Human Capabilities

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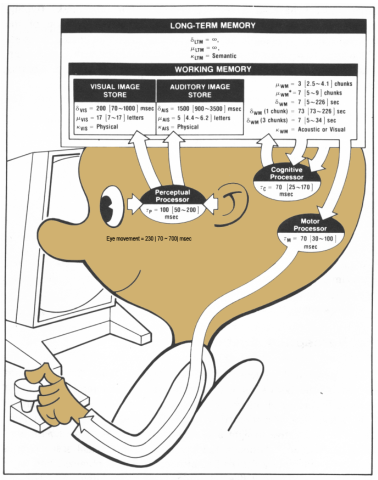
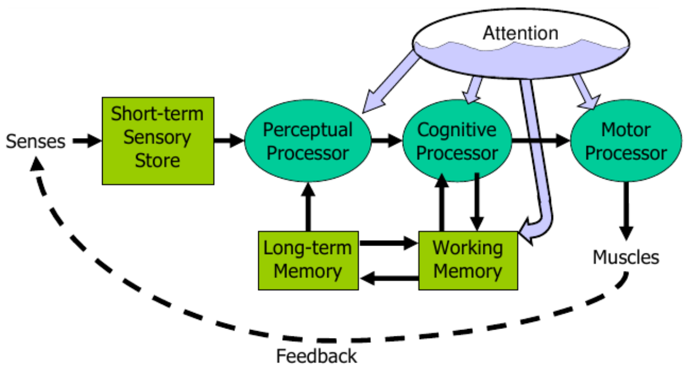
1 Overview

Model Human Processor (MHP)



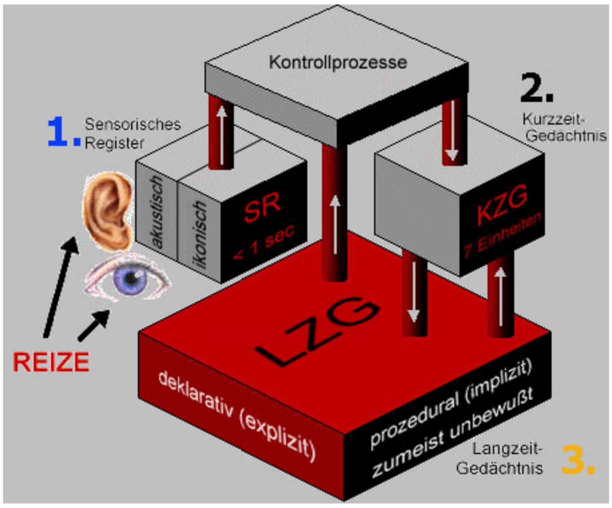
Card, Newell & Moran (1983)

Human Information Processing (HIP)



Robert Miller (2004)

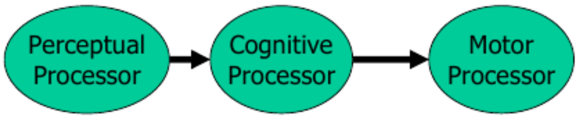
Topology



G. Mietzel http://www.supplement.de/supplement/gedaech/gedh.htm

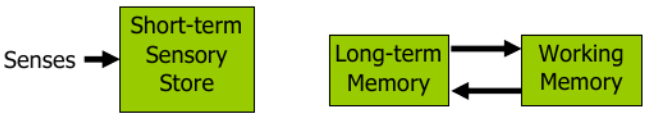
Processors

- Processors have a cycle time
  - T_p ~ 100ms [50-200 ms]
  - T_c ~ 70ms [30-100 ms]
  - T_m ~ 70ms [25-170 ms]



- Fastman may be 10x faster than Slowman; Middleman is typical (named by Card, Newell, Moran)
- Variations not only between individuals, but also depending on conditions: slow reading in the dark, fast processing when playing WoW

Memory



- **Encoding**: type of things stored
- **Size**: number of things stored
- **Decay** time: how long memory lasts

2 Perception

Short-Term Sensory Store

- Visual information store
  - encoded as physical image (curves, edges, length – not as pixels)
  - size ~ 17 [7-17] letters (convenient signals, not signs)
  - decay ~ 200 ms [70-1000 ms]
- Auditory information store
  - encoded as physical sound

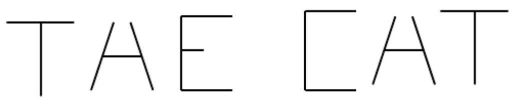
  - size ~ 5 [4.4-6.2] letters
  - decay ~ 1500 ms [900-3500 ms]
- Both are preattentional: they do not need the spotlight of attention to focus on them in order to be collected and stored
- Attention can be focused on the visual or auditory stimulus after the fact: "What did you say? Oh yeah."

Perceptual Fusion

- Two stimuli within the same PP cycle (T_p ~ 100ms) appear **fused**
  - Every cycle, the perceptual processor grabs a frame
  - Events occurring within a cycle are likely to end up in one frame
- Similar events are perceived as one event with additional properties (a moving person)
- Consequences
  - $1/T_p$ frames/sec is enough to perceive a moving picture (10 fps OK, 20 fps "smooth")
  - Computer response < T_p feels instantaneous
  - Causality is strongly influenced by fusion – a letter occurring on screen after a key is pressed seemed to be linked by causality when within the same cycle

Bottom-up vs. Top-Down Perception

- Bottom-up uses features of stimulus
  - Identifying features
- Top-down uses context of perception
  - temporal in auditory perception
  - spatial in visual perception
  - draws on long-term memory



- H and A are represented by the same shape, but can be distinguished because of their context

Chunking

- "Chunk": the unit of perception or memory
- Chunking depends on presentation and what you already know
  - defined symbols or activated past experience

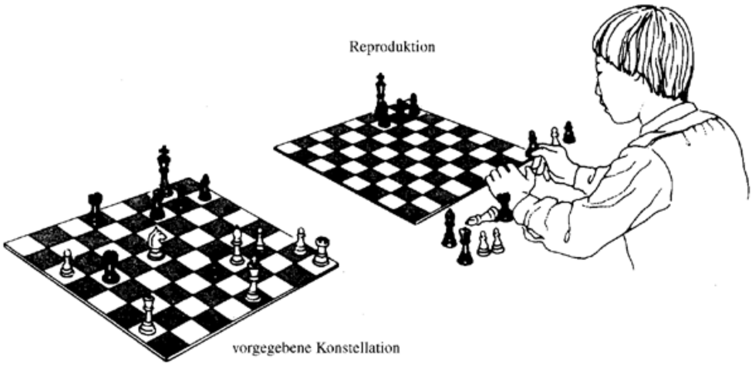
M W S A P A O L I B M F B I B
(15 chunks)

MWS APA OLI BMF BIB
(still 15 chunks to most people)

BMW SAP AOL IBM FBI
(5 chunks to most)

Chess: Experts vs. Novices

Chess masters are better than novices at remembering real game configurations, same performance on random boards



Reproduction task by Chase und Simon (1973) (in Anderson 2001, S.301).

Attention and Perception

- Spotlight metaphor:
  - You can focus your attention (and your perceptual processor) on only one input channel in your environment at a time
  - Spotlight moves serially from one input channel to another
    - a location in your visual field
    - a location or voice in your auditory field
  - Visual dominance: easier to attend to visual channels than auditory channels
  - All stimuli within spotlighted channel are processed in parallel
- Whether you want to or not
- Problem: Interference

Interference I

Say the colors of the words and time yourself (English left, German right)

- Book
- Pencil
- Hat
- Slide
- Window
- Car

- Hut
- Rutsche
- Fenster
- Auto
- Buch
- Stift

Interference II

Say the colors of the words and time yourself (English left, German right)

- Blue
- Brown
- Violet
- Red
- Green
- Orange

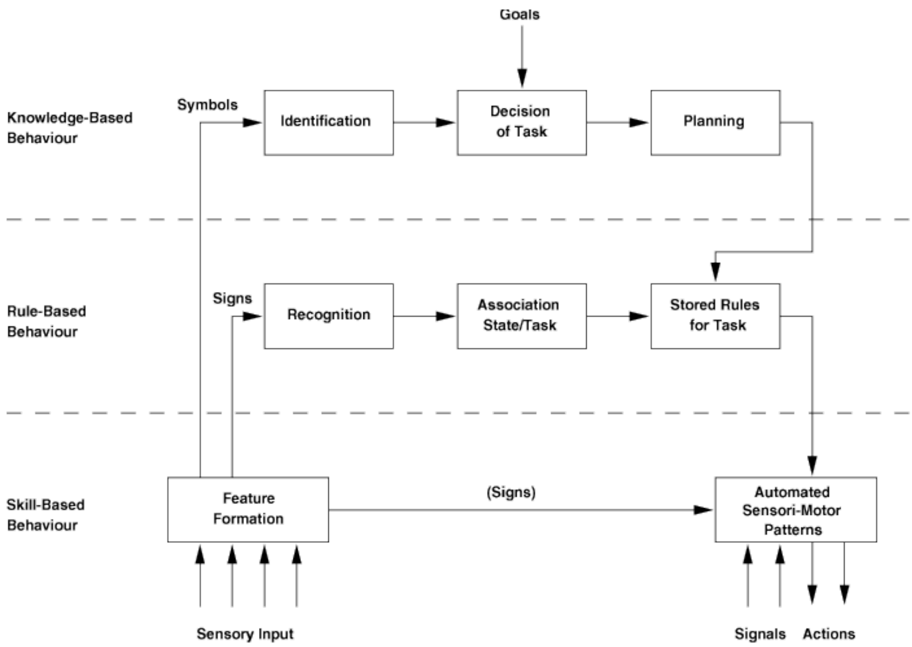
- Lila
- Rot
- Grün
- Orange
- Blau
- Braun

3 Processing

Cognitive Processing

- Cognitive processor
  - compares stimuli
  - selects a response
- Types of decision making
  - Skill-based
  - Rule-based
  - Knowledge-based

Rasmussen I



Jens Rasmussen (1983).

Rasmussen II

- Skill-Based Behaviour
  - Automatic reaction to sensory input
    - Breaking lights – breaking
- Rule-Based Behaviour
  - Based on sensory input, rules are fired
  - Happens when there is no automatic respons
  - Choice of rule based on signs recognized
    - Regulating speed and direction when exiting a freeway
- Knowledge-Based Behaviour
  - Conscious problem solving
  - Happens when there are no rules
  - Triggered by interpreted symbols
    - Stuttering motor – continue or stop?

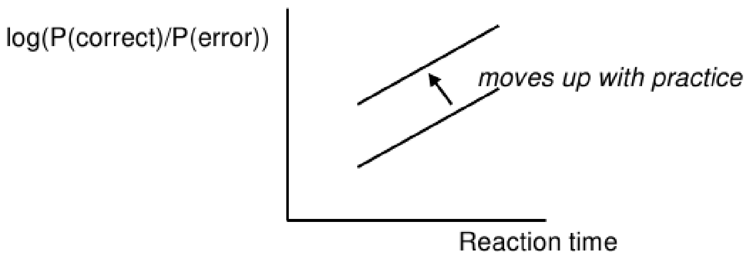
Choice-Reaction Time

- Simple reaction time – responding to a single stimulus with a single response – takes just one cycle of the human information processor, i.e. $T_p + T_c + T_m$
- Changes if the user must make a choice – choosing a different response for each stimulus
- Reaction time is proportional to amount of information of stimulus
- e.g., for N equally probable stimuli, each requiring a different response (b empirical measure):
  - $RT = b * log_2(N+1)$
- So if you double the number of possible stimuli, a human's reaction time only increases by a constant
- This law applies only to skill-based decision making

Speed-Accuracy Tradeoff

- Accuracy varies with reaction time
- We can force ourselves to make decisions faster (shorter reaction time) at the cost of getting some of those decisions wrong
- Conversely, we can slow down, take longer time for each decision and improve accuracy
- For skill-based decision making, reaction time varies linearly with the log of odds of correctness; i.e., a constant increase in reaction time can double the odds of a correct decision
- Not fixed; curve can be moved up by practicing the task
- People have different curves for different tasks

Speed-Accuracy Tradeoff II



Divided Attention & Multitasking

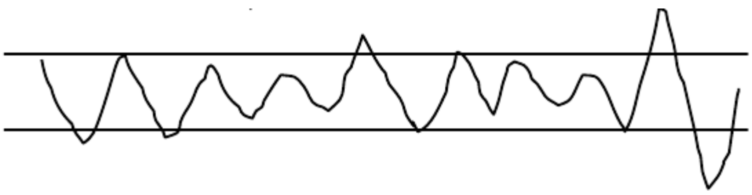
- Resource metaphor
  - Attention is a resource that can be divided among different tasks simultaneously
- Multitasking performance depends on:
  - Task structure
    * Tasks with different characteristics are easier to share; tasks with similar characteristics tend to interfere
    * Modality: visual vs. auditory
    * Encoding: spatial vs. verbal
    * Component: perceptual/cognitive vs. motor vs. WM
    * reading 2 texts more difficult then reading and listening
  - Difficulty
    * Easy or well-practiced tasks are easier to share
    * Smalltalk while driving in daylight on known road vs. during rainy night in unknown terrain

4 Action

Motor Processing I

- Open-loop control
  - Motor processor runs a program by itself
  - cycle time is T ~ 70 ms
- Closed-loop control
  - Muscle movements (or their effect on the world) are perceived and compared with desired result
  - cycle time is $T_c + T_p + T_m$ ~240 ms

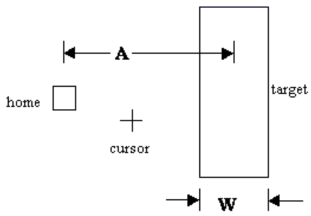
Motor Processing II

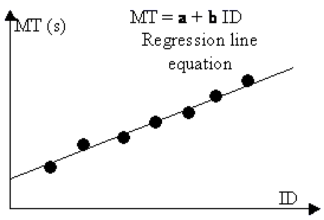


- The frequency of the sawtooth carrier wave is dictated by open-loop control
- The frequency of the wave's envelope, the corrections to be made to get the scribble back to the lines, is closed-loop control

Fitts's Law (Paul Fitts 1954)

- Positioning Time – Relationship between positioning time and distance between hand or cursor and target



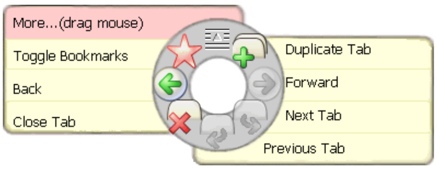


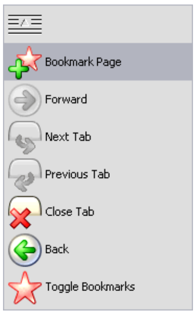
- Original version: $MT = a + b * log_2(2 * A/W)$
- MacKenzie 1992: $MT = a + b * log_2(A/W + 1)$
- a and b are constants, determined by experiment for every application
- Distance A and size W in any unit
- More: interaction-design.org/encyclopedia/

Implications

- Targets not too small
  - need to be recognized, found and hit
- Targets close together
  - For sequential tasks in a process
- Minimize far-away objects
  - Pop-Ups
- Consistency and expectations:
  - target often searched for at the same spot

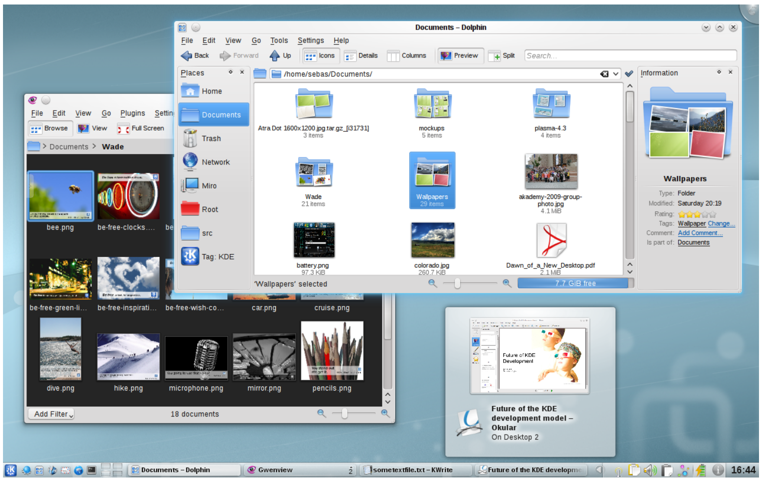
Examples I

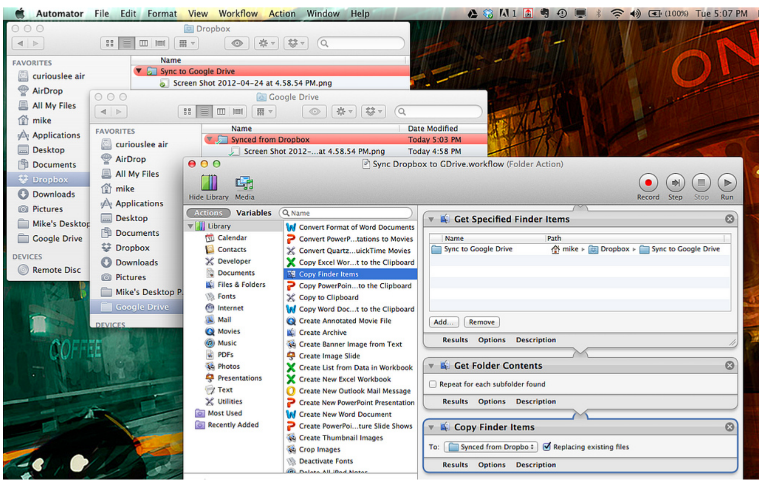




- Targets at screen edge are easy to hit
  - Mac menubar beats Windows menubar
  - Unclickable margins are foolish

Examples II



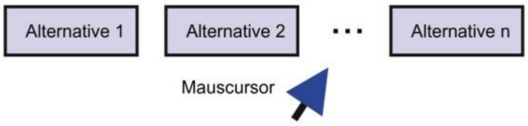


KDE: ☞ www.kde.org, OSX: ☞ Mike Lee

Problems

- Fitts's work was done
  - with physical objects
  - moving in one dimension
  - on workbenches
- Although often quoted, the results are not easily transferable to interaction with computers
- Accuracy and speed change
  - with the angle of the arm
  - within the graspable area

Hick's Law: Choice revisited



- Total reaction and movement time $TT = MT + RT$
  - $MT = a + b * log_2(A/W + 1)$
  - $RT = b * log_2(N + 1)$
- $TT = (a + b * log_2(A/W + 1)) + b * log_2(N + 1)$
  - n = number of options
  - Constants a and b as in Fitts's Law empirically defined (depending on task and subject condition)
  - Specific form for equally probable options
- General for reaction time:
  - $RT = a + b * Sum(p(i) * log_2(1/p(i) + 1))$
  - where $p(i)$ is the Probability of Choice for each option i

Power Law of Practice

- Important feature of the entire perceptual-cognitive-motor system: the time to do a task decreases with practice
- In particular, it decreases according to the power law
- The power law describes a linear curve on a log-log scale of time and number of trials
- In practice, the power law means that novices get rapidly better at a task with practice, but then their performance levels off to nearly flat (although still slowly improving):
- Time T to do a task the n^{th} time is:
  - $T_n = T_1 * n^{-\alpha}$
- α is typically 0.2-0.6

5 Memory

Working Memory (WM)

- Working memory is where you do your conscious thinking
- Working memory is where the cognitive processor gets its operands and drops its results
- Small capacity: (4 $\pm$ 2) – (7 $\pm$ 2) "chunks"
  - This number is often quoted

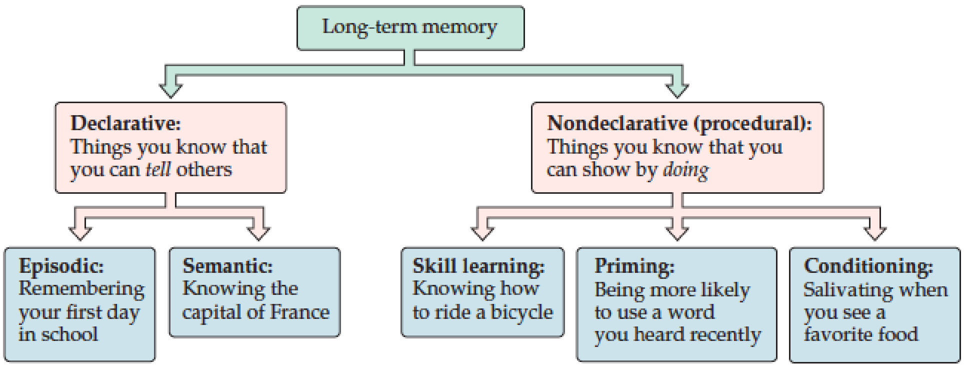
- Empirical evidence can be interpreted in different ways

- Fast decay (7 [5-226] sec)
- Maintenance rehearsal fends off decay
- Interference causes faster decay

Long-term Memory (LTM)

- Probably the least understood part of human cognition
- It contains the mass of our memories
- Huge capacity
- Little decay
- Apparently not intentionally erased; they just become inaccessible
- Maintenance rehearsal (repetition) appears to be useless for moving information into into long-term memory
- Elaborative rehearsal moves chunks from WM to LTM by making connections with other chunks
- Compare e.g. mnemonic techniques like associating things you need to remember with familiar places, like rooms in your childhood home

Memory Structure



Breedlove and Watson (2013)