Introduction to GOMS

Psyc2965

Fall'2002

Definition of GOMS

- **Characterization of a task in terms of**
  - **The user's** *Goals*
  - **The** *Operators* **available to accomplish those goals**
  - *Methods* **(frequently used sequences of operators and sub-goals) to accomplish those goals, and**
  - **If there is more than one method to accomplish a goal, the** *Selection rules* **used to choose between methods.**

What GOMS Is

- **GOMS is a task analysis technique**
  - **Very similar to Hierarchical Task Analysis (Indeed, GOMS is a hierarchical task analysis technique)**
  - **Hard part of task analysis is goal-subgoal decomposition**
    - **Hard part of GOMS is goal-subgoal decomposition**
  - **Different members of the GOMS family provide you with different sets of operators**
    - **With established parameters**
    - **But set is not complete (extensionable)**
  - **If you master GOMS at the level required for psyc645, you will be able to transfer your skills to most other task analysis techniques**

GOMS & Task Analysis

- **In formulating GOMS, Card, Moran, and Newell thought hard about building cognitive science into task analysis**
- **Not the only way to apply cognitive science, but is one way**

Model Human Processor & Task Analysis

- **Rationality Principle**
  - **P8 – Behavior is determined by goals + task + operators + inputs + knowledge + process limits**
- **Problem Space Principle**
  - **P9 – Goal directed activity 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.**

MHP & Task Analysis

- **First 7 principles tend to describe ways of estimating duration of operators; e.g.,**
  - **P1 -- Variable perceptual processor rate**
  - **P2 -- Encoding specificity principle**
  - **P3 -- Discrimination principle**
  - **P4 -- Variable cognitive processor rate principle**
  - **P5 -- Fitts's law**
  - **P6 -- Power law of practice**
  - **P7 -- Uncertainty principle**

MHP & Task Analysis

- **MHP also includes an extremely generic theory of information processing**
  - **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 LTM; these actions in turn modify the contents of working memory.**

MHP & Task Analysis

- **Newell & Card**
  - **“Psychology delivers to the bounded-rationality band the model that must be used to understand what helps the user and how”**
  - **By which they mean that whatever the task, at some level of analysis it must be realized by operators at the level of principles 1-7 of the MHP.**

MHP and Task analysis

- **Integrated Models of Cognition (N&C p. 229)**
- **Calculational models of perception**
- **Partly Linear Models**
  - **Phenomenon = Volume-part + Difficulty-part**
  - **A key concept for task analysis (pp. 232-233 of N&C)**

Partly Linear Models

- **Example from Kieras: Which are the volume parts and which are the difficulty parts?**

- **Method for goal: Proofread drawing**
  - Step 1. Find a red terminal in drawing.
  - Step 2. Decide: If no red terminals, return with goal accomplished.
  - Step 3. Accomplish Goal: Draw wire at
  - Step 4. Go to 1.

- **Method for goal: Draw a wir**
  - Step 1. Think-of starting and ending points for wire.
  - Step 2. Think-of route for wire.
  - Step 3. Invoke wire drawing function with starting point, ending point, and route.
  - Step 4. Decide: If wire is now green, return with goal accomplished.
  - Step 5. Decide: If wire is red, think-of problem with wire.
  - Step 6. Go to 1.

Figure 3. Methods incorporating color codes for syntactic drawing errors.

Partly Linear Models

- **Example from Kieras: Which are the volume parts and which are the difficulty parts?**

Difficulty Parts

- **Method for goal: Proofread drawing**
  - Step 1. Find a red[illegible]
  - Step 2. Decide: If[illegible]
  - Step 3. Accomplish[illegible]
  - Step 4. Go to 1.
- **Method for goal: Draw a wire**
  - Step 1. Think-of starting and ending points for wire.
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  - Step 5. Decide: If wire is red, think-of problem with wire.
  - Step 6. Go to 1.

Figure 3. Methods incorporating color codes for syntactic drawing errors.

Partly Linear Models

- **Example from John & Kieras:**
  - **Goal-directedness: Task situations that are less goal directed often have subgoals that need effective support**
- **Evolution from problem-solving to cognitive skill**
  - **Many tasks evolve from problem solving to routine skill after extensive use. Predicting a fully practiced user's performance is valuable, because such performance cannot be empirically measured for a system that is just being designed and not yet implemented**
- **Many tasks have elements of both routine skill and problem solving**
  - **Although a user's task may seem to be primarily a problem-solving task, there will be aspects of that task that involve routine cognitive skill. It is these aspects of the system design for which an analyst can use GOMS to improve the design to allow users to more effectively work on the nonroutine, creative parts of the overall task" p. 296.**

Where does GOMS go?

(When do you need to do a CTA versus a TA?)

- **Task analysis versus cognitive task analysis?**
- **What distinguishes GOMS cognitive task analysis from other task analysis techniques?**
  - **E.g., Cognitive Task Analysis™**

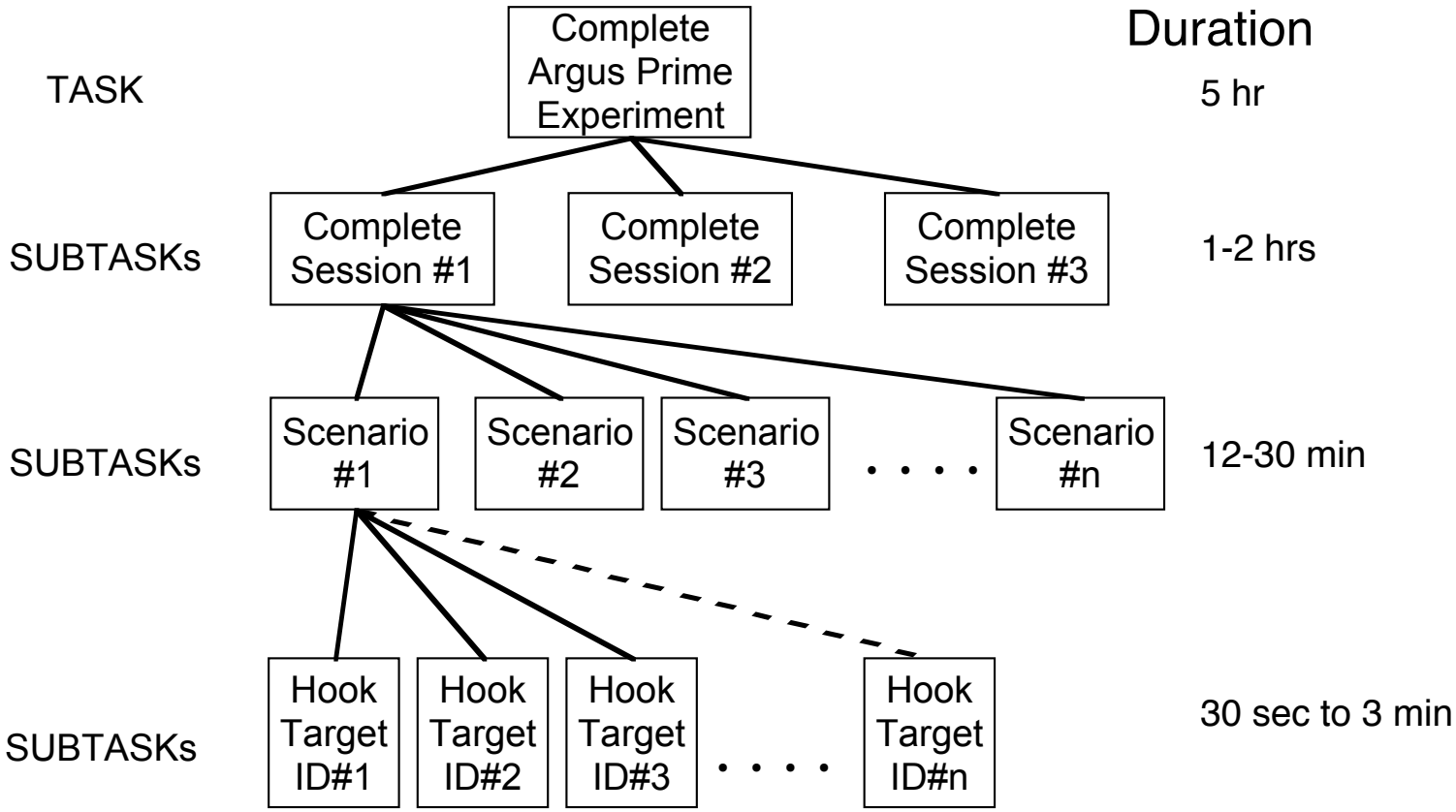
TASK ANALYSIS

Time Scale for GOMS

Levels of analysis (based on Newell's Time Scale of Human Action)

Scale (sec)	*Time Units*	*System*	*Analysis*	*World (theory)*
1000000000	decades	Technology	Culture	Social & Organizational
100000000	years	System	Development	
10000000	months	Design	Education	
1000000	week	Task		
100000	days	Task	Traditional Task Analysis	Bounded Rationality
10000	hours			
1000	10 min			
100	min	Subtask	Unit Task Analysis	
10	10 sec	Unit task	Cognitive Task Analysis	Cognitive Band (symbolic)
1	1 sec	Activities	Microstrategy Analysis	
	1/3 sec	Embodied Activities (Basic units of embodied cognition)	Production Rules	
0.1	100 ms	Production Rule	Elements (DME-MA-VA)	
0.01	10 ms	Elements	Architectural	Biological Band (subsymbolic)
0.001	1 ms	Parameters		

Level 1: Task Analysis: Task → Subtasks → Subtasks →



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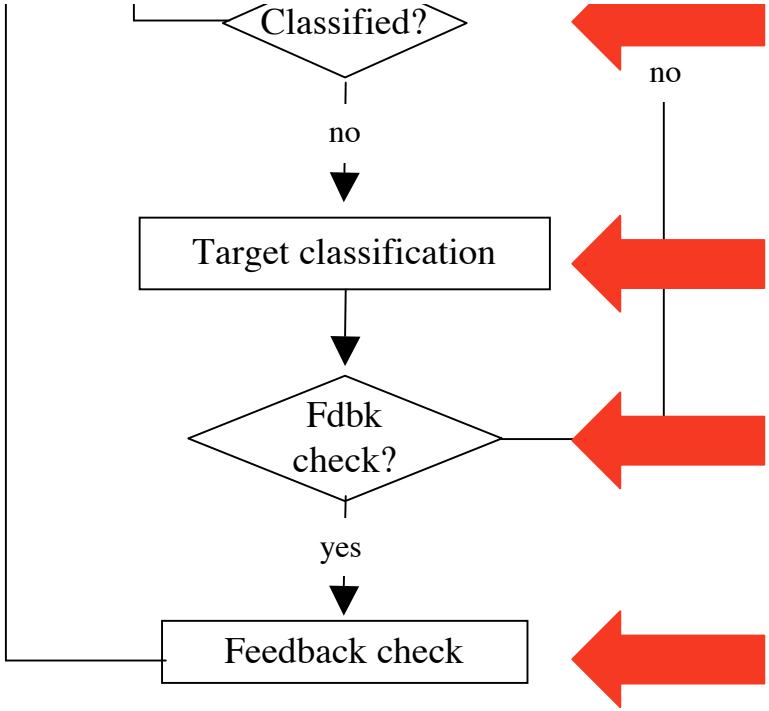
Subtask → Unit Tasks

At the next level of analysis, the subtask of "hooking a target" can be analyzed as a series of unit tasks



"The unit task is fundamentally a control construct, not a task construct" (Card, Moran, & Newell, 1983)

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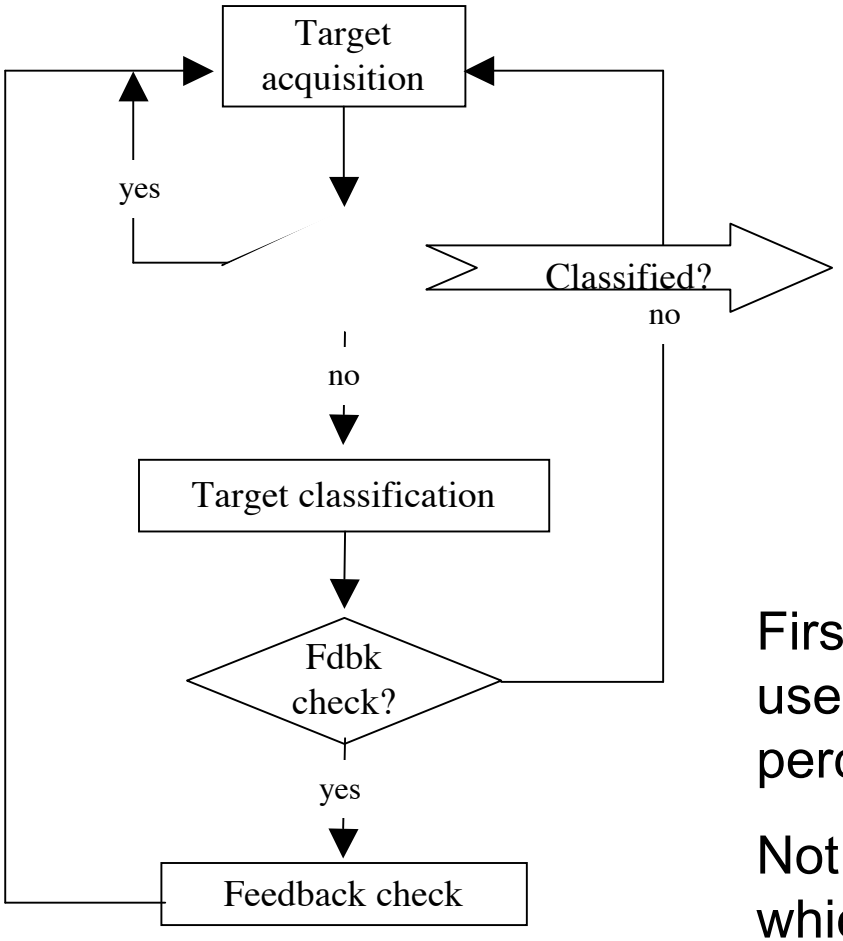
Any Given Unit Task Can be Further Analyzed into a Sequence of Activities



Method for goal: Determine if target is classified	
Step 1	Select target by mouse click
Step 2	Note target ID#
Step 3	Determine if radio button in info window is black
Step 4	Verify that info window ID# is same as target ID#

First level at which we have described user behavior in terms of cognitive, perceptual, and motor operations.

Not coincidently, it is also the first level at which we have talked about features of the interface.

Levels of analysis (based on Newell's Time Scale of Human Action)

Scale (sec)	*Time Units*	*System*	*Analysis*	*Activities/ Processes*	*World (theory)*
10^{5}	days				
10^{4}	hours	Task	Task analysis	Subtasks	Bounded Rationality
10^{3}	10 min				
10^{2}	min	Subtask	Unit Task Analysis	Unit Tasks	
10^{1}	10 sec	Unit task	Cognitive task analysis	Activities	
10^{0}	1 sec	Activity	Embodied cognition	Microstrategies	Cognitive Band
10^{-1}	100 ms	Microstrategy	Computational models of embodied cognition	Elements	
10^{-2}	10 ms	Elements	Architectural	Parameters	Biological Band
10^{-3}	1 ms	Parameters			

Activity Level → Embodiment Level

Method for goal: Determine if target is classified	
Step 1	Select target by mouse click
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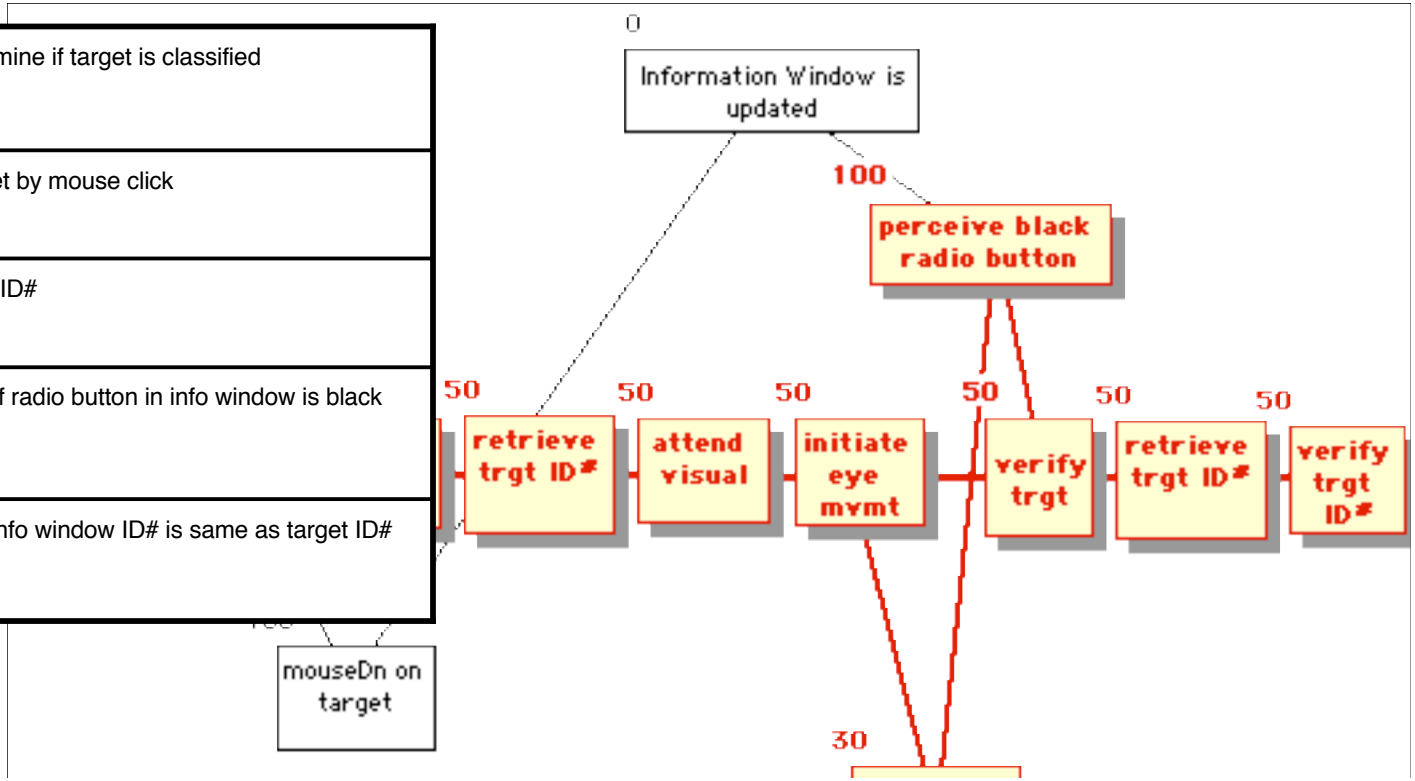


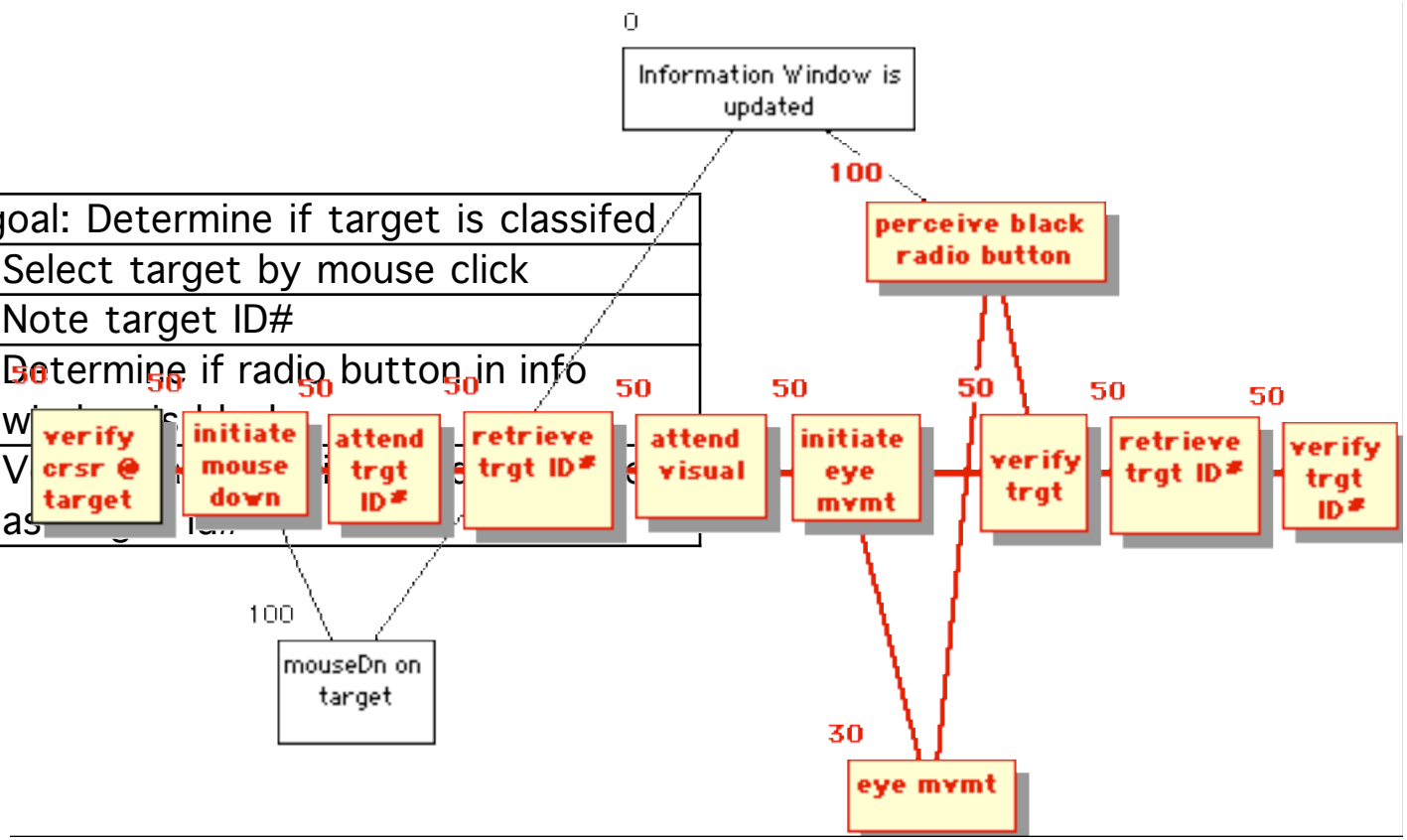
Gray, W. D., & Boehm-Davis, D. A. (2000). Milliseconds Matter: An introduction to microstrategies and to their use in describing and predicting interactive behavior. *Journal of Experimental Psychology: Applied, 6*(4), 322-335.

Gray, W. D., John, B. E., & Atwood, M. E. (1993). Project Ernestine: Validating a GOMS analysis for predicting and explaining real-world performance. *Human-Computer Interaction, 8*(3), 237-309.

John, B. E. (1990). Extensions of GOMS Analyses to Expert Performance Requiring Perception of Dynamic Visual and Auditory Information. In J. C. Chew & J. Whiteside (Eds.), *Proceedings of the ACM CHI'90 Conference on Human Factors in Computing Systems* (pp. 107-115). New York: ACM Press.

Level 4: Embodied Cognition: Activity → Microstrategy

Method for goal: Determine if target is classifed	
Step 1	Select target by mouse click
Step 2	Note target ID#
Step 3	Determine if radio button in info w[illegible]
Step 4	V[illegible] as[illegible]



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0.001	1 ms	Parameters		

Level 5: Microstrategies → Elements
(Where GOMS doesn't go!)

- **Production Rules**
- **If --> Then rules at the 50-100 msec level**
  - **If**
    - **This is true of memory &**
    - **This is true of the environment**
  - **Then**
    - **Add this fact to memory, &**
    - **Try to retrieve this other fact from memory, &**
    - **Send a command to the left-index finger to mouse down**

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Level 6: Production Rules → Elements
(Where GOMS doesn't go!)

- **Declarative memory elements**
  - **Internal (created on RHS of production rules)**
  - **External (created by shifts of attention in the external environment)**
- **Visual actions**
- **Motor actions**

Level 7: Elements → Parameters

(GOMS doesn't go here either!)

- w -- amount of attentional capacity
- d -- decay rate
- s -- fluctuations in the strength of declarative memory elements
- rt -- retrieval threshold

KR not KE

- **GOMS (as with most task analysis methods) focuses on**
  - **Knowledge representation, not on**
  - **Knowledge elicitation**
- **There are many sources of knowledge elicitation techniques, e.g.,**
  - Cooke, N. J. (1994). Varieties of Knowledge Elicitation Techniques. *International Journal of Human-Computer Studies, 41*(6), 801-849.
  - Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (Revised ed.). Cambridge, MA: The MIT Press.
  - Olson, J. R., & Biolsi, K. J. (1991). Techniques for representing expert knowledge. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 240-285). New York: Cambridge.
  - vanSomeren, M. W., Barnard, Y. F., & Sandberg, J. A. C. (1994). *The think aloud method: A practical guide to modelling cognitive processes*. New York: Academic Press.

Task Analysis versus Functionality

- **A task analysis does not guarantee functionality, see**

Kieras, D. E. (in press). Task analysis and the design of functionality, *CRC Handbook of Computer Science and Engineering*.: CRC Press, Inc.

for a cogent discussion of this issue

Definition of GOMS

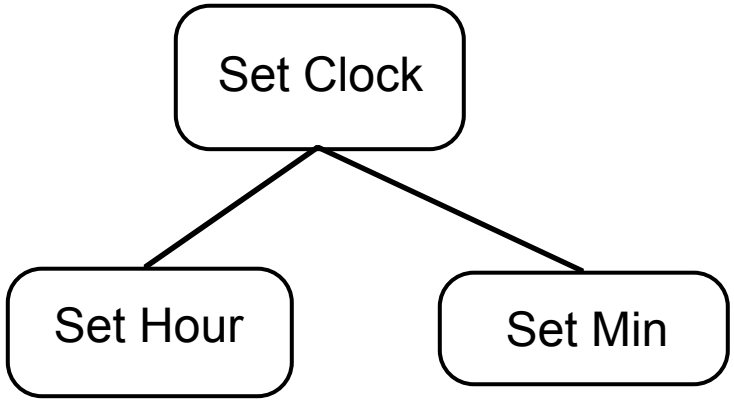
- **Characterization of a task in terms of**
  - **The user's** *Goals*
  - **The** *Operators* **available to accomplish those goals**
  - *Methods* **(frequently used sequences of operators and sub-goals) to accomplish those goals, and**
  - **If there is more than one method to accomplish a goal, the** *Selection rules* **used to choose between methods.**

Example of G-O-M-S

- To carry out a GOMS analysis of the following task involving a digital clock:
  - Set the clock
- Top level goal: SET CLOCK

Example of G-O-M-S: Goals

Goals and subgoals



Example of G-O-M-S: Operators

Operators are the most elementary steps in which you choose to analyze the task.

- **Reach <type> button**
- **Hold <type> button**
- **Release <type> button**
- **ClickOn <type> button**
- **Decide: if <x> then <y>**
- **Verify**

Example of G-O-M-S: Methods

- **Top-level user goals**

  SET-CLOCK

- **Method for goal: SET-CLOCK**

  Step 1. Hold TIME button

  Step 2. Accomplish goal: SET-HOUR

  Step 3. Accomplish goal: SET-MIN

  Step 4. Release TIME button

  Step 5. Return with goal accomplished

- **Method for goal: SET-<digit>**

  Step 1. ClickOn <digit> button

  Step 2. Decide: If target <digit> = current <digit>, then return with goal accomplished

  Step 3. Goto 1

Example of G-O-M-S: Selection rules

- **No selection rules in this example as this clock has only ONE method for accomplishing each goal, but . . .**

Selection rule for goal: SET-HOUR

If target HOUR ≤ 4 hours from current HOUR, then Accomplish Goal: ClickOn HOUR

If target HOUR > 4 hours from current HOUR, then Accomplish Goal : Click&Hold HOUR

Applications of GOMS

Case 1. Design of mouse-driven text editor

Case 2. Directory assistance workstation

Case 3. Space operations database system (for orbital objects)

Case 4. Bank deposit reconciliation system.

Case 5. CAD system for mechanical design.

Case 6. Television control system.

Case 7. Nuclear power plant operator's associate.

Case 8. Intelligent tutoring system.

Case 9. Industrial scheduling system.

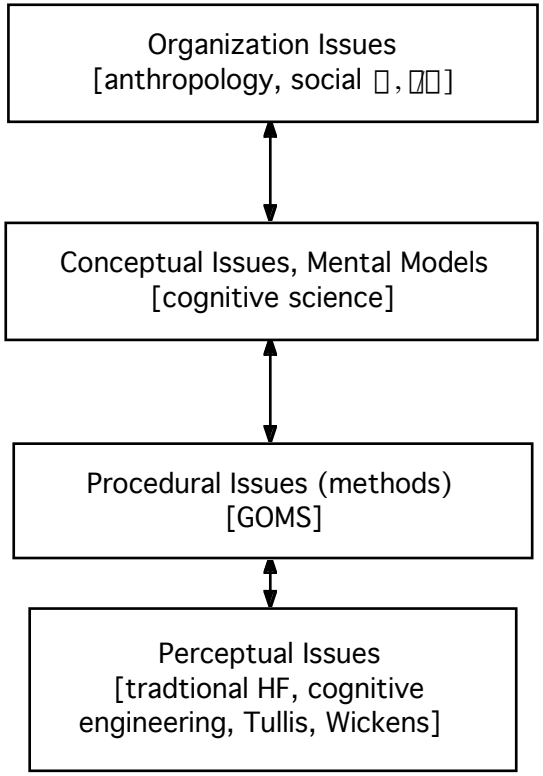
Case 10. CAD system for ergonomic design.

Case 11. Telephone operator workstation.

List compiled by John & Kieras (1997a).

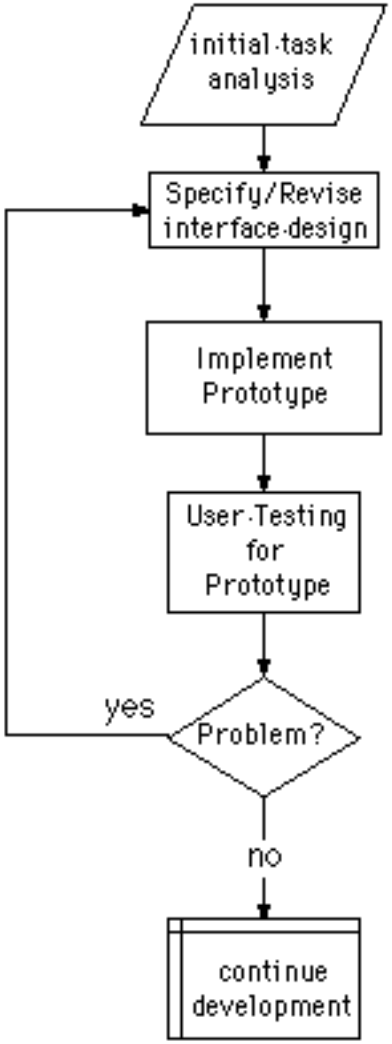
Where does GOMS go?

Usability writ large



Development process

without analytic modeling



Development process

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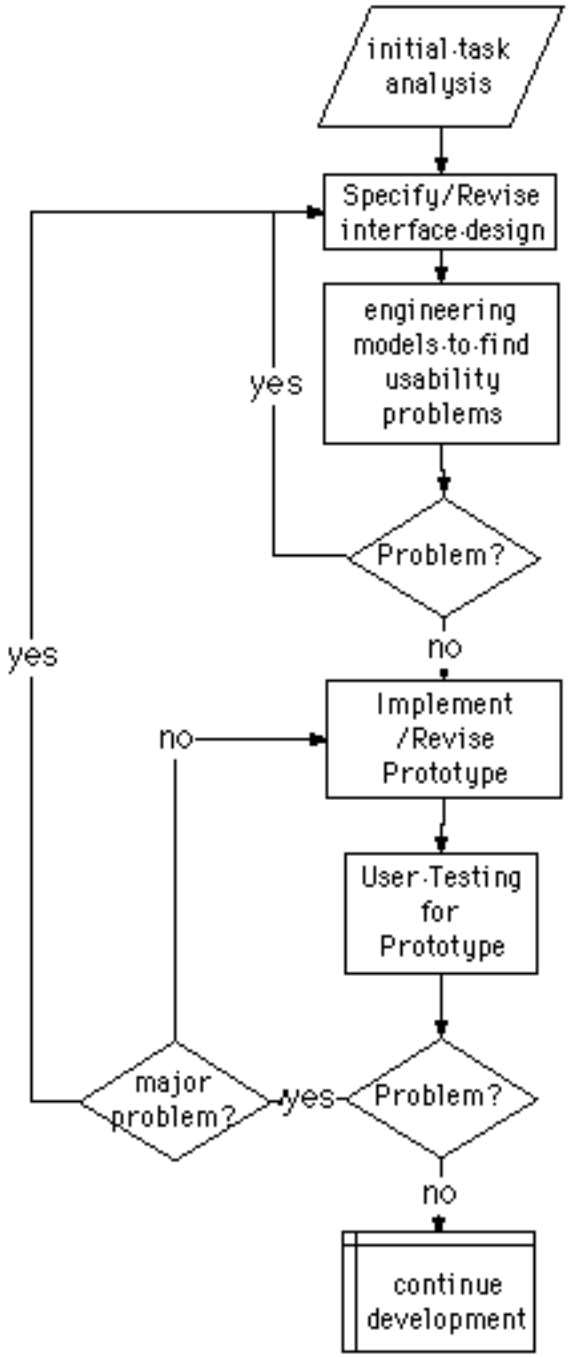

GOMS as Analytic Modeling

- GOMS analysis produces a model of behavior
- Given a task, the model predicts the methods, or sequences of operators, that a person will perform to accomplish that task
- Can look at the GOMS model in different ways to qualitatively and quantitatively assess different types of performance

Scope of GOMS: What it can *do*

- Predict the sequence of operators an expert will perform
- Predict performance time of expert users - even in real-world situations
- Predict learning time in relatively simple domains
- Predict savings due to previous learning
- Help design on-line help and manuals

Scope of GOMS: What it can *do, con't*

- **GOMS has been applied to both:**
  - **User-driven interaction**
  - **"Situated" or event-driven interaction**

Scope of GOMS: What it might be able to do

- **Research has made progress on**
  - **Predicting the number of some types of errors**
    - **see discussion in:** Gray, W. D. (2000). The nature and processing of errors in interactive behavior. *Cognitive Science, 24*(2), 205-248.
  - **Predicting the effects of display layout on performance time**

Scope of GOMS: What it can't *do*

- **Predict problem-solving behavior**
- **Predict how GOMS structure grows from user experience**
- **Predict behavior of casual users, individual differences...**
- **Predict the effects of fatigue, user preference, organizational impact...**

General Factors to Consider in GOMS Models

- When deciding what type of GOMS model you need, you must consider...
  - what control structure
  - what level of analysis
  - whether to approximate behavior with serial or parallel processes
  - ...different uses of GOMS models lead to different values of these factors
- These factors will be a recurring theme

GOMS Family of Analysis Methods

Keystroke-Level Model

CMN-GOMS

NGOMSL

CMN-GOMS for Highly Interactive Tasks

CPM-GOMS

Keystroke-Level Model: Intro

- **The simplest of all GOMS models: OM only!!!**
  - **No explicit goals or selection rules**
  - **Operators and Methods (in a limited sense) only**
- **"Useful where it is possible to specify the user's interaction sequence in detail" (CMN83, p. 259).**
- Control structure: **Flat**
- Serial or Parallel: **Serial**
- Level of Analysis: **Keystroke-level operators**

NGOMSL

- **Natural Language GOMS**
  - **based on structured natural language notation and a procedure for constructing them**
  - **models are in program form**
- **Control Structure: Hierarchical goal stack**
- **Serial or parallel: Serial**
- **Level of Analysis: As necessary for your design question**

NGOMSL - why?

- More powerful than KLM. Much more useful for analyzing large systems
- More built-in cognitive theory
- Provides predictions of operator sequence, execution time, and time to learn the methods

NGOMSL - Overall Approach

- Step 1: Perform goal/subgoal decomposition
- Step 2: Develop a method to accomplish each goal
  - List the actions/steps the user has to do goal (at as general and high-level as possible for the current level of analysis)
  - Identify similar methods/collapse where appropriate
- Step 3: Add flow of control (decides)
- Step 4: Add verifies
- Step 5: Add perceptuals, etc.
- Step 6: Add mentals for retrieves, forgets, recalls
- Step 7: Add times for each step
- Step 8: Calculate total time

CPM-GOMS Extension to GOMS

- C**ritical** P**ath** M**ethod (or Cognitive Perceptual Motor) -GOMS**
- Control structure: **Relaxed hierarchy, can be interrupted and continued based on new information in the world**
- Serial or Parallel: **Parallel**
- Level of Analysis: **Primarily elementary perceptual, cognitive and motor operators**

CPM-GOMS - why?

- Need for analysis suitable for parallel activities
- Human cognition is embodied cognition
  - In some cases we need to understand the interleaving and interdependencies between elementary cognitive, perceptual, and motor operations