An Information-Processing Theory of Human Cognition and Performance

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The Big Picture: Human versus System

User Interface Design
from the Perspective of Cognitive Psychology

Basic Framework: What the User Knows When Encountering a System

Illustration: The Problem with Digital Technology

User Interface Design
from the Perspective of Cognitive Psychology

Cognitive Psychology is a branch of experimental psychology, the scientific study of mental processes and behavior

Scientific work in experimental psychology started in late 19th century

Human factors: an applied form of experimental psychology results and methods

Cognitive psychology is concerned with human intellect processes like thinking, reading comprehension, problem-solving

• Major advances starting in 1960s
• Basic approach: human mental activity consists of processing information
• Special focus on acquisition and application of knowledge and skill
• Theoretical ideas have close relationship to Artificial Intelligence, but based on experimental results, not just speculation about the mind

Recent development: Application of cognitive psychological results and theories to practical complex task situations

"Applied cognitive psychology"
"Cognitive human factors"
"Cognitive Engineering"

Basic Framework: What the User Knows When Encountering a System

The user knows what tasks to accomplish, but also has to know how to accomplish the tasks
E.g., which buttons to press to obtain the desired result

System

Two basic kinds of knowledge about systems:
How the system works internally - structures & processes
• "Mental model" knowledge of the system
• Claim: Useful only if supports task-relevant inferences about procedures
How to use the system to perform tasks
• Procedural knowledge
• The less required, the better.
• Either learned, or inferred on the spot.

User must come up with a procedure by using strategies:
Execute an already known procedure for the same device
Simply using a routine skill - usually easy if enough practice

Get a procedure from instructions in the documentation or on the system
Can be made more efficient based on research results.
Usually moderately difficult.
Not further elaborated here.

Infer a procedure by applying problem-solving strategies:
Use analogy from a similar system with same function or purpose
• Similar systems tend to have similar procedures
Use trial and error based on:
• Behavior upon manipulation
• "Affordances" from physical appearance and constraints
Use knowledge of how the system works
• Previously known or in documentation
Illustration: The Problem with Digital Technology

User is somewhat helpless with anything digital or computer-based
- System is too complicated or novel for previous procedures.
- Few useful affordances are apparent.
- The procedures are essentially arbitrary.
  - Even detailed how-it-works knowledge is not useful.
  - Example: Microwave oven controls: dials vs. digital

Typical result is that such a system is underutilized!
Digital systems must be especially easy to learn and easy to use to make up for their intrinsic arbitrariness
"Cognitive Walkthrough" methodology attempts to identify such problems.

The Detailed Picture: A Model of Human Information Processing

The Model Human Processor (MHP)

The Model Human Processor Structure
- The Eye
- Perceptual Processor
- Image Stores and Pattern Recognition
- Working Memory (WM)
- Working Memory (continued)
- Serial Position Effect
- Production Memory and Long-Term Memory (LTM)
- Cognitive Processor
- Encoding Process
- Motor Processor
- Serial and Parallel Activity
- Example: Simple Reaction Time
  - Simple Reaction - 1
  - Simple Reaction - 2

The Model Human Processor (MHP)

Proposed by Card, Moran, & Newell (1983)
An information-processing model of human cognition
Overall structure of processors and storage systems
Some basic principles of operation
Basic theoretical claim: Complex cognitive phenomena can be analyzed in terms of the processing done by a single set of mechanisms
The last 100+ years of scientific models and data
But recast for engineering purposes
Characterize how the human head works in terms of engineering specifications
Quantitative descriptions of important phenomena
- Amount of information
- Probability of correct performance
- Processing time
Describe each component of the MHP, then go through a simple example of processing

Model Human Processor Structure

Modified from Card, Moran, & Newell (1983)
Each processor has a cycle time
Each memory has
- Information representation type
- Half-life of information (exponential decay)
- Storage capacity
The Eye

People are heavily visual
More later on the eye and vision
Eye moves in jumps, saccades, followed by fixations
  Jump time is 30 ms
  Fixation duration 60-700 ms
Perception is of continuous visual scene in spite of jumps
People tend to fixate on part of visual scene being thought about
In reading, fixation times depend on amount of processing

Perceptual Processor

Shown as separate for both auditory and visual, but roughly same properties for both
Visual, auditory input
Output to Visual and Auditory Image Stores
Sliding window property
  A “window” 100 ms wide
  Events within the window lumped together
  • Inputs within the cycle time treated as the same event
  • Inputs separated by cycle time are perceived as different
Examples
  • Two flashes within 100 ms = one brighter flash
  • Apparent motion
  • Inability to hear more than about 10 clicks/sec - if faster, still hear same

Image Stores and Pattern Recognition

Visual Image Store (VIS) - How discovered
Using very brief visual presentations (tachistoscope) - 50 ms
  • Flash array of letters, have subjects report what they see usually report a maximum of 7 or so letters
capacity of working memory (short-term memory)
  Turns out there are many more letters available than can normally be reported
  • Demonstrate by cuing immediately after display goes off which row of letters to report
  • Quite a bit more information available than ordinary report shows
    About 17 letters worth
  • Delay of cue gives estimate of how long information remains
    Half-life is about 200 ms

Auditory Image Store (AIS) is same concept as VIS
Determine parameters in same kind of way, but harder to do

Pattern Recognition
Translates physical representation into a name representation in Working Memory (WM)
In this model, assumed to be very rapid, automatic
  • About 10 ms/letter
  • Built-in memory system mechanisms
  • Bundle the time into the perceptual processor time

Working Memory (WM)

Also often called Short-Term Memory (STM)
A scratch pad memory

How discovered
Read series of items (letters, numbers) to subject
Subject has to repeat them back
Easy, but if more than 7 items, some are lost
Time delay - no effect if subject rehearses
Prevent rehearsal - e.g. count backwards by 3
Result is fairly fast loss - pretty much gone in half a minute
• Due to decay or displacement of information

Contents
Not physical form, but symbolic names
• Visually defective A gets recognized, represented in WM as “ay” visual problems no longer relevant
Often appears to contain acoustic names
• Evidence
  typical memory tasks involving strings of letters, numbers confusion errors are to misremember as one with similar sound
• But different tasks can force different kinds of codes, visual or semantic acoustic or visual
  Represented in terms of familiar codes, or chunks
  • Chunks defined by the contents of Long-Term Memory (LTM)
    • CBSIBM RICA
    • CBS IBM RCA
Working Memory (continued)

Capacity
Capacity of WM is combination of pure WM and auxiliary storage in LTM
Capacity of WM makes more sense in terms of chunks rather than items or amount of information
- But not purely so - decay time affected

Parameters
half life depends on number of chunks
- overall: 7 sec
- 1 chunk: 73 sec
- 3 chunks: 7 sec
capacity depends on whether LTM is used
- 3 chunks (pure)
- 7 chunks (extended)

Effective WM Capacity
Capacity of WM is combination of pure WM and auxiliary storage in LTM
Each WM item is processed for encoding
- Likelihood of successful encoding less if more items to be processed
At recall time, retrieval from both WM and LTM illustrated by serial position effect

Serial Position Effect

Experiment
Subject studies long list of items, presented one at a time, then tries to recall them
Plot probability of recall as a function of position in the list

Serial Position of Item
Probability of Recall

High at the beginning - full encoding effort since few items
High at end - dump from WM
Flat in the middle - once too many items to encode fully, partial encoding of each - same for all

Production Memory and Long-Term Memory (LTM)

The permanent repository of all of a person’s knowledge
Two kinds of knowledge
Procedural knowledge
- Knowledge what to do
- Represented as production rules
  IF-THEN rules
- Stored in production memory
Declarative knowledge
- Knowledge of facts
- List of interrelated facts, propositions
- Stored in Long-Term Memory

LTM contents are mainly meaning (semantic)
Contains network of related chunks
E.g. Upper & lower case A are the same letter
A is the first letter of the alphabet
A denotes a top grade in a course

LTM is essentially infinite capacity and duration
No evidence that it fills up in human lifetimes
Once stored, problem is retrieval, not loss
No implication that everything is stored
But a lot can be retrieved by cycling of cues

Cognitive Processor

Production system model for cognitive processor
“Programming” for cognitive processor consists of production rules stored in production memory
Production rules are pattern-action pairs
IF (condition) THEN (action)
IF (condition) THEN (action)
...

Patterns tested in parallel, actions performed serially
Procedures or skills composed of a sequence of rule firings

Works pretty well in more detailed theories of skill and problem-solving

Does the “thinking” by manipulating WM contents
E.g. deciding what to do in response to a stimulus represented in WM
- result of decision deposited back in WM

Recognize-act cycle
Cycle takes 70 ms
In one cycle, contents of WM and LTM can trigger associated actions
Actions can:
- Alter contents of WM
  Determine what will be triggered next
- Eventually operate on environment
  Change perceptual input, change contents of WM
**Encoding Process**

**Add WM information to LTM**
- Various memorization strategies
- Use current LTM information to choose representation for new information

**Writing into LTM is about 10 sec/chunk (pure time)**
- But retrieval can be done on each cognitive processor cycle
- Slow write/fast read

**Encoding Specificity - encoding determines what is stored, and what cues are effective**
- How stored depends on what is in LTM
- Information can be stored in ways that it is unlikely to be retrieved

**Discrimination principle - Retrieval accuracy depends on how many other items match cues**
- Information can be there, but not retrievable due to competition

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**Motor Processor**

**Responds to instructions in WM by causing motor movements**
- One basic movement per cycle time of 70 ms
- Large movements consist of micromovements, one in each cycle

**Using feedback (e.g. visual) takes much longer**
- Other processors involved
- So rapid movements made in preprogrammed bursts
- Takes longer because takes at least one cycle per processor:
  - $100 + 70 + 70 = 240$ ms
- Example: baseball swings

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**Serial and Parallel Activity**

**Processors can overlap in activity**
- E.g., skilled transcription typing
  - Perceptual process uses WM as a buffer, keeping it full of letters
  - Cognitive processor and motor processor keep emptying it

**New work on extensions of MHP to account for human performance in multiple-task situations**
- Kieras & Meyer project

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**Example: Simple Reaction Time**

**Production rule "Programming" for Simple Reaction Task**
*Push the button as soon as you see the light on the display*
Simple Reaction - 1

Stimulus Appears

Time = 0
Stimulus is processed perceptually and recognized as the stimulus

Time = 100 ms

Simple Reaction - 2

Decision made to press button

Time = 100 + 70 ms
Button gets pressed

Time = 100 + 70 + 70 ms = 240 ms