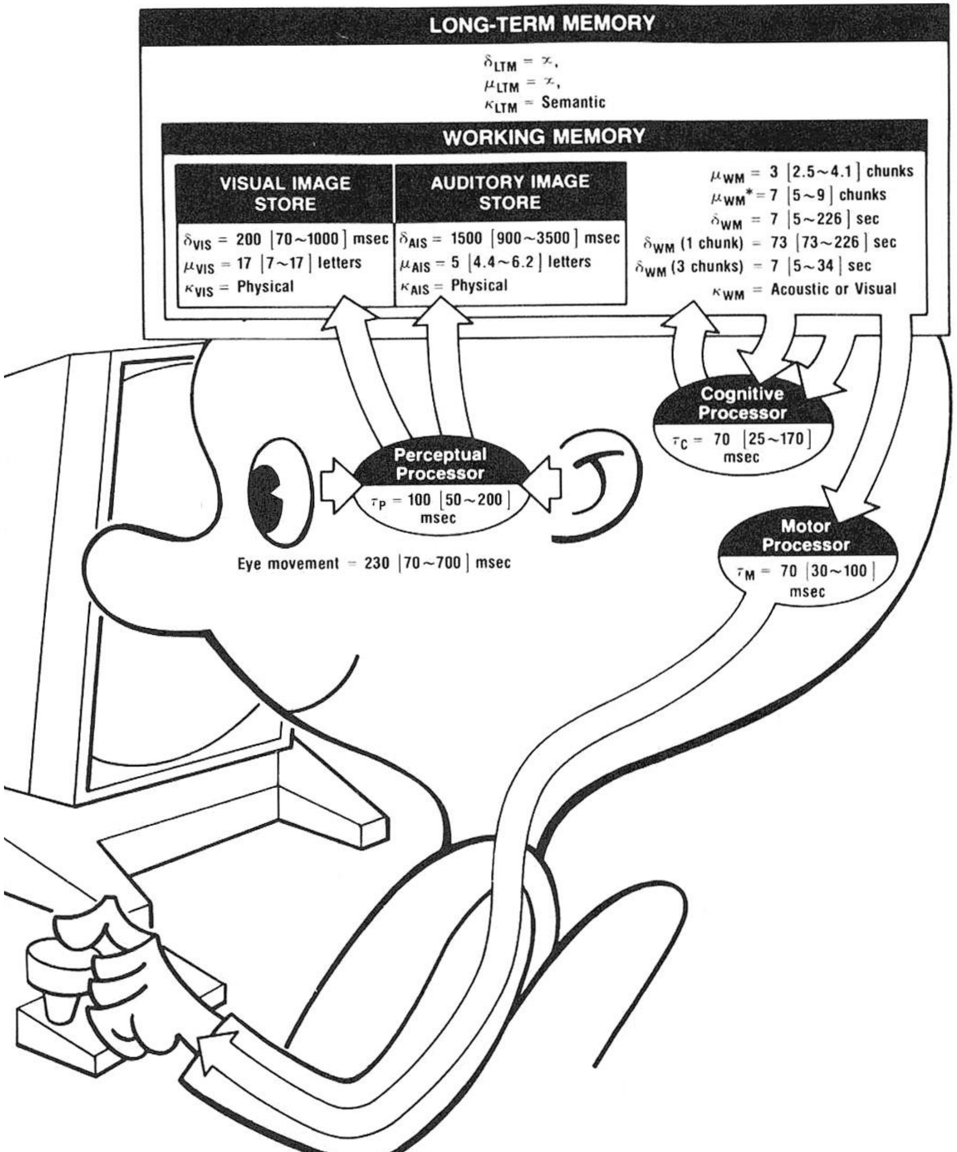
# Human Performance Modeling - 2

Xiaojun Bi
Stony Brook University
xiaojun@cs.stonybrook.edu

9/3/2019

# Review

# Human Information Processor




- Each subsystem has its own memories and processors.
- Memory
  μ, storage capacity in items
  δ, decay time of an item
  κ, main code type (physical, acoustic, visual, semantic)
- Processor
  τ, cycle time
- Three subsystems can work in parallel.

# Agenda

- Fitts’ Law

- Power Law of Practice

- Hick’s Law

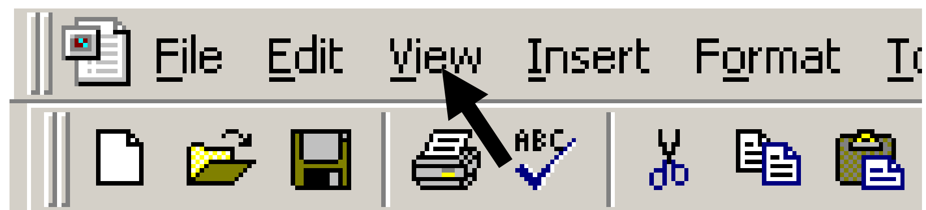
# Today's Questions

*You have a palette of tools in a graphics application that consists of a matrix of 16x16-pixel icons laid out as a 2x8 array that lies along the left-hand edge of the screen. Without moving the array from the left-hand side of the screen or changing the size of the icons, what steps can you take to decrease the time necessary to access the average tool?*

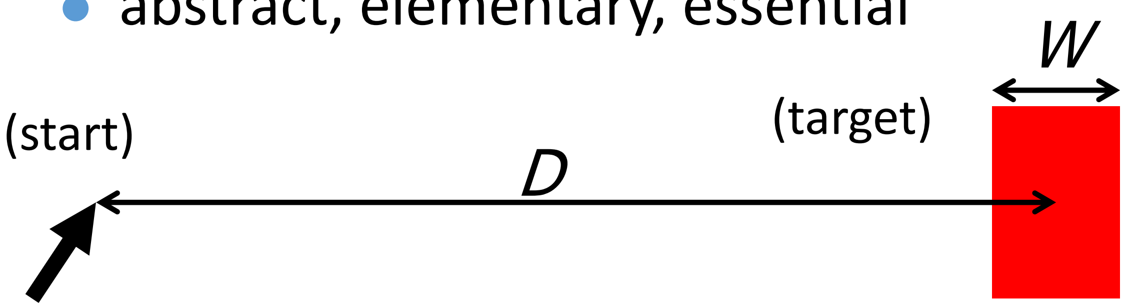
# Motor Skills

# Pointing Tasks

- Real task: interacting with GUI’s
  - Pointing is fundamental




- Experimental task: target acquisition
  - abstract, elementary, essential

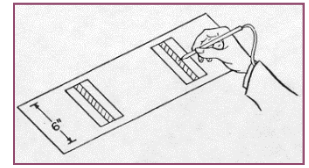


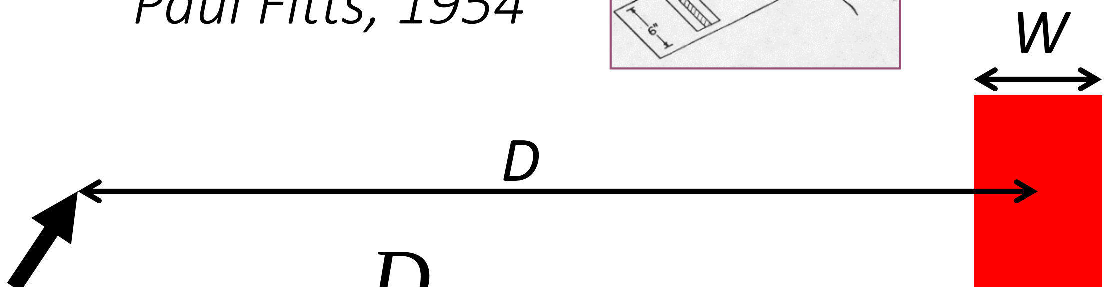

D = distance

W = target width

# Fitts' Law

*Paul Fitts, 1954*



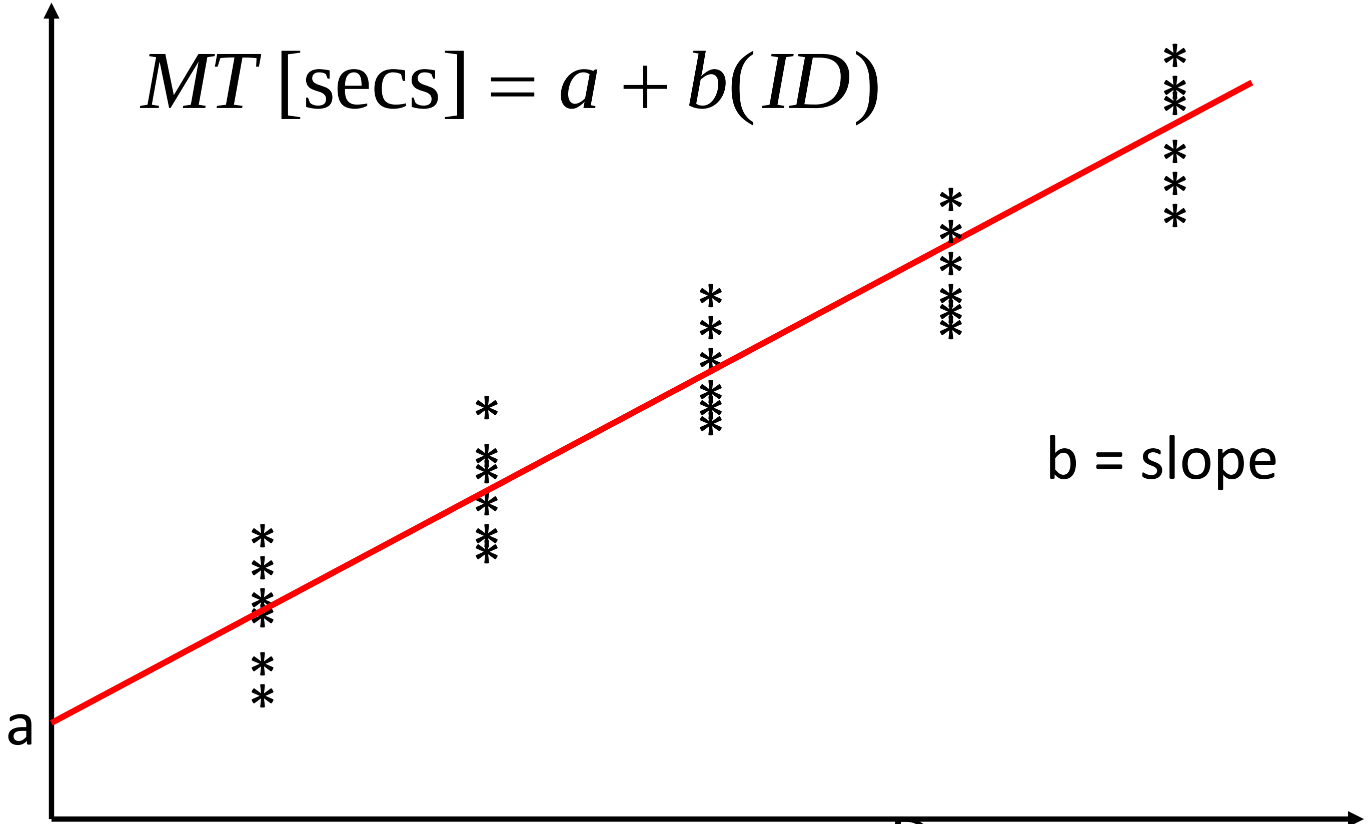



$$\underbrace{MT}_{\textbf{Movement Time}} = a + b \underbrace{\log_2\left(\frac{D}{W} + 1\right)}_{\textbf{Index of Difficulty } (\textit{ID [bits]})}$$

**Index of Performance**
*IP = ID/MT* (bits/s), or *IP = 1/b*
Also known as *bandwidth*

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

$$MT\,[\text{secs}] = a + b(ID)$$



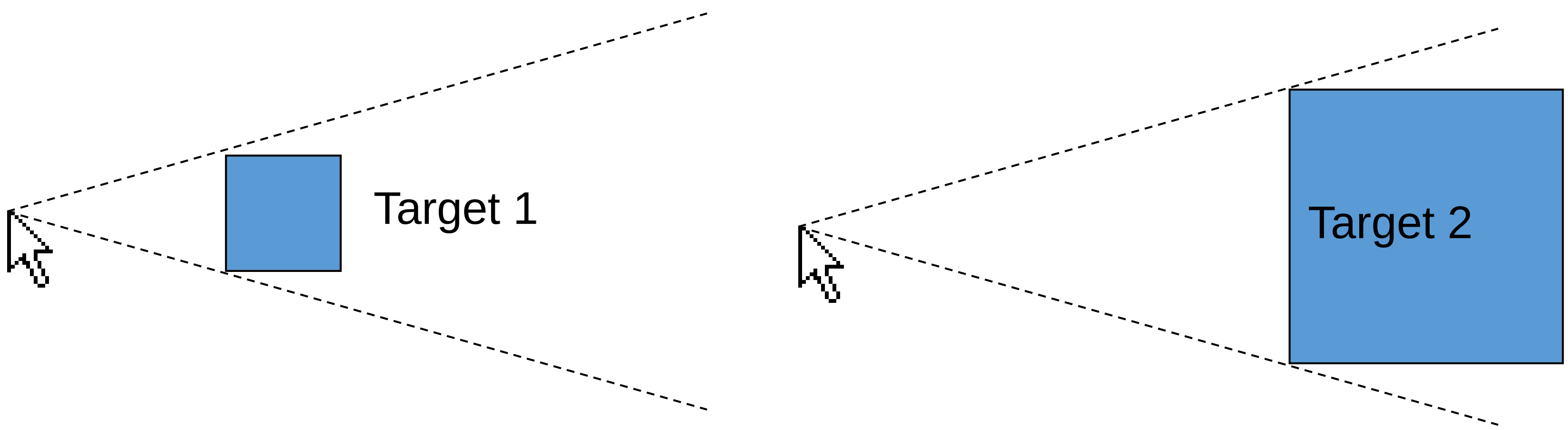

$$ID\,[\text{bits}] = \log_2\left(\frac{D}{W} + 1\right)$$

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

Only Relative Precision (D / W) Matters

# Fitts' Law

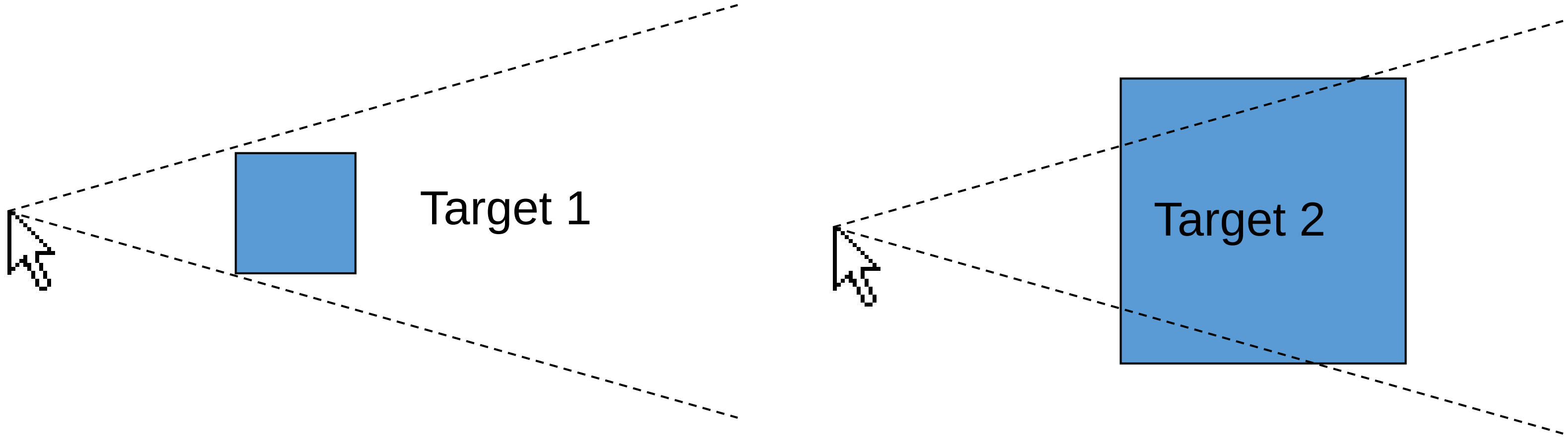
$$\text{Time} = a + b \log_2(D/S+1)$$




Same ID → Same Difficulty

# Fitts' Law

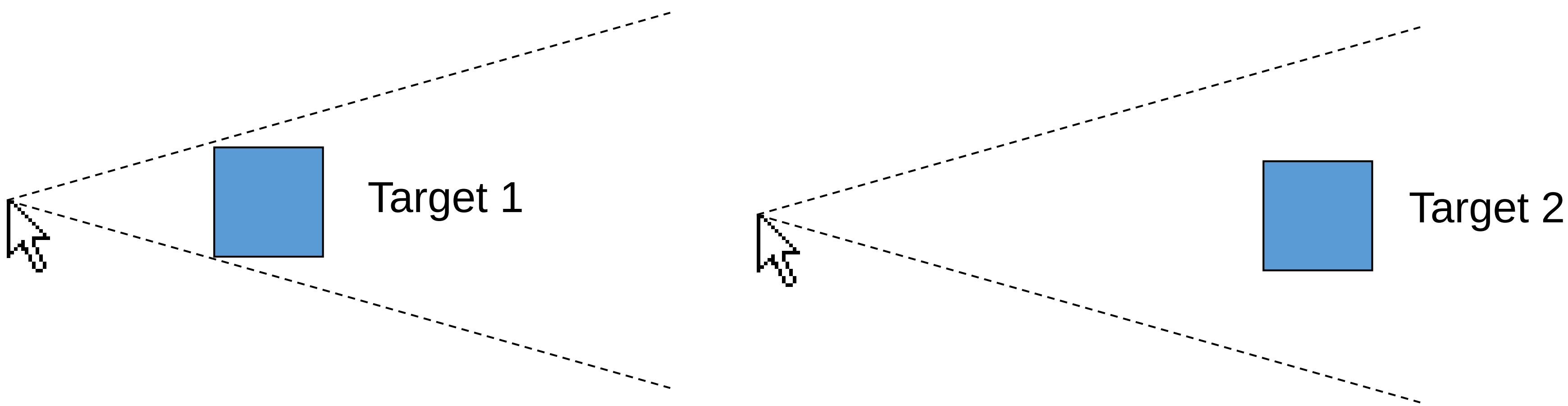
$$\text{Time} = a + b \log_2(D/S+1)$$




Smaller ID → Easier

# Fitts' Law

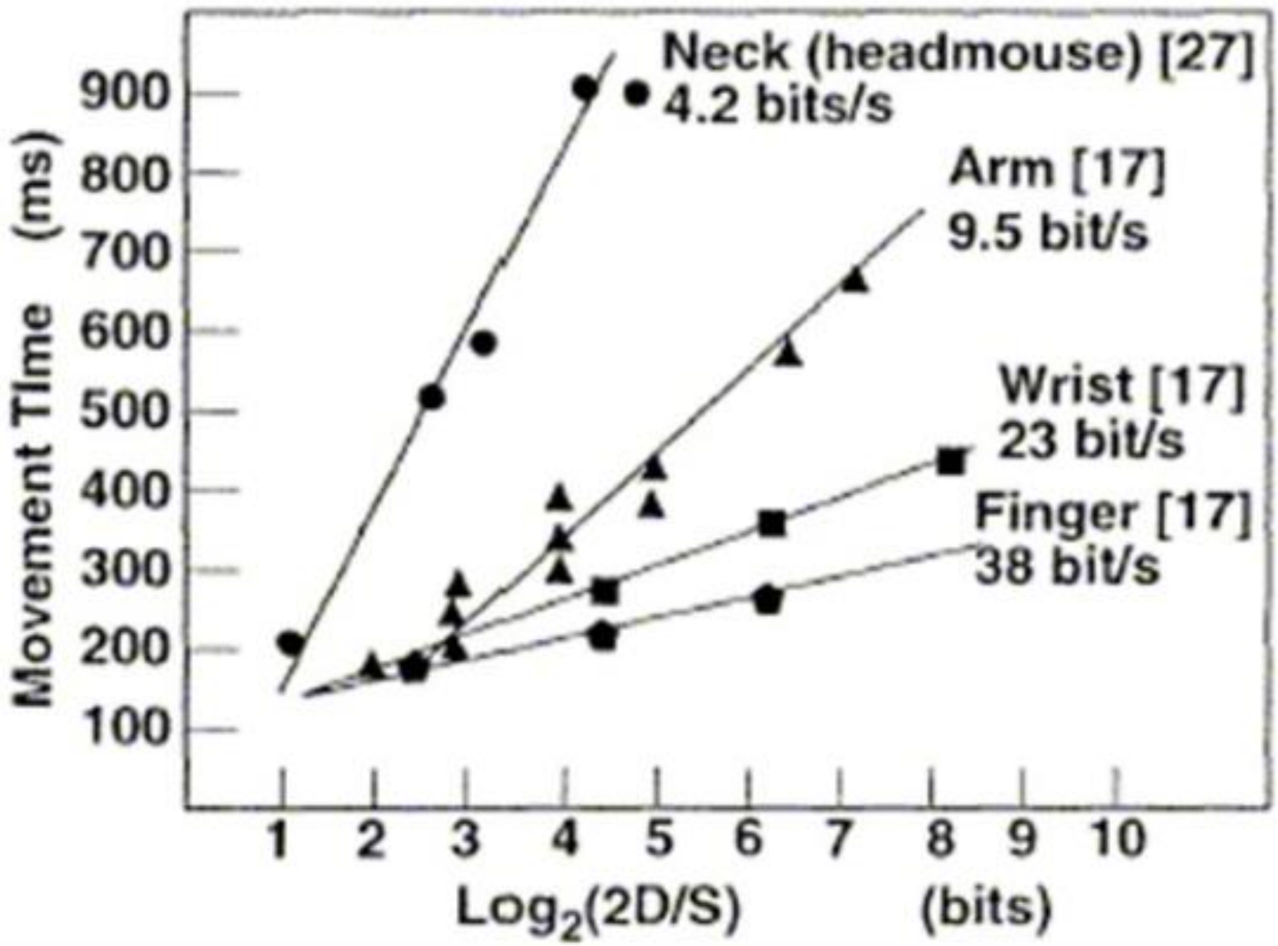
Time = a + b $\log_2(D/S+1)$




Larger ID → Harder

# Bandwidth (IP) of Human Muscle Groups

*IP = 1/b*



# Which is faster?

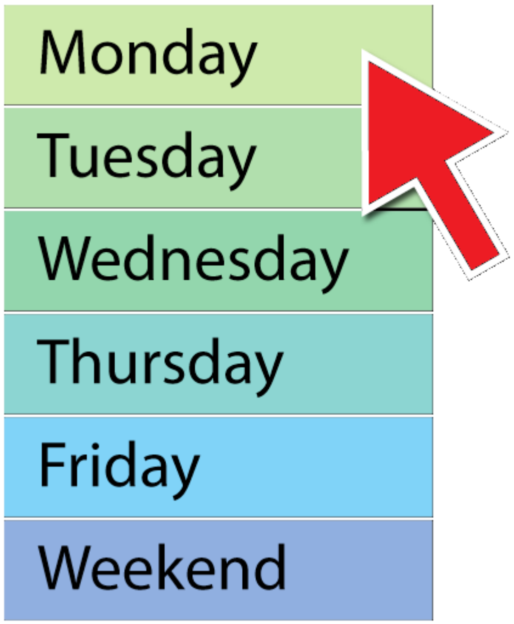

Head Mouse

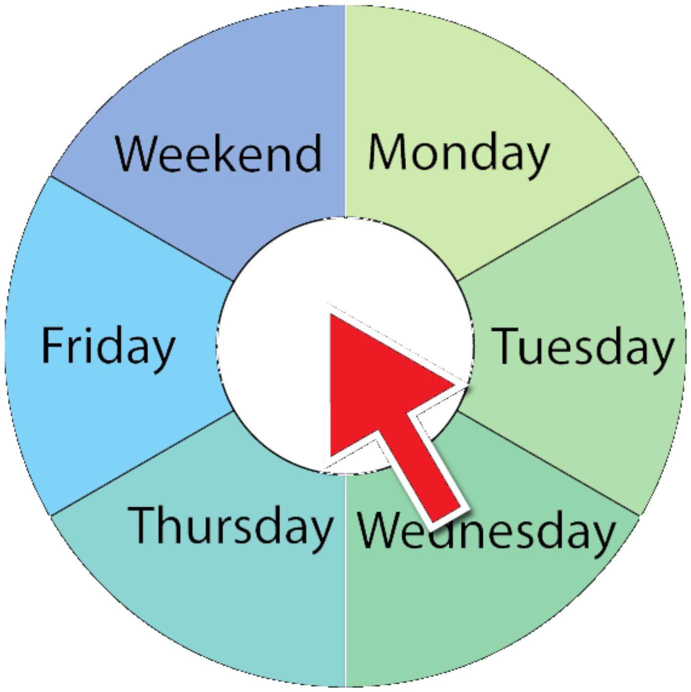
# 50 years of data

| 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*

# Fitts’ Law Example

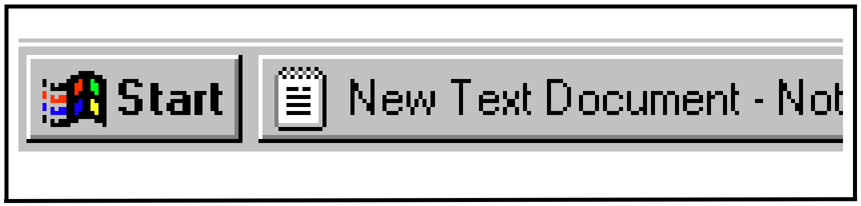


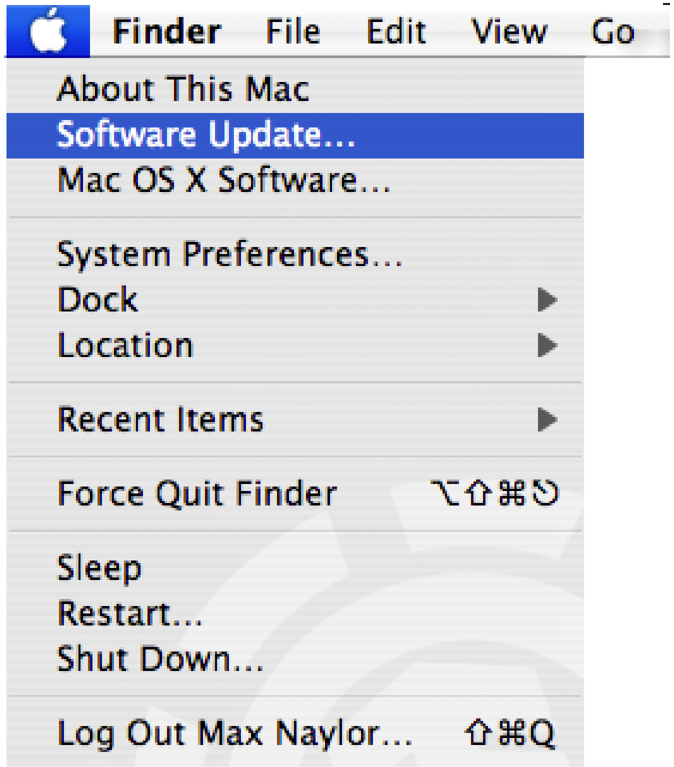

Which will be faster on average?

pie menu (bigger targets & less distance)

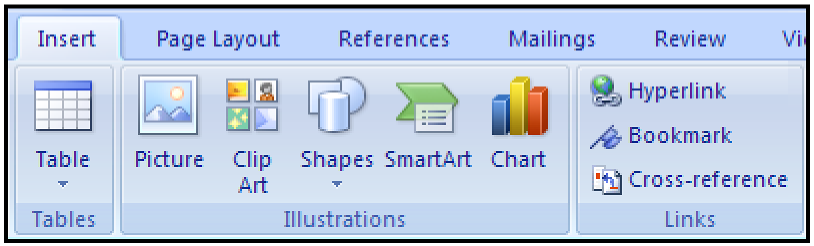
# Fitts' Law in Windows and Mac OS



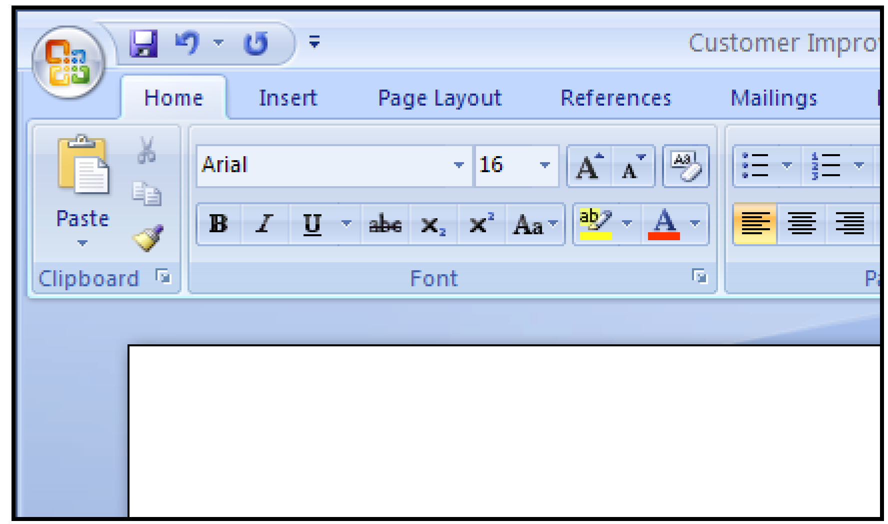

**Windows 95: Missed by a pixel**



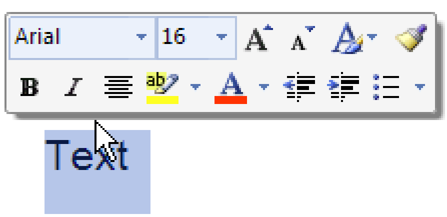
# Fitts' Law in Office 2007




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.

# 2D Fitts’ Law

- Fitts’ Law is for 1D. How about 2D?
  - Extending Fitts' law to two-dimensional tasks (CHI 92’, Mackenzie and Buxton)
    - 5 simple model proposed, 2 of them outperform according to the experiment

- Find a more accurate model?
  - Refining Fitts’ law models for bivariate pointing (CHI 02’, Johnny Accot and Shumin Zhai)
    - Consider the interaction between width and height of the target

# Extending Fitts' law to Two-Dimensional Tasks

- Original Fitts' Law

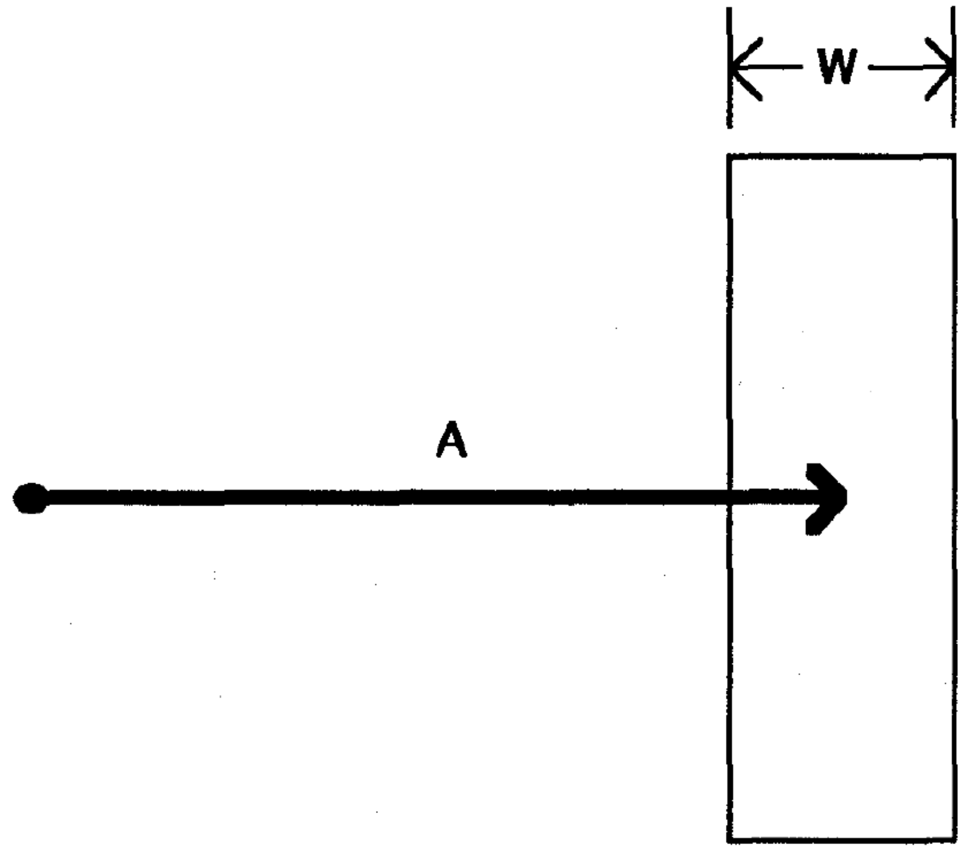
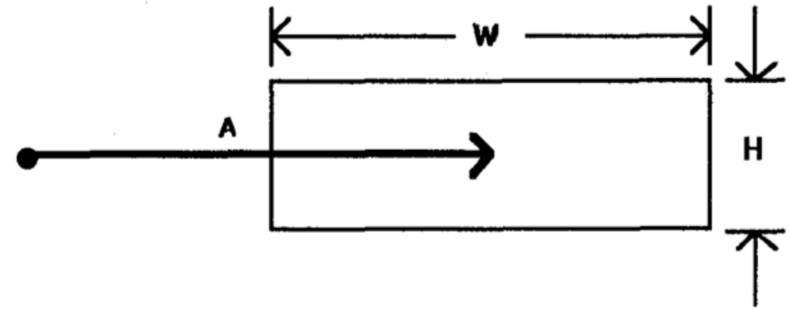


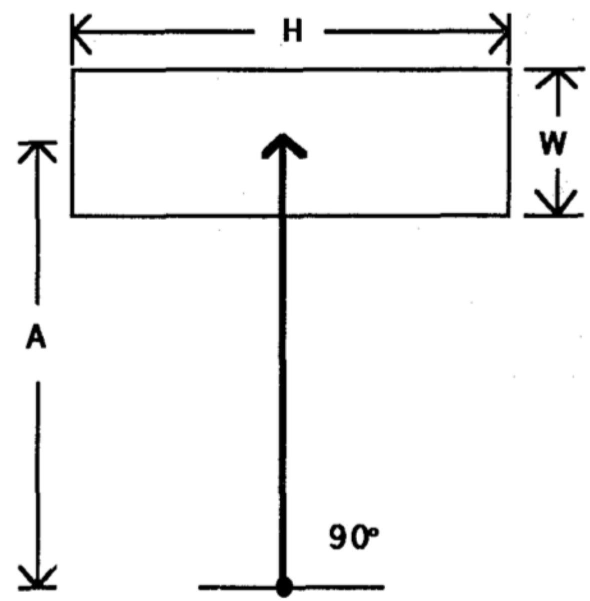

**Figure 1.** Fitts' law paradigm. The law is inherently one-dimensional since target amplitude (*A*) and width (*W*) are measured along the same axis.

# Extending Fitts' law to Two-Dimensional Tasks

- Which one should we take into account? Width? Or Height?




(a)




(b)

# Extending Fitts' law to Two-Dimensional Tasks

- How about the cases which are not horizontal or vertical?

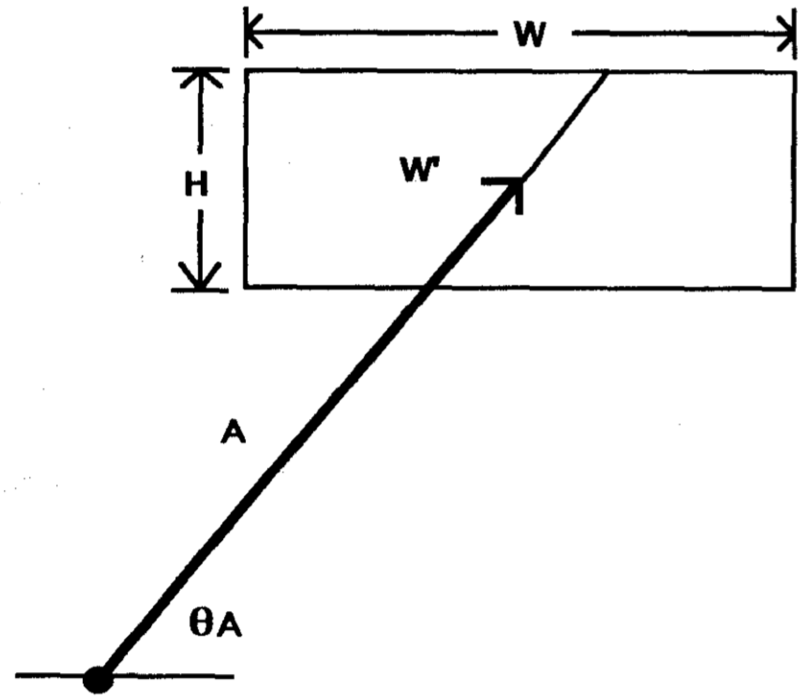



**Figure 3.** What is target width? Possibilities include *W'* (the width of the target along an approach vector) or the smaller of *W* or *H*.

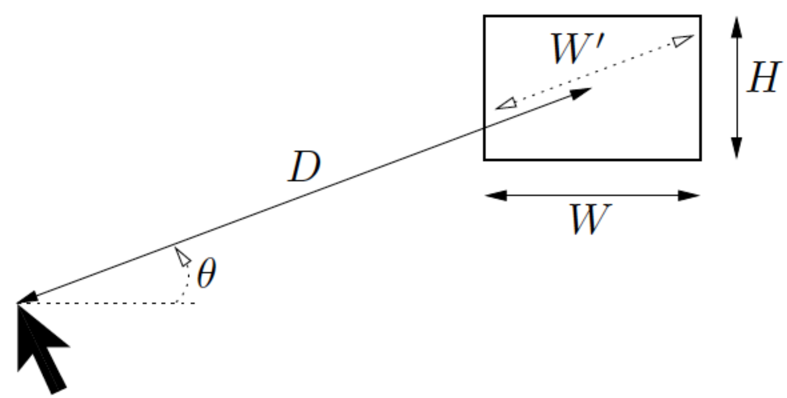
# Extending Fitts' law to Two-Dimensional Tasks

- 5 model proposed
  - "STATUS QUO" model
  - "SMALLER OF" model
  - Apparent width W' model
  - Substitute W with W*H
  - Substitute W with W+H

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

$$ID_{\min(W,H)} = \log_2\left(\frac{D}{\min(W,H)} + 1\right)$$

$$ID_{W'} = \log_2\left(\frac{D}{W'} + 1\right)$$



# Extending Fitts' law to Two-Dimensional Tasks

- Experiment Result

**Empirically, this is the best**

| Model for Target Width | *ID* Range (bits) Low | High | $r^a$ | $SE^b$ (ms) | Regression Coefficients Intercept, $a$ (ms) | Slope, $b$ (ms/bit) | *IP* (bits/s) |
|---|---|---|---|---|---|---|---|
| SMALLER-OF | 1.58 | 5.04 | .9501 | 64 | 230 | 166 | 6.0 |
| $W'$ | 1.00 | 5.04 | .9333 | 74 | 337 | 160 | 6.3 |
| $W+H$ | 0.74 | 3.54 | .8755 | 99 | 402 | 218 | 4.6 |
| $W \times H$ | 0.32 | 4.09 | .8446 | 110 | 481 | 173 | 5.8 |
| STATUS QUO | 1.00 | 5.04 | .8097 | 121 | 409 | 135 | 7.4 |

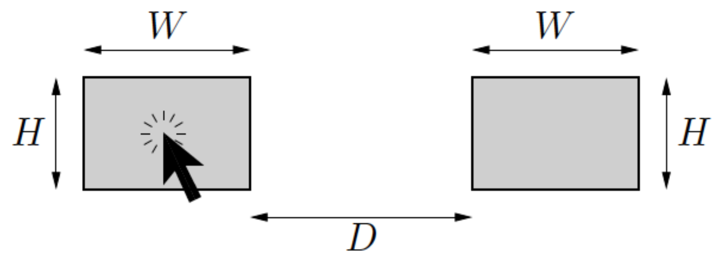
[a] $n = 78$, $p < .001$
[b] standard error of estimate

**Theoretically, this is similar to Fitts' Law**

**Figure 6.** Correlations and regression coefficients for five models for target width.

# Refining Fitts' law models for bivariate pointing

- Accot and Zhai proposed




$$T = a + b\,\log_2\left(\|X\|_{p,w} + 1\right)$$

$$X = \left(\frac{D}{W}, \frac{D}{H}\right) \qquad \|x\|_{p,w} = \left(\sum_{i=1}^{n} w_i |x_i|^p\right)^{1/p}$$

$$T = a + b\,\log_2\left(\left[\omega\left(\frac{D}{W}\right)^p + \eta\left(\frac{D}{H}\right)^p\right]^{1/p} + 1\right)$$

Johnny Accot and Shumin Zhai. 2003. Refining Fitts' law models for bivariate pointing. (CHI '03). 193-200.

# Refining Fitts' law models for bivariate pointing

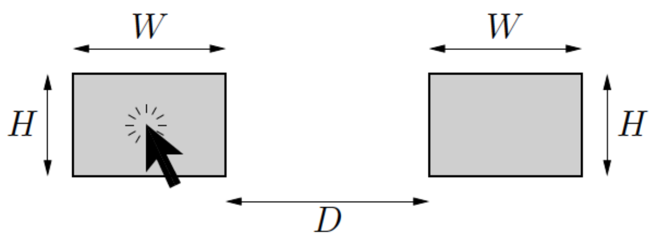
- Experiment cases

$$
\begin{array}{llllllll}
W = H: & W = H = 8 & & & W = H = 48 & & & \\
 & W = H = 24 & & & W = H = \infty & & & \\
 & & & & & & & \\
W < H: & W = 8, & H & = \{10, & 12, & 16, & 24, & 40, \ \infty\} \\
 & W = 24, & H & = \{30, & 36, & 48, & 72, & 120, \ \infty\} \\
 & W = 48, & H & = \{60, & 72, & 96, & 144, & 240, \ \infty\} \\
 & & & & & & & \\
W > H: & H = 8, & W & = \{10, & 12, & 16, & 24, & 40, \ \infty\} \\
 & H = 24, & W & = \{30, & 36, & 48, & 72, & 120, \ \infty\} \\
 & H = 48, & W & = \{60, & 72, & 96, & 144, & 240, \ \infty\}
\end{array}
$$

Table 1: Target width & height conditions

# Refining Fitts' law models for bivariate pointing

- Conclusion




$$T = a + b\log_2\left(\sqrt{\left(\frac{D}{W}\right)^2 + \eta\left(\frac{D}{H}\right)^2} + 1\right)$$

η: [1/7, 1/3]

# Power Law of Practice

- Task time on the nth trial follows a power law

  $$T_n = T_1 n^{-a} + c$$

  where a = .4 [.2 ~ .6], c = limiting constant

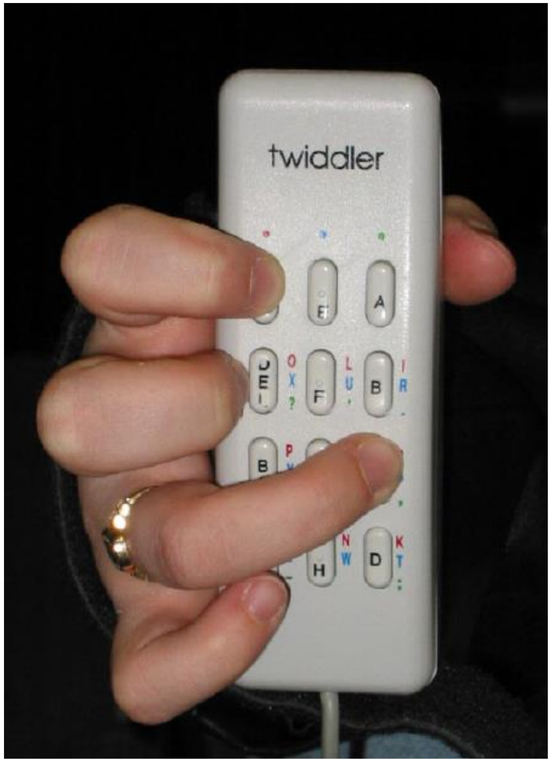
  - You get faster the more times you do it!

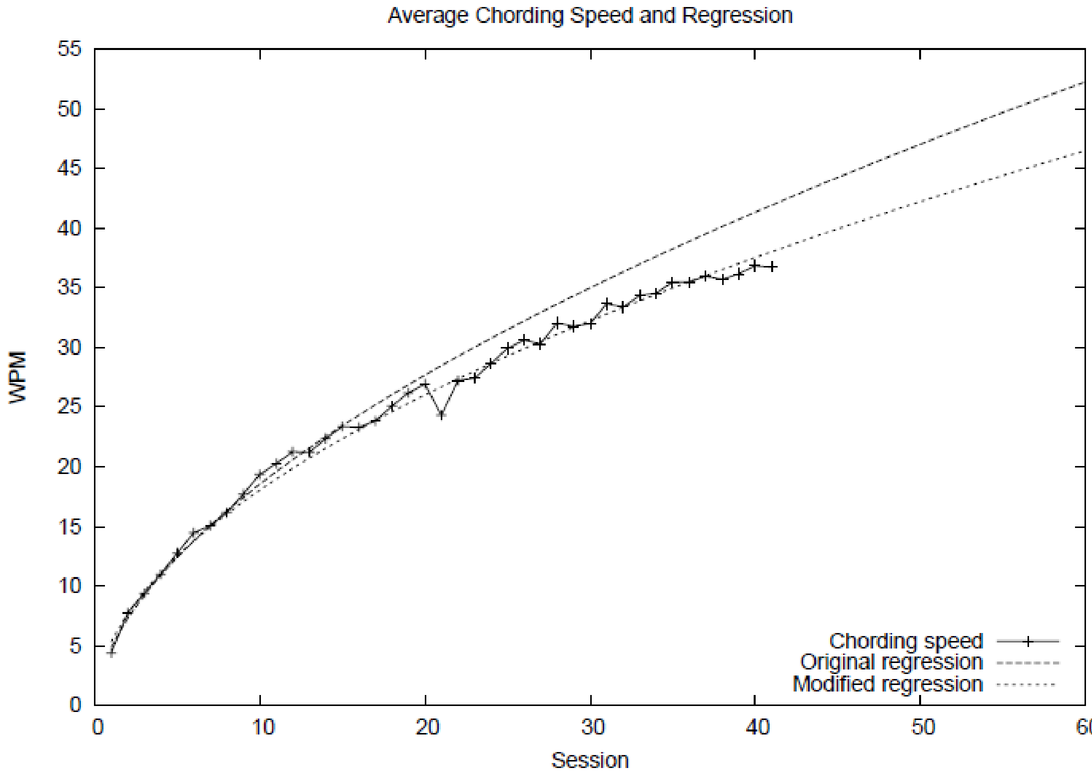
Applies to skilled behavior (sensory & motor)

Does not apply to

- Knowledge acquisition

# An Example of Power Law of Practice




$$\text{Original regression}: \quad y = 4.8987x^{0.5781}, R^2 = 0.9849$$

$$\text{Modified regression}: \quad y = 5.3503x^{0.5280}, R^2 = 0.9787$$

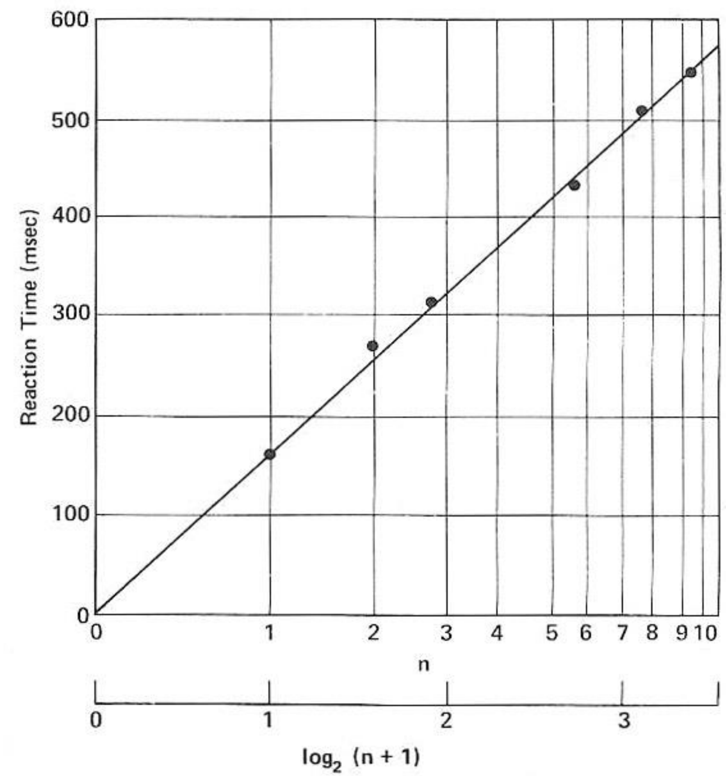
K. Lyons, D. Plaisted and T. Starner, "Expert chording text entry on the Twiddler one-handed keyboard," *Eighth International Symposium on Wearable Computers*, 2004, pp. 94-101

# Choice Reaction Time

# Hick's Law

The time it takes for a person to make a decision as a result of the possible choices he or she has: increasing the number of choices will increase the decision time logarithmically.

$$T = b \cdot \log_2(n+1)$$




At the onset of one of *n* lights, arranged in a row, the subject is to press the key located Below the light (After Welford, 1968, p62)

# Hick's Law

**Uncertainty Principle.** Decision time $T$ increases with uncertainty about the judgment or decision to be made:

$$T = I_C H,$$

where $H$ is the information-theoretic entropy of the decision and $I_C$ = 150 [0–157] ms/bit. For $n$ equally probable alternatives (called Hick's Law),

$$H = \log_2 (n + 1).$$

For $n$ alternatives with different probabilities $p_i$ of occurrence,

$$H = \Sigma_i \, p_i \log_2 (1/p_i + 1).$$

# Today’s Questions

*You have a palette of tools in a graphics application that consists of a matrix of 16x16-pixel icons laid out as a 2x8 array that lies along the left-hand edge of the screen. Without moving the array from the left-hand side of the screen or changing the size of the icons, what steps can you take to decrease the time necessary to access the average tool?*

1. Change the array to 1X16, so all the tools lie along the edge of the screen.

2. Ensure that the user can click on the very first row of pixels along the edge of the screen to select a tool. There should be no buffer zone.