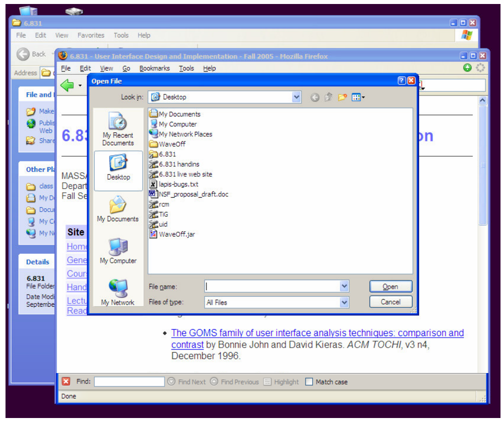
Lecture 18:
Predictive Evaluation

UI Hall of Fame or Shame?



Suggested by Vikki Chou

Today's candidate for the Hall of Fame or Shame is the **modal dialog box**.

A modal dialog box (like the File Open dialog seen here) prevents the user from interacting with the application that popped it up.

Modal dialogs do have some usability advantages, such as **error prevention** (the modal dialog is always on top, so it can't get lost or be ignored, and the user can't accidentally change the selection in the main window while working on a modal dialog that affects that selection) and **dialog closure** (you're required to proceed through the dialog rather than switching to something else).

But there are usability disadvantages too, chief among them **loss of user control** and reduced **visibility** (e.g., you can't see important information or previews in the main window). Worst of all, failures in **task analysis** might bite you hard -- forcing the user to remember information from one modal dialog to another, rather than viewing and interacting with both dialogs side-by-side.

When you try to interact with the main window, Windows gives some nice animated **feedback** – flashing the border of the modal dialog box. This helps explain why your clicks on the main window had no effect.

On most platforms, you can at least move, resize, and minimize the main window, even when a modal dialog is showing. (The modal dialog minimizes along with it). Alas, not on Windows… the main window is completely pinned! You can minimize it only by obscure means, like the Show Desktop command, which minimizes *all* windows. This is a big problem with user control and freedom.

Modeless dialogs, by contrast, don't prevent using other windows in the application. They're often used for ongoing interactions with the main window, like Find/Replace. One problem is that a modeless dialog box can get in the way of viewing or interacting with the main window (as when a Find/Replace dialog covers up the match). Another problem is a **consistency** problem: modal dialogs and modeless dialogs usually look identical. Sometimes the presence of a Minimize button is a clue that it's modeless, but that's not a very strong visual distinction. A modeless dialog may be better represented as a **sidebar**, a temporary pane in the main window that's anchored to one side of the window. Then it can't obscure the user's work, can't get lost, and is clearly visually different from a modal dialog box.

UI Hall of Fame or Shame?

On Windows, modal dialogs are generally *application-modal* – all windows in the application stop responding until the dialog is dismissed. (The old days of GUIs also had *system-modal* dialogs, which suspended *all* applications.) Mac OS X has a neat improvement, *window-modal* dialogs, which are displayed as translucent sheets attached to the titlebar of the blocked window. This tightly associates the dialog with its window, gives a little visibility of what's underneath it in the main window – and allows you to interact with other windows, even if they're from the same application.

Another advantage of Mac sheets is that they make a strong contrast with modeless dialogs – the translucent, anchored modal sheet is easy to distinguish from a modeless window.

Today's Topics

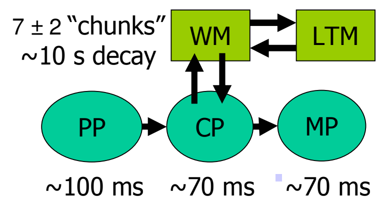
- Keystroke-level models
- GOMS
- CPM-GOMS

Fall 2004 6.831 UI Design and Implementation 4

Today's lecture is about **predictive evaluation** – the holy grail of usability engineering. If we had an accurate model for the way a human used a computer interface, we would be able to **predict** the usability of a design, without having to actually build it, test it against real people, and measure their behavior. User interface design would then become more like other fields of engineering. Civil engineers can use models (of material stress and strain) to predict the load that can be carried by a bridge; they don't have to build it and test it to destruction first. As user interface designers, we'd like to do the same thing.

Predictive Evaluation

- Predictive evaluation uses an engineering model of human cognition to predict usability
- Model is
  - abstract
  - quantitative
  - approximate
  - estimated from user experiments



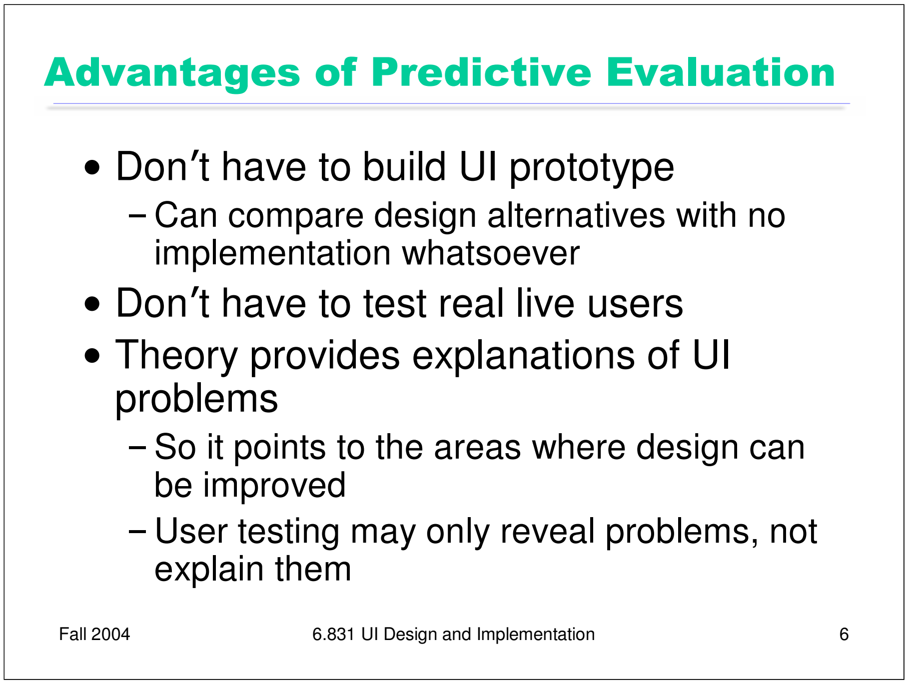
At its heart, any predictive evaluation technique requires a **model** for how a user interacts with an interface. We've already seen one such model, the Newell/Card/Moran human information processing model.

This model needs to be **abstract** – it can't be as detailed as an actual human being (with billions of neurons, muscles, and sensory cells), because it wouldn't be practical to use for prediction. The model we looked at boiled down the rich aspects of information processing into just three processors and two memories.

It also has to be **quantitative**, i.e., assigning numerical parameters to each component. Without parameters, we won't be able to compute a prediction. We might still be able to do *qualitative* comparisons, such as we've already done to compare, say, Mac menu bars with Windows menu bars, or cascading submenus. But our goals for predictive evaluation

These numerical parameters are necessarily **approximate**; first because the abstraction in the model aggregates over a rich variety of different conditions and tasks; and second because human beings exhibit large individual differences, sometimes up to a factor of 10 between the worst and the best. So the parameters we use will be averages, and we may want to take the variance of the parameters into account when we do calculations with the model.

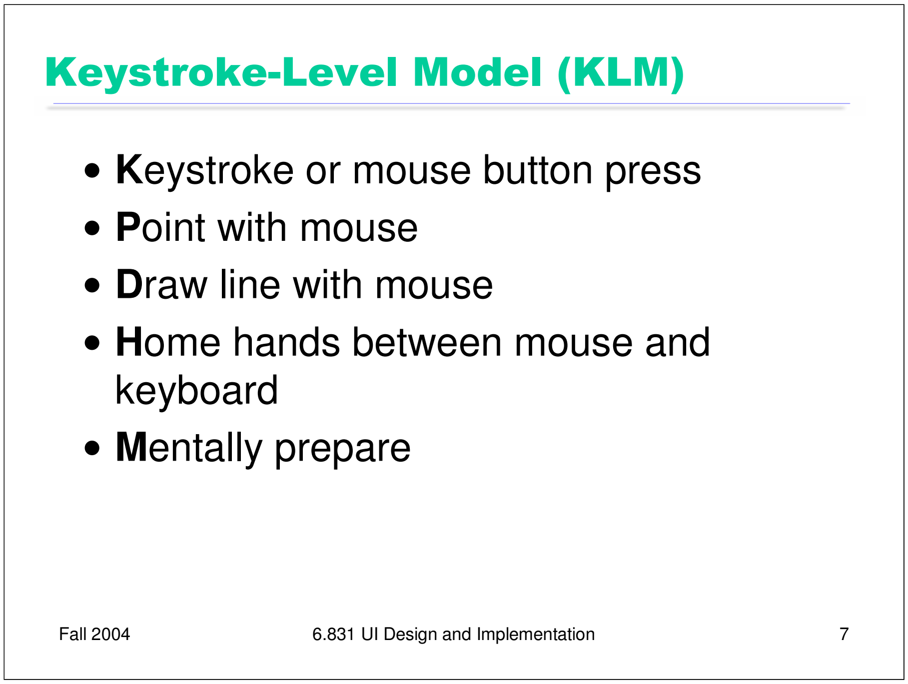
Where do the parameters come from? They're estimated from experiments with real users. The numbers seen here for the general model of human information processing (e.g., cycle times of processors and capacities of memories) were inferred from a long literature of cognitive psychology experiments. But for more specific models, parameters may actually be estimated by setting up new experiments designed to measure just that parameter of the model.



We've already seen two other evaluation approachs: inspection techniques (like heuristic evaluation and cognitive walkthroughs) and user testing (formative evaluation, field studies, controlled experiments). Predictive evaluation is a third major approach.

Recall that one advantage of inspection is that it doesn't require real users. Predictive evaluation doesn't need real users either (once the parameters of the model have been estimated, that is). Not only that, but predictive evaluation doesn't even need a **prototype**. Designs can be compared and evaluated without even producing design sketches or paper prototypes, let alone code.

Another key advantage is that the predictive evaluation not only identifies usability problems, but actually provides an **explanation** of them based on the theoretical model underlying the evaluation. So it's much better at pointing to *solutions* to the problems than either inspection techniques or user testing. User testing might show that design A is 25% slower than design B at a doing a particular task, but it won't explain *why*. Predictive evaluation breaks down the user's behavior into little pieces, so that you can actually point at the part of the task that was slower, and see why it was slower.



The first predictive model was the **keystroke level model** (proposed by Card & Moran, "The Keystroke Level Model for User Performance Time with Interactive Systems", *CACM,* v23 n7, July 1978).

This model seeks to predict efficiency (time taken by expert users doing routine tasks) by breaking down the user's behavior into a sequence of the five primitive operators shown here.

The first four operators are physical – the user is actually moving their muscles to perform them. The M operator is different – it's purely mental (which is somewhat problematic, because it's hard to observe and estimate). The M operator stands in for any mental operations that the user does. M operators separate the task into chunks, or steps, and represent the time needed for the user to recall the next step from long-term memory.

KLM Analysis

- Encode a method as a sequence of physical operators (KPHD)
- Use heuristic rules to insert mental operators (M)
- Add up times for each operator to get total time for method

Fall 2004 6.831 UI Design and Implementation 8

Here's how to create a keystroke level model for a task.

First, you have to focus on a particular **method** for doing the task. Suppose the task is deleting a word in a text editor. Most text editors offer a variety of methods for doing this, e.g.: (1) click and drag to select the word, then press the Del key; (2) click at the start and shift-click at the end to select the word, then press the Del key; (3) click at the start, then press the Del key N times; (4) double-click the word, then select the Edit/Delete menu command; etc.

Next, encode the method as a sequence of the physical operators: K for keystrokes or mouse button presses, P for pointing tasks, H for moving the hand between mouse and keyboard, and D for drawing tasks.

Next, insert the mental preparation operators at the appropriate places, before each chunk in the task. Some heuristic rules have been proposed for finding these chunk boundaries.

Finally, using estimated times for each operator, add up all the times to get the total time to run the whole method.

Estimated Operator Times

- **K**eystroke determined by typing speed

0.28 s	average typist (40 wpm)
0.08 s	best typist (155 wpm)
1.20 s	worst typist

- **P**ointing determined by Fitts's Law

$T = a + b \log(d/s + 1) = a + b\ ID$

0.8 + 0.1 ID	[Card 1978]
0.1 + 0.4 ID	[Epps 1986]
-0.1 + 0.2 ID	[MacKenzie 1990, mouse selection]
0.14 + 0.25 ID	[MacKenzie 1990, mouse dragging]

OR

T ~ 1.1 s for all pointing tasks

- **D**rawing determined by steering law

Fall 2004 6.831 UI Design and Implementation 9

The operator times can be estimated in various ways.

Keystroke time can be approximated by typing speed. Note the approximation costs us in two ways. First, the model abstracts away the difference between keystrokes and mouse buttons – K is used for both, even though there are far fewer mouse buttons to choose from (reducing the user's reaction time) and they're right under the user's fingers (eliminating lateral movement time), so mouse buttons should be faster to press. Second, if we use only an average estimate for K, we're ignoring the 10x individual differences in typing speed.

Pointing time can be modelled by Fitts's Law, but now we'll actually need numerical parameters for it. Empirically, you get a better fit to measurements if the index of difficulty is log(D/S+1); but even then, differences in pointing devices and methods of measurement have produced wide variations in the paremeters (some of them seen here). There's even a measurable difference between a relaxed hand (no mouse buttons pressed) and a tense hand (dragging). Also, using Fitts's Law depends on keeping detailed track of the location of the mouse pointer in the model, and the positions of targets on the screen. An abstract model like the keystroke level model dispenses with these details and just assumes that Tp ~ 1.1s for all pointing tasks. If your design alternatives require more detailed modeling, however, you would want to use Fitts's Law more carefully.

Drawing time, likewise, can be modeled by the steering law: T = a + b (D/S).

Estimated Operator Times

- **H**oming estimated by measurement

  0.36 s (between keyboard and mouse)
- **M**ental preparation estimated by measurement

  1.35 s

Homing time is estimated by a simple experiment in which the user moves their hand back and forth from the keyboard to the mouse.

Finally we have the **Mental** operator. The M operator does not represent planning, problem solving, or deep thinking. None of that is modeled by the keystroke level model. M merely represents the time to prepare mentally for the next **step** in the method – primarily to retrieve that step (the thing you'll have to do) from long-term memory. A step is a chunk of the method, so the M operators divide the method into chunks.

The time for each M operator was estimated by modeling a variety of methods, measuring actual user time on those methods, and subtracting the time used for the physical operators – the result was the total mental time. This mental time was then divided by the number of chunks in the method. The resulting estimate (from the 1978 Card & Moran paper) was 1.35 sec – unfortunately large, larger than any single physical operator, so the number of M operators inserted in the model may have a significant effect on its overall time. (The standard deviation of M among individuals is estimated at 1.1 sec, so individual differences are sizeable too.)

Heuristic Rules for adding M's

- Basic idea: M before every chunk in the method that must be recalled from long-term memory
- Insert M's before each K & P
  - K => MK
  - P => MP (if P points at a command, not an argument)
- Delete M's in typed chunks
  - MK MK ... MK => M KK .. K if K's form a command name, single text string, or number
- Delete anticipated M's
  - x M y => x y if x fully anticipates y
  - e.g., point-and-click is a chunk, so PMK => PK

One of the trickiest parts of keystroke-level modeling is figuring out where to insert the M's, because it's not always clear where the chunk boundaries are in the method. Here are some heuristics rules.

Example: Deleting a Word

- Shift-click selection
  M
  P [start of word]
  K [click]
  M
  P [end of word]
  K [shift]
  K [click]
  H [to keyboard]
  M
  K [Del]
- Total: 3M + 2P + 4K
  = 7.37 sec

- Del key N times
  M
  P [start of word]
  K [click]
  H
  M
  K [Del]
  x n [length of word]
- Total: 2M + P + H + (n+1)K
  = 4.44 + 0.28n sec

Fall 2004 6.831 UI Design and Implementation 12

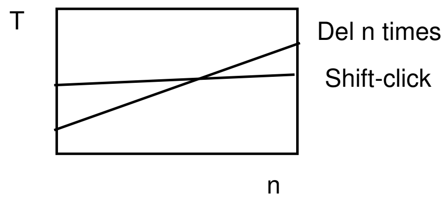
Here are keystroke-level models for two methods that delete a word.

The first method clicks at the start of the word, shift-clicks at the end of the word to highlight it, and then presses the Del key on the keyboard. Notice the H operator for moving the hand from the mouse to the keyboard. That operator may not be necessary if the user uses the hand already on the keyboard (which pressed Shift) to reach over and press Del.

The second method clicks at the start of the word, then presses Del enough times to delete all the characters in the word.

Applications of KLM

- Comparing designs & methods
- Parametric analysis



Keystroke level models can be useful for comparing efficiency of different user interface designs, or of different methods using the same design.

One kind of comparison enabled by the model is **parametric analysis** – e.g., as we vary the parameter *n* (the length of the word to be deleted), how do the times for each method vary?

Using the approximations in our keystroke level model, the shift-click method is roughly constant, while the Del-n-times method is linear in *n*. So there will be some point *n* below which the Del key is the faster method, and above which Shift-click is the faster method. Predictive evaluation not only tells us that this point exists, but also gives us an estimate for *n*.

But here the limitations of our approximate models become evident. The shift-click method isn't really constant with *n* – as the word grows, the distance you have to move the mouse to click at the end of the word grows likewise. Our keystroke-level approximation hasn't accounted for that, since it assumes that all P operators take constant time. On the other hand, Fitts's Law says that the pointing time would grow at most logarithmically with *n*, while pressing Del *n* times clearly grows linearly. So the approximation may be fine in this case.

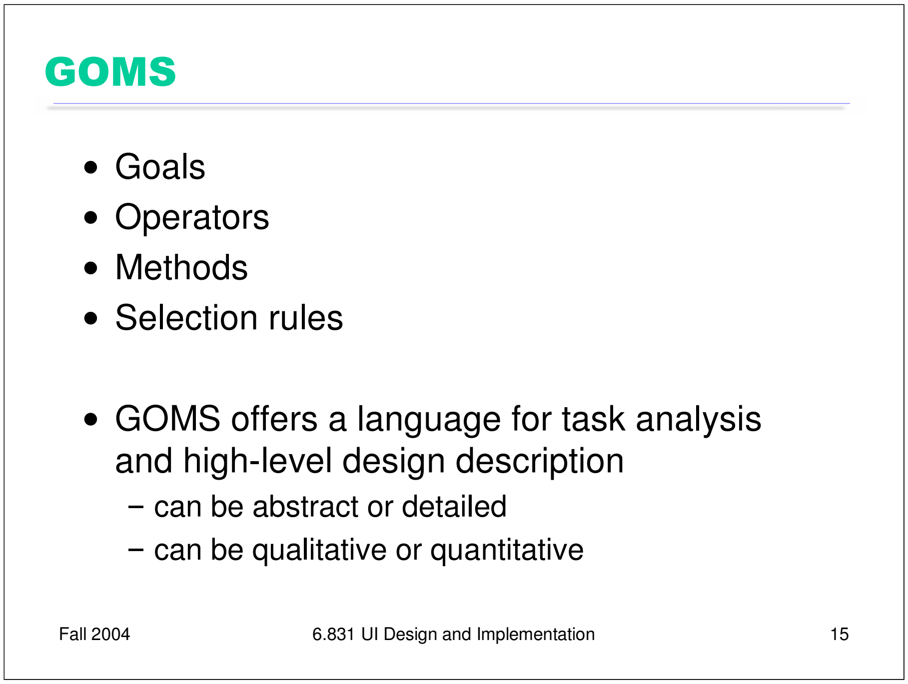
Limitations of KLM

- 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

Keystroke level models have some limitations -- we've already discussed the focus on expert users and efficiency. But KLM also assumes no errors made in the execution of the method, which isn't true even for experts. Methods may differ not just in time to execute but also in propensity of errors, and KLM doesn't account for that.

KLM also assumes that all actions are serialized, even actions that involve different hands (like moving the mouse and pressing down the Shift key). Real experts don't behave that way; they overlap operations.

KLM also doesn't have a fine-grained model of mental operations. Planning, problem solving, different levels of working memory load can all affect time and error rate; KLM lumps them into the M operator.



GOMS is a richer model that considers the planning and problem solving steps. Starting with the low-level **O**perators and **M**ethods provided by KLM, GOMS adds on a hierarchy of high-level **G**oals and subgoals (like we looked at for task analysis) and **S**election rules that determine how the user decides which method will be used to satisfy a goal.

Example

- Goal: delete text (n chars long)
  - Select: method 1 if n > 10
    method 2 if n < 10
  - Method 1: Goal: highlight text & delete
    - Goal: highlight text
      - Point
      - Click
      - Point
      - Shift
      - Click
  - Method 2: Goal: delete n chars
    ...

Here's an outline of a GOMS model for the text-deletion example we've been using. Notice the selection rule that chooses between two methods for achieving the goal, based on an observation of how many characters need to be deleted.

NGOMSL

- "Natural GOMS language"
  - formal language with restricted English syntax
- Addresses gaps in KLM modeling
  - learning time measured by the # of NGOMSL statements
  - working memory use modeled by Retain and Recall statements
  - no errors or problem solving

Fall 2004 6.831 UI Design and Implementation 17

GOMS has several variants. One of them, called NGOMSL, uses a formal language to restrict how you model goals, subgoals, and selection rules. The benefit of the formal language is that each statement roughly corresponds to a primitive mental chunk, so you can estimate the **learning time** of a task by simply counting the number of statements in the model for the task. The language also has statements that represent working memory operations (Retain and Recall), so that excessive use of WM can be estimated by executing the model.

NGOMSL

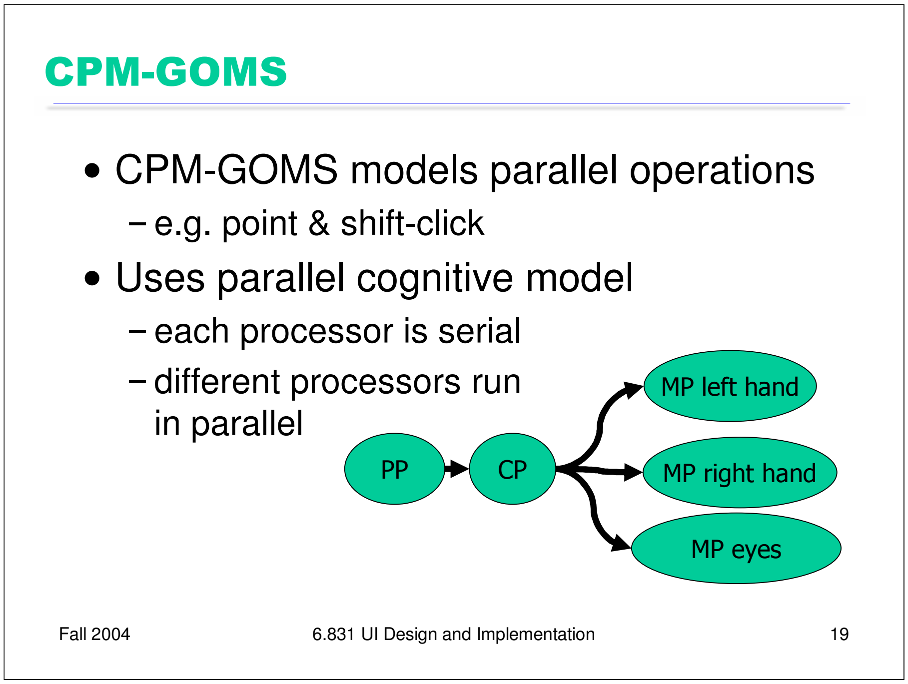
```
Method for goal: Move text
  Step 1.  Accomplish goal: Cut text.
  Step 2.  Accomplish goal: Paste text.
  Step 3.  Return with goal accomplished.

Method for goal: Cut text
  Step 1.  Accomplish goal: Highlight text.
  Step 2.  Retain that the command is CUT, and
             accomplish goal: Issue a command.
  Step 3.  Return with goal accomplished.

Method for goal: Paste text
  Step 1.  Accomplish goal: Position cursor at insertion point.
  Step 2.  Retain that the command is PASTE,
             and accomplish goal: Issue a command.
  Step 3.  Return with goal accomplished.
```

Fall 2004 6.831 UI Design and Implementation 18

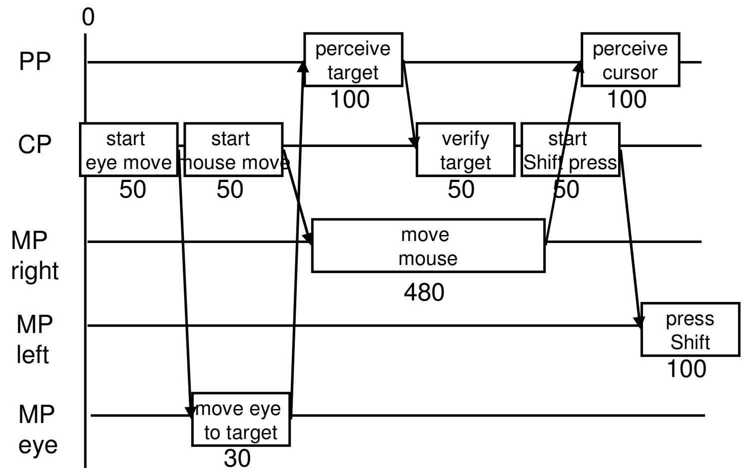
Here’s a snippet of an NGOMSL model for text editing (from John & Kieras, “The GOMS Family of User Interface Analysis Techniques: Comparison and Contrast”, *ACM TOCHI*, v3 n4, Dec 1996).



CPM-GOMS (Cognitive-Motor-Perceptual) is another variant of GOMS, which is even more detailed than the keystroke-level model. It tackles the serial assumption of KLM, allowing multiple operators to run at the same time. The parallelism is dictated by a model very similar to the Card/Newell/Moran information processing model we saw earlier. We have a perceptual processor (PP), a cognitive processor (CP), and multiple motor processors (MP), one for each major muscle system that can act independently. For GUI interfaces, the muscles we mainly care about are the two hands and the eyes.

The model makes the simple assumption that each processor runs tasks serially (one at a time), but different processors run in parallel.

Critical Path Determines Time



Fall 2004 6.831 UI Design and Implementation 20

We build a CPM-GOMS model as a graph of tasks. Here's the start of a Point-Shift-click operation.

First, the cognitive processor (which initiates everything) decides to move your eyes to the pointing target, so that you'll be able to tell when the mouse pointer reaches it.

Next, the eyes actually move (MP eye), but in parallel with that, the cognitive processor is deciding to move the mouse. The right hand's motor processor handles this, in time determined by Fitts's Law.

While the hand is moving, the perceptual processor and cognitive processor are perceiving and deciding that the eyes have found the target.

Then the cognitive processor decides to press the Shift key, and passes this instruction on to the left hand's motor processor.

In CPM-GOMS, what matters is the **critical path** through this graph of overlapping tasks – the path that takes the longest time, since it will determine the total time for the method.

Notice how much more detailed this model is! This would be just P K in the KLM model. With greater accuracy comes a lot more work.

Another issue with CPM-GOMS is that it models *extreme* expert performance, where the user is working at or near the limits of human information processing speed, parallelizing as much as possible, and yet making no errors.

Analysis of Phone Operator Workstation

- 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)

Fall 2004 6.831 UI Design and Implementation 21

CPM-GOMS had a real-world success story. NYNEX (a phone company) was considering replacing the workstations of its telephone operators. The redesigned workstation they were thinking about buying had different software and a different keyboard layout. It reduced the number of keystrokes needed to handle a typical call, and the keyboard was carefully designed to reduce travel time between keys for frequent key sequences. It even had four times the bandwidth of the old workstation (1200 bps instead of 300). A back-of-the-envelope calculation, essentially using the KLM model, suggested that it should be 20% faster to handle a call using the redesigned workstation. Considering NYNEX's high call volume, this translated into real money – every second saved on a 30-second operator call would reduce NYNEX's labor costs by $3 million/year.

But when NYNEX did a field trial of the new workstation (an expensive procedure which required retraining some operators, deploying the workstation, and using the new workstation to field calls), they found it was actually **4% slower** than the old one.

A CPM-GOMS model explained why. Every operator call started with some "slack time", when the operator greeted the caller (e.g. "Thank you for calling NYNEX, how can I help you?") Expert operators were using this slack time to set up for the call, pressing keys and hovering over others. So even though the new design removed keystrokes from the call, the removed keystrokes occurred during the slack time – not on the critical path of the call, *after* the greeting. And the 4% slowdown was due to moving a keystroke out of the slack time and putting it later in the call, *adding* to the critical path. On the basis of this analysis, NYNEX decided not to buy the new workstation. (Gray, John, & Atwood, "Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance", *Human-Computer Interaction*, v8 n3, 1993.)

This example shows how predictive evaluation can *explain* usability problems, rather than merely *identifying* them (as the field study did).