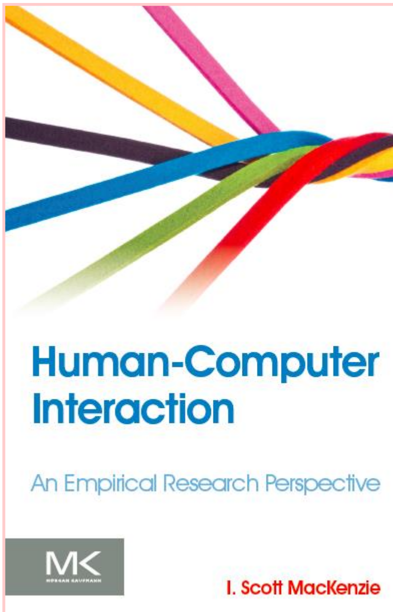


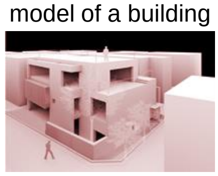
Interactive Systems Design
Prof. V. Fuccella

Chapter 7
Modeling Interaction

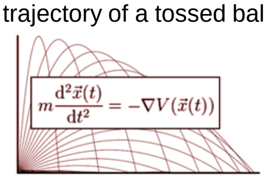
Introduction

- A *model* is a simplification of reality
- Consider…

Architect's scale model of a building



Physicist's model for the trajectory of a tossed ball



- Both are simplifications of complex phenomena
- The architect's model is a *description* → provides insight into space usage, movement of people, light, shade, etc.
- The physicist's model is a *prediction* → gives the ball's position as a function of time

2

Why Use Predictive Models

- Card et al. presented perhaps the first predictive model in HCI.[1] In many respects, their work was straight-forward experimental research; but they went further:
  - "While these empirical results are of direct use in selecting a pointing device, it would obviously be of greater benefit if a theoretical account of the results could be made. For one thing, the need for some experiments might be obviated; for another, ways of improving pointing performance might be suggested."
- This is a call for the use of predictive models in HCI
- They went on to present predictive models using Fitts' law (which we meet shortly)

[1] Card, S. K., English, W. K., & Burr, B. J. (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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Predictive Model Examples

- Linear prediction equation
- Fitts' law
- Choice reaction time
- Keystroke-level model (KLM)

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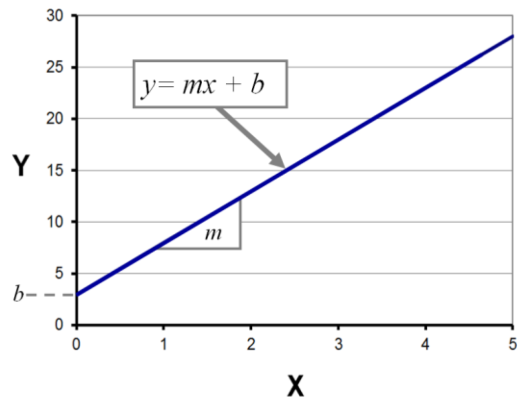
Linear Prediction Equation

- The basic prediction equation expresses a linear relationship between a predictor variable (*x*) and a criterion variable (*y*):



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Linear Regression

- A linear prediction equation is built using a statistical procedure know as *linear regression*
- Goal:
  - Given a set of *x*-*y* sample points, find the coefficients *m* and *b* (previous slide) for the line that minimizes the squared distances (*least squares*) of the points from the line
- The result is a prediction equation that gives the best estimate of *y* in terms of *x*
- The assumption, of course, is that the relationship is linear
- Want the details? Just enter “linear regression” or “least squares” into Google or Wikipedia

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Example

- A research project investigated text entry on soft keyboards[1]
- The research also asked…
  - *Can stylus tapping entry speed be predicted from touch typing entry speed?*
- Touch typing speed is the predictor variable (*x* - measured in a pre-test)
- Stylus typing speed is the criterion variable (*y* - measured experimentally)
- Data and scatter plot

[1] MacKenzie, I. S., & Zhang, S. X. (2001). An empirical investigation of the novice experience with soft keyboards. *Behaviour & Information Technology, 20*, 411-418.

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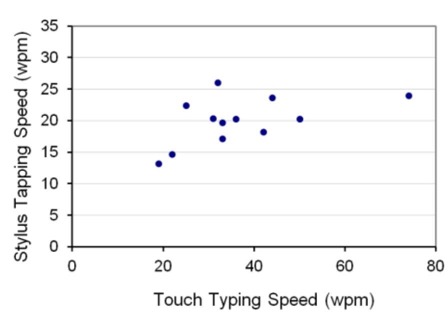
Data and Scatter Plot

Participant	Stylus Tapping Speed (wpm)	Touch Typing Speed (wpm)
P1	18.2	42
P2	23.6	44
P3	26.0	32
P4	20.3	50
P5	20.3	36
P6	17.1	33
P7	24.0	74
P8	14.7	22
P9	20.3	31
P10	19.7	33
P11	22.4	25
P12	13.1	19



There seems to be a relationship: Faster touch typists seem to be faster at stylus tapping.

Questions:
What is the prediction equation?
How strong is the relationship?

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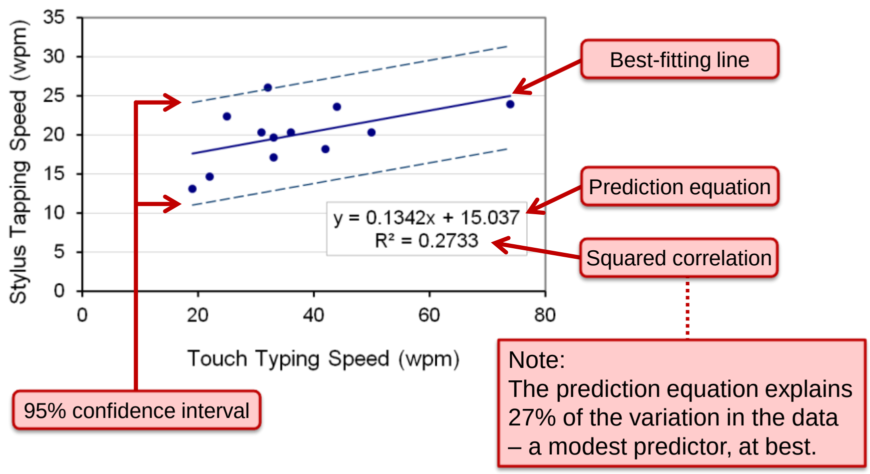
Prediction Equation



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Predictive Model Examples

- Linear prediction equation
- Fitts' law
- Choice reaction time
- Keystroke-level model (KLM)

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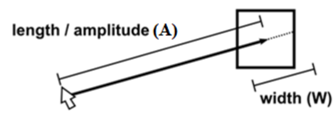
Fitts' Law

- One of the most widely used models in HCI
- Model for rapid aimed movements (e.g., moving a cursor toward a target and selecting the target)
- Main application: Use a Fitts' law prediction equation to analyse and compare design alternatives
- Origins: Two highly-cited papers in experimental psychology, one from 1954[1], the other for 1964[2]

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



[1] Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*, 381-391.
[2] Fitts, P. M., & Peterson, J. R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology, 67*, 103-112. **. It is frequently used to predict the movement of**

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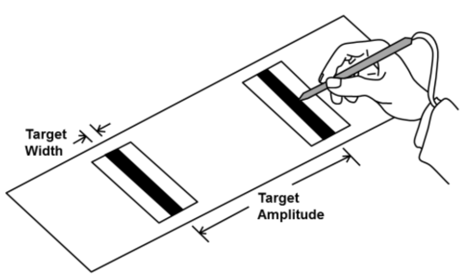
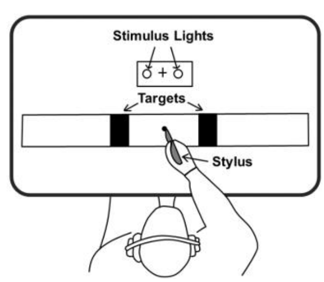
Fitts' Law – Task Paradigms



Serial task



Discrete task

These sketches were adapted from Fitts' 1954 and 1964 papers. It is easy to imagine comparable tasks implemented on computing technology.

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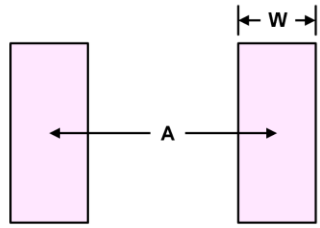
Fitts' Index of Difficulty (*ID*)

- Fitts' index of difficulty (*ID*) is a measure of the difficulty of a target selection task:

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

Units: bits



- Fitts hypothesized that the relationship between movement time (*MT*) and *ID* is linear:

$$MT = a + b\ ID$$

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Fitts' Law Models for Pointing Devices

- A research project compared four pointing devices, including two for remote pointing[1]
- Twelve participants performed a series of serial target selection tasks using the four devices
- For our purpose, we'll look at the data and models for two of the devices:

Interlink *RemotePoint*

Microsoft *Mouse 2.0*

[1] MacKenzie, I. S., & Jusoh, S. (2001). An evaluation of two input devices for remote pointing. *Proceedings - EHCI 2000*, 235-249, Heidelberg, Germany: Springer-Verlag.

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Experiment Conditions and 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

Conditions: A, W, ID. Mouse Observations: Mouse columns. RemotePoint Observations: RemotePoint columns.

For model building…

Mouse: *x* sample points (ID_e), *y* sample points (MT)

RemotePoint: *x* sample points (ID_e), *y* sample points (MT)

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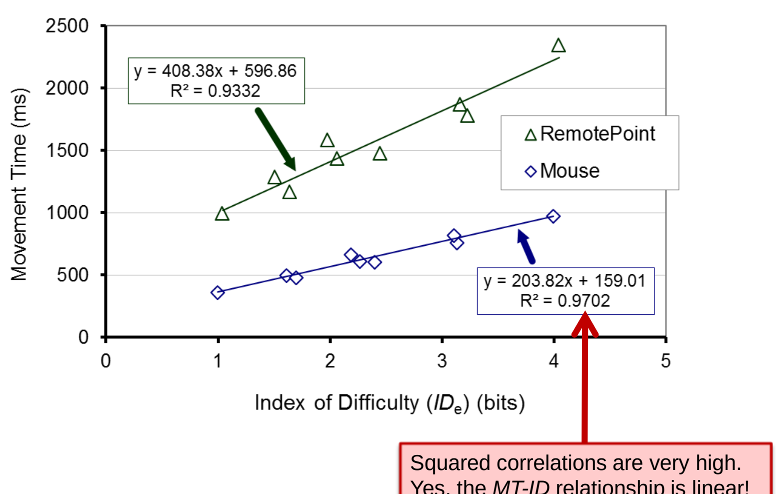
Fitts' Law Prediction Equations



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Predictive Model Examples

- Linear prediction equation
- Fitts' law
- Choice reaction time
- Keystroke-level model (KLM)

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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*
- Modeled by the Hick-Hyman law:[1 2]

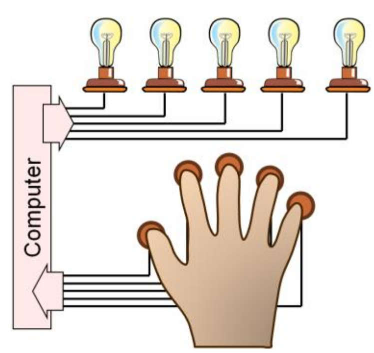
$$\boxed{RT = a + b \log_2(n + 1)}$$

- Coefficients:

  $a \approx 200$ ms

  $b \approx 150$ ms/bit

- An Information processing model (like Fitts' law)



[1] Hick, W. E. (1952). On the rate of gain of information. *Quarterly J Exp Psychol, 4*, 11-36.
[2] Hyman, R. (1953).Stimulus information as a determinant of reaction time. *J Exp Psychol, 45*, 188-196.

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HCI Applications

- Not many, but…
  - A telephone operator selects among ten buttons when a light behind a button turns on[1]
  - Time to select items in a hierarchical menu (visual search eliminated by practicing participants to expert levels)[2]
  - Activation time for mode switching with non-dominant hand in a tablet interface[3]
- Difficult to apply because additional behaviours are often present, such as visual search or movement

[1] Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, NJ: Erlbaum.
[2] Landauer, T. K., & Nachbar, D. W. (1985). Selection from alphabetic and numeric menu trees using a touch screen: Breadth, depth, and width. *Proc CHI '85*, 73-77, ACM.
[3] Ruiz, J., Bunt, A., & Lank, E. (2008). A model of non-preferred hand mode switching. *Proceedings of Graphics Interface 2008*, 49-56, Toronto: Canadian Information Processing Society.

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Predictive Model Examples

- Linear prediction equation
- Fitts' law
- Choice reaction time
- Keystroke-level model (KLM)

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Keystroke-Level Model (KLM)[1 2]

- One of the earliest and most comprehensive models in HCI
- Developed specifically for predicting human performance with interactive computing systems
- Predicts expert error-free task completion times

[1] Card, S. K., Moran, T. P., & Newell, A. (1980, July). The keystroke-level model for user performance time with interactive systems. *Communications of the ACM, 23*, 396-410.
[2] Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, NJ: Erlbaum.

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Why Use the KLM?

- Consider a task such as:

  Replace one 5-letter word with another, starting one line away.

- There are at least three ways to do the task:
  1. arrow keys, backspace, type
  2. search and replace dialog
  3. point and double click with the mouse, type
- The KLM can predict the time for each method
- If used at the design stage, design alternatives may be considered and compared → design choices follow

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A KLM Prediction

- A task is broken into a series of subtasks
- Total predicted time is the sum of the subtask times:

$$t_{EXECUTE} = t_K + t_P + t_H + t_D + t_M + t_R$$

- Operators:
  - K → keystroking P → pointing H → homing
  - D → drawing M → mental prep R → system response
- Some operators are omitted or repeated, depending on the task (e.g., if n keystroking operations are required, t_K becomes $n \times t_K$)
- Operator values (next slide)

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KLM Operators and Values

Operator	Description	Time (s)
K	PRESS A KEY OR BUTTON Pressing a modifier key (e.g., shift) counts as a separate operation, Time varies with typing skill: Best typist (135 wpm) Good typist (90 wpm) Average skilled typist (55 wpm) Average non-secretary typist (40 wpm) Typing random letters Typing complex codes Worst typist (unfamiliar with keyboard)	 0.08 0.12 0.20 0.28 0.50 0.75 1.20
P	POINT WITH A MOUSE Empirical value based on Fitts' law. Range from 0.8 to 1.5 seconds. Operator does *not* include the button click at the end of a pointing operation	1.10
H	HOME HAND(S) ON KEYBOARD OR OTHER DEVICE	0.40
$D(n_D, l_D)$	DRAW n_D STRAIGHT-LINE SEGMENTS OF TOTAL LENGTH l_D. Drawing with the mouse constrained to a grid.	$.9\ n_D + .16\ l_D$
M	MENTALLY PREPARE	1.35
R(t)	RESPONSE BY SYSTEM Different commands require different response times. Counted only if the user must wait.	t

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Original KLM Experiment

- The KLM was validated in an experiment with fourteen tasks performed using various methods and systems
- Example: Task 1 → *Replace a 5-letter word with another word (one line from previous task)*
- Using one system, POET, the task was broken down as follows:

Jump to next line	**M K**[LINEFEED]
Issue Substitute command	**M K**[S]
Type new word	**K**[word]
Terminate new word	**M K**[RETURN]
Type old word	**K**[word]
Terminate old word	**M K**[RETURN]
Terminate command	**K**[RETURN]

- 4 mental operations + 15 keystroking operations, hence →

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KLM Prediction (Example)

$$t_{\text{EXECUTE}} = 4 \times t_{\text{M}} + 15 \times t_{\text{K}}$$

- M set to 1.35 seconds (two slides back)
- K set to 0.23 seconds, based on a 5-minute pre-test
- So…

$$t_{\text{EXECUTE}} = 4 \times 1.35 + 15 \times 0.23$$
$$= 8.85 \text{ seconds}$$

- This is the prediction
- What about the observation? (next slide)

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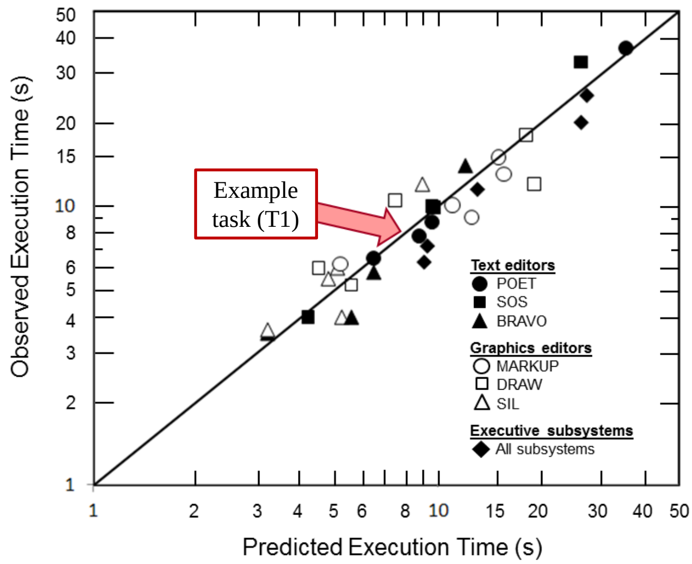
Results



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Modern Applications

- Mouse interaction was just emerging when the KLM was introduced
- An obvious KLM update is to replace the pointing constant (t_P) with a Fitts' law prediction equation, as appropriate for the device (e.g., mouse vs. touchpad) and task (e.g., point-select vs. drag-select)
- For example, using the Fitts' law equation given earlier for the mouse…

$$t_P = 0.159 + 0.204 \times \log_2\left(\frac{A}{W} + 1\right)$$

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Pointing Operator – Update

- For example, a mouse point-select operation over 3.2 cm to click a 1.2 cm wide toolbar button should take about…

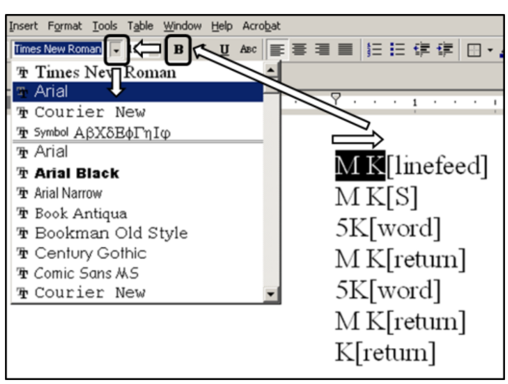
$$t_P = 0.159 + 0.204 \times \log_2\left(\frac{3.2}{1.2} + 1\right) = 0.45 \text{ seconds}$$

- If the same task involves moving the pointer 44.6 cm, the prediction becomes…

$$t_P = 0.159 + 0.204 \times \log_2\left(\frac{44.6}{1.2} + 1\right) = 1.22 \text{ seconds}$$

Pointing Operator – Example

- Develop KLM mouse and keyboard predictions for the GUI screen below
- Task: Change the font and style for “M K” to bold, Arial



Mouse Analysis

- Operations:

Mouse Subtasks	KLM Operators	t_P (s)
Drag across text to select "M K"	**M P**[2.5, 0.5]	0.686
Move pointer to Bold button and click	**M P**[13, 1]	0.936
Move pointer to Font drop-down button and click	**M P**[3.3, 1]	0.588
Move pointer down list to Arial and click	**M P**[2.2, 1]	0.501
	$\sum t_P$ =	2.71

- Prediction:

$$t_{\text{EXECUTE}} = 4 \times t_{\text{M}} + \sum t_{\text{P}} = 4 \times 1.35 + 2.71 = 8.11 \text{ seconds}$$

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Keyboard Analysis

- Operations:

Keyboard Subtasks	KLM Operators
Select text	**M K**[shift] **3K**[→]
Convert to boldface	**M K**[ctrl] **K**[b]
Activate Format menu and enter Font sub-menu	**M K**[alt] **K**[o] **K**[f]
Type *a* ("Arial" appears at top of list)	**M K**[a]
Select "Arial"	**K**[↓] **K**[enter]

- Prediction:

$$t_{\text{EXECUTE}} = 4 \times t_{\text{M}} + 12 \times t_{\text{K}} = 4 \times 1.35 + 12 \times 0.75 = 14.40 \text{ seconds}$$

Use "typing complex codes" (t_K = 0.75 s)

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Contemporary Uses of the KLM

- The KLM continues to be widely used in HCI
- Some contemporary uses include…
  - Attention shifts with mobile phones
  - Stylus-based circling gestures
  - Managing folders and messages in e-mail applications
  - Predictive text entry on mobile phones
  - Task switching in multi-monitor systems
  - Mode switching on tablet PCs
  - Distractions in in vehicle information systems (IVIS)

See **HCI:ERP** for citations

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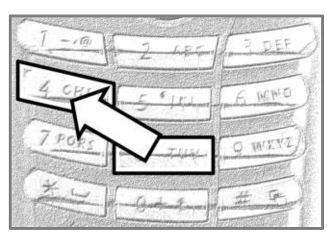
KLM and Mobile Phone Keypad

- Since input uses a single finger or thumb, the keystroking operator can be replaced with a pointing operator[1]

$$t_{P(\text{index finger})} = 0.165 + 0.052 \log_2\left(\frac{A}{W} + 1\right)$$



$$t_{P(\text{thumb})} = 0.176 + 0.064 \log_2\left(\frac{A}{W} + 1\right)$$

See **HCI:ERP** for further discussion

[1] Silfverberg, M., MacKenzie, I. S., & Korhonen, P. (2000). Predicting text entry speed on mobile phones. *Proc CHI 2000*, 9-16, New York: ACM.

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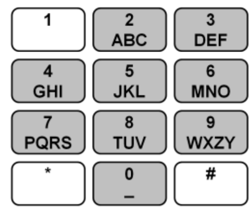
KLM and Predictive Text Entry

- Interesting because of the combination of keystroking/pointing operations and mental operations
- Consider entering "beep" on a mobile phone keypad using predictive text entry (T9):

time

Keys	Display
2	a
23	be
233	bed
2337	beer
2337n	beds
2337nn	adds
2337nnn	bees
2337nnnn	beep
2337nnnn0	beep_



Mobile phone keypad (for reference)

KLM model?

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KLM Operators for "beep"

- Perhaps the following…

$\boxed{2}\ \boxed{3}\ \boxed{3}\ \boxed{7}\ M_P\ \boxed{n}\ M_P\ \boxed{n}\ M_P\ \boxed{n}\ M_P\ \boxed{n}\ M_P\ \boxed{0}$

Mental operator for "physical matching" (in this case, between the word on the display and the word in the user's mind)

- Two questions:
  1. *Where should mental operators be placed?*
  2. *What value should the mental operator assume?*

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Expert Behaviour

- Experts know the T9 key sequences for common words (i.e., no need for M_P at end of word):
  - *the* → 8430
  - *of* → 630
  - *and* → 2630
- But, how far down a word frequency list[1] does such behaviour extend?
- What about ambiguous words?
  - *if* → 43n0
  - *no* → 66n0
  - *beep* → 2337nnnn0

"beep" is at rank 20,767. Even experts will likely require the M_P operator at the end of the word (unless, for some reason, "beep" is a word they commonly enter).

[1] The word-frequency list used here is the 64,000 word list described by Silfverberg et al. (2000).

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Ambiguous Words

- Below is a list of the top ten words requiring a press of next

Rank	Word	Keystrokes	Higher Ranking Colliding Word (rank)
47	if	43n0	he (15)
51	no	66n0	on (13)
63	then	8436n0	them (57)
72	me	63n0	of (2)
78	these	84373n0	there (35)
105	go	46n0	in (6)
118	us	87n0	up (56)
159	home	4663n0	good (115)
227	night	64448n0	might (141)
298	war	927n0	was (10)

M_P operators?

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Heuristics for M_P Operator

- It is not possible to precisely know when a user will hesitate to perform an M_P operation – a physical match between the word on the display and the word in the user's mind
- Two approaches for KLM modeling with M_P:
  - All-in → include M_P at every reasonable juncture
  - All-out → exclude all M_P operations
- The two approaches will produce upper bound (all-in) and lower bound (all-out) predictions

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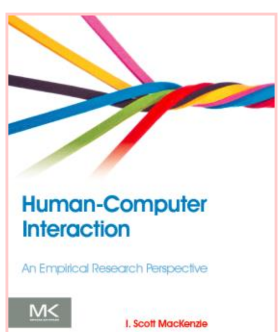
Thank You



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