HCID 520

User Interface Software & Technology

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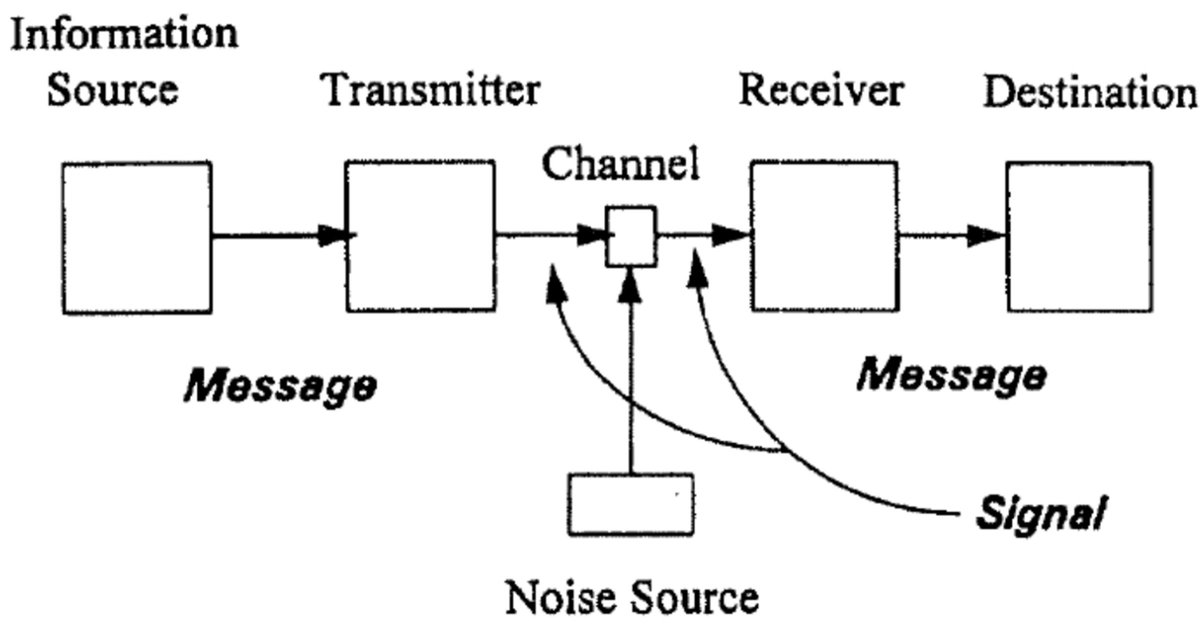
Introducing Fitts' law

- Developed in 1954 by P.M. Fitts
- Models movement time for ***aimed*** movements
  - Reaching for a control in a cockpit
  - Moving across a dashboard
  - Pulling defective items from a conveyor belt
  - Clicking on icons using a mouse
- Very powerful, widely used
  - Holds for many circumstances (e.g., under water)
  - Allows for comparison among different experiments
  - Used both to measure and to predict

Information transmission

- Claude Shannon (1948)



Law by analogy
(Fitts 1954)

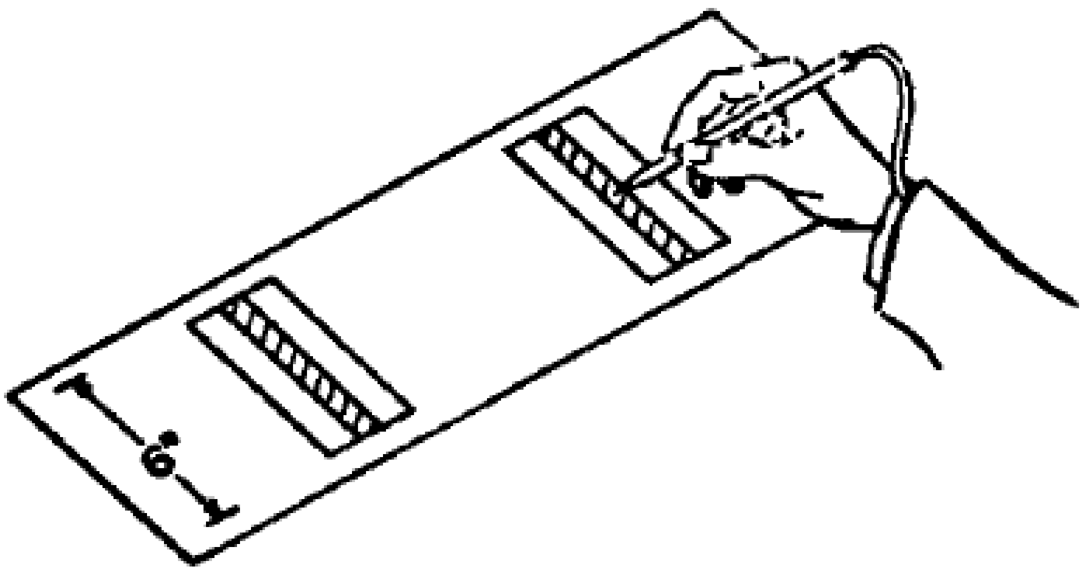
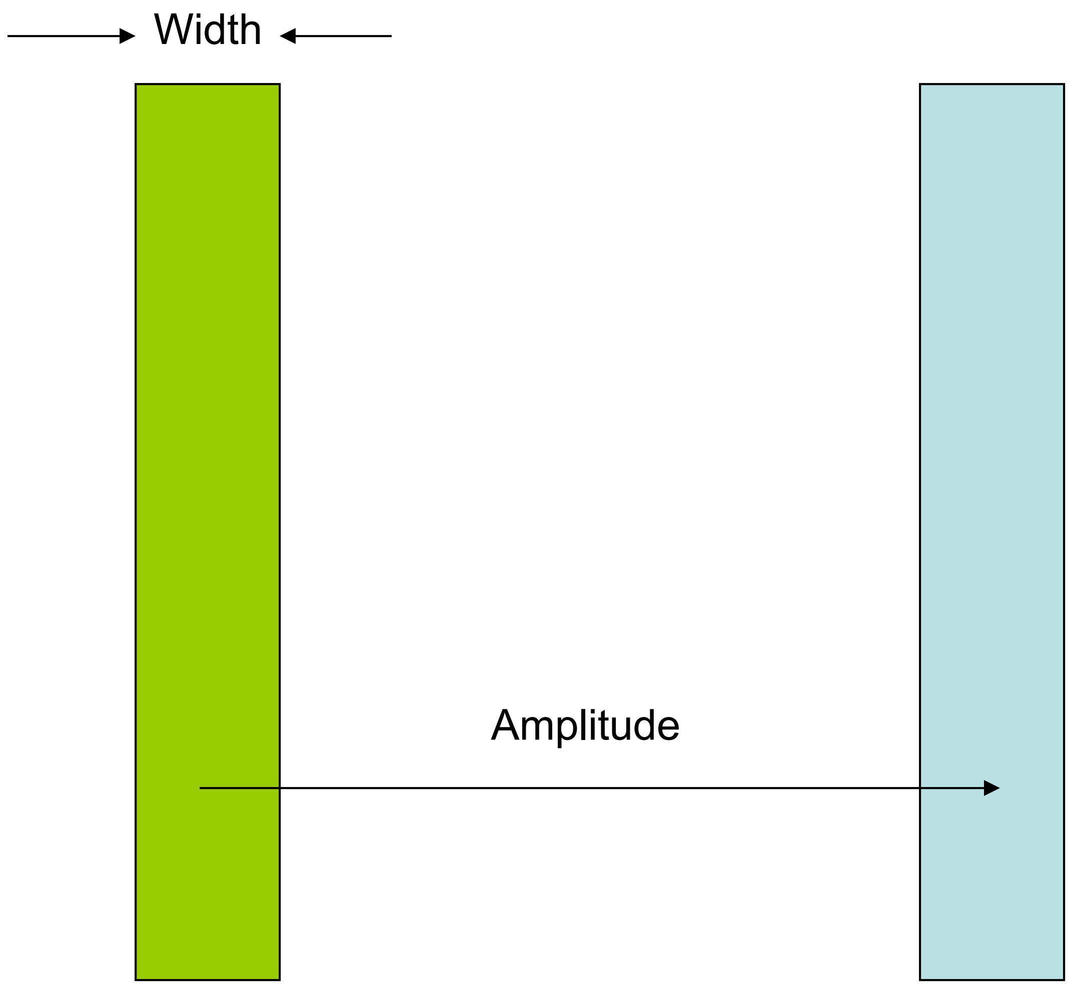


Figure 1. Reciprocal tapping apparatus. The task was to hit the center plate in each group alternately without touching either side (error) plate.

Reciprocal point-select task



Closed loop, open loop

- What is **closed loop** motion?
  - Closed-loop means the evolving system state is available to the system itself (*i.e.*, it can adjust).
  - Rapid aimed movements with feedback correction
  - Fitts' law models this

- What is **open loop** motion?
  - Open-loop means the evolving system state is not available to the system itself (*i.e.*, it is "set in motion").
  - Ballistic movements without feedback correction
  - A dart once released!
  - Schmidt's law (1979) models this (coming soon…)

Fitts' equation

- $MT = a + b \underbrace{\log_2(A / W + 1)}$
  - What kind of equation does this remind you of?

- $y = mx + b$

- $MT = a + bx$, where $x = \log_2(A / W + 1)$
  - x is called the Index of Difficulty (ID)
  - As "A" goes up, ID goes up
  - As "W" goes up, ID goes down

Index of difficulty (ID)

- $\log_2(A / W + 1)$

- Fitts' law claims that the time to acquire a target (MT) goes up ***linearly*** with the log of the ***ratio*** of the movement distance (A) to target width (W)

- Why is it significant that it is a ratio?
  – Units of A and W don't matter!
  – Allows us to compare across different experiments

- ID units in "bits"
  – Because of association with information capacity and somewhat arbitrary use of base-2 for the logarithm.

Index of performance (IP)

- $MT = a + b \log_2(A / W + 1)$
- b is slope
- 1/b is called Index of performance (IP)
  - If MT is in seconds, IP is in bits/second

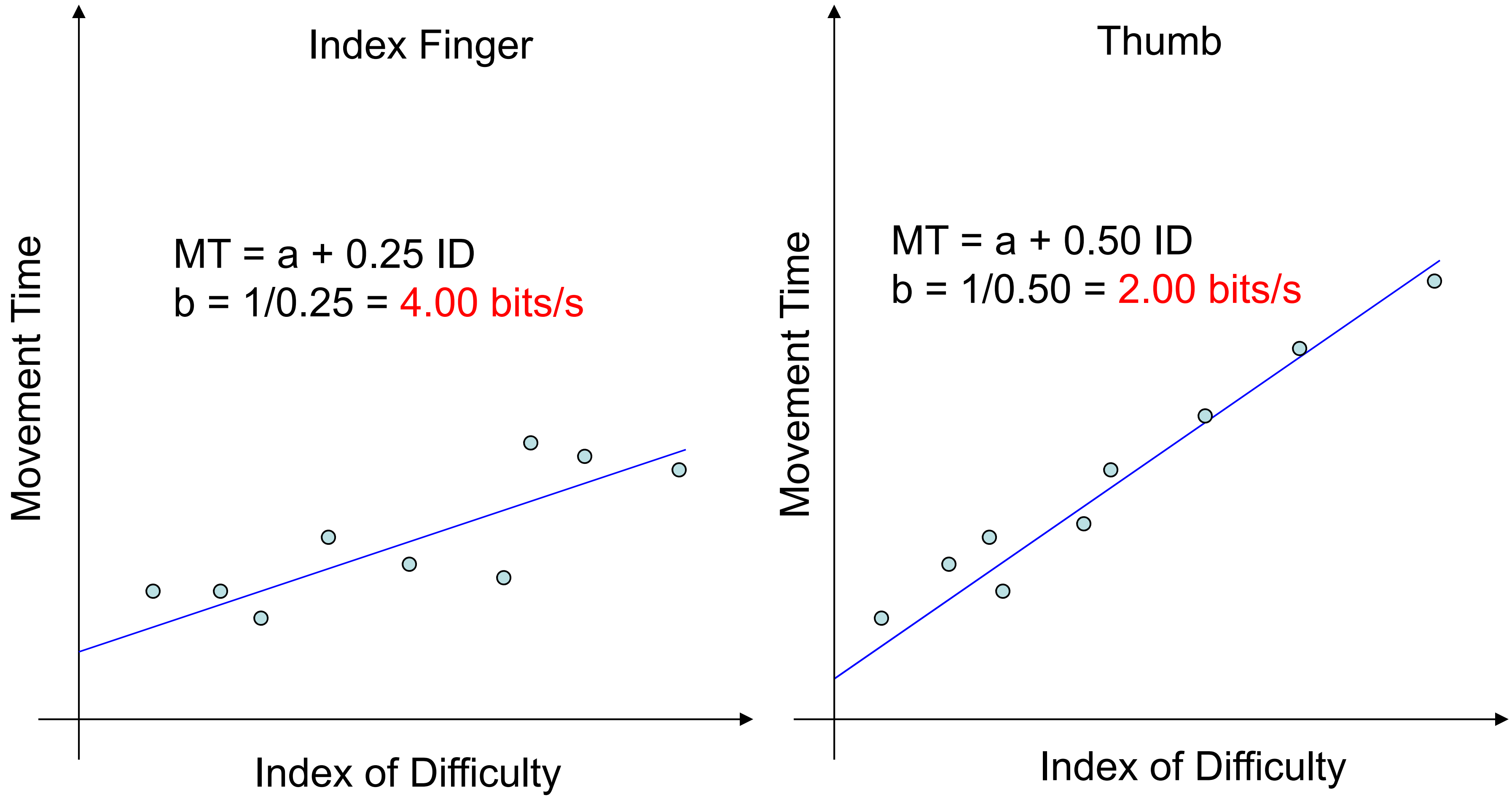
- Bits per second is also called “throughput” or “bandwidth”
  - Think of the human as an information channel from one target to another

Let's do an example

- Example: Compare index fingers to thumbs
- Use a range of target sizes (W) and movement distances (A)
  - A range of Indexes of Difficulty (IDs)
- Do all combinations with both fingers
- What can we conclude?

Data

Which finger has better performance?



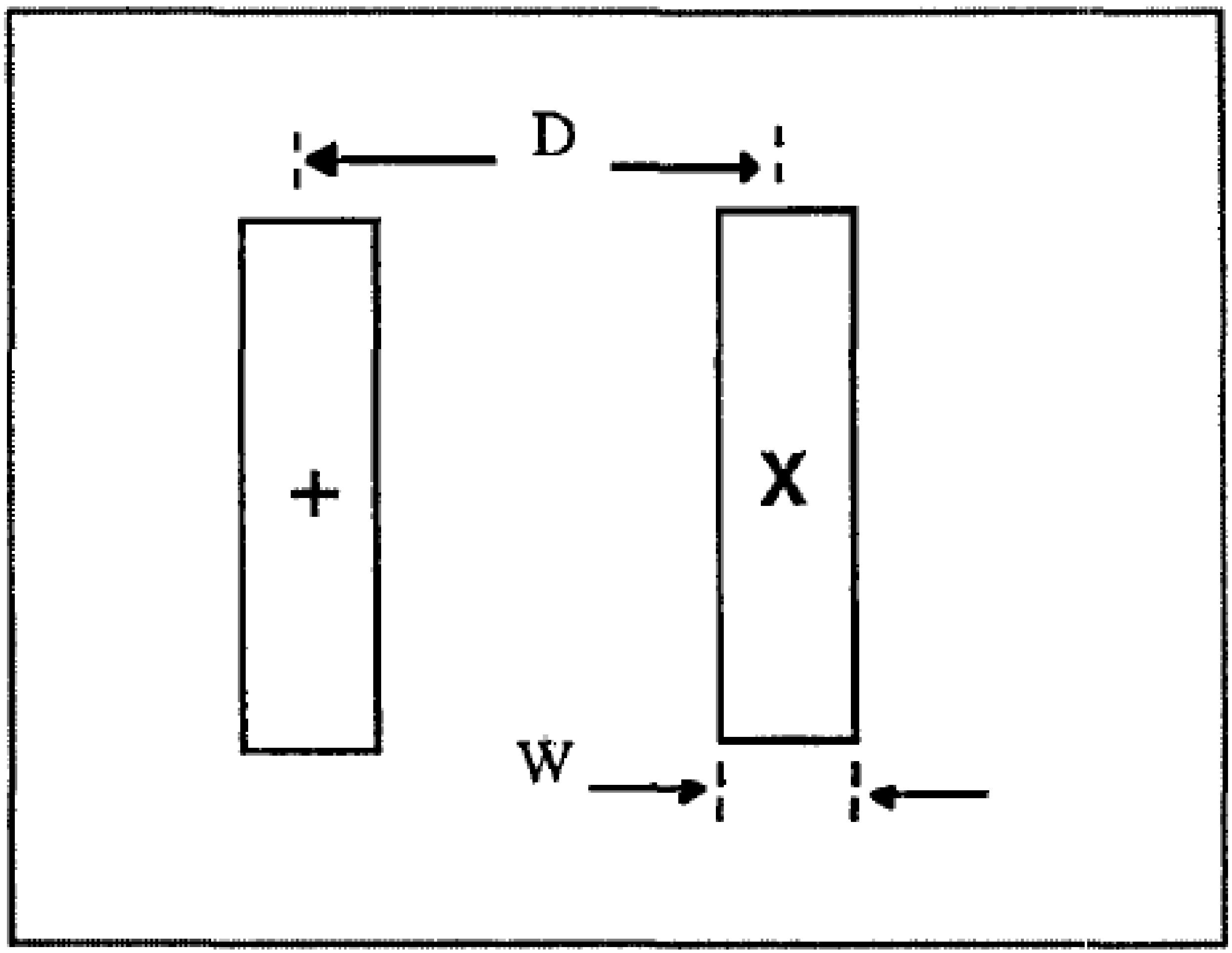
Other comparisons

- *Devices*: trackballs *vs.* mice
- *Limbs*: fingers *vs.* forearms
- *Populations*: elders *vs.* children
- *Situations*: standing vs. walking
- …

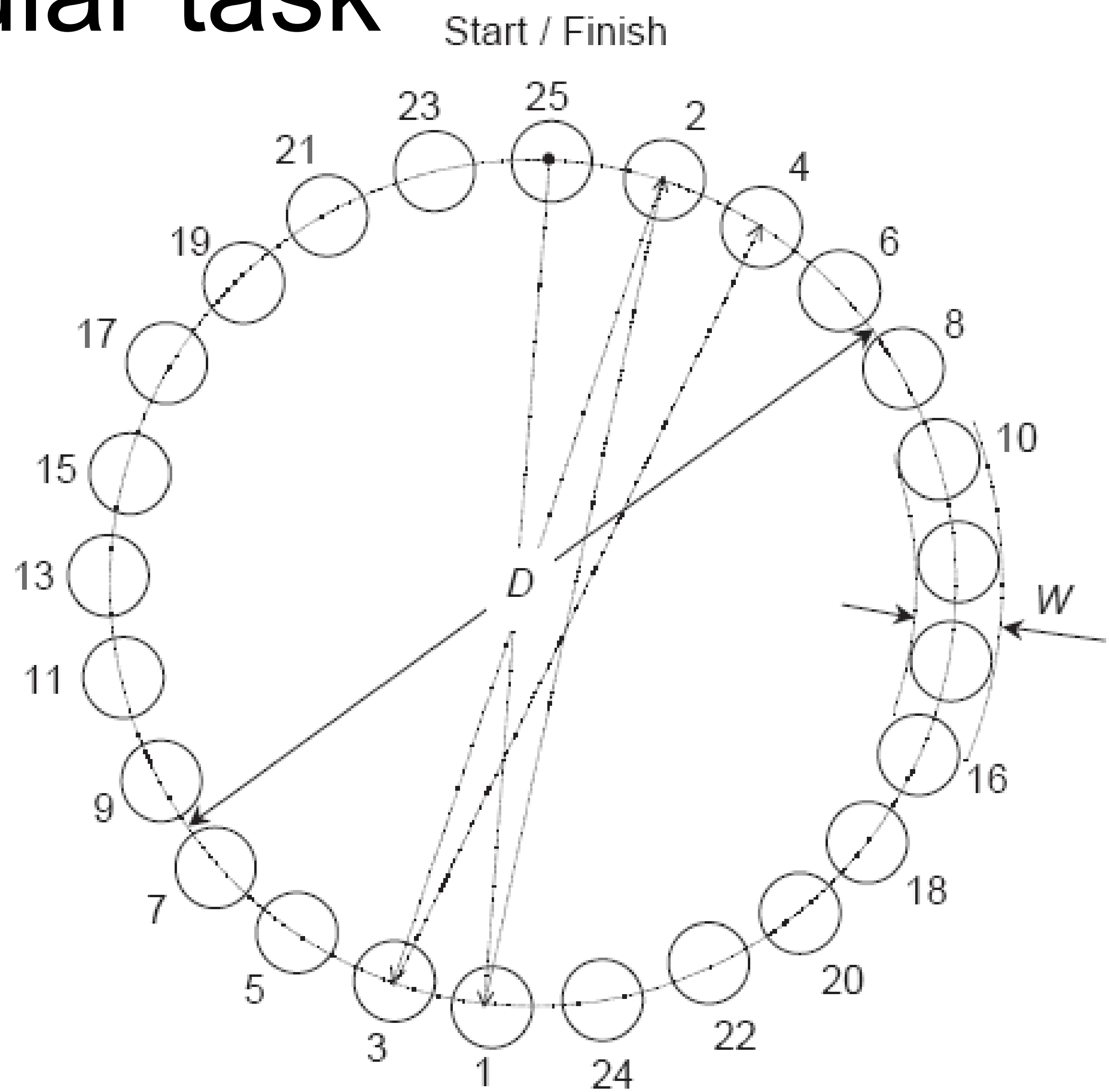
Limitations of Fitts' law

- Does not predict error rates
  - Assumes a normal distribution of hits around the target center with a ~4% error rate
- Assumes "aimed movement"
  - Not applicable to ***ballistic*** motion
- Dependent upon *a* and *b* coefficients
  - Must be elicited for each new device and user
- A law based on an unlikely analogy
  - Works great, but no *a priori* reason it should!

Reciprocal 1D pointing



Circular task



Speed-accuracy correction

- People operate with different personal speed-accuracy biases.
- How should we equitably compare “Nancy Cautious” to “Joe Reckless”?

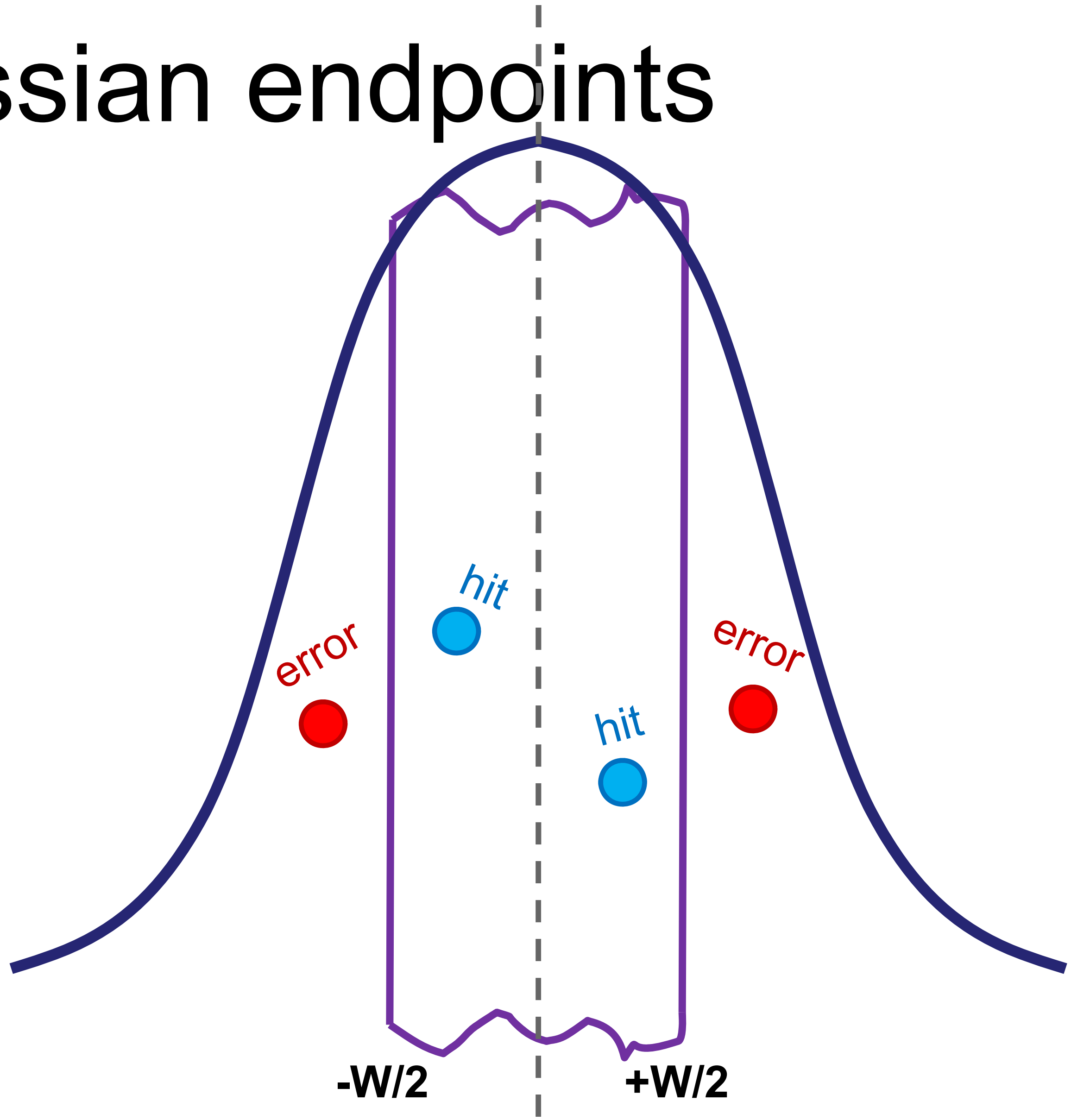
Example of problem

- Nancy Cautious: 2% errors, $\overline{MT}$ = 2.0s
- Joe Reckless: 7% errors, $\overline{MT}$ = 1.0s
- What to do with errors?
  - Drop them?
  - Include them? How?
- Who has better *throughput*?
  How to fairly compare?

~4% error rate

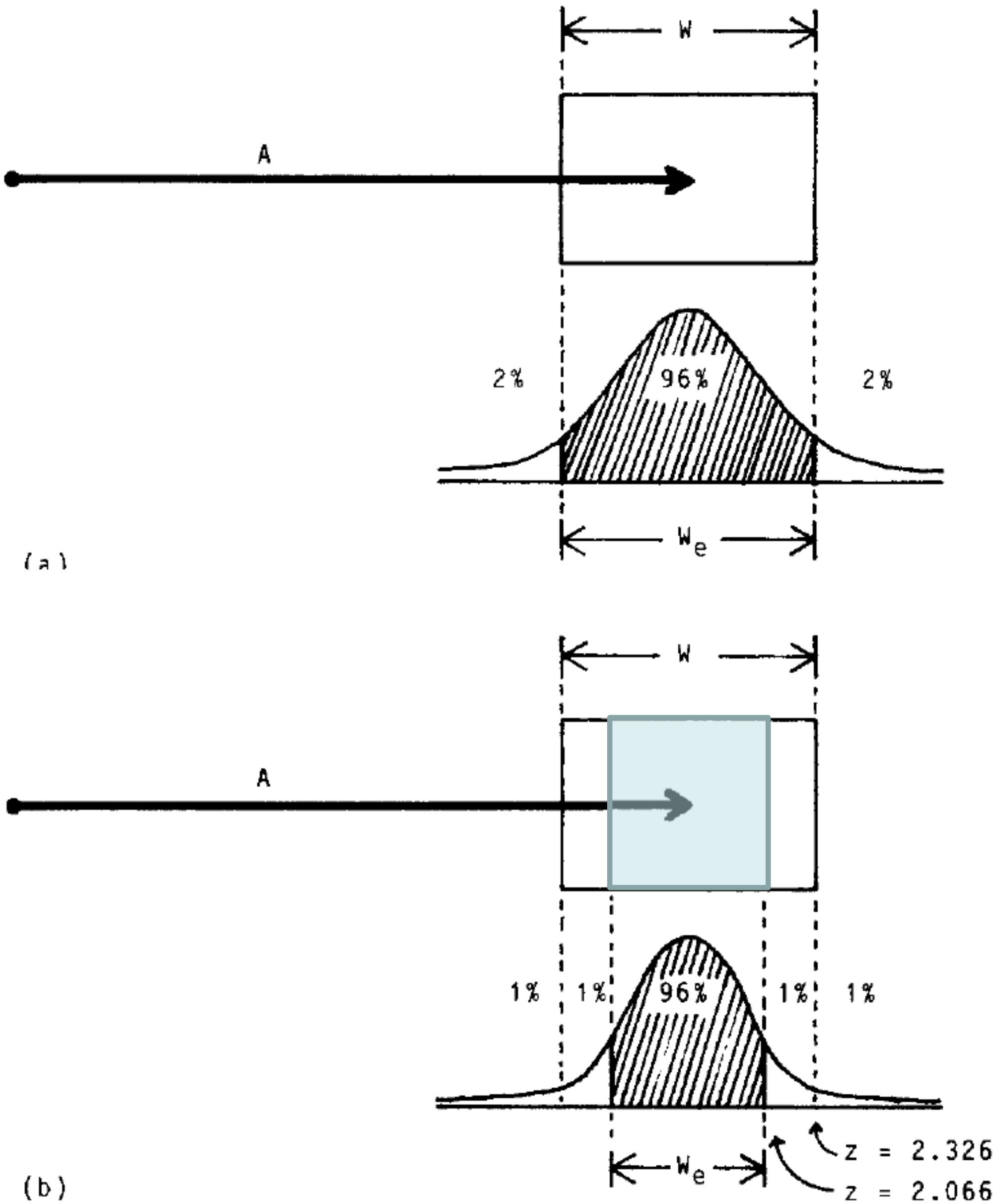
- Fitts' law assumes a 4% error rate
  - Based on Shannon's information theory, related to the entropy of a standard normal distribution.
  - Endpoint selections are normal (Gaussian) about the target center.

Gaussian endpoints



Crossman's correction (1957)

- Enforce a mathematical *post hoc* 4% error rate by adjusting W accordingly.
- Call this new width W_e, for "effective target width."



$W_e = W$

$W_e < W$

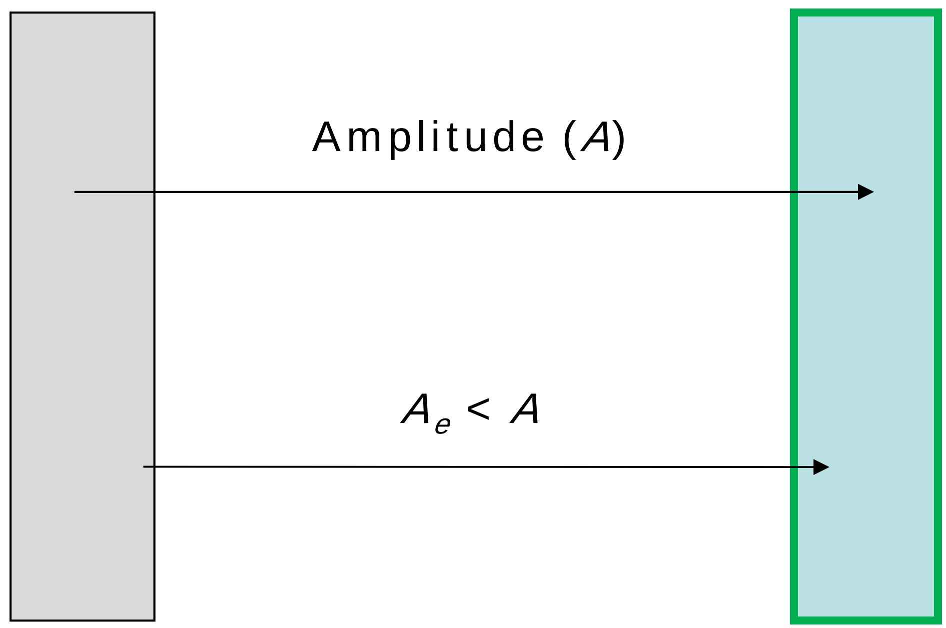
(MacKenzie 1992)

Computing W_e in 1-D

- **Method 1:** You know the coordinates of all selection endpoints.
  - Compute SD_x, the standard deviation in the x-dimension
  - $W_e = 4.133 * SD_x$
- **Method 2:** You only know the error rate *e*.
  - On a table of *z*-scores, find *z* such that ±*z* contains 100 – *e* percent of the area under the standard normal distribution, where *e* is error rate.
  - $W_e = W * 2.066/z$
  - In Excel: =(2.066/-NORMSINV(*e*/2))**W*

Effective amplitude (A_e)

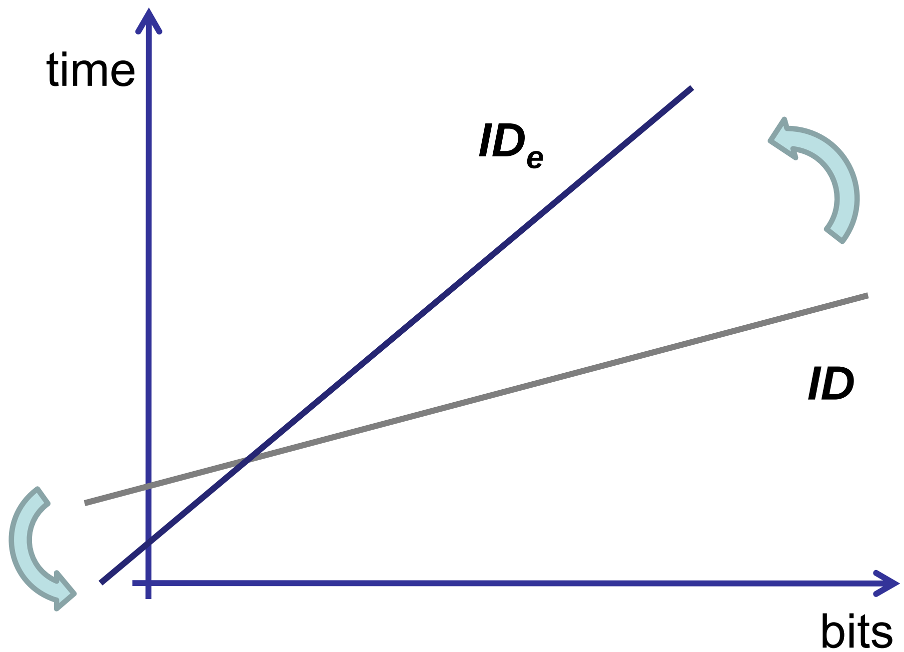
- Use the *actual* distance traveled, not the nominal distance between target centers.



Effective index of difficulty

- $ID = \log_2(A / W + 1)$
- $ID_e = \log_2(A_e / W_e + 1)$ // normalizes speed-accuracy

Usual effect of using ID_e.

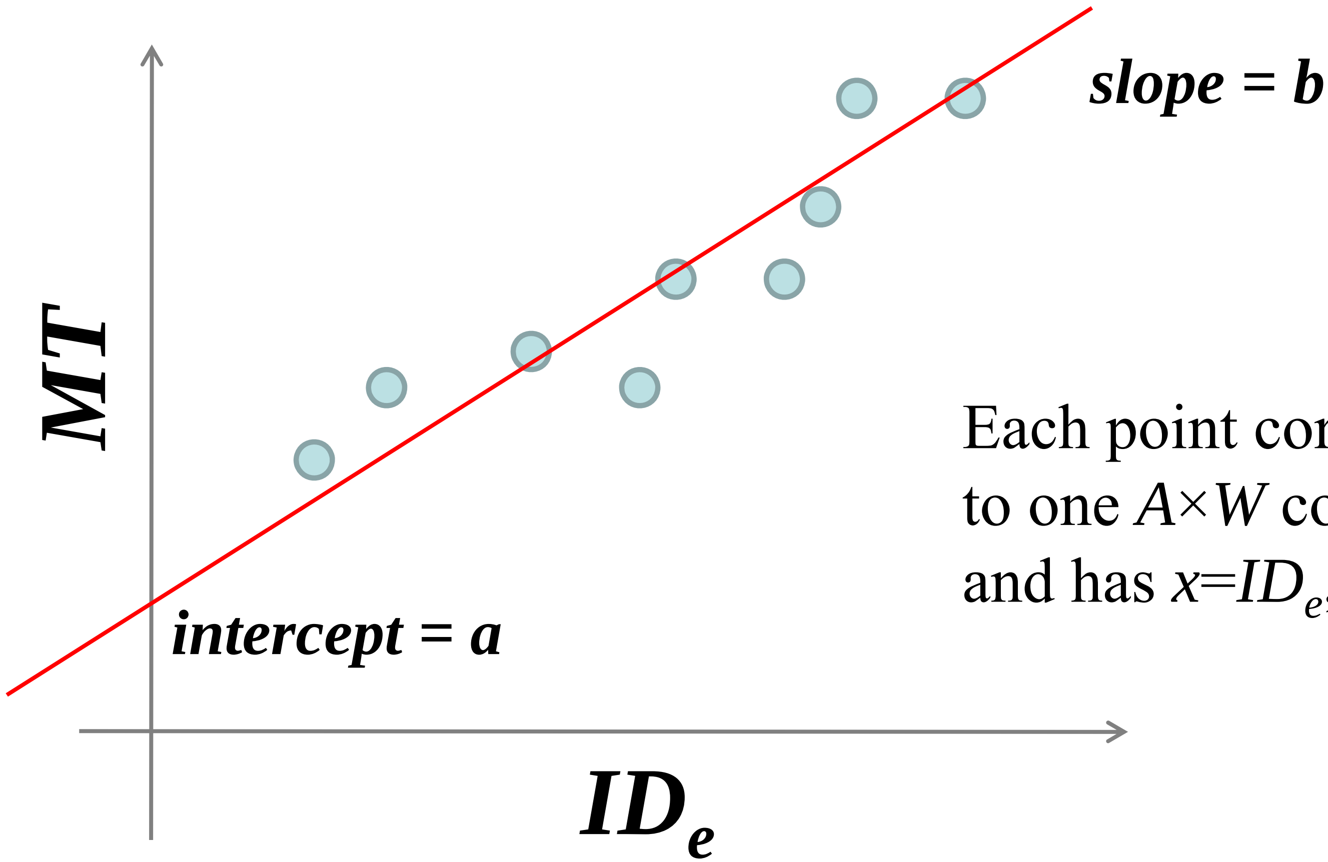


Recipe for a Fitts' law evaluation

1. Recruit S subjects.
2. Define N $A \times W$ conditions each having M targets.
3. Run each subject $s \in S$ through the N conditions.
4. For each condition $n \in N$ for each subject $s \in S$, plot one point (ID_e, MT).
5. For each subject $s \in S$, regress on their N points. Extract intercept (a) and slope (b) parameters.
6. Calculate throughput using one of two methods. (We'll talk more about this.)
7. For "grand" throughput, calculate mean of all subjects' throughputs.

Regression on what points?

Per subject:



Each point corresponds to one $A \times W$ condition, and has $x = ID_e$, $y = \overline{MT}$.

ISO 9241-9, Annex B

$$\text{Throughput} = \frac{\text{Effective index of difficulty}}{\text{Movement time}} = \frac{ID_e}{t_m}$$

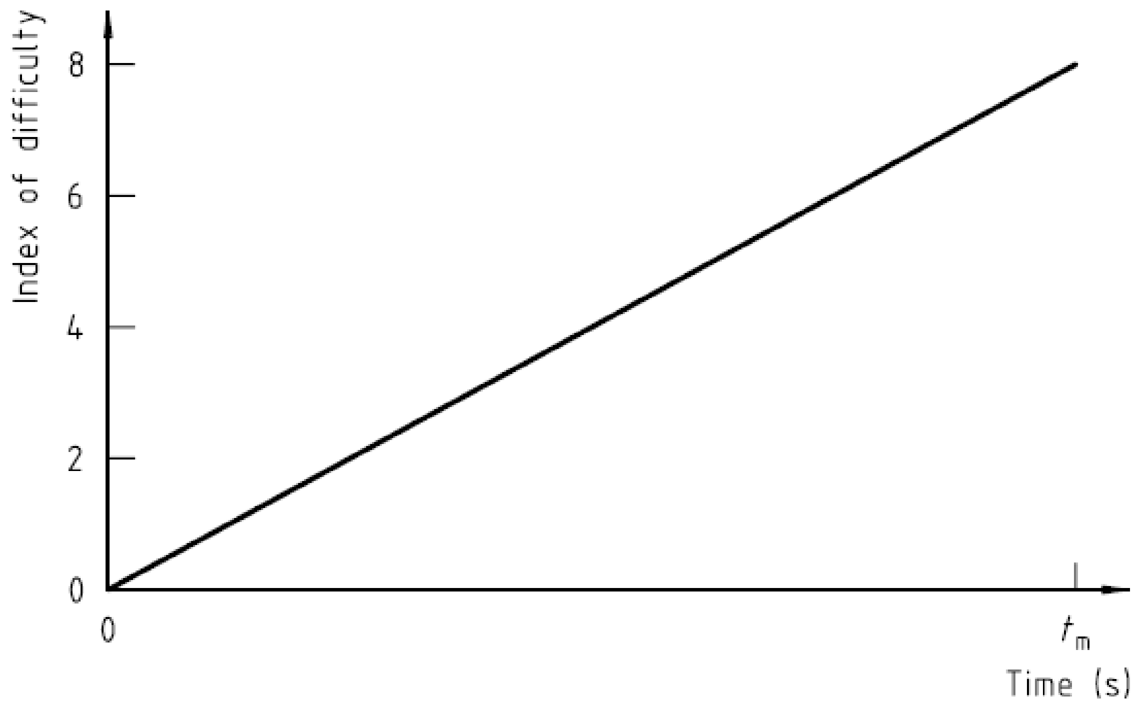
where

ID_e is the effective index of difficulty for a movement task;

t_m is the movement time, calculated from the initiation of movement of the input device to target selection.

vs.

A graph of movement time is plotted against the effective index of difficulty and a linear relationship is obtained (see Figure B.1). The slope of the line represents the throughput of the device, in bits per second.



t_m Movement time

Throughput debate

- Soukoreff and MacKenzie (2004) argue for mean of means:

$$TP = \frac{1}{S}\sum_{i=1}^{S}\left(\frac{1}{n}\sum_{j=1}^{n}\frac{ID_{e_{ij}}}{MT_{ij}}\right)$$

- Zhai (2004) argues for slope reciprocal 1/*b*, and report *a* separately. For all subjects:

$$TP = \frac{1}{S}\sum_{i=1}^{S}\frac{1}{b_i}$$

Soukoreff & MacKenzie (2004)

- $TP = {ID_e}\big/{MT}$, $ID_e = \log_2\left(\frac{A_e}{W_e} + 1\right)$
- For each subject in each *A*×*W* condition, compute: $A_e = \sum_{x=1}^{k} \frac{D_x}{k}$, $W_e = 4.133 \times SD_x$
- Each subject gets a set of $\left(ID_{e_j}, \overline{MT_j}\right)$ pairs for *j*=1 to *n* *A*×*W* conditions.
- Grand throughput for *S* subjects is: $$TP = \frac{1}{S}\sum_{i=1}^{S}\left(\frac{1}{n}\sum_{j=1}^{n}\frac{ID_{e_{ij}}}{\overline{MT_{ij}}}\right)$$

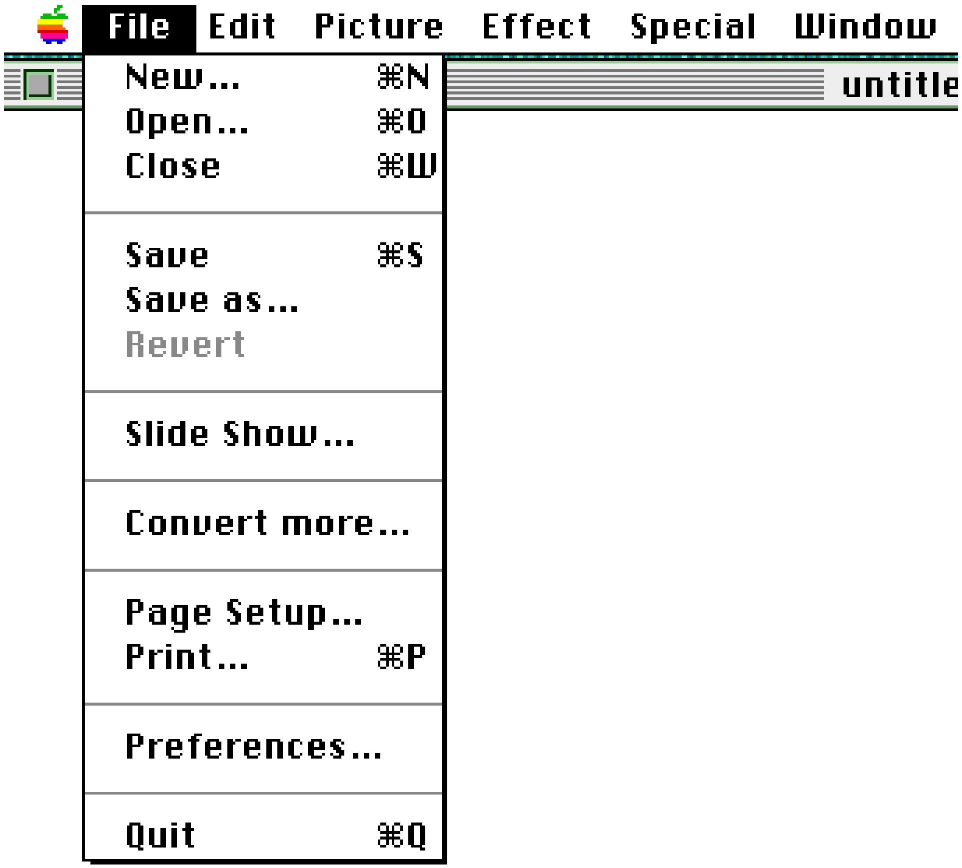
"Beating" Fitts' law

- How might we reduce movement time (MT)?
- $MT = a + b \log_2(A / W + 1)$

- Reduce A
- Increase W

Techniques in HCI

- Bring targets closer together
- Make targets bigger
- Make cursor bigger
- Some examples:
  - Gravity fields: mouse pointer gets close, gets “sucked in”
  - Constrained motion: in a drawing program holding down Shift
  - Target prediction: predict target, then jump to it, move it nearer, or expand it
  - Use impenetrable edges: put edges behind intended targets (Mac Menu bar)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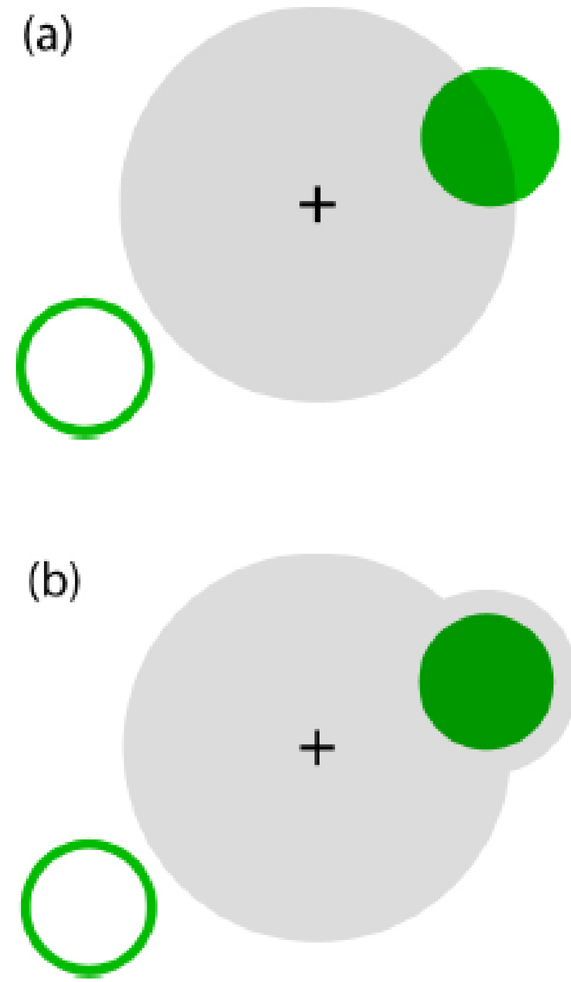
Save as...
Revert
Slide Show...
Convert more...
Page Setup...
Print... ⌘P
Preferences...
Quit ⌘Q

Bubble cursor

Grossman & Balakrishnan 2005

- Dynamically resize an area cursor to contain the closest target but not the second closest.
- Use a second bubble when the main area cursor intersects but does not fully contain a target.



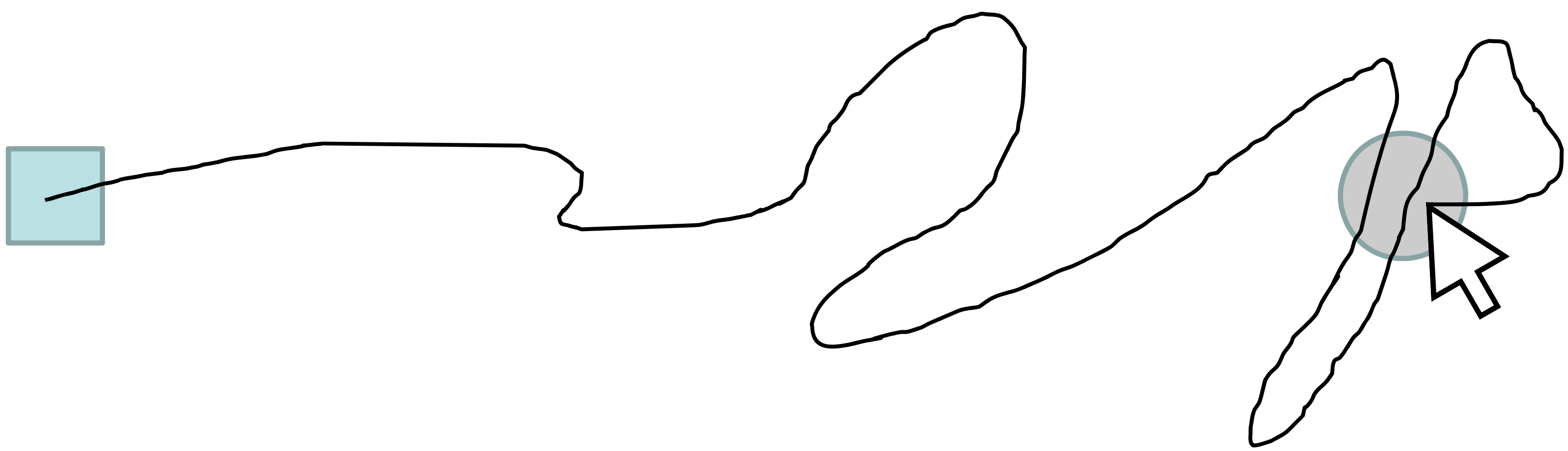
https://www.youtube.com/watch?v=JUBXkD_8ZeQ

Consider…

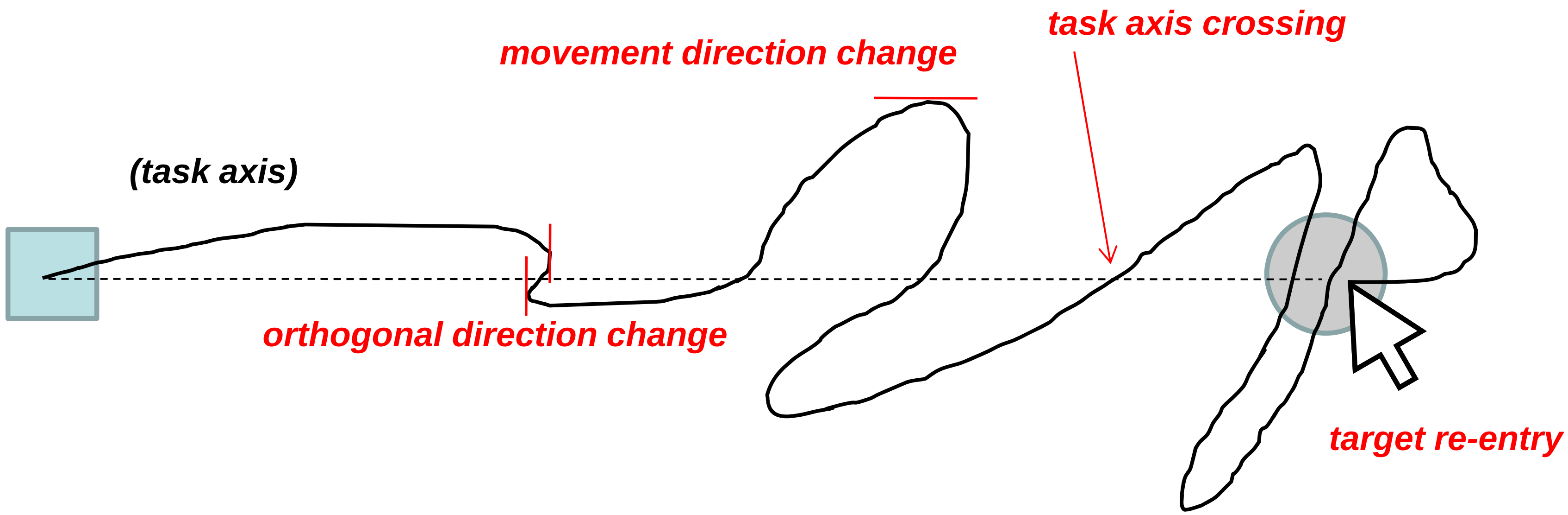
- Fitts' law gives an *aggregate measure* of movement performance.
- But it doesn't tell you what happens *during* a movement.
- For that we can use MacKenzie et al.'s (2001) path analyses.

What happens *during* movement?

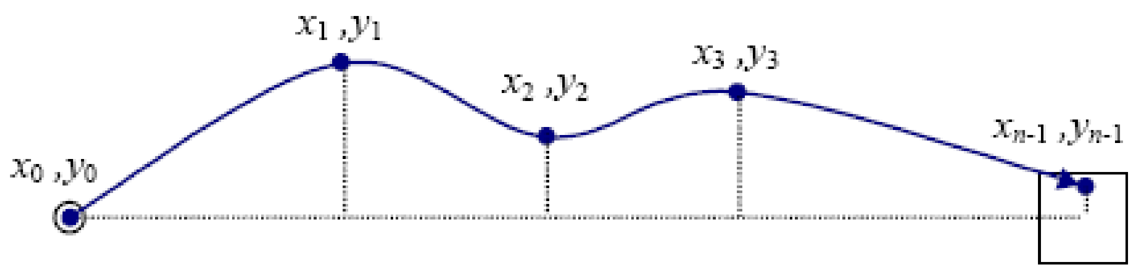
- What can quantify about this movement?



Count measures



Distance measures



- Movement variability

$$MV = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}$$

- Movement error

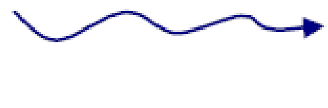
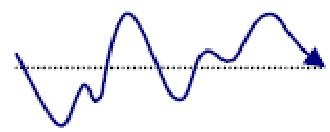
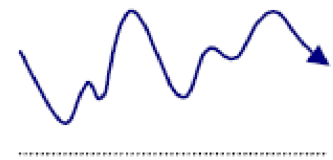
$$ME = \frac{\sum |y_i|}{n}$$

- Movement offset

$$MO = \bar{y}$$

(MacKenzie et al. 2001)

Examples

	Movement Responses			
				
Movement Variability	Low	Low	High	High
Movement Error	Low	Very High	High	Very High
Movement Offset	Low	High	Low	High

(MacKenzie et al. 2001)

Thank you

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- Questions?