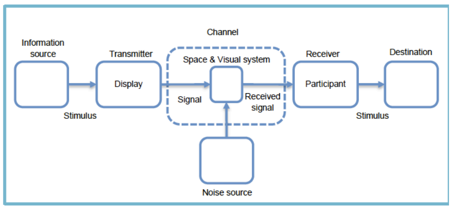
# HICK-HYMAN LAW

- 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):**

$$RT = \mathrm{a} + \mathrm{bH}_T$$

  - *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:**

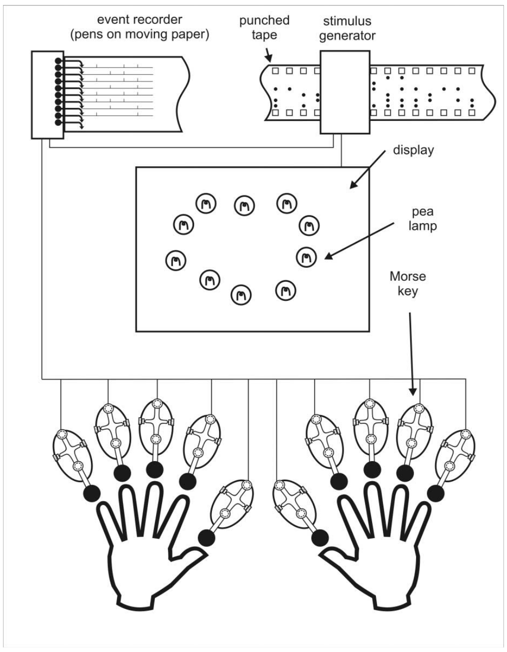
$$RT = \mathrm{a} + \mathrm{b}\log_2(n+1)$$

# 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






# HICK-HYMAN LAW. EXPERIMENTAL ASSESSMENT

- Time to answer. Reaction Time:

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

  - 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]

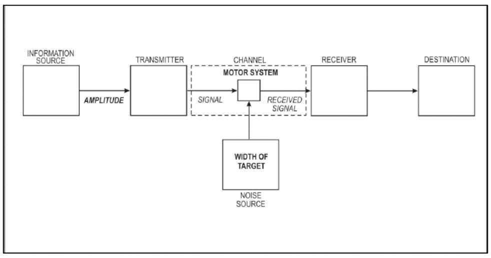
# OUTLINE

- *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

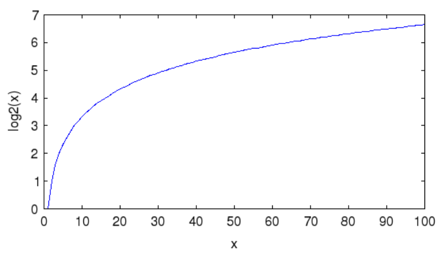


# FITTS' LAW. ORIGINAL FORMULATION

- Task difficulty:

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

  - 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:**

- Experiment 1. Reciprocal tapping:
  - 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

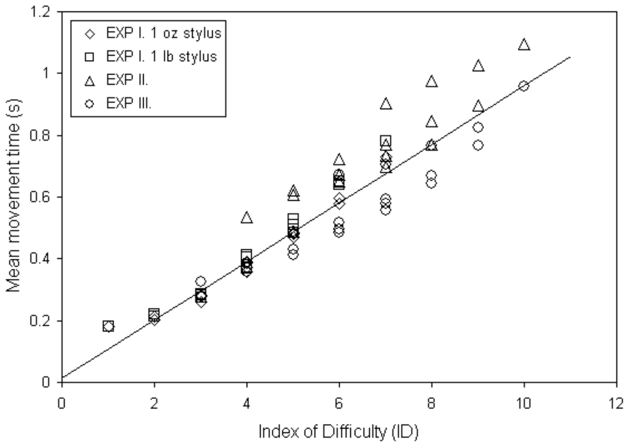
**Fitts Law. Original experiments:**

- 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

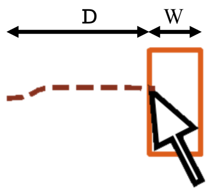
# FITTS LAW. EXTENSIONS

- 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

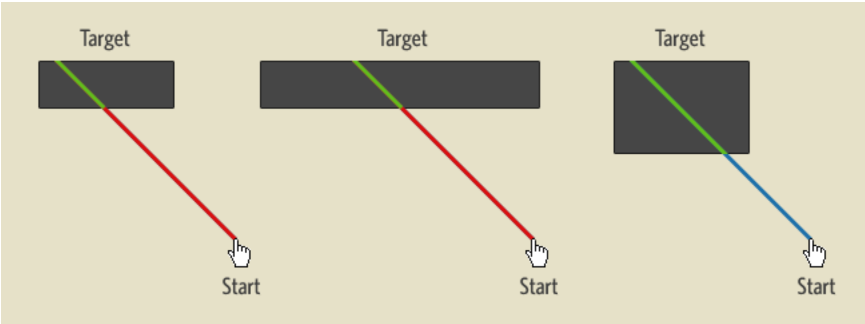
- Use in UI design or evaluation:




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

# 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
  - W is some measurement of target size
  - *a*, *b*, *c*, *d*, and *e* must be determined for each specific case



# 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

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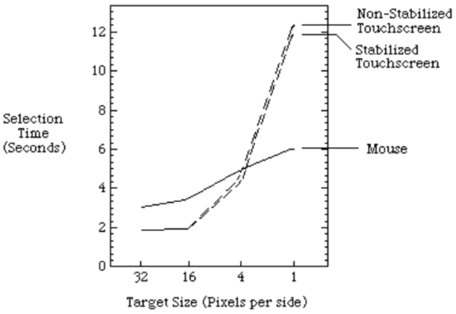
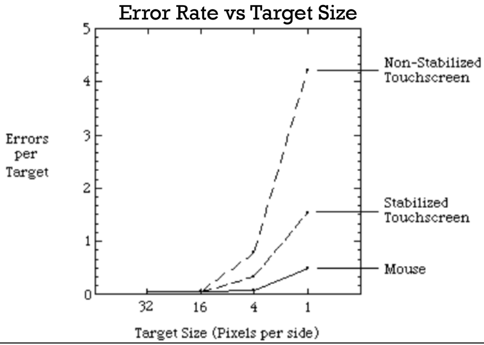
# FITTS LAW EXTENSIONS. PRECISION POINTING

- FFitts' experiments:
  - Date from 1989!
    - Tactile screens of lower resolution than mouse interaction
      - Required on purpose stabilization software

Selection Time vs Target Size




Error Rate vs Target Size

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# 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…
  - But the results cannot be extrapolate 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.