DEPARTMENT OF COMPUTER SCIENCE
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HUMAN-COMPUTER INTERACTION

Lecture 19

INFORMATION PROCESSING MODELS OF USERS AND DIALOGUES

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19.1 The Human Information Processing System

4 subsystems (Fig. 19.1)

Sensing subsystems:
Physical Stimulus —> *Sensation*
e.g., Amplitude of sound —>Loudness

More on this (via psychophysics) in 19.2

Feedback loops, expectation, vigilance, etc., not shown

Qualitative. Can we get quantitative?

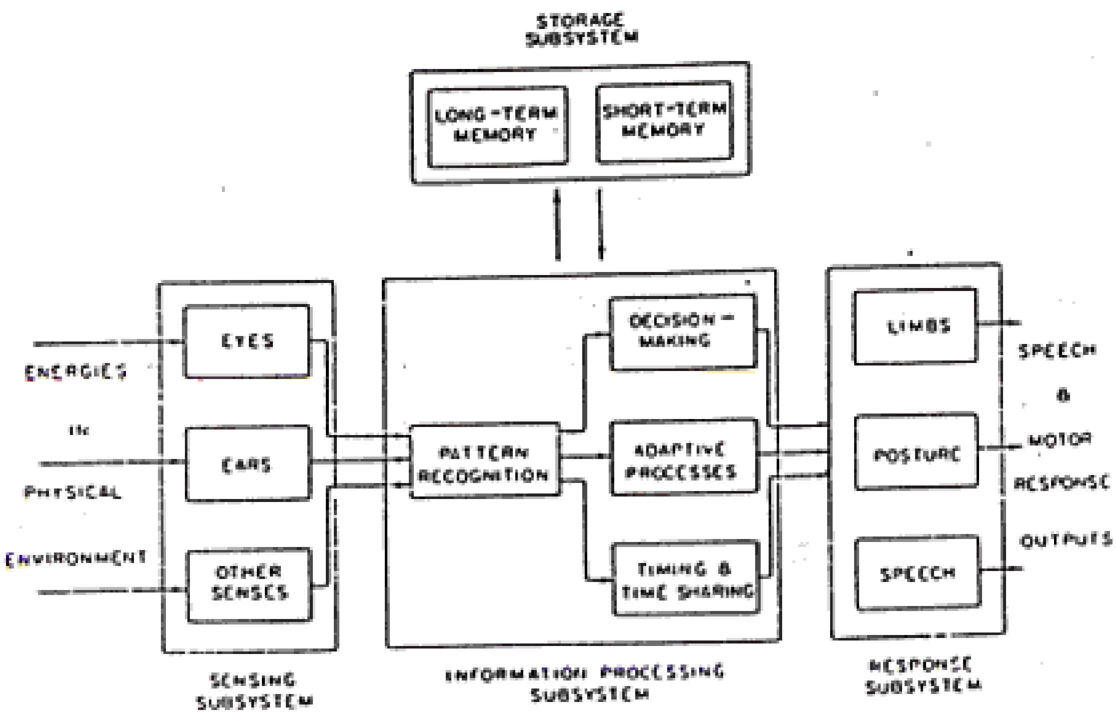

Figure 19.1: The Human Information Processing System (Van Cott & Warrick, p. 12)

19.2 The Sensing System: The Psychophysics Viewpoint

Distinguish between:

Physical stimulus magnitude (M)	*Psychological sensation (S)*
Visual intensity	Brightness
Wavelength	Hue
Aural intensity	Loudness
Frequency	Pitch

Power Law of Sensation: $S = M^p$

e.g., $p = 0.33$ for visual brightness

$p = 3.5$ for electric current applied to finger

Sensitivity range along a stimulus dimension

(from minimum perceivable to maximum tolerable):

Visual intensity: 10^{-6} mLumen to 10^{4} mLumen

Wavelength of light: 300 nm to 800 nmm

Sound frequency of pure tone: 20 Hz to 20,000 Hz

Just Noticeable Difference (JND):

Relative discrimination sensitivity

Ability to detect change in one stimulus

Ability to detect difference between two stimuli

Typically, JND in stimulus I: $\frac{\Delta I}{I} =$ *a constant* (Weber's Law)

Ability to make absolute judgments of stimuli or their magnitude along some dimension:

570 relatively discriminable intensities (white light)

But only 3 to 5 absolutely discriminable intensities

325 relatively discriminable intensities (2000 Hz sound)

But only 3 to 5 absolutely discriminable intensities

19.3 The Psychology of HCI — Card, Moran, & Newell

Card, S.K., Moran, T.P., & Newell, A., *The Psychology of Human-Computer Interaction*, Erlbaum, 1983; Also, BB, pp. 180-91; BGBG, Ch. 9 and Card & Moran paper

Goal: An applied information-processing psychology of human-computer interfaces

Scenario (CMN, pp. 9-10)

> "A system designer, the head of a small team writing the specifications for a desktop calendar-scheduling system, is choosing between having users type a key for each command and having them point to a menu with a lightpen. On his whiteboard, he lists some representative tasks users of his system must perform. In two columns, he writes the steps needed by the "key-command" and "menu" options. From a handbook, he culls the times for each step, adding the step times to get total task times. The key-command system takes less time, but only slightly. But, applying the analysis from another section of the handbook, he calculates that the menu system will be faster to learn; in fact, it will be learnable in half the time. He has estimated previously that an effective menu system will require a more expensive processor: 20% more memory, 100% more microcode memory, and a more expensive display. Is the extra expenditure worthwhile? A few more minutes of calculation and he realizes the startling fact that, for the manufacturing quantities anticipated, training costs for the key-command system will exceed unit manufacturing costs! The increase in hardware costs would be much more than balanced by the decrease in training costs, even before considering the increase in market that can be expected for a more easily learned system. Are there advantages to the key-command system in other areas, which need to be balanced? He proceeds with other analyses, considering the load on the user's memory, the potential for user errors, and the likelihood of fatigue. In the next room, the Pascal compiler hums idly, unused, awaiting his decision."

An appropriate information-processing psychology must be based on:

Task analysis, because human behaviour adapts to task environment to attain goals

Calculations, for this is the heart of useful, engineering-oriented applied science

Approximation, for if calculations are going to be created rapidly, they will need to be over-simplified — Back of the envelope, rules of thumb

Also,

Must be *relevant to design*

Must be *theory based*, i.e., must articulate a mechanism underlying the observed phenomena

19.4 The Model Human Processor

The Card Moran Newell science base is expressed in terms of a theory known as *The Model Human Processor (MHP)* (Figs. 19.2, 19.3)

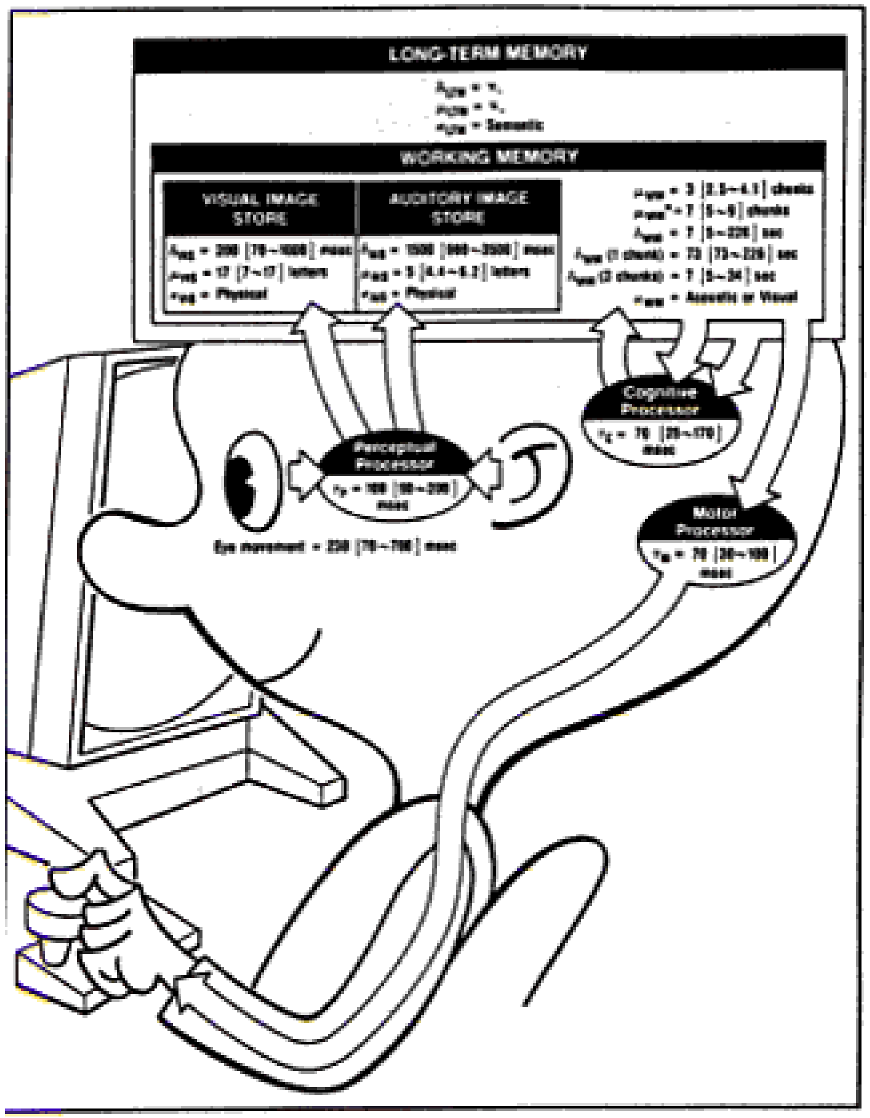

Figure 19.2. The MHP — memories and processors (CMN, p. 26; BGBG p. 590)

P0. ***Recognize-Act Cycle of the Cognitive Processor.*** On each cycle of the Cognitive Processor, the contents of Working Memory initiate actions associatively linked to them in Long-Term Memory; these actions in turn modify the contents of Working Memory.

P1. ***Variable Perceptual Processor Rate Principle.*** The Perceptual Processor cycle time τ_P varies inversely with stimulus intensity.

P2. ***Encoding Specificity Principle.*** Specific encoding operations performed on what is perceived determine what is stored, and what is stored determines what retrieval cues are effective in providing access to what is stored.

P3. ***Discrimination Principle.*** The difficulty of memory retrieval is determined by the candidates that exist in the memory, relative to the retrieval clues.

P4. ***Variable Cognitive Processor Rate Principle.*** The Cognitive Processor cycle time τ_C is shorter when greater effort is induced by increased task demands or information loads; it also diminishes with practice.

P5. ***Fitts's Law.*** The time T_{pos} to move the hand to a target of size S which lies a distance D away is given by:

$$T_{pos} = I_M \log_2 (D/S + .5)\,. \qquad (2.3)$$

where I_M = 100 [70~120] msec/bit.

P6. ***Power Law of Practice.*** The time T_n to perform a task on the nth trial follows a power law:

$$T_n = T_1 n^{-\alpha}\,. \qquad (2.4)$$

where α = .4 [.2~.6] .

P7. ***Uncertainty Principle.*** Decision time T increases with uncertainty about the judgement or decision to be made:

$$T = I_C H\,,$$

where H is the information-theoretic entropy of the decision and I_C = 150 [0~157] msec/bit. For n equally probable alternatives (called Hick's Law),

$$H = \log_2 (n + 1)\,. \qquad (2.8)$$

For n alternatives with different probabilities, p_i, of occurence,

$$H = \Sigma_i p_i \log_2 (1/p_i + 1)\,. \qquad (2.9)$$

P8. ***Rationality Principle.*** A person acts so as to attain his goals through rational action, given the structure of the task and his inputs of information and bounded by limitations on his knowledge and processing ability:

Goals + Task + Operators + Inputs
+ Knowledge + Process-limits → Behavior

P9. ***Problem Space Principle.*** The rational activity in which people engage to solve a problem can be described in terms of (1) a set of states of knowledge, (2) operators for changing one state into another, (3) constraints on applying operators, and (4) control knowledge for deciding which operator to apply next.

Figure 19.3. The MHP — principles of operation (CMN, p. 27)

MHP: Set of memories and processors

MHP: Set of principles, “principle of operation”

MHP: 3 interacting subsystems
- Perceptual system
- Motor system
- Cognitive system

Memories
- Visual Image Store
- Auditory Image Store
- Working (Short Term) Memory
- Long Term Memory
- Muscle Memory (not included)

Memory parameters
- μ: Storage capacity
- δ: Decay time
- κ: Code type (physical, acoustic, visual, semantic)

Processors
- Perceptual Processor
- Cognitive Processor
- Motor Processor

Processor parameters
- τ: Cycle Time

Parameters estimated from psychological literature

Clearly an oversimplification, but that's what all models are.
- Question is: what is its predictive power?

19.5 Principles of Operation of the MHP

P0: Recognize — Act Cycle of the Cognitive Processor
Working Memory $\Rightarrow$ Actions (based on Long Term Memory) $\Rightarrow$ Working Memory

P1: Variable Perceptual Processor Rate Principle
τ_p varies inversely with stimulus intensity
τ_p = 100[50~200] msec

P2: Encoding Specificity Principle
P3: Discrimination Principle
P4: Variable Cognitive Processor Rate Principle

P5: Fitt's Law
T_{pos} to move hand to target of size S a distance D away
$T_{pos} = I_M \log_2 (D/S + .5)$
where I_M = 100[70 ~ 120] msec/bit
(But see paper by MacKenzie in BGBG, pp. 483-493)

P6: Power Law of Practice
T_n to perform a task on nth trial
$T_n = T_1 n^{-\alpha}$ where α = .4[.2 ~ .6]

P7: Uncertainty Principle

P8: Rationality Principle
Goals + Tasks + Operators + Inputs + Knowledge + Process-limits $\Rightarrow$ Behaviour

P9: Problem Space Principle — Express rational problem-solving behaviour in terms of

1) Set of states of knowledge
2) Operators: State $\Rightarrow$ State
3) Constraints on applying operators
4) Control knowledge to decide which operator to apply next

19.6 Some Applications of the MHP

Example: User must press a button whenever a certain letter appears on VDT (CMN, p. 66)

Step A: Symbol processed by Perceptual Processor
Physical representation then in Visual Image Store
Visual code soon thereafter in Working Memory
τ_p = 100[50 ~ 200] msec

Step B: Cognitive Processor translates this to Motor Command
τ_c = 70[25 ~ 170] msec

Step C: Motor Processor pushes button
τ_m= 70[30 ~ 100] msec

Total = 240[150 ~ 470] msec

Other sample amplifications:
How fast can a person read text?
Derivation of Fitt's Law from first principles
Predict time savings of moving keys on calculator keypad
Predict relative typing speed on two keyboards
Predicting, learning, remembering of command names

19.7 Routine Cognitive Skills & Human Information Processing

Dimensions of cognitive behaviour
- Task: Text editing, programming,...
- Skill Level: Sensori-motor skill, cognitive skill, problem solving
- Perceptual processing, cognitive processing, motor processing dimensions

Examples of skilled behaviour
- Sensori-motor skills
  - Riding a bicycle
  - Tying a necktie
  - Shaving
  - Knitting
- Cognitive skills
  - Typing
  - Text editing
  - Sketching
  - Solving simultaneous equations
- Problem Solving
  - Playing chess
  - Programming

“As Welford says in his *Fundamentals of Skill:*

`Although a distinction is commonly drawn between sensory-motor and mental skills, it is very difficult to maintain completely. All skilled performance is mental in the sense that perception, decision, knowledge and judgment are required. At the same time all skills involve some kind of co-ordinate, overt activity by hand, organs of speech or other effectors. In sensory-motor skills the overt actions clearly form an essential part of the performance, and without them the purpose of the activity as a whole would disappear. In mental skills overt actions play a more incidental part, serving rather to give expression to the skill than forming an essential part of it. (Welford, 1968, p. 21)'

> Thus, all skill involves cognition. Perhaps, then, cognitive skills could be distinguished by saying that they are *primarily* cognitive. More penetrating is Welford's characterization (above) of the role of motor behaviour in mental (i.e., cognitive) skill, namely, that it *expresses* the cognitive skill. Manuscript text-editing includes the skills of keystroking and viewing the manuscript and display; however, these perceptual-motor skills are not the essential activity, but the medium through which the cognitive activity gains expression.
>
> The primacy of cognitive activity in cognitive skill does not rob the behaviour of its skillful character, taking the term *skillful* to mean \`competent, expert, rapid and accurate performance' (Welford, 1968, p. 12). This includes the sense of effortlessness — smoothly coordinated and patterned behaviour — that is the visible hallmark of skilled performance. Our text-editing experts truly fly over the keybord; and the contrast of their behavior with that of beginners leaves no room for doubt that skill, both perceptual-motor and cognitive, has been acquired" (CMN, p. 358).

Motor behaviour in cognitive skill "*expresses* the cognitive skill"!

Continuum from problem solving to cognitive skill
- Game playing (solving Towers of Hanoi puzzle, tic-tac-toe, checkers, a lesser extent chess) can move from problem solving ⇒more or less routine cognitive skill
- Some text editing behaviour was problem solving, now has become routine cognitive skill

John Anderson talks about the *compilation* of problem solving procedures into behaviour skills which are executed more or less automatically

Thus far: Very low level view of the Model Human Processor
- We would like to model and understand cognitive skills (routine cognitive skills) that are more interesting than typing, for example, text editing, or simple computer-aided design tasks

CMN do this in their book, especially with respect to text editing and to the “manuscript editing” task

Recall P8, the Rationality Principle:

Person’s Goals
+ Structure of Task
+ Available Operation (Skills)
+ Inputs of Information
+ Limitation on Knowledge
+ Limits on Processing Ability
⇒Behaviour

In the next lecture, we'll make this more concrete and more useful with the GOMS model and the Keystroke model

19.7 References

Card, S.K. (1984). Human Limits and the VDT Computer Interface. In J. Bennett, D. Case, J. Sandelin, & M. Smith (Eds.) *Visual Display Terminals: Usability Issues and Health Concerns*, Prentice-Hall, 117-155, excerpted in Baecker and Buxton (1987).

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