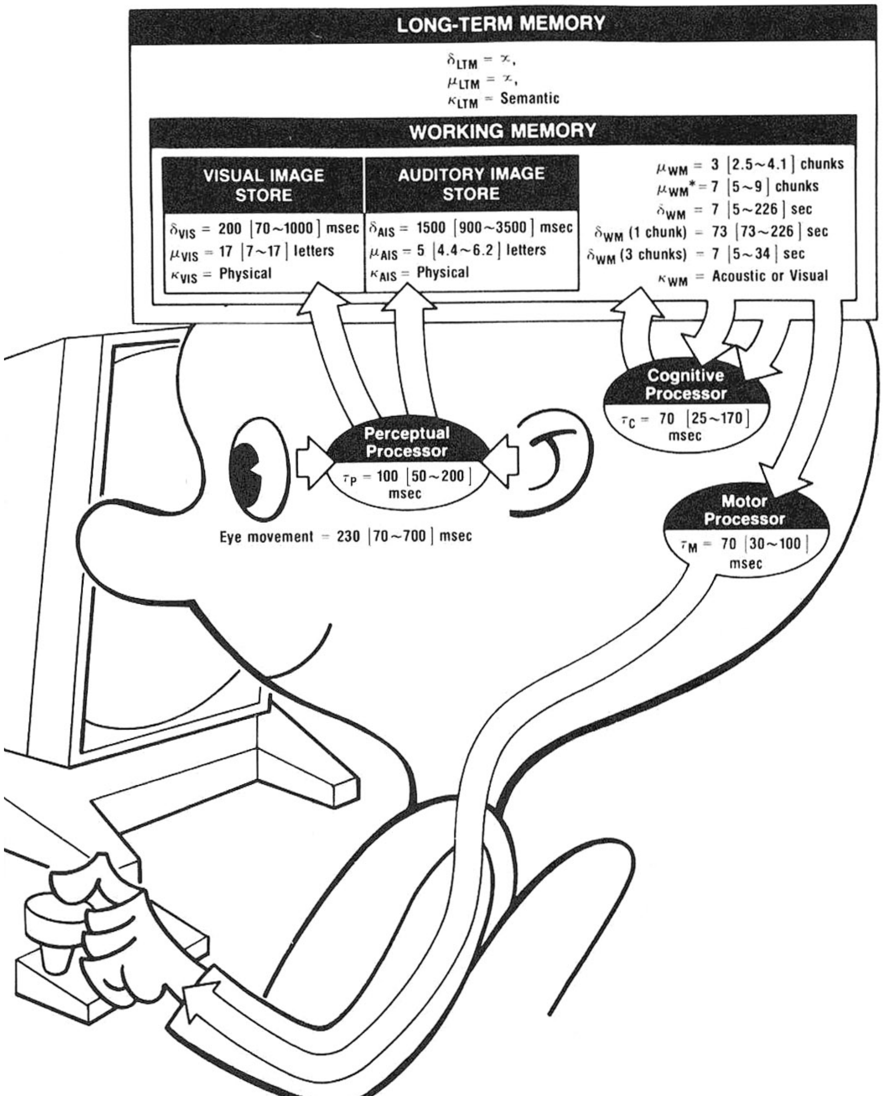
Human Information Processor I

Human Information Processor (Card, Moran, Newell)



- Unified model
  - several aspects of cognitive psychology into a unified picture
  - Recognize-act cycle
  - Simplified (limited) model
- Intended audience
  - Computer Scientists
- Predicting human behavior
  - Human performance while using the computer
- Human mind as an information processing system
- Practical and influential

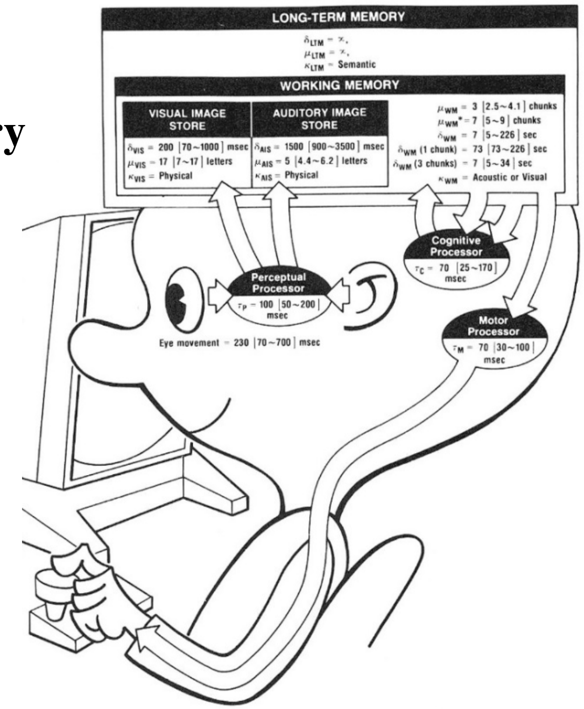
Subsytems of the Model Human Processor

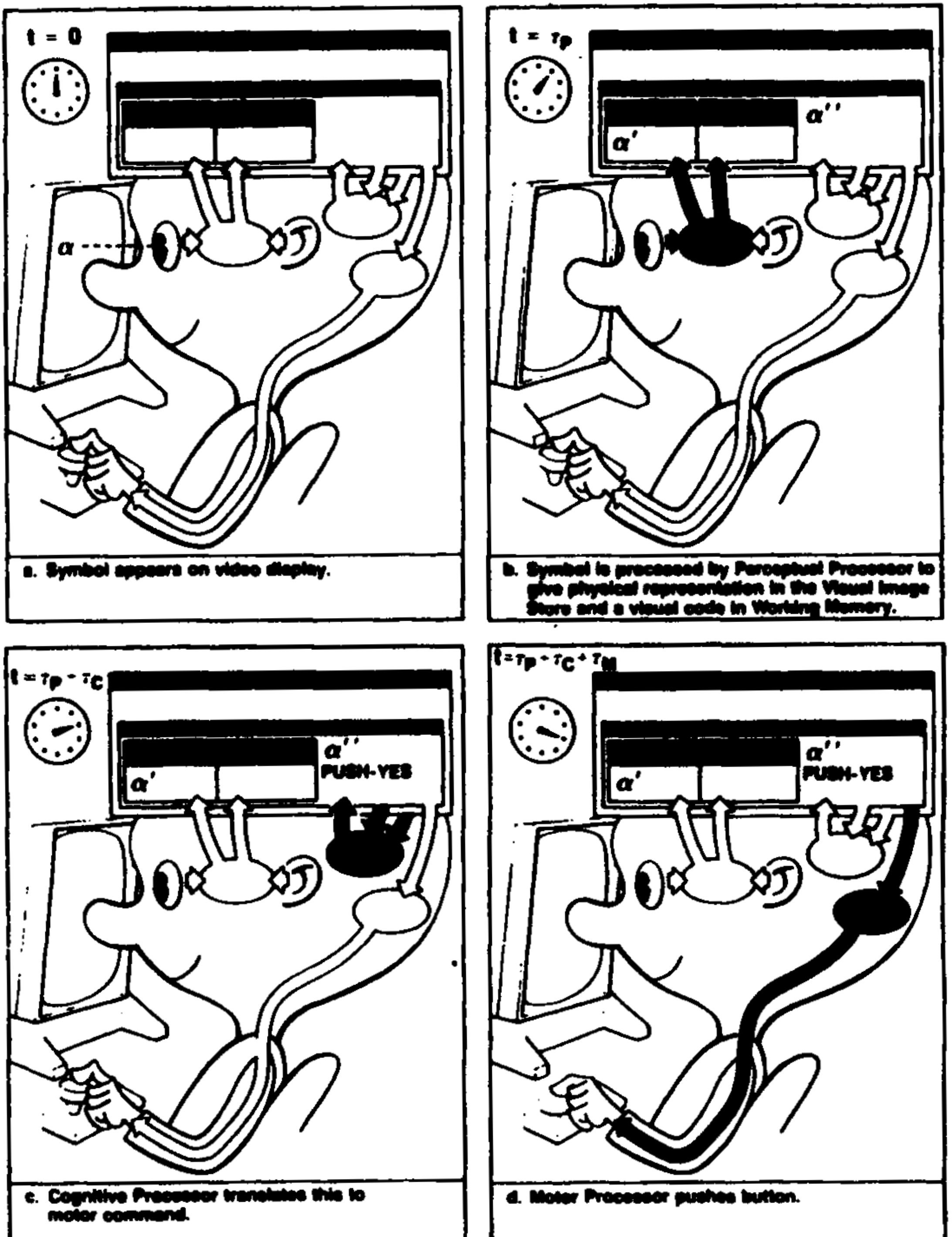
- Each system with **memory** and **processor**
  - Memory: capacity, decay time, code type (physical, acoustic, visual, semantic)
  - Processor: cycle time

- Perceptual system
  - sensors and memories (visual image store and auditory image store)
  - symbolically codes the output of the sensory system

- Cognitive system
  - receives symbolically coded info from **working memory**
  - matches info in **long term memory**
  - make **decision** about how to respond

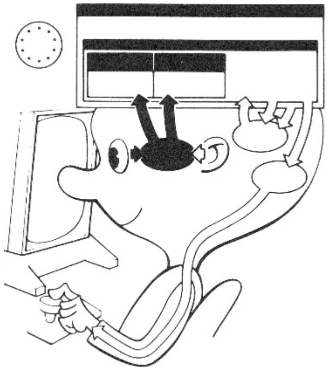
- Motor system
  - carries out response

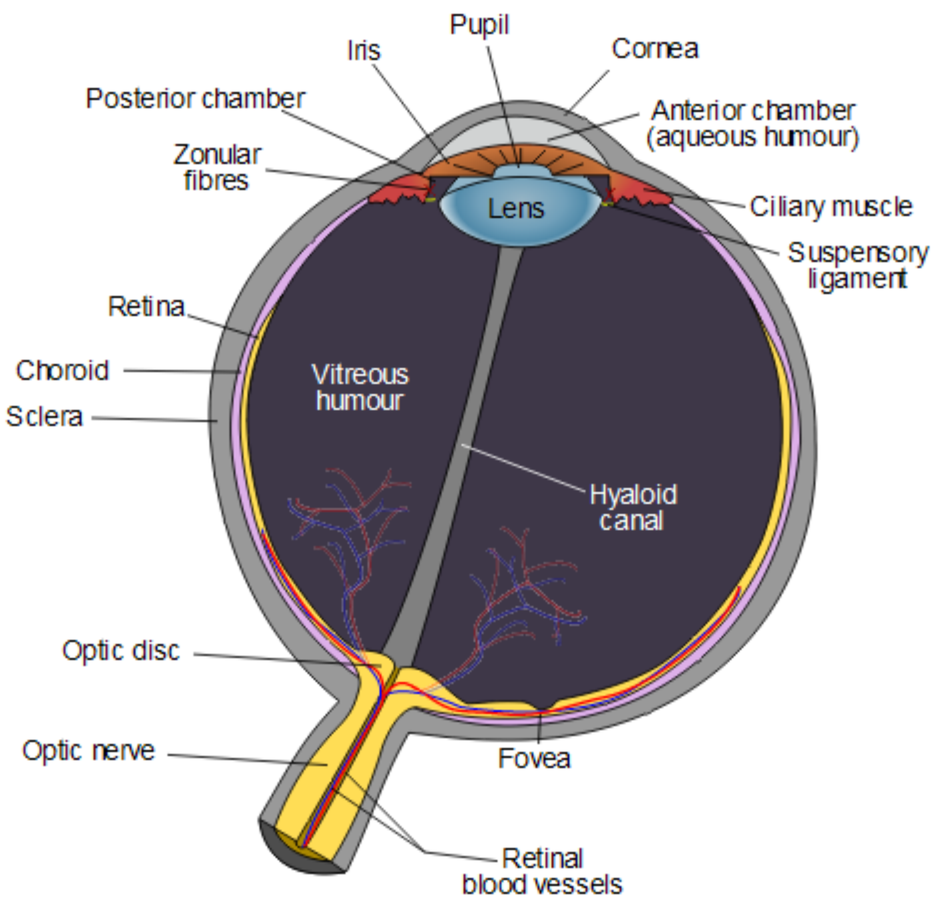




- Simple Reaction Time
  - see α on screen
  - coded representation in the visual image store (α')
  - visually coded symbol in Working Memory (α'')
  - ➔ Perceptual Processor cycle (T_P)
  - occurrence of the stimulus connected with a response (i.e. decide how to respond)
  - ➔ Cognitive Processor cycle (T_C)
  - carry out physical movement
  - ➔ Motor Processor cycle (T_M)

Perceptual System - Eye

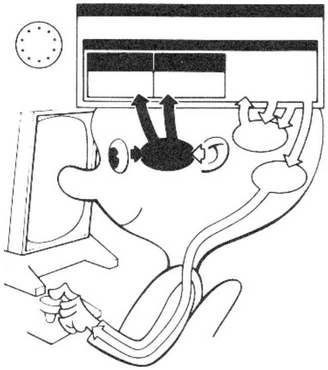




Wikipedia

- Central Vision
  - fovea
  - 2 degrees across
  - details obtained
- Peripheral Vision
  - retina
  - orientation
  - intensity
- Head Movement
  - If >30° away from fovea

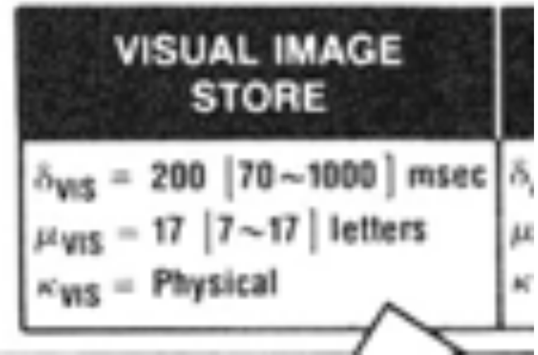
Perceptual Processor



- Physical store from our senses: see/hear/smell…
- From **physical** perception to **abstract** concept
  - color, shape, orientation, brightness, movement to “B” or “circle”

- Coded for transfer to working memory
  - Progressive decoding
    - *Example: 10ms/letter*
  - Selective decoding
    - *Spatial*
    - *Pre-attentive: color, direction…*

- Capacity
  - Example: 17 letters



Pre-attentive perception: How many 3s?

85689726984689762689764358922659865986554897689269898
02462996874026557627986789045679232769285460986772098
90834579802790759047098279085790847729087590827908754
98709856749068975786259845690243790472190790709811450
85689726984689762689764458922659865986554897689269898

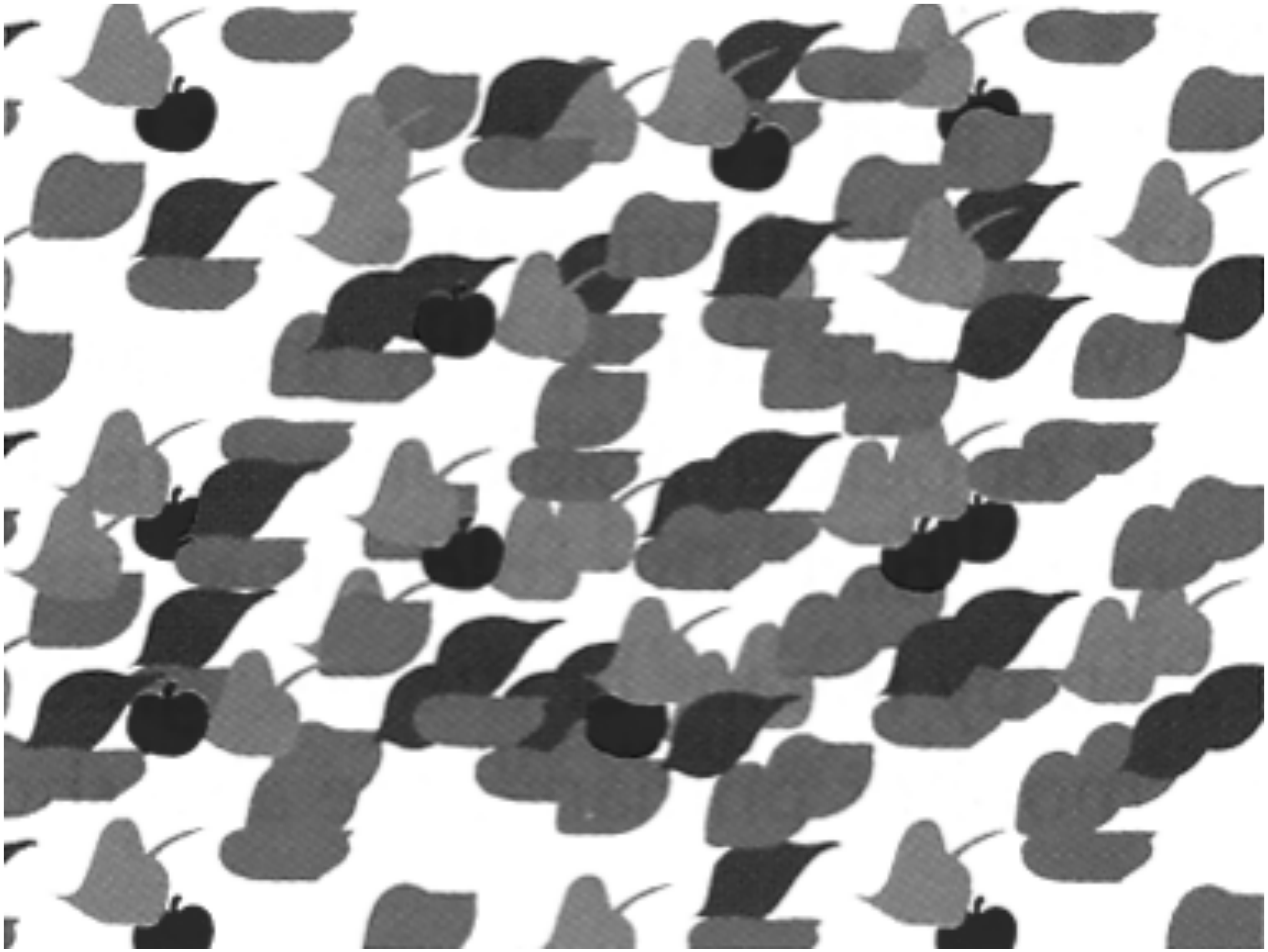
From Information Visualization, C. Ware

Pre-attentive perception: How many 3s?

85689726984689762689764**3**58922659865986554897689269898
024629968740265576279867890456792**3**2769285460986772098
908**3**4579802790759047098279085790847729087590827908754
98709856749068975786259845690243**3**790472190790709811450
85689726984689762689764458922659865986554897689269898

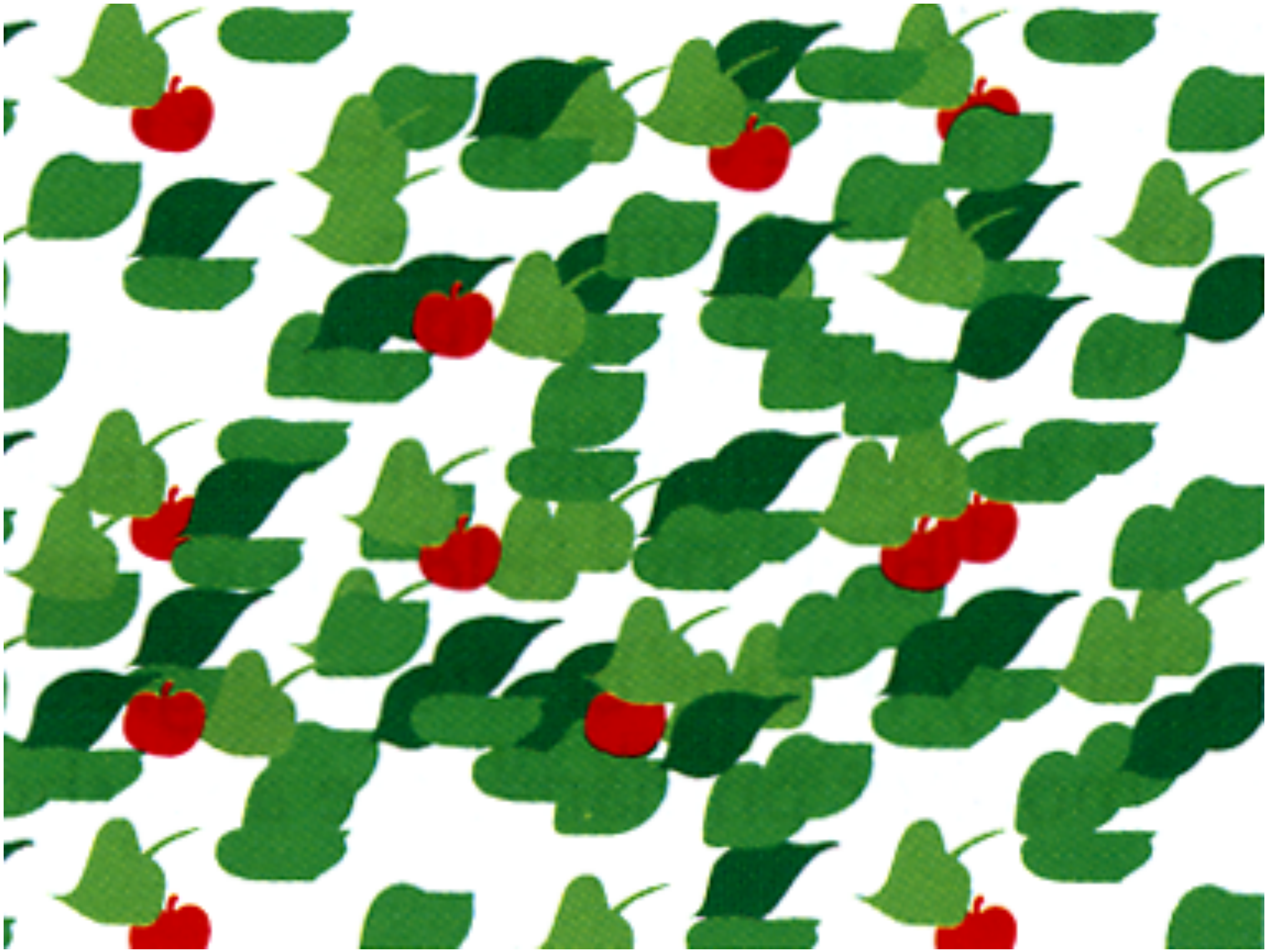
From Information Visualization, C. Ware

Where are the cherries?



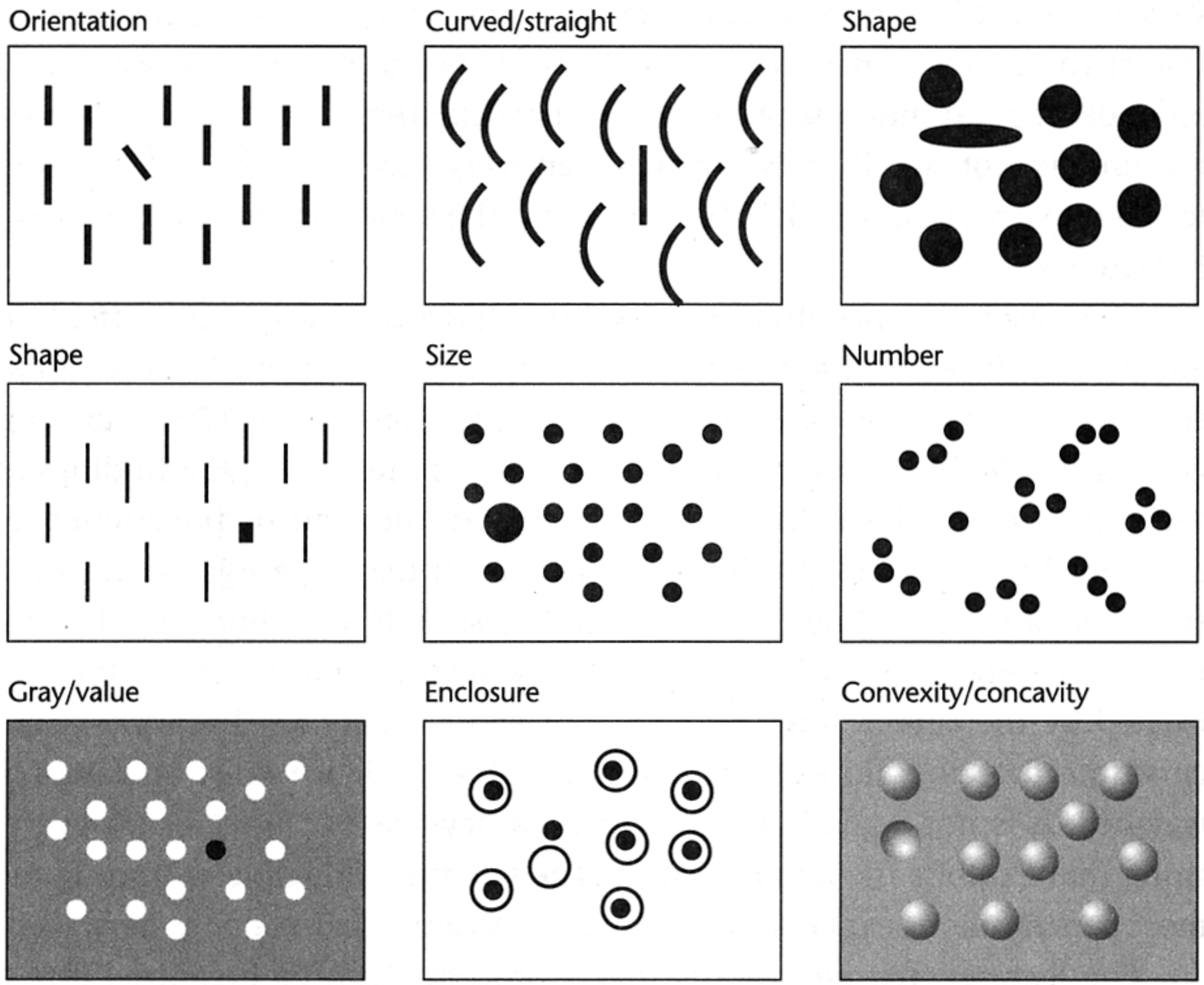
From Information Visualization, C. Ware

Where are the cherries?



From Information Visualization, C. Ware

Other examples of pre-attentive variables



From Information Visualization, C. Ware

Pre-attentive Task

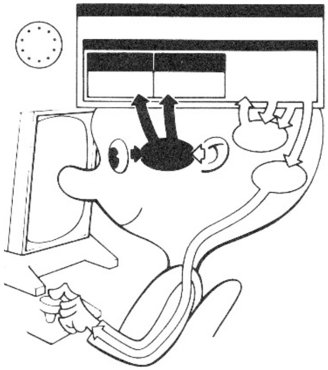
- Tasks which can be performed in less than 250ms
  - human visual system cannot decide to change its focus of attention

- Require only “a single glance” at the image being displayed

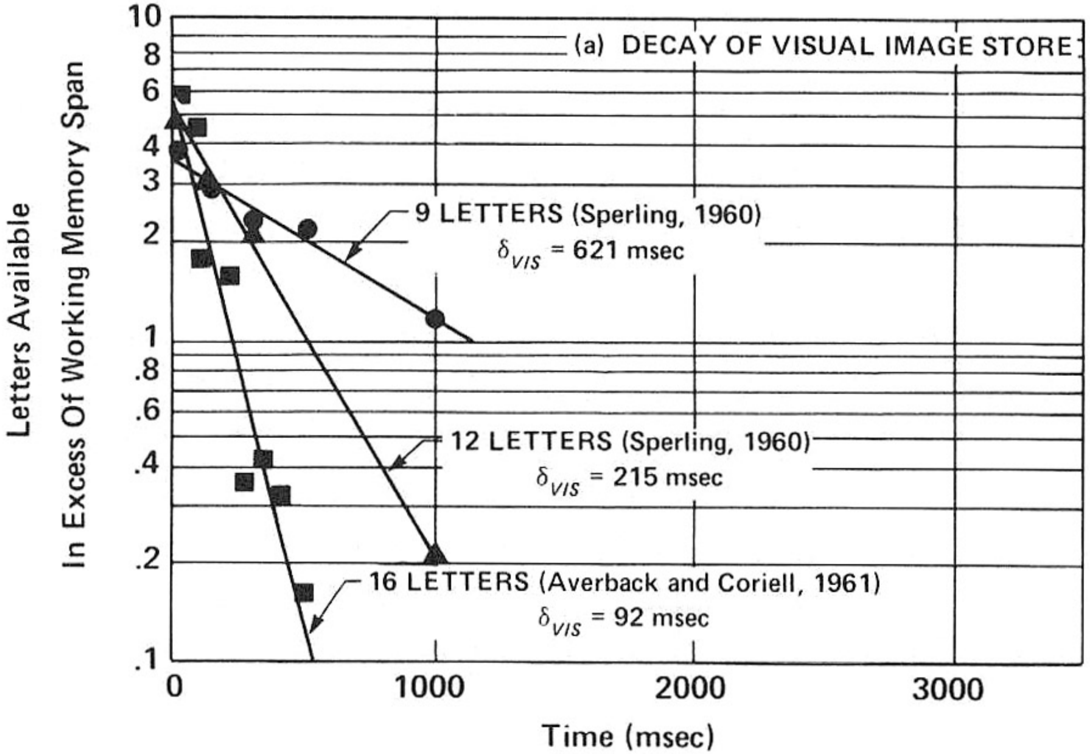
- Pre-attentive properties to assist in performing visual tasks
  - *target detection*
  - *boundary detection*
  - *counting/estimation*

http://www.csc.ncsu.edu/faculty/healey/PP/

Perceptual Processor



- Decay: 200ms [90-1000] (half-time)
- Half-life: time after which probability of retrieval < .5



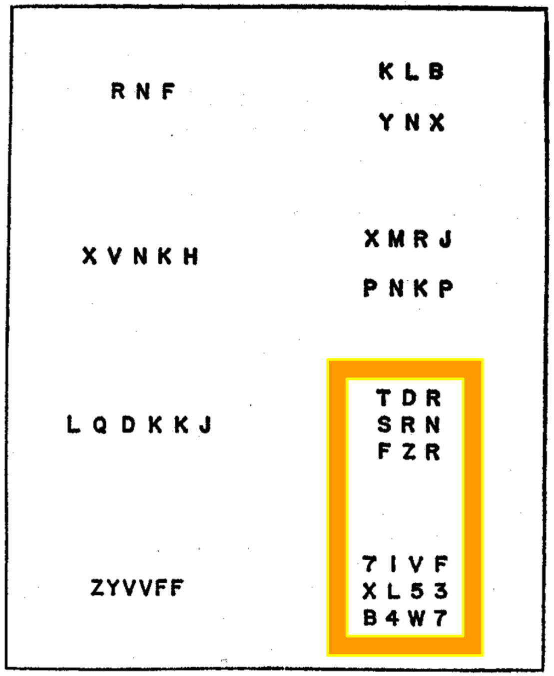
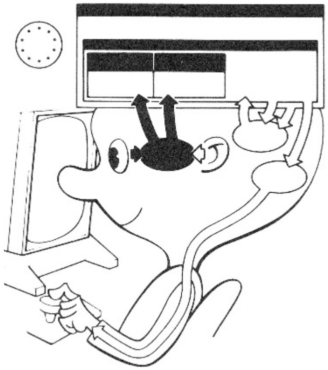


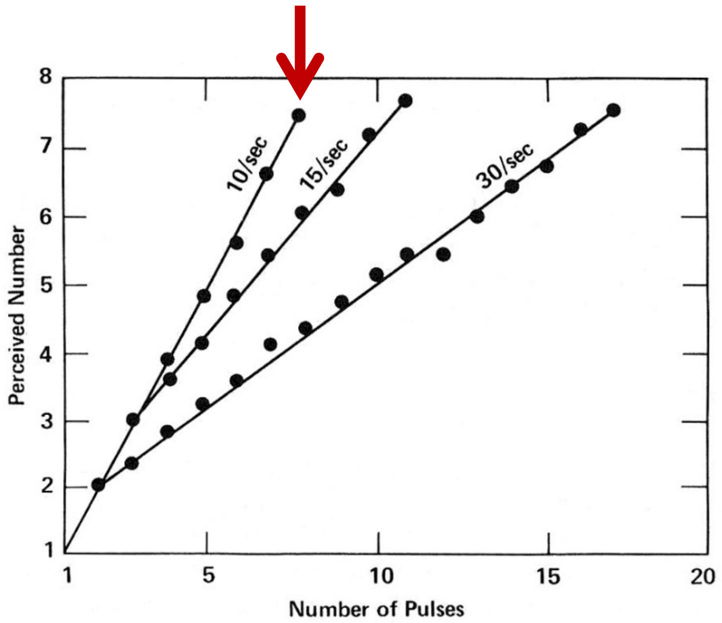
FIG. 2. Typical stimulus materials. Col. 1: 3, 5, 6, 6-massed. Col. 2: 3/3, 4/4, 3/3/3, 4/4/4 L&N.

- difficult to remember what is on the screen for more than 200 ms

Perceptual Processor



- Cycle time = Unit impulse response
  - Time that takes before human **claims to see it** after impulse
  - Time response of the visual system to a very brief pulse of light
  - Quantum experience: 100ms [50~200]
    - *Perceptual Fusion*
    - *Causality*
  - [30/sec] 3 clicks in each 100 ms cycle time are fused into a single percept



Perceptual Processor – Cycle Time

- Cycle time could vary according to conditions
  - "Variable Perceptual Processor Rate Principle"
  - The perceptual processor cycle time varies inversely with stimulus intensity
- Bloch's Law (1885): $I \cdot t = k$, $t < cycle\ time$
  - I: intensity of stimulus
  - t: lasting time of stimulus
  - example: Pulse of light lasting 10 ms with 50 has the same appearance as a pulse of 20 ms with intensity of 25

Example: Moving Picture Rate

- *Example 1*. Compute the frame rate at which frames of a moving picture must be refreshed to give illusion of movement.

At least one frame within perceptual processor cycle time

Frame rate > 1/(cycle time) = 1/100 =10 frame/sec

Perceptual Causality

- *Perceptual Fusion*: Two stimuli within a perceptual processor cycle appear ***fused***

→ the first event appears to ***cause*** the other

- 1/(PP cycle time) fps = 10 fps (frame per second)

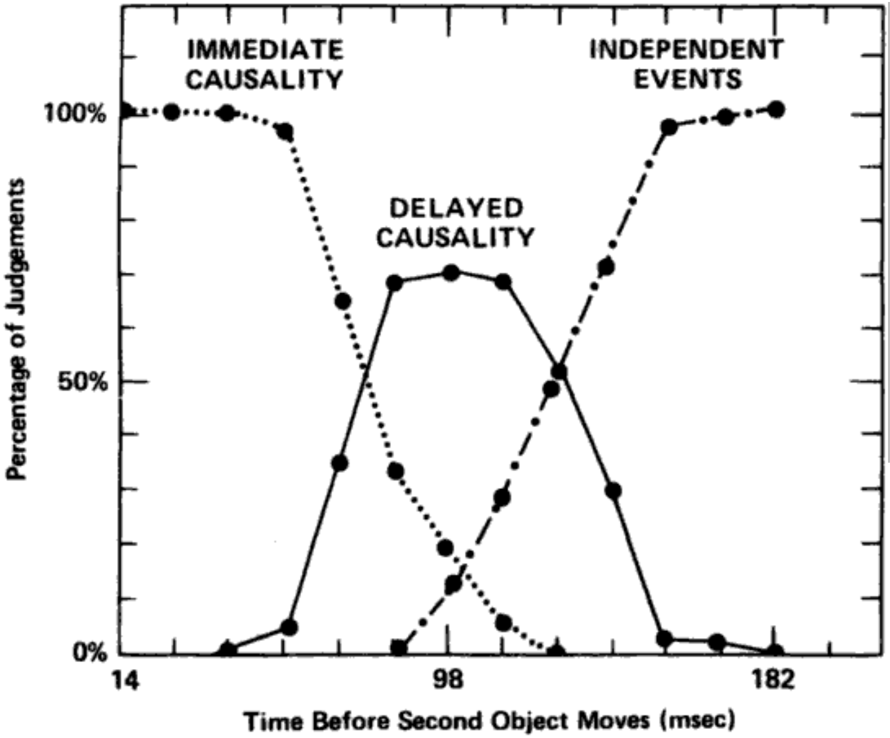
→ perceived as a moving picture

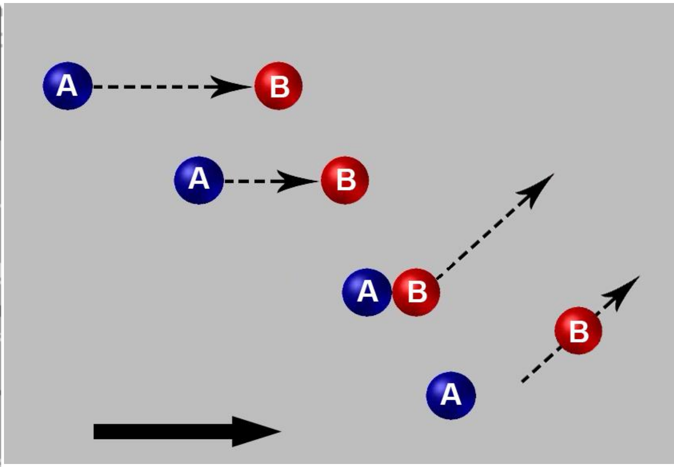
- UI responses < PP cycle time

→ appear instantaneous

Perceptual Causality

- Perceptual Fusion: Two stimuli within a perceptual processor cycle appear ***fused*** → the first event appears to ***cause*** the other

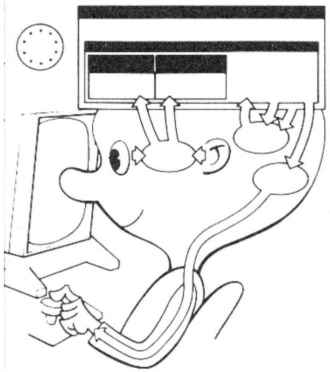




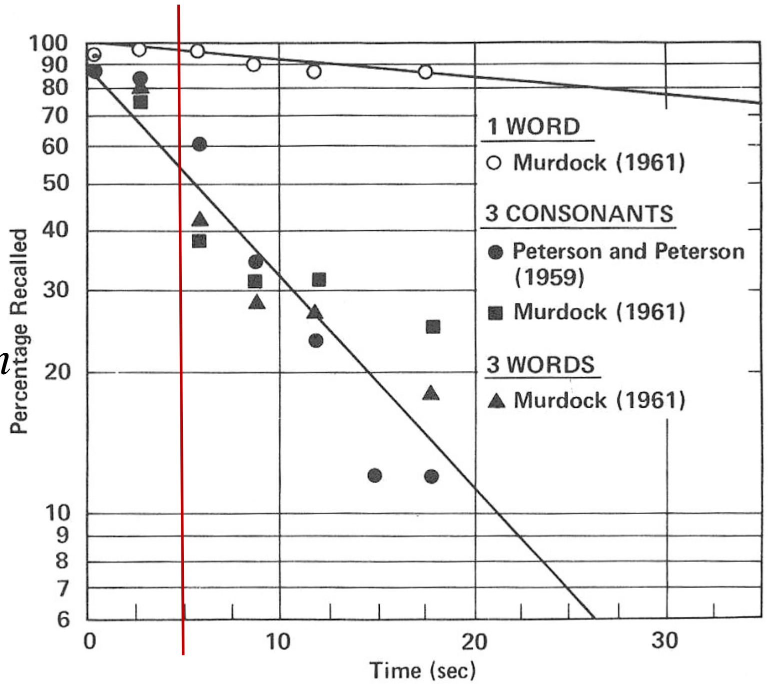
http://ccn.upenn.edu/~chatterjee/Webpage/topic1.htm

Charts from Card, S. K., T. P. Moran, et al. (1983). The psychology of human-computer interaction. Hillsdale, N.J., L. Erlbaum Associates.

Working Memory

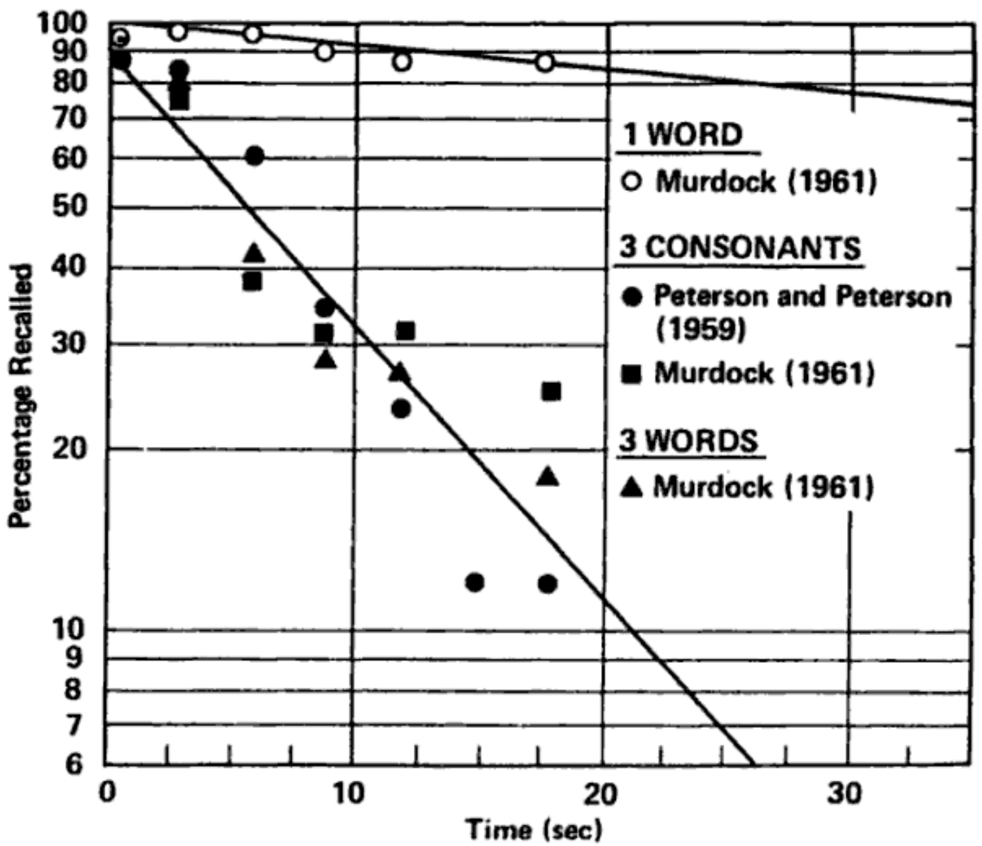


- The working memory is your register set
- Access in chunks
  - Task dependent construct
  - 7 +/- 2 (Miller)
- working memory decay with time
  - Content dependant
  - Limited attention span
    - *5s attention span seems like a good idea, since after that you will be losing most of the information*
  - commit to longer term memory
  - "external cognition tool" like writing on a piece of paper



Working Memory : Decay Rate

- Effect of **interference**
- 7 [5~226] sec half-life (73 for 1 chunk)
- Long-term memory kicks in



Charts from Card, S. K., T. P. Moran, et al. (1983). The psychology of human-computer interaction. Hillsdale, N.J., L. Erlbaum Associates.

Working Memory: Interference

Say the color of each words

Tree	*Yellow*
Computer	*Green*
Baby	*Red*
Cat	*Blue*
Graph	*Purple*
Clock	*Black*

see also:

http://www.theinvisiblegorilla.com/gorilla_experiment.html

Slide idea from slides by Prof. Robert Miller

Working Memory: Chunks

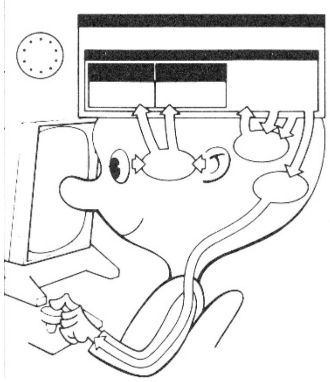
- ***chunks***
  - Activated elements in Long-Term memory
  - Unit of memory or perception
  - Depends on presentation and what you already know

  - “BCSBMICRA” vs. “CBSIBMRCA”

- Chunks can be related to other chunks
- Activation spread in LTM → interfere with old ones
  - ROBIN ROBERT BIRD WING FLY ⋯
  - Limited amount of activation resource → decay

Working Memory : Capacity

- Pure capacity: 3 [2.5~4.1] chunks
  - Number of immediately preceding digits recallable from a long series when the series unexpectedly stops
- Effective capacity (augmented by the use of LTM)
  - e.g., Longest number that can be repeated back
  - 7±2 [5~9] chunks (Miller, 1953)
  - Fastman can do 81 chunks
    - *81 decimal digits presented at a uniform rate of 1 digit per sec*



Long term memory

- Very large (or infinite) capacity
  - Semantic encoding
  - A network of related chunks, accessed associatively from the WM
- Associative access
  - Fast read: 70ms
    - *can be accessed by pattern matching during each processing cycle*
  - Expensive write: 10s
    - *noisy*
    - *Several Rehearsal and/or recall*
    - *information is stored in a semantic encoding not in perceptual information*
- Context at the time of acquisition is key for retrieval

Long-Term Memory

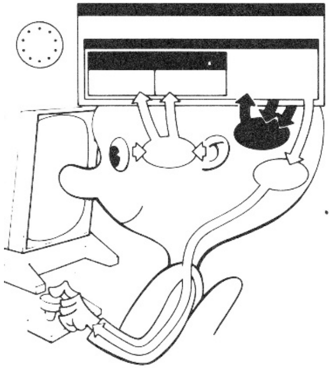
- Knowledge repository
- Unlimited capacity and little decay (no erasure)
- Retrieval could fail:
  - No effective associations
  - Interference by similar associations (<u>light</u>/dark vs. <u>light</u>/heavy)
- To remember something later
  - Associate it with items already in LTM in novel ways
  - Elaborative Rehearsal vs. Maintenance Rehearsal (repetition)

Cognitive Processor

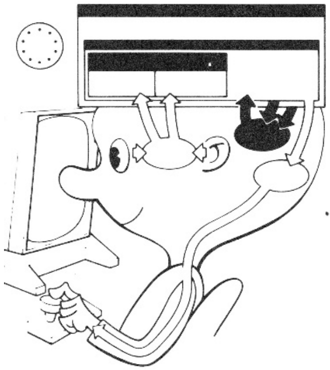
- (Recognize-Act) Cycle time: 70ms
  - Recognize: contents of WM initiate associatively-linked actions in LTM
  - Act: modify contents of WM

- Cognitive Processing Rate: 70[25~170]
  - Typical matching time
    - *Digits: 33ms*
    - *Colors: 38ms*
    - *Geometry: 50ms…*

- Variable Cognitive Processor Rate Principle
  - Cycle time is shorter when greater effort is induced
    - *by increased task demands or information loads*
  - Also decrease with practice



Cognitive Processor



- Parallel in recognition phase, serial in action phase
  - Can be aware of many things at once
  - One locus of attention at a time (i.e. cannot do more than one at a time)
    - *Eastern 401, December 1972*
      - Crew focused on checking the landing gear indicator bulb,
      - Meanwhile the aircraft is loosing altitude (horn, warning indicator…),
      - Aircraft crashed in the Everglades
      - see “The Humane Interface” by Raskin, p25
  - But what about driving, reading signs, and talking can all be kept going?
    - *Skilled intermittent allocation of control actions to each task*
    - *Interrupt-driven time-sharing sytems*

Stay in the Flow

- a key to good interface design
  - users have only one focus of attention at a time
  - divide it between your interface and what they are doing

  - Optimal: spend all their time on what they are doing
  - spend effort to maintain what is on their working memory (X)

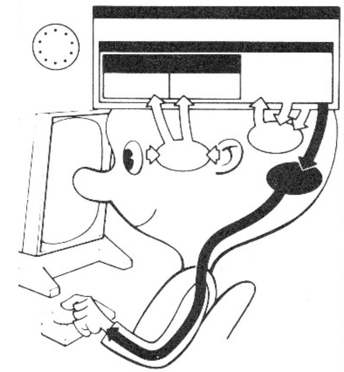
  - interface have to leave as little a cognitive foot print as possible

- Flow: The Psychology of Optimal Experience
  - by Mihaly Csikszentmihalyi
- Thinking, Fast and Slow
  - by Daniel Kahnenman

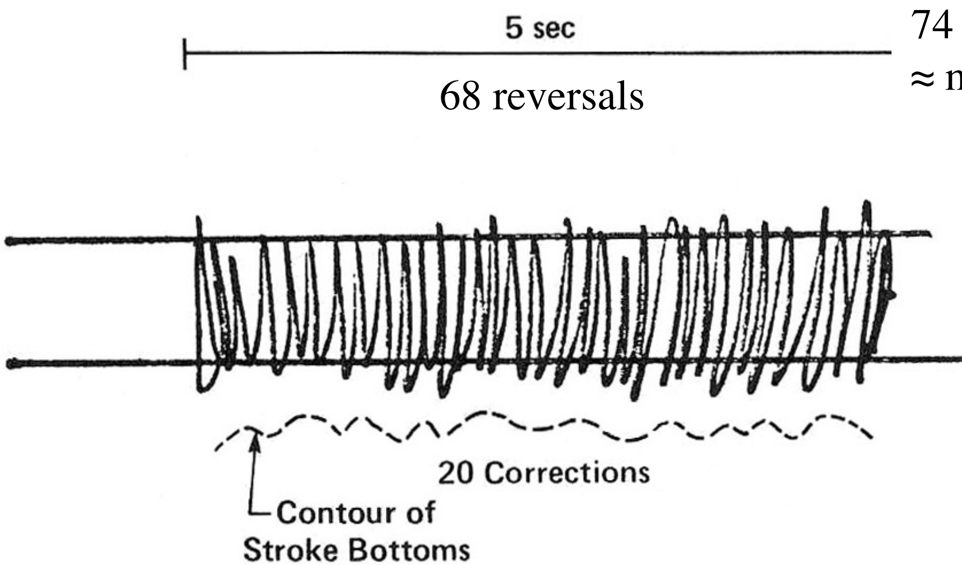
Human Performance

- To address uncertainties in parameters of Model Human Processor → three versions of the MHP model
  - Slowman : worst performance
  - Fastman : best performance
  - Middleman : nominal performance

Motor System



- Receive input from the cognitive processor
- Execute motor programs (not step-by-step)
  - Pianist: up to 16 finger movements per second
  - Point of no-return for muscle action
  - Part of the learning process is to transfer from cognitive to muscle memory



68 reversals

74 ms/reversal
≈ motor processor cycle time

Image from Card, S. K., T. P. Moran, et al. (1983). The psychology of human-computer interaction. Hillsdale, N.J., L. Erlbaum Associates.

Closed Loop vs. Open Loop

Closed Loop

- Feedback from perception through cognitive to motor
- Examples?

Open Loop

- Control is planned in advance and motor executes without perception or cognitive
- Examples?

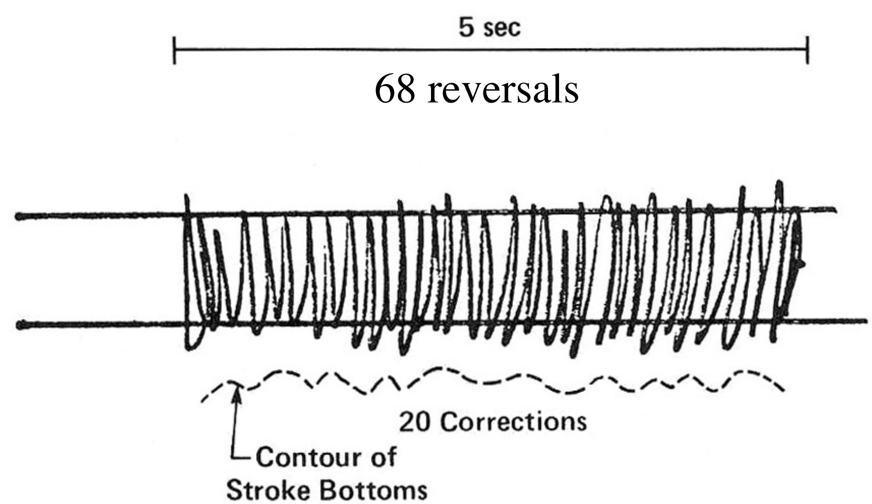
Motor Processor

- Open Loop: MP to issue commends
  - 5sec/ 68 pen reversals = 74 ms
  - Motor processor cycle time

- Closed Loop: corrections using visual feedback
  - Perception + Decision(Cognition) + Motor cycle times

    = (5 sec)/(20 corrections) = 250 ms

- Cycle time: 70 [30~100] ms



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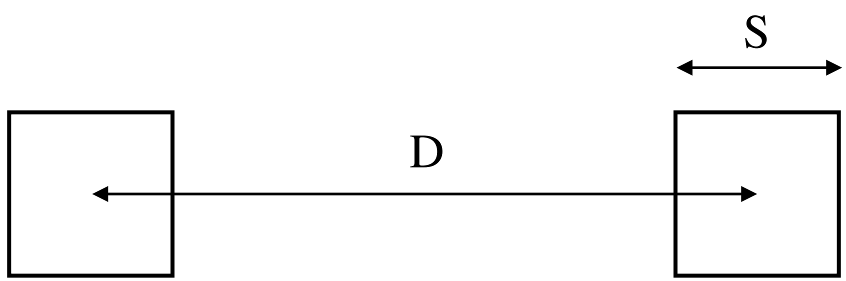
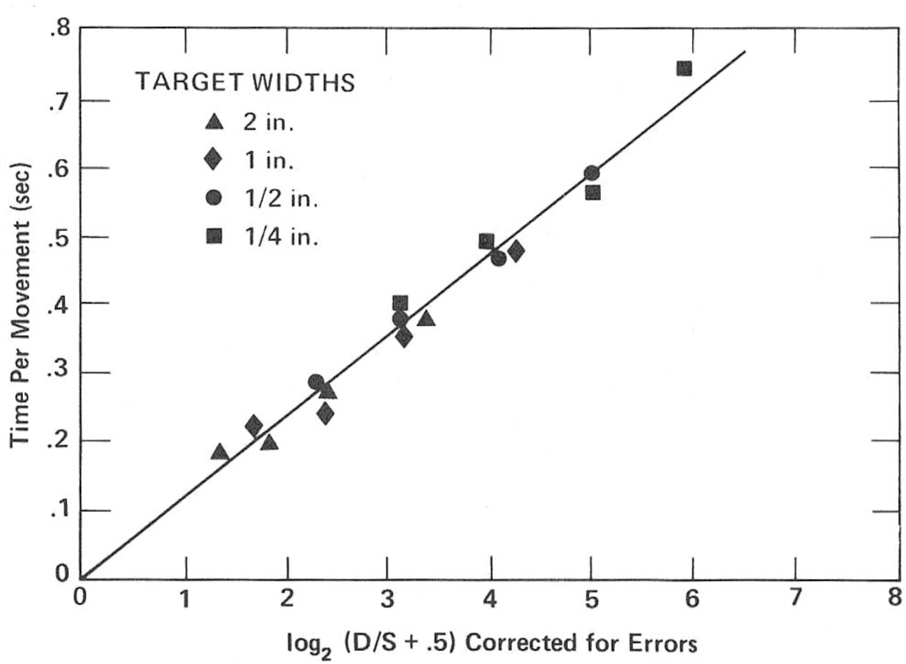
Put it together: Fitts' law (tapping task)





$$T = I_M \log_2(D/S + 0.5)$$

Fitts's Law

$$T = I_M \log_2(2D/S)$$

$$T = I_M \log_2(D/S+1)$$

$$T = I_M \log_2(D/S+0.5)$$

T: movement time

S: target width

D: distance to target

I_M: index of performance

63 msec/bit [22~122 ms/bit], (fastman~slowman)

$\log_2(2D/S)$: index of difficulty

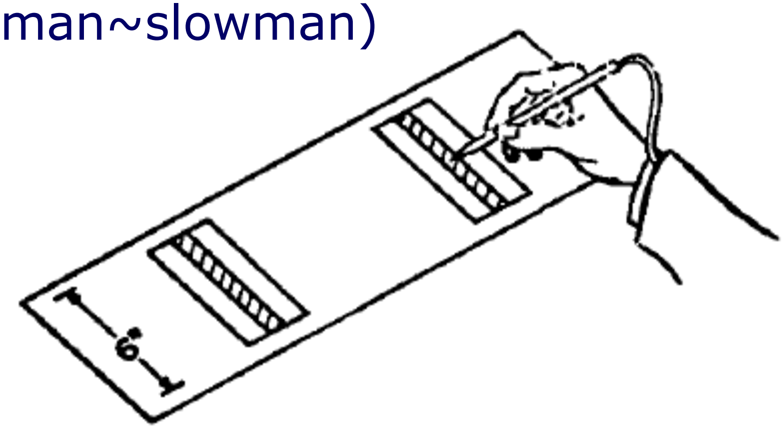


Figure 1. Reciprocal tapping apparatus. The task was to hit the center plate in each group alternately without touching either side (error) plate.

Fitts' Law

- The time to move the hand to the target $T = n(\tau_P + \tau_C + \tau_M)$
  - τ_P : observe the hand
  - τ_C : decide on the correction
  - τ_M : do the correction
- Let X_i be the distance remaining to the target after the i-th correction (X_0=D)
- Let ε be the relative accuracy of movement: $\varepsilon = X_i / X_{i-1}$

$X_1 = \varepsilon X_0 = \varepsilon D$

$X_2 = \varepsilon X_1 = \varepsilon^2 D$

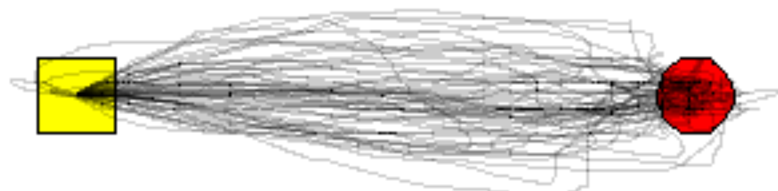
$X_n = \varepsilon^n D < 1/2\ S$ (stop condition)

$n = -\log_2(2D/S)/\log_2 \varepsilon$

$\therefore T = I_M \log_2(2D/S)$

where $I_M = -(\tau_P + \tau_C + \tau_M)/\log_2 \varepsilon$ ($\approx$ 63 msec/bit)

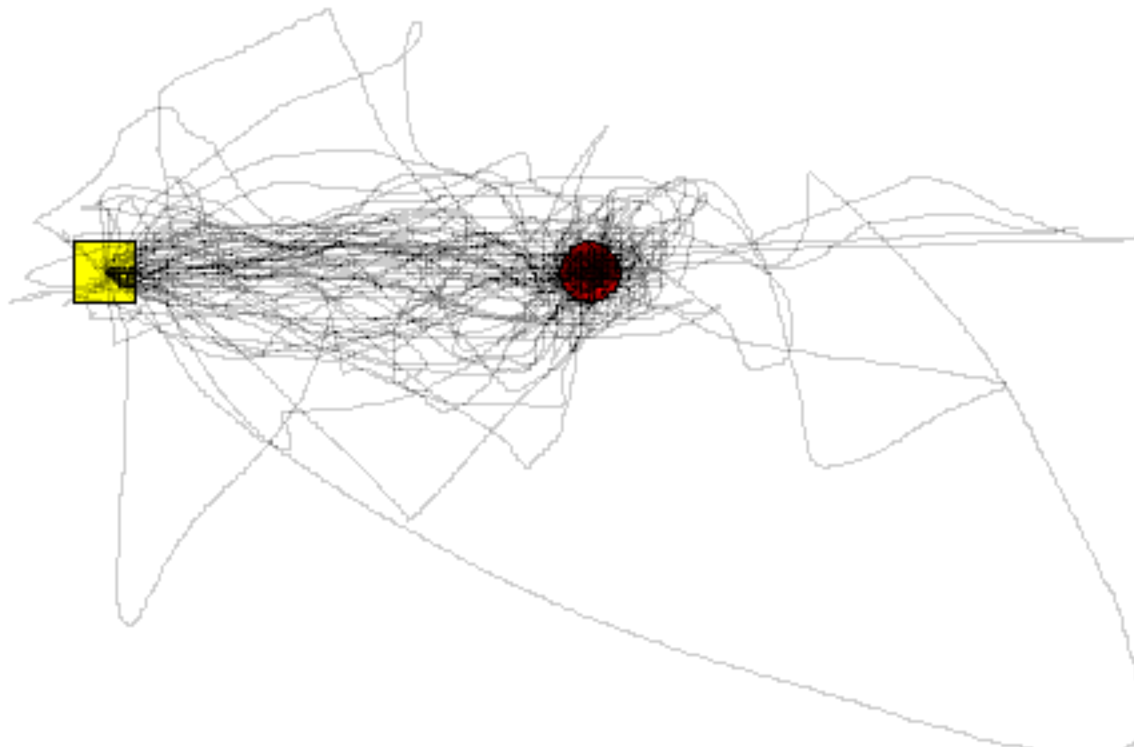
Implications: Fitts' Law



All paths taken by adult participants to click on a 32 pixel target at a distance of 256 pixels.

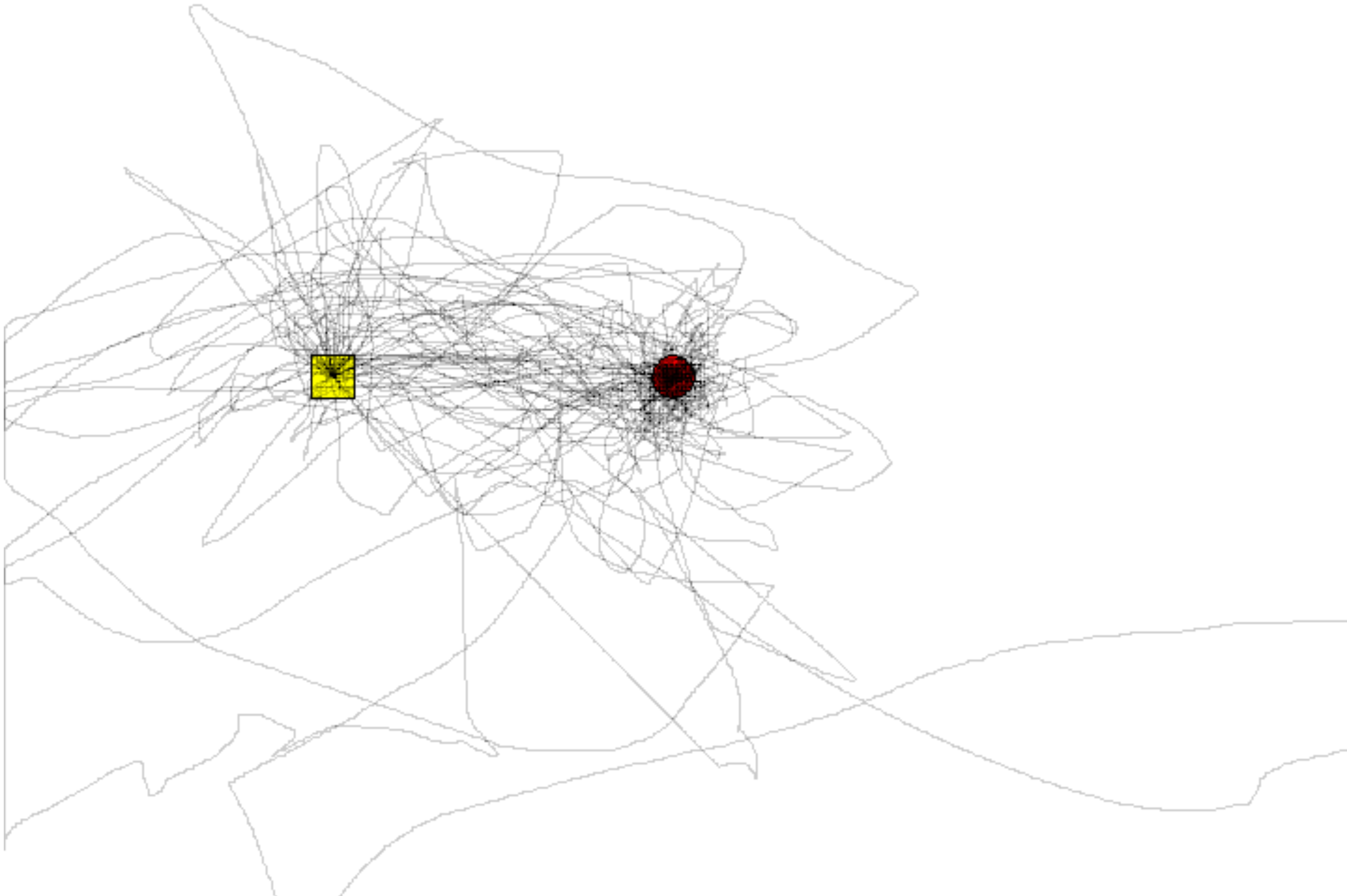
Hourcade, J. P., Bederson, B. B., Druin, A., & Guimbretière, F. (2004) **Accuracy, Target Reentry and Fitts' Law: Performance of Preschool Children Using Mice**, *Transactions on Computer-Human Interaction*, New York: ACM, 11 (4), pp. 357-386.

Implication: Fitts' Law



All paths taken by 5 year-old participants to click on a 32 pixel target at a distance of 256 pixels.

Implication: Fitts' Law

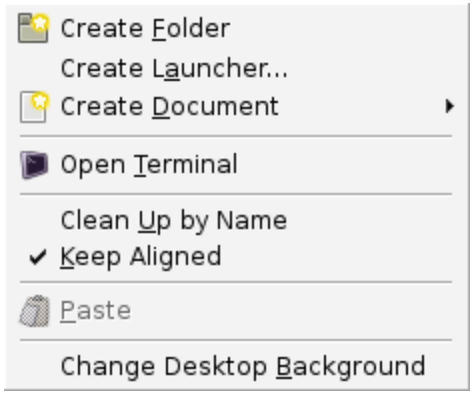


All paths taken by 4 year-old participants to click on a 32 pixel target at a distance of 256 pixels.

Fitts's Law

- Relies on "Closed Loop" control of Motor System

- Implications:
  - Larger (Closer) targets are easier to click
  - Macintosh menu bar is faster to use (correction time)
  - Pie menu is faster than popup menu



Images from Wikipedia

Power Law of Practice

$$T_n = T_1 n^{-\alpha}$$

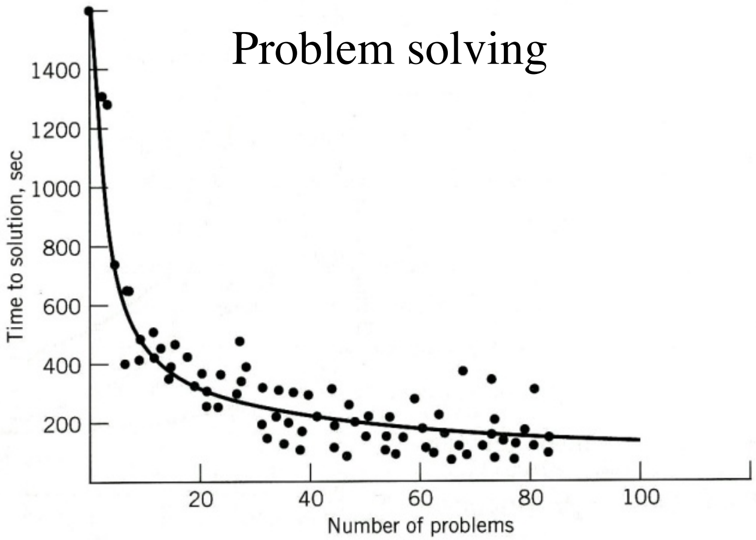
- The time to do a task decreases with practice

- The rate of decrease is proportional to a power of the amount of practice

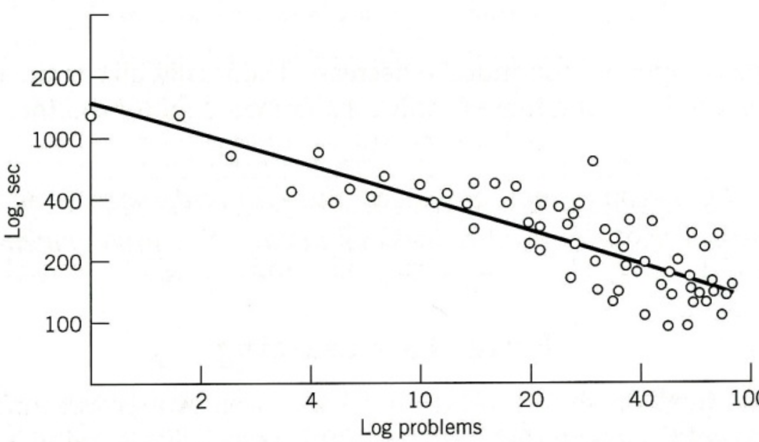
- Typical values for α are [.2~.6]

Learning
("Learning and memory" Anderson)

- Power law of learning



(a)



(b)