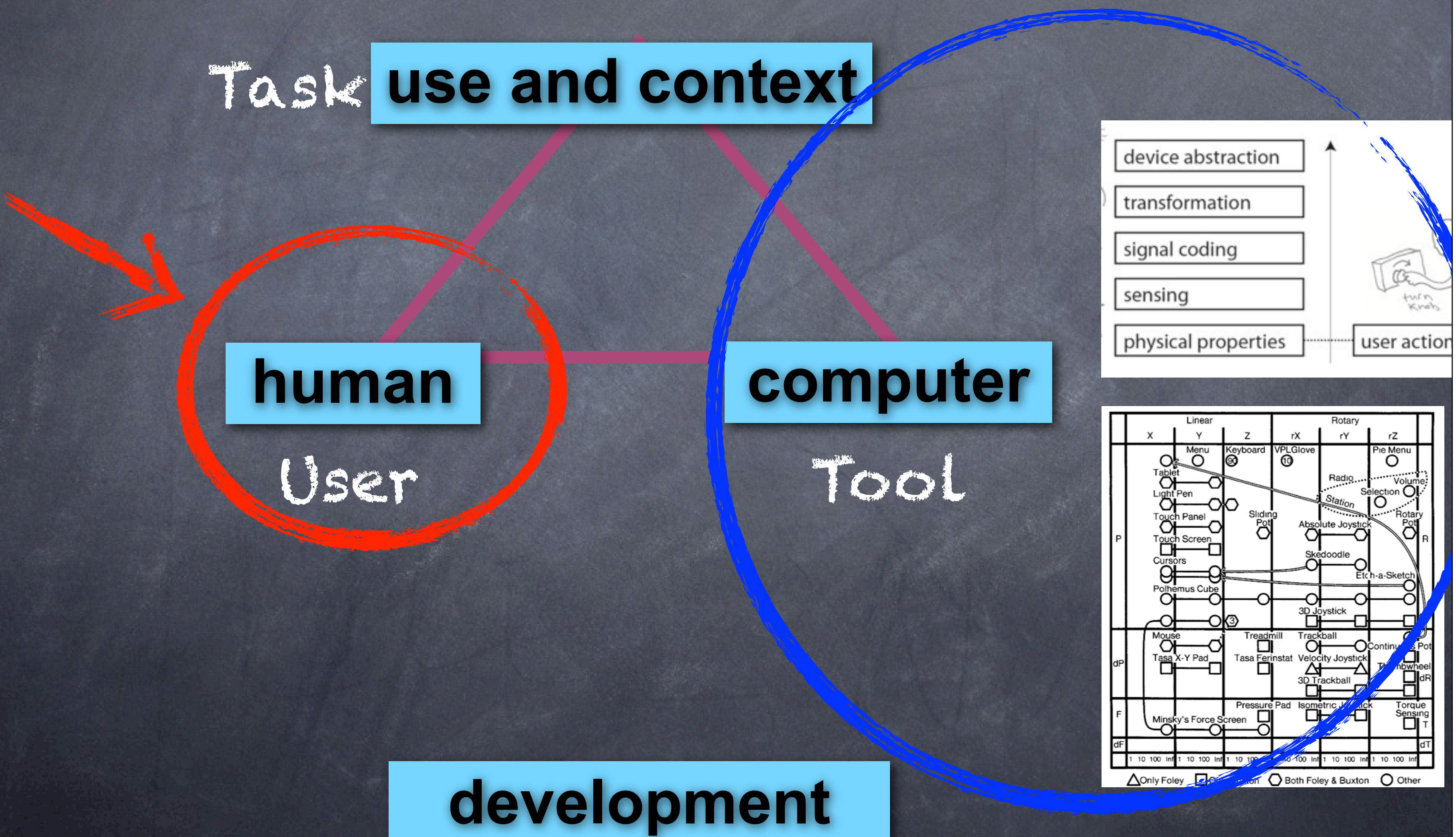
User Theory

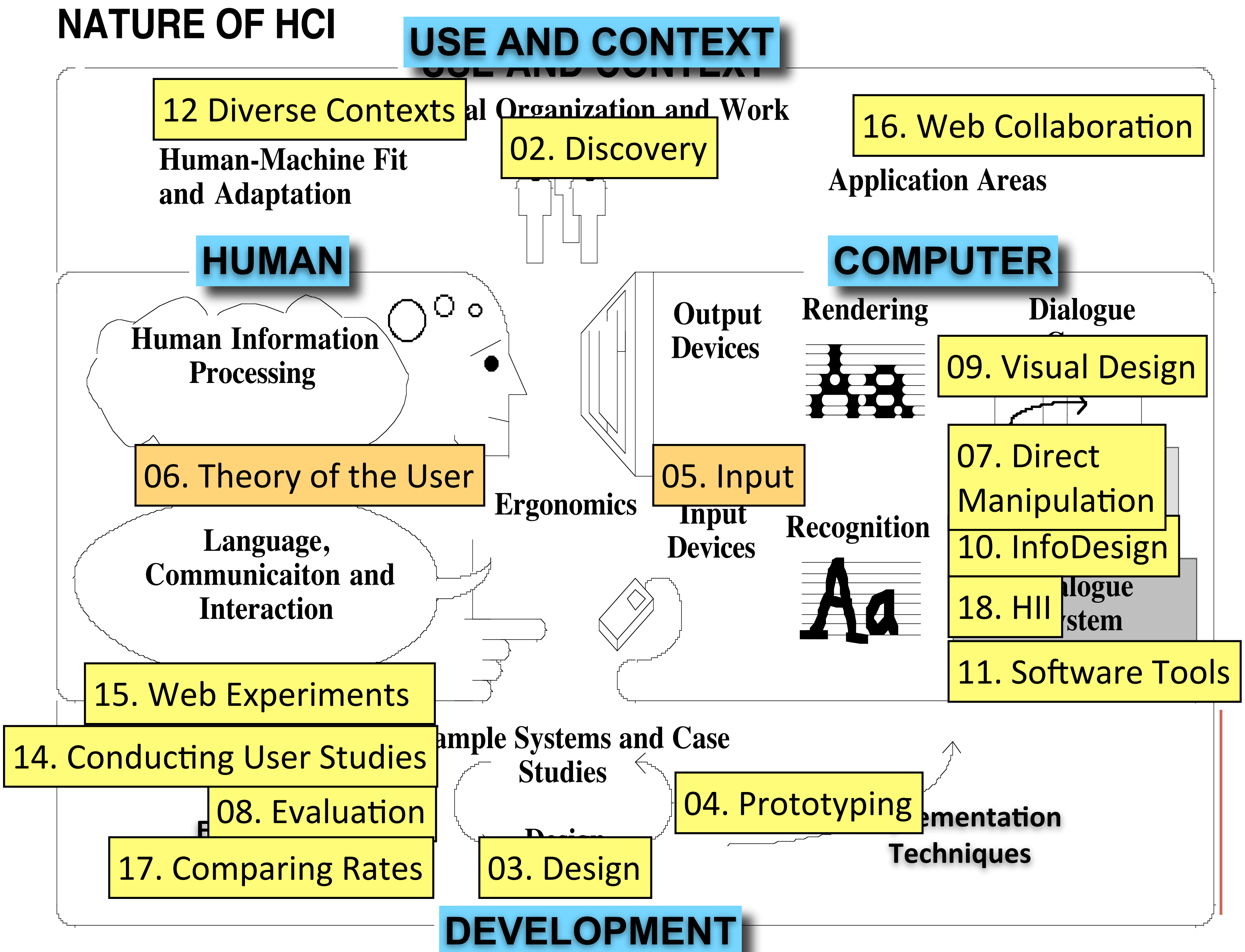
Stuart Card

19 October 2011

Human-Computer Interaction



The Field of HCI



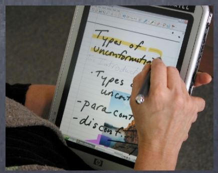
The Human Side of Input

Bands of Behavior

TIME SCALE OF HUMAN ACTION

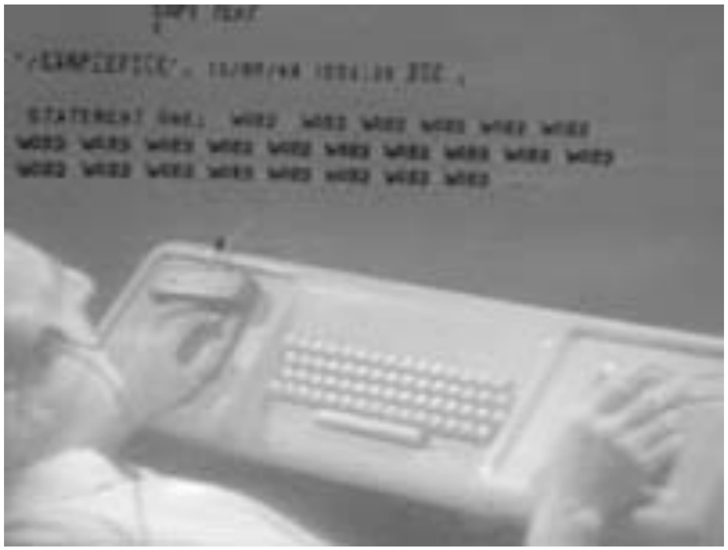
Scale (sec)	Time Units	System	World (theory)
10^7	months		SOCIAL BAND
10^6	weeks		
10^5	days		
10^4	hours	Task	RATIONAL BAND
10^3	10 min	Task	
10^2	minutes	Task	
10^1	10 sec	Unit task	COGNITIVE BAND
10^0	1 sec	Operations	
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	BIOLOGICAL BAND
10^{-3}	1 ms	Neuron	
10^{-4}	100 µs	Organelle	

Figure 3-3. Time scale of human action.

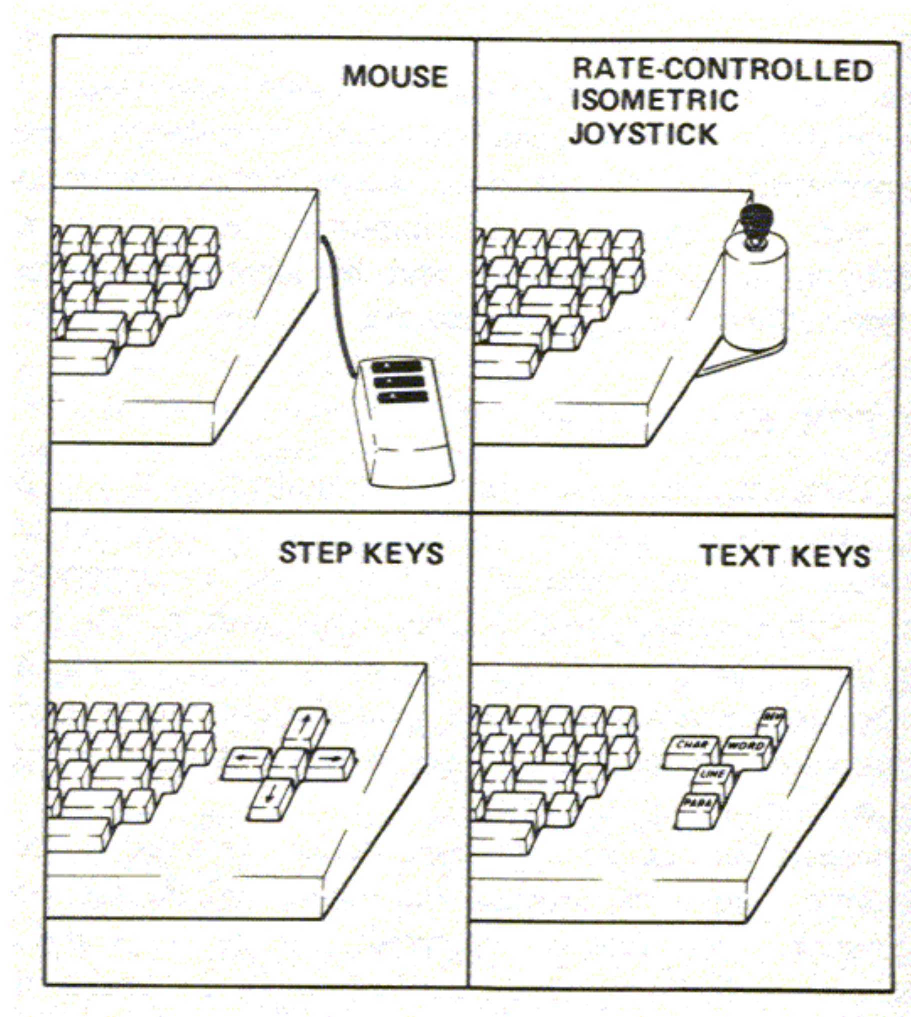


Newell & Card (1985), Newell (1990) 37

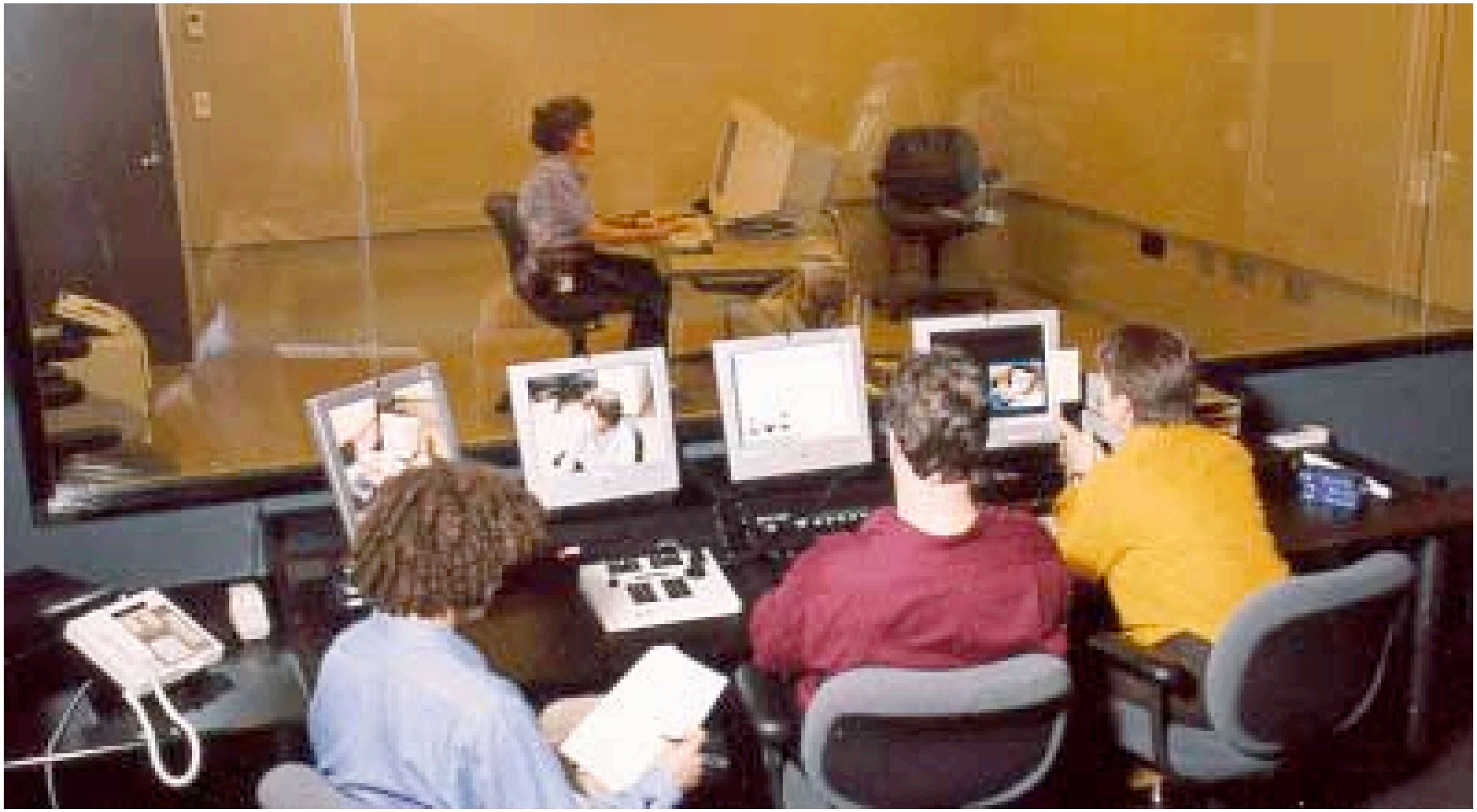
How to analyze pointing devices



Engelbart



TRADITIONAL METHOD: EVALUATION

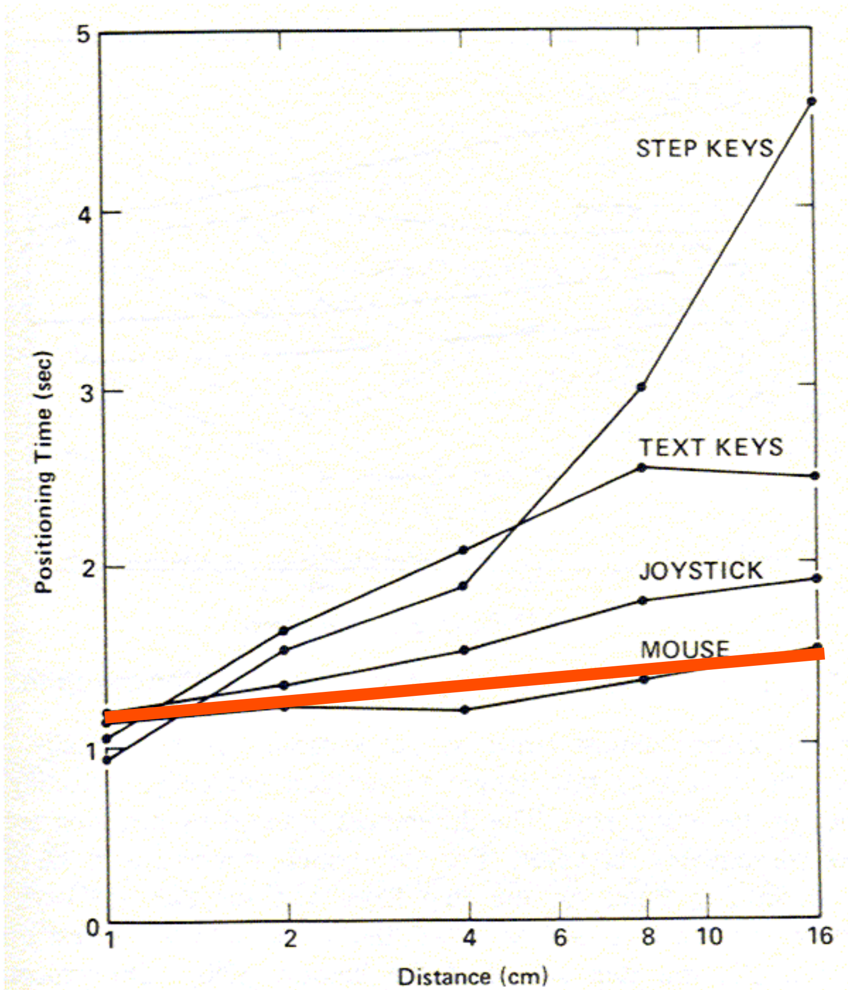


Sun Labs

Results -- Mouse Best

	Reach (sec) +	Move (sec) =	Total (sec)	Error (%)
Mouse	0.36	**1.29**	**1.66**	**5%**
Joystick	0.26	1.57	1.83	11%
Step Keys	**0.21**	2.31	2.51	13%
Text Keys	0.32	1.95	2.26	9%

EXPERIMENT: MICE ARE FASTEST



WHY?

Exam Question Material!

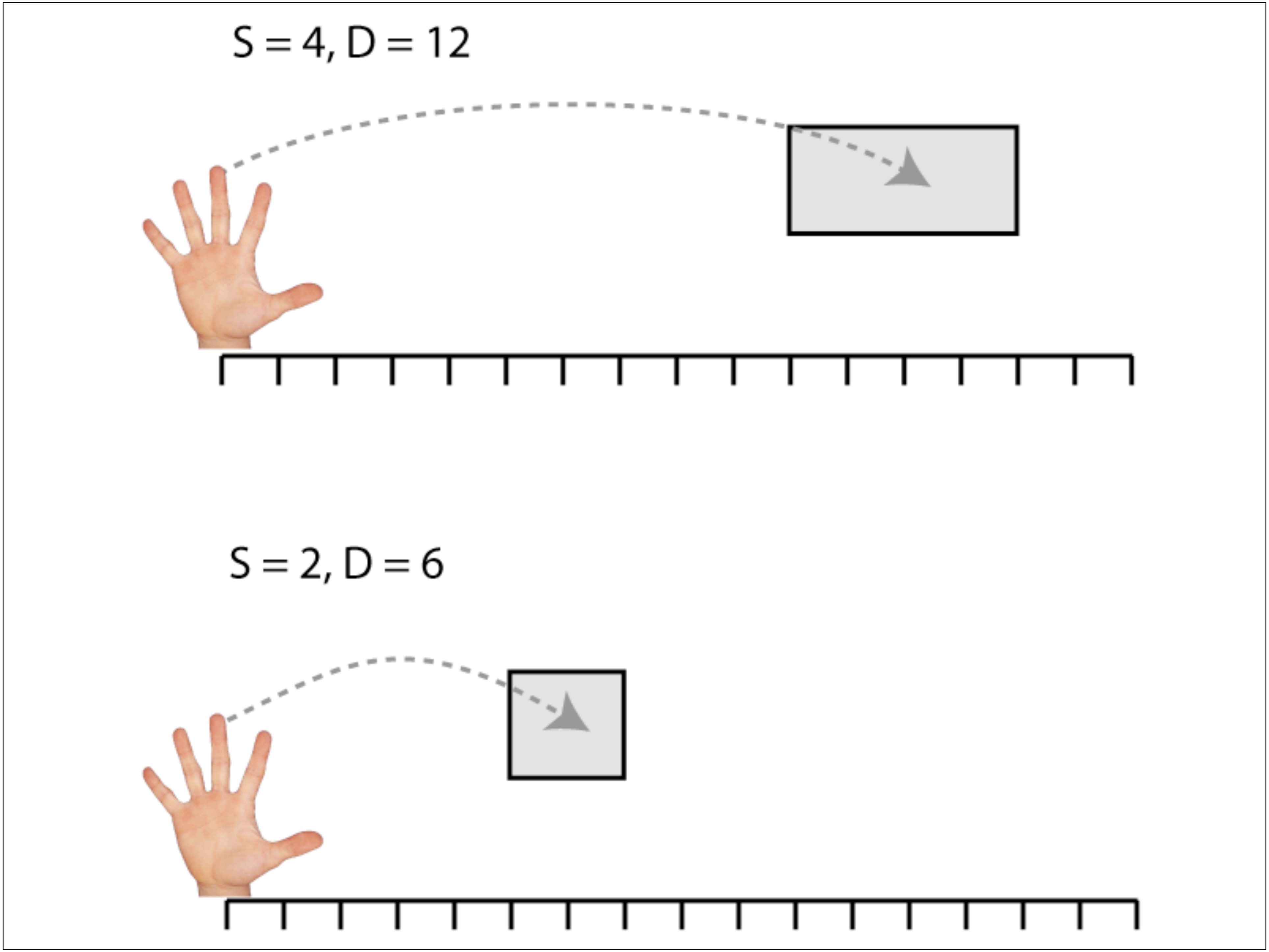
Fitts' Law

- Time T_{pos} to move the hand to target size S which is distance D away is given by:

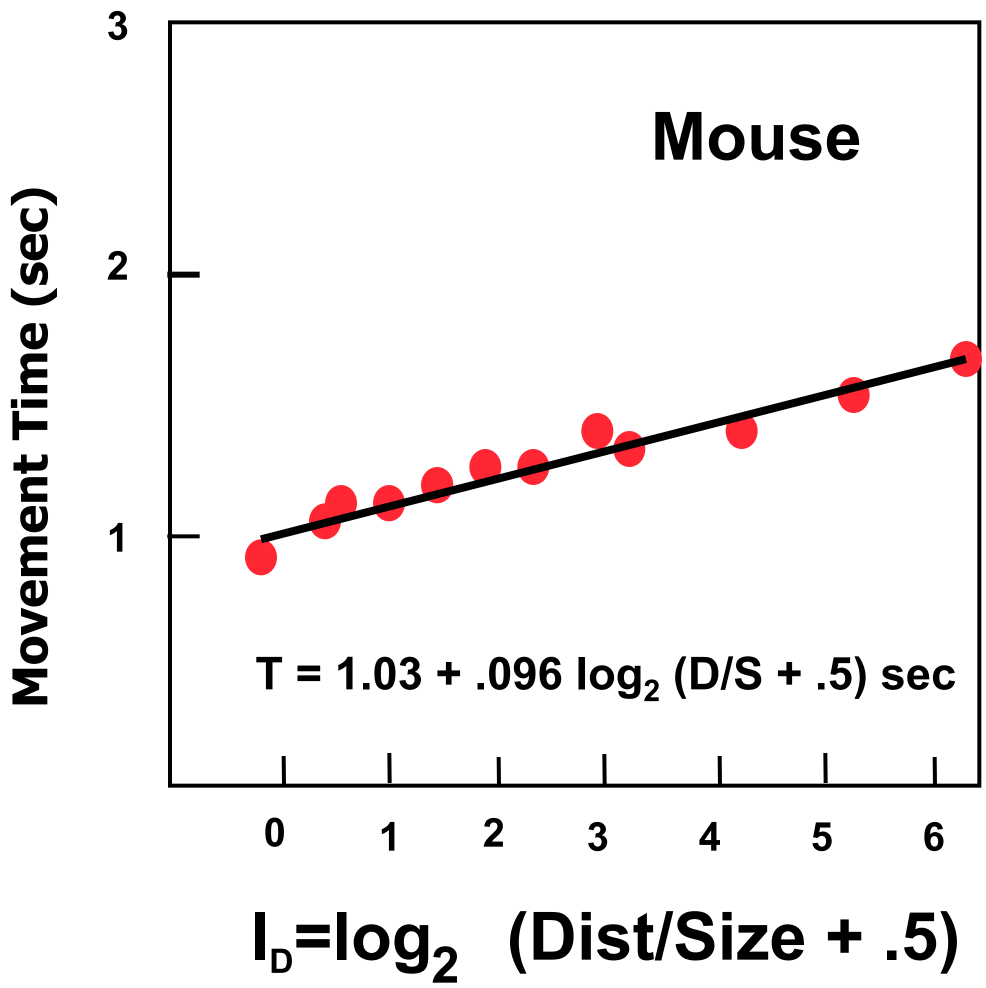
$$T_{pos} = a + \underbrace{b \log}_{\text{Device Characteristics}}{}_2 (D/S + 1)$$

Device Characteristics
(bandwidth of human muscle group & of device)

a: start/stop time
b: speed


S = 4, D = 12
S = 2, D = 6

WHY? (ENGINIEERING ANALYSIS)



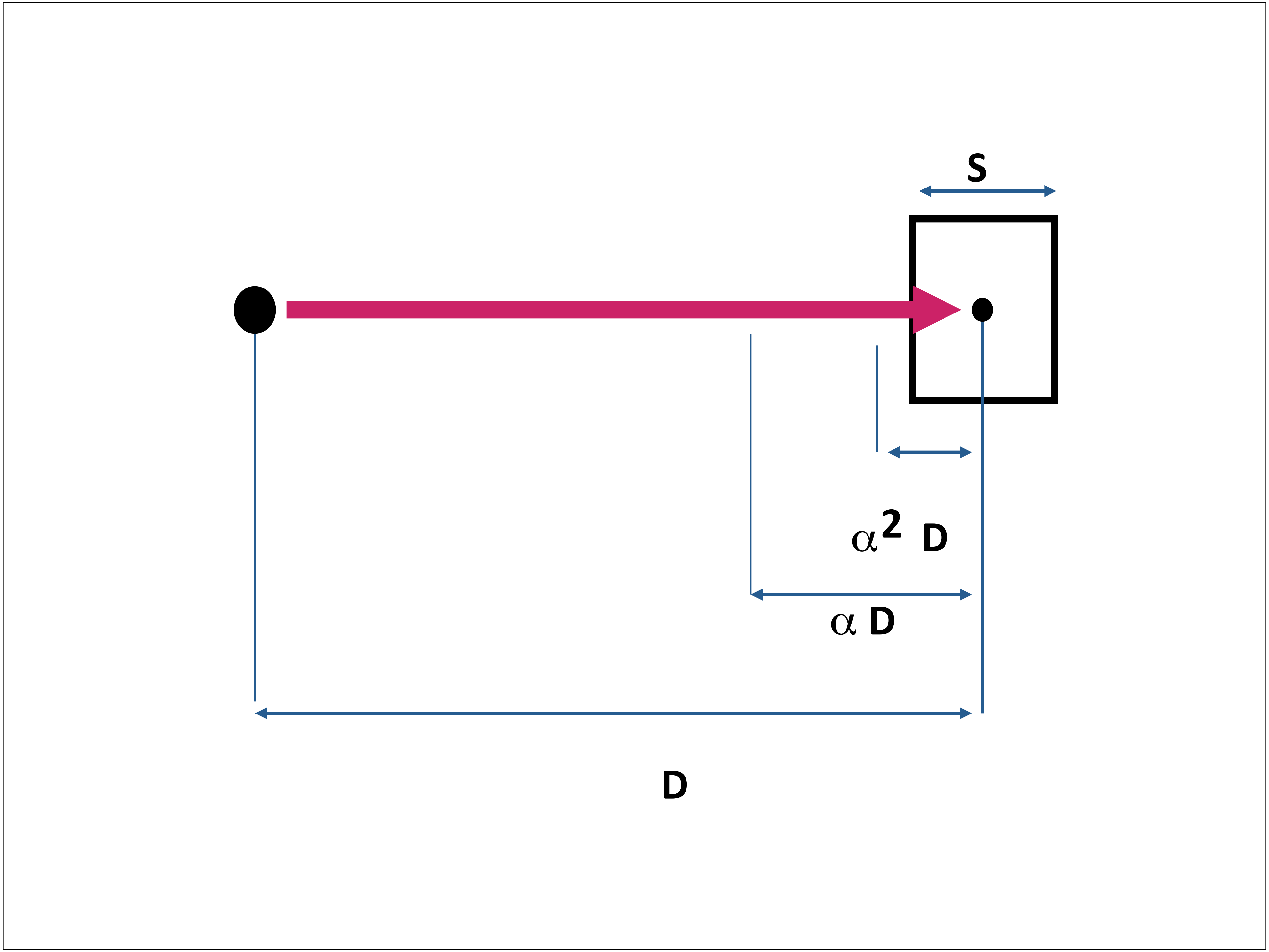
Why these results?

Time to position mouse proportional to Fitts' Index of Difficulty I_D.

Proportionality constant = 10 bits/sec, same as hand.

Therefore speed limit is in the eye-hand system, not the mouse.

Therefore, mouse is a near optimal device.

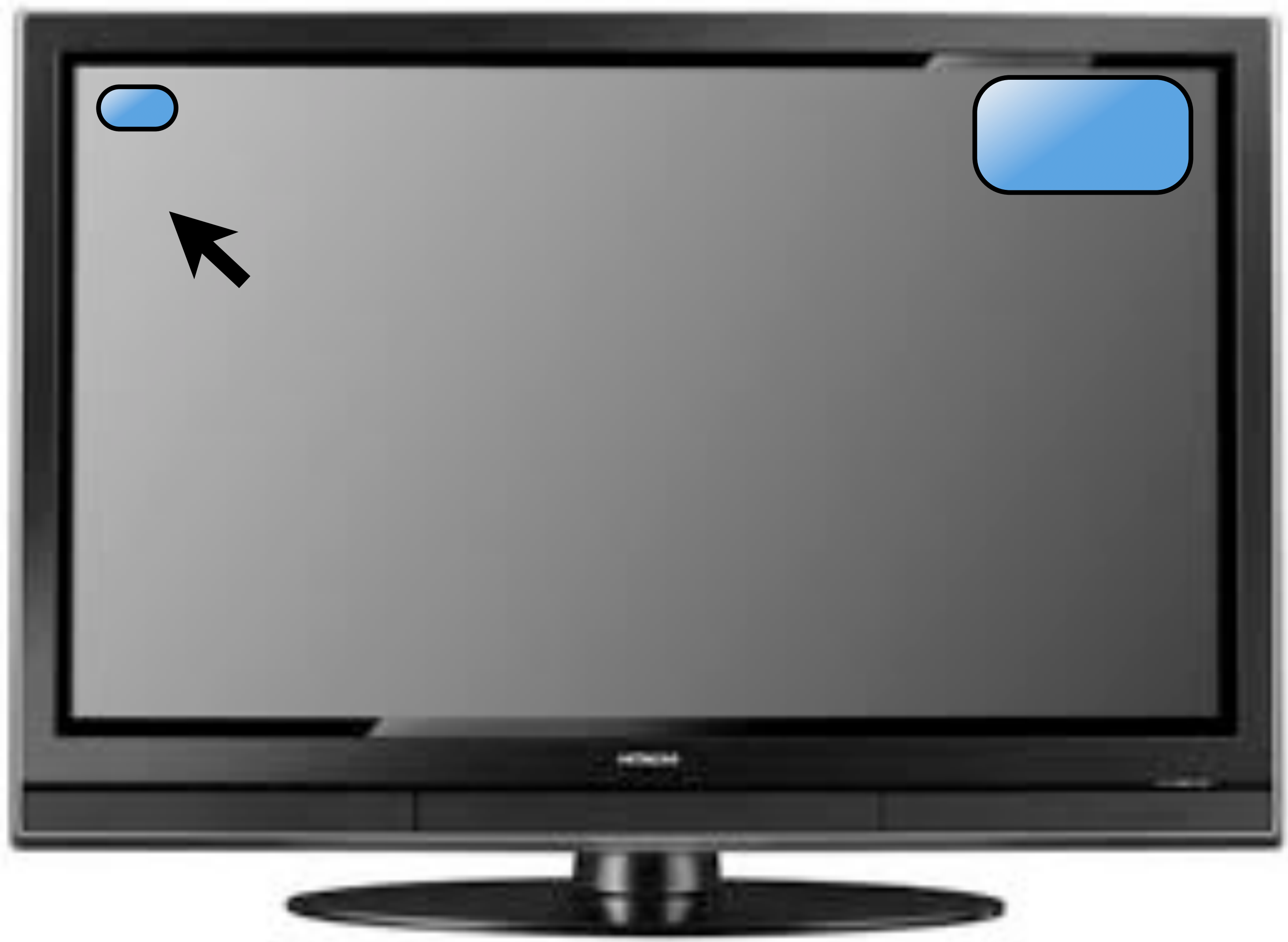

S
α² D
α D
D

How can we apply this theory?

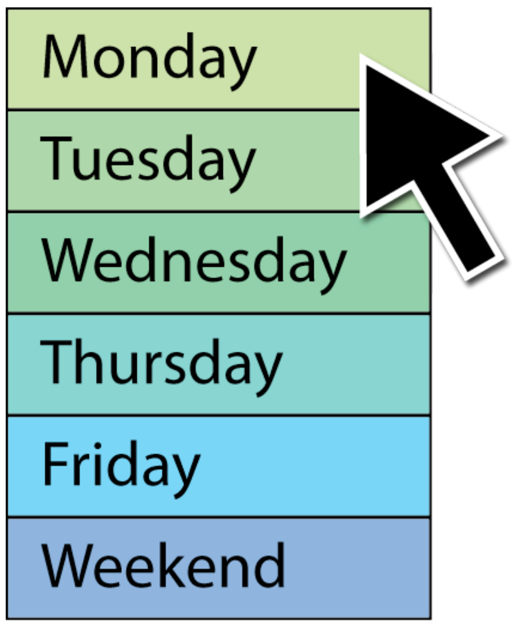
How can we apply this theory?

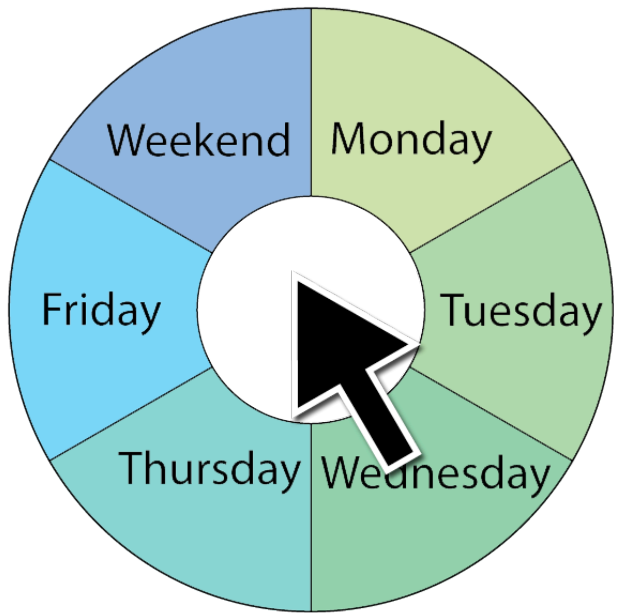
1. As a heuristic design principle

Size Compensates for Distance



Fitts' Law Example

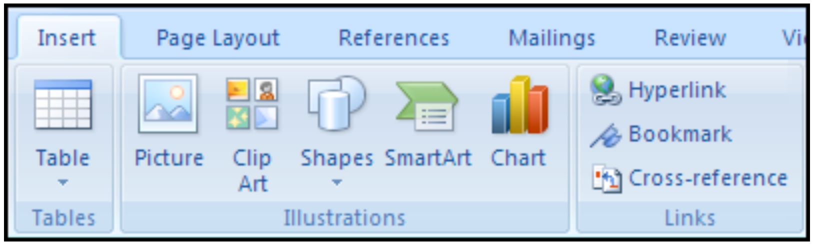




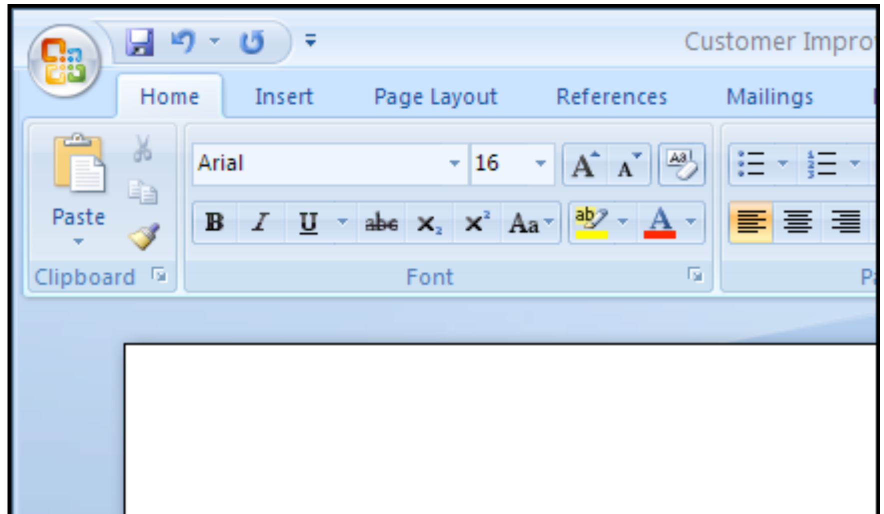
- Which will be faster on average?
  – pie menu (bigger targets & less distance)

Source: Landay, James. "Human Abilities". CS160 UC Berkeley.

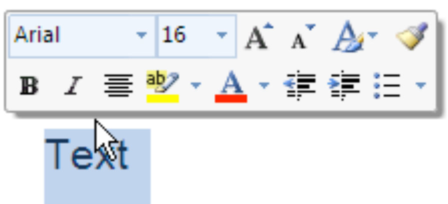
Fitts' Law in Microsoft Office 2007



Larger, labeled controls can be clicked more quickly



Magic Corner: Office Button in the upper-left corner



Mini Toolbar: Close to the cursor

Source: Jensen Harris, An Office User Interface Blog : Giving You Fitts. Microsoft, 2007.

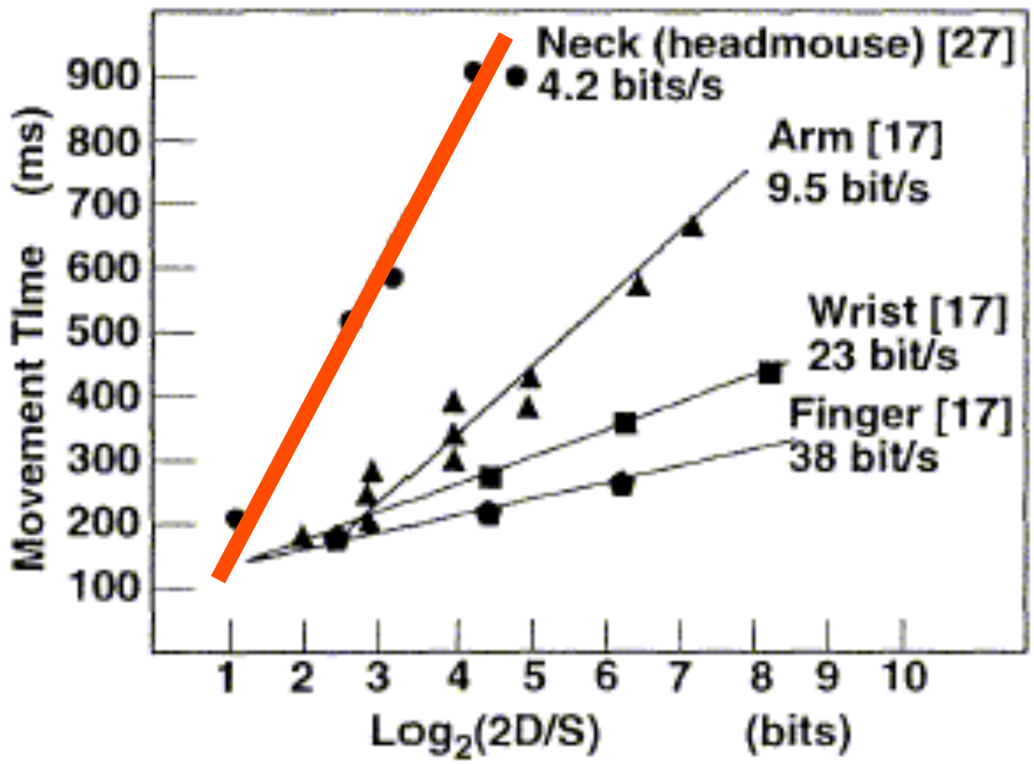
How can we apply this theory?

1. As a heuristic design principle
2. To critique new designs

EXAMPLE: ALTERNATIVE DEVICES

Headmouse: No chance to win

ATTACHING POINTING DEVICE

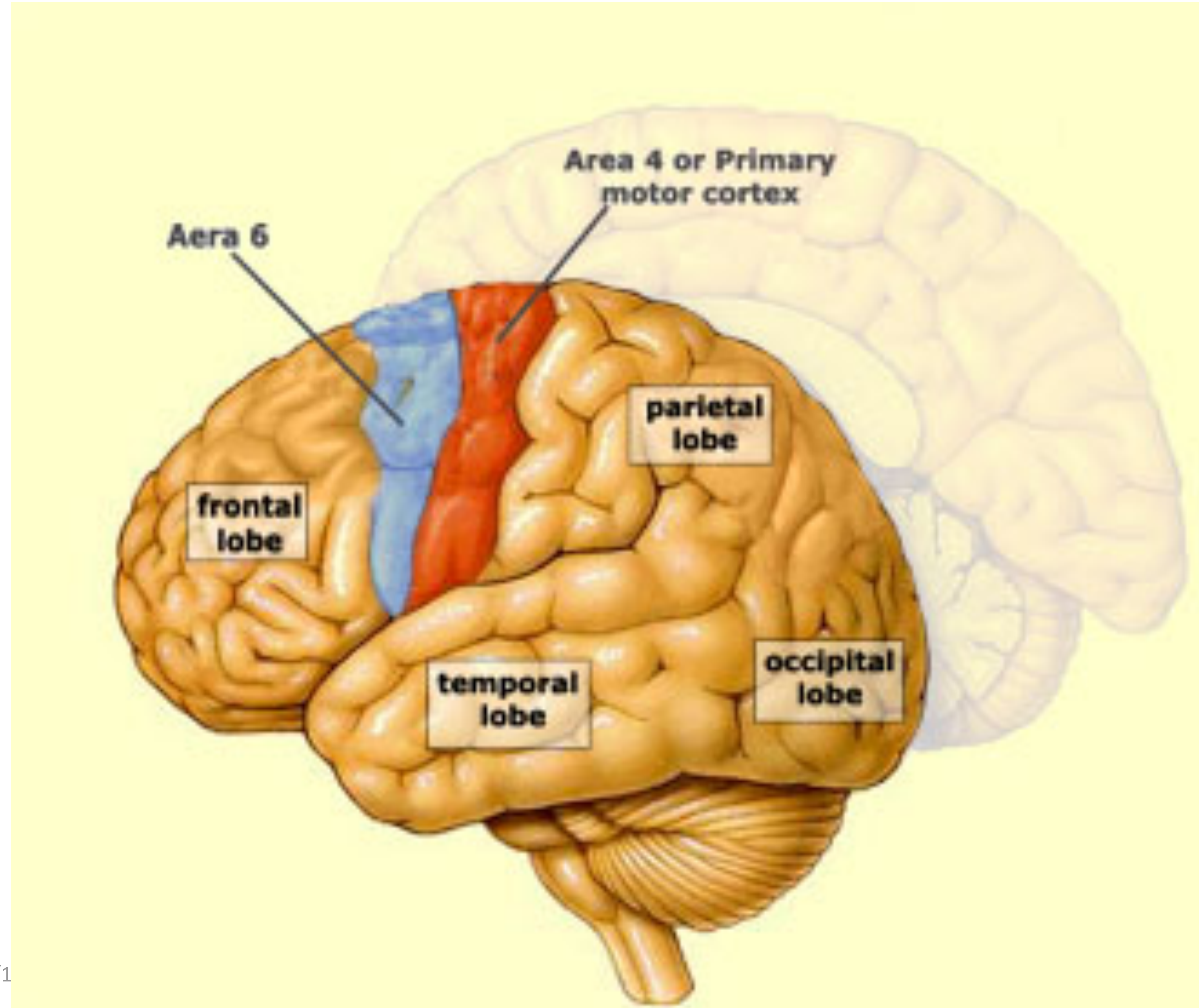


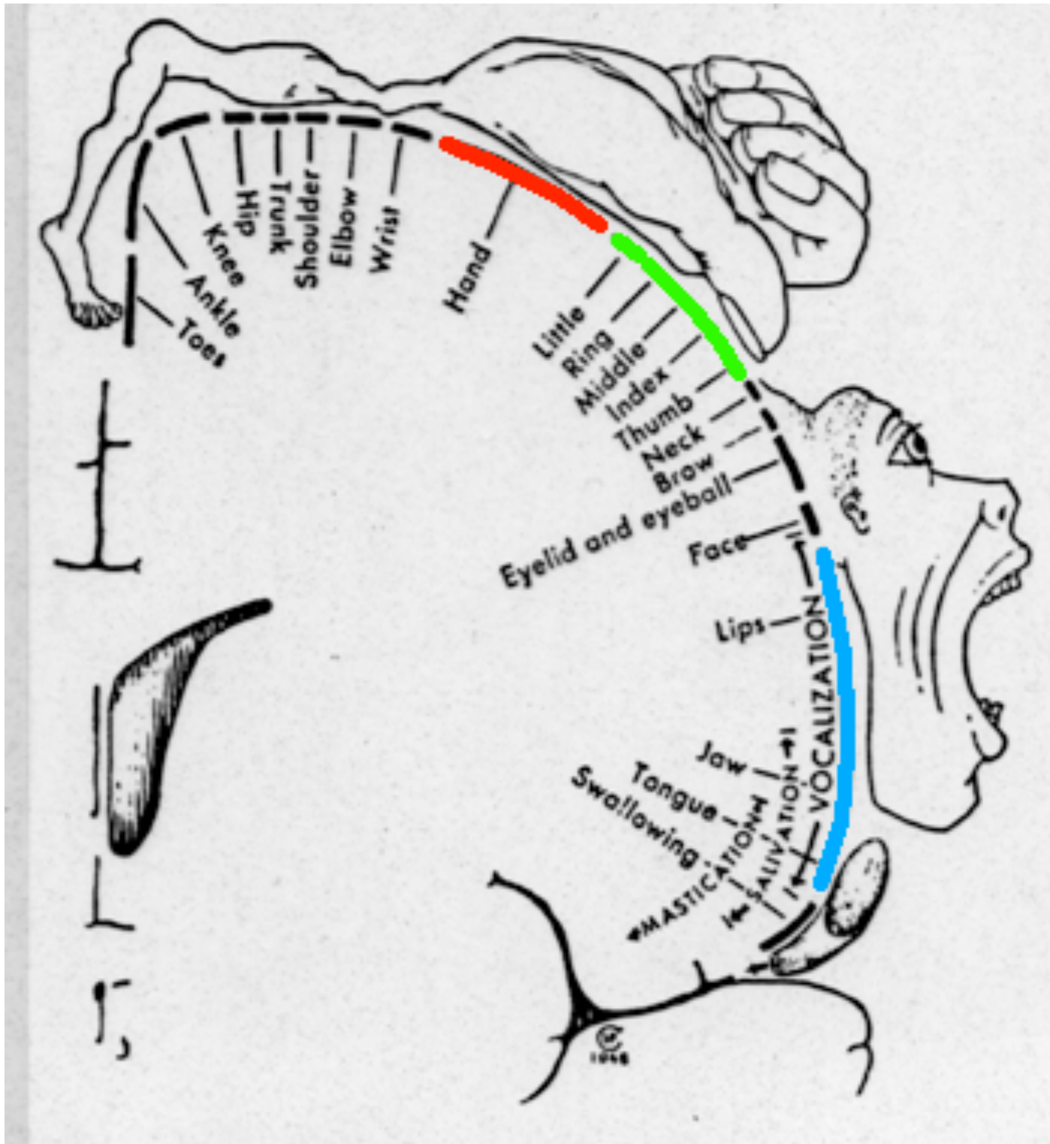
Use transducer on high bandwidth muscles

Langoff

How can we apply this theory?

1. As a heuristic design principle
2. To critique new designs
3. To generate new designs


Area 4 or Primary motor cortex
Aera 6
parietal lobe
frontal lobe
temporal lobe
occipital lobe

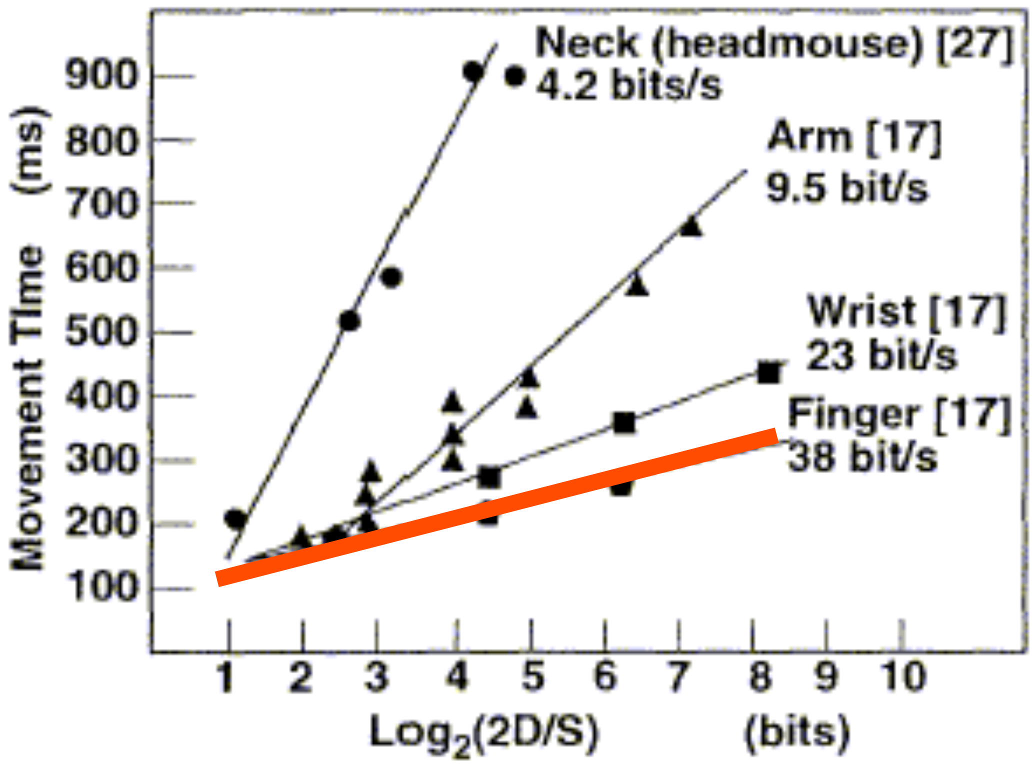


The Motor Homunculus

Penfield

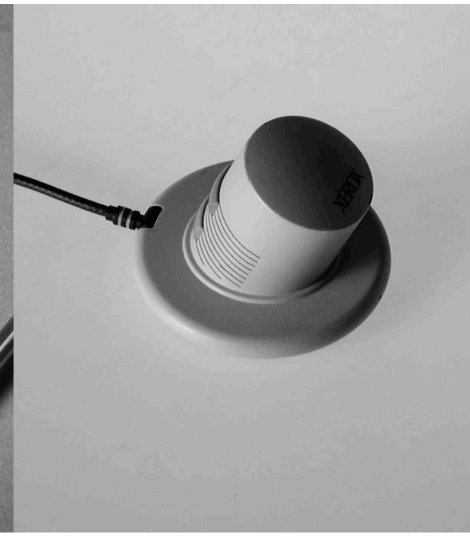

at a man would look like, if
of his body grew in relation to
f the cortex that controls it.

Idea: Attach the Input Device to the Promising Bits of Motor Cortex Real Estate



Use transducer on high bandwidth muscles

DESIGNS FROM RESTRUCTURED TASK

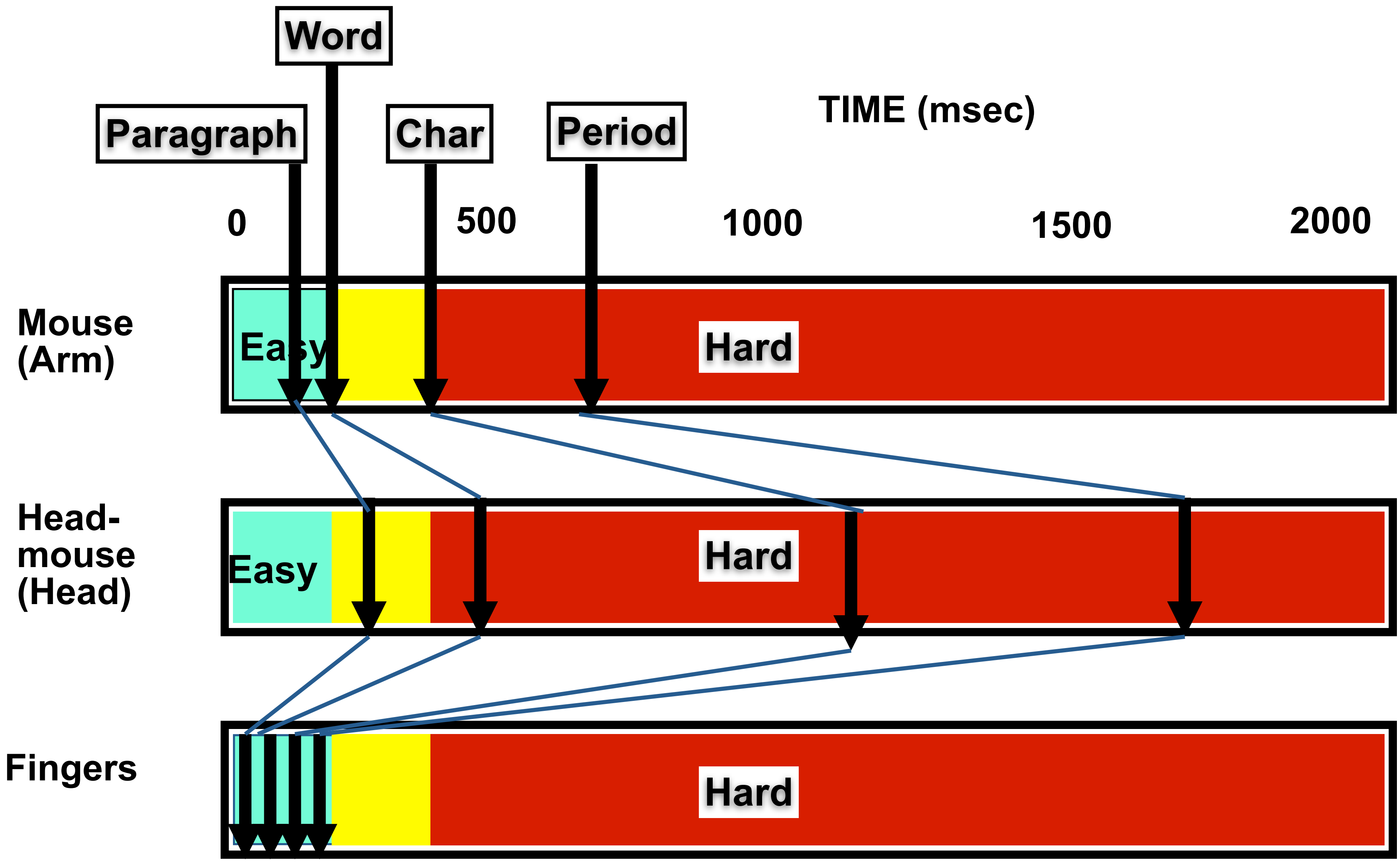







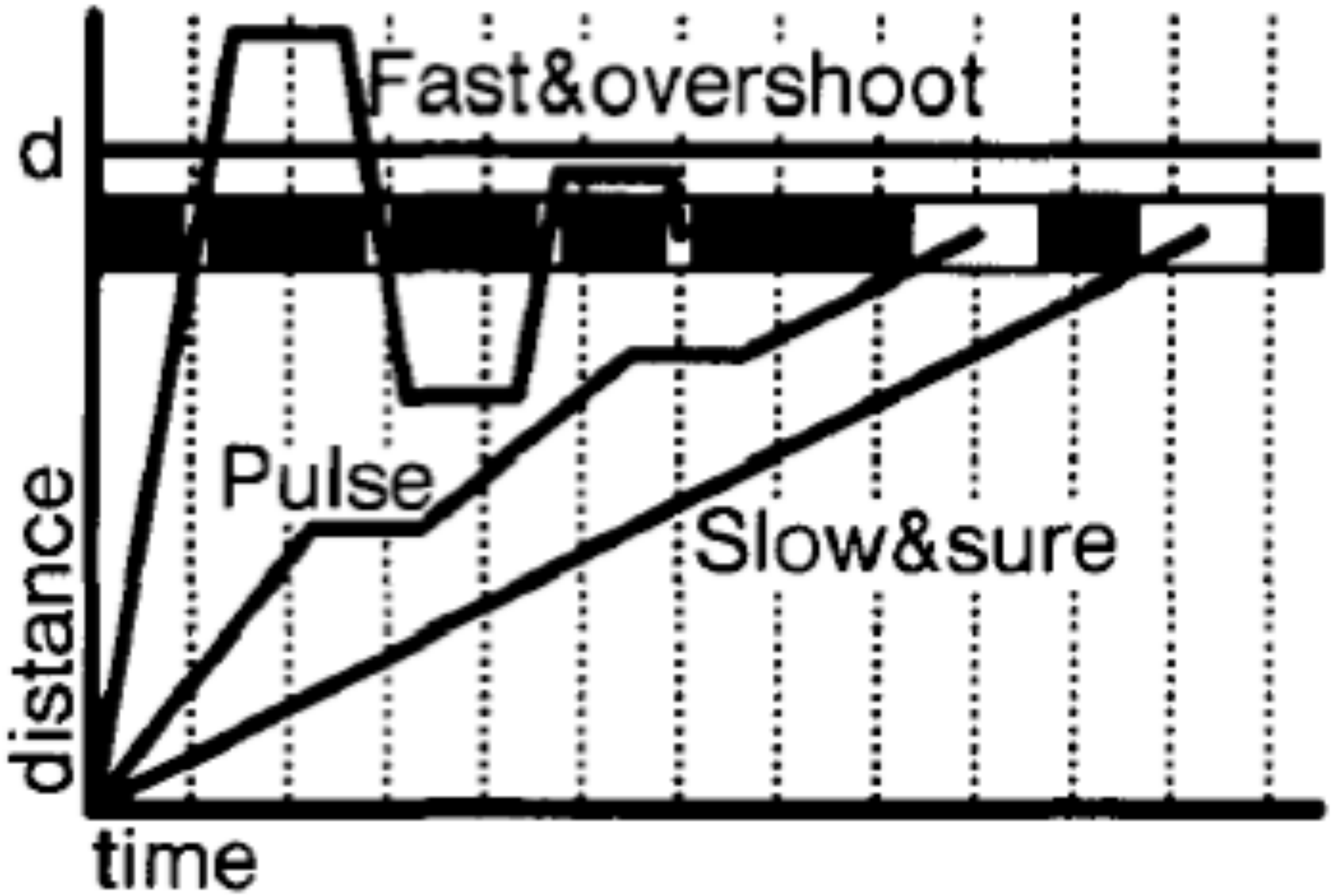
Work with Bill Moggridge, IDEO

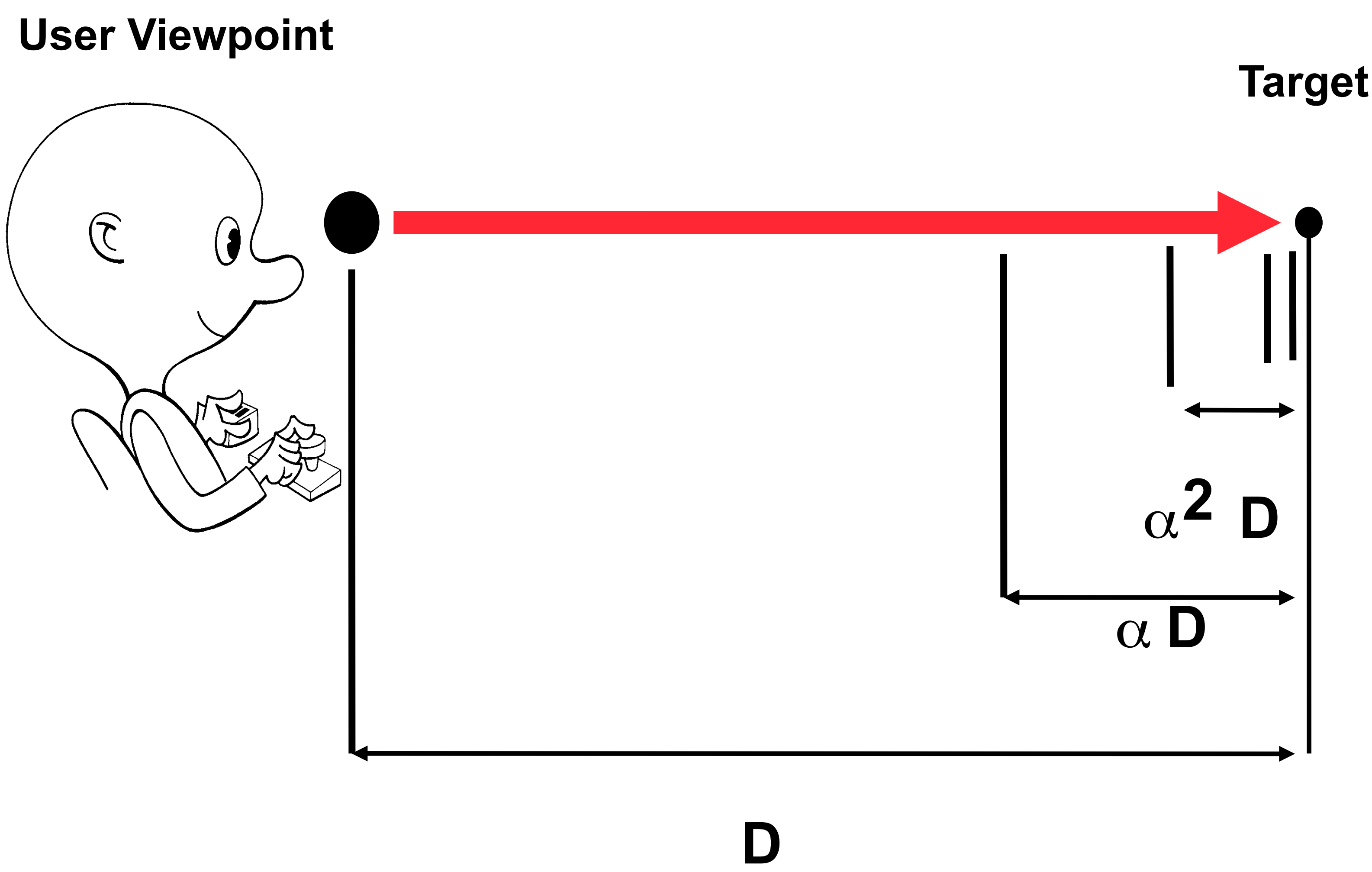
How Bandwidth of the Input Device changes the Structure of the Task Space

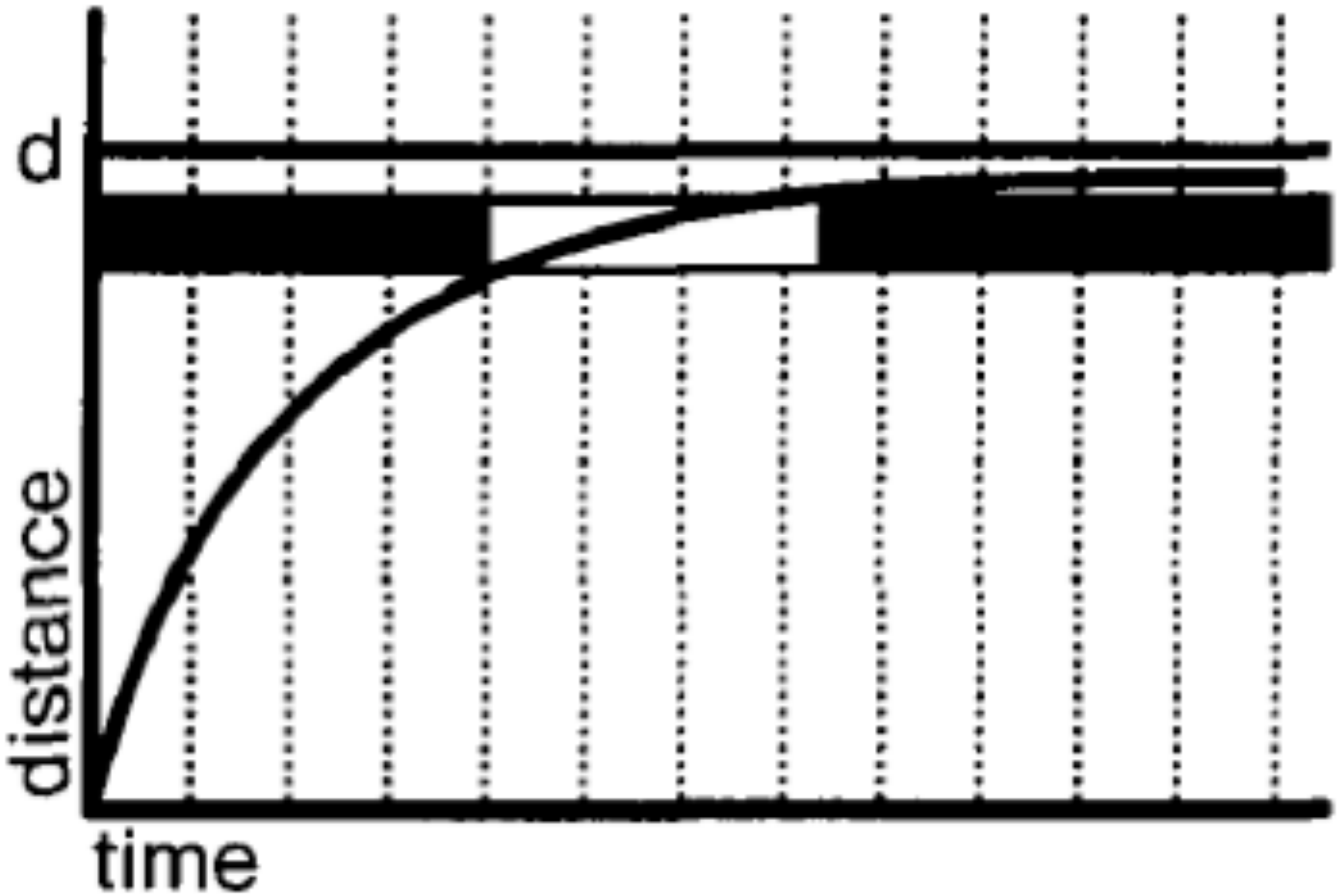


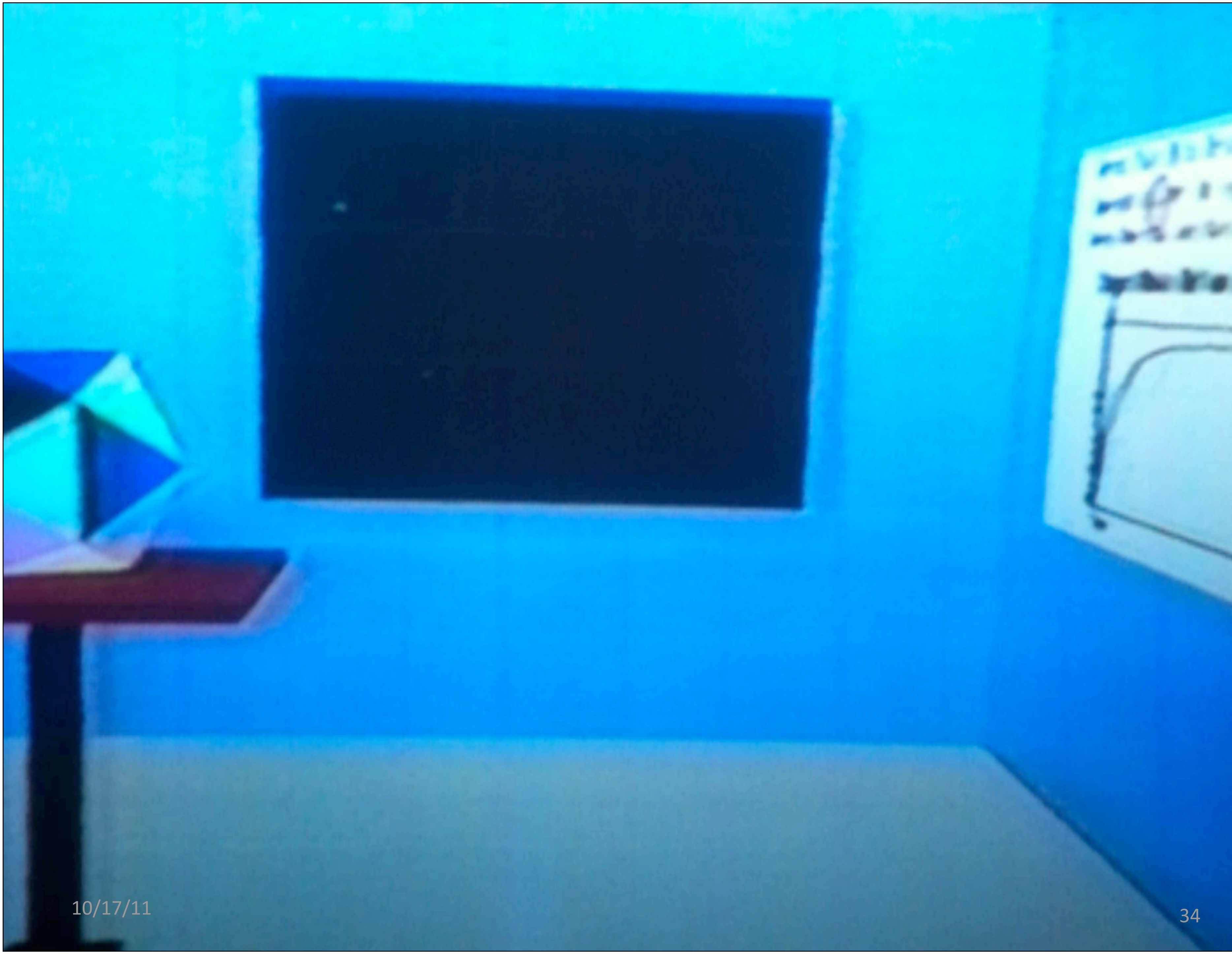
How can we apply this theory?

1. As a heuristic design principle
2. To critique new designs
3. To generate new designs
4. To generate designs in other areas


Fast&overshoot
d
Pulse
Slow&sure
distance
time


User Viewpoint
Target
α^2 D
α D
D


d
distance
time



Bands of Behavior

TIME SCALE OF HUMAN ACTION

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10^{-1}	100 ms	Deliberate act	
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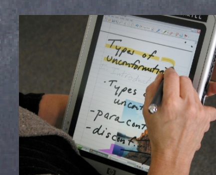
Figure 3-3. Time scale of human action.



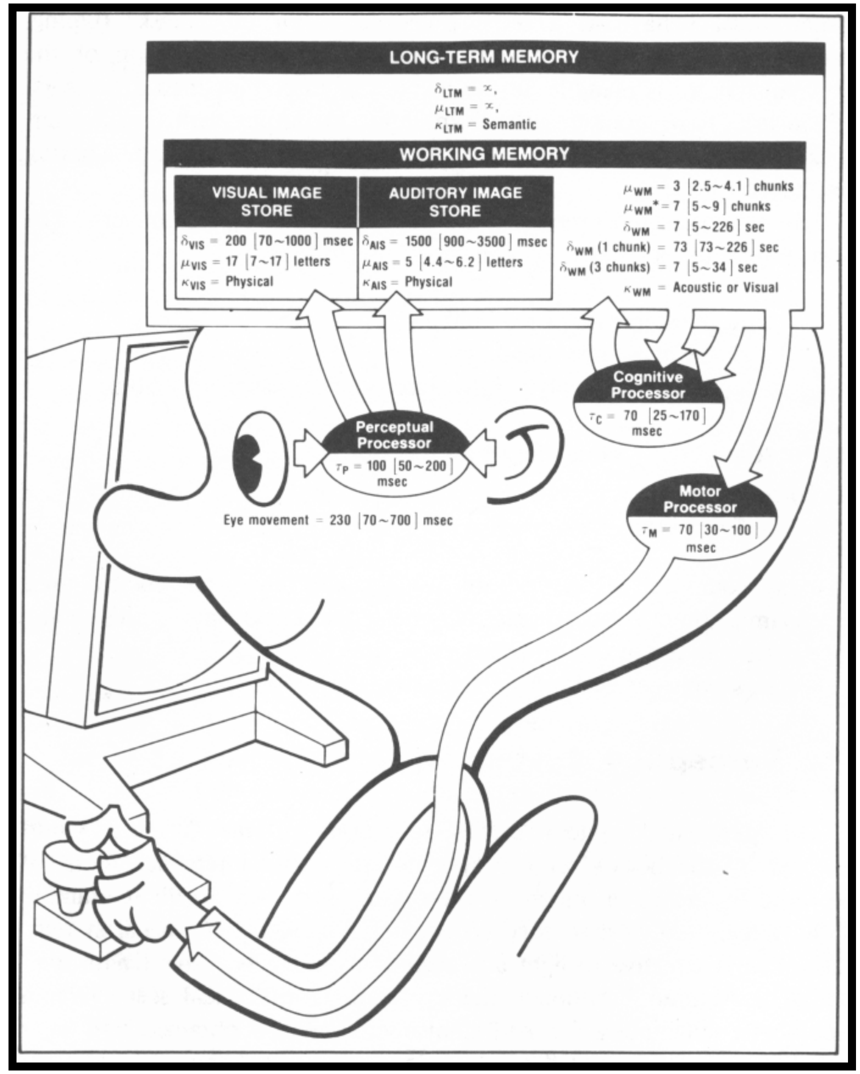
Newell & Card (1985), Newell (1990) 37

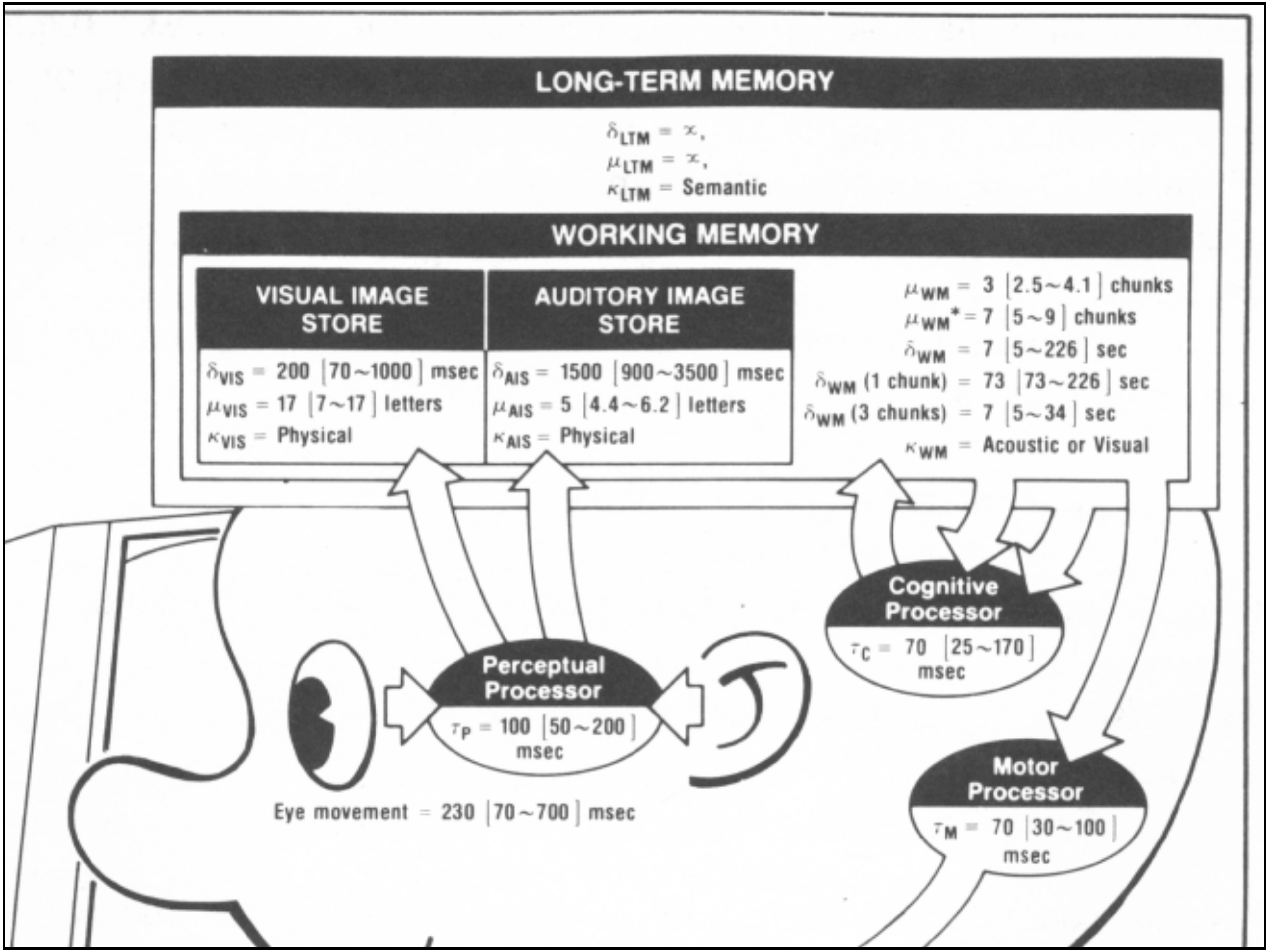
- For system design, we need abstractions about the human side of the system that enable us to do:
  - Task Analysis
  - Approximation
  - Calculation

Calculational Psychology for System Design: The Model Human Processor

MODEL HUMAN PROCESSOR

- **Processors and Memories applied to human**
- **Used for routine cognitive skill**




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
Cognitive Processor
τ_C = 70 [25~170] msec
Perceptual Processor
τ_P = 100 [50~200] msec
Eye movement = 230 [70~700] msec
Motor Processor
τ_M = 70 [30~100] msec

Processors

Perceptual

τ_P = 100 [50 ~ 100] mse

Cognitive

τ_C = 70 [25 ~ 170] msec

Motor

= 70 [30 ~ 100] msec

Animation Rate

- PROBLEM: Compute the frame at which an animated image must be refreshed to give the illusion of movement.
- ANSWER: Images closers together than 1 perceptual processor cycle fuse together. So

  Frame rate > $1/\tau_P$ = 1/100 msec
  = 10 frames/sec

How fast to be sure?

- NOTE: There are second order effects
  - Brightness
  - Distance between image on subsequent frames

- ANSWER: Do Fastman Computation

Frame rate > $1/\tau_P$ = 1/100 [50 ~ 200] msec
= 1/50 msec
= 20 frames/sec

How fast to be sure?

- NOTE: There are second order effects
  - Brightness
  - Distance between image on subsequent frames

- ANSWER: Do Fastman Computation

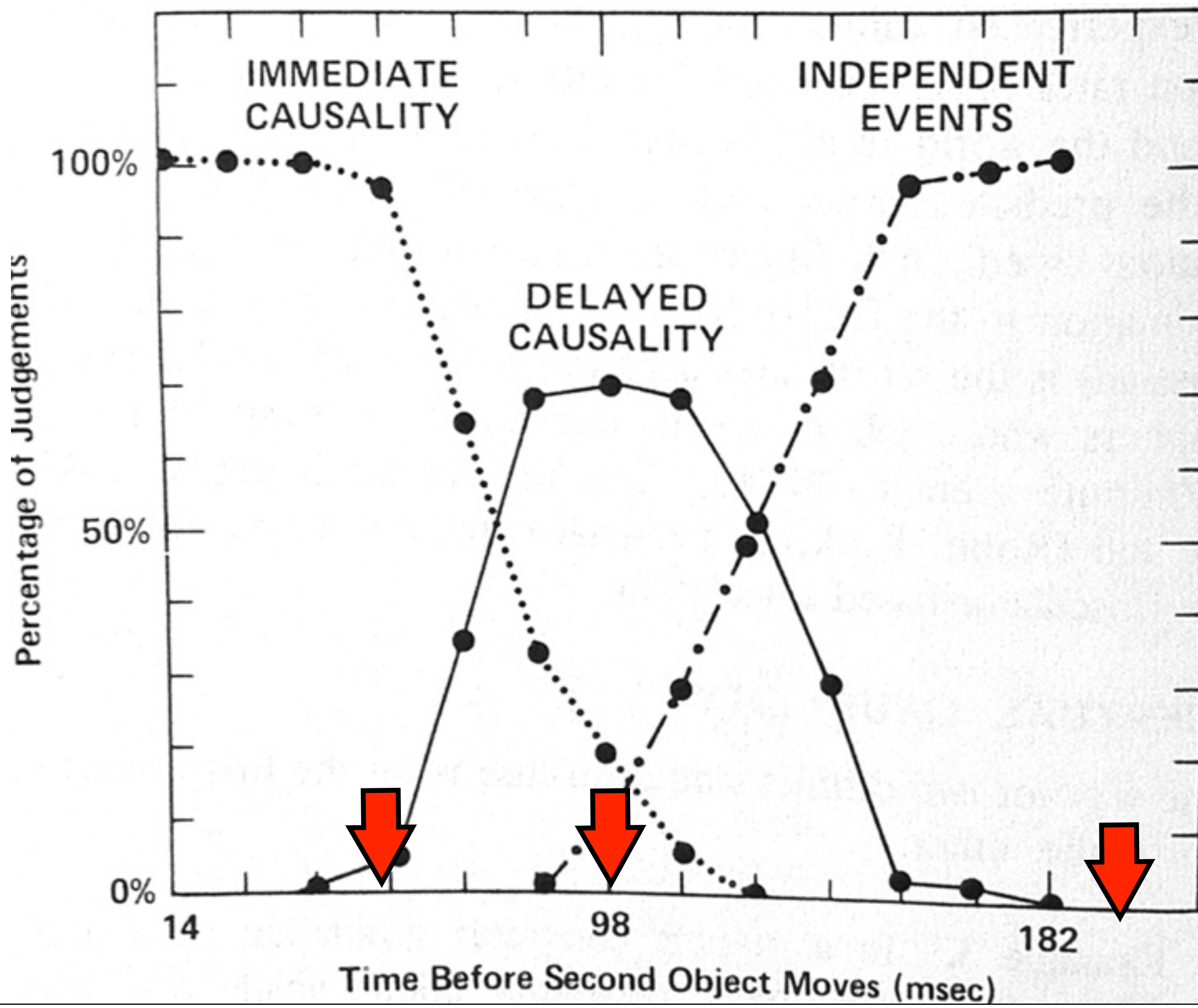
Frame rate > $1/\tau_P$ = 1/100 [50 ~ 200] msec
= 1/50 msec
= 20 frames/sec

Visual Causation

- PROBLEM: In a pool game simulation, one ball hits another causing it to move. If the computation has to be done after the collision, how long is available to do the computation?
- ANSWER: Ball must begin to move within the 100 msec interval.

Frame rate < $1/\tau_P$ = 1/100 [50 ~ 200]msec
= 10 [20 ~ 5] frames/sec

Bounds of Calculation



Michotte

Calculate Reading Rate

- PROBLEM: How fast can a person read text?
- ANSWER: Assume reading is limited by how fast a person can move their eyes.

Saccade time = 230 [70 ~ 700] msec

If read letter by letter (5 letters/word)

Reading rate = (60 sec/min) / (0.230 sec/saccade) (5 saccade/word)

= 52 words/min

If read word by word

Reading rate = (60 sec/min) / (0.230 sec/saccade) (1 saccade/word)

= 261 words/min

If read phrase by phrase (assume 13 characters = 2.5 words/phrase)

Reading rate = (60 sec/min) / (0.230 sec/saccade) (1 saccade/2.5 words)

= 652 words/min words/min

THEREFORE: Speed readers skim.

Calculate Simple Reaction Time

PROBLEM: User has to press a bar every time any simple comes up on the display. How fast can the user respond?

ANSWER:

Object comes up and processed by Perceptual Processor in $\tau_{P.}$

Stimulus connected to response in τ_{C} .

User presses the +bar in τ_{M} .

So,

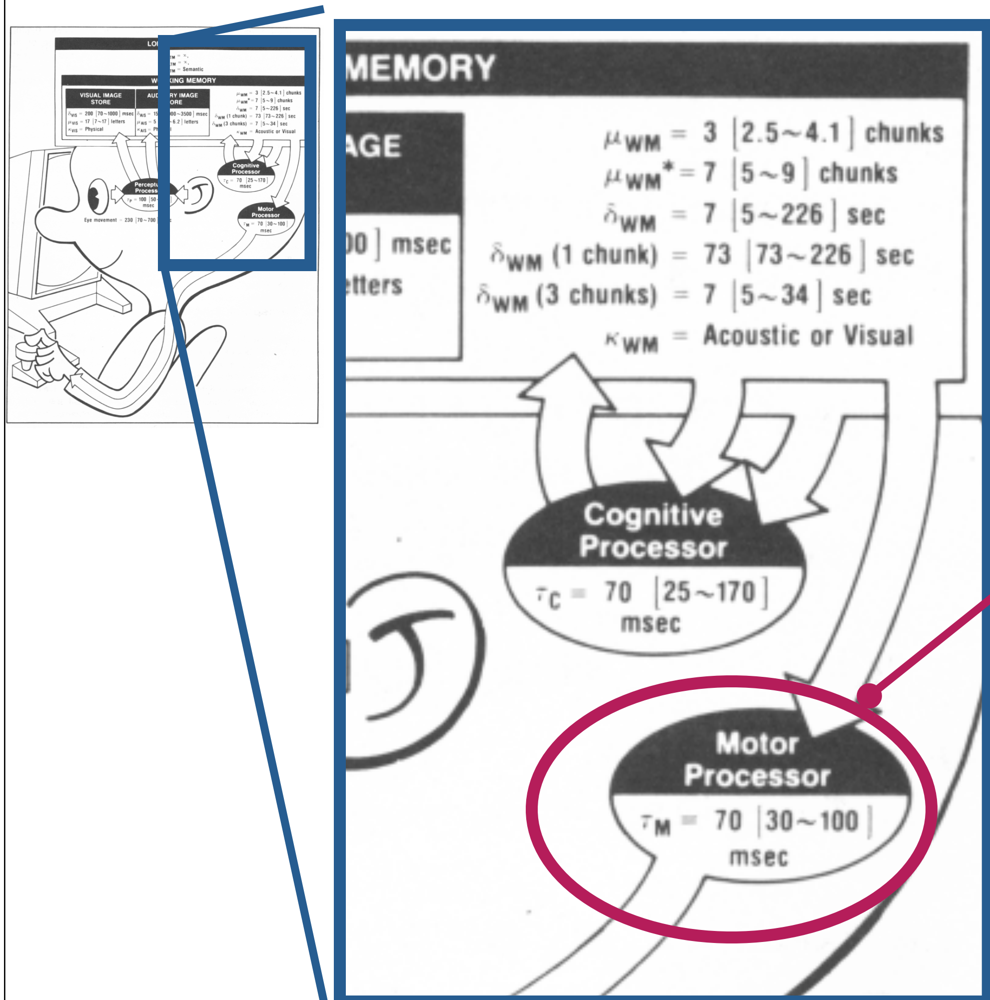
Response Time = $\tau_P + \tau_C + \tau_M$

= 100 + 70 + 70 = 240 msec

Fastest Response

= 50 + 25 + 30 = 105 msec

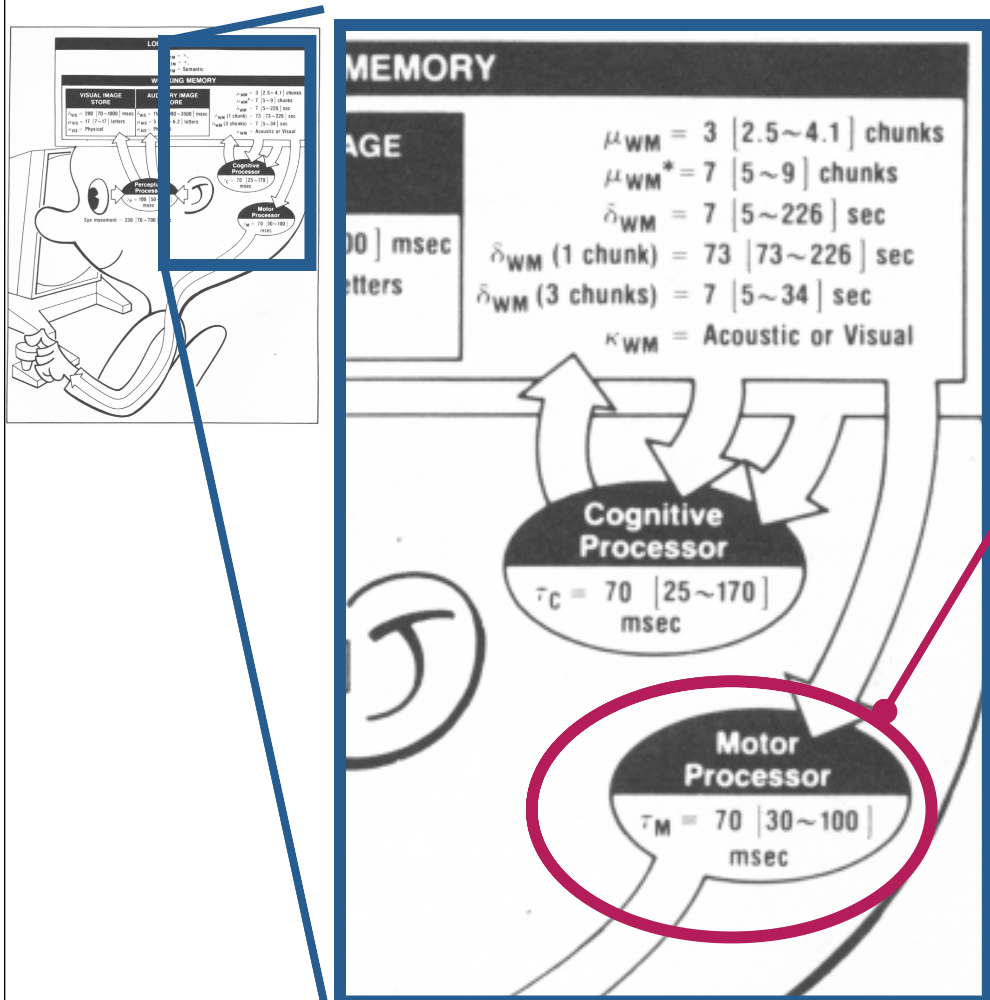
Super Typewriter Product



- **Problem:**
  Inventor claims he invented 600 wpm typewriter. License and develop?
- **Solution 1:**
  Half stroke:
  τ_M = 70 ms/char
  Whole stroke:
  $\tau_M + \tau_M$ = 140 ms/char

  but if between hands, overlap:
  τ_M = 70 ms
  = 131 words/min

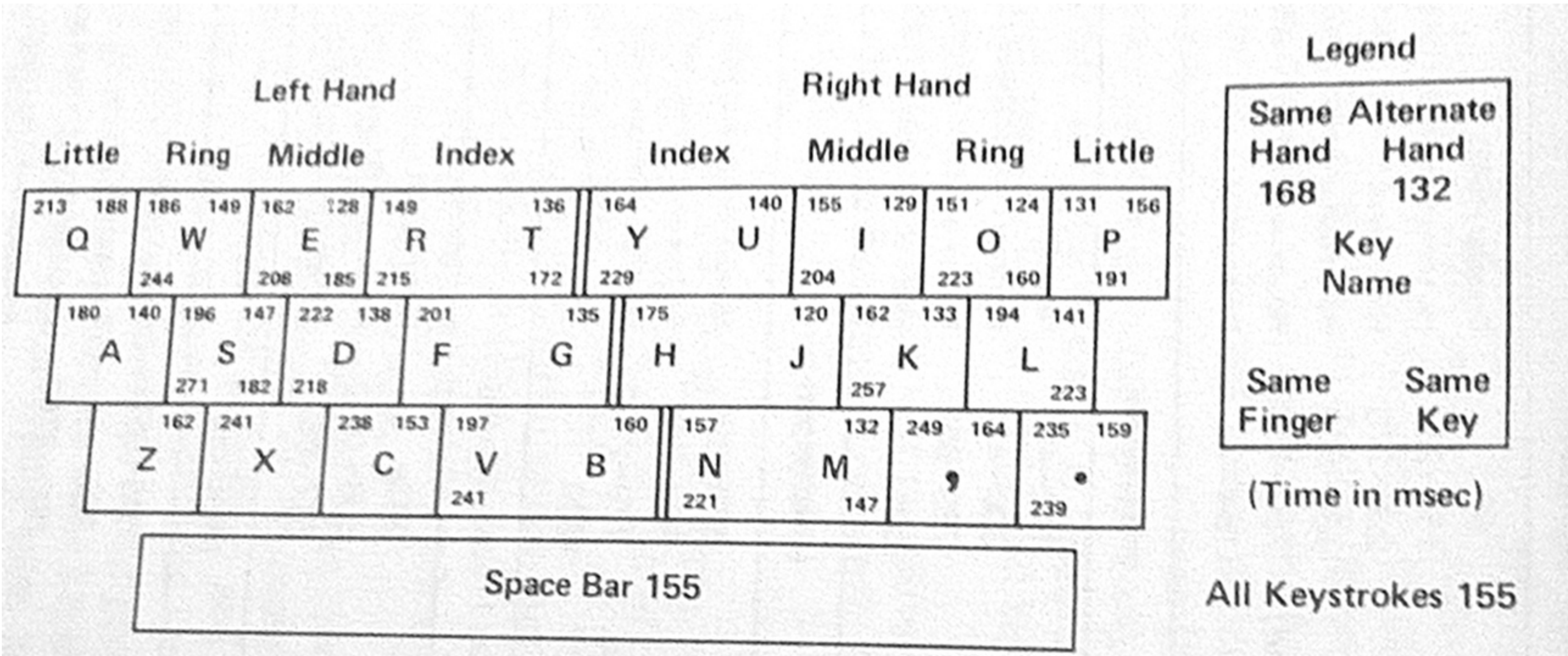
EXAMPLE: ZERO-PARAMETER CALC



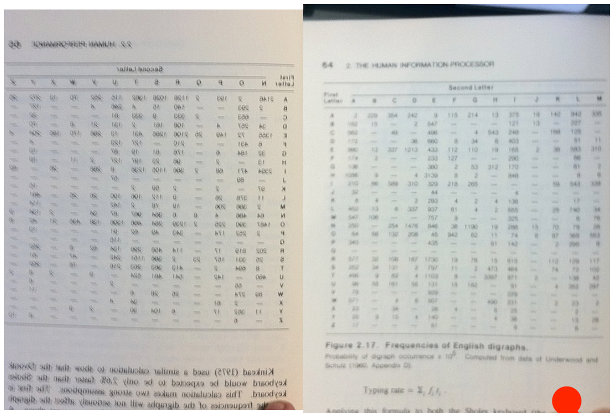
- **Solution 2: (range calculation)**
  Half stroke:
  τ_M=70 [30~100] ms/char
  = 131 [308~92] words/min
- **Conclusion:**
  Bogus claim. Throw him out!

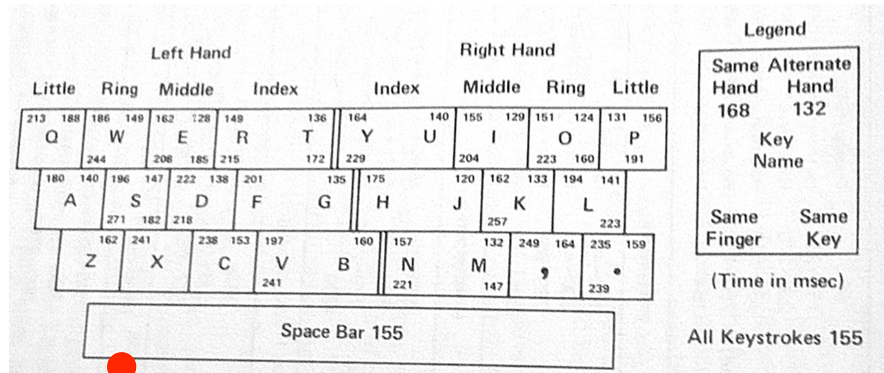
How Much Better is Dvorak?

Data: 155,000 Keystrokes. 22 Typists



Kinkead, 1975





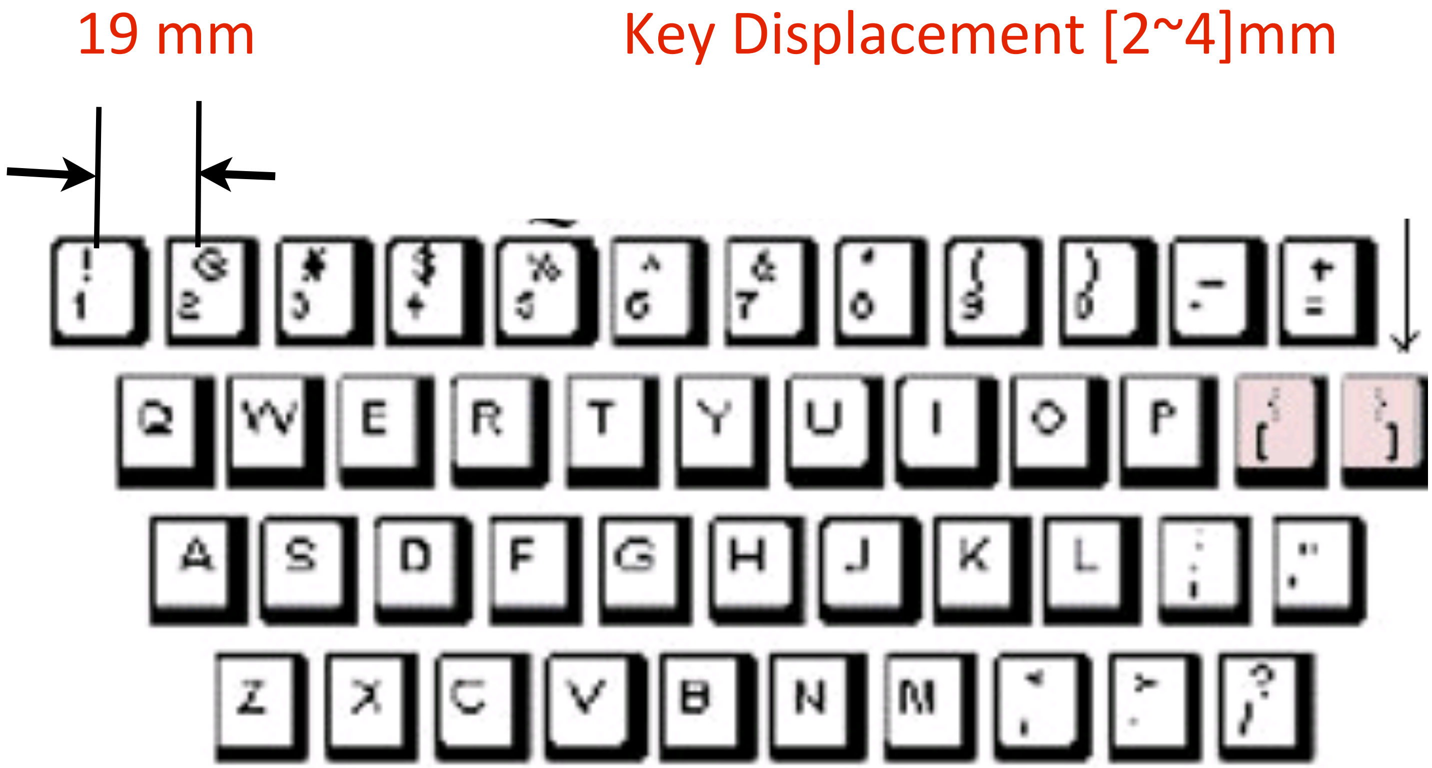
Typing Rate = $\Sigma_i f_i t_i$

Typing Rate (Sholes) = 152 msec/keystroke = 72 words/min

Typing Rate (Alphabetic) = 8% slower

Typing Rate (Dvorak) = 2.6% faster

Good Keyboards



Ideal Force Displacement Curve

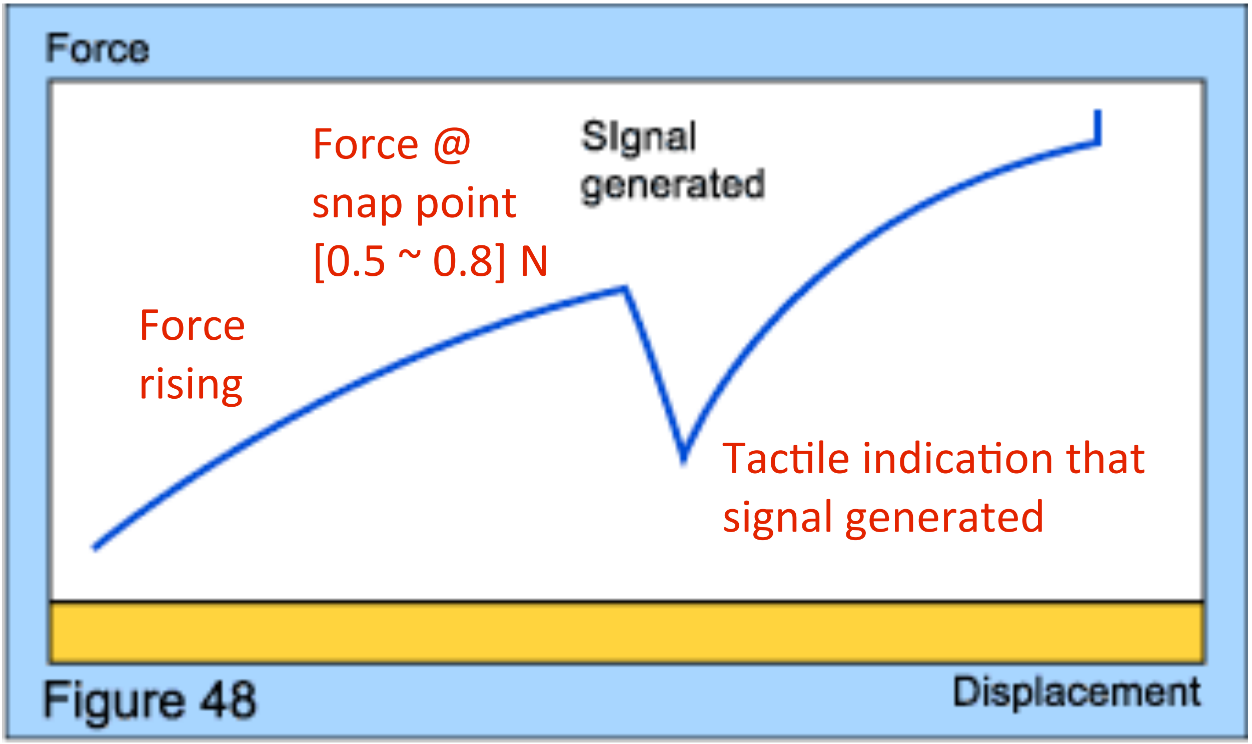
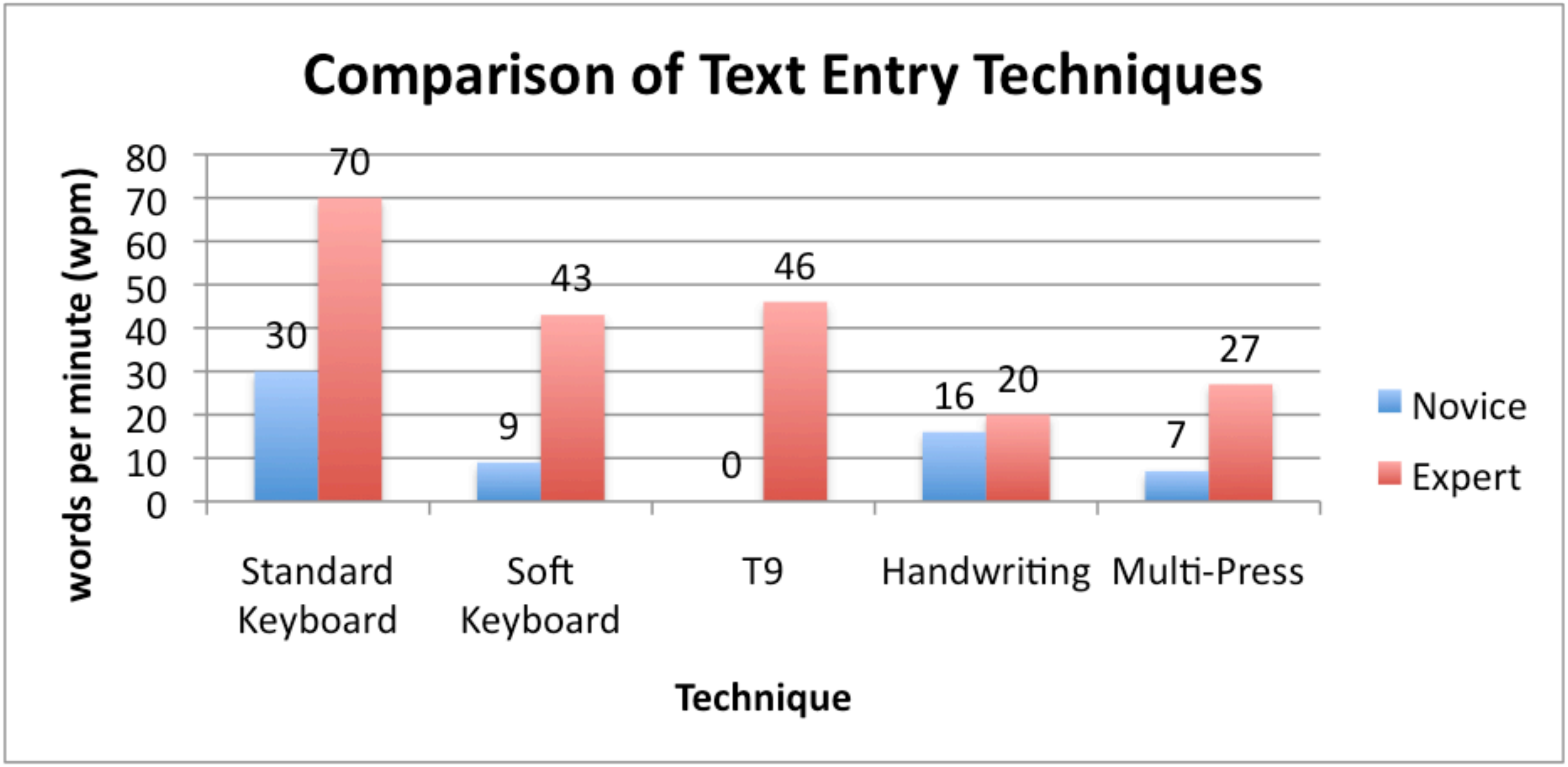


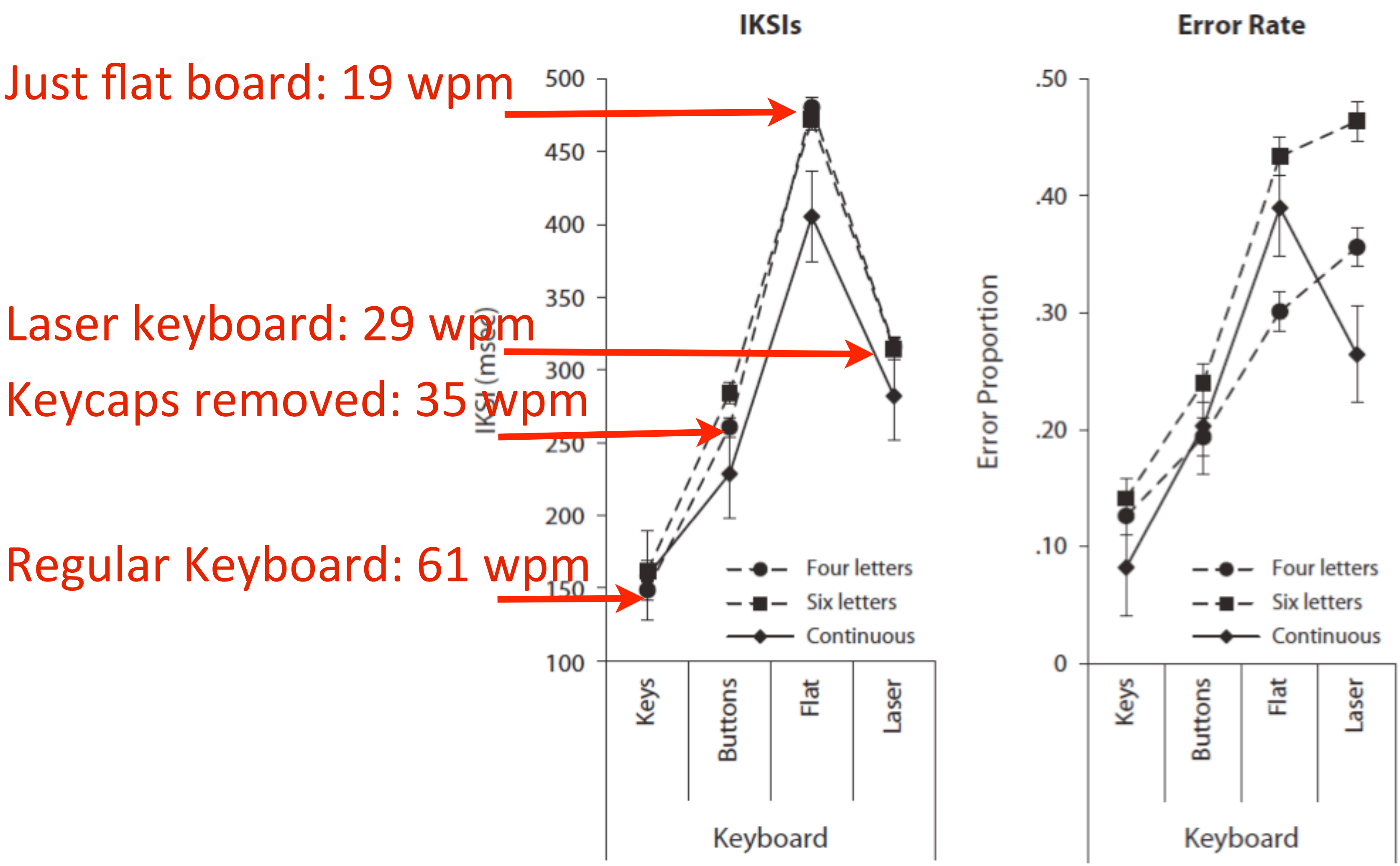
Figure 48

ISO 9241, (Clare, 1970)

Which is fastest?



Typing needs tactile feedback



Crump & Logan (2010)

Amaze Your Friends!

- Yes. You, too, can do amazing calculations like these!
  - Design tall systems in a single bound.
  - Cut to the coding, while others slave on user experiments.
- **ALL IT TAKES IS A LITTLE USER THEORY.**
- And it's free!

Remember these 3 Cognitive Band Numbers!

TIME SCALE OF HUMAN ACTION

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10^{5}	days		
10^{4}	hours	Task	
10^{3}	10 min	Task	RATIONAL BAND
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10^{1}	10 sec	Unit task	
10^{0}	1 sec	Operations	COGNITIVE BAND
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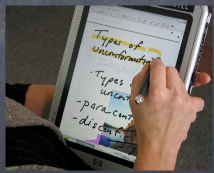
Figure 3-3. Time scale of human action.



Newell & Card (1985), Newell (1990) 37

Cognitive Band Magic Time Key

- **0.1 sec**
  - "Psychological Moment"
  - Events < 0.1 sec causally fuse into single percept
  - System must acknowledge user contact like button push
- **1 sec**
  - "Unprepared response time constant"
  - Smallest user action
  - System can give informative response like animation as long as it takes less than this
- **10 sec**
  - "Unit Task"
  - Command unit of task
  - Must be able to do an application action in 10 [3 ~ 30] sec

Task Analysis/Unit Tasks

Boundary between Cognitive and Rational Bands

TIME SCALE OF HUMAN ACTION

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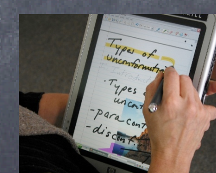
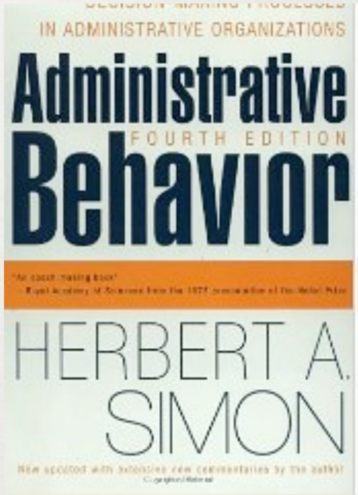
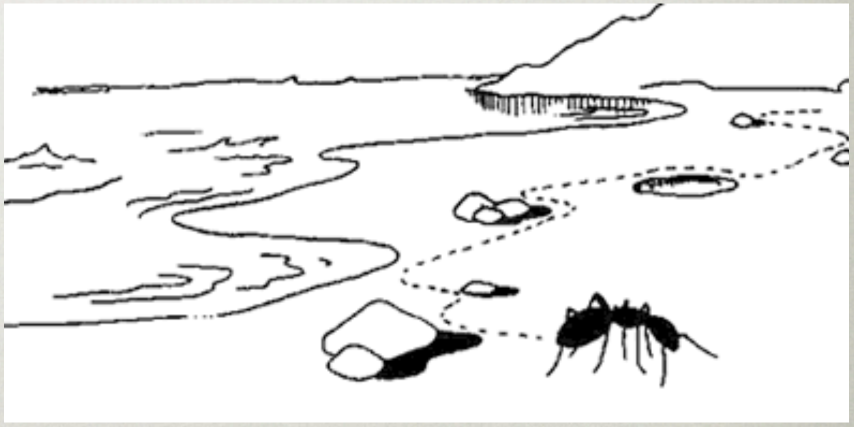


Newell & Card (1985), Newell (1990) 37

Bounded Rationality

- Economics: Limitations in Rational Man model
- Psychology: Simon's Ant-- **Complexity of behavior is in the environment**
- Inner environment (Proximal mechanisms)vs outer environment (Task environment)





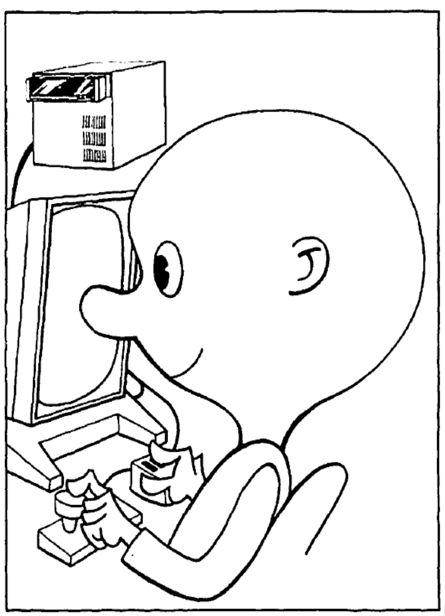
IMMEDIATE BEHAVIOR

- Immediate Behavior: Little search
  - E.g., Routine cognitive skills like text editing.
- Since much of the behavior is determined by the constraints, we analyze it by
  - Goals
  - Operators
  - Methods (Groups of Goals and Operators)
  - Selection Rules (Rules for choosing among

task analysis

TASK ANALYSIS: GOMS
(GOALS, OPERATORS, METHODS, SELECTION RULES)

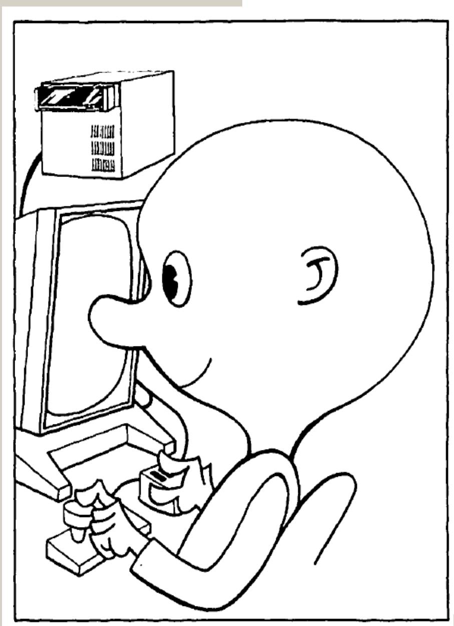
```
GOAL: EDIT-MANUSCRIPT                                  • repeat until done
    GOAL: EDIT-UNIT-TASK
        GOAL: ACQUIRE-UNIT-TASK                        • if not remembered
            GET-NEXT-PAGE                              • if at end of page
            GET-NEXT-TASK                              • if an edit task found
        GOAL: EXECUTE-UNIT-TASK
            GOAL: LOCATE-LINE                          • if task not on line
                [select : USE-QS-METHOD
                          USE-LF-METHOD]
            GOAL: MODIFY-TEXT
                [select USE-S-COMMAND
                        USE-M-COMMAND]
```

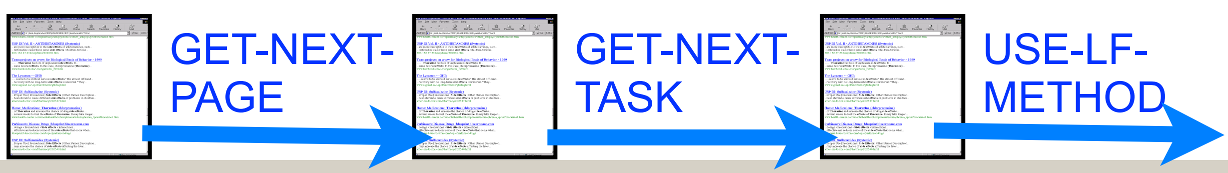


IMMEDIATE BEHAVIOR: GOMS (GOALS, OPERATORS, METHODS, SELECTION RULES)

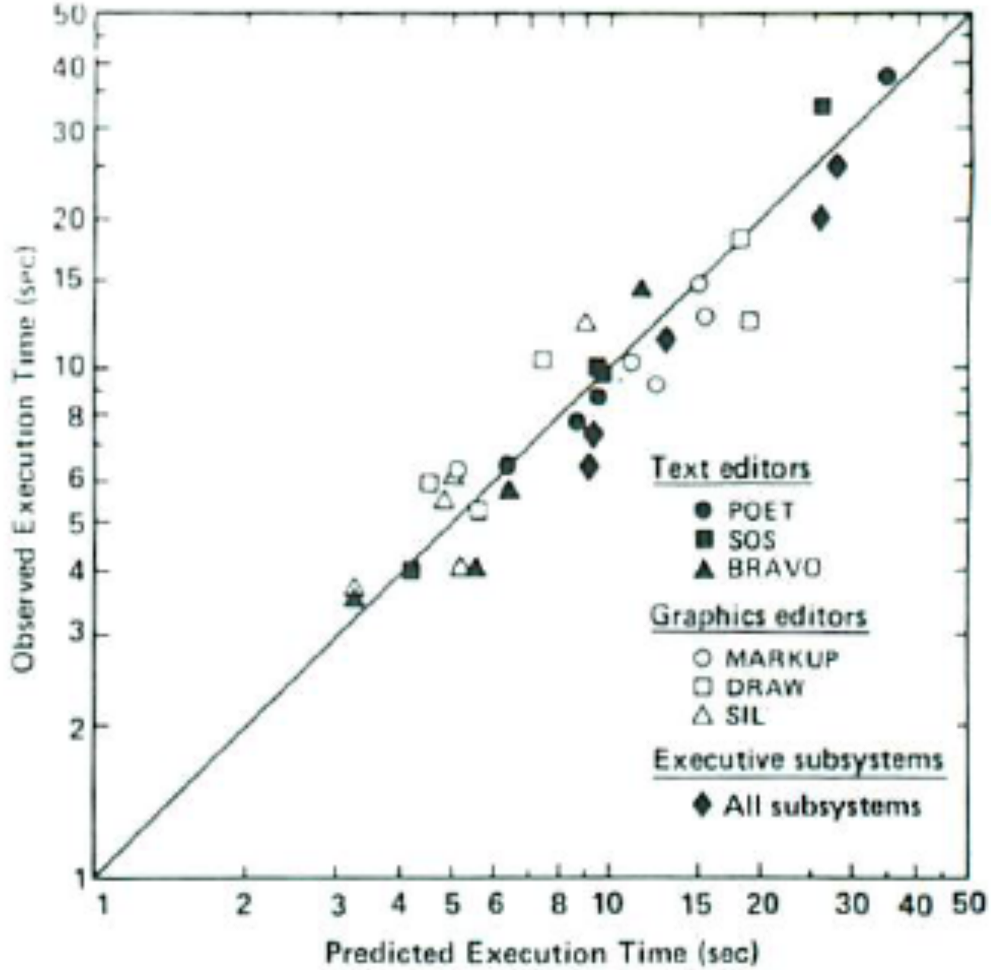
- GOAL: EDIT-MANUSCRIPT
  - GOAL: EDIT-UNIT-TASK
    - GOAL: ACQUIRE-UNIT-TASK
      - GET-NEXT-PAGE
      - GET-NEXT-TASK
    - GOAL: EXECUTE-UNIT-TASK
      - GOAL: LOCATE-LINE
        - [select : USE-QS-METHOD
          USE-LF-METHOD]
      - GOAL: MODIFY-TEXT
        - [select USE-S-COMMAND
          USE-M-COMMAND] GET-NEXT-PAGE

- repeat until done
- if not remembered
- if at end of page
- if an edit task found
- if task not on line





PREDICTS TIME WITHIN ABOUT 20%



Application of GOMS: SAE RECOMMENDED PRACTICE J2365

Dario Salvucci

- Predict task times for car navigation systems
- Check compliance with SAE J2364 (15-Second Rule)
- Note: To estimate times while driving, multiply by 1.3 to 1.5.
- Based on GOMS and work by Paul Green at Univ. of Michigan Transportation Research Institute.

SAE J2365 OPERATOR TIMES

Code	Name	Time (s)	
		Young (18-30	Old (55-60)
Rn	Reach near	0.31	0.53
Rf	Reach far	0.45	0.77
C1	Cursor once	0.80	1.36
C2	Cursor 2 times or more	0.40	0.68
L1	Letter or space 1	1.00	1.70
L2	Letter or space 2 times or more	0.50	0.85
N1	Number once	0.90	1.53
N2	Number 2 times or more	0.45	0.77
E	Enter	1.20	2.04
F	Function keys or shift	1.20	2.04
M	Mental	1.50	2.55
S	Search	2.30	3.91
Rs	Response time of system-scroll	0.00	0.00
Rm	Response time of system-new menu	0.50	0.50

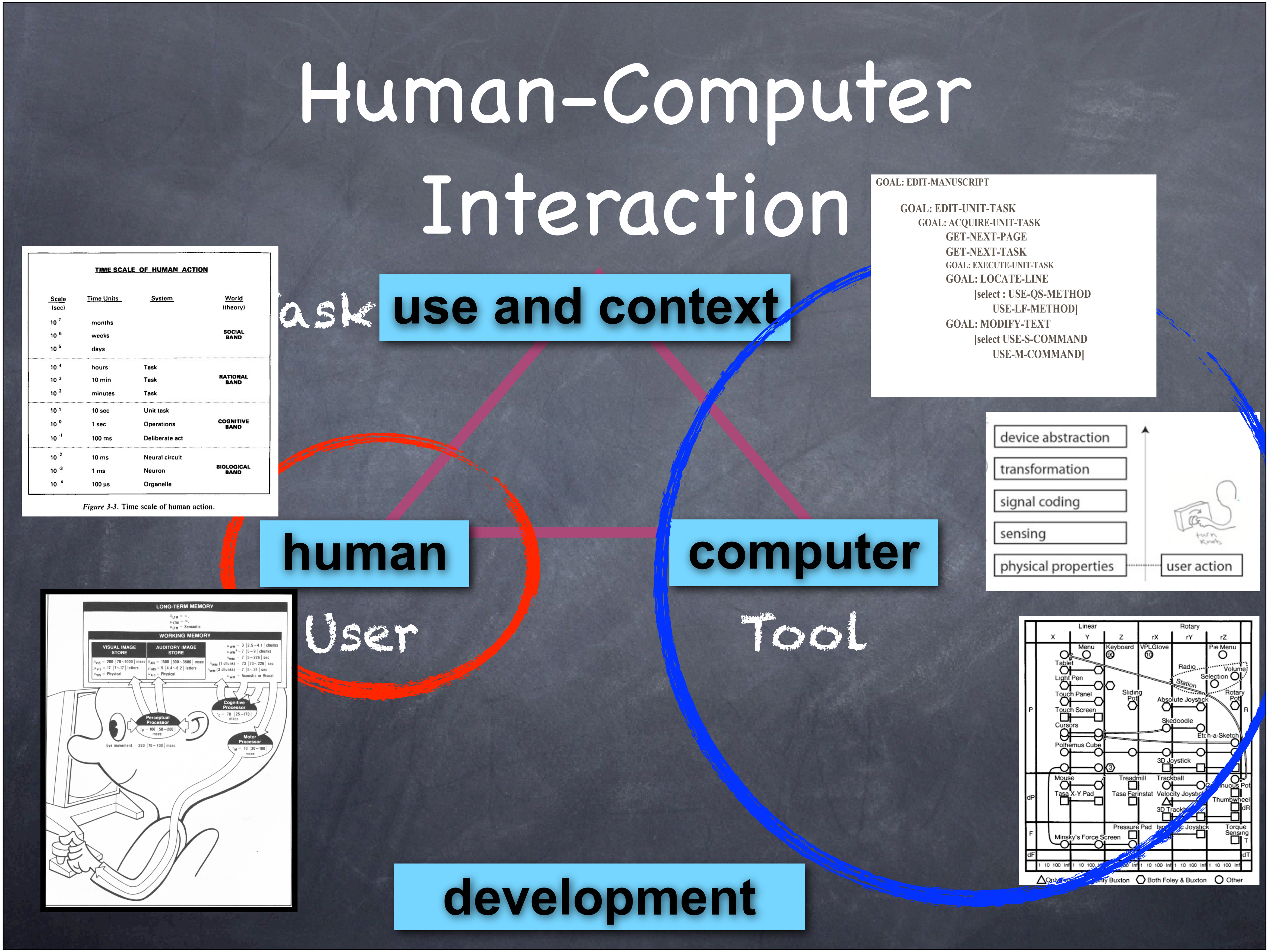
Paul Green UMITRI

Application of GOMS: LHX HELICOPTER SIMULATION

(Corker, Davis, Papazian, & Pew, 1986)

POP-UP-AND-SCAN
    POP-UP-FOR-SCAN
        [in parallel-do:
            LOOK-FOR
            POP-UP]
    STABILIZE-CRAFT
HOVER-AND-SCAN
        [in-parallel-do:
            HOVER
            SCAN]

GOMS used as task analysis to code doctrine


Human-Computer Interaction
task
use and context
human
computer
User
Tool
development
TIME SCALE OF HUMAN ACTION
Scale (sec)
Time Units
System
World (theory)
months
weeks
days
SOCIAL BAND
hours
10 min
minutes
Task
RATIONAL BAND
10 sec
1 sec
100 ms
Unit task
Operations
Deliberate act
COGNITIVE BAND
10 ms
1 ms
100 μs
Neural circuit
Neuron
Organelle
BIOLOGICAL BAND
Figure 3-3. Time scale of human action.
GOAL: EDIT-MANUSCRIPT
GOAL: EDIT-UNIT-TASK
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GET-NEXT-PAGE
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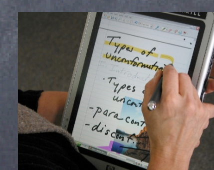
GOAL: LOCATE-LINE
[select : USE-QS-METHOD
USE-LF-METHOD]
GOAL: MODIFY-TEXT
[select USE-S-COMMAND
USE-M-COMMAND]
device abstraction
transformation
signal coding
sensing
physical properties
user action
LONG-TERM MEMORY
WORKING MEMORY
VISUAL IMAGE STORE
AUDITORY IMAGE STORE
Perceptual Processor
Cognitive Processor
Motor Processor
Linear
Rotary
Mouse
Trackball
Tablet
Light Pen
Touch Panel
Touch Screen
Joystick
Treadmill
Thumbwheel
Torque Sensing

Other Bands of Behavior

TIME SCALE OF HUMAN ACTION

Scale (sec)	Time Units	System	World (theory)
10^7	months		SOCIAL BAND
10^6	weeks		
10^5	days		
10^4	hours	Task	RATIONAL BAND
10^3	10 min	Task	
10^2	minutes	Task	
10^1	10 sec	Unit task	COGNITIVE BAND
10^0	1 sec	Operations	
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	BIOLOGICAL BAND
10^{-3}	1 ms	Neuron	
10^{-4}	100 µs	Organelle	

Figure 3-3. Time scale of human action.



Newell & Card (1985), Newell (1990)

Newell & Card (1985), Newell (1990)

- Each of other bands of behavior has its own theories and frameworks that can be used in user experience design. For example:
  - Rational Band
    - Information foraging theory, information scent, problem solving, heuristic search, anchoring
  - Social Band
    - Network behavior, wisdom of the crowds, Condorcet jury theorem, information cascades, persuasive interfaces

"Science is method. All else is commentary."
--Allen Newell