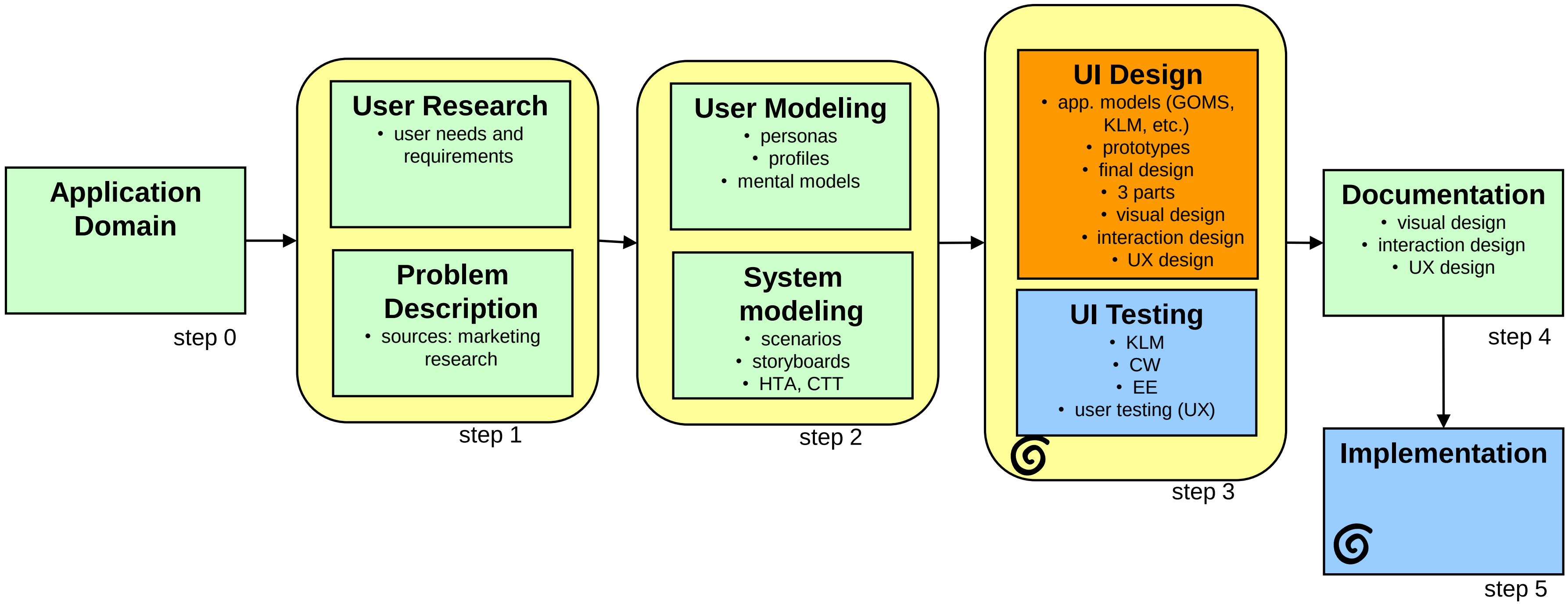
NUR Psychological aspects

MHP, GOMS, KLM, Fitt’s Law, Hick’s Law

DCGI

User interface design - big picture



What is a model?

- A model is…
  - a simplification of reality
- A model is useful only if it...
  - helps in designing and evaluating
  - provides a basis for understanding the behavior of a complex artifact
- To be useful, a model must be…
  - simpler than the behavior it models
    - i.e., extremely complex models are of questionable value

Cognitive Modeling: Definition

- A theory that produces a computational model of how people perform tasks and solve problems by using psychological principles and empirical studies.

Cognitive Modeling: Role

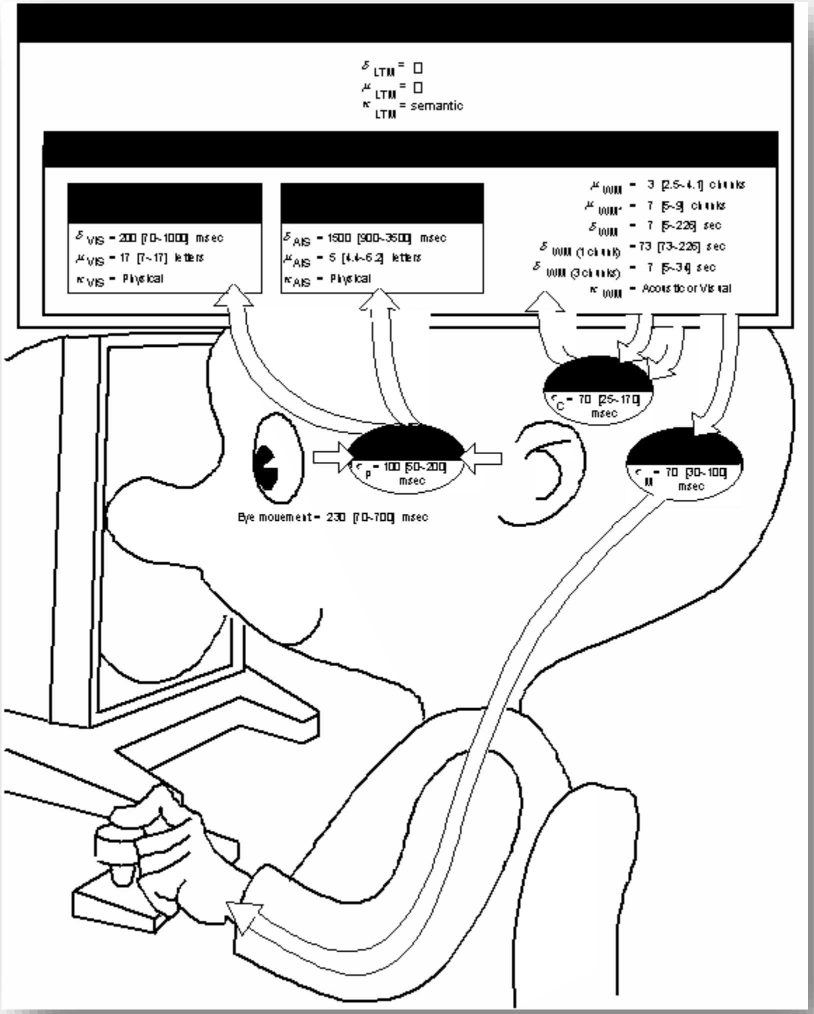
- Limits the design space
- Answers specific design decisions
- Estimates total task time
- Estimates training time
- Identifies complex, error-prone stages of the design
- A means of testing current psychological theories

HOW TO MODEL HUMANS

Model Human Processor (MHP)

Card, Moran & Newell (1983)

- Most influential model of user interaction
  - used in GOMS analysis
- 3 interacting subsystems
  - cognitive, perceptual & motor
  - each with processor & memory
    - described by parameters (e.g., capacity, cycle time)
  - serial & parallel processing



Adapted from slide by Dan Glaser

MHP

PROCESSING

- Input/output
- Serial
  - pressing key in response to light conditions
- Parallel
  - reading signs & hearing

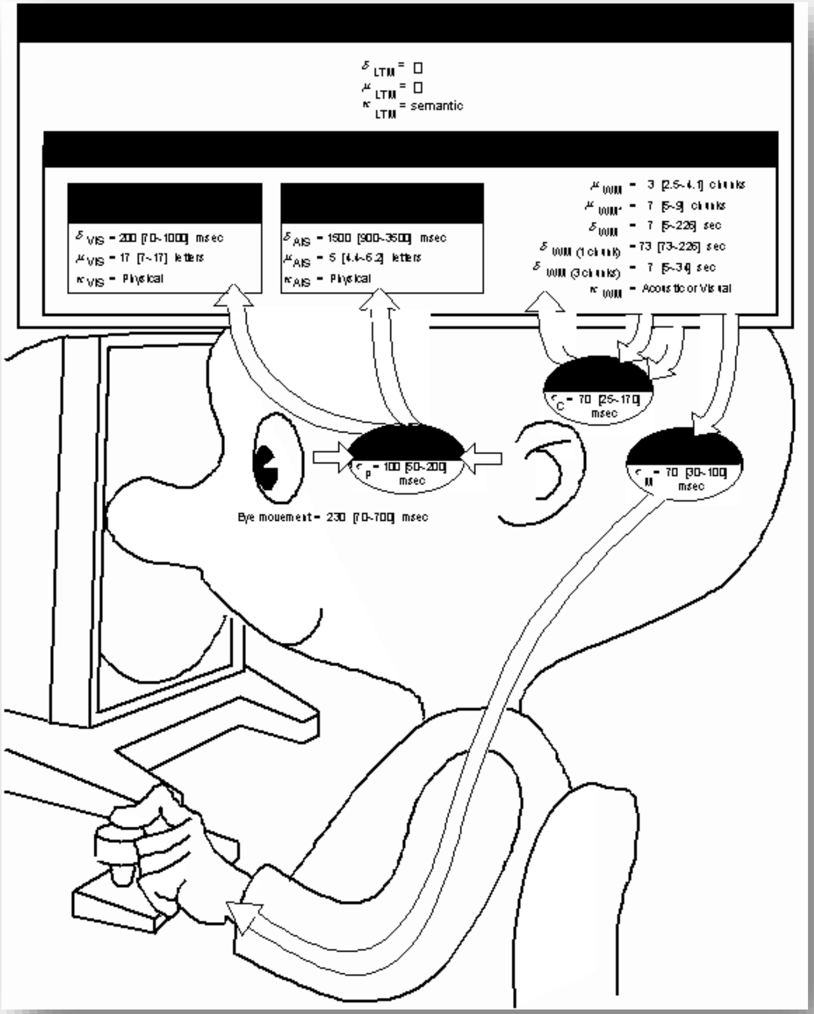
PARAMETERS

- Based on empirical data (word processing)

- Processors have
  - cycle time (τ)
- Memories have
  - storage capacity (μ)
  - decay time of an item (δ)
  - info code type (κ)
    - physical, acoustic, visual & semantic

MHP: Perceptual Subsystem

- Processor
  - cycle time (τ) = 100 msec
- Visual Image Store
  - storage capacity (μ) = 17 letters
  - decay time of an item (δ) = 200 msec
  - info code type (κ) = physical
    - physical properties of visual stimulus
      - –e.g., intensity, color, curvature, length
- Auditory Image Store
  - similar parameters



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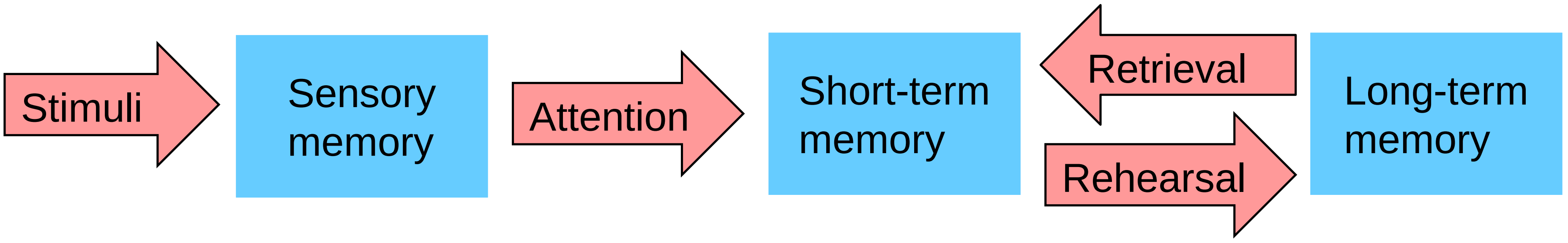
MHP: Memory structure



MHP: Memory

MHP: Sensory memory

- Buffers for stimuli received through senses
  - iconic memory: visual stimuli
  - echoic memory: aural stimuli
  - haptic memory: tactile stimuli
- Examples
  - “sparkler” trail
  - stereo sound
- Continuously overwritten

MHP: Short-term memory (STM)

- Scratch-pad for temporary recall
  - rapid access ~ 70 ms
  - rapid decay ~ 200 ms
  - limited capacity – 3 ± 1 chunks

STM: Examples

212348278493202

0121 414 2626

HEC ATR ANU PTH ETR EET

STM: Brown-Peterson task (about forgetting)

- Subjects presented with trigram (XQJ)
- Experimenter presents number (257)
- Subject counts backwards by 3's
- After several seconds, subjects recall trigram

STM: Other memory test (capacity)

Shepard & Tehgtsoonian (1961)

- Presented 200 3-digit numbers in a row.
- E.g. … 492, 865, 931, 758… 865, …
- Task: report when you hear a repeated number

STM: Memory processes (chunking)

Say the following list of words once to yourself, and then, immediately thereafter, try to recall all the words, in any order, without looking back at them:

table, cloud, book, tree, shirt, cat, light, bench, chalk, flower, watch, bat, rug, soap, pillow

table, book, light, bench, chalk

cloud, tree, cat, flower, bat

pillow, soap, shirt, watch, rug

MHP: Long-term memory (LTM)

- Repository for all our knowledge
  - slow access ~ 100 msec
  - slow decay, if any
  - huge or unlimited capacity

- Structure
  - declarative (facts, data, events)
    - episodic
      - serial memory of events
    - semantic
      - structured memory of facts, concepts
  - procedural (how to do thinks)

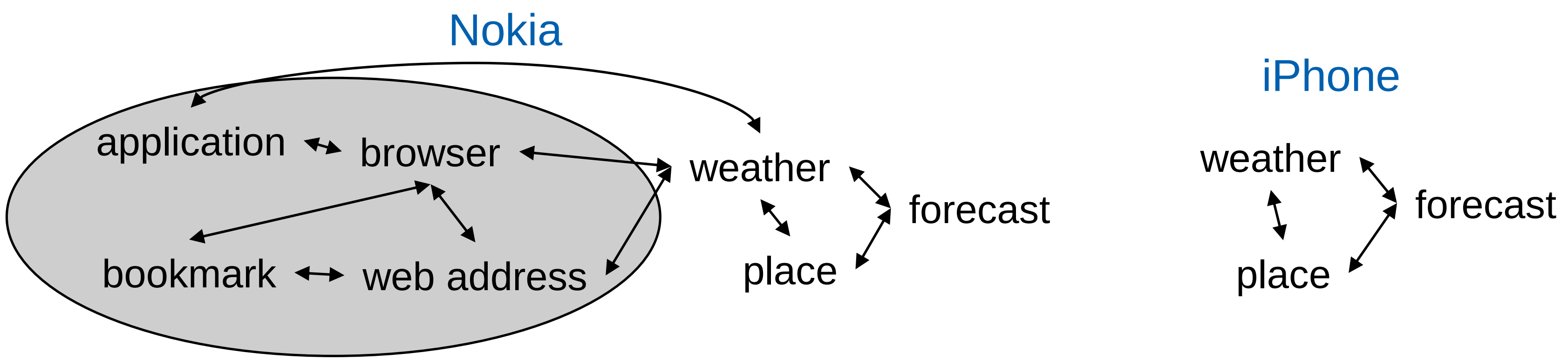
  - semantic LTM derived from episodic LTM

MHP: Long-term memory (cont.)

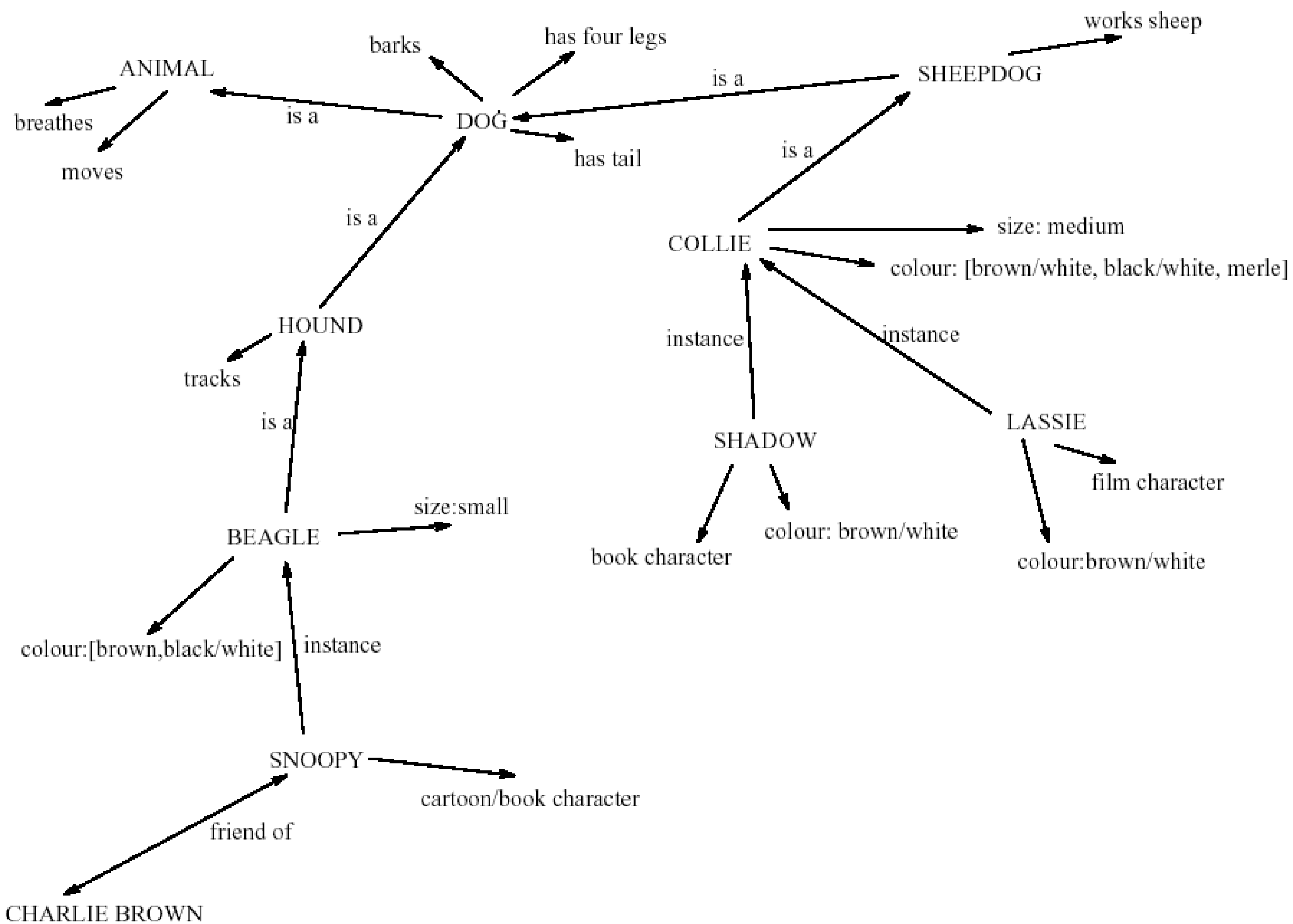
- Semantic memory structure
  - provides access to information
  - represents relationships between bits of information
  - supports inference

- Model: semantic network
  - inheritance – child nodes inherit properties of parent nodes
  - relationships between bits of information explicit
  - supports inference through inheritance

MHP: LTM - semantic network



MHP: LTM - semantic network



Models of LTM - Production rules

Representation of procedural knowledge.

Condition/action rules

if condition is matched

then use rule to determine action.

IF dog is wagging tail
THEN pat dog

IF dog is growling
THEN run away

LTM - Storage of information

- rehearsal
  - information moves from STM to LTM
- total time hypothesis
  - amount retained proportional to rehearsal time
- distribution of practice effect
  - optimized by spreading learning over time
- structure, meaning and familiarity
  - information easier to remember

LTM - Forgetting

decay

- information is lost gradually but very slowly

interference

- new information replaces old: retroactive interference
- old may interfere with new: proactive inhibition

so may not forget at all memory is selective …

… affected by emotion – can subconsciously `choose' to forget

LTM - retrieval

recall

- information reproduced from memory can be assisted by cues, e.g. categories, imagery

recognition

- information gives knowledge that it has been seen before
- less complex than recall - information is cue

LTM - retrieval

- Recognition
  - You see or hear a stimuli which helps you retrieve info from LTM
- Recall
  - You have to retrieve info from LTM without a specific stimuli
- Which is easier?
- Implications for UI design?

MHP: Cognitive subsystem

Four Major Cognitive Processes

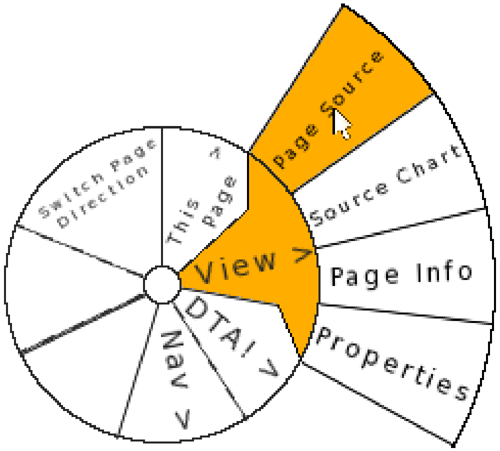
1. Selective Attention
2. Learning
3. Problem Solving
4. Language

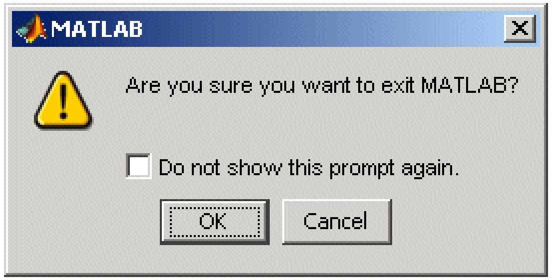
1 Selective Attention

- We can focus on one particular thing
  - Cocktail party chit-chat - hearing key words can shift our attention
  - Driving while talking - take customary route, may not be where are going
- Prominent visual cues can facilitate selective attention
  - Examples?

2 Learning

- Two types
  - Procedural – How to do something
  - Declarative – Facts about something
- Involves
  - Memorization
  - Understanding concepts & rules
  - Acquiring & automating motor skills
    - Tennis, Swimming, Bike riding, Typing, Writing.
    - Navigating in menu
    - Interaction with dialogues





2 Learning

- Facilitated
  - By structure & organization
  - By similar knowledge, as in consistency in UI design
  - By analogy
  - If presented in incremental units
  - Repetition
- Hindered
  - By previous knowledge
    - Try moving from Mac to Windows
    - MS Office traditional menu vs. “ribbon” menu

=> Consider user’s previous knowledge in your interface design

3 Problem Solving

- Storage in LTM, then application
- Reasoning
  - Deductive - If A, then B
  - Inductive - Generalizing from previous cases to learn about new ones
  - Abductive - Reasoning from a fact to the action or state that caused it

4 Language

- Rule-based
  - How do you make plurals?
- Productive
  - We make up sentences
- Key-word and positional
  - Patterns
- Should systems have natural language interfaces?

The Left and Right Brain

Left Brain

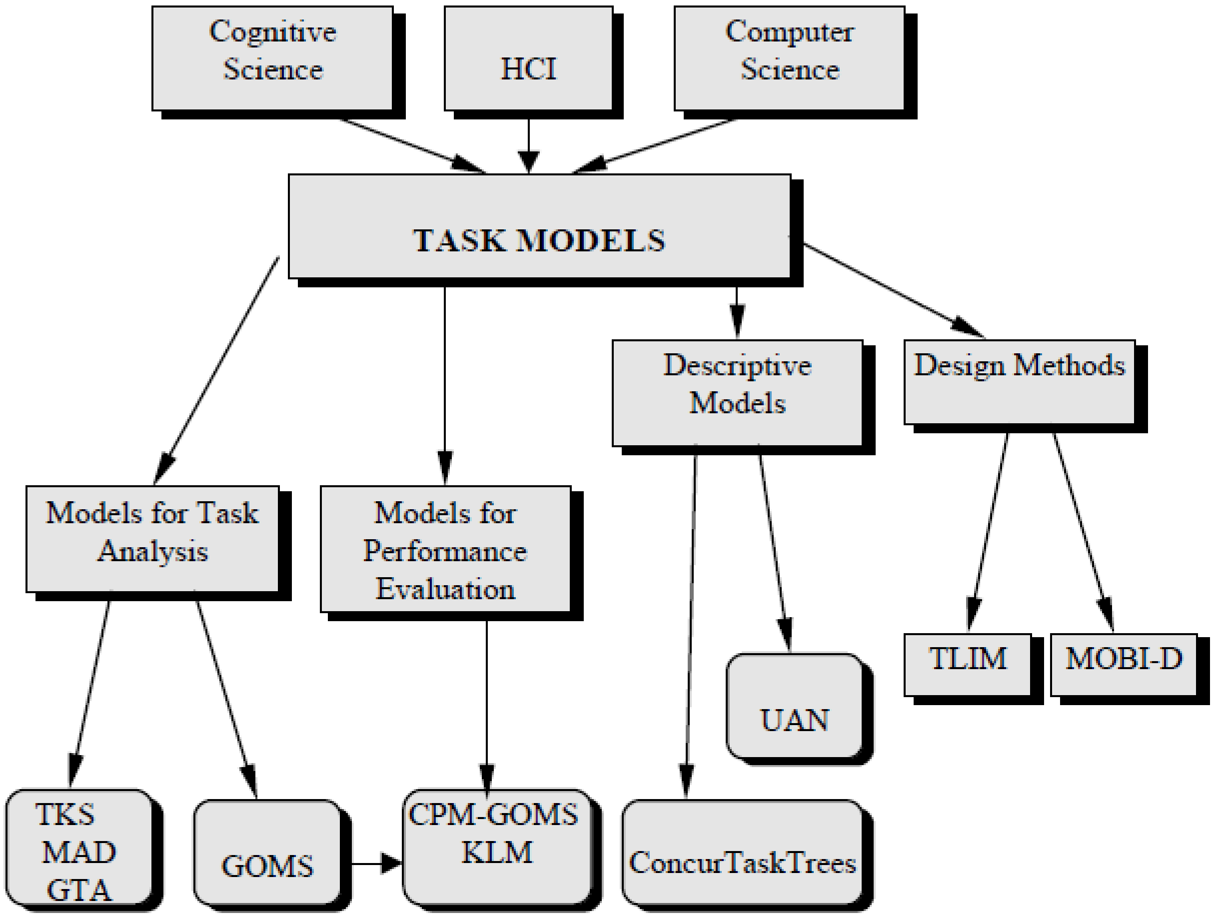
- Words
- Analysis
- Logic
- Sequential
- Simple Tasks
- Must be Taught

Right Brain

- Images and Patterns
- Overall Situation
- Spatial Relationships
- Parallel Processing
- Complex Scenes
- No Teaching Required

MODELS OF HUMAN BEHAVIOR

Task models – and their purpose



Tools and Methods based on Task Models

GOMS

- **<u>G</u>**oals, **<u>O</u>**perators, **<u>M</u>**ethods, **<u>S</u>**election Rules
  - Developed by Card, Moran and Newell
- Probably the most widely known and used technique in this family

- predict user performance
  - execution time (count statements in task structure)
  - short-term memory requirements (stacking depth of task structure)
- benefits
  - apply before implementation (comparing alternative designs)

GOMS - quick example

- Goal (the big picture)
  - go from hotel to the airport
- Methods
  - walk, take bus, take taxi, rent car, take train
- Operators (or specific actions)
  - locate bus stop; wait for bus; get on the bus;...
- Selection rules (choosing among methods)?
  - Example: Walking is cheaper, but tiring and slow
  - Example: Taking a bus is complicated abroad

GOMS: Goals

- Something the user wants to achieve
- Examples?
  - go to airport
  - delete file
  - create directory
- Subgoals
  - goal decomposition (hierarchical structure)
  - Example: Go to the airport: Check-in luggage, Proceed through security check, Proceed to the plain

GOMS: Methods

- Sequence of operators (procedures) for accomplishing a goal (may be multiple)

- Assumes method is learned & routine
  - error-free expert is expected

- Example: Select sentence
  - Move mouse pointer to first word
  - Depress button
  - Drag to last word
  - Release

GOMS: Operators

- Specific actions (small scale or atomic)
- Lowest level of analysis
  - can associate with times
- Examples
  - Locate icon for item on screen
  - Move cursor to item
  - Hold mouse button down
  - Locate destination icon
  - User reads the dialog box

GOMS: Selection Rules

- If > 1 method to accomplish a goal, Selection rules pick method to use

- Examples
  - IF <*condition*> THEN accomplish <*GOAL*>
  - IF <*car has automatic transmission*> THEN <*select drive*>
  - IF <*car has manual transmission*> THEN <*find car with automatic transmission*>

GOMS Output

- Execution time
  - add up times from operators
- Assumes
  - experts!
- Rank ordering
- Absolute accuracy 10-20%

Assumptions for GOMS

- “Expert” is performing UI operations
- Interacting with system is problem solving
- Decompose into subproblems
- Determine goals to attack problem
- Know sequence of operations used to achieve the goals
- Timing values for each operation

GOMS: Limitations

- GOMS is not for
  - Tasks where steps are not well understood
  - Inexperienced users
- Why?

GOMS Analysis – How To

- Generate task description
  - Pick high-level user Goal
  - Write Method for accomplishing Goal - may invoke subgoals
  - Write Methods for subgoals
    - This is recursive
    - Stop when Operators are reached
  - Revise set of Operators
- Evaluate description of task
- Apply results to UI
- Iterate

GOMS example: Delete a word

- Goal: delete a word in a sentence.
- Method #1: use the menu
  - Recall that the word has to be highlighted.
  - Recall that the command is “cut”.
  - Recall that “cut” is in the Edit Menu.
  - Accomplish goal of selecting and executing “cut”.
  - Return: goal accomplished.

GOMS example: Delete a word (cont.)

- Method #2: use the delete key
  - Recall where to position cursor in relation to word to be deleted.
  - Recall which key is delete key.
  - Press “delete” key to delete each letter.
  - Return: goal accomplished.
- Operators used in these methods
  - Click mouse, Drag cursor over text, Select menu, Move cursor, Press KB key, Think, ...

GOMS example: Delete a word (cont.)

- Selection rules:
  - Use mouse/menu method (#1) if there's a lot of text to delete.
  - Else use "delete" key (method #2).

KLM (a low-level variant of GOMS)

- Keystroke Level Model (KLM)
- Simple, but accurate. Widely used.
- Scope:
  - *skilled* users
  - doing a task *error-free*.
  - using a *specific method* in a UI.

KLM Operators

- User Operators
  - K (keystroke), P (point), H (homing), D (drawing), M (mental: think)
  - Times for each are provided to you
    - based on extensive research/empirical data
- System Operator
  - R (respond)

Procedure

- How KLM works
  - Assigns times to different operators
  - Plus: Rules for adding M's (mental preparations) in certain spots

KLM = subset of GOMS

- Six keystroke-level primitive operators
  - K - press a key or button
  - P - point with a mouse
  - H - home hands
  - D - draw a line segment
  - M - mentally prepare to do an action
  - R - system response time
- No selections

KLM: Example

Move Sentence

1. Select sentence

Reach for mouse	H	0.40
Point to first word	P	1.10
Click button down	K	0.60
Drag to last word	P	1.20
Release	K	<u>0.60</u>
		3.90 secs

2. Cut sentence

Press, hold ^		Point to menu
Press and release 'x'	or	Press and hold mouse
Release ^		Move to "cut"
		Release

3. ...

Delete a file by dragging it to the trash

1. Point to file icon (P)
2. Press & hold mouse button (B)
3. Drag file to trash icon (P)
4. Release mouse button (B)
5. Point to original window (P)

3P + 2B = 3.5 sec.

New Design: Adding a command to menu

1. Point to file icon (P)
2. Click button (BB)
3. Point to file menu (P)
4. Press and hold button (B)
5. Point to delete command (P)
6. Release mouse button (B)
7. Point to original window (P)

$$4P + 4B = 4.8 \text{ sec.}$$

Assumptions

- These previous scenarios work only if the user is currently able to view all the needed windows and icons.
- If the trash icon for example is buried under other windows the first procedure is slowed down quite a bit.

Inserting Mental Operators: Where does the user stop and think?

1. Initiating a process.
2. Making strategic decisions.
3. Retrieving a chunk from user’s short term memory
4. Finding something on the screen.
5. Verifying intended action is complete.

Mental Operators - New vs Experienced Users

- New users stop and check feedback after every step
- New users have small chunks
- Experienced users have elaborate chunks
- Experienced users may overlap mental operators with physical operators

Delete a file by dragging icon to trash

1. Initiate delete. (M)
2. Find file icon. (M)
3. Point to file icon. (P)
4. Press & hold button. (B)
5. Verify icon reverse video. (M)
6. Find trash icon. (M)
7. Drag file to trash icon. (P)
8. Verify trash reverse video. (M)
9. Release button. (B)
10. Verify bulging trash icon. (M)
11. Find original window. (M)
12. Point to window. (P)

$$3P + 2B + 7M = 12.6 \text{ sec.}$$

Human Behavior Laws

Other human features

- Besides time “constants” we have to take into account also other features
- E.g. when we perform a task repeatedly – we get better and better (time necessary shrinks)
- Besides MHP we have to use additional “rule”

Power Law of Practice

- Task time T_N on the N^{th} trial follows a power law:

$$T_N = T_1 * N^{-a}$$

  - T1 ... time for the first trial
  - N ... number of trials
  - a = 0.2 – 0.6 (learning rate)

- you get faster the more times you do it!
- applies to skilled behavior (perceptual & motor)
- does not apply to knowledge acquisition or quality

Hick's Law

- Time it takes for a user to make a decision.
- Given n equally probable choices, the average reaction time T required to choose among them:

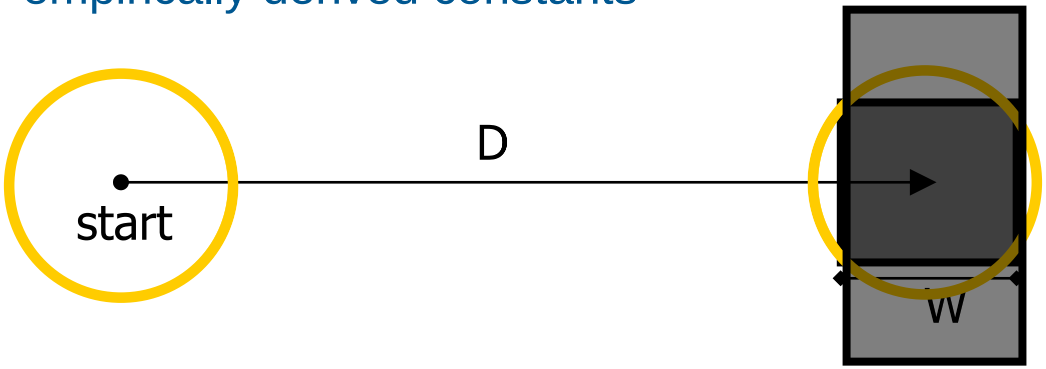
$$T = b \log_2(n + 1)$$

Fitt's Law

- Models movement time for selection tasks
- The movement time for a well-rehearsed selection task:
  - increases as the distance to the target increases
  - decreases as the size of the target increases

Fitt's Law

- Time T to move your hand to a target of width W at distance D away is
  - $T = a + b*\log_2 (2D/W)$
  - a, b – empirically derived constants



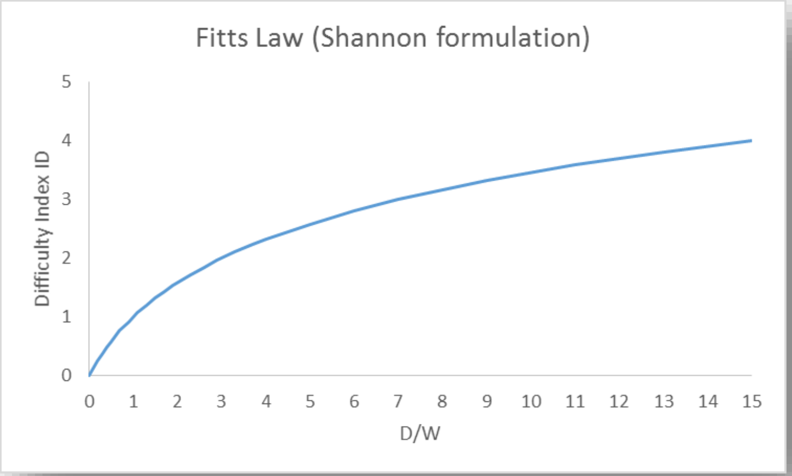
  - Index of difficulty: $ID = \log_2 (2D/W)$

    W is in direction of motion ("length" arbitrary)

    Note that distance is between center points

Shannon formulation of Fitt's Law

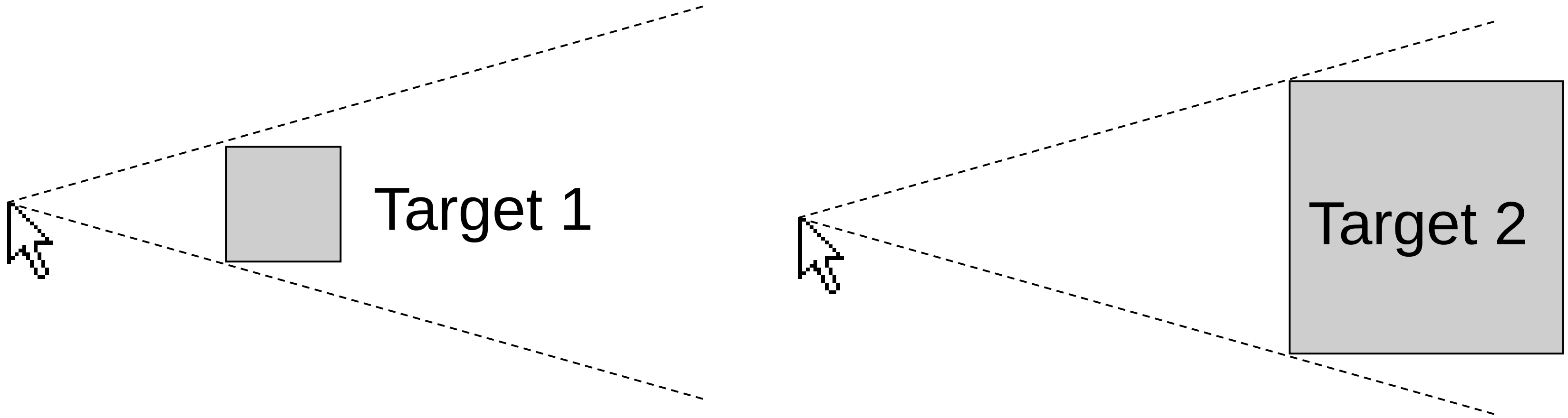
- most frequently used in HCI
  - standardized by ISO 9241 in 2002
- proposed by Scott MacKenzie
- driven by information theory (Shannon-Hartley theorem)
  - difficulty of pointing equated to a quantity of information transmitted



- Index of difficulty
  $ID = \log_2 (D/W + 1)$
- Time to move
  $T = a + b*\log_2 (D/W + 1)$

Fitt's Law

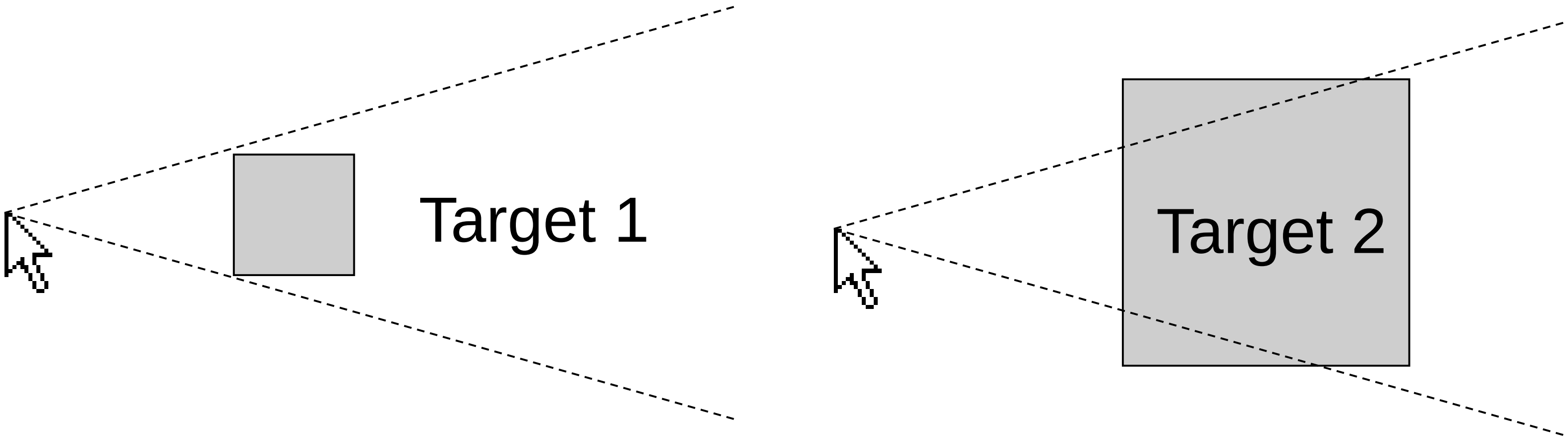
$$Time = a + b*\log_2(D/W+1)$$



Same ID → Same Difficulty

Fitt's Law

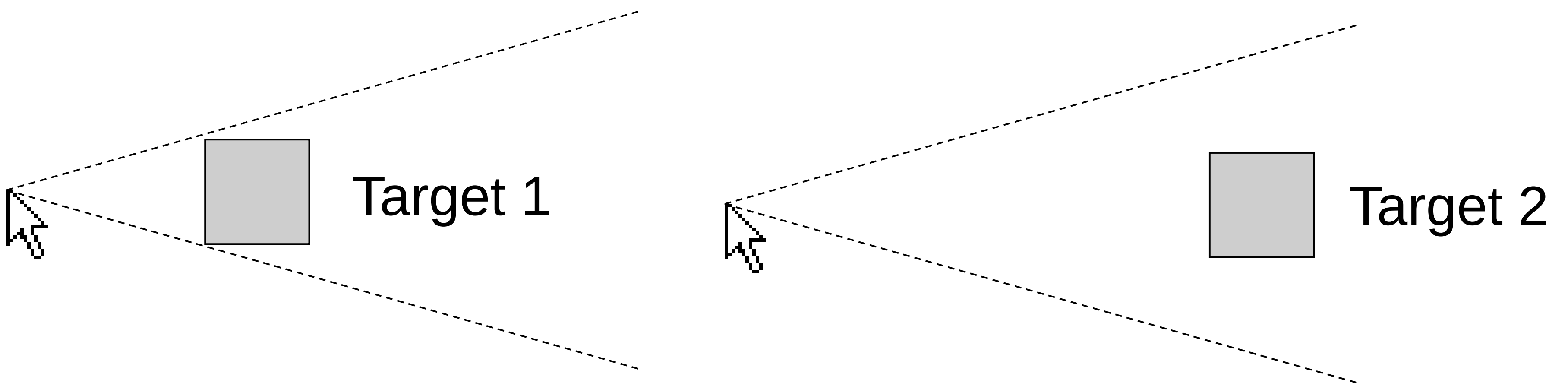
$$\text{Time} = a + b*\log_2(D/W+1)$$



Smaller ID → Easier

Fitt's Law

$$\text{Time} = a + b*\log_2(D/W+1)$$



Larger ID → Harder

Determining Constants for Fitt's Law

- To determine ***a*** and ***b***
  - design a set of tasks with varying values for D and W (conditions)
- For each task condition
  - multiple trials conducted and the time to execute each is recorded and stored electronically for statistical analysis
- Accuracy is also recorded
  - either through the x-y coordinates of selection or
  - through the error rate — the percentage of trials selected with the cursor outside the target

Thank you for attention