

INTERACTION DESIGN AND EVALUATION. SESSION 1

Dept. Computer Science – UPC

MOTIVATION

- Usability & Design Principles
- Perception Laws

DIRECT MANIPULATION INTERFACES (Pointing, choice selection)

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

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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

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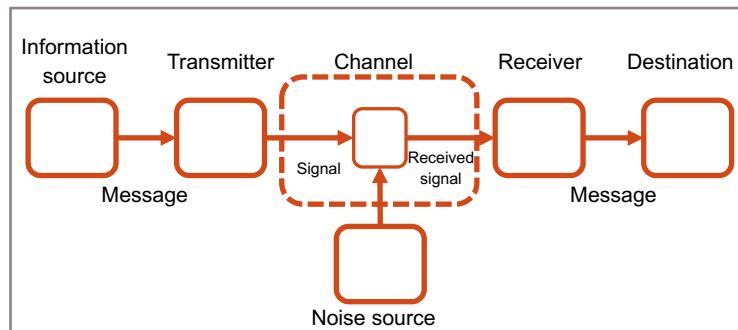
BACKGROUND. BASICS

- **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

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BACKGROUND. BASICS

- Information Theory. Elements (telegraph):



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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.

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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 $\log_2(3)$

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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.

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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!

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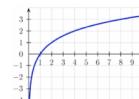
BACKGROUND. INFORMATION MEASURES

- 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 $\log_2(6) \rightarrow \log_2(2) + \log_2(3) = \log_2(6)$.

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BACKGROUND. INFORMATION MEASURES

- M symbols with equal probability → each symbol has probability $P=1/M$
 - Rewriting the uncertainty
$$\log_2(M) = \log_2\left(\left(\frac{1}{M}\right)^{-1}\right) = \log_2(P^{-1}) = -\log_2(P)$$
- **$-\log_2(P)$** 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



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

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

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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

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BACKGROUND. INFORMATION MEASURES

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

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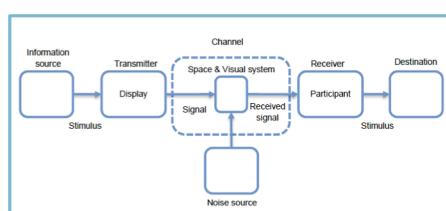
OUTLINE

- *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)



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HICK-HYMAN LAW

- Time to make a decision (Reaction Time):

$$RT = a + bH_T$$

- a, b constants
- H_T : transmitted information

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HICK-HYMAN LAW

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

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

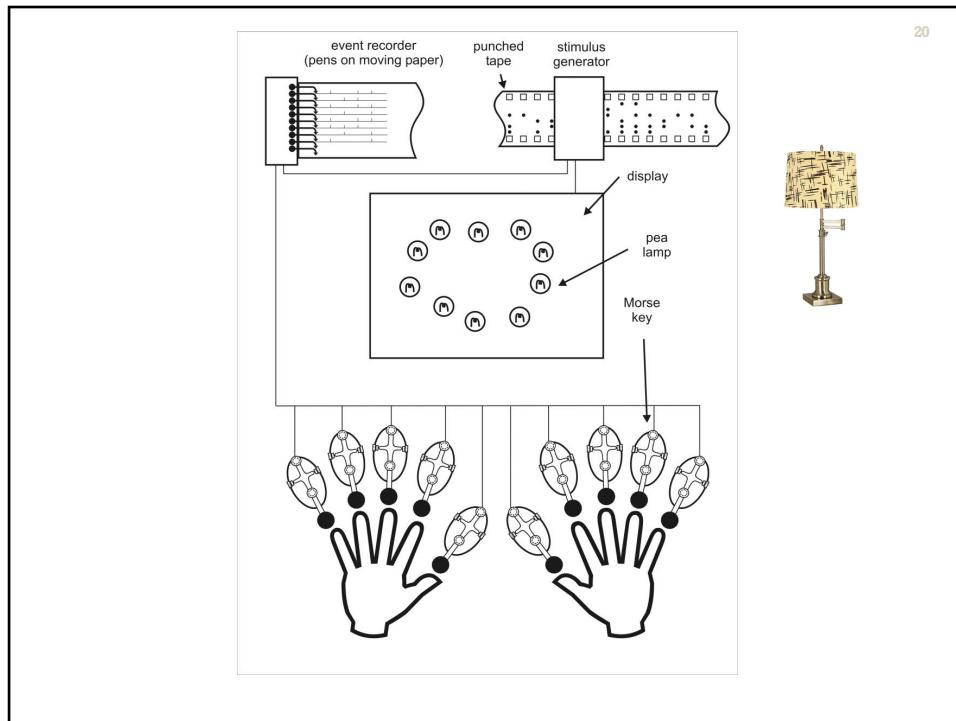
- n are the equiprobable alternatives
- original formulation did not have the "+1"
attempts for the uncertainty whether to respond or not
- Time to answer is the Reaction Time:

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

HICK-HYMAN LAW. EXPERIMENTAL ASSESSMENT

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- 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

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- 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

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- **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]

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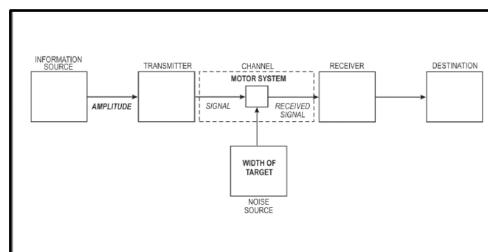
OUTLINE

- *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

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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*



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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

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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

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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

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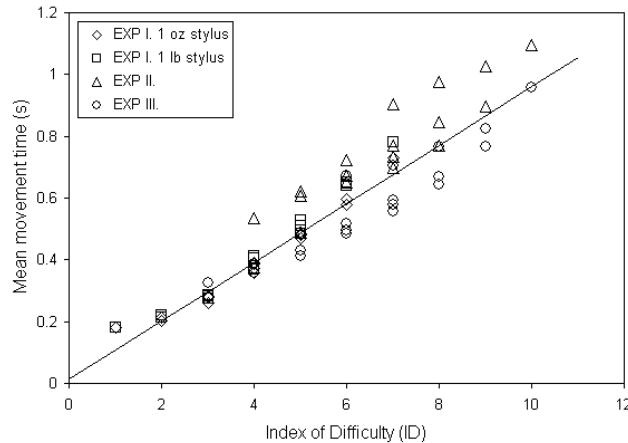
Fitts' Law. Original experiments:

- Experiment 2: Disk transfer
 - Participants had to transfer stack round plastic disks (with holes drilled through 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

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- Fitts' Law. Results. Curve fitted: $MT = 12.8 + 94.7 ID$



FITTS' LAW. EXPERIMENTAL EVIDENCES

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- 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

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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

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FITTS' LAW. VARIANTS

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

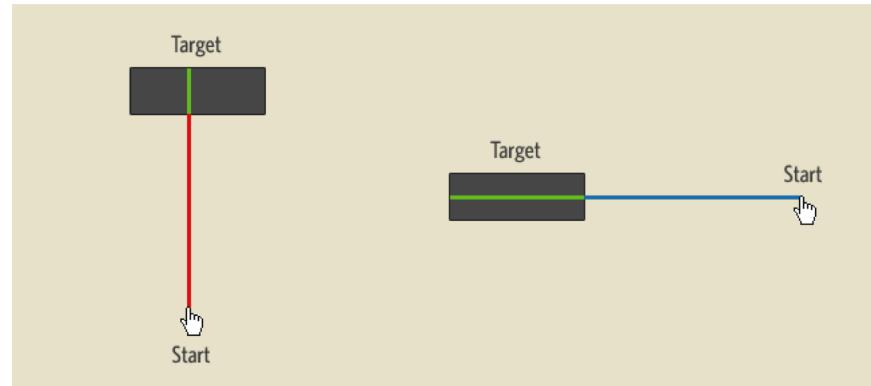
$$MT = a + b \log_2 \left(\frac{D}{W} + 1 \right)$$

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

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FITTS' LAW. VARIANTS

- Vertical and horizontal movements can be treated equally



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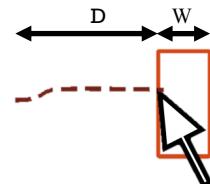
FITTS' LAW. EXTENSIONS

- 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

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FITTS' LAW. EXTENSIONS

- Use in UI design or evaluation:

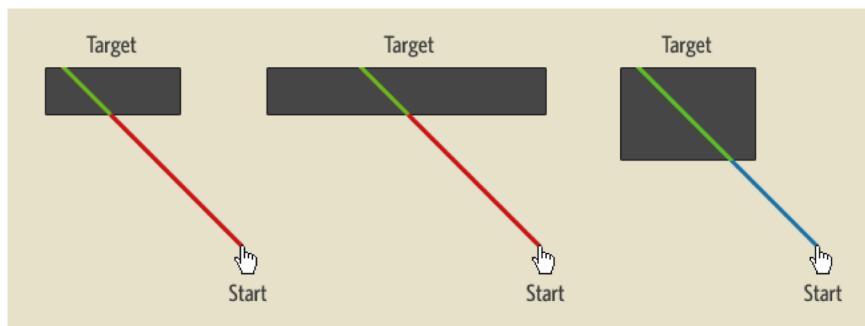


- D is the distance the pointer (mouse) covers to reach the target (button)
- W is the width of the target (button)

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FITTS' LAW. EXTENSIONS. 2D

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



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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]:

$$MT = a + b \log_2 \left(\sqrt{\left(\frac{D}{W} \right)^2 + \eta \left(\frac{D}{H} \right)^2} + 1 \right)$$

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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

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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 :

$$FFitts = a + bID + dID_2$$

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

FITTS' LAW EXTENSIONS. PRECISION POINTING

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- **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

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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**

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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!

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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. $ID \approx 3.4$.
- b. $2 < ID < 3$.
- c. $ID \approx 4.3$.
- 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