Human Performance

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Lecture notes in this series are based on

- Ahmed Sabbir Arif. 2021. Statistical Grounding. *Intelligent Computing for Interactive System Design: Statistics, Digital Signal Processing, and Machine Learning in Practice*, ACM
- Ann Blandford, Dominic Furniss, Stephann Makri. 2016. Qualitative HCI Research: Going Behind the Scenes. Morgan & Claypool
- Jonathan Lazar, Jinjuan Feng, Harry Hochheiser. 2017. Research Methods in Human-Computer Interaction. Morgan Kaufmann
- I. Scott MacKenzie. 2013. Human-Computer Interaction: An Empirical Research Perspective, Morgan Kaufmann
- Interaction Design Foundation. 2022. Design Thinking
- Lecture notes of Amy Bruckman, Mark Dunlop, Niels Henze, I. Scott MacKenzie, Laura Moody, Albrecht Schmidt, Kami Vaniea

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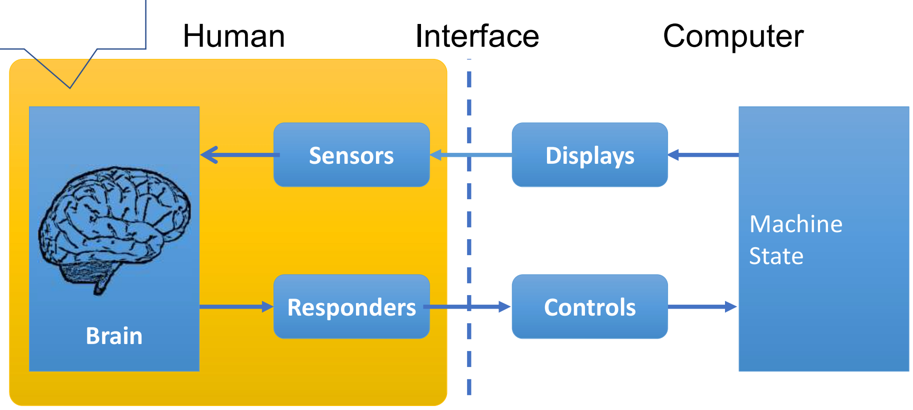
Human Factors Model

- Human Performance
- Skilled Behavior
- Skill Transfer
- Attention



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Human Performance

- Humans uses their sensors, brain, and responders to do things
- When the three work together to achieve a *goal*, human performance arises
- Examples:
  - Tying shoelaces
  - Folding clothes
  - Searching the web
  - Entering a text message on a smartphone

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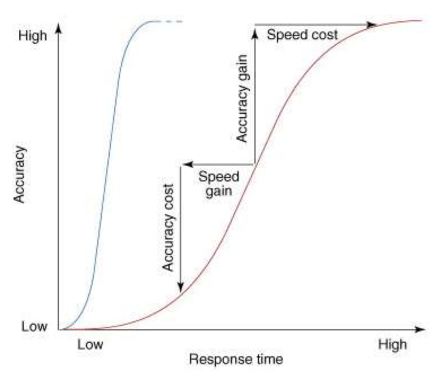
Speed-Accuracy Trade-Off

- In perceptual-motor tasks, there is a tradeoff between how fast a task can be performed and how many mistakes are made in performing the task
  - Users can either perform *very fast with many errors* or *very slow with few errors*
- Our goal is to design interfaces and interaction techniques that are both fast and accurate
  - Or maintain a reasonable balance between the two



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Skill Acquisition

Power Law of Learning

Skill Acquisition

- When learning a skill, we begin as *novices*
- Initial performance is poor, but with practice, we acquire skill
- With continued practice, we become proficient, perhaps *experts*

- The novice to expert transition is well suited to predictive modeling
  - Dependent variable: proficiency (e.g., the time or speed in doing a task)
  - Independent variable: amount of practice (e.g., hours, days, months, blocks, sessions)

Power Law of Learning

- Relationship between proficiency and practice is non-linear
  - At first, a small amount of practice yields *substantial* improvement
  - Later, the same amount of practice yields *only a slight* improvement
- Relationship best expressed by a power function:

$$\boxed{y = b \times x^a}$$

General Form

$$\boxed{T_n = T_1 \times n^a}$$

Power Law of Learning

T_n the time to do the task on the n^{th} trial
T_1 the time to do the task on the 1^{st} trial (a constant)
n the trial indicator (e.g., hours, days, blocks, sessions)
a a constant setting the shape of the curve

Note: a is negative since task completion time decreases with practice

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Power Law of Learning: Speed Variation

- Dependent variable can be speed, the reciprocal of time
- Model predicts *tasks per unit time*, like words per minute

$$\boxed{S_n = S_1 \times n^a}$$

Power Law of Learning (Speed)

S_n is the speed on the n^{th} trial
S_1 is the speed on the 1^{st} trial (a constant)
n is the trial indicator (e.g., hours, days, blocks, sessions)
a is a constant setting the shape of the curve

Note: a is positive and < 1 reflecting the diminishing return with practice

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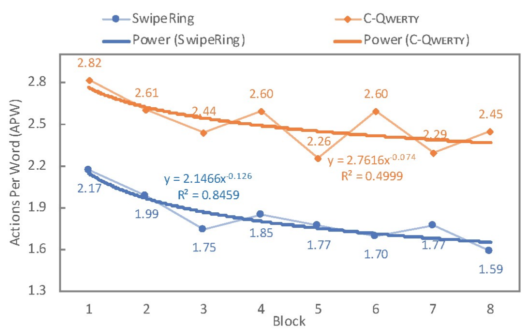
Power Law of Learning: Curve Shapes

$$T_n = T_1 \times n^a$$

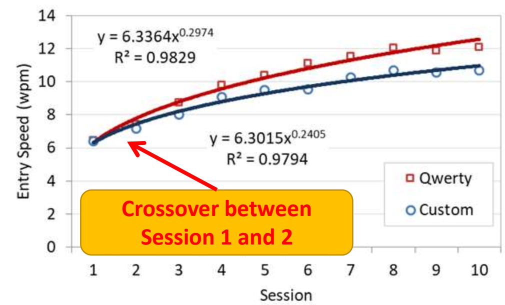
Predicting Time



Gulnar Rakhmetulla, Ahmed Sabbir Arif, Steven J. Castellucci, I. Scott MacKenzie, Caitlyn Seim. 2021. Using Action-Level Metrics to Report the Performance of Multi-Step Keyboards. Graphics Interface Conference (GI 2021). Article 15, 127-137.

$$S_n = S_1 \times n^a$$

Predicting Speed



Steven J. Castellucci, I. Scott MacKenzie, Mudit Misra, Laxmi Pandey, Ahmed Sabbir Arif. 2019. TiltWriter: Design and Evaluation of a No-touch Tilt-based Text Entry Method for Handheld Devices. International Conference on Mobile and Ubiquitous Multimedia (MUM 2019). ACM, Article 7, 8 pages.

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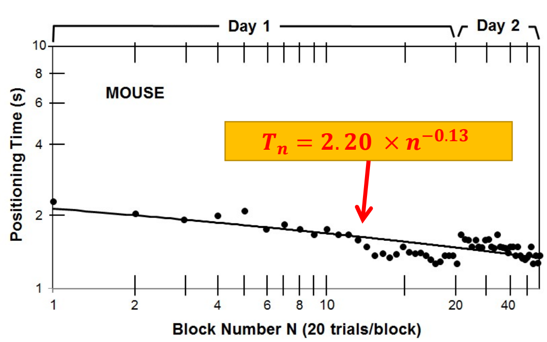
Power Law of Learning: Log-log Model

- If x and y data are transformed to log scales, the relationship is linear



S. K. Card, W. K. English, B. J. Burr. 1978. Evaluation of Mouse, Rate-Controlled Isometric Joystick, Step Keys, and Text Keys for Text Selection on a CRT. *Ergonomics, 21*, 601-613.

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Reaction Time

Fitts' Law

Hick-Hyman Law

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Human Diversity

- Human performance is highly complex:
  - Humans differ (age, gender, skill, motivation, etc.)
  - Environmental conditions affect performance
  - Secondary tasks often present
- Human diversity and human performance often shown in a distribution

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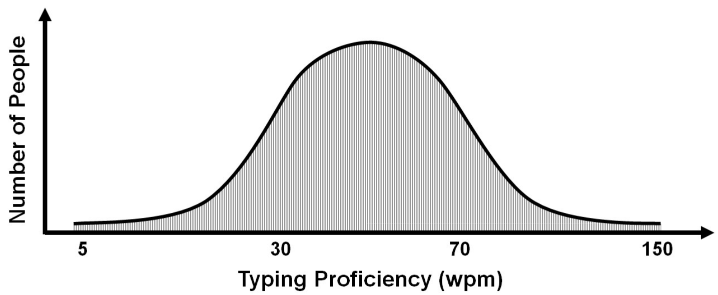
Human Diversity and Performance



- *Where are you on this chart?*
- *Where is your mother or grandmother?*
- *Where is an 8-year-old, just learning to use a computer?*
- *Where is someone with a physical disability?*
- *Where are you while using your smartphone on a crowded bus, standing?*

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Reaction Time

- A most primitive manifestations of human performance is *simple reaction time*
- Reaction time is the delay between the occurrence of a single fixed stimulus and the initiation of a response assigned to it
  - Such as, pressing a button in response to the onset of a stimulus light

P. M. Fitts, M. I. Posner. 1968. Human Performance. Belmont, CA. Brooks/Cole Publishing Company.

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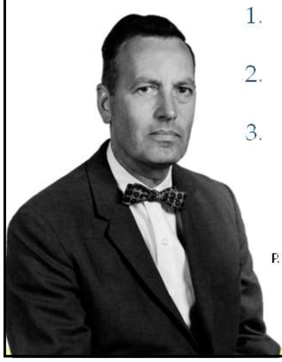
Fitts' Law

- One of the most widely used models in HCI
- Model for rapid aimed movements
  - Such as, moving a cursor toward a target and selecting the target
- Three applications:



1. Use a Fitts' law prediction equation to analyse and compare design alternatives (predictive)
2. Use Fitts' *index of performance* (now *throughput*) as a dependent variable in a comparative evaluation
3. Determine if a device or technique conforms to Fitts' law

P. M. Fitts. 1954. The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement. Journal of Experimental Psychology, 47, 381-391.
P. M. Fitts, J. R. Peterson. 1964. Information Capacity of Discrete Motor Responses. Journal of Experimental Psychology, 67, 103-112.

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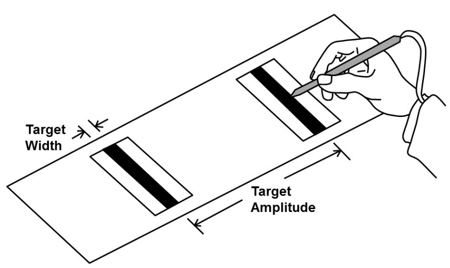
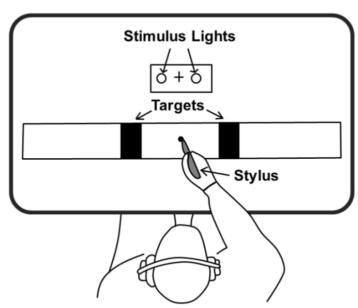
Fitts' Law: Task Paradigms

Serial task



Discrete task



- Serial tasks are composed of a series of discrete tasks

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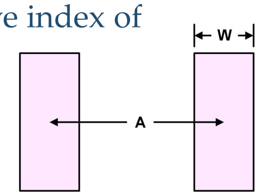
Fitts' Law: Metrics

- Fitts' index of difficulty (ID) is a measure of the difficulty of a target selection task
- Normally the prediction equation is built using the effective index of difficulty (ID_e) that includes an "adjustment for accuracy"



$$ID = log_2\left(\frac{A}{W} + 1\right)$$

Units: bits

- The movement time (MT) is measured in seconds for each trial, then averaged over the sequence of trials
- Fitts hypothesized that the relationship between movement time (MT) and ID is linear

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

Units: seconds

a (units: seconds) and b (units: seconds per bit) are input device-dependent constants 17

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Fitts' Law: Throughput

- In the 1990s, Fitts' law was included in the ISO 9241-9 (revised: ISO 9241-411) standard for evaluating non-keyboard input devices by using Fitts' throughput (TP) as a dependent variable

$$TP = \frac{ID}{MT}$$

Units: bits per second

- Alternative definition:

$$TP = \frac{1}{b}$$

Units: bits per second

b is the slope of the regression line; equivalent to $\frac{ID}{MT}$ when $a = 0$

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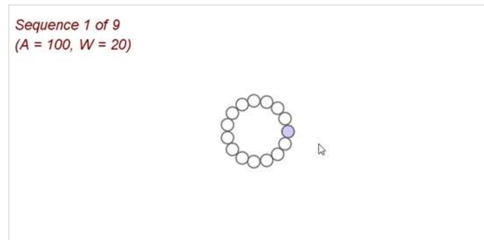
Fitts' Law Application: Pointing Devices

- Task: compare four pointing devices
  - 12 participants performed a series of serial target selection tasks using the four devices
  - We will only look at the data and models for two of the devices

Interlink *RemotePoint*

Microsoft *Mouse 2.0*



ISO 9241-411

I. S. MacKenzie, S. Jusoh. 2001. An Evaluation of Two Input Devices for Remote Pointing. In: Little M.R., Nigay L. (eds) Engineering for Human-Computer Interaction. EHCI 2001. Lecture Notes in Computer Science, vol 2254. Springer, Heidelberg.

Fitts' Law Application: Results

Conditions | Mouse Observations | RemotePoint Observations

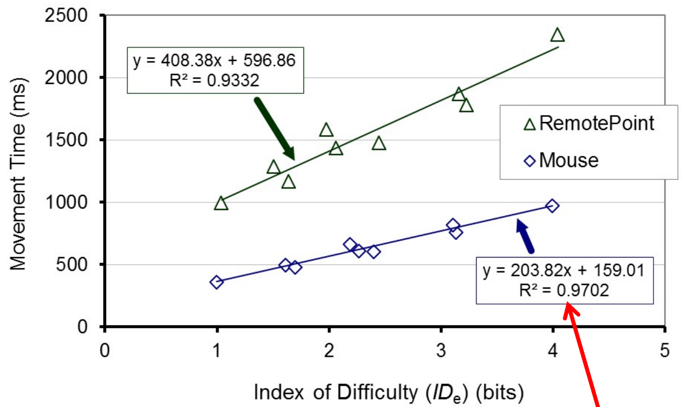
A (pixels)	*W* (pixels)	*ID* (bits)	Mouse W_e (pixels)	Mouse ID_e (bits)	Mouse *MT* (ms)	Mouse *TP* (bits/s)	RemotePoint W_e (pixels)	RemotePoint ID_e (bits)	RemotePoint *MT* (ms)	RemotePoint *TP* (bits/s)
40	10	2.32	11.23	2.19	665	3.29	13.59	1.98	1587	1.25
40	20	1.58	19.46	1.61	501	3.21	21.66	1.51	1293	1.17
40	40	1.00	40.20	1.00	361	2.76	37.92	1.04	1001	1.04
80	10	3.17	10.28	3.13	762	4.11	10.08	3.16	1874	1.69
80	20	2.32	18.72	2.40	604	3.97	25.21	2.06	1442	1.43
80	40	1.58	35.67	1.70	481	3.53	37.75	1.64	1175	1.40
160	10	4.09	10.71	3.99	979	4.08	10.33	4.04	2353	1.72
160	20	3.17	21.04	3.11	823	3.77	19.09	3.23	1788	1.81
160	40	2.32	41.96	2.27	615	3.69	35.97	2.45	1480	1.65
		Mean	23.25	2.38	644	3.60	23.51	2.35	1555	1.46

For model building…

x sample points
y sample points

x sample points
y sample points

Fitts' Law Application: Prediction



Squared correlations are very high
Thus, the MT-ID relationship is linear

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Fitts' Law: Limitations

- Only models movement
- Repeat exercises to remove user reaction (thinking)
- Predicts "expert" behavior
- Weak link between Shannon model and Shannon's information theory on bits of information

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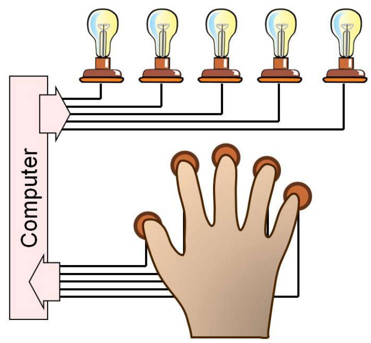
Choice Reaction Time

- Given *n* stimuli, associated one-for-one with *n* responses, the time to react to the onset of a stimulus is the *choice reaction time*



Hick-Hyman Law

- Increasing the number of choices increases the decision time logarithmically
- Modeled by the Hick-Hyman law: Given n equally probable choices, the average reaction time (RT) required to choose among the choices is approximately:

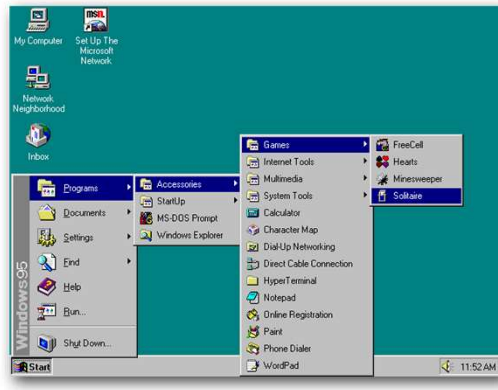
$$RT = a + b\,log_2(n+1)$$

a ≈ 200 milliseconds
b ≈ 150 milliseconds per bit

W. E. Hick. 1952. On the Rate of Gain of Information. *Quarterly J Exp Psychol, 4*, 11-36.
R. Hyman. 1953. Stimulus Information as a Determinant of Reaction Time. *J Exp Psychol, 45*, 188-196.

Hick-Hyman Law: Application

- Time to select items in a hierarchical menu
- Activation time for mode switching with non-dominant hand in a tablet interface



T. K. Landauer, D. W. Nachbar. 1985. Selection from Alphabetic and Numeric Menu Trees Using a Touch Screen: Breadth, Depth, and Width. SIGCHI Bull. 16, 4 (April 1985), 73–78.
Jaime Ruiz, Andrea Bunt, and Edward Lank. 2008. A model of non-preferred hand mode switching. In Proceedings of Graphics Interface 2008 (GI '08). Canadian Information Processing Society, CAN, 49-56.

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Hick-Hyman Law: Limitations

- Difficult to apply because additional behaviours are often present, such as visual search or movement
- An interesting variation of the Hick-Hyman law occurs if the stimuli occur with different frequencies
- If the frequency of activation differs by stimulus, the information content of the task goes down because there is a small opportunity for the user to anticipate the stimulus
- Combined with Fitts' Law:
  Andy Cockburn, Carl Gutwin, Saul Greenberg. A Predictive Model of Menu Performance. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07). ACM, NY, USA, 627-636

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Sensory Stimuli & Reaction Time

- Delay time varies by type of sensory stimuli
- Approximate values
  - Auditory 150 ms
  - Visual 200 ms
  - Smell 300 ms
  - Pain 700 ms

R. W. Bailey. 1996. Human Performance Engineering: Designing High Quality, Professional User Interfaces for Computer Products, Applications, and Systems (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

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Skilled Behavior

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Skilled Behavior

- For many tasks, human performance improves considerably and continuously with practice
- However, very little improvement with practice in simple reaction time tasks
- In these tasks, there is interest in studying the progression of learning and the performance achieved according to the amount of practice
- Categories of skilled behavior:
  1. Sensory-motor skill (e.g., darts, gaming)
  2. Mental skill (e.g., chess, programming)
  - Some tasks required a lot of both (skilled behavior)

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Skilled Behavior: Example

Laparoscopic Surgery

The Centre of Excellence for Simulation Education and Innovation at Vancouver General Hospital

Typing

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Interface Design Tips

- Facilitate learning by trying
  - Users must be able to get work done while practicing
- Facilitate **skill transfer** by:
  - Exploiting natural interactions (more on this later)
  - Exploiting interactions learned in another commonly used system
- Reduce crossover time
  - Users are likely to lose interest if a system require too much training
    - Both/either in terms of time and effort
    - Remember Yerkes-Dodson Law (relationship between pressure and performance) and information overload

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