i213 User Interface Design and Development

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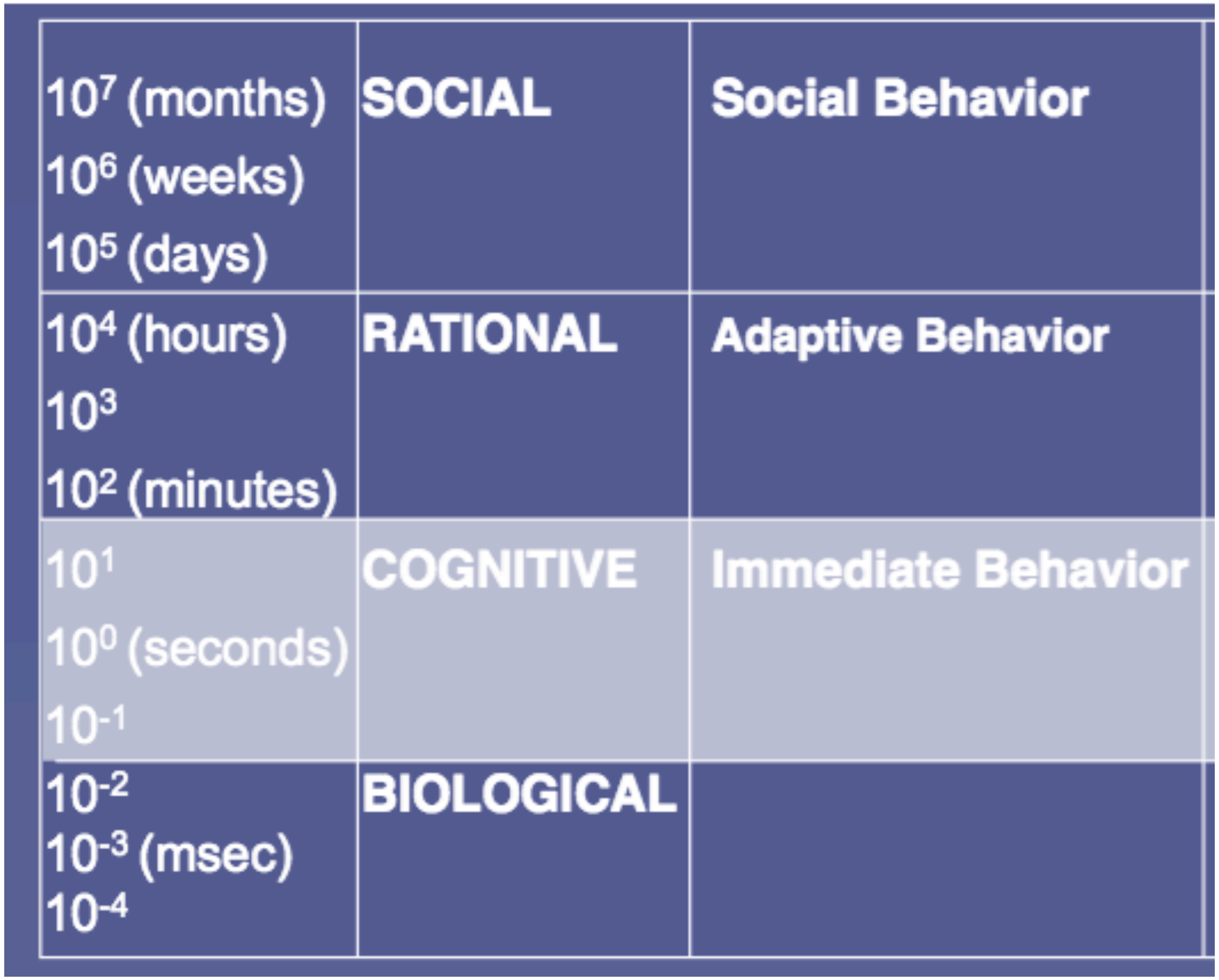
Cognitive Modeling

Cognitive approach to HCI attempts to predict user performance based on a model of cognition

Start with a model of how humans act

Use that model to predict how humans would complete tasks using a particular UI

Provided theoretical foundation of HCI in the 1970s and 1980s



10^7 (months) 10^6 (weeks) 10^5 (days)	SOCIAL	Social Behavior
10^4 (hours) 10^3 10^2 (minutes)	RATIONAL	Adaptive Behavior
10^1 10^0 (seconds) 10^{-1}	COGNITIVE	Immediate Behavior
10^{-2} 10^{-3} (msec) 10^{-4}	BIOLOGICAL	

Source: Stuart Card, Lecture on Human Information Interaction, 2007

Cognitive Models are…

Abstract

Quantitative

Approximate

Estimated from experiments

Based on a theory of cognition

Advantages

Can predict without implementing / prototype

Don't need to test with real users

Theory has explanatory power

Motivation: Provide a scientific foundation for design, like other engineering fields

Cognitive Theories in HCI

Fitts' Law - Predicts how long it will take a user to select a target; used for evaluating device input

KLM (Keystroke-Level Model) - Description of user tasks based on low-level actions (keystrokes, etc.)

GOMS (Goals, Operators, Methods, Selectors) - Higher-level then KLM, with structure and hierarchy

Model Human Processor (MHP) - Model of human cognition underlying these theories

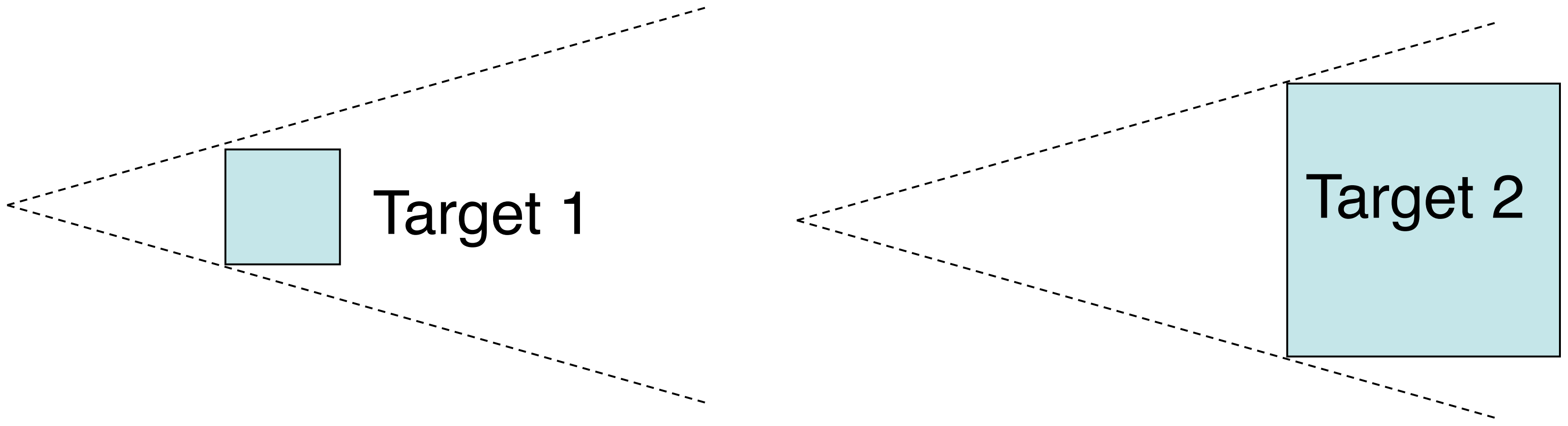
Fitts’ Law

Fitts' Law Intuition

Time depends on *relative precision* (d/s)

Time is not limited by motor activity of moving your arm / hand, but rather by the cognitive activity of keeping on track

In below example, time will be the same because the ratio d/s is the same



Fitts' Law

Predicts movement time for selection

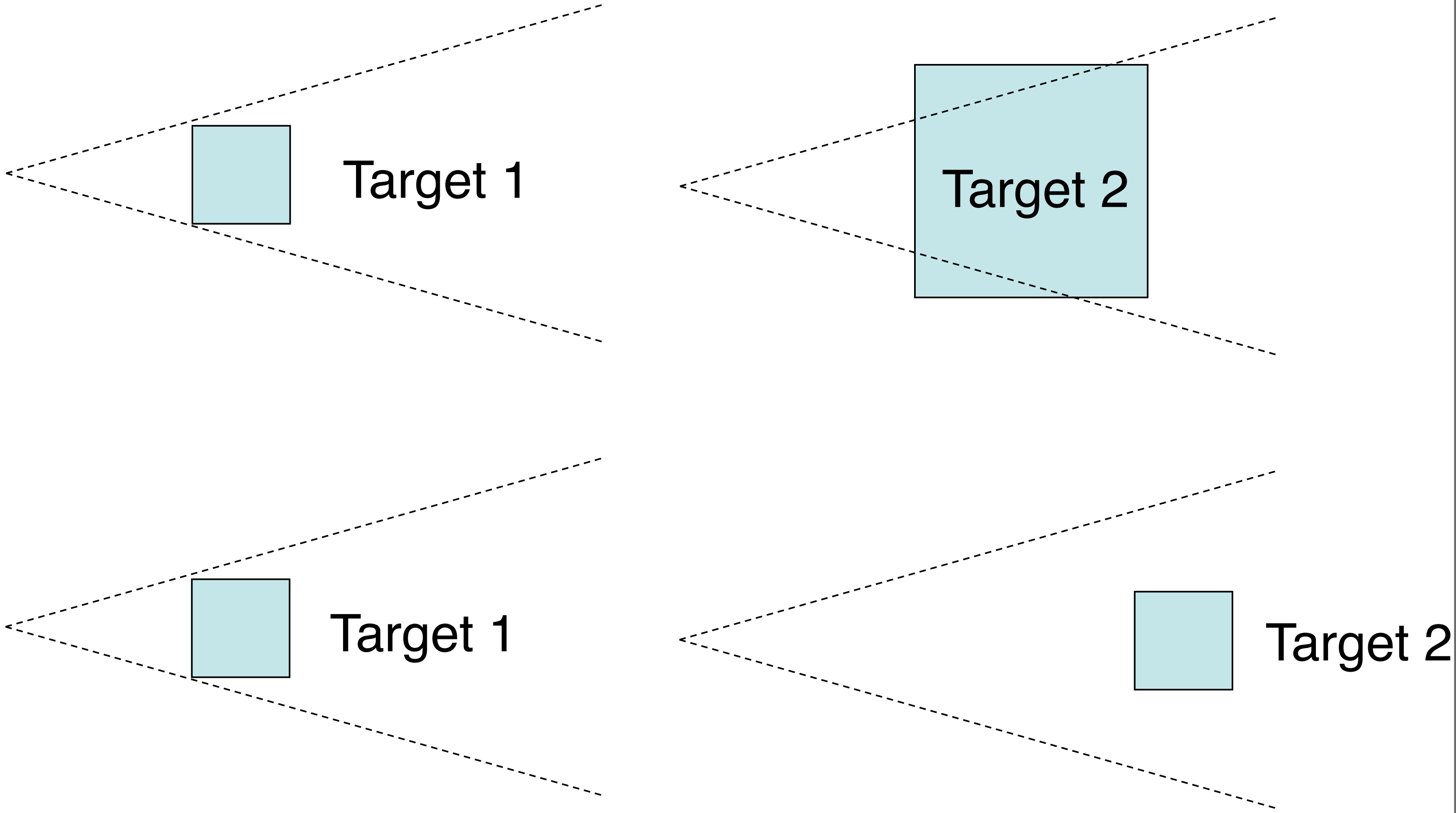
Movement time for a rehearsed task

- Increases with distance to target (d)
- Decreases with width of target (s)
- Depends only on relative precision (d/s), assuming target is within arms reach

First demonstrated for tapping with finger (Fitts 1954), later extrapolated to mouse and other input devices

Adapted from Hearst, Newstetter, Martin

Fitts' Law Examples



Adapted from Hearst, Irani

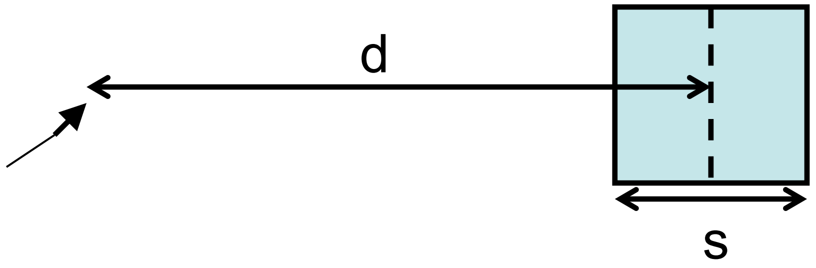
Fitts' Law Equation

$$T_{msec} = a + b \log_2 (d/s + 1)$$

a, b = empirically-derived constants

d = distance, s = width of target

ID (Index of Difficulty) = $\log_2 (d/s + 1)$



Determining a,b Constants

Conduct experiments varying d,s; but keeping everything else the same

Measure execution time, error rate, accuracy

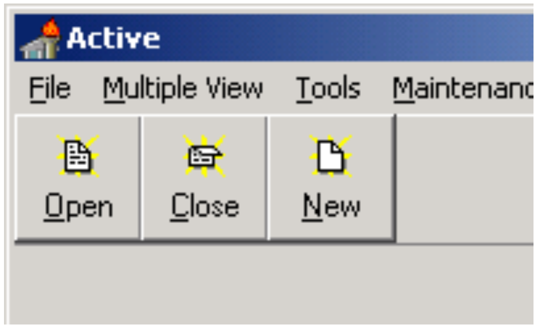
Exclude erroneous trials

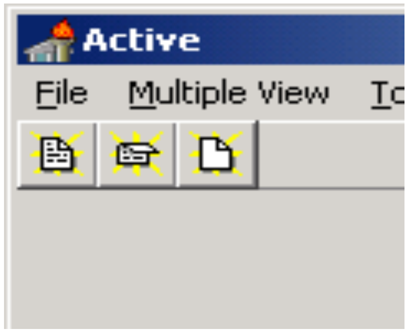
Perform linear regression

Fitts in Practice

Microsoft Toolbars allow you to either keep or remove the labels under Toolbar buttons

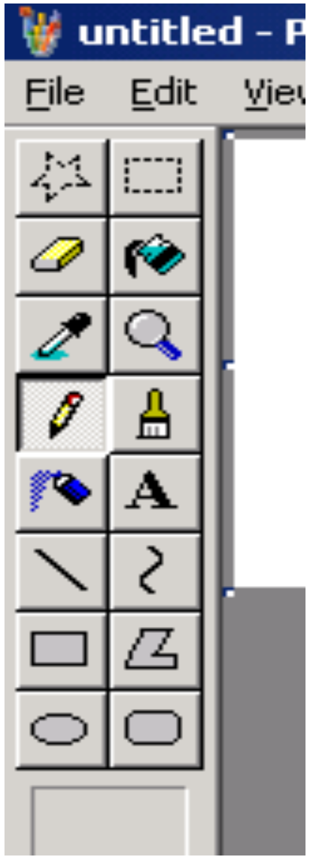
According to Fitts' Law, which is more efficient?





Source: http://www.asktog.com/columns/022DesignedToGiveFitts.html

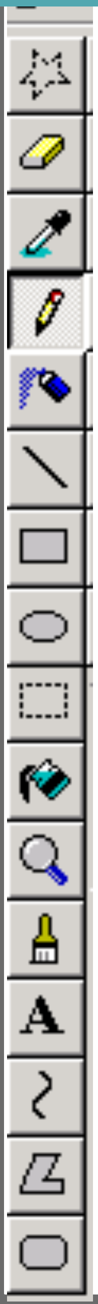
Fitts in Practice



You have a toolbar with 16 icons, each with dimensions of 16x16

Without moving the array from the left edge of the screen, or changing the size of the icons, how can you make this more efficient?

Fitts in Practice

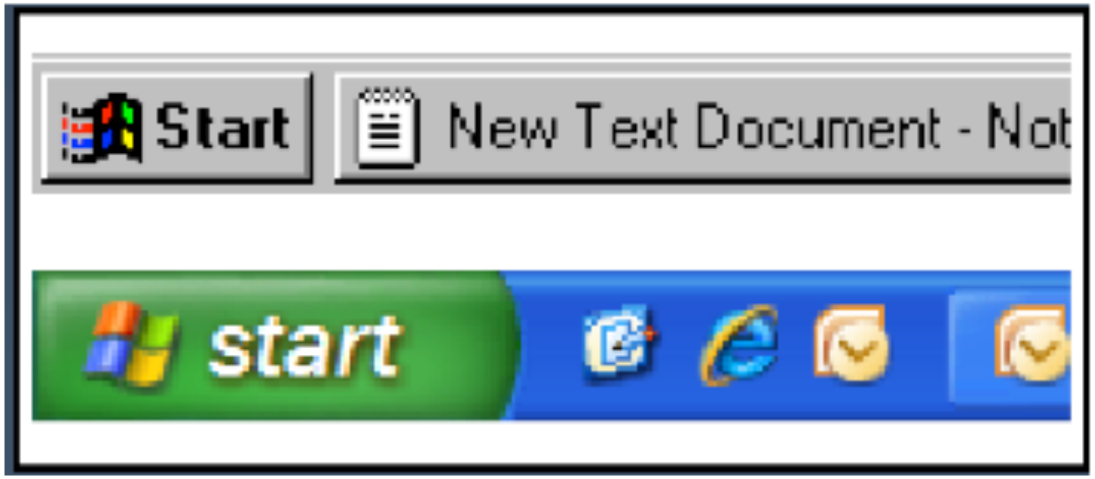


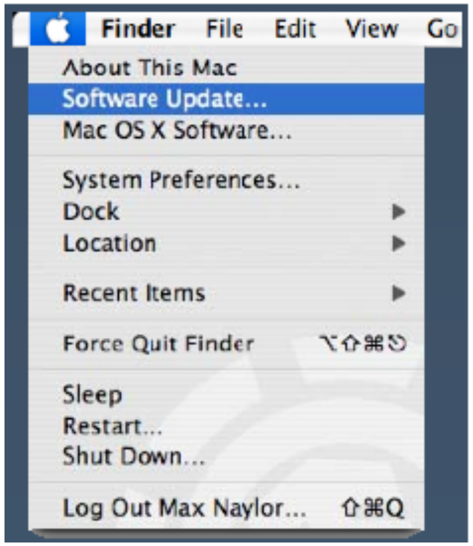
Answer: Line up all 16 icons on the left hand edge of the screen

Make sure that each button can be activated up to the last pixel on the left hand edge

Why? Because you cannot move your mouse off of the screen, the effective width s is infinite

Fitts in Practice





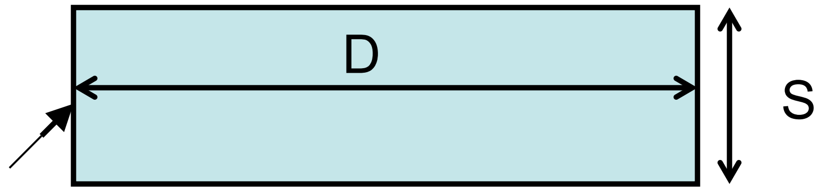
Adapted from Landay, Sinha, Klemmer

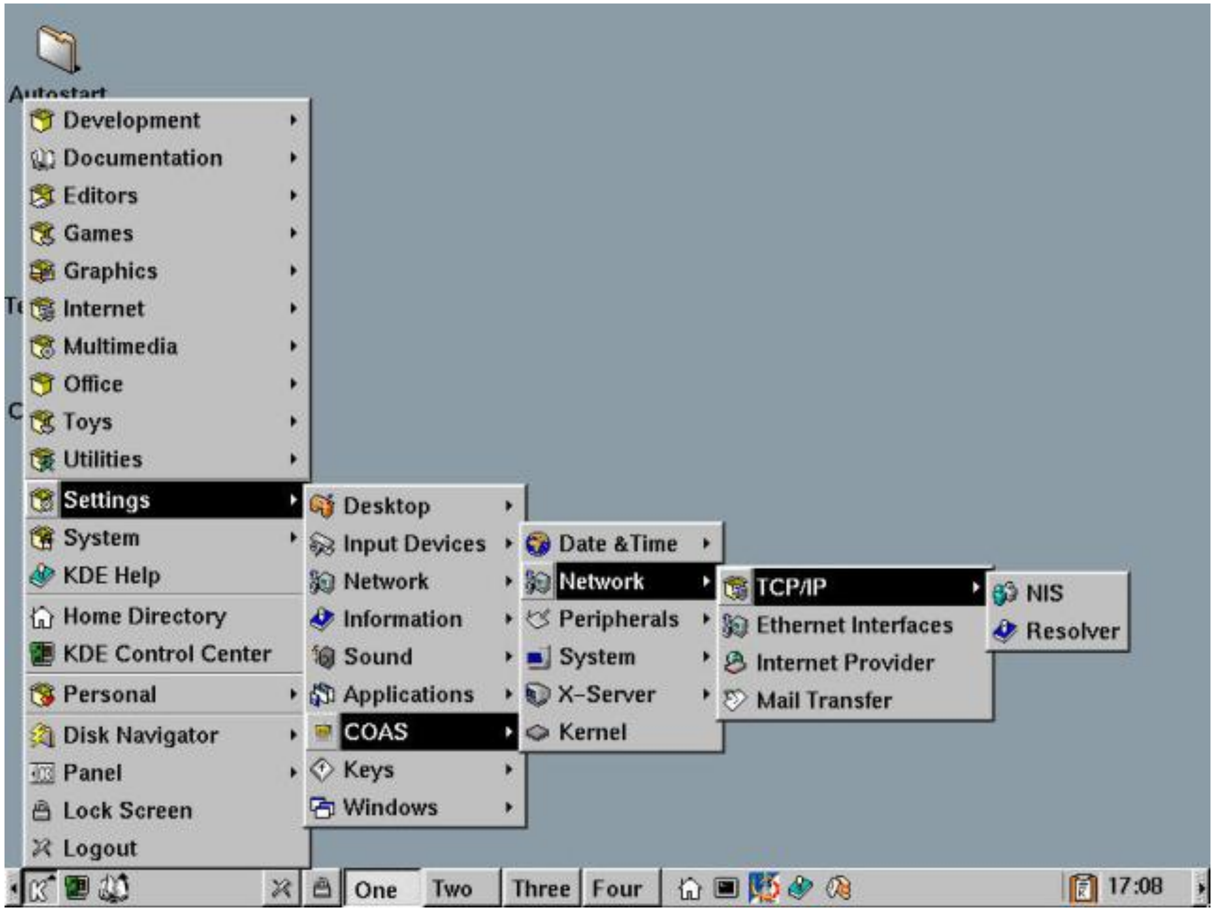
Steering Law

Applies same principles to *steering* through a tunnel (Accot, Zhai 1997)

Must keep the pointer within the boundaries throughout, not only at the target

Fitts' Law used for pointing, Steering Law used for drawing





Source: http://linuxbook.orbdesigns.com/ch09/btlb_c09.html

Steering Law Equation

$T_{msec} = a + b\ (d/s)$

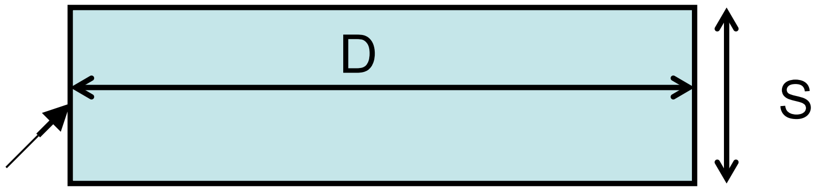
a, b = empirically-derived constants

d = distance, s = width of tunnel

ID (Index of Difficulty) = (d/s)

Index of Difficulty now *linear*, not logarithmic

(i.e. steering is more difficult then pointing)



Keystroke-Level Model (KLM)

Cognitive Analysis (KLM, GOMS, etc.)

Walk through a task, listing the actions needed to complete it

Use heuristics to insert "thinking" operators (for example, place M's in front of all P's that select a command)

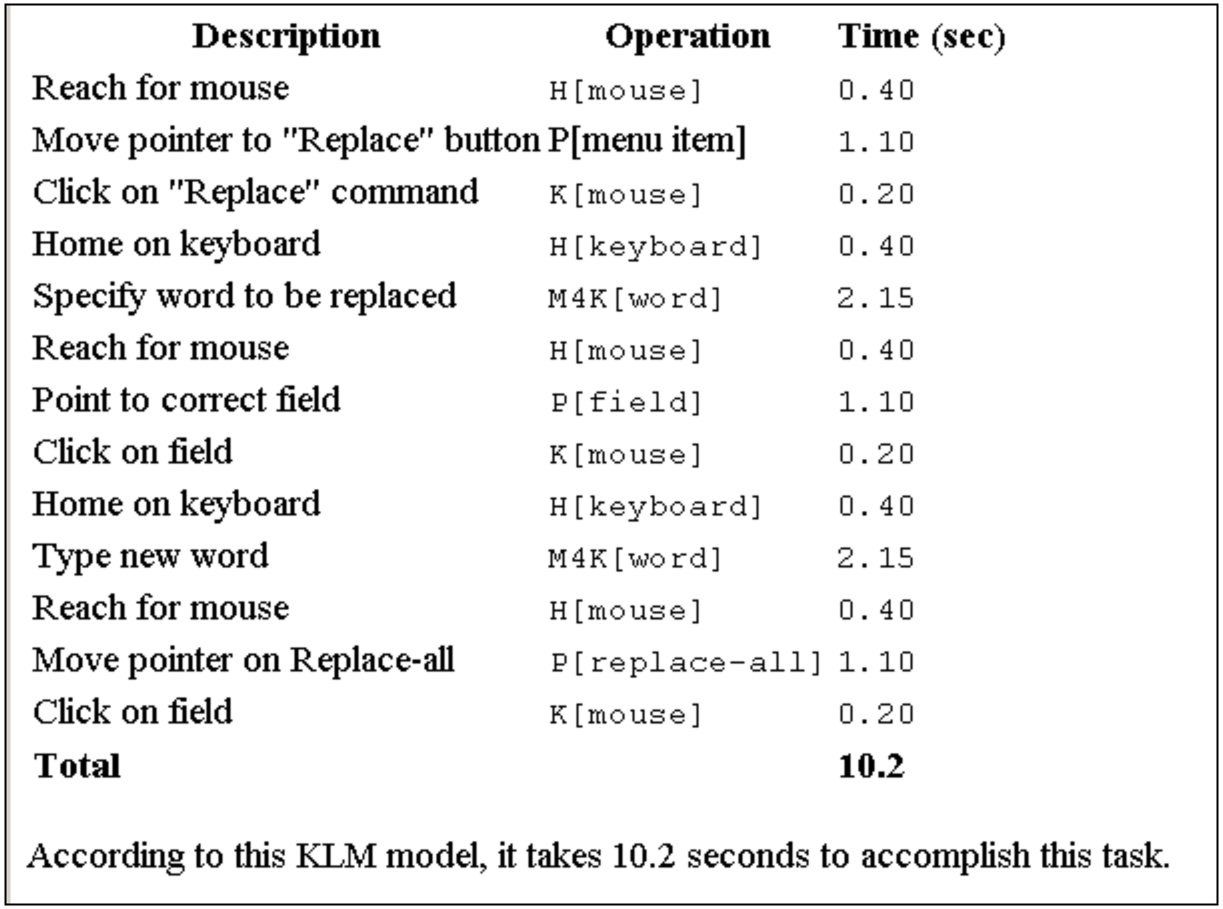
- These can be different for different UI styles

Based on estimates for each operator, calculate the amount of time required to complete the task

KLM Operators

K	Press a key or button
P	Point to a target on the display
H	Home hands on input device
D	Draw a line segment
M	Mentally prepare for an action
R	(system response time)

Example: Replacing a word



Description	Operation	Time (sec)
Reach for mouse	H[mouse]	0.40
Move pointer to "Replace" button	P[menu item]	1.10
Click on "Replace" command	K[mouse]	0.20
Home on keyboard	H[keyboard]	0.40
Specify word to be replaced	M4K[word]	2.15
Reach for mouse	H[mouse]	0.40
Point to correct field	P[field]	1.10
Click on field	K[mouse]	0.20
Home on keyboard	H[keyboard]	0.40
Type new word	M4K[word]	2.15
Reach for mouse	H[mouse]	0.40
Move pointer on Replace-all	P[replace-all]	1.10
Click on field	K[mouse]	0.20
Total		**10.2**

According to this KLM model, it takes 10.2 seconds to accomplish this task.

Adapted from Lorin Hochstein

Operator Estimates

- Keystroke determined by typing speed
  - 0.28s for average typist (40 wpm), 0.08s for fast typist (155 wpm), 1.20s for worst typist
- Pointing determined by Fitts' Law (or general approximation)
  - $T = a + b \log (d/s + 1)$ OR
  - $T = 1.1s$
- Drawing determined by Steering Law
  - $T = a + b (d/s)$

Operator Estimates

Homing estimated by measurement

T = 0.36s (between keyboard and mouse)

Mental prep estimated by measurement

T = 1.35s

(estimated by taking the total task time, subtracting physical operator time, and dividing by the number of M operations)

Heuristics for adding M's

Basic idea: Put an **M** before each step requiring access of a "chunk" from long-term memory

Insert **M**'s before each sequence of Ks and P

K -> MK; P -> MP

Remove **M**'s in the middle of typing a word or string

MKMKMK -> MKKK

Delete **M**'s within repetitive composite actions (for example, point and click)

MPMK -> MPK

Example: Deleting a word

Using Shift-Click

M
P [start of word]
K [click]
M
P [end of word]
K [shift]
K [click]
H [to keyboard]
M
K [Del]

Total: 3M + 2P + 4K
= 7.37 sec

Using Delete

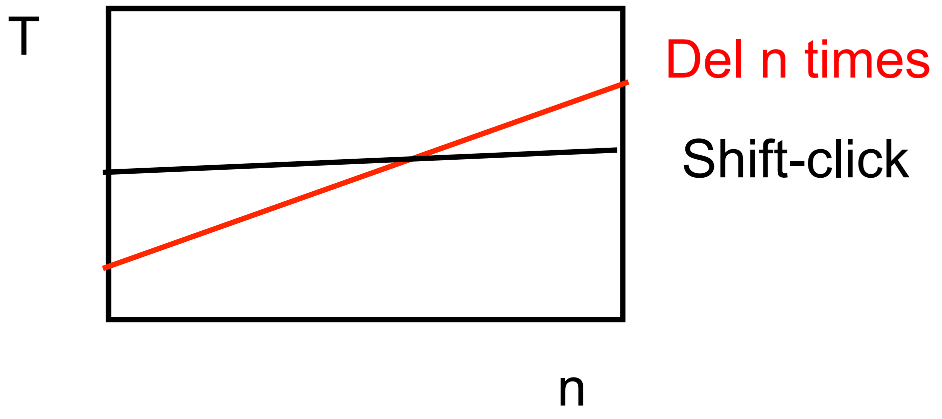
M
P [start of word]
K [click]
H
M
K [Del] x n [length of word]

Total: 2M + P + H + (n+1) K
= 4.44 + 0.28n sec

Adapted from Rob Miller

Using KLM

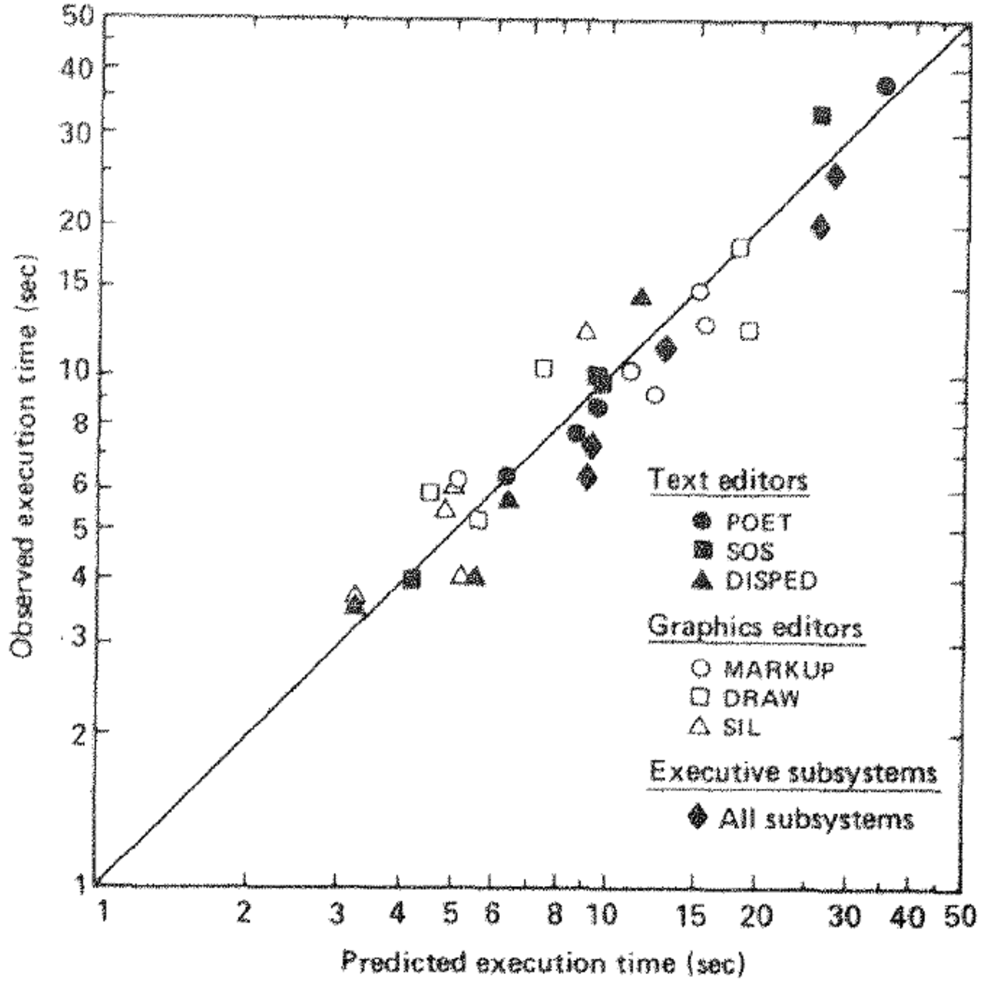
KLM can help evaluate UI designs, interaction methods and trade-offs, using parametric analysis



If common tasks take too long or consist of too many statements, can provide shortcuts

Empirical Validation of KLM

Fig. 6. Predicted vs. observed execution times in the experiment.



Source: Card, Moran and Newell, "The Keystroke Level Model for User Performance Time with Interactive Systems"

Limitation of KLM

Only applies to expert users doing routine (well-learned) tasks

Only predicts time; not error rate, memorizability, learnability, etc.

Impractical for all but the simplest tasks

Ignores

- Parallel processing, Multi-tasking
- Daydreaming
- Mental workload (working memory limits, fatigue)
- Planning and problem-solving (how to select a method?)

GOMS

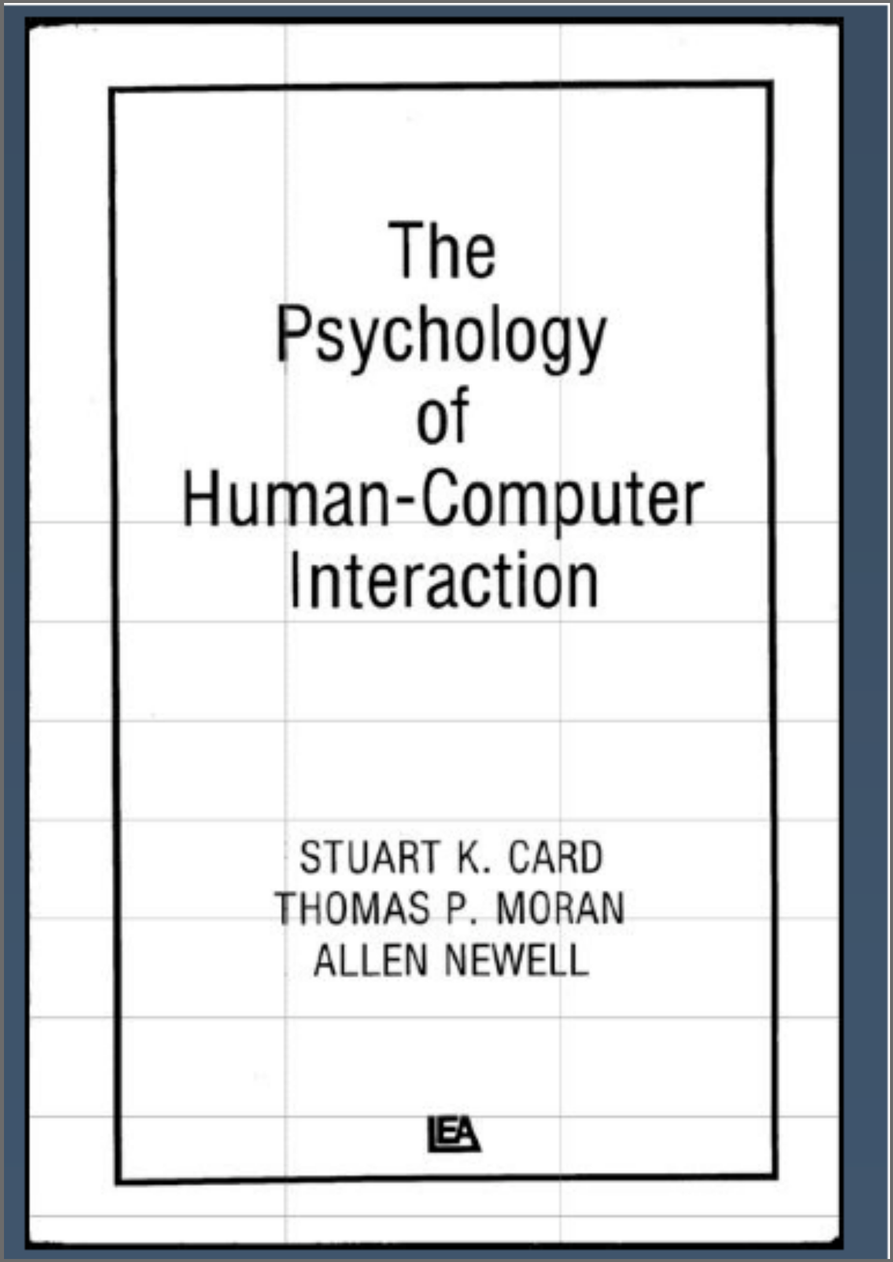
GOMS provides a higher-level language for task analysis and UI modeling

Generates a set of quantitative and qualitative predictions based on description of the task and user interface

Provides a hierarchy of goals and methods to achieve them

Different GOMS variants use different terms, operate at various levels of abstraction, and make different simplifying assumptions

Model Human Processor



The Psychology of Human-Computer Interaction

STUART K. CARD
THOMAS P. MORAN
ALLEN NEWELL

LEA

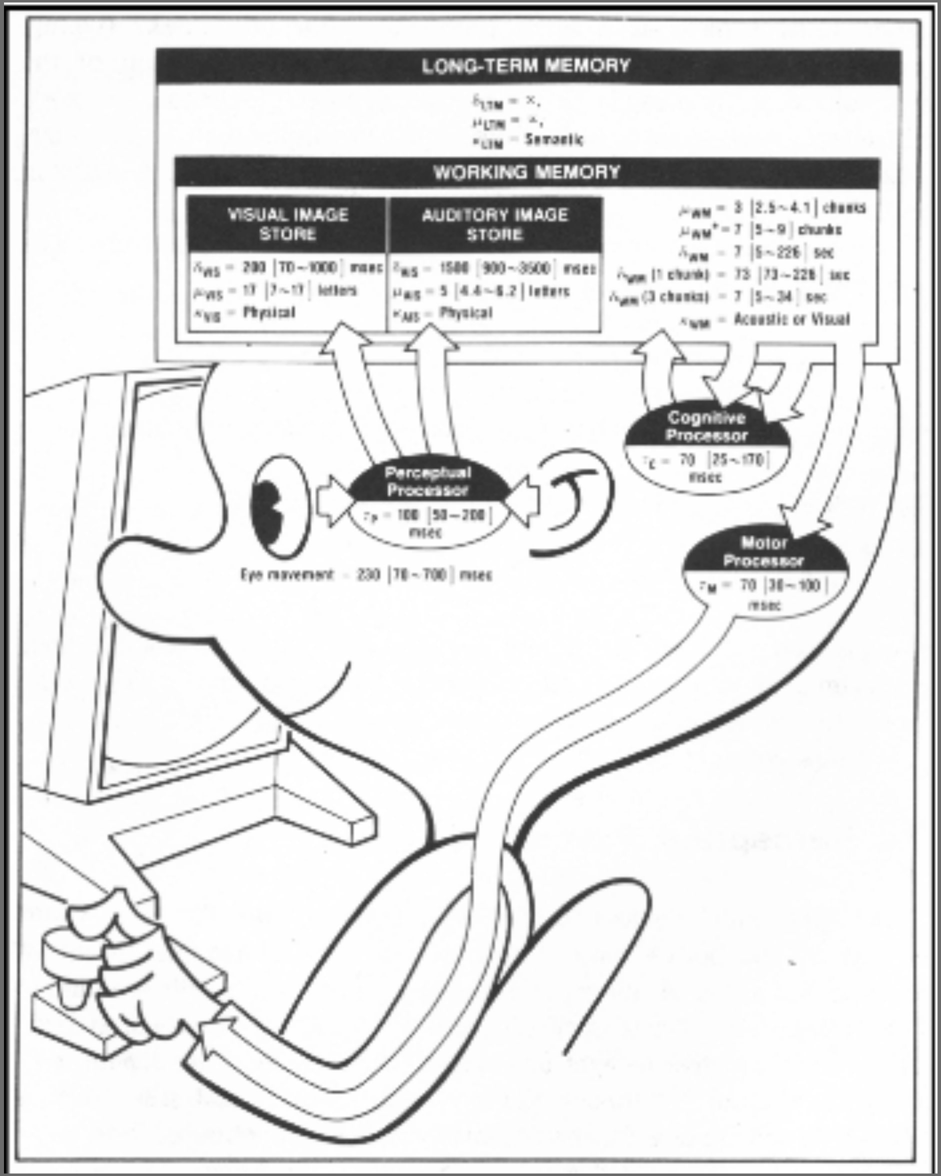
Model Human Processor

Model of human cognition useful for developing user interfaces

Drew upon decades of prior psychology research

Not an exact model of how the brain operates, but provides a useful approximation for understanding and estimating certain kinds of actions and reactions

Organized similar to computer hardware and memory


LONG-TERM MEMORY
$\delta_{LTM} = \infty$,
$\mu_{LTM} = \infty$,
κ_{LTM} = Semantic
WORKING MEMORY
VISUAL IMAGE STORE
δ_{VIS} = 200 [70~1000] msec
μ_{VIS} = 17 [7~17] letters
κ_{VIS} = Physical
AUDITORY IMAGE STORE
δ_{AIS} = 1500 [900~3500] msec
μ_{AIS} = 5 [4.4~6.2] letters
κ_{AIS} = Physical
μ_{WM} = 3 [2.5~4.1] chunks
μ_{WM}^* = 7 [5~9] chunks
δ_{WM} = 7 [5~226] sec
δ_{WM} (1 chunk) = 73 [73~226] sec
δ_{WM} (3 chunks) = 7 [5~34] sec
κ_{WM} = Acoustic or Visual
Perceptual Processor
τ_P = 100 [50~200] msec
Cognitive Processor
τ_C = 70 [25~170] msec
Motor Processor
τ_M = 70 [30~100] msec
Eye movement = 230 [70~700] msec

Source: Card, Moran, Newell, The Psychology of Human-Computer Interaction

Model Human Processor

Processors
- Perceptual
- Cognitive
- Motor

Memories
- Sensory Image Store
- Working Memory
- Long-term Memory

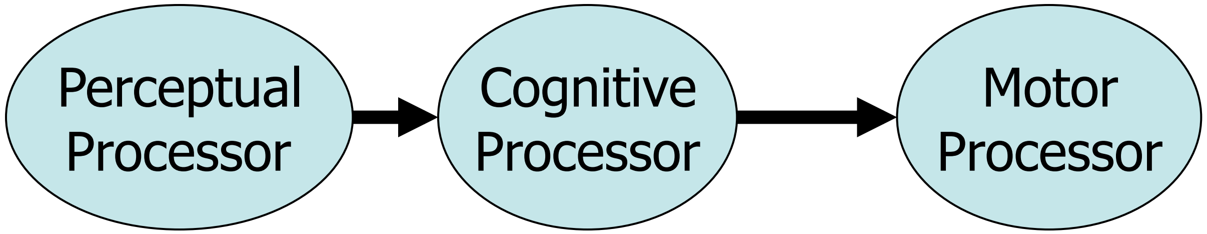
Principles of Operation

Model Human Processor

Perceptual
- Processes sensory input
- Populates sensory image store

Motor
- Execute physical actions
- Operates on working memory

Cognitive
- Connects perceptions to actions
- Operates on working and long-term memory



Model Human Processor

"The perceptual system consists of sensors and associated buffer memories… The cognitive system receives symbolically coded information [from the perceptual system] in its working memory, and uses previously stored information from long-term memory to make decisions about how to respond. The motor system carries out the response"

Source: Card, Moran, Newell, The Psychology of Human-Computer Interaction

Cycle time

Each processor has a cycle time

T_p ~ 100ms [50-200 ms]

- Based on *unit impulse response*
- There is a *quantum* of experience
- Shorter for more intense stimuli

T_m ~ 70ms [25-170 ms]

- Movement is also not continuous, but consists of a sequence of discrete movements (sometimes preprogrammed - talking, typing, etc.)

Cycle time

T_c ~ 70ms [30-100 ms]

- Based on *recognize-act* cycle
- Parallel recognition, serial action
- Can be shorter with lighter task / information loads, and practice

For each of the cycle times, there can be up to 10x difference between the fastest and slowest human beings - cycle times calculated both as nominal amounts and ranges

Power law of practice

The time to do a task decreases with practice

$T_n = T_1 n^{-a}$

T_n = time to do task on nth iteration
T_1 = time to do task on first iteration
A = constant (0.2 - 0.6)

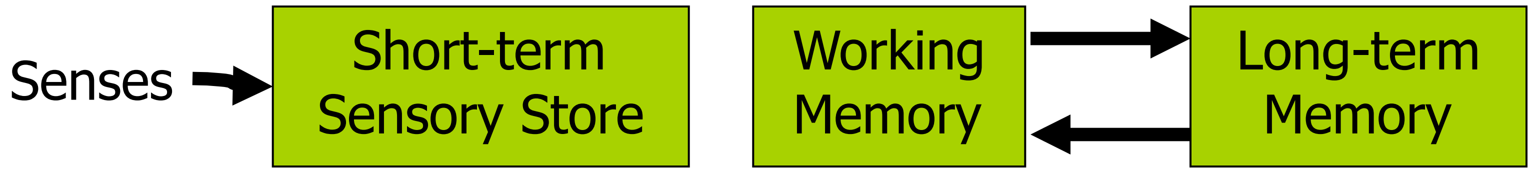
Applies only to skilled behavior, not to knowledge stored in long-term memory

Adapted from Robert Miller

Memories

Properties of memories:

- Encoding: how things stored
- Size: number of things stored
- Decay time: how long memory lasts (measured as half-life)



Adapted from Robert Miller

Sensory Image Store

Visual information store

- encoded as physical image
- size ~ 17 [7-17] letters
- decay ~ 200 ms [70-1000 ms]

Auditory information store

- encoded as physical sound
- size ~ 5 [4.4-6.2] letters
- decay ~ 1500 ms [900-3500 ms]

Perceptual memory fades before all of it can be coded and transferred to working memory

Perceptual Fusion

Two stimuli within the same PP cycle (T_p ~ 100ms) appear fused

- Intuition: will be in the same SIS frame

Consequences

- 1/ T_p frames/sec is enough to perceive a moving picture (10 fps OK, 20 fps smooth)
- Computer response < Tp feels instantaneous
- Causality is strongly influenced by fusion

Chunking

"Chunk": unit of perception or memory

Chunking depends on presentation and what you already know

M W R C A A O L I B M F B I B

MWR CAA OLI BMF BIB

BMW RCA AOL IBM FBI

Working Memory

Holds intermediate products of thinking and coded representations produced by perceptual system

- encoded as acoustic or visual codes
- organized as "chunks" of information
- decay ~ 7s [5-226s]
- decay rate is dependent on the number of chunks being recalled
- *Maintenance rehearsal* can keep chunks in working memory
- *Interference* between similarly coded (primarily acoustic) chunks can reduce chance of retrieval
- size ~ 7 [5-9] chunks

Long term memory

Holds most of the user's knowledge and experiences

Network of inter-linked chunks, accessed associatively from working memory

- primarily encoded as semantic links
- decay ~ infinite
- size ~ infinite
- fast-read, slow-write

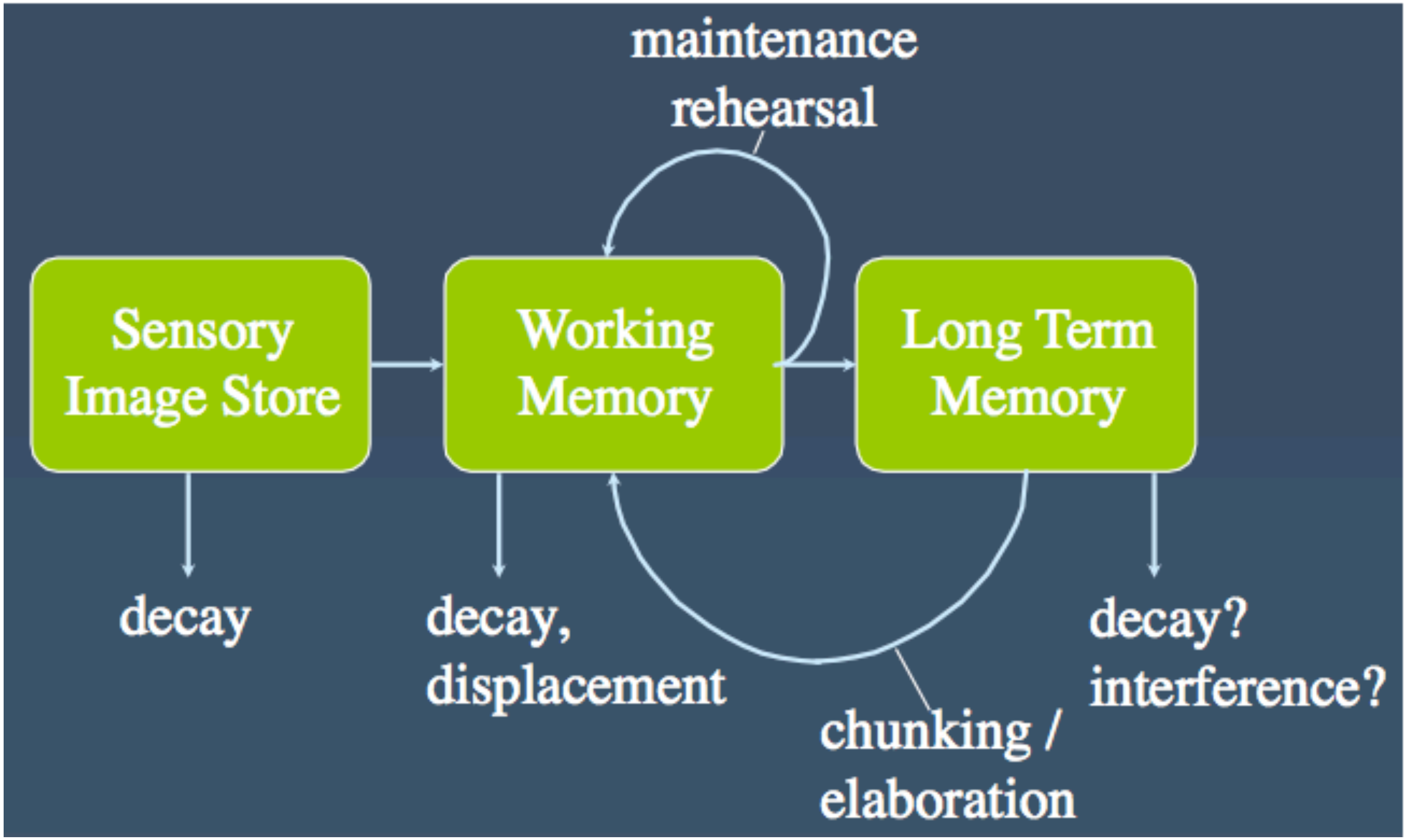
Working on complicated tasks means less time for transferring from working memory to long-term memory

Retrieval from LTM

Retrieval of LTM chunks is based on what other chunks it is associated with (retrieval cues)

Elaborative rehearsal can create more links, increasing chances of retrieval

Interference between similarly coded (semantically similar) can reduce chances of retrieval



Adapted from Landay, Sinha, Klemmer

Uncertainty Principle

Response time RT increases with uncertainty about the judgment or decision to be made; proportionally to the information content of the stimuli

For example, for n equally probably stimuli, each requiring a different response

$RT = c + d \log_2 (n + 1)$

Where c, d are constants

For next time

Keep working on functional prototype and experiment design

Awesome guest lectures!