Designing Interactive Systems I

GOMS, Interface Efficiency

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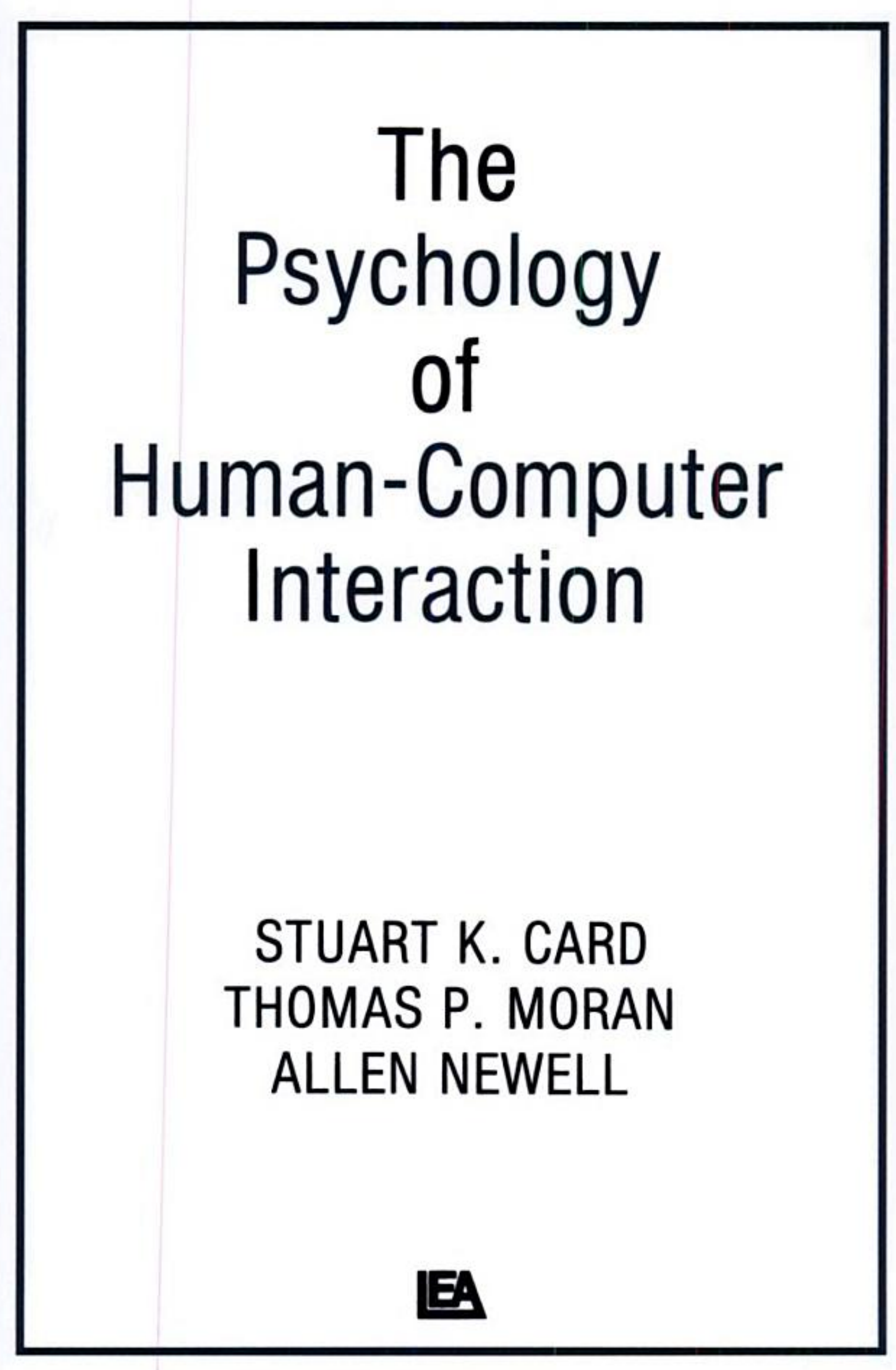
GOMS

A Story

- In 1995, now-famous web guru Jakob Nielsen had less than 24 hours to recommend if adding three new buttons to Sun's home page was a good idea
    - Check out his articles at the Nielsen Norman Group for good (and often fun) web design advice
- He found that each new, but unused button costs visitors 0.5 million $ per year
- 2 of the 3 new buttons were taken back out
- The method he used for his estimate: GOMS

GOMS

- **G**oals, **O**perators, **M**ethods, **S**election rules
- In Card, Moran, Newell: The Psychology of HCI, 1983
- To estimate execution and learning times *before* a system is built



The Psychology of Human-Computer Interaction

STUART K. CARD
THOMAS P. MORAN
ALLEN NEWELL

LEA

GOMS: Components

- Goals describe users' end goals
  - Routine tasks, not too creative/ problem-solving
    - E.g., "copyedit manuscript"
  - Leads to hierarchy of subgoals
- Operators are elementary user actions
  - Key presses, menu selection, drag & drop, reading messages, gestures, speech commands, …
  - Assign context-independent duration (in ms)
- Methods are "procedures" to reach a goal
  - Consist of subgoals and/or operators
- Selection rules
  - Which method to use for a (sub)goal
    - E.g., to delete some text (individual preferences apply!)

Sample Method and Operators in Copyediting

GOAL: HIGHLIGHT-ARBITRARY-TEXT

A. MOVE-CURSOR-TO-BEGINNING	1.10s
B. CLICK-MOUSE-BUTTON	0.20s
C. MOVE-CURSOR-TO-END	1.10s
D. SHIFT-CLICK-MOUSE-BUTTON	0.48s
E. VERIFY-HIGHLIGHT	1.35s

GOMS Variants

- GOMS (Card, Moran, and Newell 1983)
  - Model of goals, operators, methods, selection rules
  - Predict time an experienced worker needs to perform a task in a given interface design
- Keystroke-level model (simplified version)
  - Comparative analyses of tasks that use mouse (GID) and keyboard
  - Correct ranking of performance times using different interface designs
- CPM-GOMS (critical path method)
  - Computes accurate absolute times
  - Considers overlapping time dependencies
- NGOMSL (natural GOMS language)
  - Considers non-expert behavior (e.g., learning times)

KLM: Keystroke-Level Model

- Execution time for a task = sum of times required to perform the serial elementary gestures of the task
- Typical gesture timings
  - **Keying** K = 0.2 s (tap key on keyboard, includes immediate corrections)
  - **Pointing** P = 1.1 s (point to a position on display)
  - **Homing** H = 0.4 sec (move hand from keyboard to mouse or v.v.)
  - **Mentally preparing** M = 1.35 sec (prepare for next step, routine thinking)
  - **Responding** R (time a user waits for the system to respond to input)
- Responding time R effects user actions
  - Causality breakdown after 100 ms
  - User will try again after 250 ms ⇒ R
  - Give feedback that input received & recognized

Keystroke-Level Calculation

- List required gestures
  - E.g., HK = move hand from mouse to keyboard and type a letter
- Compute mental preparation times Ms
  - Difficult: user stops to perform unconscious mental operations
  - Placing of Ms described by rules
- Add gesture timings
  - E.g., HMPK = H + M + P + K = 0.4 + 1.35 + 1.1 + 0.2 = 3.05 sec
- Rule terminology
  - **String:** sequence of characters
  - **Delimiter:** character marking beginning (end) of meaningful unit
  - **Operators:** K, P, and H
  - **Argument:** information supplied to a command

Rules for Placing Ms

- Rule 0, initial insertion for candidate Ms
  - Insert Ms in front of all Ks
  - Place Ms in front of Ps that select commands, but not Ps that select arguments for the commands
- Rule 1, deletion of anticipated Ms
  - Delete M between two operators if the second operator is fully anticipated in the previous one
    - E.g., PMK ⇒ PK
- Rule 2, deletion of Ms within cognitive units (contiguous sequence of typed characters that form a name)
  - In a string of MKs that form a cognitive unit, delete all Ms except the first
    - E.g., "dir" ⇒ MK MK MK ⇒ MK K K

Rules for Placing Ms

- Rule 3, deletion of Ms before consecutive terminators
  - If K is redundant delimiter at end of a cognitive unit, delete the M in front of it
    - E.g., “bla↵↵” ⇒ M 3K MK MK ⇒ M 3K MK K
- Rule 4, deletion of Ms that are terminators of commands
  - If K is a delimiter that follows a constant string then delete the M in front of it (not for arguments or varying strings)
    - E.g., “clear↵” ⇒ M K K K K K MK ⇒ M K K K K K K

      Note that the ‘clear’ command does not take any arguments, and is therefore a constant string. ‘ls,’ on the other hand, can take arguments and Rule 4 cannot be applied there.
- Rule 5, deletion of overlapped Ms
  - Do not count any M that overlaps an R
    - E.g., user waiting for computer response

Exercise: Temperature Converter

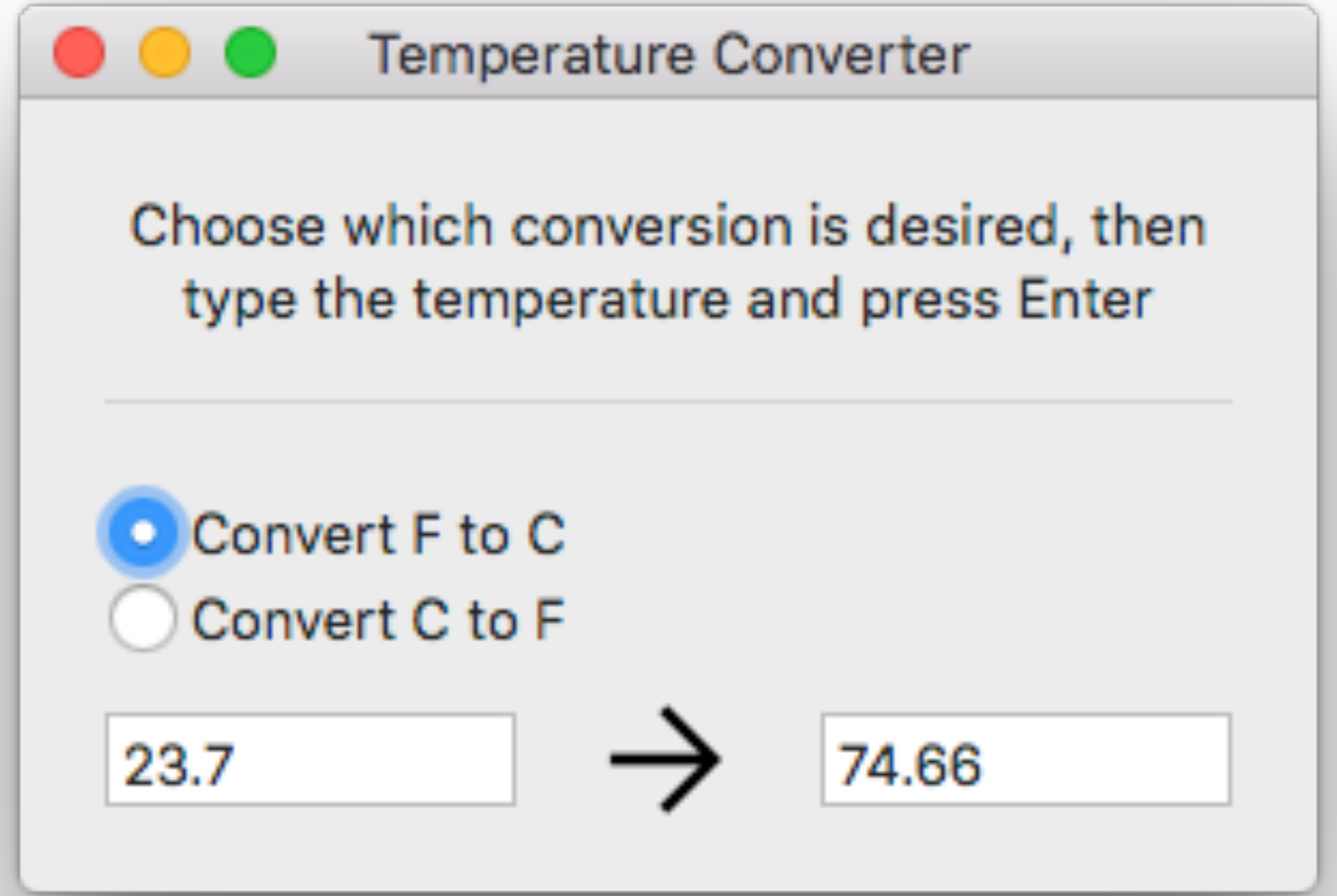
- Convert from degrees Fahrenheit (F) to Celsius (C) or vice versa, requests equally distributed

- Use keyboard or mouse to enter temperature

- Assume active window awaiting input, an average of four typed characters (including point and sign), and no typing errors

- Task: create and analyze your own interface!
  - **Keying** K = 0.2 s, **Pointing** P = 1.1 s, **Homing** H = 0.4 s, **Mentally preparing** M = 1.35 s

The Dialog Box Solution with Radio Buttons…



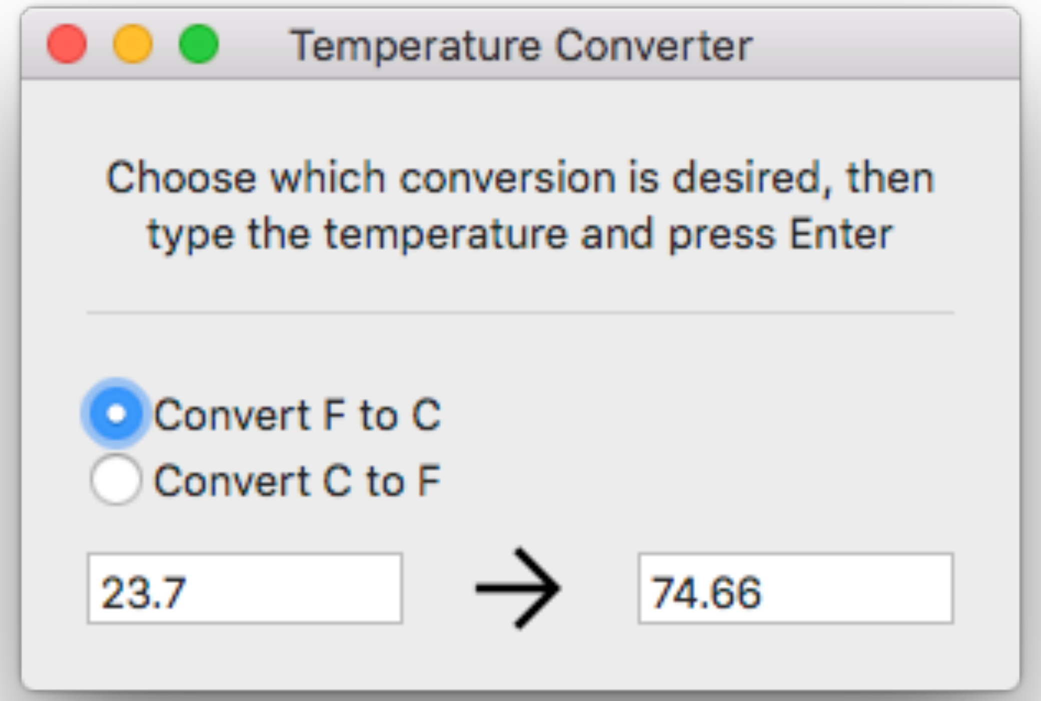
Choose which conversion is desired, then type the temperature and press Enter

● Convert F to C

○ Convert C to F

23.7 → 74.66

…And Its Keystroke-Level Model


Temperature Converter

Choose which conversion is desired, then type the temperature and press Enter

● Convert F to C
○ Convert C to F

23.7 → 74.66

- Case 1: select conversion direction
  - Move hand to mouse, point to desired button, click on radio button (HPK)
  - Move hands back to keyboard, type four characters, tap enter (HPK HKKKK K)
  - Rule 0 (insert M's): (HMPMK HMKMKMKMK MK)
  - Rule 1 (deletion of anticipated M's): (HMP_K HMKMKMKMK MK)
  - Rule 2 (deletion of M's within cog. units): (HMP_K HMK_K_K_K MK)
  - Result: HMPK HMKKKK MK
  - Estimated time = 7.15 sec
- Case 2: correct conversion direction already selected
  - MKKKKMK = 3.7 sec
- Average time = (7.15 + 3.7) / 2 = 5.4 sec

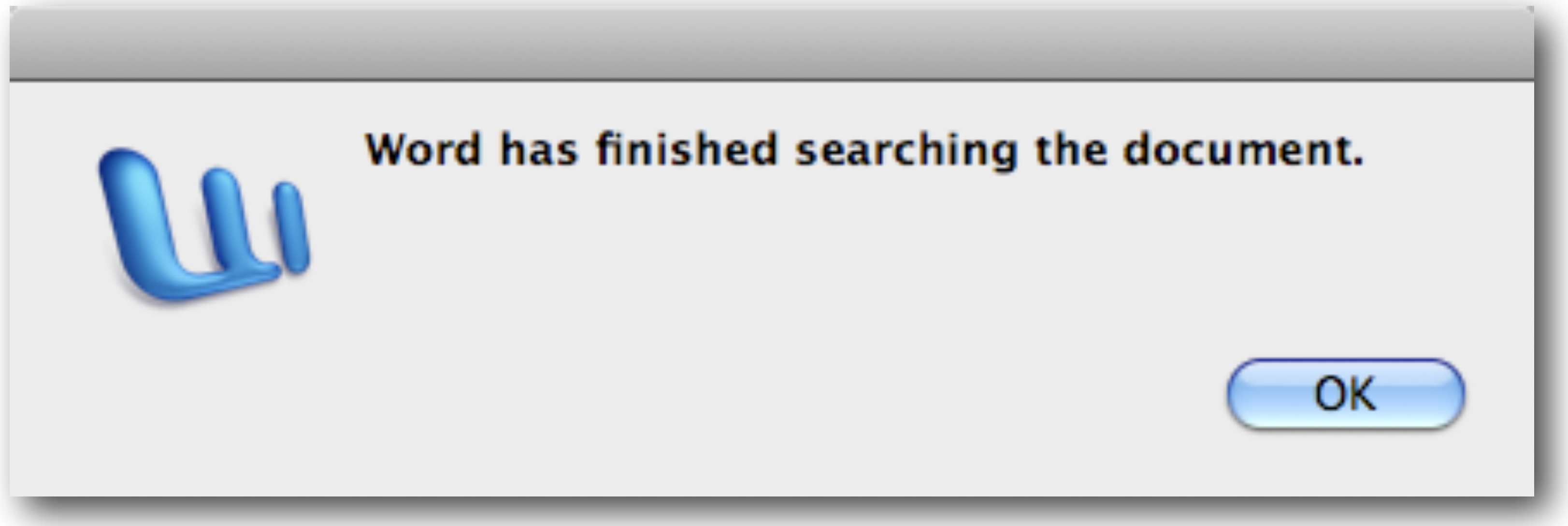
GOMS Results

- Execution (& learning) times of **trained, routine users** for **repetitive tasks** (goals), leading to cost of training, daily use, errors
  - Can be linked to other costs (purchase, change, update system), resulting in $$$ answers
  - Use to model alternative system offers
    - E.g., “new NYNEX computers cost $2M/year more” [Gray93]
- Estimate effects of redesign
  - Training cost vs. long-term work time savings
- Starting point for task-oriented documentation
  - Online help, tutorials, …
- Don’t use for casual users or new UI techniques
  - Operator times not well defined

Information Efficiency

Measuring Interface Efficiency

- How fast can you **expect** an interface to be?
- Information as quantification of amount of data conveyed by a communication (Information theory)
  - E.g., speech, messages sent upon click…



Word has finished searching the document.

- Lower bound on amount of information required for task is independent of interface design
- Information-theoretic efficiency $E = \frac{\text{Minimal info required for the task}}{\text{Info supplied by user}}$
  - $E \in [0, 1]$ (e.g., $E = 0$ for providing unnecessary information)
- **Character efficiency** $= \frac{\textbf{Minimal number of characters required for the task}}{\textbf{Number of characters entered in the UI}}$

[Jef Raskin: The Humane Interface, 2000]

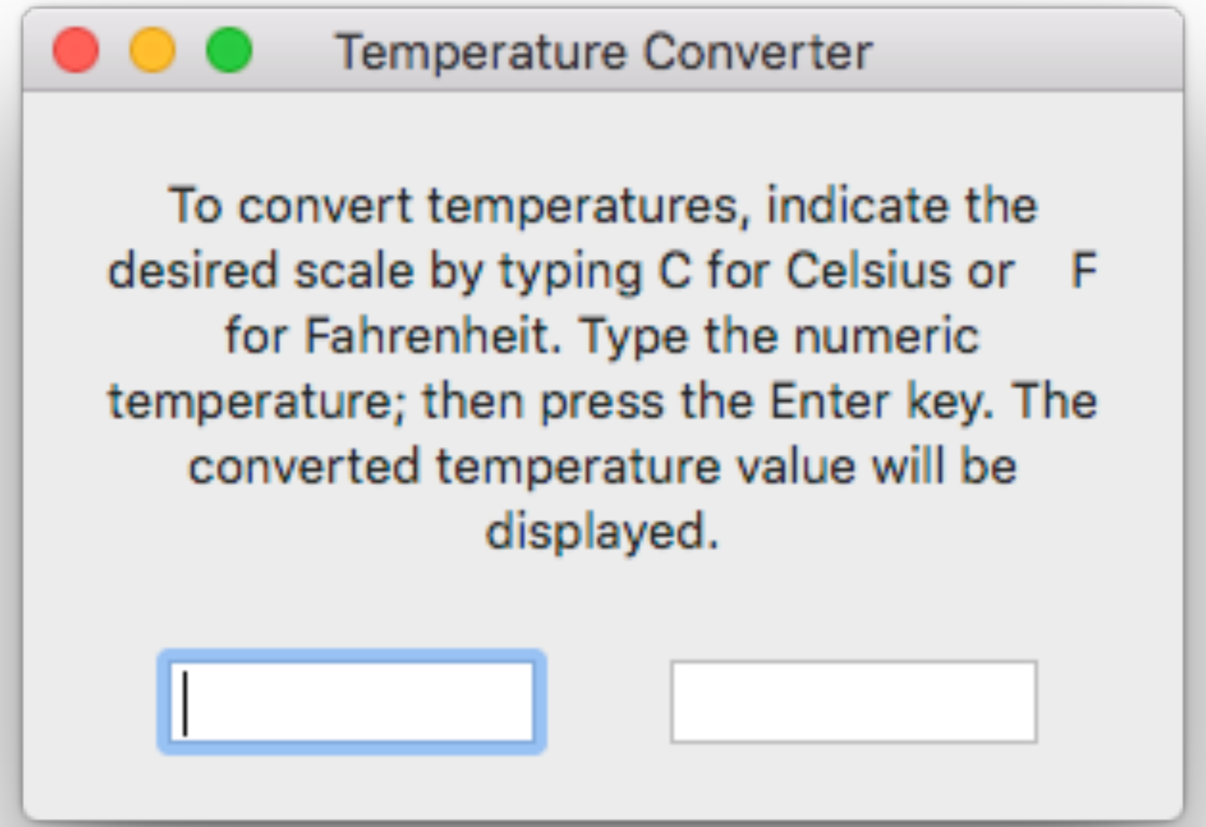
How to Measure Information Required

- Information is measured in bits
  - 1 bit represents choice between 2 alternatives
- n equally likely alternatives
  - Total information amount: $\log_2(n)$
  - Information per alternative: $\frac{1}{n}\log_2(n)$
- n alternatives with different probabilities $p(i)$
  - Information per alternative: $p(i) \cdot \log_2(\frac{1}{p(i)})$
  - Total amount = sum over all alternatives
- Consider situation as a whole
  - Probability of messages required
  - Information measures freedom of choice (information ≠ meaning)

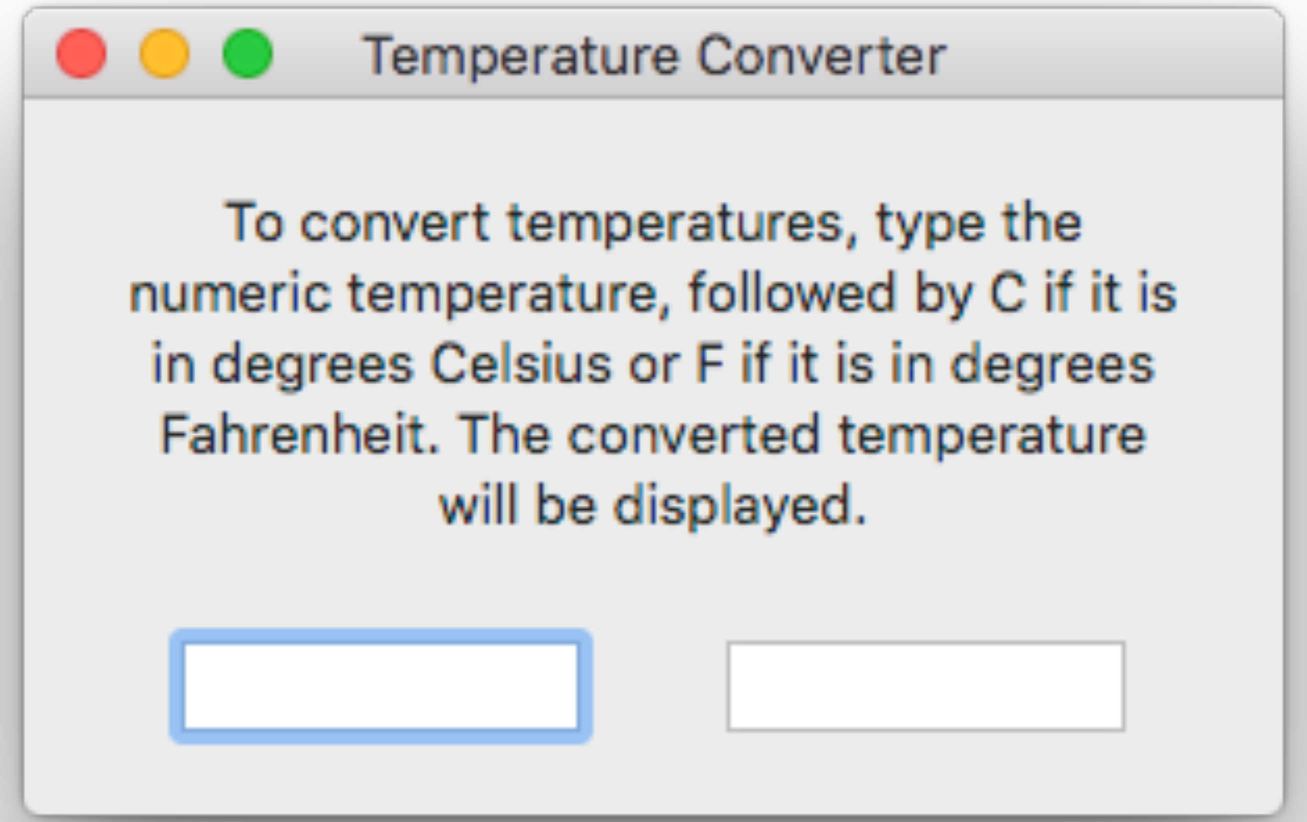
How Much Info Does Temperature Converter Need?

- Input assumptions (given)
  - 50% Fahrenheit, 50% Degree Celsius
  - 75% positive, 25% negative
  - only decimal input (no integer numbers)
  - All digits are equally likely
  - Only four characters input

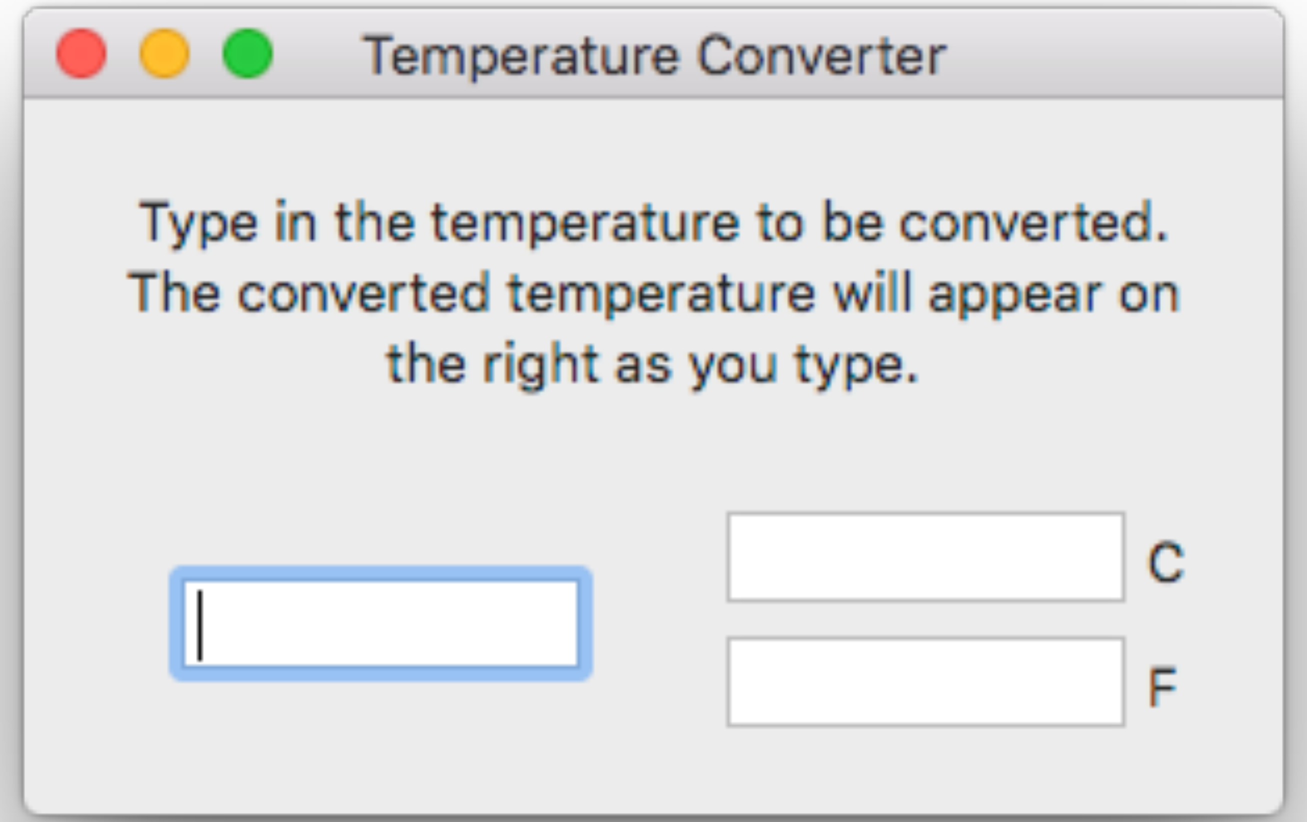
Character Efficiency Of Temperature Converters



To convert temperatures, indicate the desired scale by typing C for Celsius or F for Fahrenheit. Type the numeric temperature; then press the Enter key. The converted temperature value will be displayed.



To convert temperatures, type the numeric temperature, followed by C if it is in degrees Celsius or F if it is in degrees Fahrenheit. The converted temperature will be displayed.



Type in the temperature to be converted. The converted temperature will appear on the right as you type.

Type C or F, value, enter	Type value, then C or F	Bifurcated
↓	↓	↓
M K K K K K M K	M K K K K M K	M K K K K
↓	↓	↓
3.9s char. eff. 67%	3.7s char. eff. 80%	2.15s char. eff. 100%

Minimum for Temp. Converter

Information per alternative:

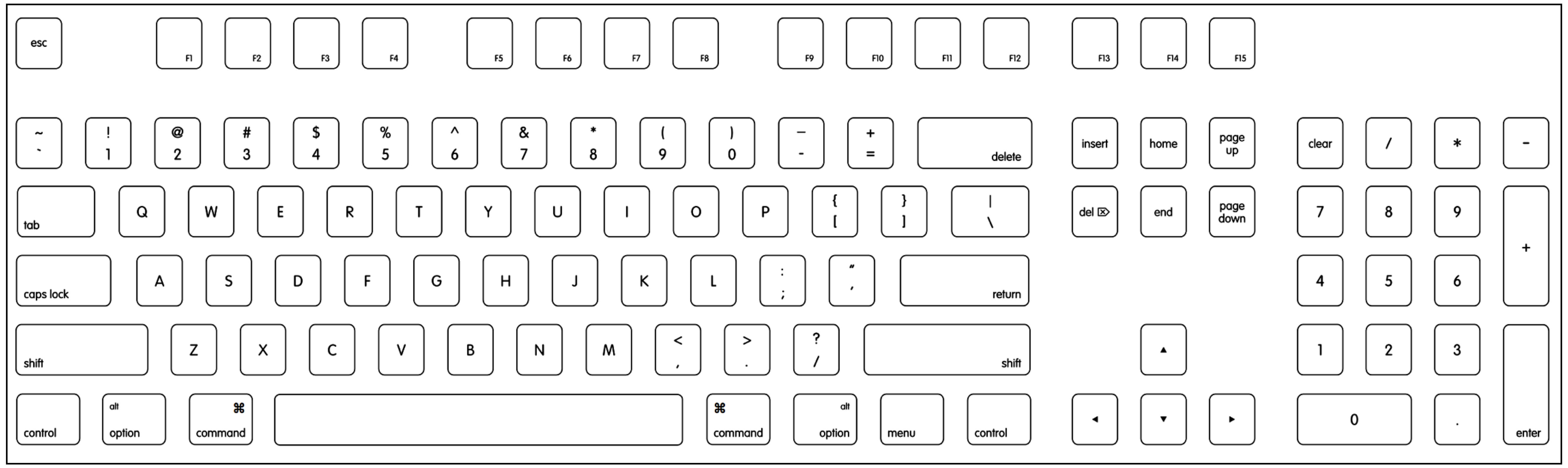
$$p(i) \cdot \log \frac{1}{p(i)}$$

Numbers	Prob.	Values	$p(i)$	Information in bits	Overall (values × information in bits)
-.dd	12.5 %	100	0.00125	0.012	1.2
-d.d	12.5 %	100	0.00125	0.012	1.2
.ddd	25 %	1000	0.00025	0.003	3
d.dd	25 %	1000	0.00025	0.003	3
dd.d	25 %	1000	0.00025	0.003	3

⇒ Minimal info required for the task = 11.4 bits/message

⇒ Simple approach: $4 \log_2(12) \approx$ 14 bits

Temperature Converter With Diff. Keyboards



- Information efficiency: $E = \dfrac{\text{11.4 bits}}{\text{Info supplied by user}}$
  - 128 keys standard keyboard (~5 bits/key in practice): $E = \dfrac{11.4}{4 \cdot 5} \approx 55\,\%$
  - 16 keys numeric keypad: $E = \dfrac{11.4}{4 \cdot 4} \approx 70\,\%$
  - 12 keys dedicated keypad: $E = \dfrac{11.4}{4 \cdot 3.6} \approx 80\,\%$