Week 8: GOMS-KLM-COGTOOL-MHP

CS4249 Phenomena and Theories of HCI
Shengdong Zhao
Fall, 2014

Acknowledgement: some of the slides are taken from James Landay and Ivory Melanie
Announcement

• Assignment 2 released
  – You need to find a partner to work on section 2 by Oct. 15
  – The final report is due Oct. 27
Review

• The process of memory
• How we encode information?
• How we filter and store information?
• What happens when we “forget”?
• How our ability of memory is developed and ages?
How do we remember different faces?
Review

• On a high level, how do we think?
• What is Affect Heuristic?
• What is Availability Heuristic?
• What is Confirmation Bias?
• What is Halo Effect?
Outline

- GOMS and KLM
- Review quiz answers
- CogTool workshop
Remember AutoComPaste?

Video

http://www.youtube.com/watch?v=KoDT3UeAoRE
Which **Copy-Paste** Technique Is Better?

**Answer this by tomorrow!**
Not enough time for an experiment

Are there any faster alternatives?
If we can model and analyze HCI tasks, we can ...

Tasks

Model of HCI Tasks

Abstract the properties, constraints, common patterns
Introducing GOMS

employ user model (MHP) to predict performance of tasks in HCI
What is GOMS?
Card, Moran & Newell (1983)

Engineering model of user interaction
– task analysis (“how to” knowledge)
  • Goals - user’s intentions (tasks)
  • Operators - actions to complete task
  • Methods - sequences of actions (operators)
  • Selections - rules for choosing appropriate method
Engineering Model

• A model is a representation (or abstraction)
• It captures not all attributes of the represented thing, but rather only those seeming relevant
  – for a certain purpose and stakeholders
Engineering Model

Applying knowledge to

Build (invent, design, maintain, improve)

Structures (machines, devices, systems, materials, processes)
Engineer Model 4 User Interaction

Engineering
• apply knowledge to
• build
• structure

Model
• representation or abstraction
• with attributes
• for certain purpose

Engineering model for user interaction
• representation/abstraction (with attributes) of human interacting with computers
• such representation can be used to build structure of user interaction tasks
Question: What are the attributes?

Answer: Goal, Methods, Operators, Selection Rules
Quick Example

• **Goal (the big picture)**
  – go from hotel to the airport

• **Methods (or subgoals)?**
  – 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
Hierarchical Analysis

**Goals**
- Operations
- Operations
- Operations
- Operations

**Methods**
- Selection rules
- Goals
- Goals

**Operations**
- Locate bus stop
- Wait for bus
- Get on the bus
- Walk
- Bus
- Taxi
- Go to airport from hotel

Walking is cheaper, but tiring and slow.
What is GOMS in HCI?
Card, Moran & Newell (1983)

Engineering model of user interaction
– task analysis (“how to” knowledge)
  • **Goals** - user’s intentions (tasks)
    – e.g., delete a file, edit text, assist a customer
  • **Operators** - actions to complete task
    – cognitive, perceptual & motor (MHP)
    – low-level (e.g., move the mouse to menu)
  • **Methods** - sequences of actions (operators)
    – based on error-free expert
    – may be multiple methods for accomplishing same goal
      » e.g., shortcut key or menu selection
  • **Selections** - rules for choosing appropriate method
    – method predicted based on context
Usage of GOMS

• User interface design and evaluation
  – automating usability assessment

• Training and documentation

• Input: detailed description of UI/task(s)

• Output: qualitative & quantitative measures
Family of Models

- Card, Moran and Newell GOMS (CMN-GOMS)
- Critical-Path Method GOMS (CPM-GOMS)
- Keystroke-Level Model (KLM)
- Natural GOMS Language (NGOMSL)/Cognitive Complexity Theory
- Executable GOMS Language (GOMSL)/GLEAN
Family of Models

- Card, Moran and Newell GOMS (CMN-GOMS)
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In order to understand GOMS models that have arisen in the last decade and the relationships between them, an analyst must understand each of the components of the model (goals, operators, methods, and selection rules), the concept of level of detail, and the different computational forms that GOMS models take. In this section, we will each of these concepts; in subsequent sections we will categorize existing GOMS models according to these concepts.
In order to understand GOMS models that have arisen in the last decade and the relationships between them, an analyst must understand each of the components of the model (goals, operators, methods, and selection rules), the concept of level of detail, and the different computational forms that GOMS models take. In this section, we will each of these concepts; in subsequent sections we will categorize existing GOMS models according to these concepts.
GOAL: EDIT-MANUSCRIPT
  . GOAL: EDIT-UNIT-TASK ...repeat until no more unit tasks
  . . GOAL: ACQUIRE UNIT-TASK ...if task not remembered
  . . . GOAL: TURN-PAGE ...if at end of manuscript page
  . . . GOAL: GET-FROM-MANUSCRIPT
  . GOAL: EXECUTE-UNIT-TASK ...if a unit task was found
  . . . GOAL: MODIFY-TEXT
  . . . . [select: GOAL: MOVE-TEXT* ...if text is to be moved
  . . . . . GOAL: DELETE-PHRASE ...if a phrase is to be deleted
  . . . . . GOAL: INSERT-WORD] ...if a word is to be inserted
  . . . . . VERIFY-EDIT

*Expansion of MOVE-TEXT goal
GOAL: MOVE-TEXT
  . GOAL: CUT-TEXT
  . . GOAL: HIGHLIGHT-TEXT
  . . . [select**: GOAL: HIGHLIGHT-WORD
  . . . . . MOVE-CURSOR-TO-WORD
  . . . . . DOUBLE-CLICK-MOUSE-BUTTON
  . . . . . VERIFY-HIGHLIGHT
  . . . . . GOAL: HIGHLIGHT-ARBITRARY-TEXT
  . . . . . . MOVE-CURSOR-TO-BEGINNING 1.10
  . . . . . . CLICK-MOUSE-BUTTON 0.20
  . . . . . . MOVE-CURSOR-TO-END 1.10
  . . . . . . SHIFT-CLICK-MOUSE-BUTTON 0.48
  . . . . . . VERIFY-HIGHLIGHT] 1.35
  . . GOAL: ISSUE-CUT-COMMAND
  . . . MOVE-CURSOR-TO-EDIT-MENU1.10
  . . . PRESS-MOUSE-BUTTON 0.10
  . . . MOVE-MOUSE-TO-CUT-ITEM 1.10
  . . . VERIFY-HIGHLIGHT 1.35
  . . . RELEASE-MOUSE-BUTTON 0.10
  . GOAL: PASTE-TEXT
  . . GOAL: POSITION-CURSOR-AT-INSERTION-POINT
  . . . MOVE-CURSOR-TO-INSERTION-POINT 1.10
  . . . CLICK-MOUSE-BUTTON 0.20
  . . . VERIFY-POSITION 1.35
  . GOAL: ISSUE-PASTE-COMMAND
  . . MOVE-CURSOR-TO-EDIT-MENU1.10
  . . PRESS-MOUSE-BUTTON 0.10
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TOTAL TIME PREDICTED (SEC) 14.38

**Selection Rule for GOAL: HIGHLIGHT-TEXT:
If the text to be highlighted is a single word, use the HIGHLIGHT-WORD method, else use the HIGHLIGHT-ARBITRARY-TEXT method.
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    .  .  .  GOAL: HIGHLIGHT-ARBITRARY-TEXT
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    .  .  PRESS-MOUSE-BUTTON 0.10
    .  .  MOVE-MOUSE-TO-CUT-ITEM 1.10
    .  .  VERIFY-HIGHLIGHT 1.35
    .  .  RELEASE-MOUSE-BUTTON 0.10
  GOAL: PASTE-TEXT
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                  GOAL: INSERT-WORD] ...if a word is to be inserted
               8. VERIFY-EDIT
*Expansion of MOVE-TEXT goal

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        . . .  VERIFY-HIGHLIGHT
        .  .  .
        .  .  .  GOAL: HIGHLIGHT-ARBITRARY-TEXT
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        .  .  .  RELEASE-MOUSE-BUTTON 0.10

TOTAL TIME PREDICTED (SEC) 14.38
Question: Why GOMS can provide accurate time predictions for operators?
Answer: GOMS models only error free, expert behavior
Here comes another assumption of CNM-GOMS:
Human perform sub-tasks in a serial fashion
Critical Path Method GOMS
2. CPM GOMS

- Critical-Path Method GOMS (CPM-GOMS)
  - activation of several goals
    - uses schedule chart (PERT chart) to represent operators & dependencies
    - critical path method for predictions
Level of Details

In order to understand GOMS models that have arisen in the last decade and the relationships between them, an analyst must understand each of the components of the model (goals, operators, methods, and selection rules). The concept of level of detail and the different computational forms that GOMS models take. In this section, we will discuss these concepts; in subsequent sections we will categorize existing GOMS models according to these concepts.

Human says:
Move text from A to B

**Selection Rule for GOAL: HIGHLIGHT-TEXT:**
If the text to be highlighted is a single word, use the HIGHLIGHT-WORD method, else use the HIGHLIGHT-ARBITRARY-TEXT method.

**Level of Details**

<table>
<thead>
<tr>
<th>Goal: Edit-Manuscript</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOVE-TEXT* if text is to be moved</td>
</tr>
<tr>
<td>DELETE-PHASE if a phrase is to be deleted</td>
</tr>
<tr>
<td>INSERT-WORD if a word is to be inserted</td>
</tr>
</tbody>
</table>

**Expansion of MOVE-TEXT goal**

**Goal: Move-Text**

- **Goal: Cut-Text**
  - **select**: HIGHLIGHT-WORD
  - **select**: MOVE-CURSOR-TO-WORD
  - **select**: DOUBLE-CLICK-MOUSE-BUTTON
  - **select**: VERIFY-HIGHLIGHT

<table>
<thead>
<tr>
<th><em>Goal: Highlight-Text</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>MOVE-CURSOR-TO-BEGINNING</td>
</tr>
<tr>
<td>CLICK-MOUSE-BUTTON</td>
</tr>
<tr>
<td>MOVE-CURSOR-TO-END</td>
</tr>
<tr>
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<thead>
<tr>
<th>Goal: Paste-Text</th>
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<tbody>
<tr>
<td>Goal: Position-Cursor-at-Insertion-Point</td>
</tr>
<tr>
<td>CLICK-MOUSE-BUTTON</td>
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<tr>
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</tbody>
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<tr>
<th>Goal: Issue-Cut-Command</th>
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</thead>
<tbody>
<tr>
<td>MOVE-CURSOR-TO-EDIT-MAIL</td>
</tr>
<tr>
<td>PRESS-MOUSE-BUTTON</td>
</tr>
</tbody>
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**TOTAL TIME PREDICTED (SEC):** 14.38
Text-Editing Example (CPM-GOMS)

*Expansion of MOVE-TEXT goal

GOAL: MOVE-TEXT
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  .  .  .  .  .  CLICK-MOUSE-BUTTON
  .  .  .  .  .  .  MOVE-CURSOR-TO-END
  .  .  .  .  .  .  SHIFT-CLICK-MOUSE-BUTTON
  .  .  .  .  .  .  VERIFY-HIGHLIGHT]
Text-Editing Example (CPM-GOMS)

Visual Perception Operators

Cognitive Operators

Right Hand Motor Operators

Left Hand Motor Operators

Eye Movement Motor Operators

These two cognitive operators accomplish the mental preparation to set up the move-text task.

These cognitive and motor operators accomplish the goal click-mouse-button, which is an operator in the KLM, CMN-GOMS and NGOMSL models.

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GOAL: MOVE-TEXT
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        . VERIFY-HIGHLIGHT
      . MOVE-CURSOR-TO-BEGINNING 1.10
        . CLICK-MOUSE-BUTTON 0.20
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        . SHIFT-CLICK-MOUSE-BUTTON 0.48
        . VERIFY-HIGHLIGHT 1.35

KEY:

critical path

operator name

start time (msec)
duration (msec)
Text-Editing Example (CPM-GOMS)

These two cognitive operators accomplish the mental preparation to set up the move-text task.

These cognitive and motor operators accomplish the goal click-mouse-button, which is an operator in the KLM, CMN-GOMS and NGOMS models.

 Expansion of MOVE-TEXT goal
GOAL: MOVE-TEXT
  - GOAL: CUT-TEXT
    - GOAL: HIGHLIGHT-TEXT
      - [select**]: GOAL: HIGHLIGHT-WORD
        - MOVE-CURSOR-TO-WORD
        - DOUBLE-CLICK-MOUSE-BUTTON
        - VERIFY-HIGHLIGHT
          - GOAL: HIGHLIGHT-ADJUNCTARY-TEXT
            - MOVE-CURSOR-TO-BEGINNING 1.10
            - CLICK-MOUSE-BUTTON 0.20
            - MOVE-CURSOR-TO-END 1.10
            - SHIFT-CLICK-MOUSE-BUTTON 0.48
            - VERIFY-HIGHLIGHT 1.35

KEY:
- start time (msec)
- duration (msec)

operator name

Bold indicates critical path
It says …

• Goal: Highlight arbitrary text
  – Move cursor to the beginning of the text
  – Click mouse button
  – …
Text-Editing Example (CPM-GOMS)

Visual Perception Operators

Cognitive Operators

Right Hand Motor Operators

Left Hand Motor Operators

Eye Movement Motor Operators
Text-Editing Example (CPM-GOMS)

Visual Perception Operators

Cognitive Operators
...model continues

Right Hand Motor Operators

Left Hand Motor Operators

Eye Movement Motor Operators

These two cognitive operators accomplish the mental preparation to set up the move-text task.
Text-Editing Example (CPM-GOMS)
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Text-Editing Example (CPM-GOMS)

These two cognitive operators accomplish the mental preparation to set up the move-text task.

These cognitive and motor operators accomplish the goal 'click-mouse-button', which is an operator in the KLM, CMN-GOMS and NGOMSL models.

*Expansion of MOVIE-TEXT goal
GOAL: MOVE-TEXT
  . GOAL: CUT-TEXT
    . GOAL: HIGHLIGHT-TEXT
      . [select**]: GOAL: HIGHLIGHT-WORD
        . MOVE-CURSOR-TO-WORD
        . DOUBLE-CLICK-MOUSE-BUTTON
        . VERIFY-HIGHLIGHT
        . GOAL: HIGHLIGHT-AND-BUTTON-TEXT
          . MOVE-CURSOR-TO-BEGINNING 1.10
          . CLICK-MOUSE-BUTTON 0.20
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          . VERIFY-HIGHLIGHT} 1.35
Summary of CPM GOMS

• Consider multiple (potentially parallel) operators
• Critical path determines total time
• Analysis is more accurate and more tedious

For mission critical tasks that needs precise prediction, it is needed, but for many everyday tasks, this is an overkill!
Remember this?
Do we have something simpler?

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The Keystroke-Level
GOMS Model (KLM)
Most common cases

KLM
GOMS

Critical path
method

All cases,
difficult to model

CNM
GOMS
All cases
Most common cases
Critical path method
All cases, difficult to model
KLM
GOMS
CNM
GOMS
Assumptions

- Expert only
- Error free
- Only for desktop/laptop computers that use mouse and keyboard
- Only consider the most common operators
Keystroke-Level Model (KLM)

- Simplest type of GOMS
  - Based on 6 operators: K,P,B,H,R,M

  K – Keystroke
  P - Point with mouse to a target on the display
  B - Press/release mouse button
  H - Home hands to keyboard or mouse
  R - Wait for system response
  M - Mental act of thinking.
Operators and Times for the Keystroke-Level Model

**K** – Keystroke

- Pressing a key or button on the keyboard.
- Different experience levels have different times.
- .12 – 1.2 sec;
- Use .28 sec for ordinary user.
- Note: pressing SHIFT or CONTROL key is a separate keystroke.
- Use type operator $T(n)$ for a series of $n$ Ks done as a unit.
Operators and Times for the
Keystroke-Level Model

K – Keystroke
P - Point with mouse to a target on the display
B - • Follows Fitts' law - use if possible.
   • Typically ranges from .8 to 1.5 sec, average (text editing) is 1.1 sec.
H - R -
M - Mental act of thinking.
Operators and Times for the Keystroke-Level Model

K – Keystroke
P - Point with mouse to a target on the display
B - Press/release mouse button
H - • .1 sec; click is .2
R - • Highly practiced, simple reaction.
M - Mental act of thinking.
Operators and Times for the Keystroke-Level Model

K – Keystroke
P - Point with mouse to a target on the display
B - Press/release mouse button
H - Home hands to keyboard or mouse
R - .4 sec
M - Mental act of thinking.
Operators and Times for the Keystroke-Level Model

K – Keystroke
P - Point with mouse to a target on the display
B - Press/release mouse button
H - Home hands to keyboard or mouse
R - Wait for system response
M -
  • Only when user is idle because can not continue
  • Have to estimate from system behavior
  • Often essentially zero in modern systems
Operators and Times for the Keystroke-Level Model

K – Keystroke
P - Point with mouse to a target on the display
B - Press/release mouse button
H - Home hands to keyboard or mouse
R - Wait for system response
M - Mental act of thinking.

- Represents pauses for routine activity (not problem-solving).
- New users must often pause to remember or verify every step.
- Experienced users pause and think only when logically necessary.
- Estimates ranges from .6 to 1.35 sec; 1.2 sec is good single value.
The KLM Method
Card, Moran, & Newell (1983)

1. Choose one or more representative task scenarios.
2. Have design specified to the point that keystroke-level actions can be listed.
3. List the keystroke-level actions (operators) involved in doing the task.
4. Insert mental operators for when user has to stop and think.
5. Look up the standard execution time to each operator.
6. Add up the execution times for the operators.
7. The total is the estimated time to complete the task.
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5. Look up the standard execution time to each operator.
6. Add up the execution times for the operators.
7. The total is the estimated time to complete the task.
Video link: https://www.youtube.com/watch?v=yJLaqYzk55E
Heuristic Rules for adding M’s

• **Basic idea:**
  – M before every chunk in the method that must be recalled from long-term memory or that involves a decision
• Before each task or subtask
• Deciding which way to do a task
• Retrieving a chunk from memory
  – Command name
  – File name
  – Parameter value
• Finding something on screen
  – So P is often preceded by M
  – Unless the location is well-known from practice, in which case the visual search is overlapped with the motor action
• Verifying entry or action result
  – e.g. before pressing OK on a dialog

http://courses.csail.mit.edu/6.831/archive/2008/lectures/L18-predictive-evaluation/L18-predictive-evaluation.html
In-class Exercise: Deleting a Word

Double click selection  Del key N times

K – Keystroke
P - Point with mouse to a target on the display
B - Press/release mouse button
H - Home hands to keyboard or mouse
R - Wait for system response
M - Mental act of thinking.

http://courses.csail.mit.edu/6.831/archive/2008/lectures/L18-predictive-evaluation/L18-predictive-evaluation.html
Answer: Deleting a Word

Double-click selection
• M
• P [middle of word]
• B + B [double click]
• H [to keyboard]
• M
• K [del]

Total: 2M + P + 2B + H + K = ?

Del key N times
• M
• P [end of word]
• B [click]
• H
• M
• K [Del] x n [length of word]

Total: 2M + P + H + nK + B = ?

http://courses.csail.mit.edu/6.831/archive/2008/lectures/L18-predictive-evaluation/L18-predictive-evaluation.html
Fig. 6. Predicted vs. observed execution times in the experiment.
Limitations of KLM

- Only expert users doing routine (well-learned) tasks
- Only measures efficiency
  - Not learnability, memorability, errors, etc.
- Ignores
  - errors (methods must be error-free)
  - parallel action (shift-click)
  - mental workload (e.g. attention & WM limits)
  - planning & problem solving (how does user select the method?)
  - fatigue
Remember CPM-GOMS?

These two cognitive operators accomplish the mental preparation to set up the move-text task.

These cognitive and motor operators accomplish the goal click-mouse-button, which is an operator in the KLM, CMN-GOMS and NGOMSL models.

*Expansion of MOVE-TEXT goal

GOAL: MOVE-TEXT
  . GOAL: CUT-TEXT
    . GOAL: HIGHLIGHT-TEXT
      . [select**: GOAL: HIGHLIGHT-WORD
        . MOVE-CURSOR-TO-WORD
        . DOUBLE-CLICK-MOUSE-BUTTON
        . VERIFY-HIGHLIGHT
        . GOAL: HIGHLIGHT-AND-DELETE-TEXT
          . MOVE-CURSOR-TO-BEGINNING 1.10
          . CLICK-MOUSE-BUTTON 0.20
          . MOVE-CURSOR-TO-END 1.10
          . SHIFT-CLICK-MOUSE-BUTTON 0.48
          . VERIFY-HIGHLIGHT 1.35

KEY:

- start time (msec)
- duration (msec)

Bold indicates critical path
CPM-GOMS vs. KLM

- CPM-GOMS models parallel operations
  - e.g. point & shift-click
- Uses parallel cognitive model
  - each processor is serial
  - different processors run in parallel
Text-Editing Example (CPM-GOMS)
CPM-GOMS vs. KLM (real story)

- Phone company considering redesign of a workstation (keyboard + software) for telephone operators (411 service)
  - Reduced keystrokes needed for common tasks
  - Put frequently-used keys closer to user’s fingers
- But new design was 4% slower than old design
  = 1 sec/call = $3 million/year
- Keystroke-level model has no explanation
- But CPM-GOMS explained why:
  - Keystrokes removed were not on the critical path
    - Used during slack time, while greeting customer
  - A keystroke was moved from the beginning of call (during slack time) to later (putting it on the critical path)
However, KLM is simple and useful. No reasons not to use it if you can!
CogTool Workshop