Lecture 10 – Human Abilities
Motor Processing

Joanna McGrenere

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includes slides from Jessica Dawson
next week (March 20-24)
  - Class is cancelled: no lecture, no prep assignment
  - No office hours

– Workshop: *Lightweight video editing*
  - Optional – targeted at those who’ve done little/no video editing
  - Will be expected to bring a few things (some video footage, music files, headphones)
  - Details will be posted to piazza in advance
  - Attending workshop *mandatory for all* – project time for those of you who don’t need video instruction

→ Lots of extra project time!!!
To allow adequate time for all Parts A, B & C, we suggest the following workplan below. You have ~3 weeks for parts A/B. Part C overlaps with MS V.

By the end of the 1st week: Complete Step 1 and Step 9.

- Team discusses pilot results and finalizes modifications to the experiment protocol. Team also discusses the plan for the project video. Use workshop time to get feedback from the course staff on both these issues.

By the end of the 2nd week: Complete Step 2 and have Steps 3, 4, 5, 6 and 10 underway.

- Mix of group and individual work (consult milestone)
- Gist: Team discusses preliminary analysis of the full set of data and preliminary conclusions. But graphs, interpretation of, formulation of conclusions, etc. are written and presented individually in the experiment write up.
- Team and TA feedback should be solicited on the video data clips selected as well as those new clips that have been created from scratch to be part of the final project video.
MSIV: Workplan Recommendation

By the end of the 3 week: Up to Step 6 completed and submitted, Steps 7, 8 and 10 underway.

- Brainstorm the components in Steps 7 & 8.
- Work on video, identify clips to use in MSV.
TODAY’S LEARNING GOALS

- a refresher on human info processing
  - knowledge from 344 on this topic is assumed
- introduce human motor processing
- theories of performance
  - empirical ‘laws’
    - actually, models of simple movements
  - examples
    - Fitts, Hicks, Power, Steering
- some implications for UI design
MODEL HUMAN PROCESSOR
MODEL HUMAN PROCESSOR (MHP):
ONE MODEL FOR PERCEPTION → MEMORY → COGNITION
(BASED ON ANALOGY WITH THE PROCESSING AND STORAGE AREAS OF A COMPUTER)

- “The Psychology of Human-Computer Interaction”, 1983
- Card, Moran, & Newell
MHP Basics

- Based on empirical data
- Three interacting subsystems
  - perceptual, motor, cognitive
- Sometimes serial, sometimes parallel
  - serial in action & parallel in recognition
    - pressing key in response to light
    - reading and hearing at once
- Parameters
  - processors have cycle time \((T) \sim 100-200 \, \text{ms}\)
  - memories have capacity, decay time, & type (physical, acoustic, visual, semantic)
WHAT’S MISSING FROM MHP?

Long-term Memory (LTM)

Working Memory (WM)

Visual Image Store

Auditory Image Store

Perceptual Processor

Motor Processor

Cognitive Processor

Eyes

Ears

sensory buffers (Dix)

...you should be able to identify 4 things from 344!
PERCEPTION & ACTION SUBSYSTEMS

• subsystems may operate in parallel (theory):

input (perception):
  – **visual** subsystem for what we see (most studied)
  – **acoustic** subsystem for what we hear
  – **haptic** subsystem for what we feel

output (action):
  – **vocal** (**articulatory**) subsystem for what we speak
  – **motor** subsystem for how we move
CHARACTERISTIC CYCLE TIMES

- each subsystem has a typical processing time

<table>
<thead>
<tr>
<th>subsystem</th>
<th>average</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceptual</td>
<td>100 msec</td>
<td>50-200 msec</td>
</tr>
<tr>
<td>cognitive</td>
<td>70 msec</td>
<td>25-170 msec</td>
</tr>
<tr>
<td>motor</td>
<td>70 msec</td>
<td>30-100 msec</td>
</tr>
</tbody>
</table>
USER OUTPUT MODALITY: MOTOR CONTROL

• used in **lots of very different ways**, e.g.
  – discrete control (buttons) e.g. keyboard, ecard swipe
  – continuous control (handles) e.g. steering, violin

• **limited** by speed, strength, coordination, flexibility, size, ...

• **neurally integrated** w/ haptic sense (reflexes)

• **muscle memory**: learning of spatial “home”
  – e.g., reaching for gearshift in car; position tells you what gear you’re in
  – e.g., adaptive menus can be problematic
WHY IS THIS VALUABLE?

• Provides one way to evaluate the usability of an interface – system designer can user the MHP to predict performance with respect to time it takes a person to complete a task *without* performing experiment

• Can also build dynamic models of an interface.

e.g., Key Stroke Level Modelling for predicting expert performance:
http://en.wikipedia.org/wiki/Keystroke-Level_Model
THEORIES OF PERFORMANCE
THEORIES OF HUMAN PERFORMANCE

- type of theories and models used in HCI:
  - when look at low enough level (cognitive / motor),
    *people are the same.*
  - dynamic models: can predict performance

- empirical laws

- explanatory theories
  - social: messy! hard to apply numbers.
    - but, perhaps richest insights to be gained
    - ....many tasks aren’t just about speed
EMPIRICAL LAW

• quantitative model that provides predictions
  – based on experiments (controlled studies)

• examples:
  – Fitts’ Law
  – Hick’s Law
  – Power Law of Practice
  – Steering Law
EXAMPLE: POINTING DEVICE EVALUATION

real task: interacting with GUI’s
  – pointing is fundamental

experimental task: target acquisition
  • abstract, elementary, essential

D = distance
W = target width
Fitts’ Law
Paul Fitts, 1954

Index of Performance (IP) = ID/MT (bits/s)

- sometimes called bandwidth or throughput

Movement Time
Index of Difficulty (ID [bits])

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

task difficulty is analogous to information:
execution time is interpreted as human rate of processing information
first way to calculate IP

<table>
<thead>
<tr>
<th>ID</th>
<th>MT (ms)</th>
<th>Error (%)</th>
<th>IP (bits/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>254</td>
<td>0.0</td>
<td>4.3</td>
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<tr>
<td>8</td>
<td>353</td>
<td>1.9</td>
<td>6.1</td>
</tr>
<tr>
<td>16</td>
<td>344</td>
<td>0.8</td>
<td>6.4</td>
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<td>8</td>
<td>481</td>
<td>1.7</td>
<td>6.4</td>
</tr>
<tr>
<td>16</td>
<td>472</td>
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<td>6.6</td>
</tr>
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<td>32</td>
<td>501</td>
<td>0.6</td>
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<td>3.3</td>
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<tr>
<td>64</td>
<td>1137</td>
<td>9.9</td>
<td>6.3</td>
</tr>
</tbody>
</table>

**Mean**: 645 3.6 6.3

**SD**: 243 3.1 0.6

a experimental units; 1 unit = 8 pixels

\[ MT \text{ [secs]} = a + b(ID) \]

\[ ID \text{ [bits]} = \log_2 \left( \frac{D}{W} + 1 \right) \]

second way to calculate IP

\[ b = \text{slope} \quad IP = \frac{1}{b} \]
**HOW CAN WE USE FITTS’ LAW?**

So what can we do with this information?

**50 years of data**

<table>
<thead>
<tr>
<th>Device</th>
<th>Study</th>
<th>IP (bits/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand</td>
<td>Fitts (1954)</td>
<td>10.6</td>
</tr>
<tr>
<td>Mouse</td>
<td>Card, English, &amp; Burr (1978)</td>
<td>10.4</td>
</tr>
<tr>
<td>Joystick</td>
<td>Card, English, &amp; Burr (1978)</td>
<td>5.0</td>
</tr>
<tr>
<td>Trackball</td>
<td>Epps (1986)</td>
<td>2.9</td>
</tr>
<tr>
<td>Touchpad</td>
<td>Epps (1986)</td>
<td>1.6</td>
</tr>
<tr>
<td>Eyetracker</td>
<td>Ware &amp; Mikaelian (1987)</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Table Reference:
WHAT DOES FITTS’ LAW REALLY MODEL?

velocity

distance

target width

(a)

(b)

(c)
MAKING COMPARISONS

• what are some caveats / limitations of trying to make comparisons between devices using Fitts Law?

• speed accuracy tradeoff normalization: if input type A is faster than input type B, but A also yields more errors. . . . which is really faster?
  • can normalize by calculating an effective width
    • don’t need to know HOW to calculate, but should know why
BEYOND POINTING: TRAJECTORY-BASED TASKS
FROM TARGETS TO TUNNELS…

1 goal to pass through:

\[ ID = \log_2 \left( \frac{D}{W} + 1 \right) \]

2 goals to pass through:

\[ ID = 2 \log_2 \left( \frac{D}{2W} + 1 \right) \]

N goals to pass through:

\[ ID = N \log_2 \left( \frac{D}{NW} + 1 \right) \]

∞ goals to pass through:

\[ ID_\infty = \frac{D}{W \ln 2} \]
STEERING LAW (ACCOT-ZHAI, 1997)

“BEYOND FITTS’ LAW: MODELS FOR TRAJECTORY BASED HCI TASKS.”
PROCEEDINGS OF ACM CHI 1997 CONFERENCE

fixed width tunnel:

\[ ID = \frac{D}{W}, \quad MT = a + b \frac{D}{W} \]

narrowing tunnel:

\[ ID = \int_{0}^{D} \frac{dx}{W(x)} \]

general Steering Law:

\[ ID = \int_{c}^{s} \frac{ds}{W(s)} \]
SOME RESULTS (FROM ACCOT-ZHAI, 1997)
Recap

– steering law mathematically derived using Fitts’s Law and integral calculus (derivation not shown in these slides)
– then empirically proven (data from experiments with human subjects)
– MT is linearly related to the ID
  • slopes differ for the different tasks, i.e., different throughput

– work is a strong indicator of the robustness of Fitts’ law
USE THESE LAWS TO PREDICT PERFORMANCE / JUSTIFY DESIGN

Q: Which law applies?
Q: Is the contribution to overall movement time likely to be the same for vertical and horizontal segments?
USE THESE LAWS TO PREDICT PERFORMANCE / JUSTIFY DESIGN

• which ‘Format’ menu bar option is likely to be the faster target to hit on average?
USE THESE LAWS TO PREDICT PERFORMANCE / JUSTIFY DESIGN

- which would you predict to be easier to use (faster, less error prone) on average?
Hick’s Law

- describes the time it takes for a user to make a decision as a function of the possible choices he or she has.
- Original experiment:
  - up to 10 lamps with corresponding keys.
  - Lamps light up randomly every 5 seconds.
  - User must press key for lit up lamp.
  - Measure response time from 2 – 10 lamps.

  - note: this is not about motor processing, but example of a relevant empirical law.
– Given $n$ equally probable choices, the average reaction time $T$ required to choose among them is approximately

$$T = b \log_2(n + 1)$$

• where
  – $n =$ number of choices
  – $b =$ empirically determined constants (from fitting regression line)
  – $\log_2(n+1)$ represents depth of our choice hierarchy, with $n+1$ accounting for number of items. (why log2)?
  – $T =$ time to *make* decision; does not include *acting* on decision

• if unequal probabilities:  
  $$T = b \sum_{i=1}^{n} p_i \log_2 \left( \frac{1}{p_i} + 1 \right)$$
EXAMPLE

- A: where each line gets an equal number of calls
- B: where two lines are used heavily, getting 50% and 40% of the calls, with the other 10% divided evenly among the other eight lines

Which of these situations do you expect will be faster to react to?

- A:
- B:
LIMITATIONS OF APPLYING HICKS

• Sometimes applied to justifying menu design
  – but should do so cautiously!

• Useful ONLY for predicting quick, fairly mindless, option selections
  – over simplifies in many cases where other factors may be at play (e.g., search)

• E.g., What confounds occur trying to apply Hicks to an alphabetical vs. randomly ordered menu?
USE THESE LAWS TO PREDICT PERFORMANCE / JUSTIFY DESIGN

• compare the ‘swipe left to close’ interaction over ‘select the x to close’ interaction. Which do you think is better?
USE THESE LAWS TO PREDICT PERFORMANCE / JUSTIFY DESIGN

pop-up linear menu

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>Sunday</td>
<td>Monday</td>
<td>Tuesday</td>
<td>Wednesday</td>
</tr>
<tr>
<td>Thursday</td>
<td>Friday</td>
<td>Saturday</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pop-up pie menu

Which will be faster on average?
Power Law of Practice

- task time on n\textsuperscript{th} trial follows a power law
  - \( T_n = T_1 n^{-a} \), where \( a = .4 \) (empirically determined)

  - i.e., you get faster the more times you do it! (until you become expert)
  - applies to skilled behavior (sensory & motor) -- is an example of the learning curve effect on performance
  - does not apply to knowledge acquisition or quality

  - another way of stating: law states that the \textit{logarithm} of the reaction time for a particular task decreases linearly with the \textit{logarithm} of the number of practice trials taken
EXAMPLE OF POWER LAW OF PRACTICE

DATA FOR ONE LABORATORY SUBJECT

Reaction Time (msec) vs. Number of Responses
WHAT IS THE IMPORTANCE OF THE POWER LAW OF PRACTICE TO HCI?
ON DECK

• In 2 weeks...

• More human abilities: visual processing

• Prep assignment

• Workshop next Friday:
  – Will be a posting to piazza with some details
  – Be prepared to bring video footage!