

cpsc 444: advanced methods for
human-computer interaction

human abilities – motor processing

class 4

administrivia

- extra laptop needed (one per team) for
Friday's tutorial

2

today's learning goals

- brief discussion of MSII
- 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

3

brief discussion of MSII

4

<refresher>

5

Model Human Processor (MHP) :
one model for perception → memory → cognition

The diagram illustrates the Model Human Processor (MHP). At the top, a box represents memory, divided into Long-term Memory (LTM) and Working Memory (WM). Within WM, there are two sub-components: Visual Image Store and Auditory Image Store. Below this, three yellow ovals represent the Perceptual Processor, Motor Processor, and Cognitive Processor. Arrows show the flow of information: Eyes and Ears provide input to the Perceptual Processor. The Perceptual Processor sends information to the Visual Image Store. The Motor Processor sends information to the Auditory Image Store. The Cognitive Processor interacts bidirectionally with both the Visual and Auditory Image Stores. The Motor Processor outputs to 'Fingers, etc.'. The Cognitive Processor also has bidirectional connections with the LTM section of the memory box.

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

6

MHP Basics

The diagram is identical to the one in slide 6, showing the flow of information from sensory input through the Perceptual, Motor, and Cognitive processors, and their interaction with Working Memory and Long-term Memory.

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
 - driving, reading signs, & hearing at once

Parameters

- processors have cycle time (T) ~ 100-200 ms
- memories have capacity, decay time, & type (physical, acoustic, visual, semantic)

7

what's missing from MHP?

The diagram is identical to the one in slide 6, showing the flow of information from sensory input through the Perceptual, Motor, and Cognitive processors, and their interaction with Working Memory and Long-term Memory.

...you should be able to identify 4 things from 344!

8

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

9

characteristic cycle times

each subsystem has a typical processing time

<i>subsystem</i>	<i>average</i>	<i>range</i>
• perceptual	100 msec	50-200 msec
• cognitive	70 msec	25-170 msec
• motor	70 msec	30-100 msec

relevance to GOMS (Goals Operators Methods Selection)

e.g., KLM (Keystroke Level Model)

http://en.wikipedia.org/wiki/Keystroke-Level_Model

10

user output modalities: **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

11

</refresher>

12

context: theories of human performance

type of theories and models used in HCI:

empirical laws } when look at low enough level (cognitive / motor), people are the same.
 dynamic models } → can predict performance

explanatory theories

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

13

empirical law

quantitative model that provides predictions

- based on experiments (controlled studies)

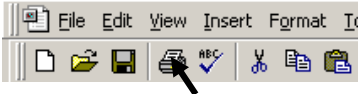
examples: **Fitts' Law**, **Hick's Law**, **Power Law of Practice & Steering Law**

14

example: pointing device evaluation

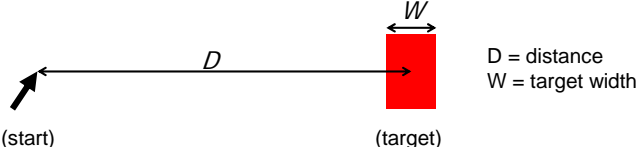
real task: interacting with GUI's

- pointing is fundamental



experimental task: target acquisition

- abstract, elementary, essential

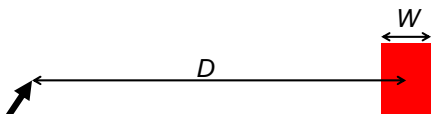


D = distance
W = target width

15

Fitts' Law

Paul Fitts, 1954



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

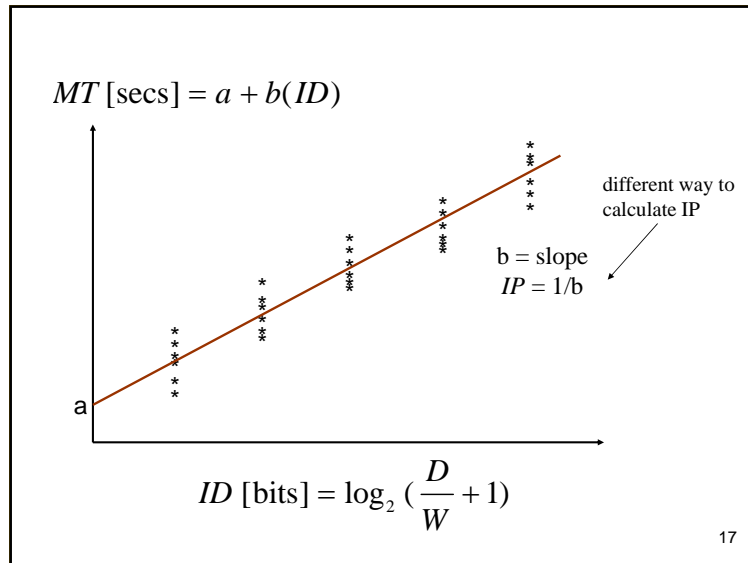
Movement Time Index of Difficulty (ID [bits])

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

- sometimes called *bandwidth* or *throughput*

task difficulty is analogous to information:
→ execution time is interpreted as human rate of processing information

16

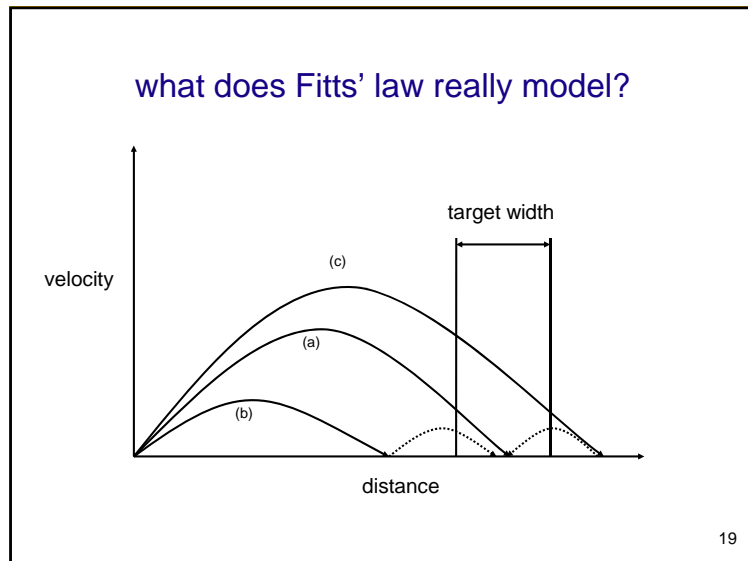


50 years of data

Device	Study	IP (bits/s)
Hand	Fitts (1954)	10.6
Mouse	Card, English, & Burr (1978)	10.4
Joystick	Card, English, & Burr (1978)	5.0
Trackball	Epps (1986)	2.9
Touchpad	Epps (1986)	1.6
Eyetracker	Ware & Mikaelian (1987)	13.7

Reference:
MacKenzie, I. Fitts' Law as a research and design tool in human computer interaction. *Human Computer Interaction, 1992, Vol. 7, pp. 91-139*

18



- ### a lot more on Fitts' law in tutorial
- plus there is more in the reading, that I am not covering in lecture but that you are expected to know, including:
 - Welford vs. Shannon formulations
 - extension to 2 dimensions
 - normalization and speed-accuracy tradeoff
 - my general philosophy: lecture complements reading, but does not always cover salient aspects of reading
- 20

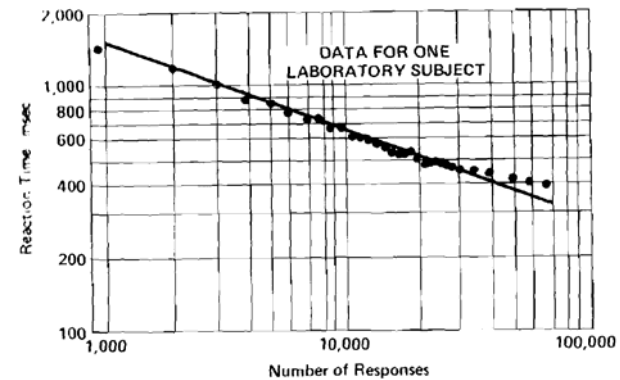
Power Law of Practice

task time on n^{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 **logarithm** of the **reaction time** for a particular task decreases linearly with the **logarithm of the number of practice trials** taken

21

example of Power Law of Practice



22

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

note: this is not about motor processing, but is a relevant empirical law

23

example

A secretary has a telephone console with 10 buttons for answering calls on 10 lines. When a light behind a button comes on, his job is to push the button and answer the phone.

Which of these situations is going to be faster to react to?

- 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.

24

decision time $T = a + b / \log_2(n+1)$, where

- n = number of choices
- a, b = empirically determined constants
- $\log_2(n+1)$ represents amount of information processed by human operator (in Bits)
- T = time to *make* decision; does not include *acting* on decision

if unequal probabilities p_i :

$$T = a + b \sum_{i=1}^n p_i \log_2 \left(\frac{1}{p_i} + 1 \right)$$

25

answer?

- 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

A:
B:

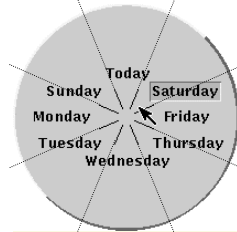
26

use these laws to predict performance

pop-up linear menu



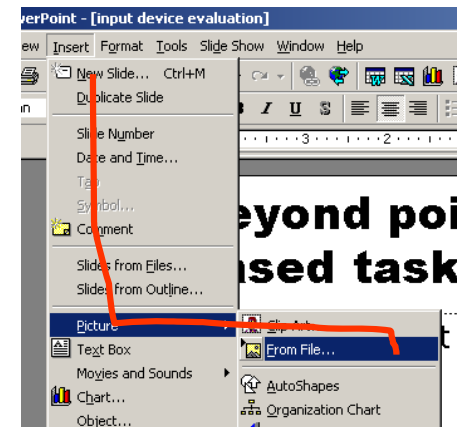
pop-up pie menu



which will be faster on average?

27

beyond pointing: trajectory-based tasks



28

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:
 $ID_{\infty} = \frac{D}{W \ln 2}$

The diagrams illustrate the transition from a single target to a tunnel. The first diagram shows a single target of width W at a distance D. The second shows two targets of width W/2 at distance D/2. The third shows N targets of width W/N at distance D/N. The fourth shows a continuous tunnel of width W at distance D.

29

Steering law (Accot, 1997)

"Beyond Fitts' Law: Models for trajectory based HCI tasks."
 Proceedings of ACM CHI 1997 Conference

fixed width tunnel:
 $ID = \frac{D}{W}, MT = a + b \frac{D}{W}$

narrowing tunnel:
 $ID = \int_0^D \frac{dx}{W(x)}$

general Steering Law:
 $ID = \int_c \frac{ds}{W(s)}$

The diagrams illustrate different tunnel types. The first is a fixed width tunnel of width W and length D. The second is a narrowing tunnel where width W(x) decreases from W1 to W2 over distance D. The third is a general steering law diagram showing a curved path from point c to a target, with width W(s) and path length ds.

30

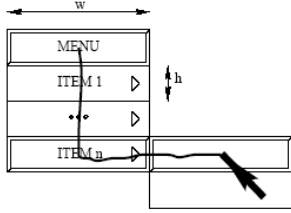
some results (from Accot, 1997)

The three scatter plots show a strong linear relationship between Time (ms) and Index of Difficulty for different tunnel types. The top-left plot is for a fixed width tunnel (Time up to 5000, ID up to 60). The top-right plot is for a narrowing tunnel (Time up to 8000, ID up to 80). The bottom-right plot is for a general steering law (Time up to 10000, ID up to 60). Each plot includes a small diagram of the corresponding tunnel type.

A visualization of a trajectory through a spiral target, showing multiple paths in different colors (green, red, blue) converging on the center.

31

- steering law mathematically derived using Fitts' 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
- 32



estimate MT for a menu
using Accot's Law

are a, b likely to be the
same for vertical and
horizontal segments?

$$T_n = \overbrace{a + b \frac{nh}{w}}^{\text{Vertical}} + \overbrace{a + b \frac{w}{h}}^{\text{Horizontal}}$$

$$= 2a + b \left(\frac{n}{x} + x \right) \text{ with: } x = \frac{w}{h}$$

33

today

theories of human motor performance

- empirical 'laws'
actually, models of simple movements

examples

- Fitts, Hicks, Power, Steering

34

on deck

- Wed lab: finalizing details for your field study (all data collection instruments and protocol)
- Fri tut: Fitts' Law tutorial
- next lecture: Experiments I
 - relies on readings (handouts)
- NOTE: I had to separate this lecture from the second "human abilities" lecture due to scheduling constraints; it will come much later in the term
 - visual processing: color and pre-attentive, and human memory

35