

# INTERACTION DESIGN AND EVALUATION. SESSION 1

Dept. Computer Science – UPC

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## MOTIVATION

- 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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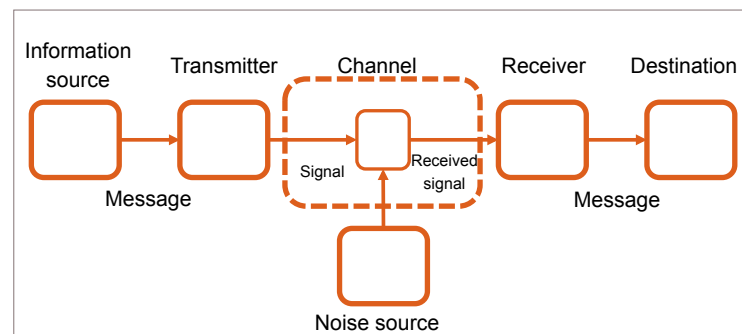
## BACKGROUND. BASICS

- **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  $\rightarrow \log_2(M)$ .
  - 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.

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

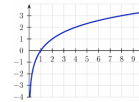
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## BACKGROUND. INFORMATION MEASURES

- M symbols with equal probability → each symbol has probability  $P=1/M$

- **Rewriting the uncertainty**

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



- $-\log_2(P)$  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

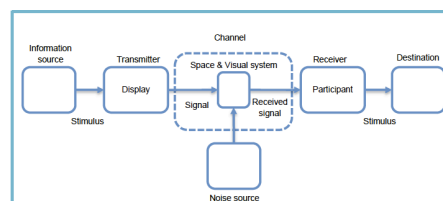
- Applications of Shannon entropy:
  - All types of signal transmission and storage:
    - Measuring information
    - Dictionary creation for compression
    - ...

# 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)





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

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

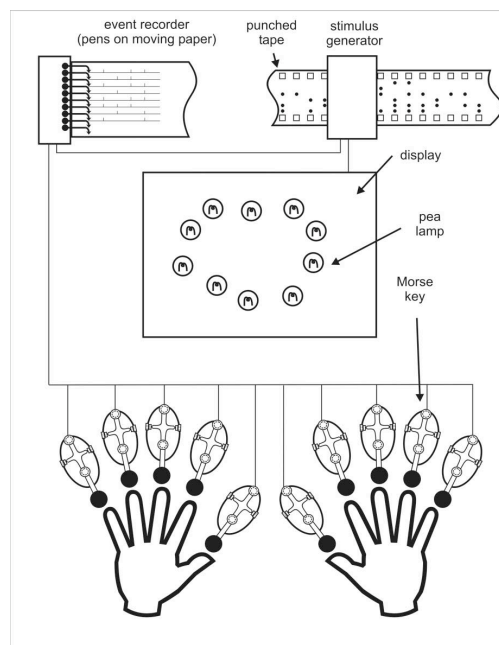
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## HICK-HYMAN LAW. EXPERIMENTAL ASSESSMENT

- 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



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## 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

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## 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]

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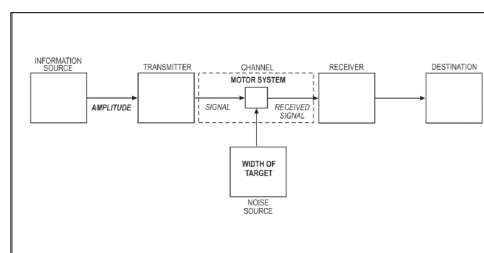
## OUTLINE

- *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

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# 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!

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# FITTS LAW. EXPERIMENTAL EVIDENCES

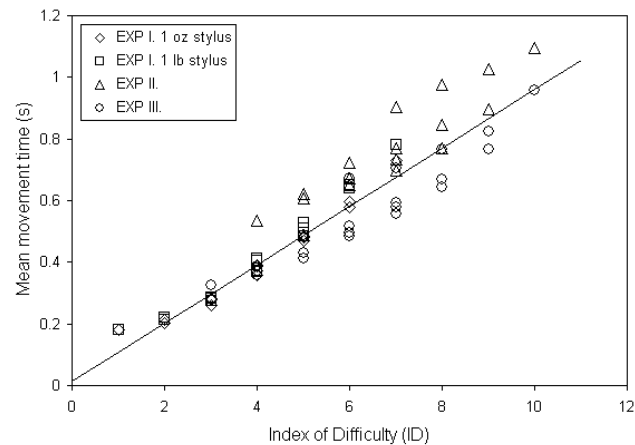
## Fitts Law. Original experiments:

- 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

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# FITTS LAW. EXPERIMENTAL EVIDENCES

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



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# 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

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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:

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

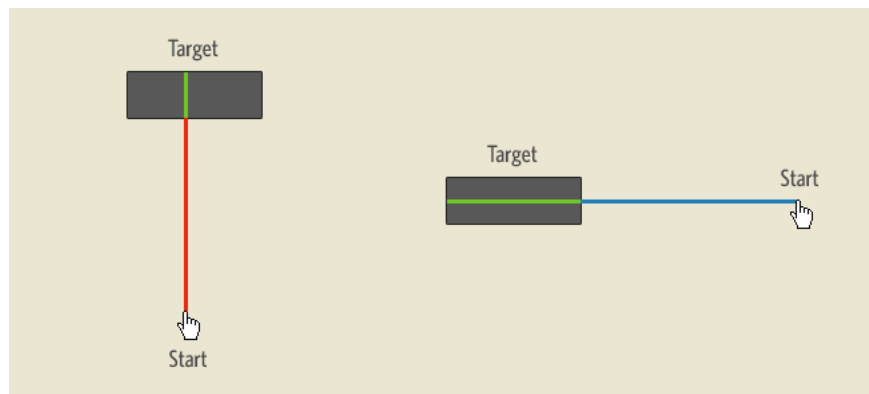
- D is the distance of movement
- W is the width of the target



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## FITTS' LAW. VARIANTS

- Vertical and horizontal movements can be treated equally



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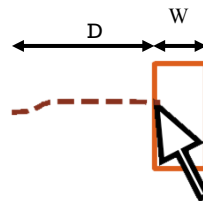
## FITTS LAW. EXTENSIONS

- 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:

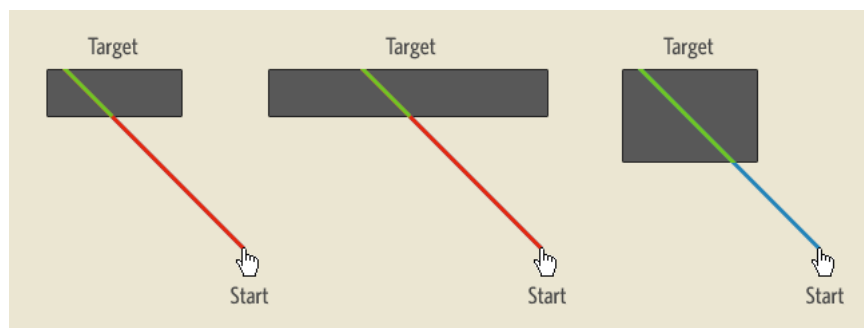


- D is the distance the pointer (mouse) covers to reach the target (button)
- W is the width of the target (button)

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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.

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## 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 :

$$FFits = a + bID + dID_2$$

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

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## 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

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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!

## 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.