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

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Motivation and goals

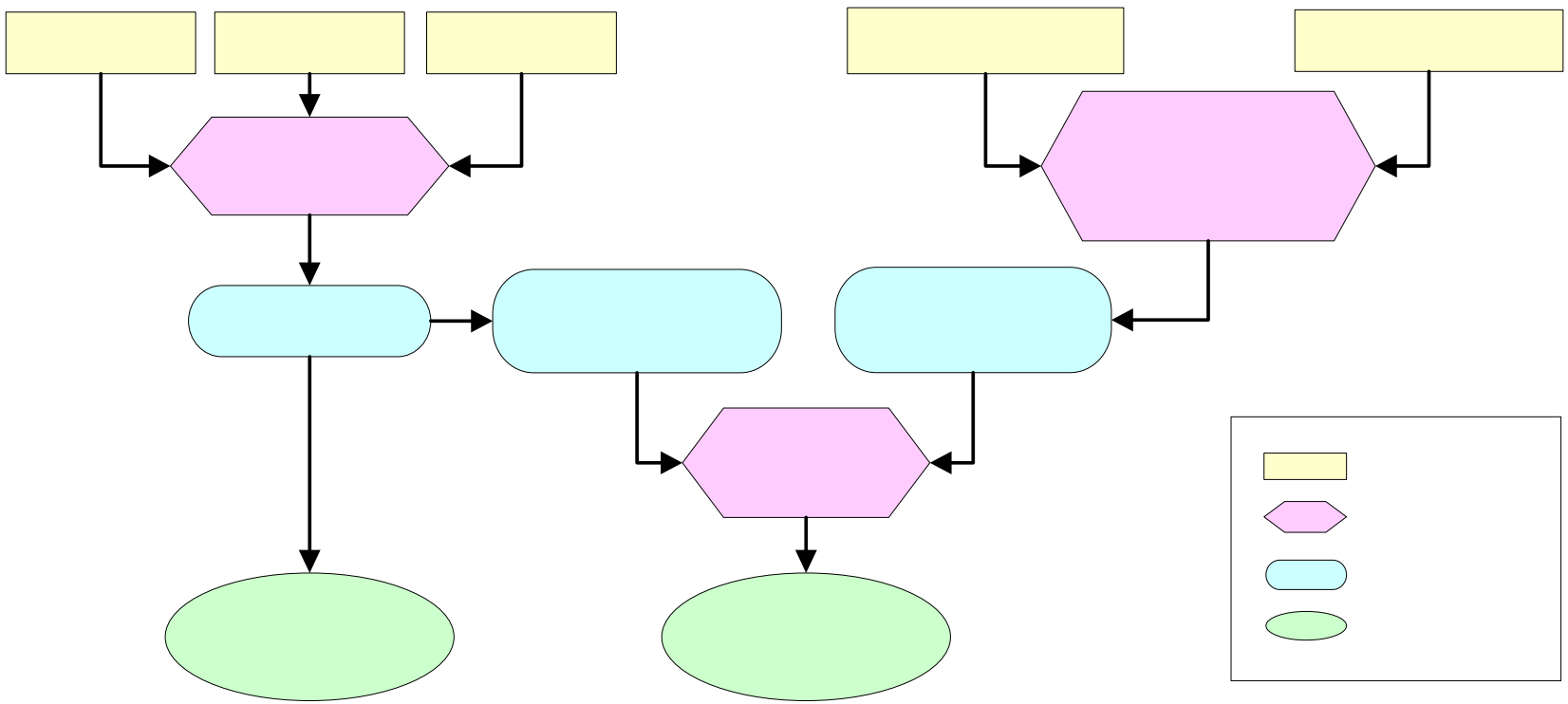
- Energy consumption from user interaction
  - Wide variety of user interaction methods
  - Highly interactive tasks
  - Unavailability of application at design time
  - High cost to conduct user study
- Keystroke-Level Energy Model (KLEM)
  - Keystroke-Level Model (KLM) extended
  - Predicts expert 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 = Σ 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



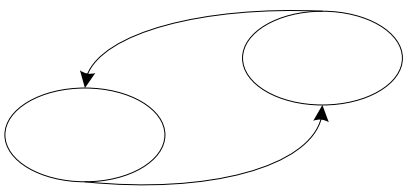
Modeling process

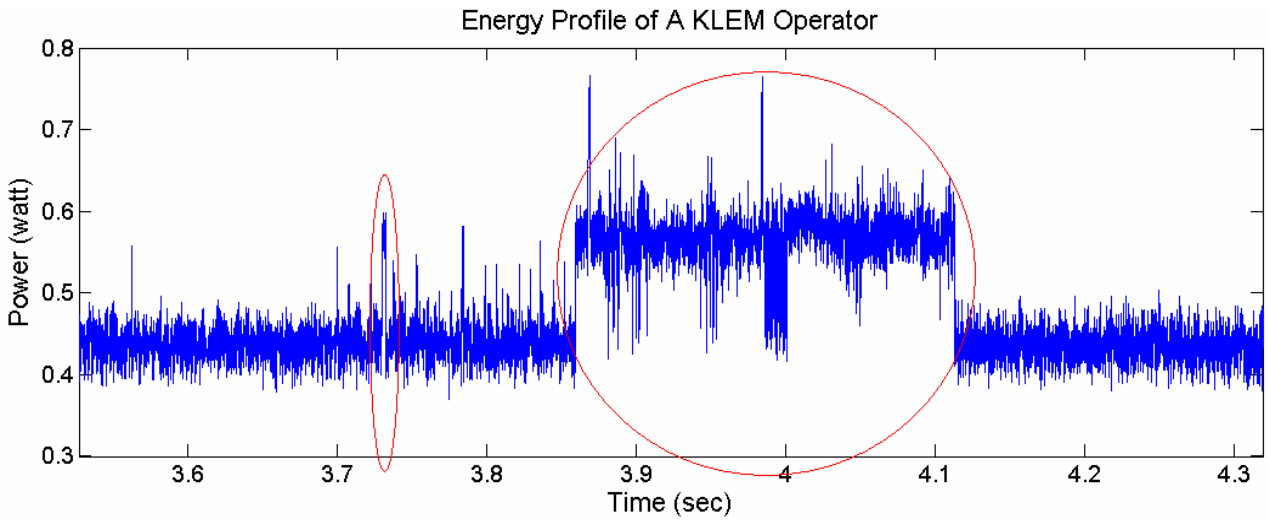
- Using CogTool http://www.cs.cmu.edu/~bej/cogtool/
  - Support touch-screen and voice-based interfaces
  - Create KLM by demonstrating task on storyboards
- Sample model trace:

```
...
    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



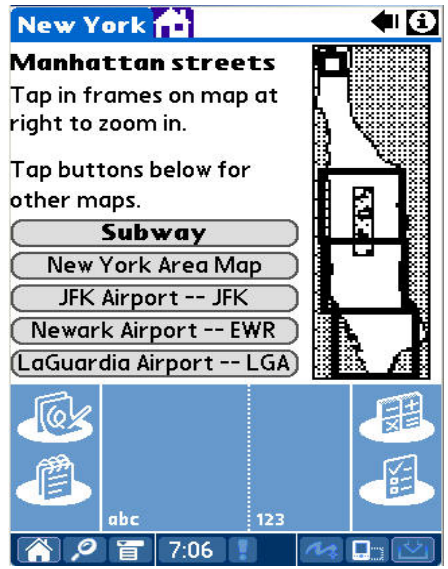


Interaction benchmarks

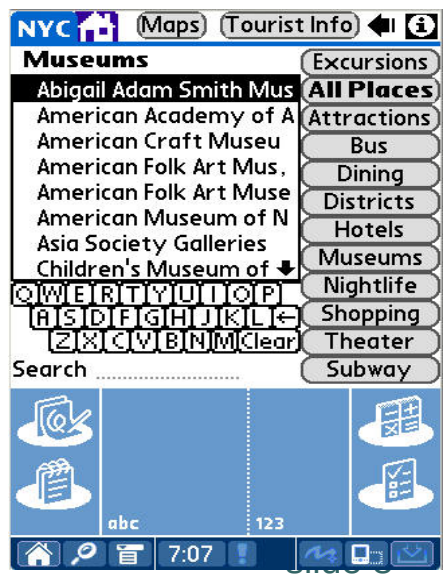
Widget	Operation	System Activity	
Button	Tap	Small, Medium, Large	*Selection*
Checkbox	Tap	Small	
List box	Tap	Small	
Dropdown list	Tap+ Tap	Small	
Radio button	Tap	Small	
Menu	Tap	Small, Medium, Large	
Hardware button	Tap	Small, Medium, Large	
Tab	Tap	Medium, Large	*Navigation*
Scrollbar	Tap/Drag	Small, Medium, Large	
Slider	Tap/Drag	Small	
Soft keyboard	Tap	Small	*Text Input*
Handwriting	Stroke	Medium, Large	

Task: information query

- Platforms:
  - Windows Mobile (iPaq)
  - Palm OS (Tungsten)
- Method 1: map navigation interface

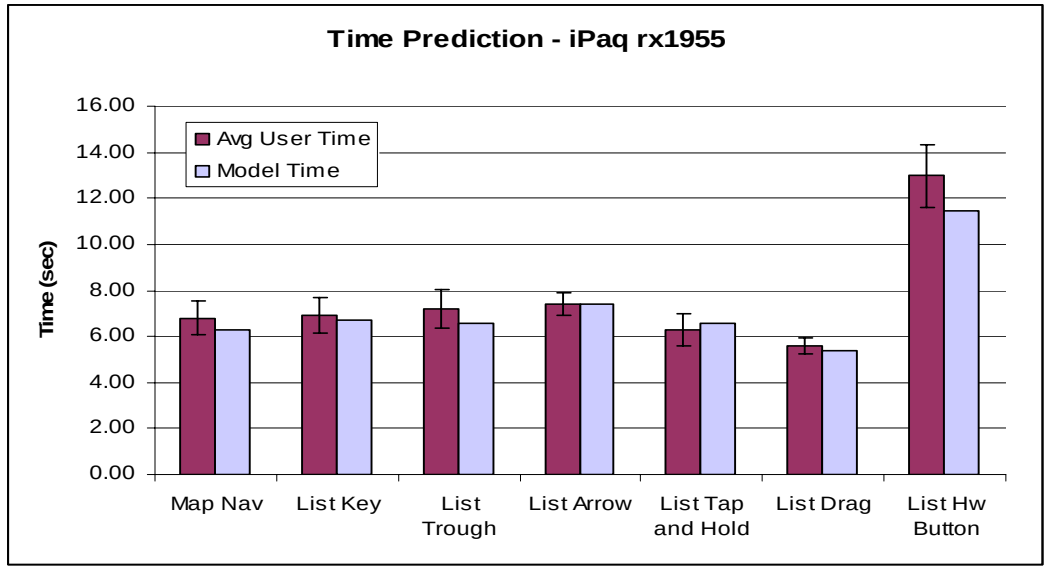


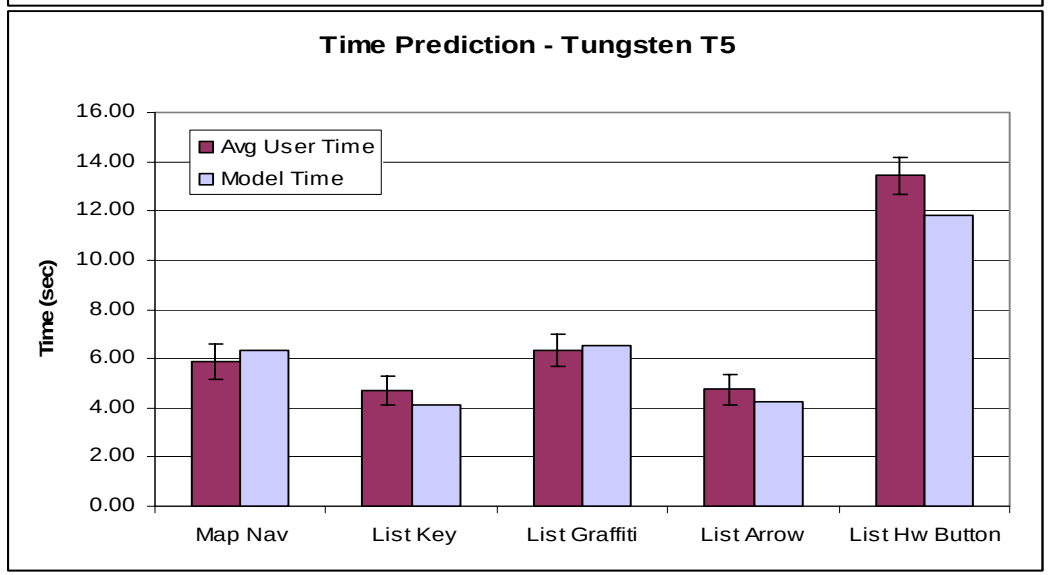
- Method 2,3,4: scroll list interface



Model verification: user time

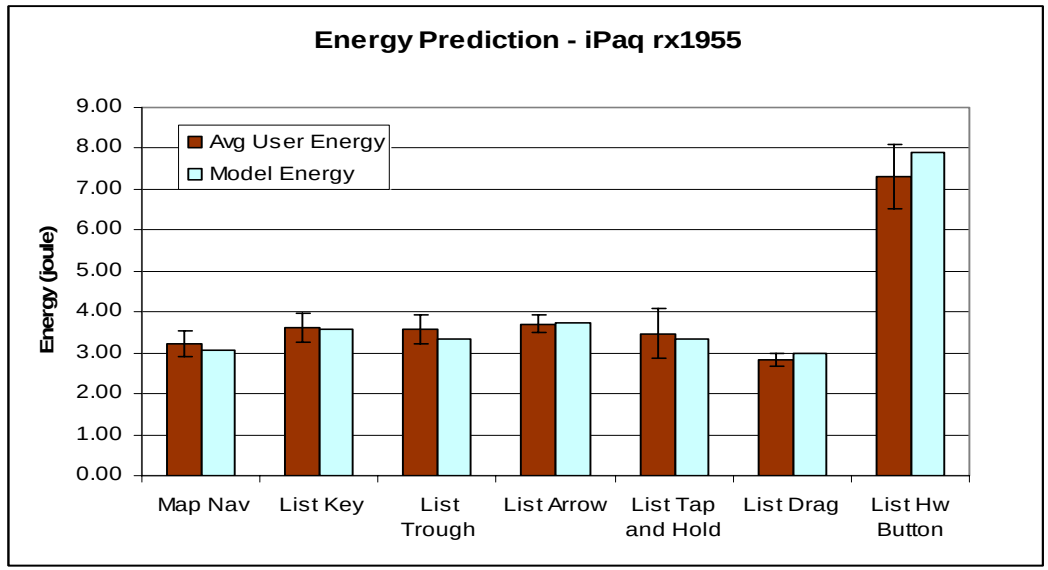
- User study:
  - 10 participants
  - Two platforms
  - 12 tasks in total
- Measurement:
  - Total task execution time
- Prediction error:
  - 5.6% for iPaq
  - 8.8% for Tungsten

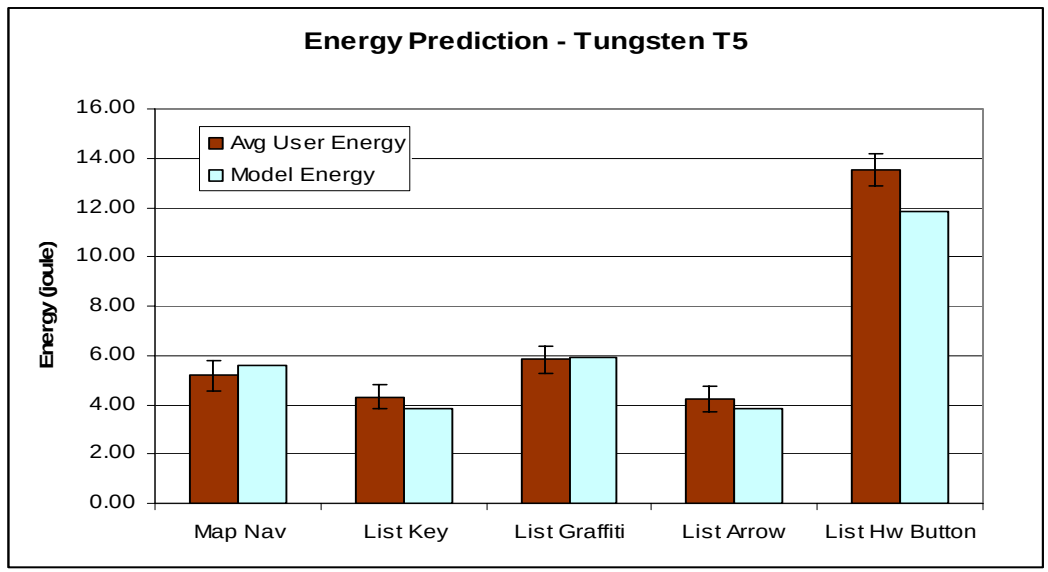




Model verification: task energy

- 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