# *COMS W4170*
# *UI Theory 3*

Steven Feiner
Department of Computer Science
Columbia University
New York, NY  10027

September 13, 2018



## *CPM-GOMS*

W. Gray, B. John, and M. Atwood, Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance, *Human-Computer Interaction,* 8(3), 1993

- Back-of-envelope calculations predicted 20% increase in performance
  - Each second saved per average call = $3M/year
- But
  - CPM-GOMS analysis showed .63 seconds *slower* (weighted for call types and frequency)
  - Field trial showed .65 seconds *slower*
  - Predicted loss = $2M/year

# *CPM-GOMS*

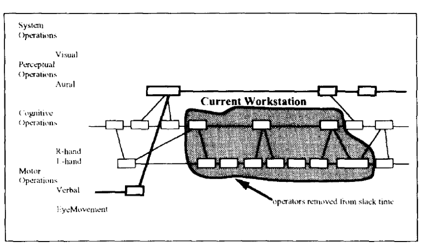
W. Gray, B. John, and M. Atwood, Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance, *Human-Computer Interaction,* 8(3), 1993

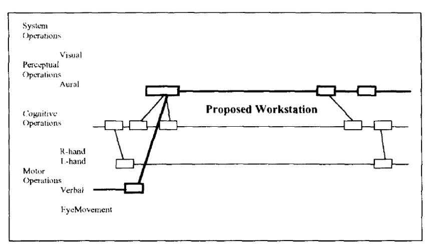
- Reasons for performance decrease
  - Eliminated keystrokes not on CP (Critical Path)—ones that didn't affect overall timing, and
  - When reducing keystrokes, some were moved from off CP to on CP, introducing delay



# *CPM-GOMS*

W. Gray, B. John, and M. Atwood, Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance, *Human-Computer Interaction,* 8(3), 1993

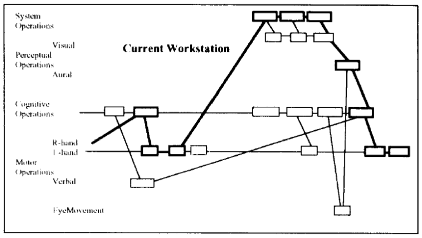


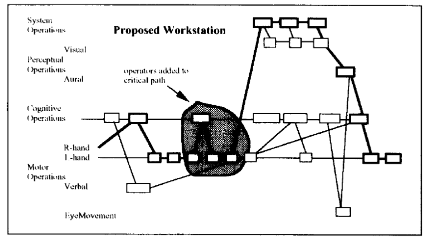




- Section of CPM-GOMS analysis near beginning of call
  - Proposed workstation (right) removes 2 keystrokes (7 motor & 3 cognitive ops), but none are on CP (in bold).

# CPM-GOMS

W. Gray, B. John, and M. Atwood, Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance, *Human-Computer Interaction,* 8(3), 1993




- Section of CPM-GOMS analysis at end of call
  - Proposed workstation (right) adds 1 keystroke (3 motor & 1 cognitive op) **directly on CP** (in bold)
- Net result is that subtracting two keystrokes and adding one keystroke makes the task take longer!



# CPM-GOMS

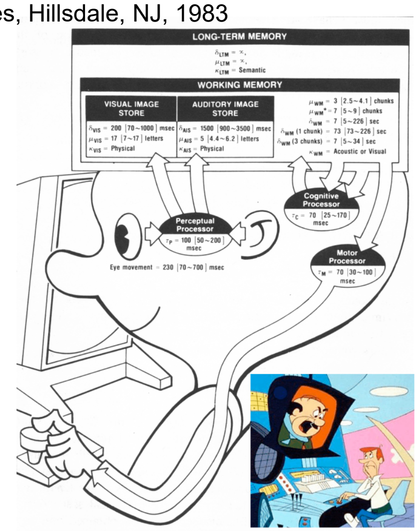
W. Gray, B. John, and M. Atwood, Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance, *Human-Computer Interaction,* 8(3), 1993

- Reasons for performance decrease
  - Decreased parallelism in use of hands
    - Old: LH pressed a key, moving while RH still keying, so was ready when RH done
    - New: That key was moved closer to other keys, so RH would press it in sequence, on CP
  - Added wait to see crucial info
    - Old: Displayed first line faster (info in CP)
    - New: Whole screen displayed faster, but first line was delayed by > .5 seconds

# Model Human Processor

S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

- Model (inspired by computers) of how humans perceive, process, and act on information
- Processors
  - Perceptual processor
  - Cognitive processor
  - Motor processor
- Memory
  - Visual image store
  - Auditory image store
  - Working memory
  - Long-term memory



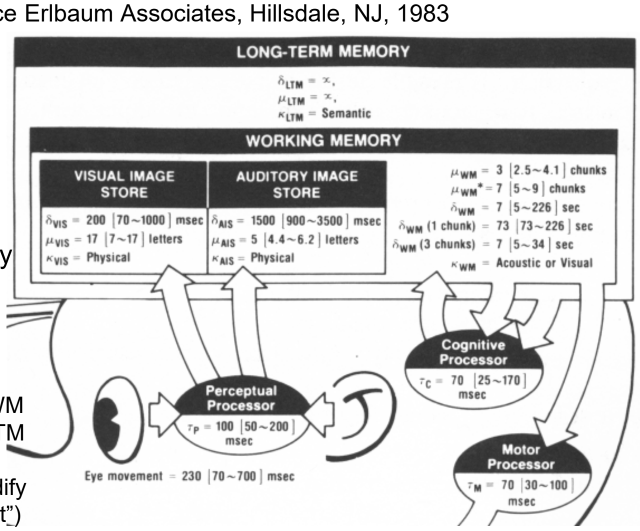



# Model Human Processor

S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

- Processor
  - τ Cycle time
- Memory
  - δ Decay
  - μ Capacity
  - κ Coding

Cognitive Processor has *Recognize–Act* cycle: Contents of WM retrieve actions in LTM (“recognize”), which are executed to modify contents of WM (“act”)



# *Model Human Processor*

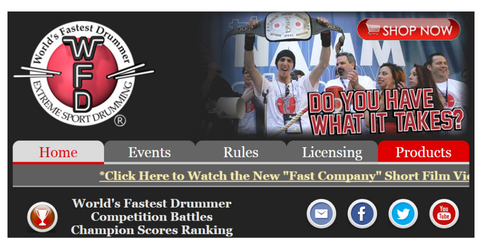
S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

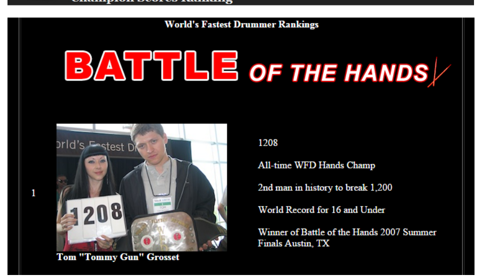
- Values derived from studies of people
- $\tau_P$ Perceptual processor cycle time
  - < 100 msecs visual stimulus for *n* msecs is perceived same as double intensity stimulus for *n*/2 msecs 100 [50~200] msecs
- $\tau_C$ Cognitive processor cycle time
  - Time to count mentally 70 [25~170] msecs
- $\tau_M$ Motor processor cycle time
  - Tapping 70 [30~100] msecs

9

# *Motor Processor Cycle Time: Anecdotal Evidence*

- 1208 / 60 = 20.13 bps (two hands)
- 20.13 / 2 = 10.07 bps (one hand)
- Implies $\tau_M \leq 99.3$ msec
  - Includes fatigue ☺



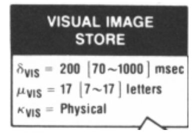


http://worldsfastestdrummer.com
https://en.wikipedia.org/wiki/World%27s_Fastest_Drummer

10

# *Model Human Processor*

S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983




- $\delta_{VIS}$ Visual store decay
  - Show letters for 50 msecs

    A X Q R P
    L B C M J

  - Blank screen for specified time *n*
  - Show pointer @ random letter location for 50 msecs

    O

  - Can user identify letter @ pointer location?
  - Can do 50% of the time for *n* ≤ 200 msecs



# *Model Human Processor*

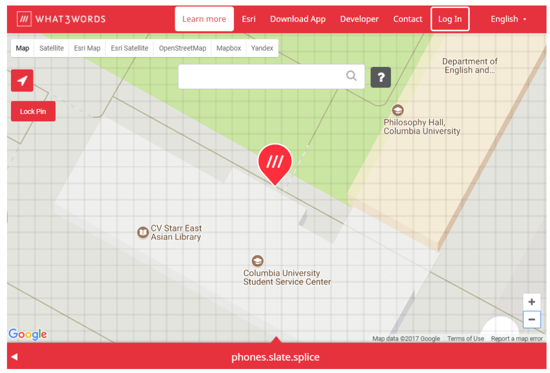
S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

- $\delta_{WM}$ 7 [5~226] secs (no rehearsal)
  - Present items, keep user from rehearsing
- $\mu_{WM}$ Working memory capacity (no rehearsal)
  - Present set of letters briefly, then ask users to report ones they see. Always limited, even though they say they see all. ~ 3 chunks

# *Model Human Processor*

S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

- Taking advantage of $\mu_{WM}$
  - What3Words (https://what3words.com) Divide world into 3m×3m squares and assign each a three-word address
  - Eases communication of locations (emergencies, package delivery, directions,…)




phones.slate.splice



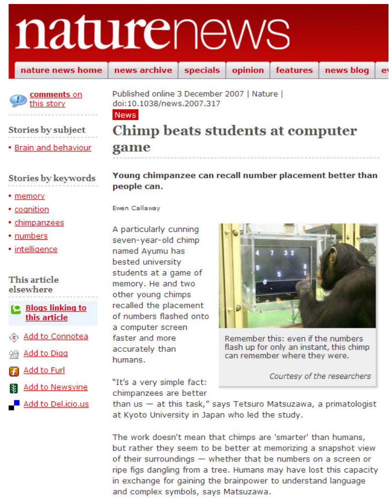
# *Model Human Processor*

S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction,* Lawrence Erlbaum Associates, Hillsdale, NJ, 1983

- $\mu_{WM^*}$ 7±2 chunks (with rehearsal)
  - George Miller, 1956
- $\mu_{VIS}$ Visual store capacity
  - Present *q* rows of *n* letters each, followed by a pointer to one row. Then ask what was in the row. If subject gives *m* of *n* letters, $\mu_{vis} = (m/n) \times q$   17 [7~17] letters

# Memory Capacity and Decay

- Human Processor v. Chimpanzee Processor


naturenews

nature news home | news archive | specials | opinion | features | news blog

comments on this story

Stories by subject
- Brain and behaviour

Stories by keywords
- memory
- cognition
- chimpanzees
- numbers
- intelligence

This article elsewhere
- Blogs linking to this article
- Add to Connotea
- Add to Digg
- Add to Furl
- Add to Newsvine
- Add to Del.icio.us

Published online 3 December 2007 | Nature | doi:10.1038/news.2007.317

News

**Chimp beats students at computer game**

**Young chimpanzee can recall number placement better than people can.**

Ewen Callaway

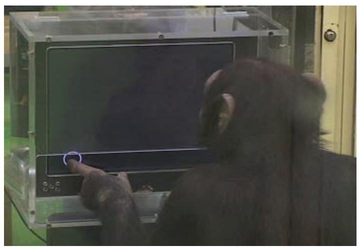
A particularly cunning seven-year-old chimp named Ayumu has bested university students at a game of memory. He and two other young chimps recalled the placement of numbers flashed onto a computer screen faster and more accurately than humans.

Remember this: even if the numbers flash up for only an instant, this chimp can remember where they were.

*Courtesy of the researchers*

"It's a very simple fact: chimpanzees are better than us — at this task," says Tetsuro Matsuzawa, a primatologist at Kyoto University in Japan who led the study.

The work doesn't mean that chimps are 'smarter' than humans, but rather they seem to be better at memorizing a snapshot view of their surroundings — whether that be numbers on a screen or ripe figs dangling from a tree. Humans may have lost this capacity in exchange for gaining the brainpower to understand language and complex symbols, says Matsuzawa.



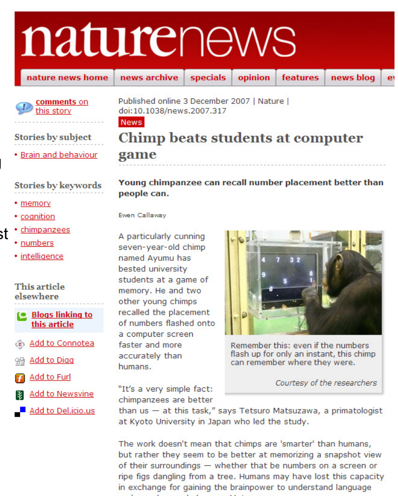
http://www.nature.com/news/2007/071203/full/news.2007.317.html



# Memory Capacity and Decay

- Human Processor v. Chimpanzee Processor
  - Try it yourself!
    https://web.archive.org/web/20140209070358/http://games.lumosity.com/chimp.html (*Trained chimp hard version!*)

    https://www.cambridgebrainsciences.com/science/tests/monkey-ladder (*Untrained human easy version!*)


naturenews

nature news home | news archive | specials | opinion | features | news blog

Published online 3 December 2007 | Nature | doi:10.1038/news.2007.317

**Chimp beats students at computer game**

**Young chimpanzee can recall number placement better than people can.**

Ewen Callaway

A particularly cunning seven-year-old chimp named Ayumu has bested university students at a game of memory. He and two other young chimps recalled the placement of numbers flashed onto a computer screen faster and more accurately than humans.

Remember this: even if the numbers flash up for only an instant, this chimp can remember where they were.

*Courtesy of the researchers*

"It's a very simple fact: chimpanzees are better than us — at this task," says Tetsuro Matsuzawa, a primatologist at Kyoto University in Japan who led the study.

The work doesn't mean that chimps are 'smarter' than humans, but rather they seem to be better at memorizing a snapshot view of their surroundings — whether that be numbers on a screen or ripe figs dangling from a tree. Humans may have lost this capacity in exchange for gaining the brainpower to understand language and complex symbols, says Matsuzawa.

# *Seven Stages of Action*

*D. Norman, 1988*

"The basic idea is simple. To get something done, you have to start with some notion of what is wanted—the goal that is to be achieved. Then, you have to do something to the world, that is, take action to move yourself or manipulate someone or something. Finally, you check to see that your goal was made. So there are four different things to consider: the goal, what is done to the world, the world itself, and the check of the world. The action itself has two major aspects: doing something and checking. Call these *execution* and *evaluation.*"

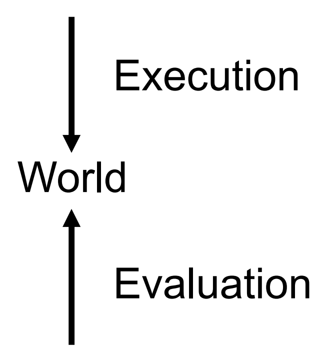
— D. Norman,
*The Psychology of Everyday Things*, 1988



# *Seven Stages of Action*

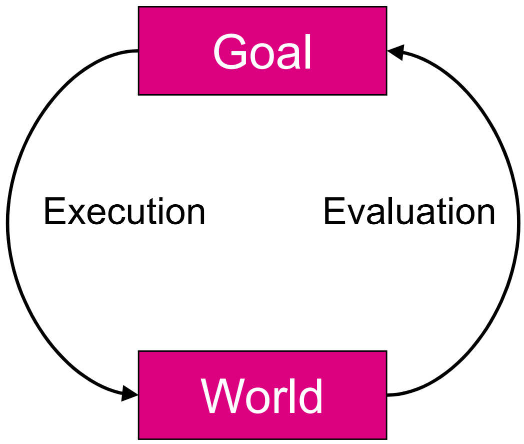
*D. Norman, 1988*

1. Form goal
2. Form intention
3. Specify action
4. Execute action
5. Perceive world state
6. Interpret world state
7. Evaluate outcome



## *Seven Stages of Action*

*D. Norman, 1988*




- Gulf of execution
  - Mismatch between what you want to do and what you can do
- Gulf of evaluation
  - Mismatch between what world state tells you and what you want to know

19

## *Seven Stages of Action*

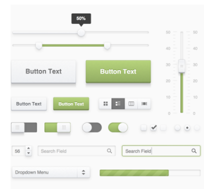
*Norman 1988*

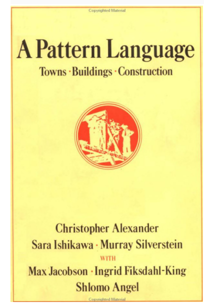
- Principles of good design
  - Visible state and action alternatives
  - Good, consistent conceptual model
  - Good mappings between stages
  - Continuous feedback
- Points of failure
  - Inadequate goal
  - Cannot find correct user interface components
  - Cannot execute desired action
  - Cannot understand feedback

20

# *Widget-Level Models*

- Apply KLM approach not just to low-level actions (key presses and mouse motion), but to interactions with high-level "widgets"
- Evaluate individual widgets, then make predictions about UIs composed of those widgets
- Develop standard *design patterns*
  - Inspired by C. Alexander, S. Ishikawa, and M. Silverstein. *A Pattern Language: Towns, Buildings, Construction.* NY: Oxford University Press, 1977

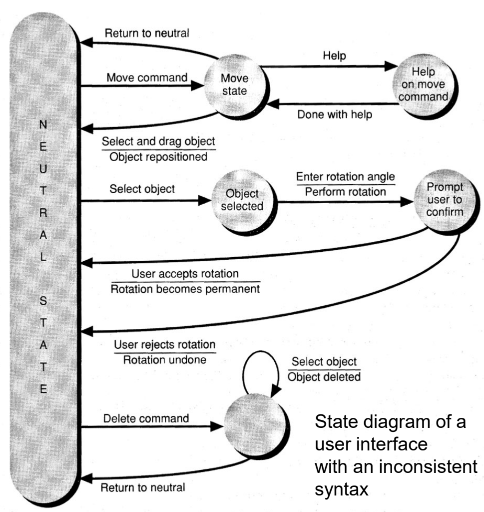







# *Transition Networks*

- Show UI states and actions that cause transitions between states
- Can be used to analyze consistency / simplicity




State diagram of a user interface with an inconsistent syntax

Foley et al. 90

# Grammars

- Express structure of a UI
- Can be used to analyze consistency/simplicity



# Evaluating UIs through Formal Grammars
## P. Reisner, 81

- Evaluated “action language” of two drawing system UIs: ROBART 1 and ROBART 2
  - ROBART 2 was designed to be easier (and tests showed it was)
- Described each language as a formal grammar (modified BNF)
- Showed ROBART 2 had simpler grammar. For example,
  - ROBART 1 had two different ways to select type of object to create (text different—just type at keyboard) and differing numbers of actions for other objects
  - ROBART 2 had only one way to select type of object to create
- Used the grammars to predict how users would perform
  - Robart 2 would be easier to learn/remember
  - A user would take varying amounts of time to learn/remember how to select objects in Robart 1, but not in Robart 2
  - A user would try to treat text the same way as other objects after first learning how to select other object types to create
- Predictions confirmed by analysis of time to learn with documentation, observations of use without documentation, error rate, and questionnaires

## *Evaluating UIs through Formal Grammars*

*P. Reisner, 81*

- Prior “conventional wisdom”: In order of decreasing priority:
  - Minimize # lowest level action primitives
  - Minimize length of action sequences
  - Minimize # rules
- Reisner showed *this order should be reversed* to ease learning for naïve users doing nonroutine tasks



## *Task Action Grammars (TAGs)*

*S. Payne & T. Greene, 86*

- Context-Free Grammar maps tasks to user actions
- TAG consists of
  - Dictionary: List of simple tasks
  - Rule schemata: Grammar for language syntax
- Can be used to analyze
  - Consistency/simplicity
  - Completeness

# *Task Action Grammars (TAGs)*

*S. Payne & T. Greene, 86*

- Dictionary of simple tasks
  - Move cursor one char fwd {dir=fwd, unit=char}
  - Move cursor one char back {dir=back, unit=char}
  - Move cursor one word fwd {dir=fwd, unit=word}
  - Move cursor one word back {dir=back, unit=word}
- Features and values
  - dir={fwd, back}
  - unit={char, word}
- Rule schemata
  - task [dir, unit] → modifier [dir] + letter [unit]
  - modifier [dir=fwd] → <ctrl>
  - modifier [dir=back} → <alt>
  - letter [unit=char] → “c”
  - letter [unit=word] → “w”
- Commands
  - Move cursor one char fwd <ctrl> c Move cursor one char back <alt> c
  - Move cursor one word fwd <ctrl> w Move cursor one word back <alt> w

- Is user interface
  - Consistent?
  - Simple?
  - Complete?