Human Factors and User Interfaces in Energy Efficiency

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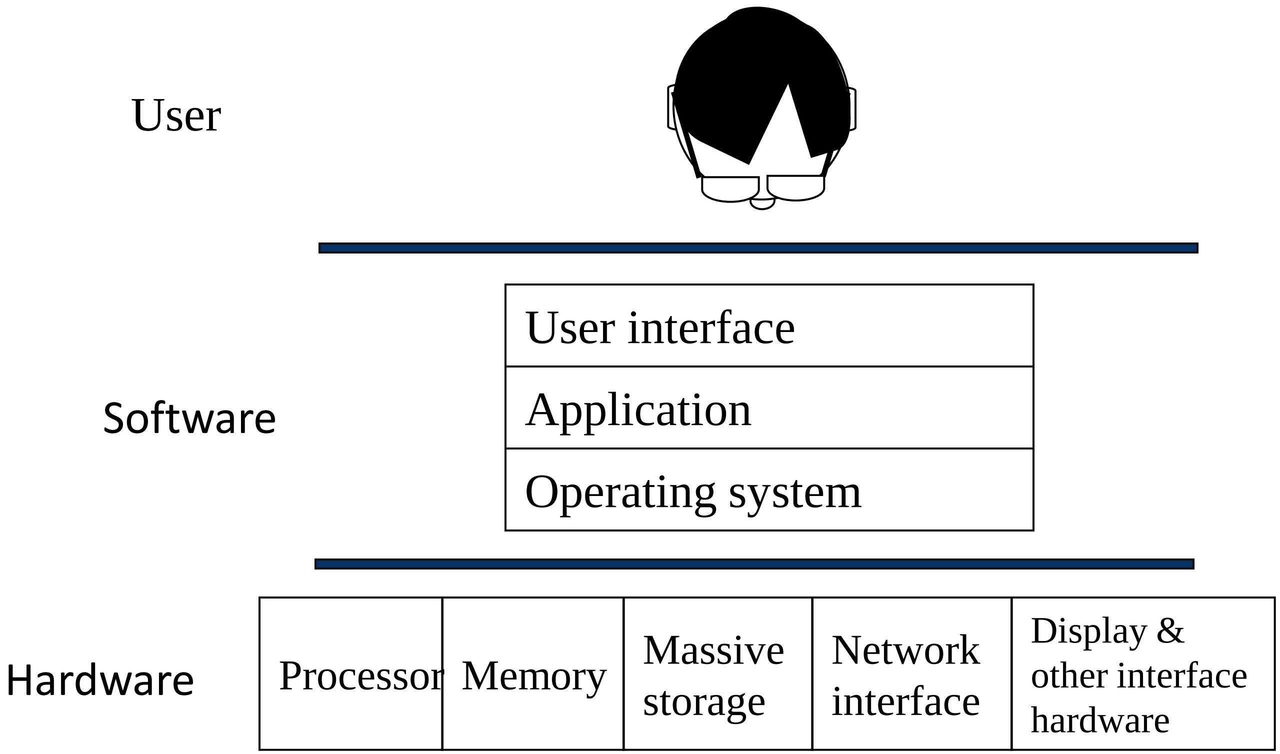
ELEC518, Spring 2011

Motivation


User
Software
User interface
Application
Operating system
Hardware
Processor
Memory
Massive storage
Network interface
Display & other interface hardware

Energy efficiency: definition

$$\text{Energy efficiency} = \frac{\text{User productivity}}{\text{Avg. power consumption}}$$

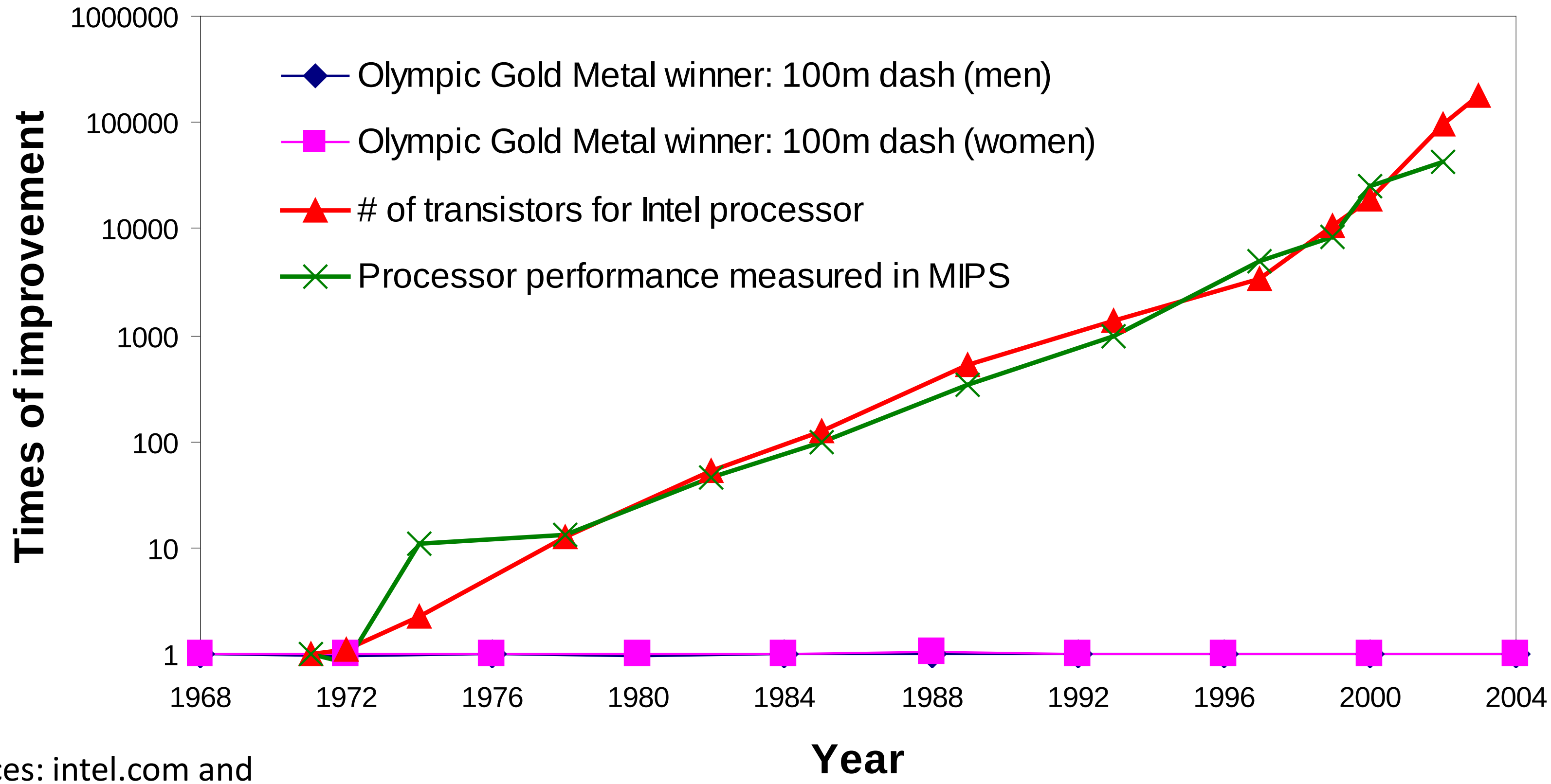
$$= (\text{User productivity}) \times (\text{Power efficiency})$$

Human-computer interaction (HCI) → Low-power design

Limits

- Minimal power/energy requirements
- Human speeds

Speed mismatch



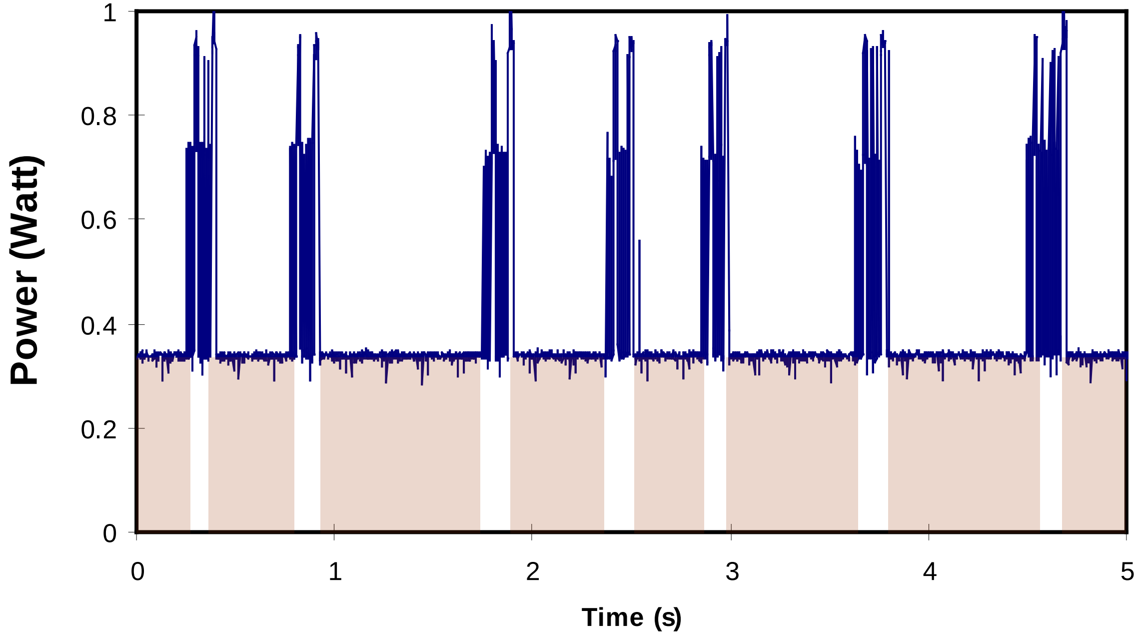
Sources: intel.com and factmonster.com

A constantly slow user

An increasingly powerful computer

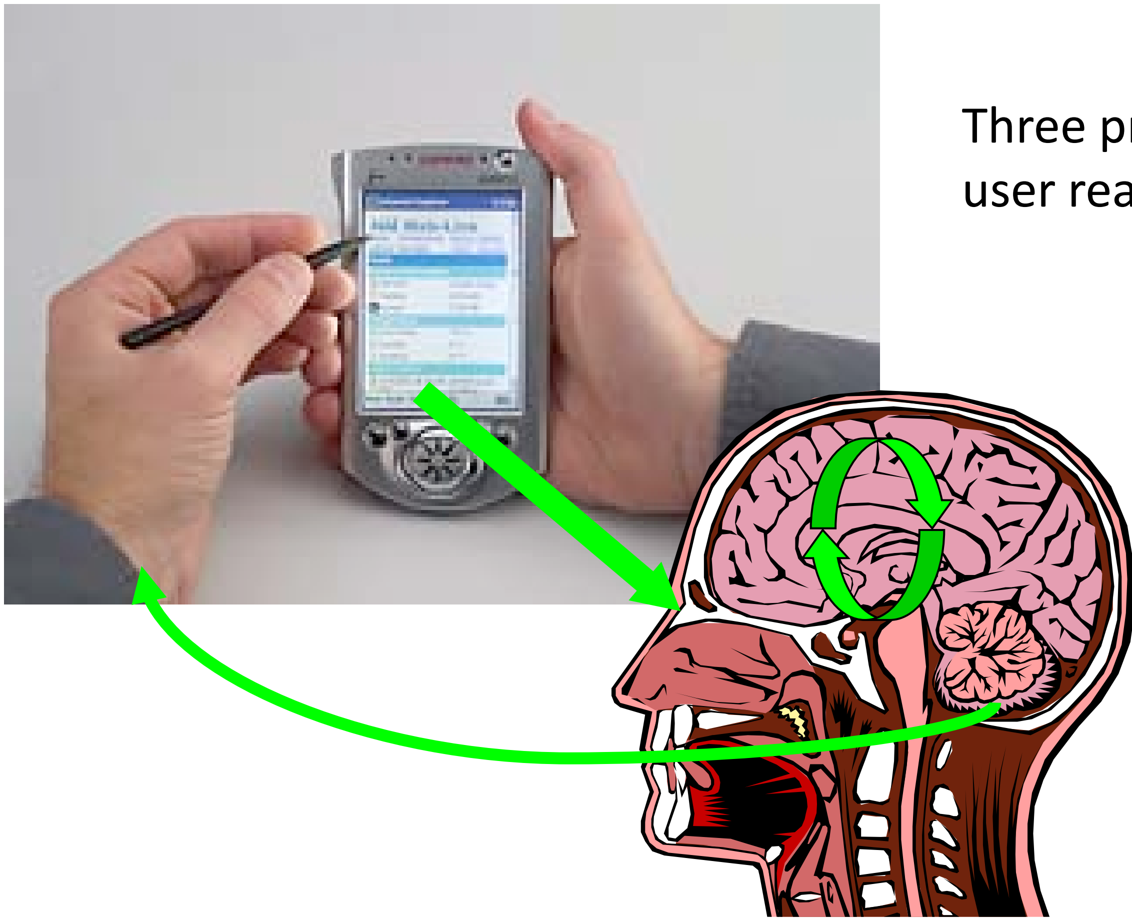
Slow-user problem

A computer spends most of its energy in interfacing

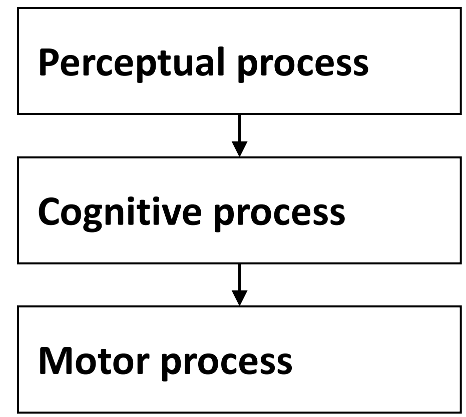


Slow-user problem cannot be alleviated by a “better” or more powerful interface

Model Human Processor



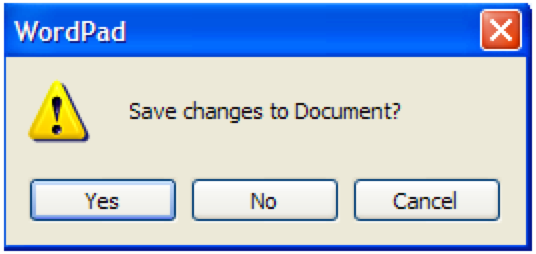
Three processes involved in the user reaction to a computer



Model Human Processor: Card, Moran & Newell'83

Perceptual process

- Fixations and saccades
  - Fixation: information absorbed in the fovea (60ms)
  - Saccades: quick movements between fixations (30ms)
  - Each GUI object requires one fixation and one saccade
- Rauding rate
  - Raud: read with understanding
  - 30 letters/second (Carver, 1990)



Cognitive process

- Hick-Hyman Law
  - *N* distinct and equally possible choices

$$\text{Cognitive delay} = \frac{1}{7}\log_2\left(N+1\right) \quad (s)$$

- Applicable only to simple cognitive tasks
  - Selection: menu, buttons, list

General form

- Hick-Hyman Law

  – p_i : the probability that the *ith* choice is selected

$$\text{Cognitive delay} = \frac{1}{7}\sum_{i=1}^{N} p_i \log\left(1 + \frac{1}{p_\mathrm{i}}\right)$$

  – p_i can be estimated based on history

Motor process

- Stylus operation

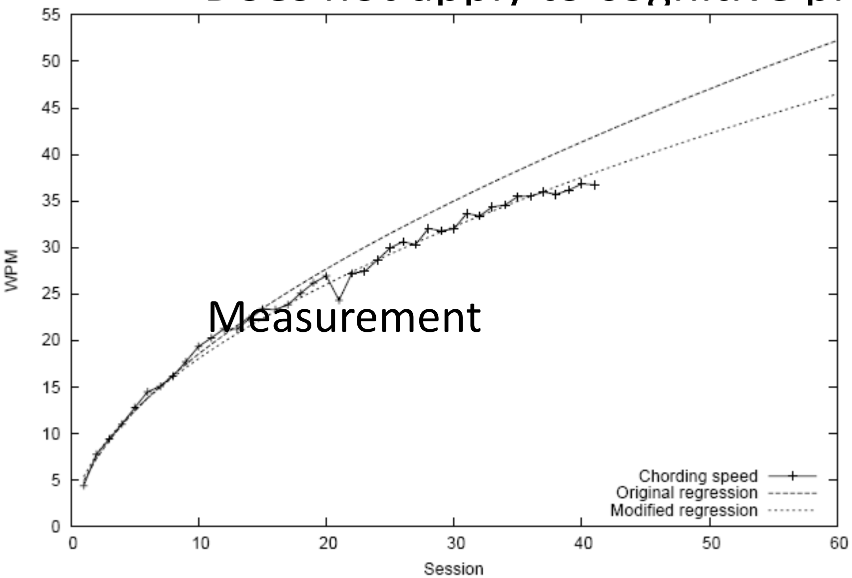
- Fitts' Law
  - *A*: distance to move
  - *W*: target dimension along the moving direction

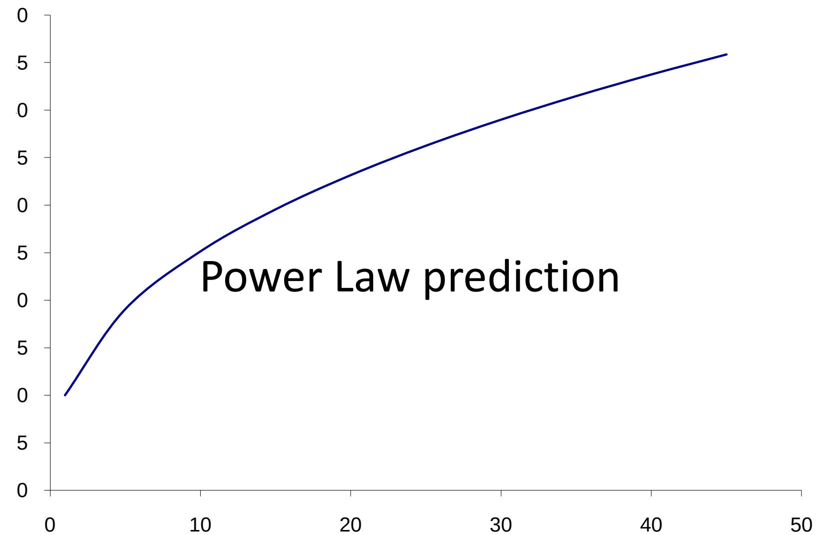
$$\text{Motor delay} = 0.23 + 0.166 \log_2\left(\frac{A}{W} + 1\right) \ \text{(s)}$$

  - Parameters adopted from (MacKenzie and Buxton, 1992)

Power Law of practice

- Speed on n^{th} trial
  - $S_n = S_1 n^a$, where a ≈0.4
  - Applies to perceptual & motor processes
  - Does not apply to cognitive process or quality



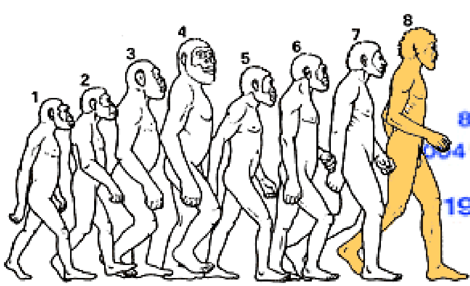


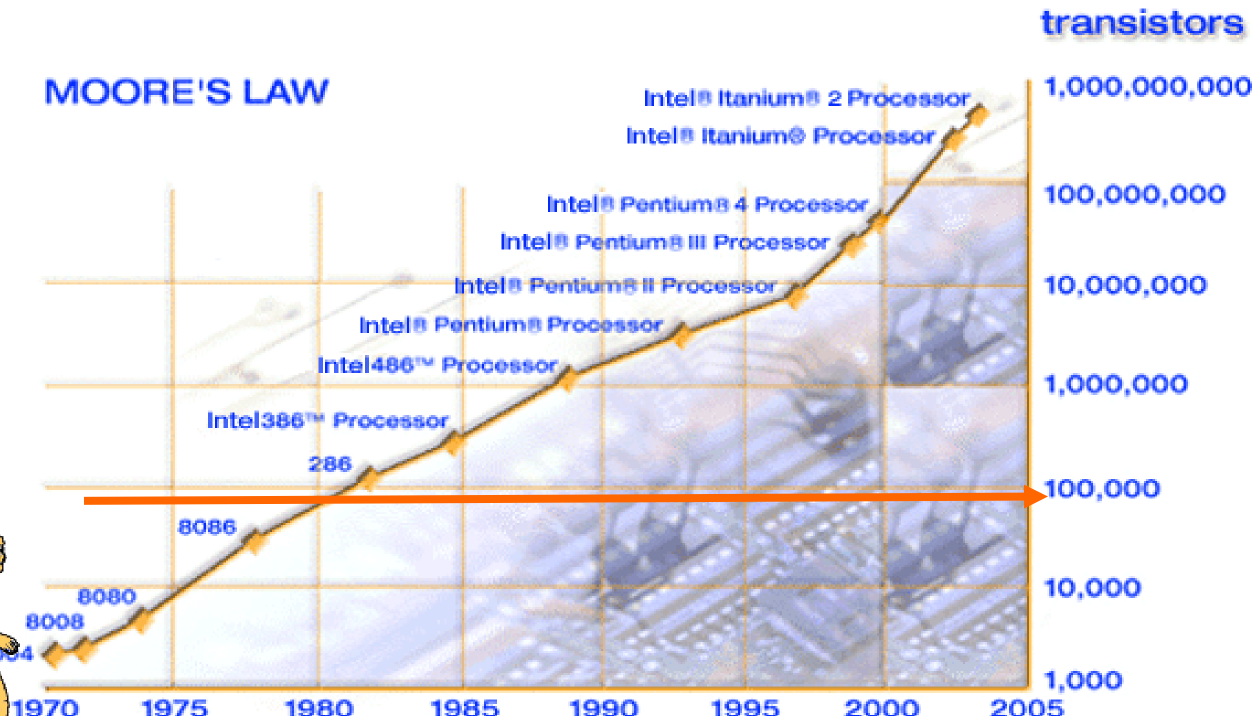
Learning curve of text entry using Twiddler, Lyons, 2004

Human capacity limitations

- Perceptual
- Cognitive
- Motor
- ……

Human capacity





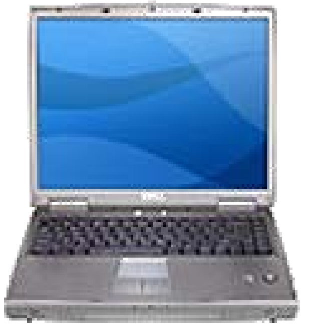
Cache

	Memory cache	*Interface cache*
Speed mismatch	CPU & memory	*Computer & user*
Cost to reduce	Memory access latency	*Interfacing energy*
Task to outsource	Frequently accessed data	*Frequent interactions*

Alleviate slow-user problem with a "worse" or less powerful interface

Interface cache: examples

Flip phones



Average time spent on laptop per day declined from 11.1 hours to 6.1 hours 5 months after Blackberry deployment

-----Goldman Sachs Mobile Device Usage Study

Human thermal comfort

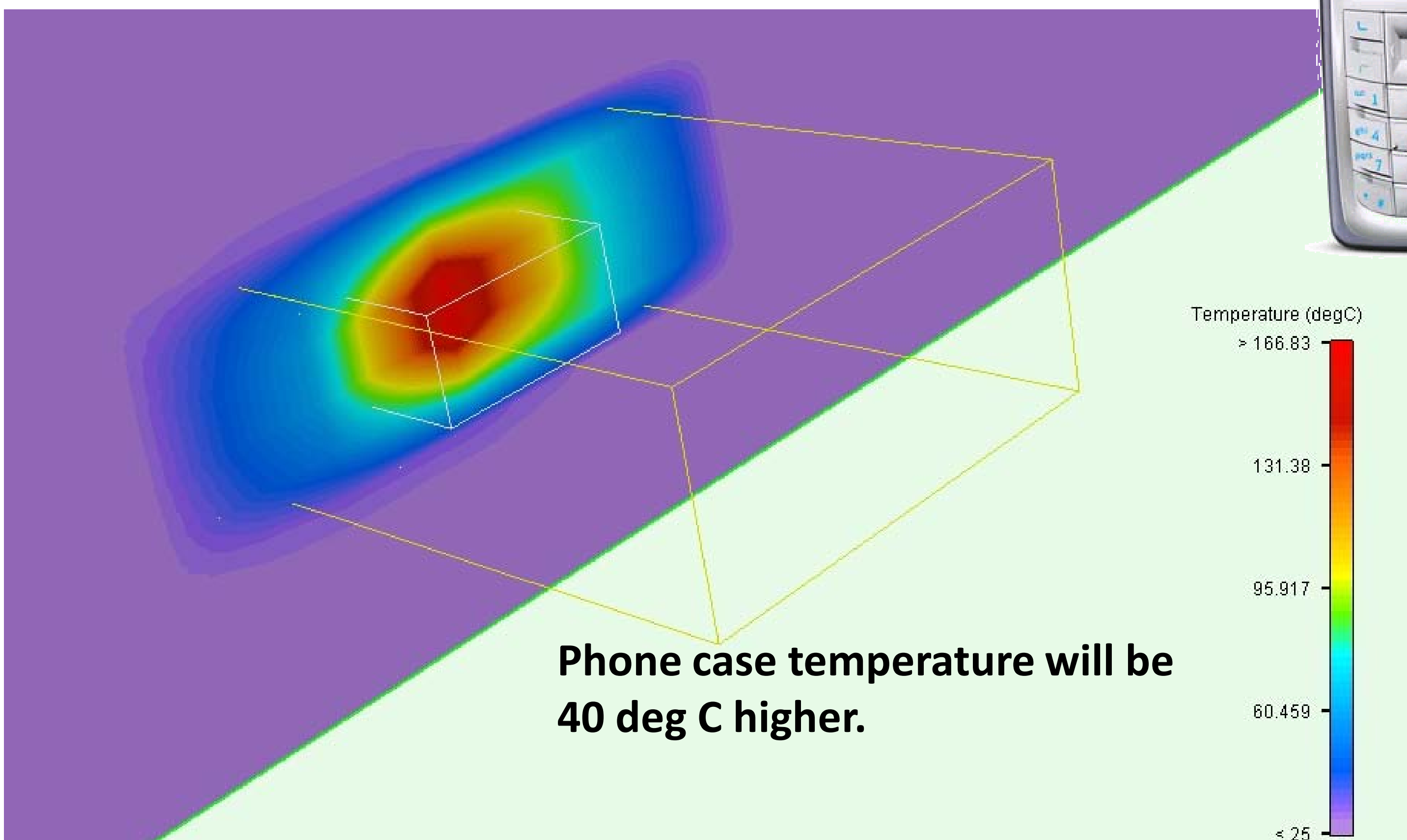
Skin temperature sensations.

Skin temp., °C	State
45	tissue damage
43–41	threshold of burning pain
41–39	threshold of transient pain
39–35	hot
37–35	initial sense of warmth
34–33	neutral
33–15	increasing cold
15–5	intolerably cold

Starner & Maguire, 1999 and Kroemer et al, 1994

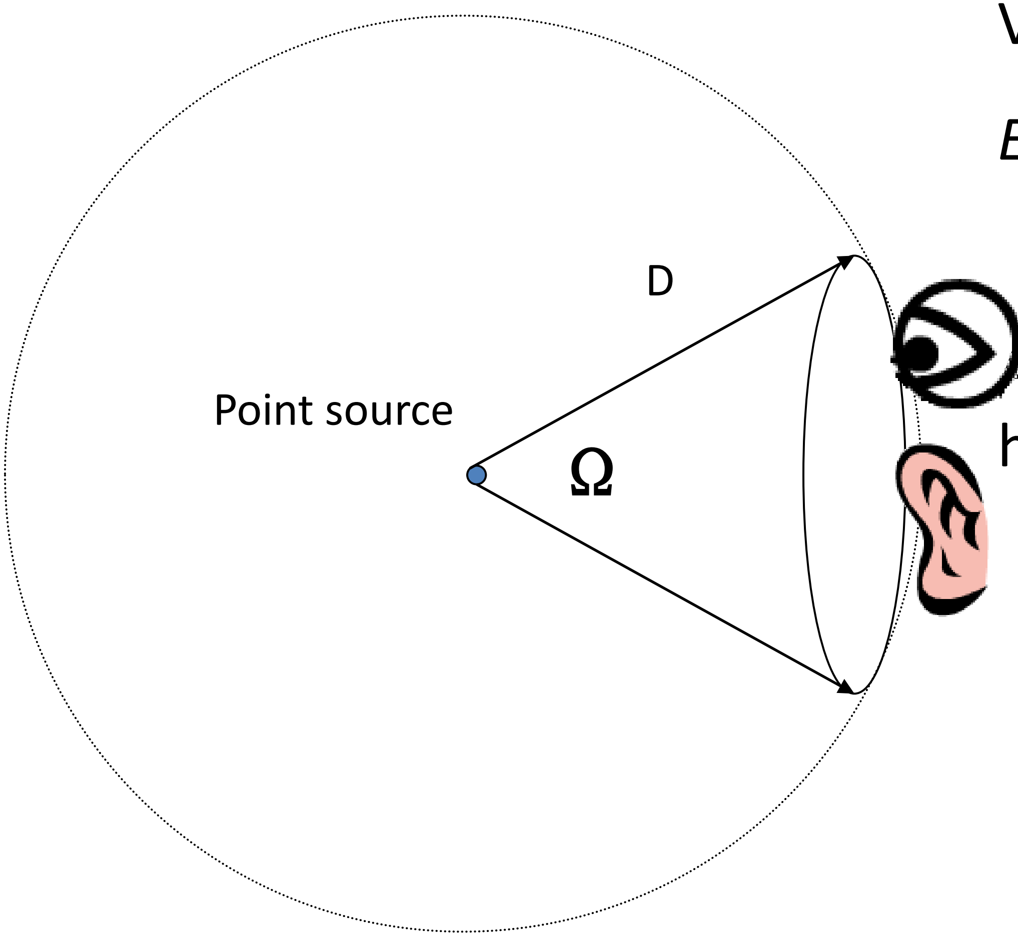
A hot case: 3-Watt Nokia 3120

Every One Watt increases surface temperature by about 13 deg C



Phone case temperature will be 40 deg C higher.

Minimal power/energy requirement



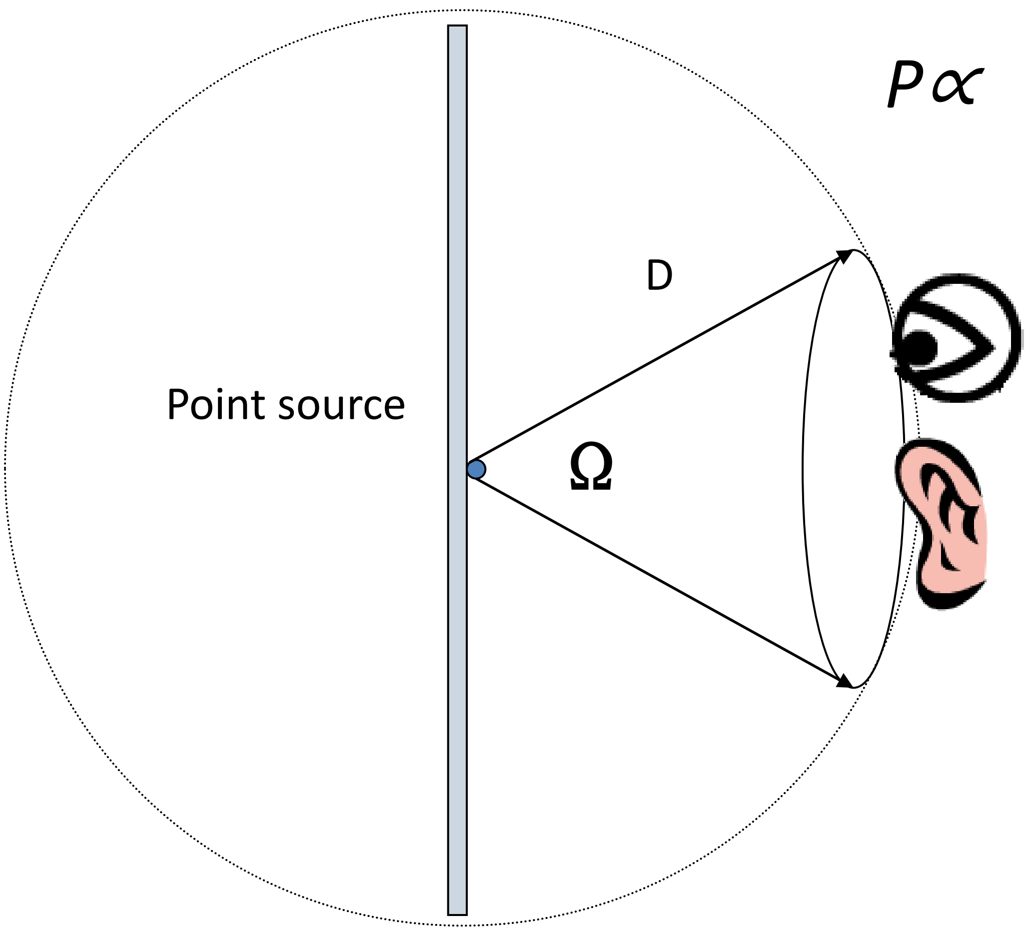
Visual and auditory output

$E_{min} \approx \Omega \cdot D^2 \cdot 10^{-13}$ (Joule)

About 10^{-14} (Joule) for most handheld usage

Minimal energy requirement for 1-bit change
with irreversible computing
10^{-21} (Joule)
(Landauer, 1961)

Insights for power reduction



Reflective layer
to control Ω

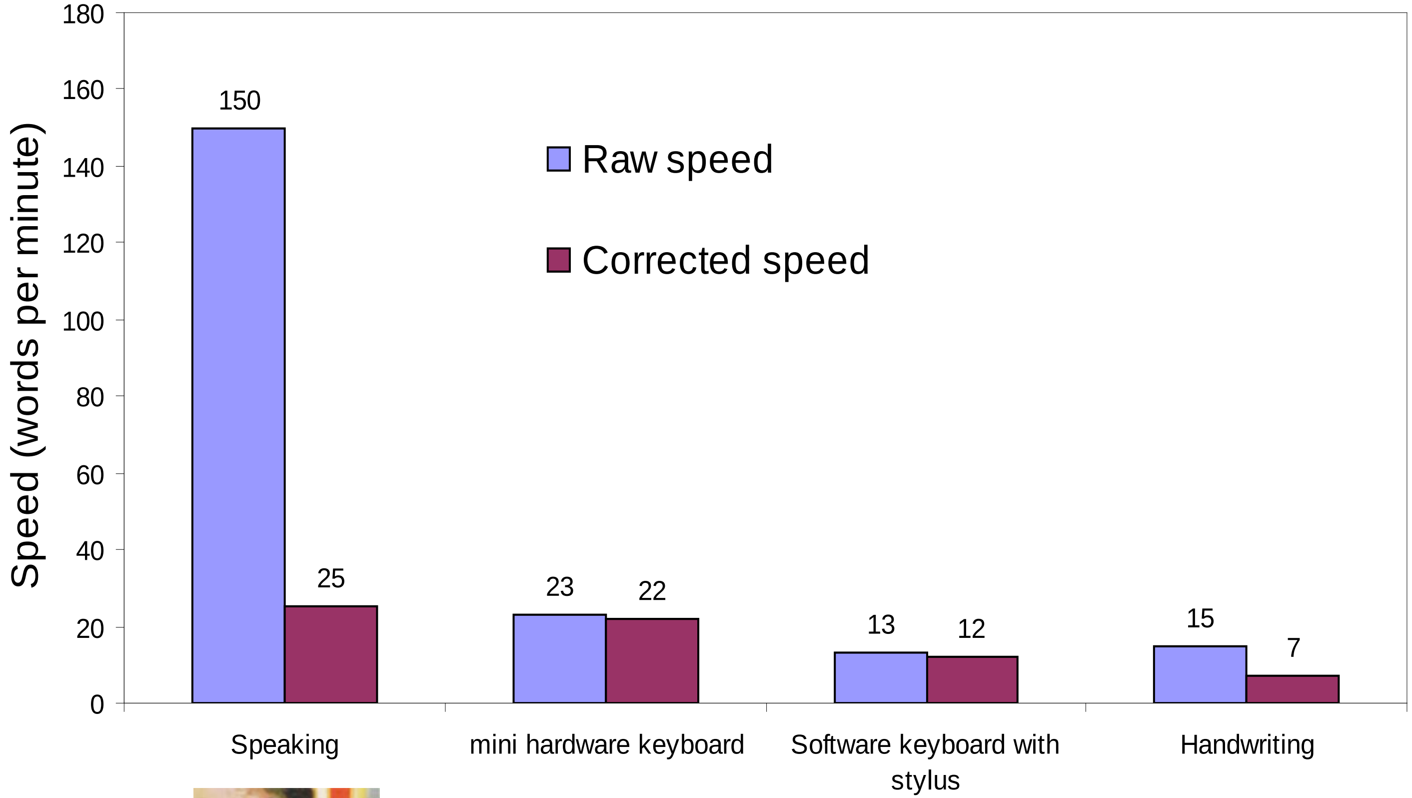
$$P \propto \frac{\Omega \cdot D^2}{\eta(\lambda) \cdot V(\lambda)}$$

λ: wavelength of light/sound

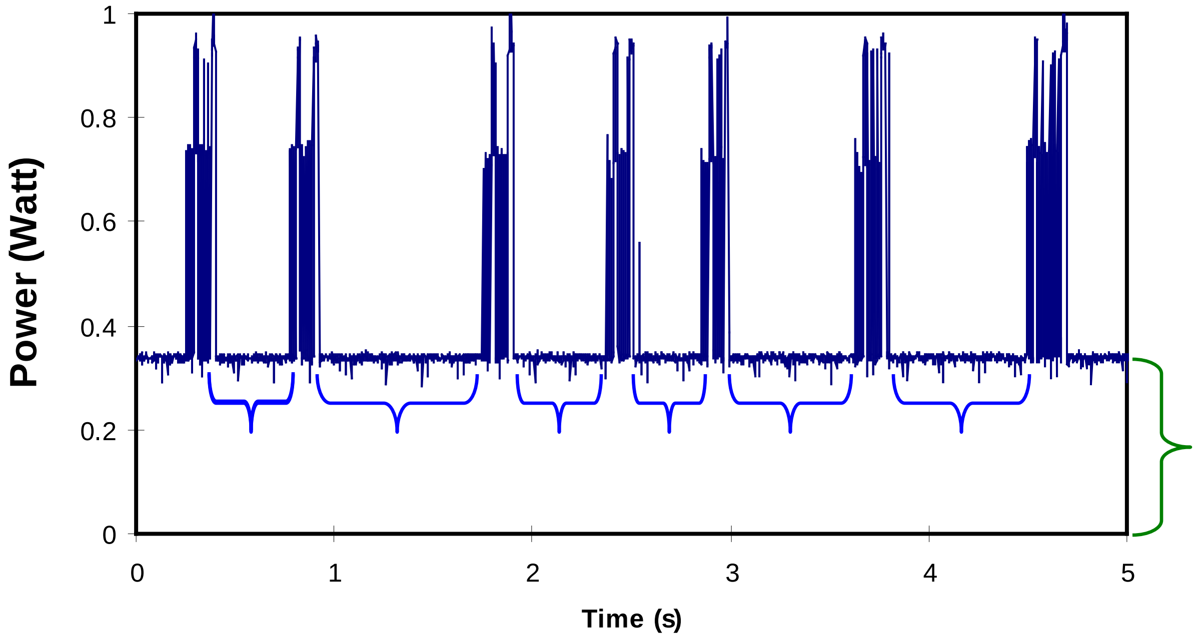
$\eta(\lambda)$: conversion efficiency from electrical power

$V(\lambda)$: relative human sensitivity factor

Text entry speed (productivity)



Impact of human factors



Using Calculator on Sharp Zaurus PDA

Length of idle periods cannot be significantly reduced

Power consumption in idle periods is dominated by interfacing devices

99% time and 95% energy spent in idle periods during interaction

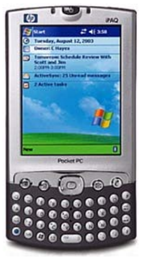
Experimental setup

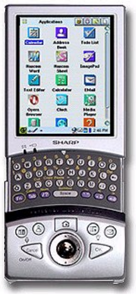
Devices

HP iPAQ 4350

Sharp Zaurus SL-5600

Windows
Transflective/back light
Bluetooth
Speech recog.





Linux/Qt
Reflective/front light

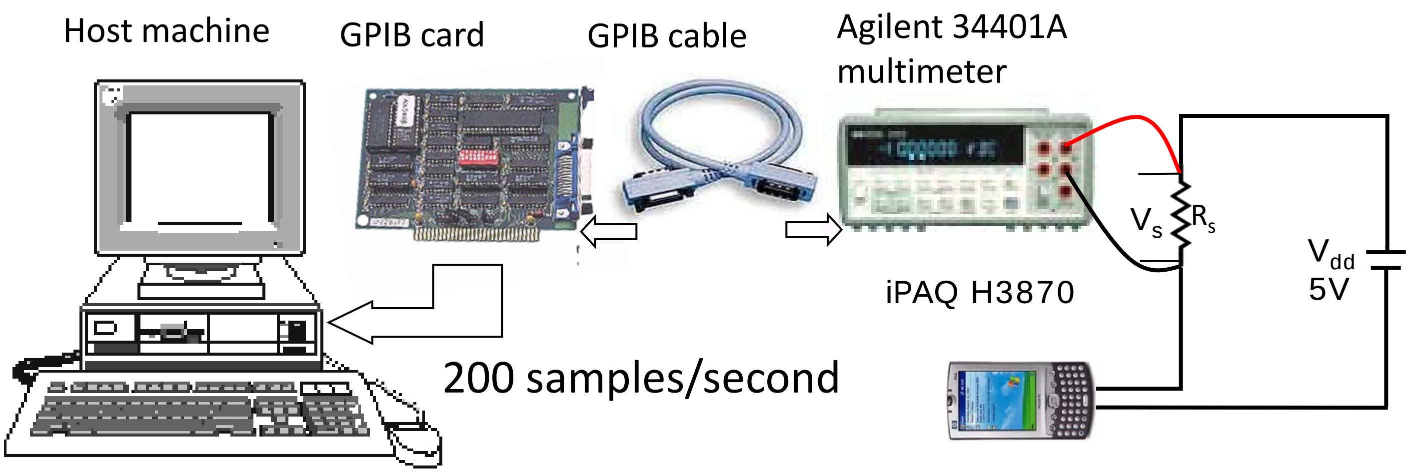
Intel Xscale 400Mhz

240X320, 16-bit color

mic., speaker & headphone jack

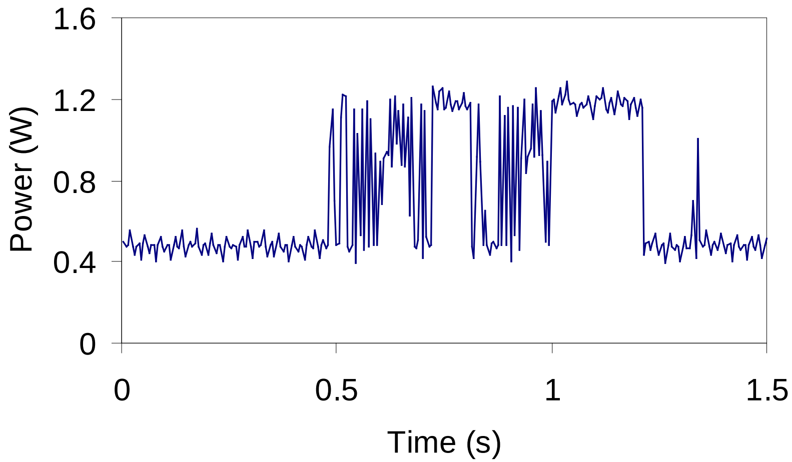
Experimental setup (*Contd.*)

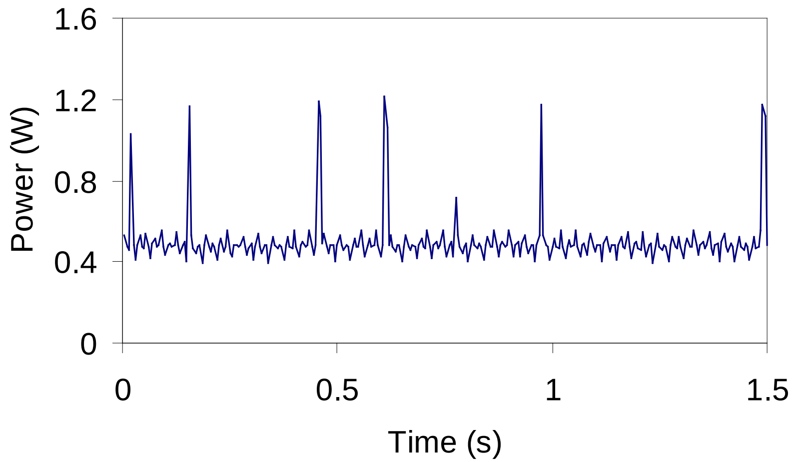
Measurement



Experimental setup (*Contd.*)

Write “x” with
stylus/touchscreen

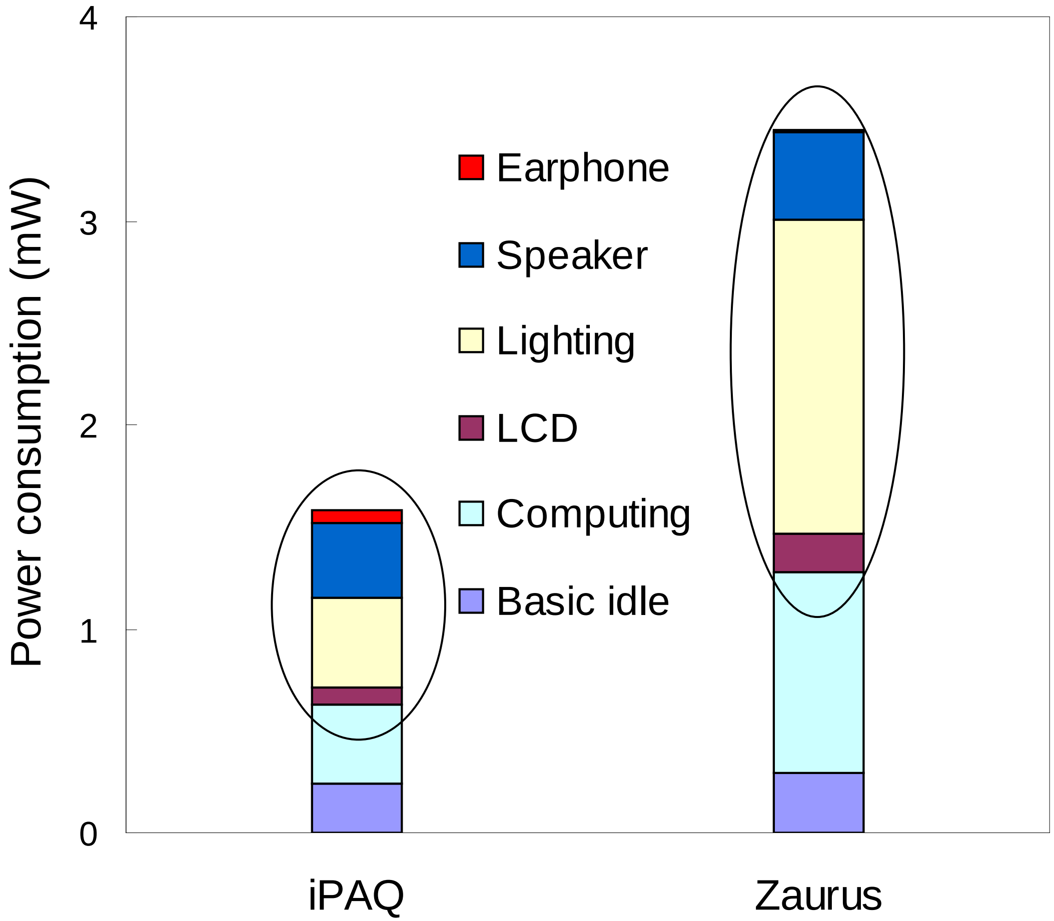




Extra energy consumption by
writing “x”

Extra energy/power consumption of an event is obtained through differential measurement

Power breakdown



A handheld usually spends most time being idle but the display has to be on most time

If the display is not on, the speaker subsystem is usually on

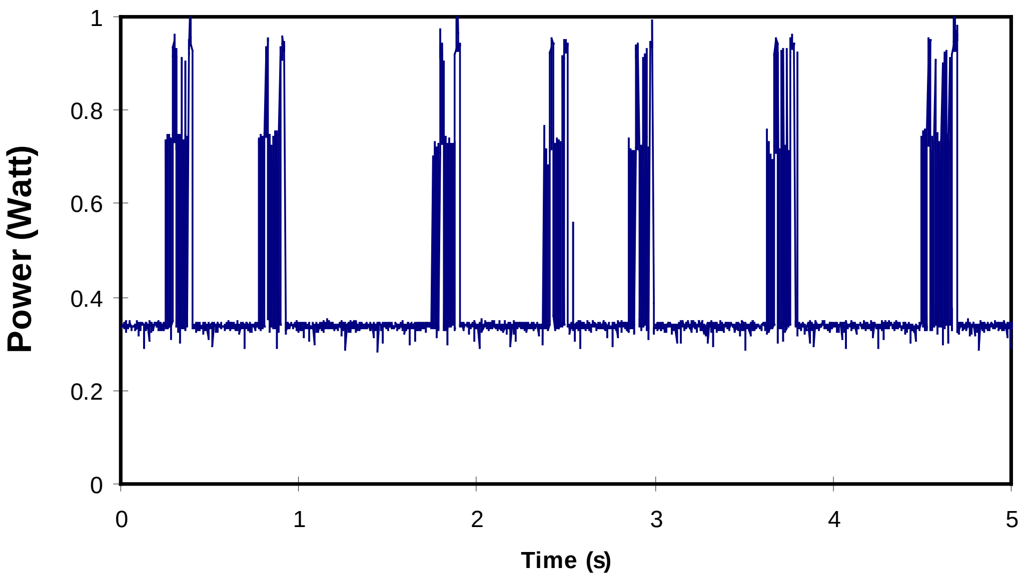
Computing: carrying out DCT repetitively

Energy characterization

- Visual interfaces
  - Graphical user interfaces (GUIs)
  - Digital camera
- Auditory interfaces
  - Recording/playback
  - Speech recognition & synthesis
- Manual text entry

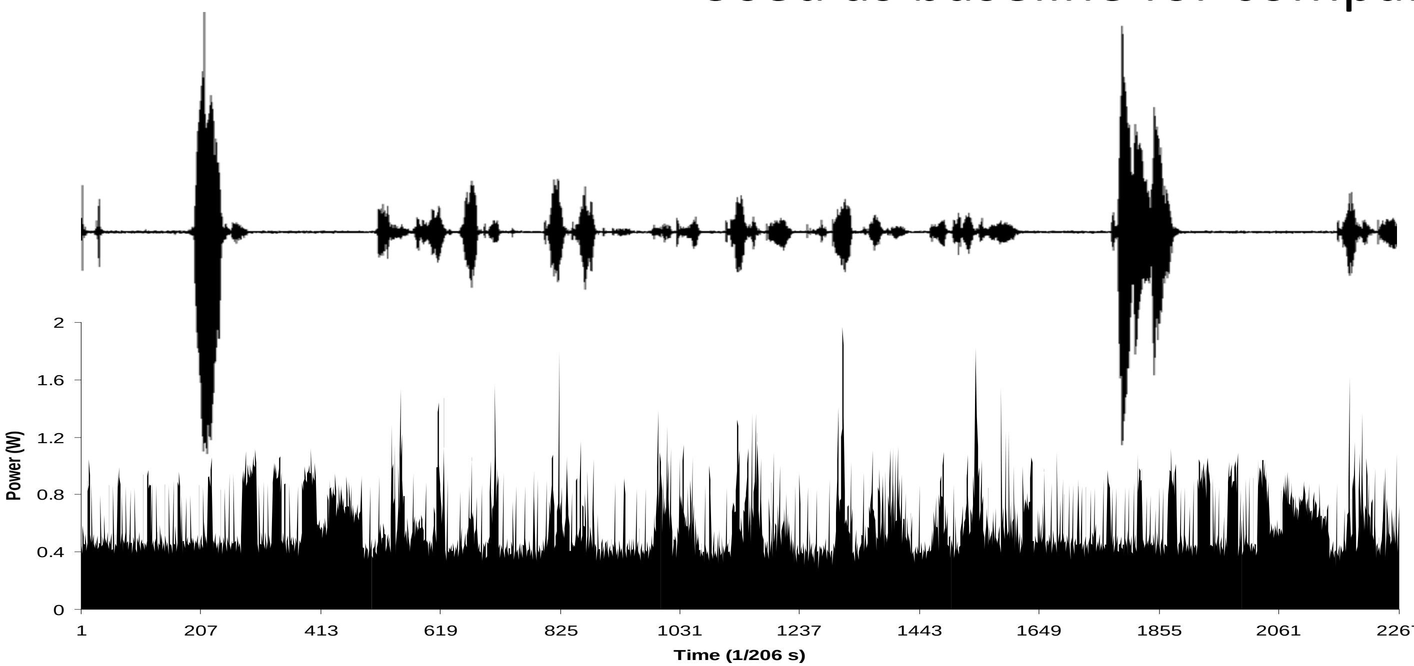
GUIs

- Stylus/Touch-screen
- Most energy/time spent in idle periods
  - Energy consumed by computing negligible
- Task time determines energy consumption



Speech synthesis & recognition

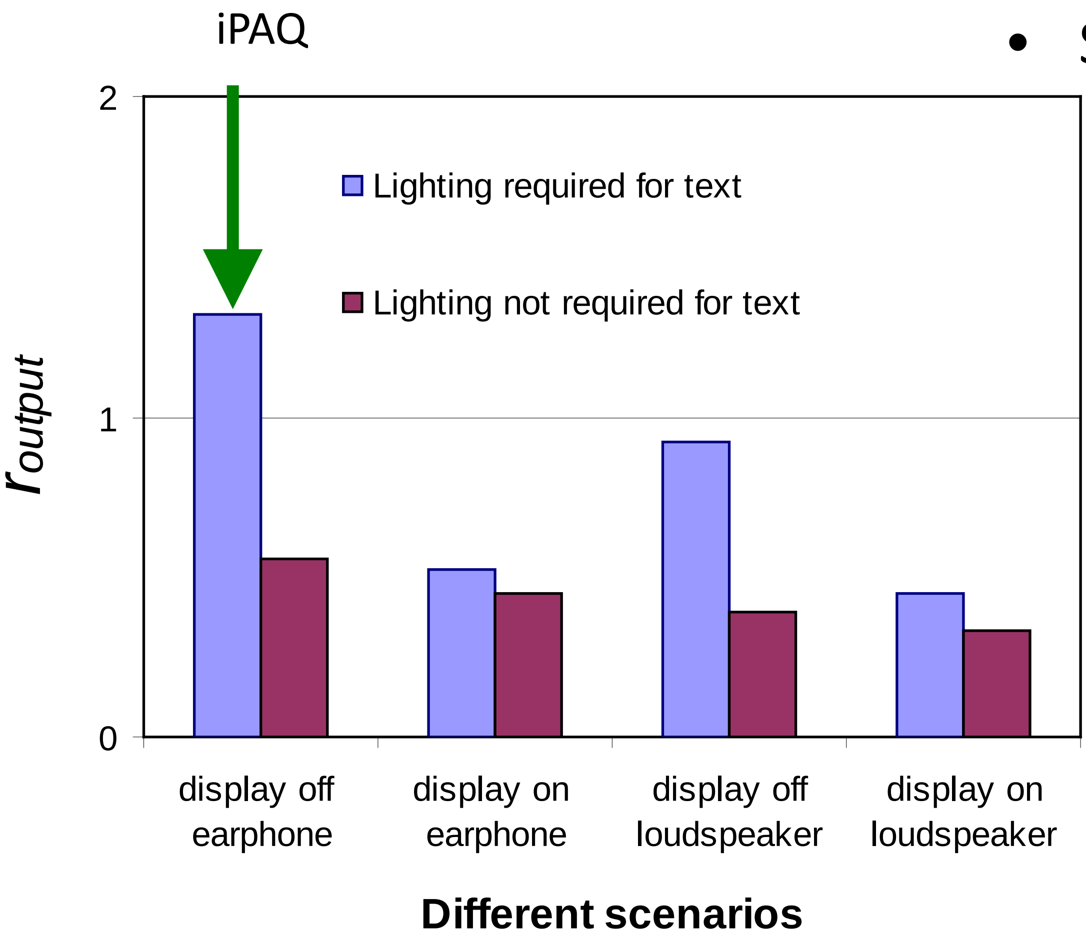
- Infer the behavior of *Voice Command* by comparing voice recording and power trace
- Computing is not demanding
- Used as baseline for comparison



Voice recording

Power trace

Comparison: Output



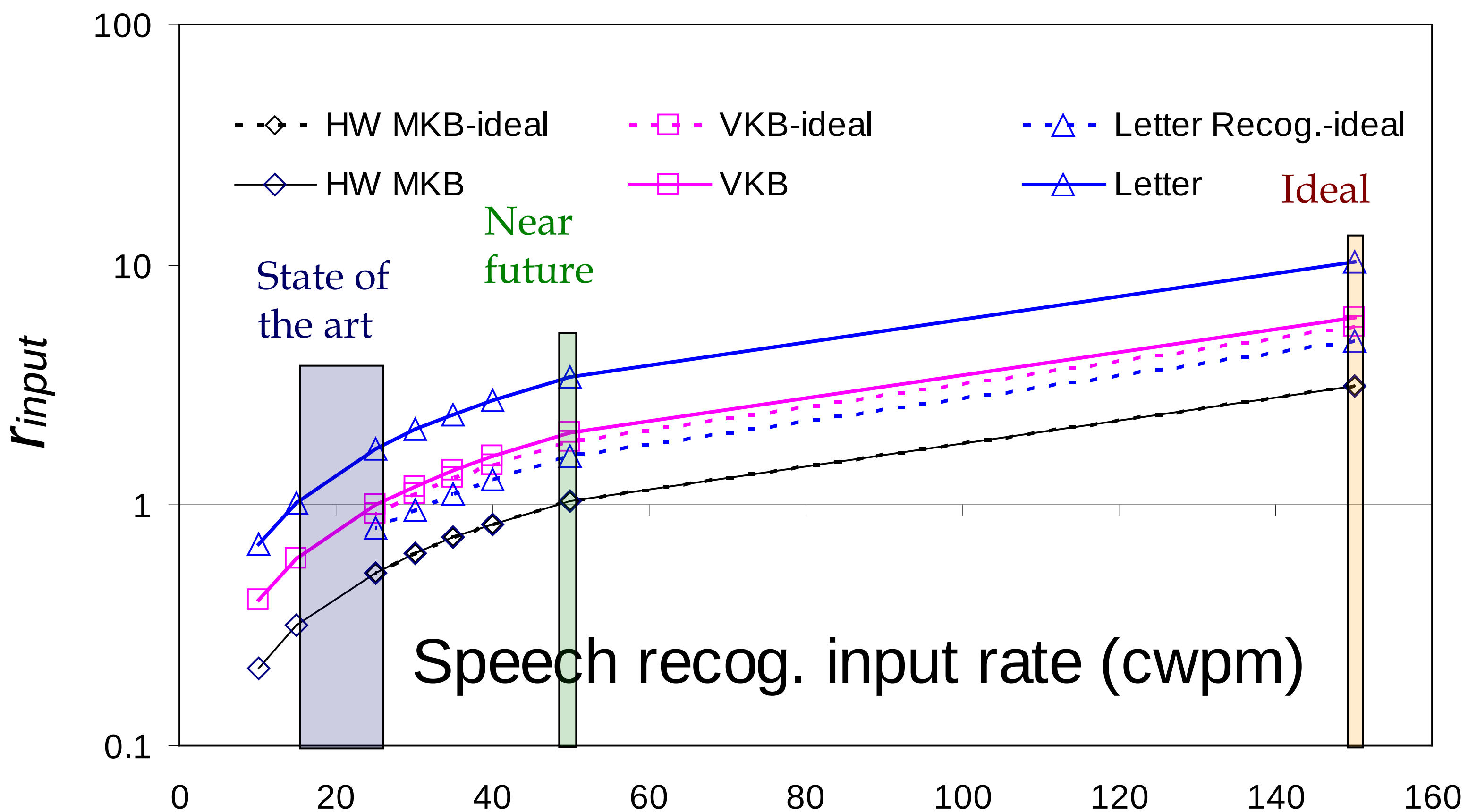
- Speech is better only when
  - display is turned off
  - earphone is used
  - nighttime usage

Energy efficiency ratio

$$r = \frac{R_{spk}}{R_{rd}} \cdot \frac{P_{txt}}{P_{spk}}$$

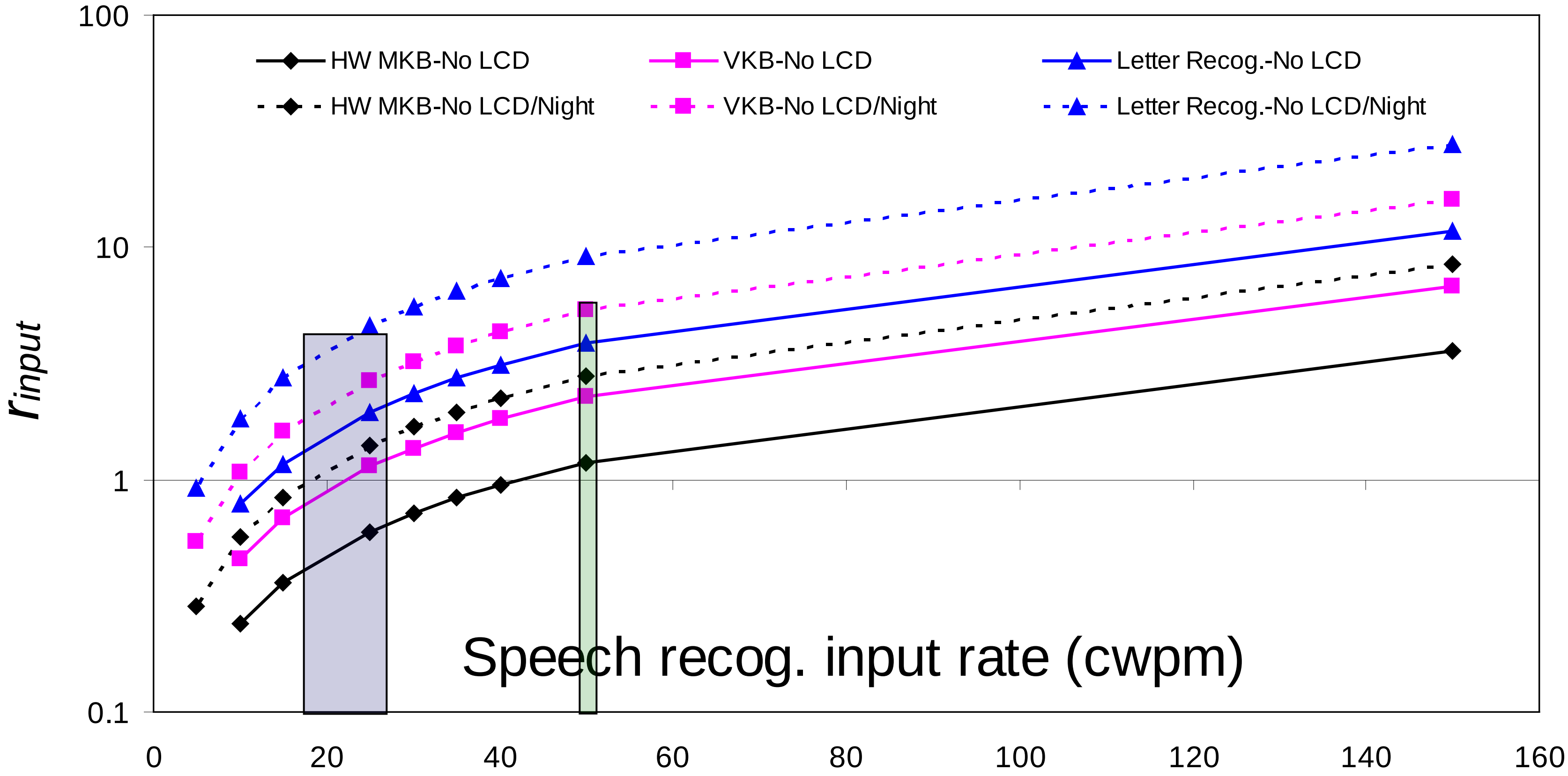
If *r >1*, speech output is more energy-efficient

Comparison: Text entry



If *r >1*, speech recognition is more energy-efficient

Comparison: Text entry (Contd.)

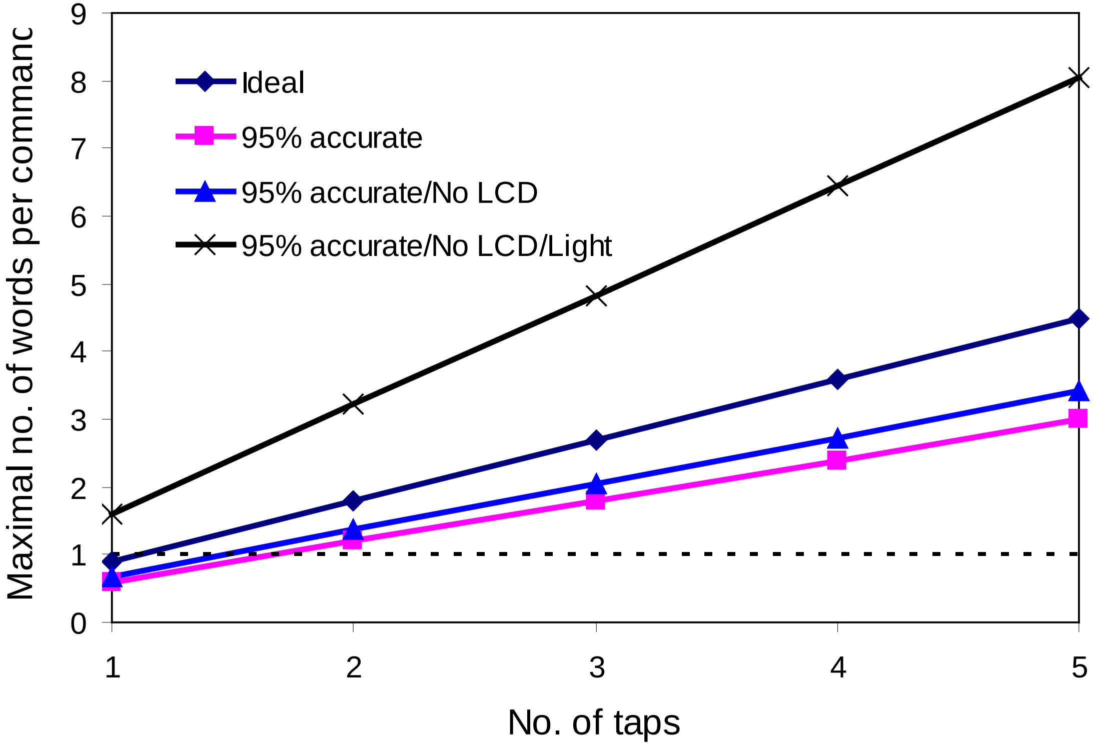


Handwriting recognition is inferior to alternatives

Speech recognition can be the most energy-efficient

Comparison: Command & control

- Speech vs. GUI operation



Assume each stylus tapping takes 750ms

Single word voice command is more energy-efficient than GUI operation with 2 taps

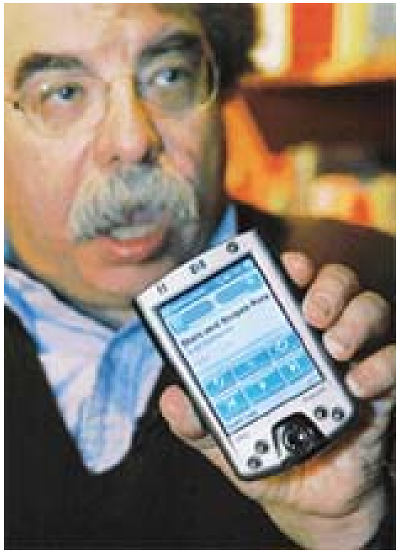
Observations

- User productivity (speed) is critical
  - energy consumed being idle is significant
- Handwriting-based text entry is inferior
- Speech-based text entry can be superior
  - Turning off display is important
  - Accuracy
- Loudspeaker consumes significant power
  - Earphone incurs usability issue
  - Wireless audio delivery not energy-efficient
- “Computing” usually consumes trivial energy

Examples of energy inefficient interfaces

Kyocera KX2325

LG VX 6100



Microsoft Voice Command 1.01

Energy efficiency: definition

$$\text{Energy efficiency} = \frac{\text{User productivity}}{\text{Avg. power consumption}}$$

$$= (\text{User productivity}) \times (\text{Power efficiency})$$

Human-computer interaction (HCI) → Low-power design

Model of Man

- Herbert Simon
  - Turing Award (1975)
  - Nobel Prize in Economics (1978)
- Human mind is simple; its apparent complexity is due to the environment's complexity
  - Short-term memory is fast but small (~7)
  - Long-term memory is unlimited but writing takes time (10 to 30 seconds)
  - Retrieval from long-term memory is associative and depends on the storage structure

Bounded rationality

- Limitation on ability to plan long behavior sequences
- Tendency to set aspiration levels for each goal
- Tendency to operate on goals sequentially rather than simultaneously
- Satisficing rather than optimizing search behavior

http://www.princeton.edu/~smeunier/JonesBounded1.pdf