KLEM: A Method for Predicting User Interaction Time and System Energy Consumption during Application Design

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ISWC’07 – October 12, 2007
Motivation and goals

- Energy consumption from user interaction
  - Wide variety of user interaction methods
  - Highly interactive tasks
  - Unavailability of application at design time
  - High cost to conduct user study

- Keystroke-Level Energy Model (KLEM)
  - Keystroke-Level Model (KLM) extended
  - Predicts expert user task time
  - Predicts system energy consumption of task
KLM in brief

- Created by Card, Moron, and Newell in 1980
- Describe a task by placing operators in a sequence
  - K – keystroke (Physical operators)
  - P – point with mouse
  - H – homing (move hand from mouse to keyboard)
  - D (takes parameters) – drawing
  - R (takes parameters) – system response time
  - M – mental preparation (Mental operator)
- Five heuristic rules to insert candidate Ms into the sequence
- Task execution time = \( \Sigma \) all operators involved
- KLM for pen-based handheld user interfaces [LuoJohn05]
KLEM: an overview

- **Given**: a task, the methods to execute the task, the design, and a target platform
- **Predict**: user time and task energy
Modeling process

- Using CogTool [http://www.cs.cmu.edu/~bej/cogtool/]
  - Support touch-screen and voice-based interfaces
  - Create KLM by demonstrating task on storyboards

- Sample model trace:

```
...  
0.400  MOTOR    INITIATION-COMPLETE  
0.400  PROCEDURAL  CONFLICT-RESOLUTION  
0.683  MOTOR    MOVE-CURSOR-ABSOLUTE #(278.0 177.0)  
0.683  Storyboard transitioning to frame "List1"  
0.683  PROCEDURAL  CONFLICT-RESOLUTION  
0.733  MOTOR    FINISH-MOVEMENT  
0.733  PROCEDURAL  CONFLICT-RESOLUTION  
0.768  VISION    Encoding-complete LOC1-0 NIL  
0.768  PROCEDURAL  PRODUCTION-SELECTED WAIT-FOR-SYSTEM-5  
0.768  PROCEDURAL  BUFFER-READ-ACTION GOAL  

...  
0.768  PROCEDURAL  BUFFER-READ-ACTION GOAL  
0.768  PROCEDURAL  QUERY-BUFFER-ACTION MANUAL  
0.818  VISION    CHANGE-STATE LAST NONE PREP FREE  
1.324  COGTOOL  Restoring display at end of system wait (0.556)  
...  
```
Energy characterizing process

- Measurement based approach
- Power state correspondence of KLM operators
  - “Busy” (K, D, R): MOTOR, WAIT-FOR-SYSTEM...
  - “Idle” (M): VISION, PROCEDUAL...
- Operator time decided by KLM and benchmarks
## Interaction benchmarks

<table>
<thead>
<tr>
<th>Widget</th>
<th>Operation</th>
<th>System Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button</td>
<td>Tap</td>
<td>Small, Medium, Large</td>
</tr>
<tr>
<td>Checkbox</td>
<td>Tap</td>
<td>Small</td>
</tr>
<tr>
<td>List box</td>
<td>Tap</td>
<td>Small</td>
</tr>
<tr>
<td>Dropdown list</td>
<td>Tap+ Tap</td>
<td>Small</td>
</tr>
<tr>
<td>Radio button</td>
<td>Tap</td>
<td>Small</td>
</tr>
<tr>
<td>Menu</td>
<td>Tap</td>
<td>Small, Medium, Large</td>
</tr>
<tr>
<td>Hardware button</td>
<td>Tap</td>
<td>Small, Medium, Large</td>
</tr>
<tr>
<td>Tab</td>
<td>Tap</td>
<td>Medium, Large</td>
</tr>
<tr>
<td>Scrollbar</td>
<td>Tap/Drag</td>
<td>Small, Medium, Large</td>
</tr>
<tr>
<td>Slider</td>
<td>Tap/Drag</td>
<td>Small</td>
</tr>
<tr>
<td>Soft keyboard</td>
<td>Tap</td>
<td>Small</td>
</tr>
<tr>
<td>Handwriting</td>
<td>Stroke</td>
<td>Medium, Large</td>
</tr>
</tbody>
</table>

*Selection, Navigation, Text Input*
Task: information query

- Platforms:
  - Windows Mobile (iPaq)
  - Palm OS (Tungsten)

- Method 1: map navigation interface

- Method 2, 3, 4: scroll list interface
Model verification: user time

- **User study:**
  - 10 participants
  - Two platforms
  - 12 tasks in total

- **Measurement:**
  - Total task execution time

- **Prediction error:**
  - 5.6% for iPaq
  - 8.8% for Tungsten
Model verification: task energy

- **Measurement:**
  - System energy consumption during task
- **Prediction error:**
  - 4.4% for iPaq
  - 8.4% for Tungsten
Conclusion & Future work

- Contributions of this paper:
  - A methodology based on well-established HCI theory and practices is introduced to make design-time prediction on interactive task energy consumption.
  - The energy efficiency of different user interaction methods on the same task is compared and analyzed. We show when using different interaction modalities, the energy consumption can vary by a factor of three in achieving the same user goal.

- Future work:
  - Extend KLEM to other interaction modalities.
  - Comprehensive user interaction and power benchmarks.