User Modeling – Cognitive & Physical Models

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Agenda

- User modeling – cognitive models
  - Model Human Processor
  - GOMS
  - Cognitive Complexity Theory
  - Keystroke-level models
- Physical modeling
  - Fitt's Law

User/Cognitive Modeling

- Idea: If we can build a model of how a user works, then we can predict how s/he will interact with the interface
  - – Predictive modeling, predictive evaluation

Modeling Goals

- Goals (Salvendy, 1997):
  1. Predict performance of design alternatives
  2. Evaluate suitability of designs to support and enhance human abilities and limitations
  3. Generate design guidelines that enhance performance and overcome human limitations

Note: Not even a mockup is required

Components

- Model some aspects of user’s understanding, knowledge, intentions and processing
- Vary in representation levels: high level plans and problem-solving to low level motor actions such as keypresses

Differing Approaches

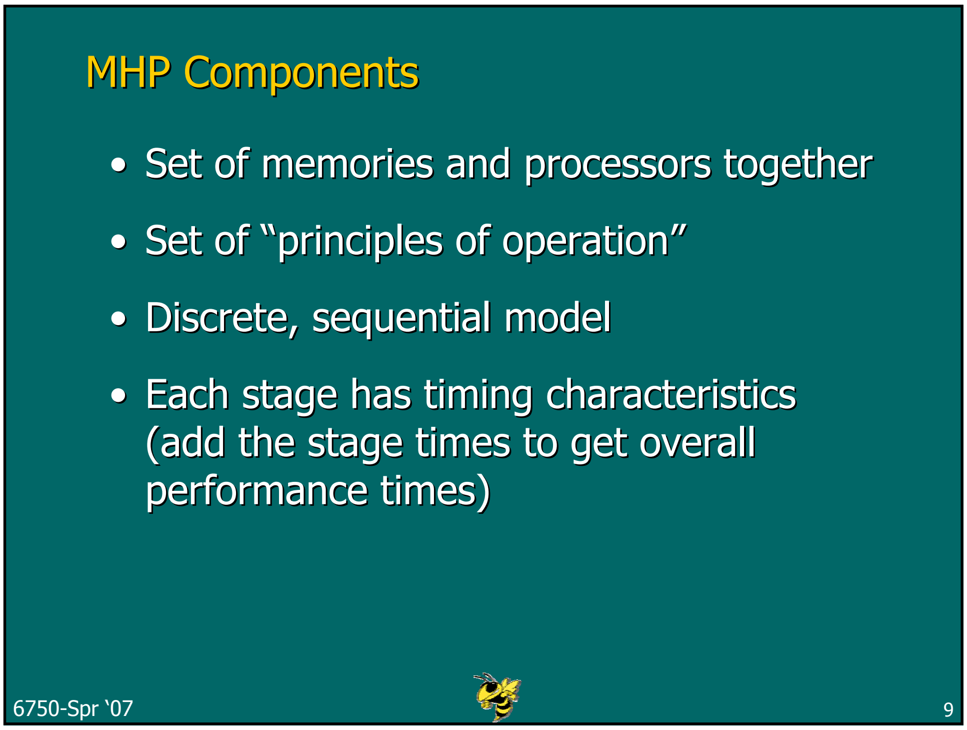
- Human as information processing machine
  - “Procedural models”
  - Many subfamilies and related models
- Human as biomechanical machine
- Human as a social actor in context
  - Situation action
  - Activity theory
  - Distributed cognition

Cognitive Models

1. Model Human Processor
2. GOMS
3. Production Systems
4. Grammars

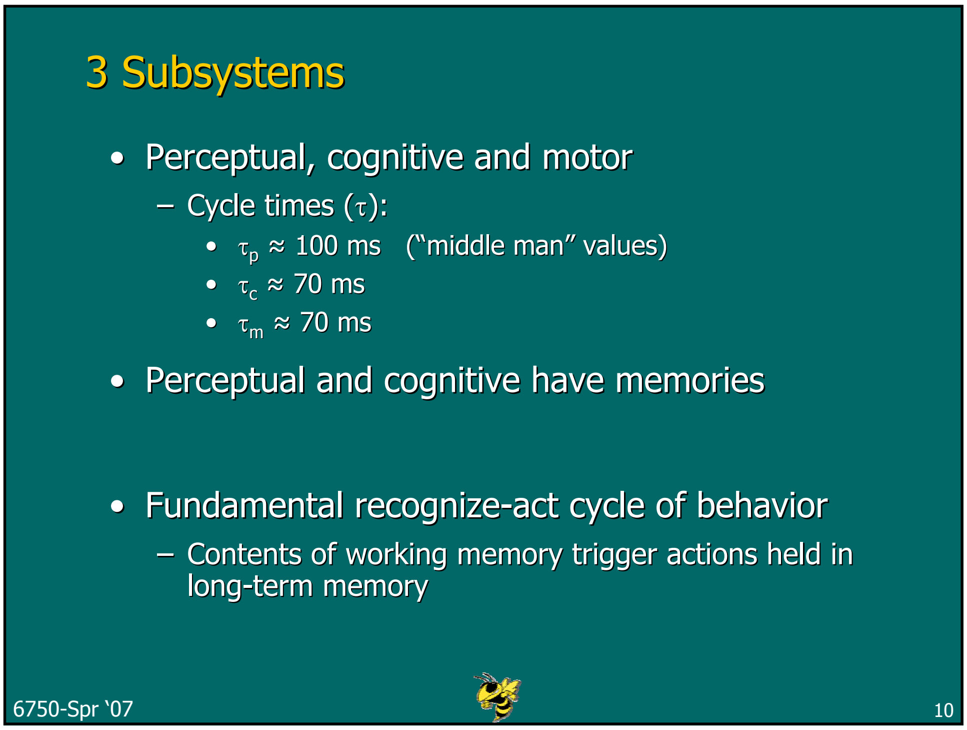
1. Model Human Processor

- Consider humans as information processing systems
  - Predicting performance
  - Not deciding how one would act
  - A "procedural" model
    - People learn to use products by generating rules for their use and "running" their mental model while interacting with system
- From Card, Moran, and Newell (1980's)



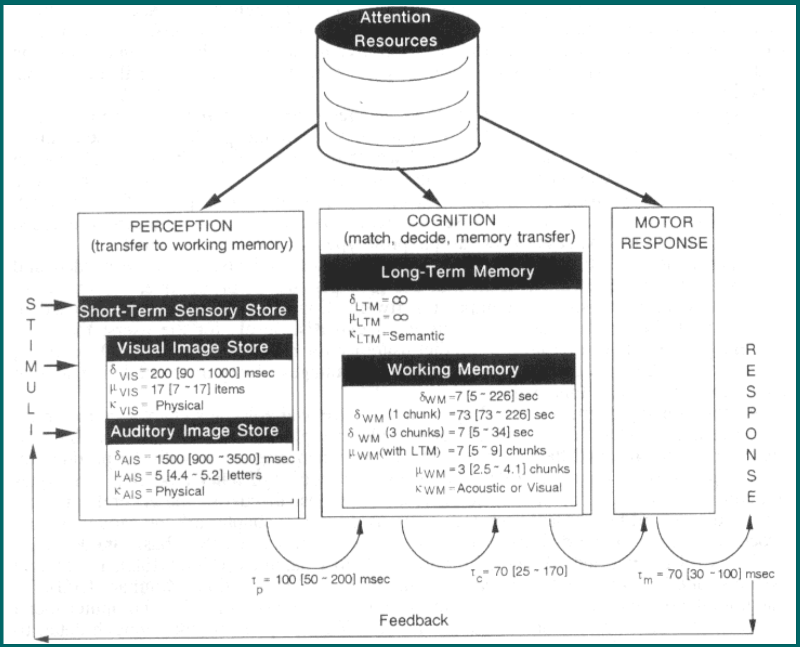
MHP Components

- Set of memories and processors together
- Set of "principles of operation"
- Discrete, sequential model
- Each stage has timing characteristics (add the stage times to get overall performance times)



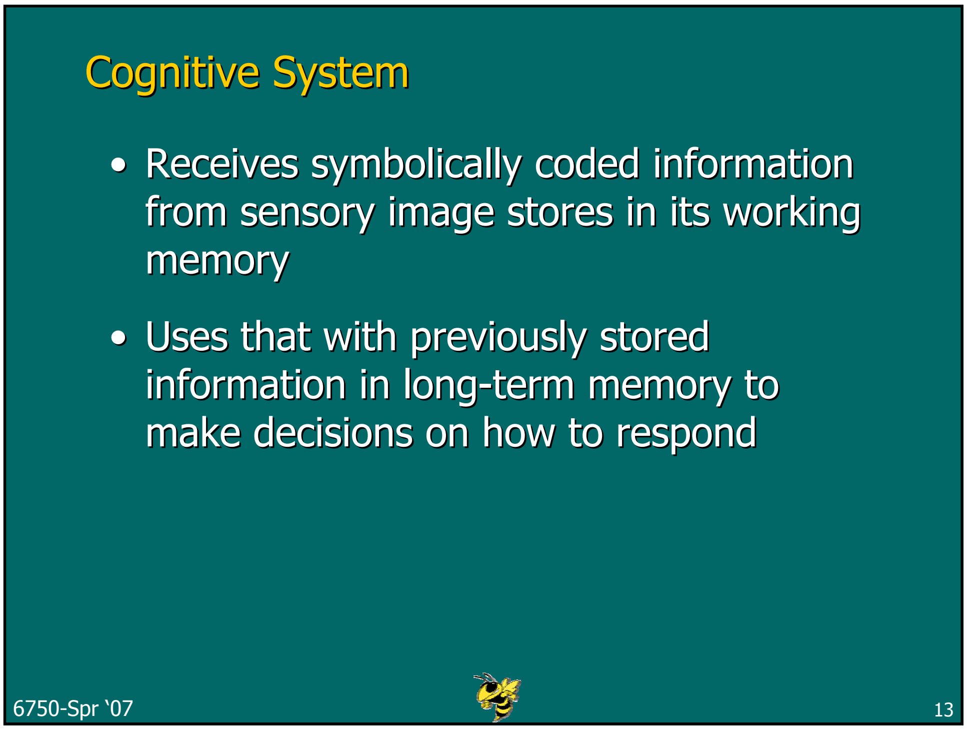
3 Subsystems

- Perceptual, cognitive and motor
  - Cycle times (τ):
    - $\tau_p \approx 100$ ms ("middle man" values)
    - $\tau_c \approx 70$ ms
    - $\tau_m \approx 70$ ms
- Perceptual and cognitive have memories
- Fundamental recognize-act cycle of behavior
  - Contents of working memory trigger actions held in long-term memory


Attention Resources
PERCEPTION (transfer to working memory)
Short-Term Sensory Store
Visual Image Store
δ VIS = 200 [90 - 1000] msec
μ VIS = 17 [7 - 17] items
κ VIS = Physical
Auditory Image Store
δ AIS = 1500 [900 - 3500] msec
μ AIS = 5 [4.4 - 5.2] letters
κ AIS = Physical
COGNITION (match, decide, memory transfer)
Long-Term Memory
δ LTM = ∞
μ LTM = ∞
κ LTM = Semantic
Working Memory
δ WM = 7 [5 - 226] sec
δ WM (1 chunk) = 73 [73 - 226] sec
δ WM (3 chunks) = 7 [5 - 34] sec
μ WM (with LTM) = 7 [5 - 9] chunks
μ WM = 3 [2.5 - 4.1] chunks
κ WM = Acoustic or Visual
MOTOR RESPONSE
STIMULI
RESPONSE
τp = 100 [50 - 200] msec
τc = 70 [25 - 170]
τm = 70 [30 - 100] msec
Feedback

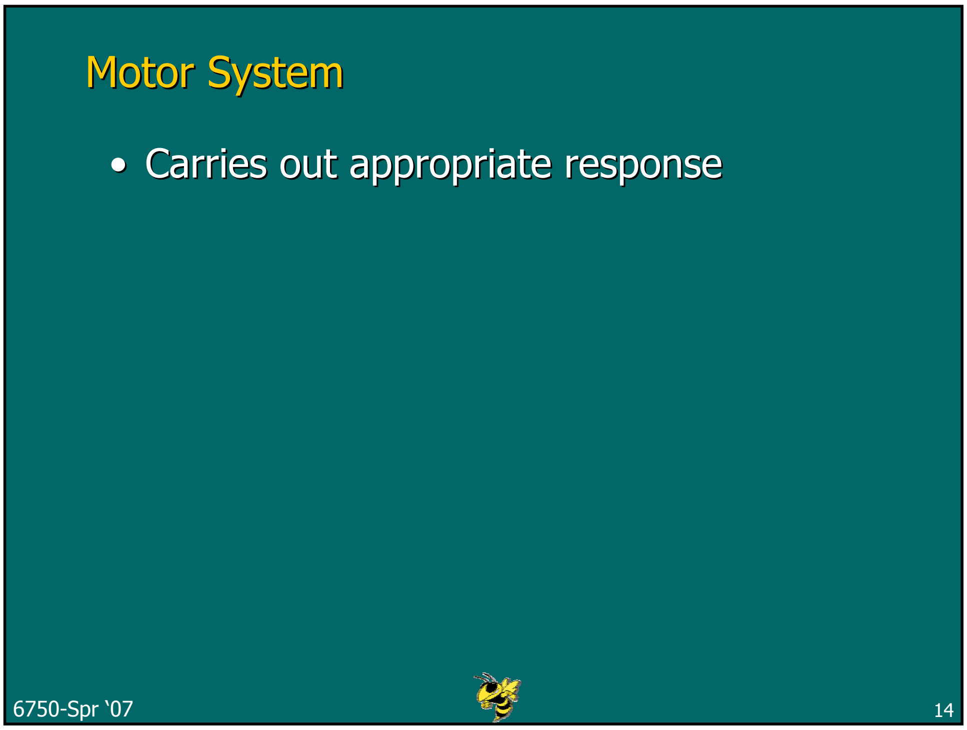
Perceptual System

- Consists of sensors and associated buffer memories
  - Most important memories being visual image store and audio image store
  - Hold output of sensory system while it is being symbolically coded



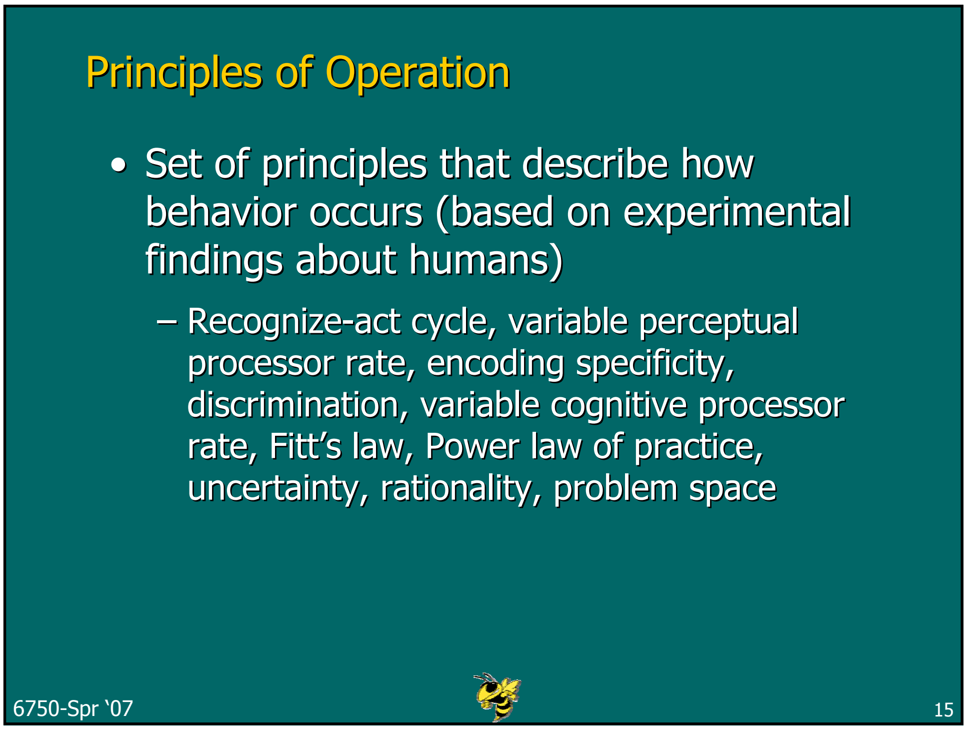
Cognitive System

- Receives symbolically coded information from sensory image stores in its working memory
- Uses that with previously stored information in long-term memory to make decisions on how to respond



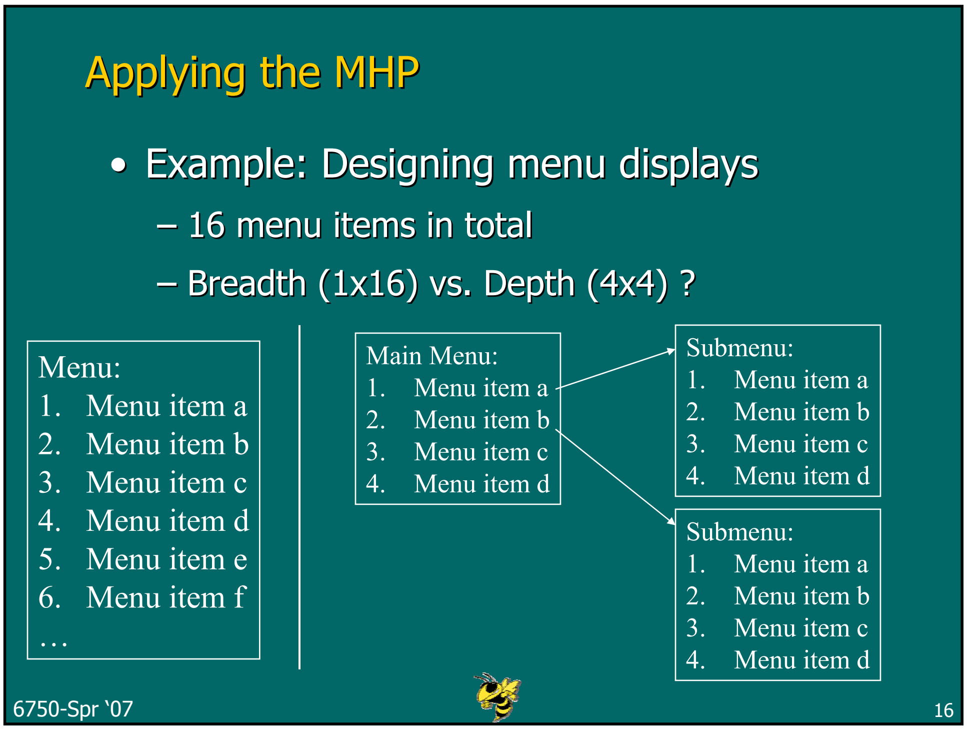
Motor System

- Carries out appropriate response



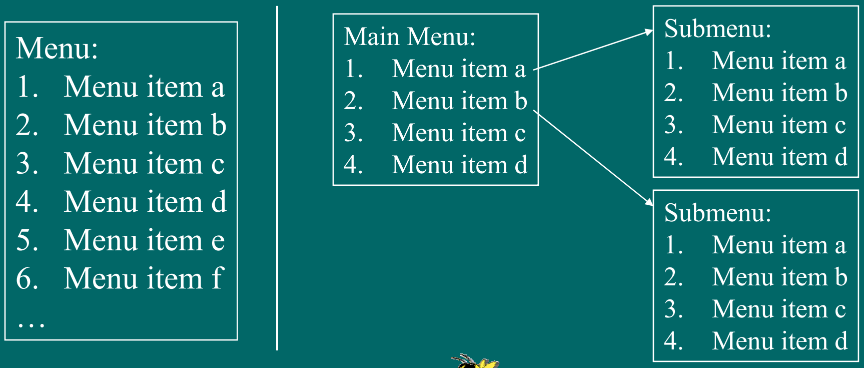
Principles of Operation

- Set of principles that describe how behavior occurs (based on experimental findings about humans)
  - Recognize-act cycle, variable perceptual processor rate, encoding specificity, discrimination, variable cognitive processor rate, Fitt’s law, Power law of practice, uncertainty, rationality, problem space



Applying the MHP

- Example: Designing menu displays
  - 16 menu items in total
  - Breadth (1x16) vs. Depth (4x4) ?



MHP: Calculations

Breadth (1x16):

τ_p perceive item, transfer to WM

τ_c retrieve meaning of item, transfer to WM

τ_c Match code from displayed to needed item

τ_c Decide on match

τ_m Execute eye mvmt to (a) menu item number (go to step 6) or (b) to next item (go to step 1)

τ_p Perceive menu item number, transfer to WM

τ_c Decide on key

τ_m Execute key response

Time = $[((16+1)/2)\ (\tau_p + 3\tau_c + \tau_m)] + \tau_p+\tau_c+\tau_m$

Time = 3470 msec

Serial terminating search over 16 items

Depth (4x4):

Same as for breadth, but with 4 choices, and done up to four times (twice, on average):

Time = $2 \times [((4+1)/2)\ (\tau_p + 3\tau_c + \tau_m)] + \tau_p+\tau_c+\tau_m$

Time = 2380 msec

Therefore, in this case, 4x4 menu is predicted to be faster than 1x16.

Related Modeling Techniques

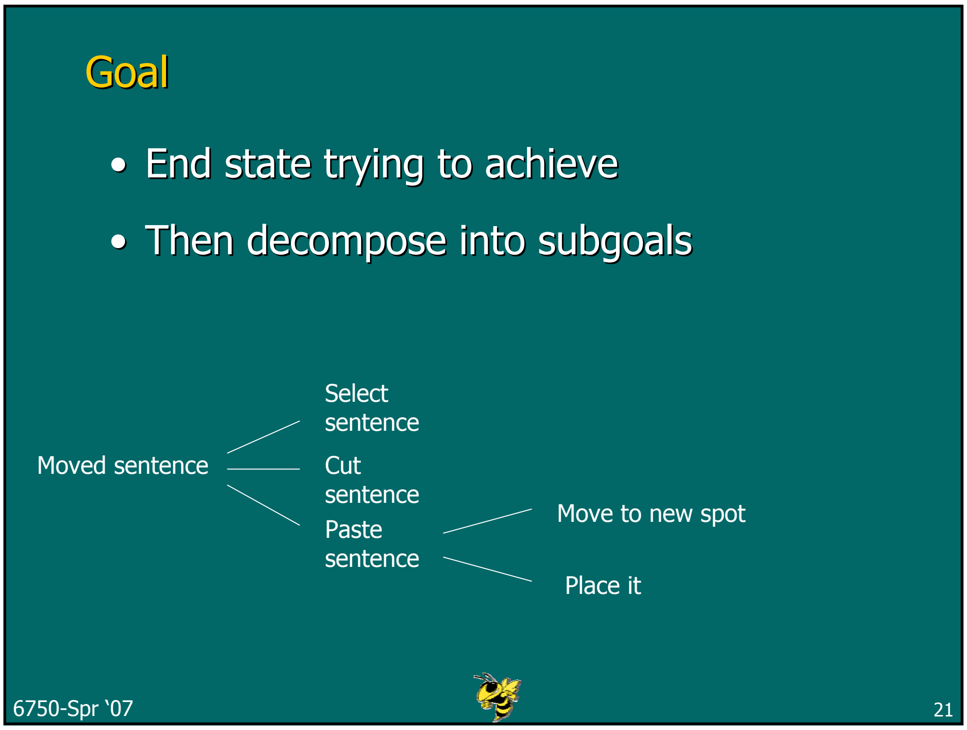
- Many techniques fall within this "human as information processor" model
- Common thread - hierarchical decomposition
  - Divide behaviors into smaller chunks
  - Questions:
    - What is unit chunk?
    - When to start/stop?

2. GOMS

- **G**oals, **O**perators, **M**ethods, **S**election Rules
  - Developed by Card, Moran and Newell '83
- Probably the most widely known and used technique in this family

Assumptions

- "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



Goal

- End state trying to achieve
- Then decompose into subgoals

Moved sentence

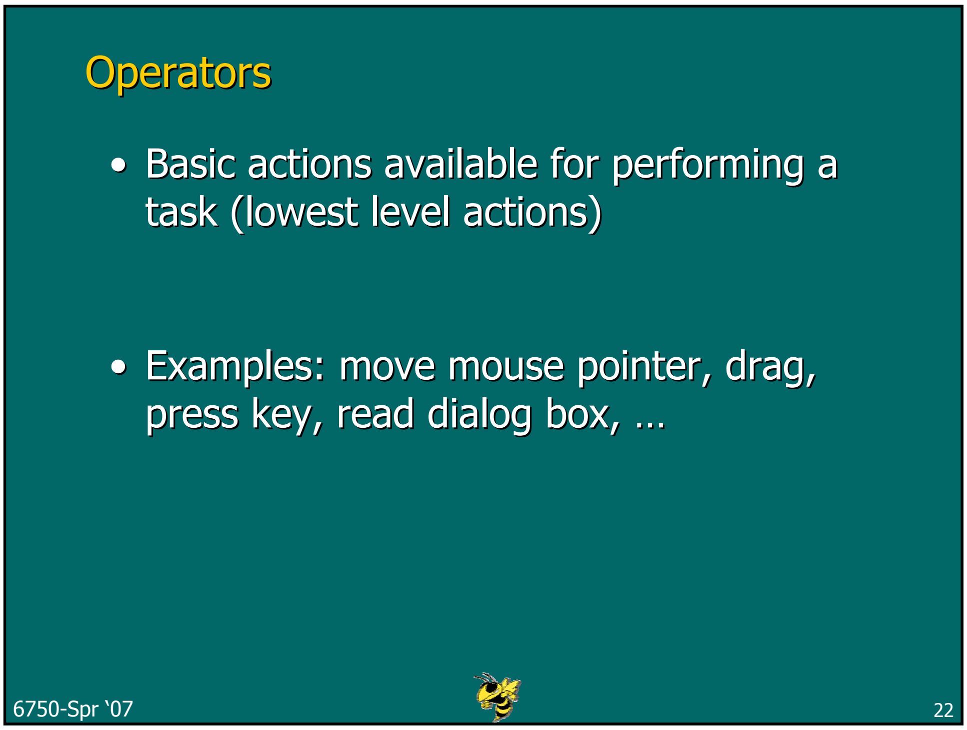
Select sentence

Cut sentence

Paste sentence

Move to new spot

Place it



Operators

- Basic actions available for performing a task (lowest level actions)
- Examples: move mouse pointer, drag, press key, read dialog box, …

Methods

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

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

Selection Rules

- Invoked when there is a choice of a method
- GOMS attempts to predict which methods will be used

- Example: Could cut sentence either by menu pulldown or by ctrl-x

GOMS Procedure

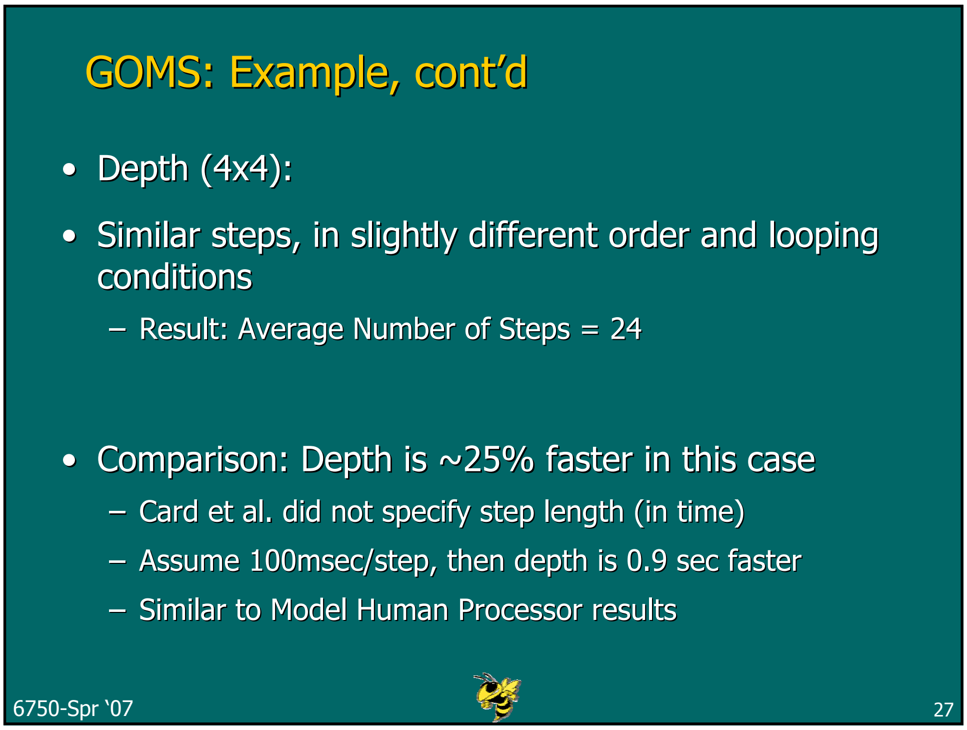
- Walk through sequence of steps
- Determine branching tree of operators, methods, and selections, and add up the times

GOMS: Example

- Menu structure (breadth vs. depth, again)
- Breadth (1x16):

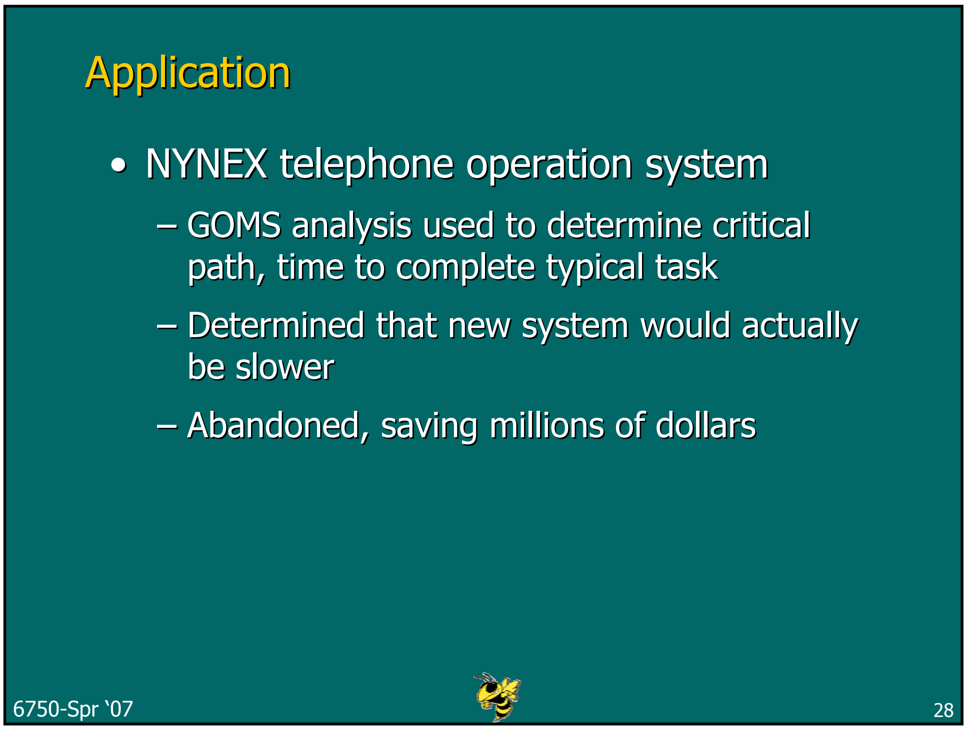
Goal: perform command sequence
- **Goal**: perform unit task of the command
  - Loops
  - **Goal**: determine which unit task to do
    - **Operator**: Look at screen, determine next command
  - **Goal**: Execute unit task
    - **Select**: Which method to enter number of command
      e.g. IF item # between 1 & 9 THEN use 1-KEY METHOD
    - **Operator**: Use 1-Key Method
    - **Operator**: Verify Entry… etc.

Result: Average Number of Steps = 33



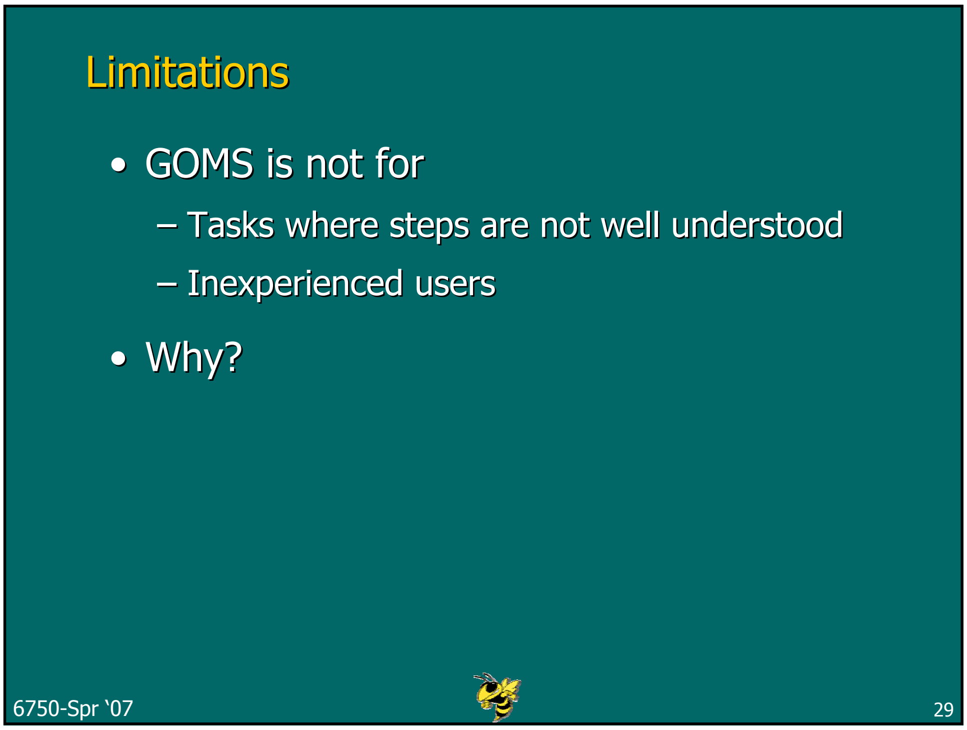
GOMS: Example, cont'd

- Depth (4x4):
- Similar steps, in slightly different order and looping conditions
  - Result: Average Number of Steps = 24
- Comparison: Depth is ~25% faster in this case
  - Card et al. did not specify step length (in time)
  - Assume 100msec/step, then depth is 0.9 sec faster
  - Similar to Model Human Processor results



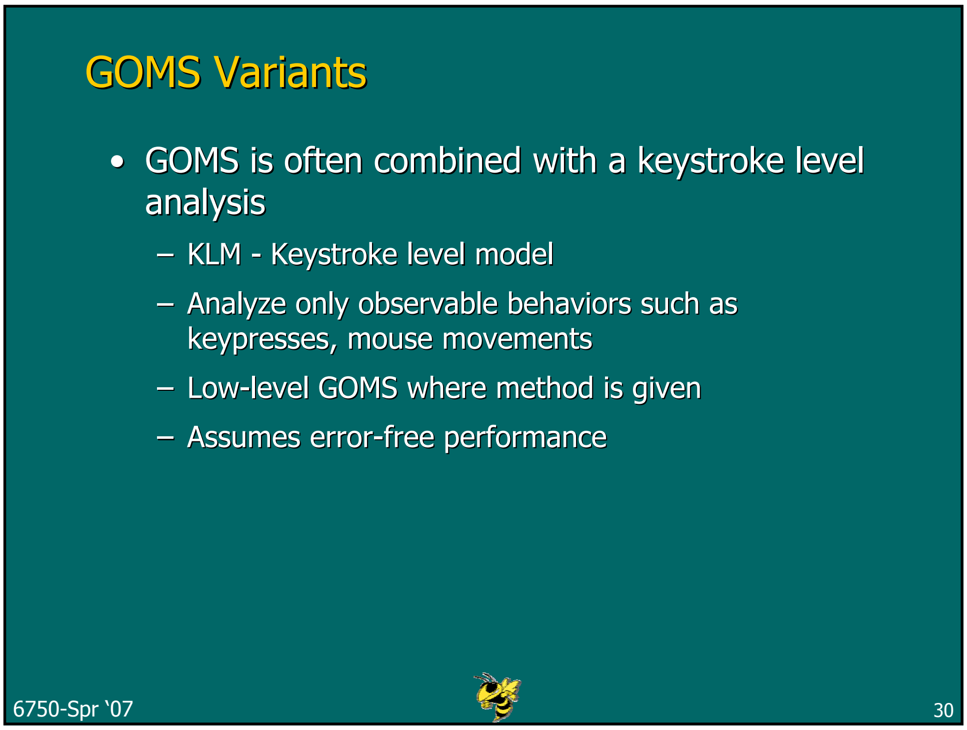
Application

- NYNEX telephone operation system
  - GOMS analysis used to determine critical path, time to complete typical task
  - Determined that new system would actually be slower
  - Abandoned, saving millions of dollars



Limitations

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



GOMS Variants

- GOMS is often combined with a keystroke level analysis
  - KLM - Keystroke level model
  - Analyze only observable behaviors such as keypresses, mouse movements
  - Low-level GOMS where method is given
  - Assumes error-free performance

KLM Characteristics

- Operators:
  - K: keystroke, mouse button push
  - P: point with pointing device
  - D: move mouse to draw line
  - H: move hands to keyboard or mouse
  - M: mental preparation for an operation
  - R: system response time
- Tasks split into two phases
  - Acquisition of task - user builds mental rep.
  - Execution of task - using system facilities

KLM predicts

Procedure

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

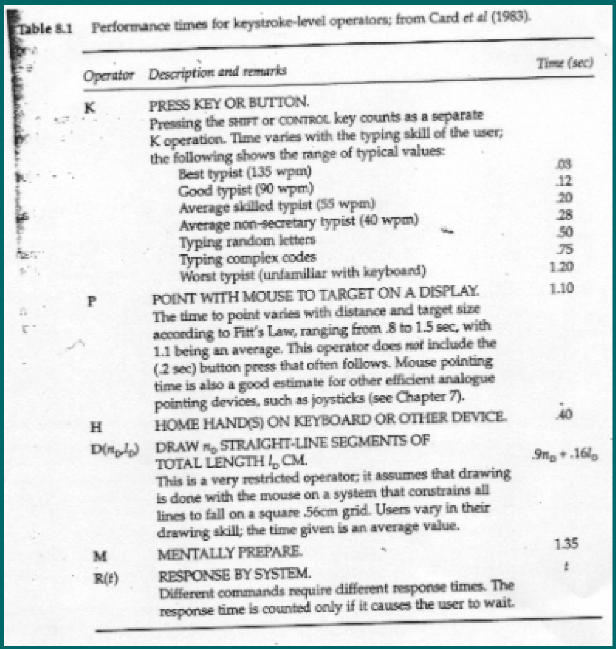
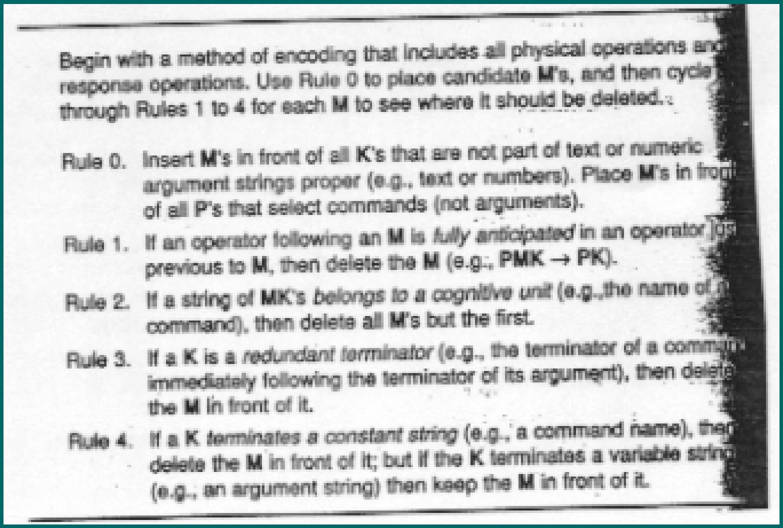


Table 8.1 Performance times for keystroke-level operators; from Card *et al* (1983).

Operator	*Description and remarks*	*Time (sec)*
K	PRESS KEY OR BUTTON. Pressing the SHIFT or CONTROL key counts as a separate K operation. Time varies with the typing skill of the user; the following shows the range of typical values:	
	Best typist (135 wpm)	.08
	Good typist (90 wpm)	.12
	Average skilled typist (55 wpm)	.20
	Average non-secretary typist (40 wpm)	.28
	Typing random letters	.50
	Typing complex codes	.75
	Worst typist (unfamiliar with keyboard)	1.20
P	POINT WITH MOUSE TO TARGET ON A DISPLAY. The time to point varies with distance and target size according to Fitt's Law, ranging from .8 to 1.5 sec, with 1.1 being an average. This operator does *not* include the (.2 sec) button press that often follows. Mouse pointing time is also a good estimate for other efficient analogue pointing devices, such as joysticks (see Chapter 7).	1.10
H	HOME HAND(S) ON KEYBOARD OR OTHER DEVICE.	.40
$D(n_D, l_D)$	DRAW n_D STRAIGHT-LINE SEGMENTS OF TOTAL LENGTH l_D CM. This is a very restricted operator; it assumes that drawing is done with the mouse on a system that constrains all lines to fall on a square .56cm grid. Users vary in their drawing skill; the time given is an average value.	$.9n_D + .16l_D$
M	MENTALLY PREPARE.	1.35
R(*t*)	RESPONSE BY SYSTEM. Different commands require different response times. The response time is counted only if it causes the user to wait.	*t*



Begin with a method of encoding that includes all physical operations an response operations. Use Rule 0 to place candidate **M**'s, and then cycle through Rules 1 to 4 for each **M** to see where it should be deleted.

Rule 0. Insert **M**'s in front of all **K**'s that are not part of text or numeric argument strings proper (e.g., text or numbers). Place **M**'s in fro of all **P**'s that select commands (not arguments).

Rule 1. If an operator following an **M** is *fully anticipated* in an operator [o previous to **M**, then delete the **M** (e.g., **PMK** → **PK**).

Rule 2. If a string of **MK**'s *belongs to a cognitive unit* (e.g.,the name of command), then delete all **M**'s but the first.

Rule 3. If a **K** is a *redundant terminator* (e.g., the terminator of a comman immediately following the terminator of its argument), then delete the **M** in front of it.

Rule 4. If a **K** *terminates a constant string* (e.g., a command name), the delete the **M** in front of it; but if the **K** terminates a variable string (e.g., an argument string) then keep the **M** in front of it.

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	0.60
		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. ...

Example of KLM

- Breadth menu (1x16)
  - M: Search 16 items
  - 1 or 2 K: Enter 1 or 2-digit number
  - K: Press return key

Time=M + K(first digit) + 0.44K(second digit) + K(Enter)

(Look up values, and when to apply "M" operator)

Time=1.35 + 0.20 + 0.44(0.20) + 0.20 = 1.84 seconds

Note: Many assumptions about typing proficiency, M's, etc.

Also ignores most of the time spent determining which task to perform, and how to perform it.

Example of KLM, cont'd

- Depth menu (4x4)
  - M: Search 4 items
  - K: Enter 1-digit number (no M, since expert user)
  - K: Press return key

  Time=M + K(Digit) + K(Enter)

  Time=1.35 + 0.20 + 0.20 = 1.75 seconds

- Compare the various models in terms of times and predictions:
  - Vary in times, but not in performance predictions

Other GOMS Variants

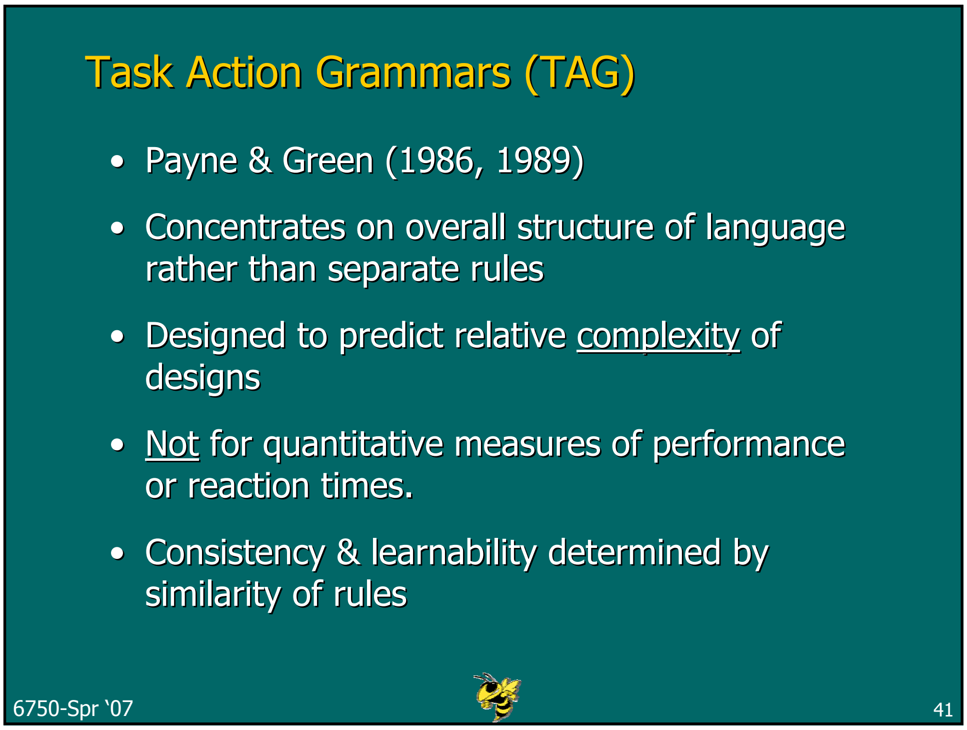
- NGOMSL (Kieras)
  - Very similar to GOMS
  - Goals expressed as noun-action pair, eg., delete word
  - Same predictions as other methods
  - More sophisticated, incorporates learning, consistency
  - Handles expert-novice difference, etc.

3. Production Systems

- IF-THEN decision trees (Kieras & Polson '85)
  - Cognitive Complexity Theory
  - Uses goal decomposition from GOMS and provides more predictive power
  - Goal-like hierarchy expressed using production rules
    - if condition, then action
    - Makes a generalized transition network
- Very long series of decisions
  - Note: In practice, very similar to NGOMSL
    - Bovair et al (1990) claim they are identical
  - NGOMSL model easier to develop
  - Production systems easier to program

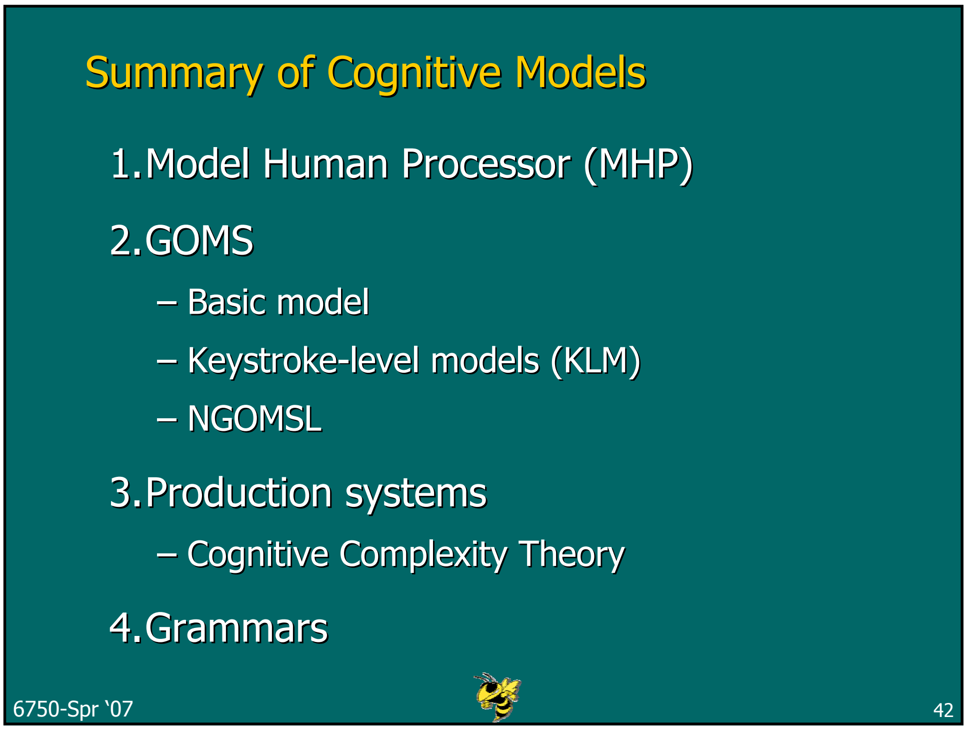
4. Grammars

- To describe the interaction, a formalized set of productions rules (a language) can be assembled.
- "Grammar" defines what is a valid or correct sequence in the language.
- Reisner (1981) "Cognitive grammar" describes human-computer interaction in Backus-Naur Form (BNF) like linguistics
- Used to determine the consistency of a system design



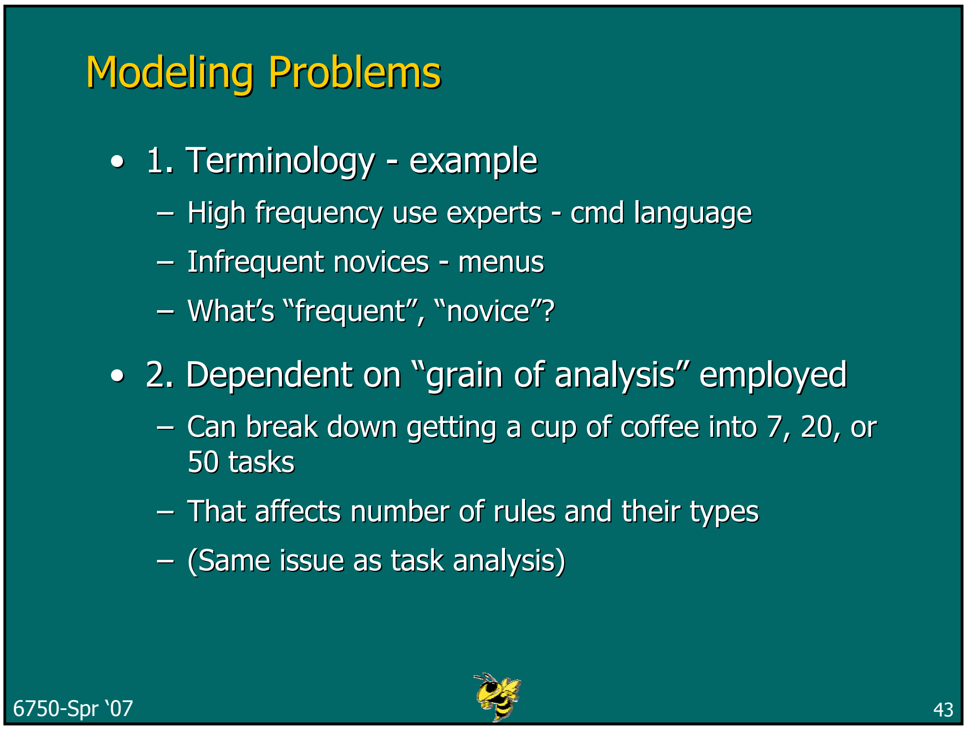
Task Action Grammars (TAG)

- Payne & Green (1986, 1989)
- Concentrates on overall structure of language rather than separate rules
- Designed to predict relative <u>complexity</u> of designs
- <u>Not</u> for quantitative measures of performance or reaction times.
- Consistency & learnability determined by similarity of rules



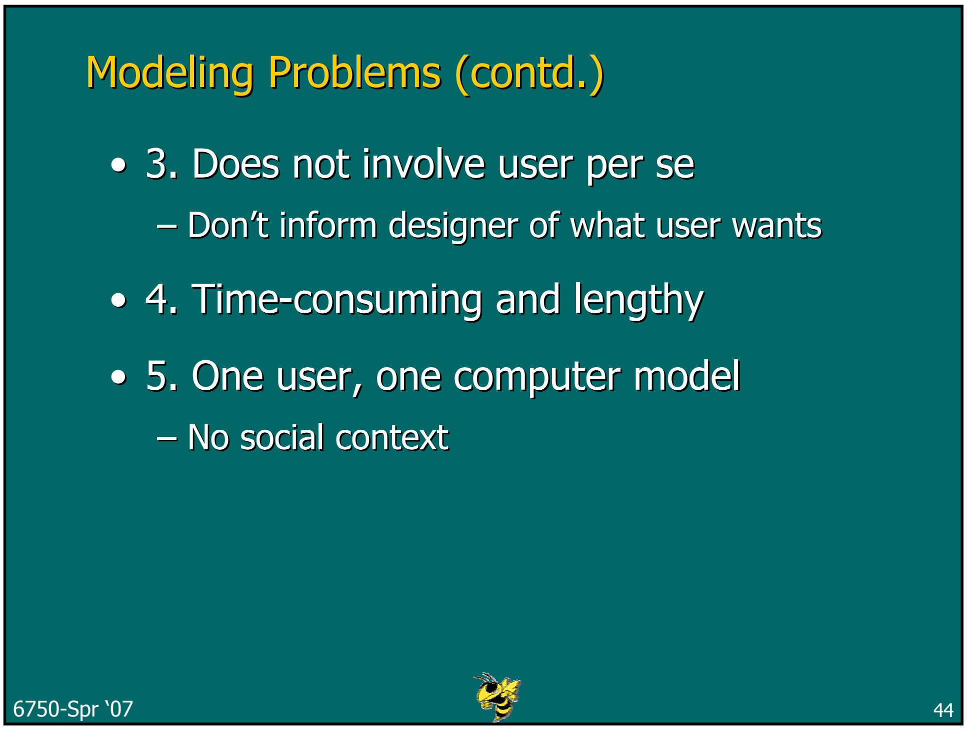
Summary of Cognitive Models

1. Model Human Processor (MHP)
2. GOMS
   - Basic model
   - Keystroke-level models (KLM)
   - NGOMSL
3. Production systems
   - Cognitive Complexity Theory
4. Grammars



Modeling Problems

- 1. Terminology - example
  - High frequency use experts - cmd language
  - Infrequent novices - menus
  - What's "frequent", "novice"?
- 2. Dependent on "grain of analysis" employed
  - Can break down getting a cup of coffee into 7, 20, or 50 tasks
  - That affects number of rules and their types
  - (Same issue as task analysis)



Modeling Problems (contd.)

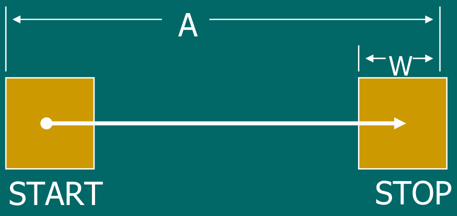
- 3. Does not involve user per se
  - Don't inform designer of what user wants
- 4. Time-consuming and lengthy
- 5. One user, one computer model
  - No social context

Lower Level Models

- More physically-based
  - Human as biomechanical machine
- Fitt's Law
  - Models movement times for selection tasks
- Basic idea: Movement time for a well-rehearsed selection task
  - Increases as the distance to the target increases
  - Decreases as the size of the target increases

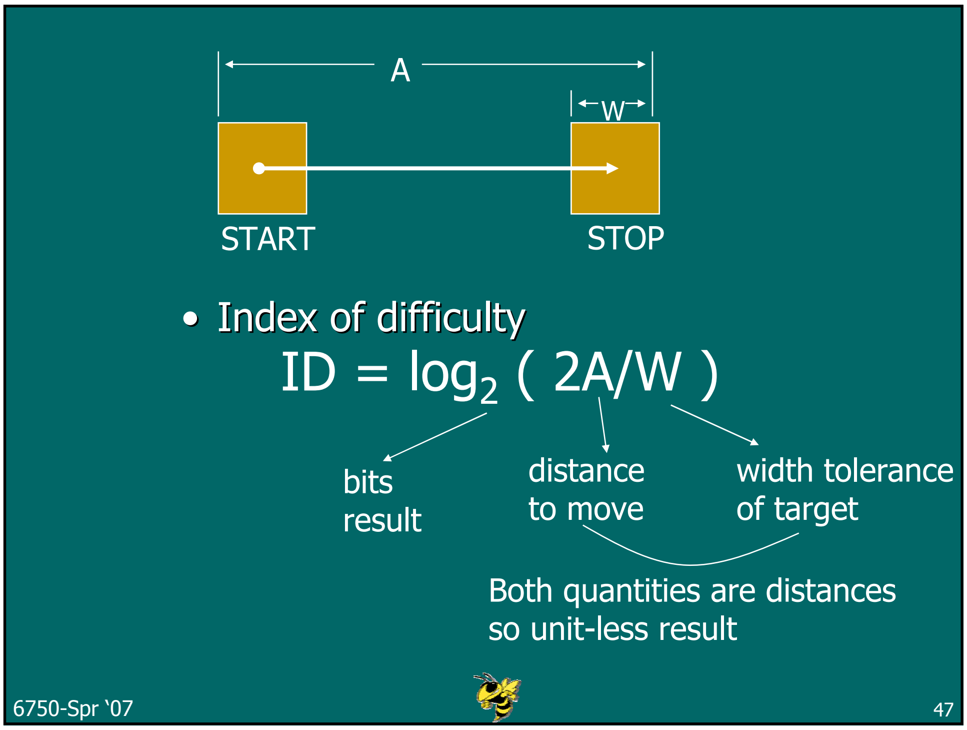
Model Description 1

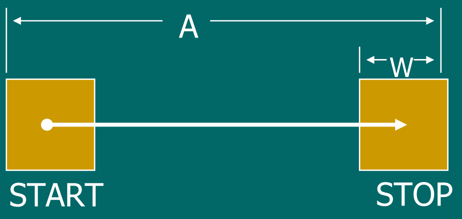
- Move from START to STOP



- Index of difficulty

$$ID = \log2 (2A/W)$$





- Index of difficulty

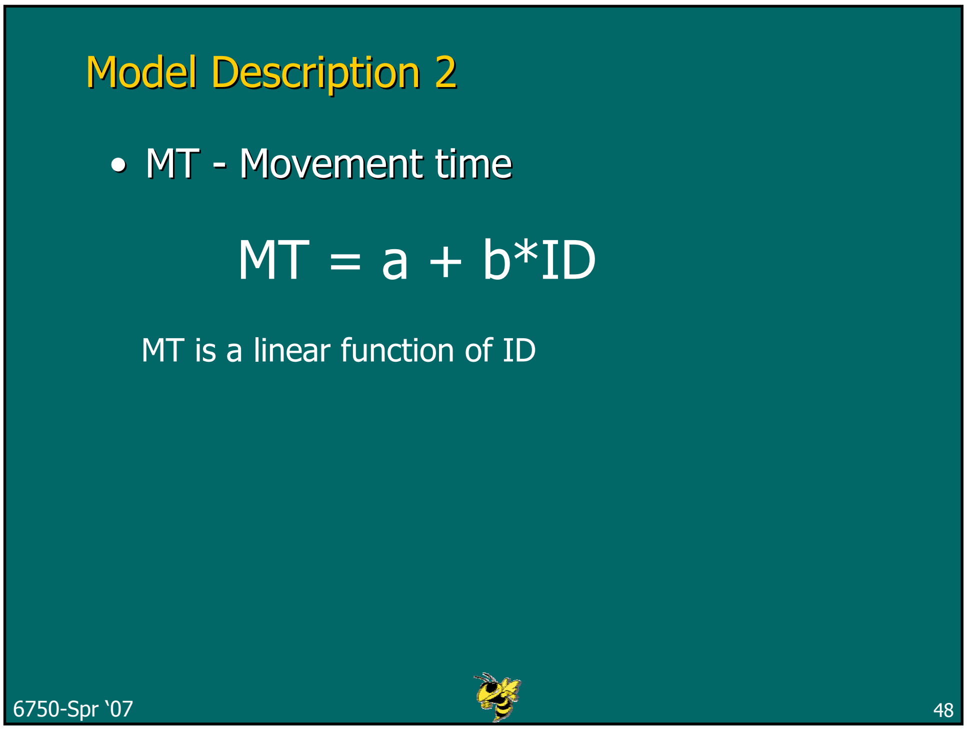
$$ID = \log_2 (2A/W)$$

bits
result

distance
to move

width tolerance
of target

Both quantities are distances
so unit-less result



Model Description 2

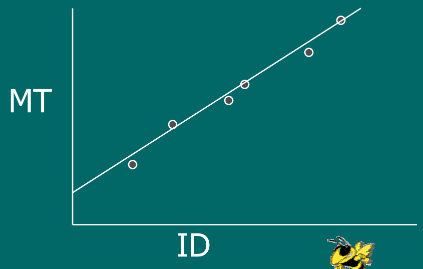
- MT - Movement time

$$MT = a + b*ID$$

MT is a linear function of ID

Exact Equation

- Run empirical tests to determine a and b in $MT = a + b*ID$
- Will get different ones for different input devices and ways the device is used

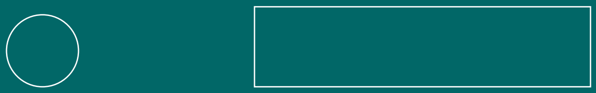


Common Equation

- $MT = a + b \log_2 (A/W + 1)$
- Provides useful numbers

Questions

- What do you do in 2D?



- Where can this be applied in user interface design?

Video

- IBM keyboard pointing stick

Upcoming

- Descriptive Cognitive Models
  - Social context
- Evaluation
  - Experimental design
  - Data collection
  - Subjective measures
  - Data analysis