Designing Interactive Systems I

Introduction, The CMN Model, Fitts' Law

Prof. Dr. Jan Borchers
Media Computing Group
RWTH Aachen University

Winter Semester ’23/’24

https://hci.rwth-aachen.de/dis
Who am I?

Studied CS at Karlsruhe (& Imperial)
  • Human-Computer Interaction
PhD CS, TU Darmstadt (& Linz, Ulm)
  • Interaction with multimedia
  • HCI design patterns
Assistant professor at Stanford & ETH Zurich
  • Interactive rooms
  • UbiComp user interfaces
Full professor at RWTH since Oct. 2003
  • Augmented Reality, Wearable & Textile UIs
  • Personal Fabrication, IDEs, Soft Robotics
Our Team

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The Question Flow Chart :)
Human–Computer Interaction?
What is HCI?

Use and Context

U1 Social Organization and Work

U2 Application Areas

U3 Human-Machine Fit and Adaptation

Human

H1 Human Information Processing

H2 Language, Communication and Interaction

H3 Ergonomics

Computer

C1 Input and Output Devices

C2 Dialogue Techniques

C3 Dialogue Genre

C4 Computer Graphics

C5 Dialogue Architecture

Development Process

D1 Design Approaches

D2 Implementation Techniques and Tools

D3 Evaluation Techniques

D4 Example Systems and Case Studies

ACM SIGCHI Curriculum 1992
Class Topics

Human
- Performance
- Models of interaction
  - Affordances
  - Mappings
  - Constraints
  - Types of knowledge
  - Errors
- Design principles

Case Studies
- History of HCI
- Visions
- Phases of Technology

Development Process
- Iterative design
- User observation
- Ideation
- Prototyping
- User studies and evaluation
- Interaction design notation

For more details, see hci.rwth-aachen.de/dis.
Textbooks

Required Reading

The DESIGN of EVERYDAY THINGS

Don Norman

Recommended Reading

HUMAN–COMPUTER INTERACTION

Third Edition
Media Computing Group
# Our Classes

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<thead>
<tr>
<th>When?</th>
<th>Type</th>
<th>Credits (ECTS)</th>
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<tr>
<td>WS</td>
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<td>The Media Computing Project</td>
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<td>WS, SS</td>
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<td>4</td>
<td>Post-Desktop User Interfaces</td>
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<td>V/Ü</td>
<td>6</td>
<td>Current Topics in HCI</td>
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<td>iOS Application Development</td>
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Course Structure
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**Flipped-Classroom Lecture**
Watch videos at home; Discuss content in class

**Lab**
- Discuss assignments
  
  Oct 24th – Dec 5th

**UX Project (graded)**
- Create your own UX project in a group of six
- Finally, showcase your project in a video

Dec 12th – Jan 30st
Final Grade Distribution

To pass the course, you must pass both project and final exam.
Registering for this Class

• Register via RWTHonline and upload the **Declaration of Compliance** until tomorrow, Oct 25, at 23:59

• You can also sign and submit it today

• If you want to, **you can visit the class in Aachen**, but it might happen that traveling to Bonn is necessary during the project

• **Register for both** DIS1 courses in RWTHonline

• **Write us an email** with the subject **“[DIS1] Moodle Access for MI”** with your name and matriculation number
The Human
Model Human Processor: The CMN Model

The Psychology of Human-Computer Interaction

STUART K. CARD
THOMAS P. MORAN
ALLEN NEWELL
Model Human Processor

- 3 processors with associated memory
- Slow, middle, fast performers
In-Class Experiment 1: Perceptual Processor

• Work in pairs of two

• Read out the text from *Experiment 1* to your group partner

• The other partner observes the eye movement of the reading person

• Then switch

• What did you observe?
Perception

- Eye saccades: 230 ms
- Explains reading rates
  - Maximum: 13 characters/saccade
    ⇒ 652 words/minute
Perceptual Processor

• Stores sensor signals in visual & auditory stores

• Perception time: $\tau_P \approx 100$ ms
  
  • Explains Bloch’s Law
    
    • $R = I \times t$
    
    • $R$ is response
    
    • $I$ is intensity
    
    • $t$ is exposure time

• Constant response for $t < 100$ms
In-Class Experiment: Bloch’s Law
In-Class Experiment: Bloch’s Law
In-Class Experiment: Bloch’s Law
A: 0 ms delay
B: 50 ms delay
C: 100 ms delay
Perceptual Processor

- Perception time: $\tau_P \approx 100$ ms
  - Explains animation rates (10 fps for “MiddleMan”)
  - Explains max. delay before causality breaks down
  - Shortens with intensity
In-Class Experiment 2: Cognitive System

• As a group of two
  • One of you (P1) reads out a random sequence of 5 digits from your sheet to the other (P2)
  • Then P2 counts backwards aloud from 50
  • Then P1 asks P2 another question (like what they had for dinner three days ago?)
  • Then P2 writes down the numbers that they still remember.
• Switch roles, repeat with 9 digits.
• Finally, switching roles again, read the long sequence of numbers to your partner, stopping somewhere suddenly. See how many of the last numbers they can repeat immediately.
Cognitive System

• Chunks depend on user & task

• Working memory:
  • Capacity: \( \mu_{\text{WM}} = 7 \pm 2 \) chunks (Miller ’56)
  • Half life: \( \delta_{1,\text{WM}} = 73 \) s (1 chunk)
    \( \delta_{3,\text{WM}} = 7 \) s (3 chunk)
  • Visual/acoustic encoding

• In 2001, Nelson Cowen showed that \( \mu_{\text{WM}} \) is actually 4±1 chunks.
Cognitive System

• Cognitive processor:
  • Processing time $\tau_C = 70$ ms

• Long-term memory:
  • Infinite capacity and half life
  • Semantic encoding (associations)
  • Fast read, slow write

$\Rightarrow$ Remembering items maxes out at 7 s/chunk learning speed (1 pass)
Model Human Processor
In-Class Experiment 3: Motor System

• Experiment: draw strokes between lines for 5s. Try to reach both lines.
• Count number of reversals
  • How many milliseconds per reversal?
• Create a contour of stroke bottoms, count number of corrections
  • How many milliseconds per correction?

34 reversals/side = 68 total reversals

10 corrections/side = 20 total corrections
Motor System

• Motor processor (open loop)
  • $\tau_M = 70$ ms
  ⇒ Average time between each reversal

74 ms/reversal
250 ms/correction
Motor System

74 ms/reversal
250 ms/correction

• Closed loop:
  • $\tau_P + \tau_C + \tau_M = 240 \text{ ms}$

$\implies$ Average time between each correction
Fitts’ Law
In-Class Experiment 5: Tapping Task

Tap for 10 s, count taps afterwards

1cm

Same for 0.5 cm and 2 cm wide strips

4cm

8cm

16cm
Tapping Task Results

• Doubling the distance adds roughly a constant to execution time
  ⇒ indicates logarithmic nature

• Doubling the target width (W) gives about same results as halving the distance (D)
  ⇒ indicates connection of D/W in formula
Motor System: Fitts’ Law

- Goal: Predict time to press buttons (physical or on-screen) as function of distance and size

  - Result (Fitts, 1954): \( T_{pos} = I_M \cdot I_D \)

  - \( T_{pos} \) time to reach button
  - \( I_M = 100 \text{ ms/bit} \) index of movement, constant
  - \( I_D = \log_2(2D / W) \) index of difficulty, in bits
  - Fitts’ law can be derived from CMN model
Visualizing Fitts’ Law

Experiment: fixed distance $D$, varying width $W$

$$I_D = \log_2(2D/W) \text{ [bits]}$$

$slope = I_M$

- $D = 2$ inches
- $D = 0.5$ inches
Deriving Fitts’ Law from CMN (1)

\[ D_i := \text{remaining distance to target after } i \text{ movements} \]

\[ \epsilon := \frac{D_i}{D_{i-1}} < 1 \quad (\text{relative movement precision, experiment shows}) \]

\[ \epsilon = 0.07 \quad (\text{constant according to CMN model}) \]

\[ D_1 = \epsilon \cdot D_0 = \epsilon \cdot D \]
\[ D_2 = \epsilon \cdot D_1 = \epsilon^2 \cdot D \]
\[ \vdots \]
\[ D_n = \epsilon \cdot D_{n-1} = \epsilon^n \cdot D \quad \leq W/2 \quad (\text{hand reaches target after } n \text{ movements}) \]

\[ \epsilon^n \leq \frac{W}{2D} \]

\[ \Leftrightarrow n \geq \log_{\epsilon} \left( \frac{W}{2D} \right) \quad (\text{log for base } < 1 \text{ turns inequality sign}) \]

\[ \Leftrightarrow n \geq \frac{\log_2 \left( \frac{W}{2D} \right)}{\log_2 \epsilon} \]

\[ \Leftrightarrow n \geq \frac{\log_2 \left( \frac{2D}{W} \right)}{\log_2 \epsilon} \]

\[ \text{for } n=2: \]

\[ D_0 = D \]
\[ 240\text{ms} \]
\[ D_1 \]
\[ 240\text{ms} \]
\[ D_2 \]
\[ = 0.07 \cdot D_0 \]
Total positioning time is $T_{pos} = n \cdot (t_{WP} + t_{KP} + t_{MP})$

Insert $n$ to arrive at Fitts’s Law:

$$T_{pos} = \frac{\log_2 \left( \frac{2D}{W} \right)}{\log_2 \epsilon} \cdot (t_{WP} + t_{KP} + t_{MP})$$

(rearrange)

$$= -\frac{(t_{WP} + t_{KP} + t_{MP})}{\log_2 \epsilon} \cdot \log_2 \left( \frac{2D}{W} \right)$$

$$= -\frac{240 \text{ ms}}{\log_2 (0.07)} \cdot \log_2 \left( \frac{2D}{W} \right)$$

(240 ms is CMN estimate)

$$\approx 100 \text{ ms} \cdot \log_2 \left( \frac{2D}{W} \right)$$

$$= I_M \cdot I_D$$

q.e.d.
**Improvements**

- **Welford’s Formulation, 1968:**
  \[ T_{pos} = I_M \cdot \log_2 \left( \frac{D}{W} + 1 \right) \]

- **Shannon’s Formulation, ISO, 80’s:**
  \[ T_{pos} = a + b \cdot \log_2 \left( \frac{D}{W} + 1 \right) \]
  - \(a, b\) depend on device, determine experimentally
  
  Use \(a = 0\) ms, \(b = I_M = 100\) ms for quick and dirty estimates

  Improved curve fit, no negative times for infinite-size targets
Target Width

[MacKenzie & Buxton, CHI’92]
In-Class Exercise: Mobile Phone

- How much faster does calling become by moving the “call” button from 30 mm distance to 14 mm distance, measured from the middle of the keypad? The size of the call button is 2 x 2 mm

- Shannon’s Formulation: \( T_{pos} = a + b \cdot \log_2\left(\frac{D}{W} + 1\right) \)

- Use \( a = 0 \) ms, \( b = 100 \) ms/bit
Solution

\[ T_{pos1} = a + b \cdot \log_2\left(\frac{D_1}{W} + 1\right) \quad T_{pos2} = a + b \cdot \log_2\left(\frac{D_2}{W} + 1\right) \]

\[ T_{Diff} = T_{pos1} - T_{pos2} = a + b \cdot \log_2\left(\frac{D_1}{W} + 1\right) - (a + b \cdot \log_2\left(\frac{D_2}{W} + 1\right)) \]

\[ = b \cdot (\log_2\left(\frac{D_1}{W} + 1\right) - \log_2\left(\frac{D_2}{W} + 1\right)) \]

\[ = b \cdot (\log_2\left(\frac{30}{2} + 1\right) - \log_2\left(\frac{14}{2} + 1\right)) = b \cdot (\log_2(16) - \log_2(8)) \]

\[ = b \cdot (4\text{bit} - 3\text{bit}) = b \cdot 1\text{bit} = 100 \frac{ms}{\text{bit}} \cdot 1\text{bit} = 100ms \]

\[ \Rightarrow \text{Moving the call button speeds up each call by an average of about 100ms.} \]
Summary

• The Media Computing Group does cool stuff

• HCI is about humans, computers, the design process, and the social context

• The CMN model allows estimating reaction times and memory performance

• You can calculate the average movement time of pointing devices using Fitts’ Law

• You’ve experienced that mathematical laws seem to govern your perception, memory, and movement
What to Do Now

Today

1. Register for the course on RWTHonline
2. Upload your signed Declaration of Compliance on our website
   (If you have done this already, you don’t need to upload it again)

File Name: DIS1_DoC_<your last name>_<matriculation number>.pdf

Before next Lab on Tuesday

• Buy Don Norman’s The Design of Everyday Things (2nd edition, 2013)