Review

- What are the main components of the CMN Model?
  - What are the key numbers from the CMN Model?
- What is Fitts' Law?
- Why evaluate?
- Lab vs. field studies?
- Participatory Design?
- Techniques to evaluate without users?
  - Literature review
  - Cognitive walkthrough
  - Heuristic evaluation
  - Model-based evaluation

Theory

✓ Models of interaction
- ✓ Affordances, mappings, constraints, types of knowledge, errors

✓ Design principles

⇒ Human cognition and performance

- History and vision of HCI

Practice

✓ Sketching

✓ User observation

✓ Iterative design

✓ Prototyping

✓ Ideation

⇒ User study and evaluation

Evaluation Techniques

Evaluating Without Users

E1 Literature Review
E2 Cognitive Walkthrough
E3 Heuristic Evaluation
E4 Model-based Evaluation (GOMS,...)

Evaluating With Users

Qualitative

E5 Model Extraction
E6 Silent Observation
E7 Think Aloud
E8 Constructive Interaction
E9 Retrospective Testing

Quantitative

E10 Controlled Experiments

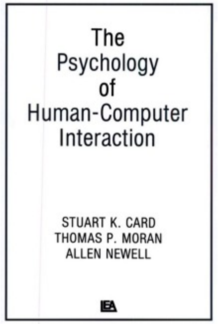
\+ Interviews, questionnaires,...

A Story

- In 1995, now-famous web guru Jakob Nielsen had less than 24 hours to recommend if adding three new buttons to Sun's home page was a good idea.

  Check out his "Alertbox" online column for good (and often fun) web design advice
- He found that each new, but unused button costs visitors .5 million $ per year.
- 2 of the 3 new buttons were taken back out.
- The method he used for his estimate: GOMS.

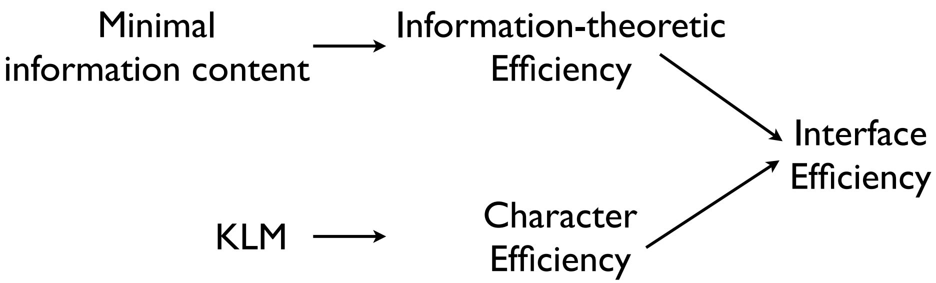
GOMS



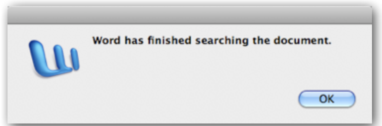
- Goals, Operators, Methods, Selection rules
- Card, Moran, Newell: The Psychology of HCI, 1983
- To estimate execution and learning times before a system is built

E4: Model-based Evaluation

- Some models exist that offer a framework for design and evaluation
- Examples:
  - ⇒ Information efficiency
  - ⇒ GOMS KLM, GOMS
  - Design Rationale (History of design decisions with reasons and alternatives)
  - Design Patterns



Measuring Interface Efficiency



- How fast can you expect an interface to be?
- Information as quantification of amount of data conveyed by a communication (Information theory)
  - E.g., speech, messages sent upon click…
- Lower bound on amount of information required for task is independent of interface design
- Information-theoretic efficiency $E = \frac{\text{Minimal info required for the task}}{\text{Info supplied by user}}$
  - $E \in [0, 1]$ (e.g., $E = 0$ for providing unnecessary information)
- Character efficiency $= \frac{\text{Minimal number of characters required for the task}}{\text{Number of characters entered in the UI}}$

Information Content (Detailed)

- Information is measured in bits
  - 1 bit represents choice between 2 alternatives
- n equally likely alternatives
  - Total information amount: $\log_2(n)$
  - Information per alternative: $(1/n)\log_2(n)$
- n alternatives with different probabilities $p(i)$
  - Information per alternative: $p(i)\log_2(1/p(i))$
  - Total amount = sum over all alternatives
- Consider situation as a whole
  - Probability of messages required
  - Information measures freedom of choice (information ≠ meaning)

Example: NRW Area Code

- Four digits
  - First digit: 0
  - Second digit: 2 (70%), 5 (30%)
  - Third, Fourth digits: [0, 9] with equal probability
- E.g., 0241 for Aachen, 0525 for Paderborn
- What is the minimal information content of NRW landline area code?
  - Information per alternative: $p(i)\log_2(1/p(i))$

Example: NRW Area Code

- Four digits
  - First digit: 0
  - Second digit: 2 (70%), 5 (30%)
  - Third, Fourth digits: [0, 9] with equal probability

	Probability	Values	$p(i)$	$p(i)\log2(1/p(i))$ (bits/alternative)	Total bits	
02XX	0.7	100	$\frac{0.7}{100} = 0.007$	$0.007 \times \log_2(1/0.007) = 0.05$	$100 \times 0.05 = 5$	$5 + 2 = 7$
05XX	0.3	100	$\frac{0.3}{100} = 0.003$	$0.003 \times \log_2(1/0.003) = 0.02$	$100 \times 0.02 = 2$	

Example: NRW Area Code

- Minimal information required: 7 bits
- What is the information content of the shown numeric keyboard for 4 digits?

1	2	3
4	5	6
7	8	9
	0	

Alternatives:	[0,9]	[0,9]	[0,9]	[0,9]
Counts:	10	10	10	10

Information content = $4\log_2(10) = 13.29$ bits

- What is the information-theoretic efficiency when you use this keyboard for NRW area code?
  - $E = \frac{\text{Minimal info required for the task}}{\text{Info supplied by user}} = \frac{7}{13.29} = 52.67\%$

Example: NRW Area Code

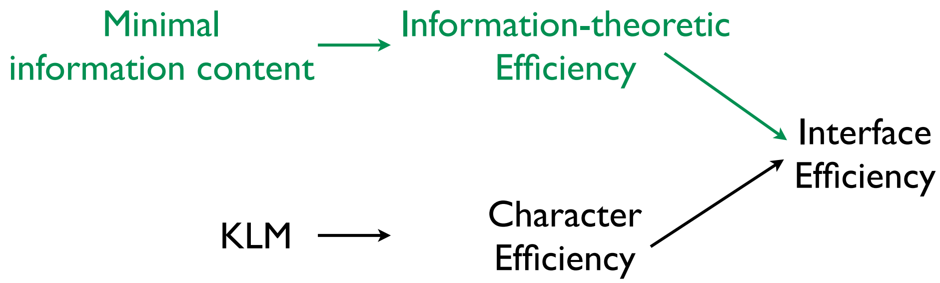
- Minimal information required: 7 bits
- What is the information content of the shown numeric keyboard for 3 digits (because the first digit is always zero)?

1	2	3
4	5	6
7	8	9
	0	

	0	___	___	___
Alternatives:		[0,9]	[0,9]	[0,9]
Counts:	0	10	10	10

Information content = $4 \log_2(10) = 9.97$ bits

- What is the information-theoretic efficiency when you use this keyboard for NRW area code?
  - $E = \frac{\text{Minimal info required for the task}}{\text{Info supplied by user}} = \frac{7}{9.97} = 70.21\%$ Saved 17.54%!



Keystroke-Level Model

- Execution time for a task = sum of times required to perform the serial elementary gestures of the task
- Typical gesture timings
  - Keying K = 0.2 sec (tap key on keyboard, includes immediate corrections)
  - Pointing P = 1.1 sec (point to a position on display)
  - Homing H = 0.4 sec (move hand from keyboard to mouse or v.v.)
  - Mentally preparing M = 1.35 sec (prepare for next step, routine thinking)
  - Responding R (time a user waits for the system to respond to input)
- Responding time R effects user actions
  - Causality breakdown after 100 ms
  - User will try again after 250 ms ⇒ R
  - Give feedback that input received & recognized

Keystroke-Level Calculation

- List required gestures
  - E.g., HK = move hand from mouse to keyboard and type a letter
- Compute mental preparation times Ms
  - Difficult: user stops to perform unconscious mental operations
  - Placing of Ms described by rules
- Add gesture timings
  - E.g., HMPK = H + M + P + K = 0.4 + 1.35 + 1.1 + 0.2 = 3.05 sec
- Rule terminology
  - String: sequence of characters
  - Delimiter: character marking beginning (end) of meaningful unit
  - Operators: K, P, and H
  - Argument: information supplied to a command

Rules for Placing Ms

- Rule 0, initial insertion for candidate Ms
  - Insert Ms in front of all Ks
  - Place Ms in front of Ps that select commands, but not Ps that select arguments for the commands
- Rule 1, deletion of anticipated Ms
  - Delete M between two operators if the second operator is fully anticipated in the previous one

    E.g., PMK ⇒ PK
- Rule 2, deletion of Ms within cognitive units (contiguous sequence of typed characters that form a name)
  - In a string of MKs that form a cognitive unit, delete all Ms except the first

    E.g., "ls⏎" ⇒ MK MK MK ⇒ MK K MK

Rules for Placing Ms

- Rule 3, deletion of Ms before consecutive terminators
  - If K is redundant delimiter at end of a cognitive unit, delete the M in front of it,

    E.g., "bla⏎⏎" ⇒ M 3K MK MK ⇒ M 3K MK K
- Rule 4, deletion of Ms that are terminators of commands
  - If K is a delimiter that follows a constant string then delete the M in front of it (not for arguments or varying strings)

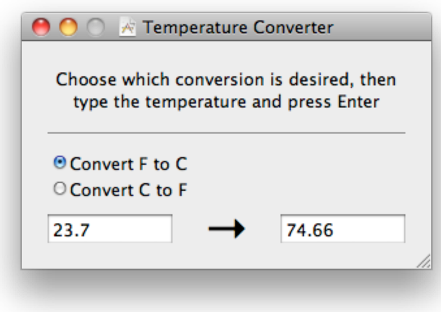
    E.g., "ls⏎" ⇒ M K K MK ⇒ M K K K
- Rule 5, deletion of overlapped Ms
  - Do not count any M that overlaps an R

    E.g., user waiting for computer response

Exercise: Temperature Converter

- Convert from degrees Fahrenheit (F) to Celsius (C) or vice versa, requests equally distributed
- Use keyboard or mouse to enter temperature
- Assume active window awaiting input, an average of four typed characters (including point and sign), and no typing errors
- Task: create and analyze your own interface!

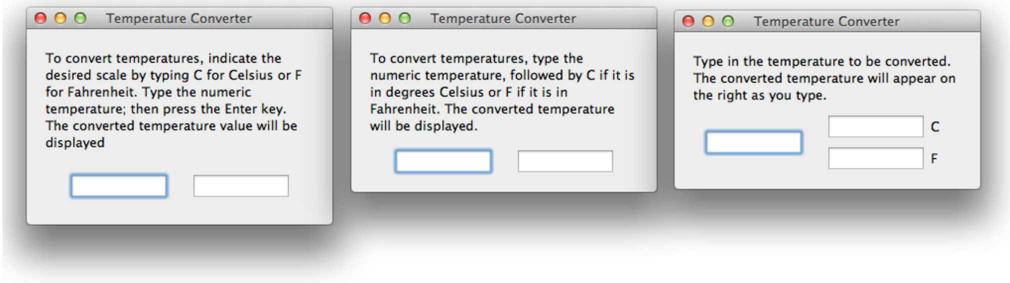
The Dialog Box Solution with Radio Buttons…



…and Its Keystroke-level Model

- Case 1: select conversion direction
  - Move hand to mouse, point to desired button, click on radio button (HPK)
  - Move hands back to keyboard, type four characters, tap enter (HPKHKKKKK)
  - Rule 0 (HMPMKHMKMKMKMKMK)
  - Rule 1, 2, 4 (HMPKHMKKKKMK)
  - Estimated time = 7.15 sec
- Case 2: correct conversion direction already selected
  - MKKKKMK = 3.7 sec
- Average time = (7.15 + 3.7) / 2 = 5.4 sec

Example: Temperature Converter



- Keystroke efficiency
  - Type C or F, value, enter: M K K K K K M K ⇒ 3.9 sec (char. eff. 67 %)
  - Type value, then C or F: M K K K K M K ⇒ 3.7 sec (char. eff. 80%)
  - Bifurcated: M K K K K = 2.15 sec (char. eff. 100 %)

Example: Temperature Converter

- Input assumptions (given)
  - 50% Fahrenheit, 50% Degree Celsius
  - 75% positive, 25% negative
  - 10% integer, 90% decimal
  - All digits are equally likely
  - Only four characters input

Example: Temperature Converter

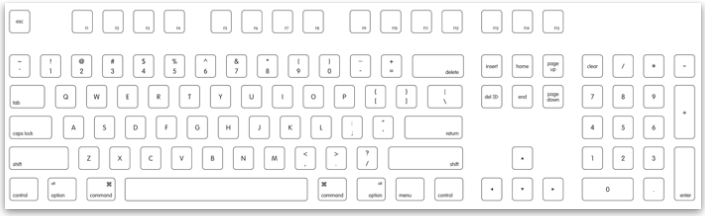
Information per alternative $p(i)\log_2(1 / p(i))$

Numbers	Prob.	Values	$p(i)$	Information in bits	Overall (values x information in bits)
-.dd	12.5%	100	0.00125	0.012	1.2
-d.d	12.5%	100	0.00125	0.012	1.2
.ddd	25%	1000	0.00025	0.003	3
d.dd	25%	1000	0.00025	0.003	3
dd.d	25%	1000	0.00025	0.003	3

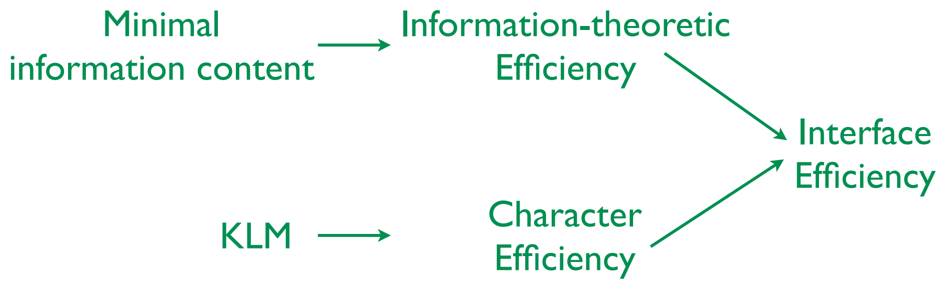
⇒ Minimal info required for the task = 11.4 bits/message

⇒ Simple approach: $4 \log_2(12) \approx$ 14 bits

Example: Temperature Converter



- Information efficiency: $E = \frac{\text{11.4 bits}}{\text{Info supplied by user}}$
  - 128 keys standard keyboard (5 bits/key): E = 11.4 / (4 x 5) ≈ 55%
  - 16 keys numeric keypad: E = 11.4 / (4 x 4) ≈ 70%
  - 12 keys dedicated keypad: E = 11.4 / (4 x 3.5) ≈ 80%



GOMS: Components

- Goals describe user's end goals
  - Routine tasks, not too creative/problem-solving

    E.g., "copyedit manuscript"
  - Leads to hierarchy of subgoals
- Operators are elementary user actions
  - Key presses, menu selection, drag & drop, reading messages, gestures, speech commands, …
  - Assign context-independent duration (in ms)
- Methods are "procedures" to reach a goal
  - Consist of subgoals and/or operators
- Selection rules
  - Which method to use for a (sub)goal

    E.g., to delete some text (individual preferences apply!)

Sample Method and Operators

GOAL: HIGHLIGHT-ARBITRARY-TEXT

1. MOVE-CURSOR-TO-BEGINNING	1.10s
2. CLICK-MOUSE-BUTTON	0.20s
3. MOVE-CURSOR-TO-END	1.10s
4. SHIFT-CLICK-MOUSE-BUTTON	0.48s
5. VERIFY-HIGHLIGHT	1.35s

GOMS Results

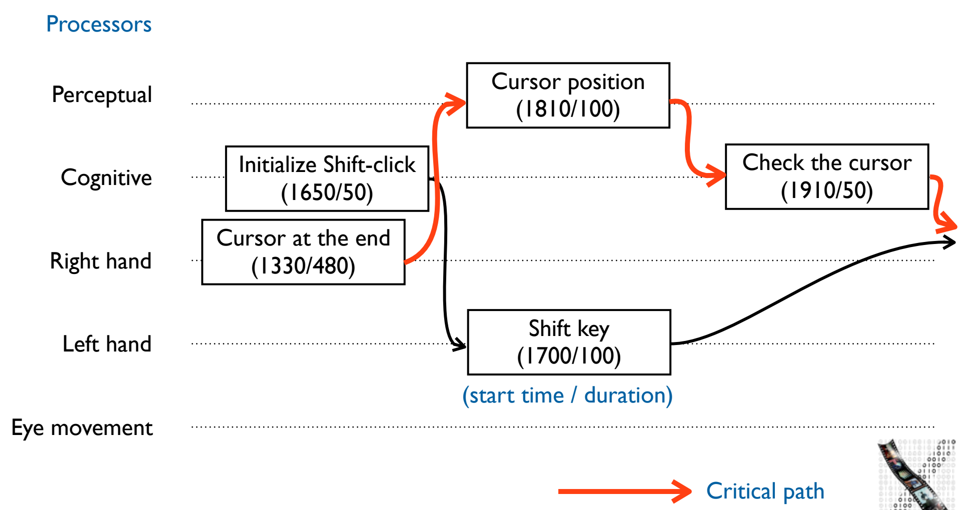
- Execution (& learning) times of trained, routine users for repetitive tasks (goals), leading to cost of training, daily use, errors
  - Can be linked to other costs (purchase, change, update system), resulting in $$$ answers
  - Use to model alternative system offers

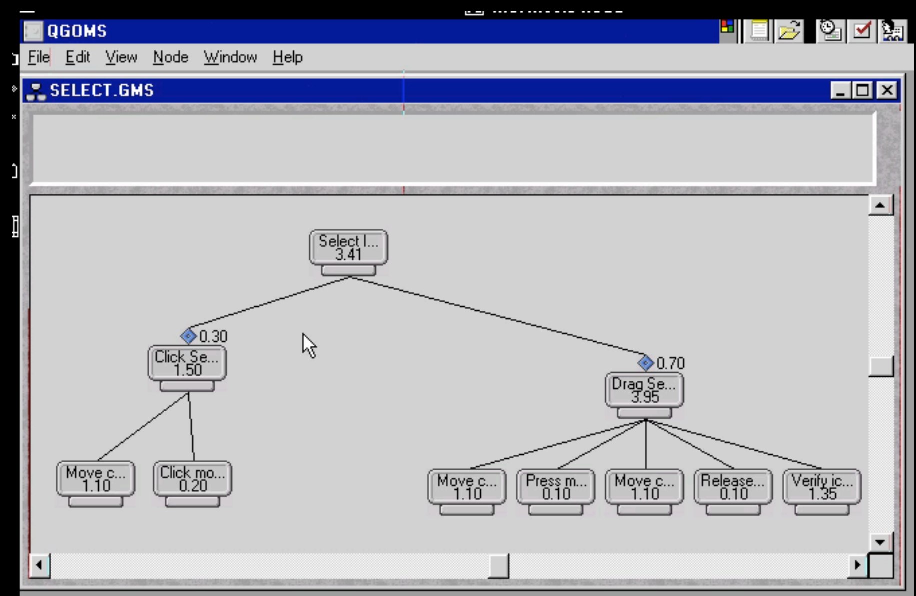
    E.g., "new NYNEX computers cost $2M/year more" [Gray93]
- Estimate effects of redesign
  - Training cost vs. long-term work time savings
- Starting point for task-oriented documentation
  - Online help, tutorials, …
- Don't use for casual users or new UI techniques
  - Operator times not well defined

Variants of GOMS

- GOMS (Card, Moran, and Newell 1983)
  - Model of goals, operators, methods, selection rules
  - Predict time an experienced worker needs to perform a task in a given interface design
- Keystroke-level GOMS model (simplified version)
  - Comparative analyses of tasks that use mouse (GID) and keyboard
  - Correct ranking of performance times using different interface designs
- NGOMSL (natural GOMS language)
  - Considers non-expert behavior (e.g., learning times)
- CPM-GOMS (critical path method)
  - Computes more accurate absolute times
  - Considers overlapping time dependencies

CPM-GOMS Example (Excerpt)

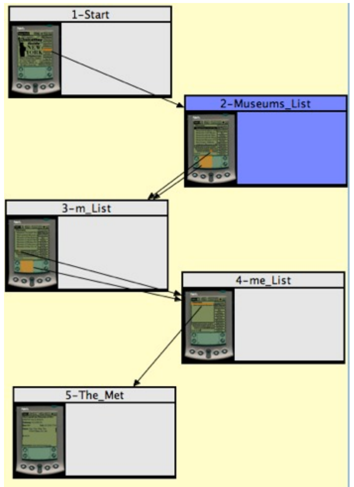


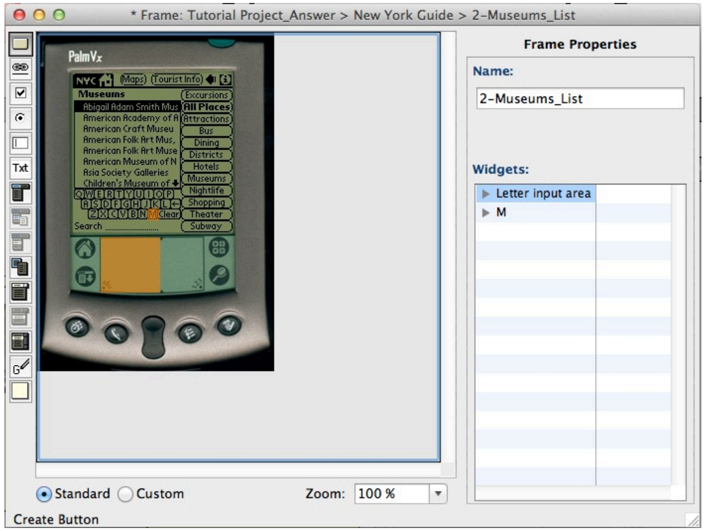


Sample tool: QGOMS [Beard96]

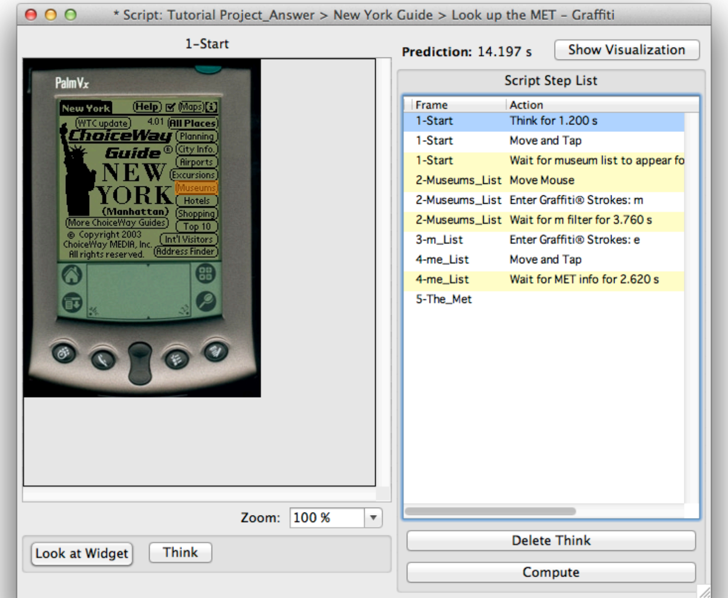
CogTool

- UI prototyping tool with predictive human performance model
  - Create different storyboards
  - Demonstrate tasks on the storyboards
  - Produce cognitive model
- Available for free, Java
- http://cogtool.hcii.cs.cmu.edu/

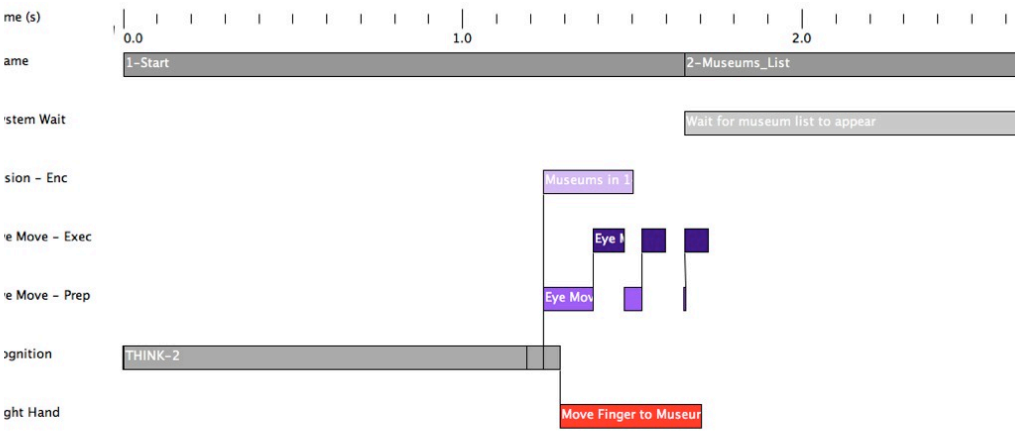




CogTool: Defining hit zones for the UI



CogTool: Record interactions



CogTool: Visualize interactions in a timeline

Evaluation Techniques

Evaluating Without Users

E1 Literature Review
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E4 Model-based Evaluation (GOMS,...)

Evaluating With Users

Qualitative

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Quantitative

E10 Controlled Experiments

+ Interviews, questionnaires,...

Evaluating with Users

- E1–E4 evaluate designs without the user
- As soon as implementations (prototypes) exist they should also be tested with users, using the following methods

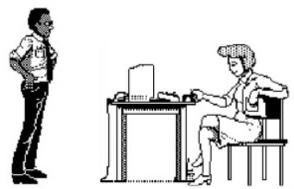
E5: Model Extraction

- Designer shows user prototype or screen shots
- User tries to explain elements and their function

+ Good to understand naïve user’s conceptual model of the system

— Bad to understand how the system is learned over time

E6: Silent Observation



Saul Greenberg

- Designer watches user in lab or in natural environment while working on one of the tasks
- No communication during observation

+ Helps discover big problems

— No understanding of decision process (that lead to problems) or user’s mental model, opinions, or feelings

E7: Think Aloud

- As E7, but user is asked to say aloud
  - What she thinks is happening (state)
  - What she is trying to achieve (goals)
  - Why she is doing something specific (actions)
- Most common method in industry

\+ Good to get some insight into user's thinking, but:

- — Talking is hard while focusing on a task
- — Feels weird for most users to talk aloud
- — Conscious talking can change behavior

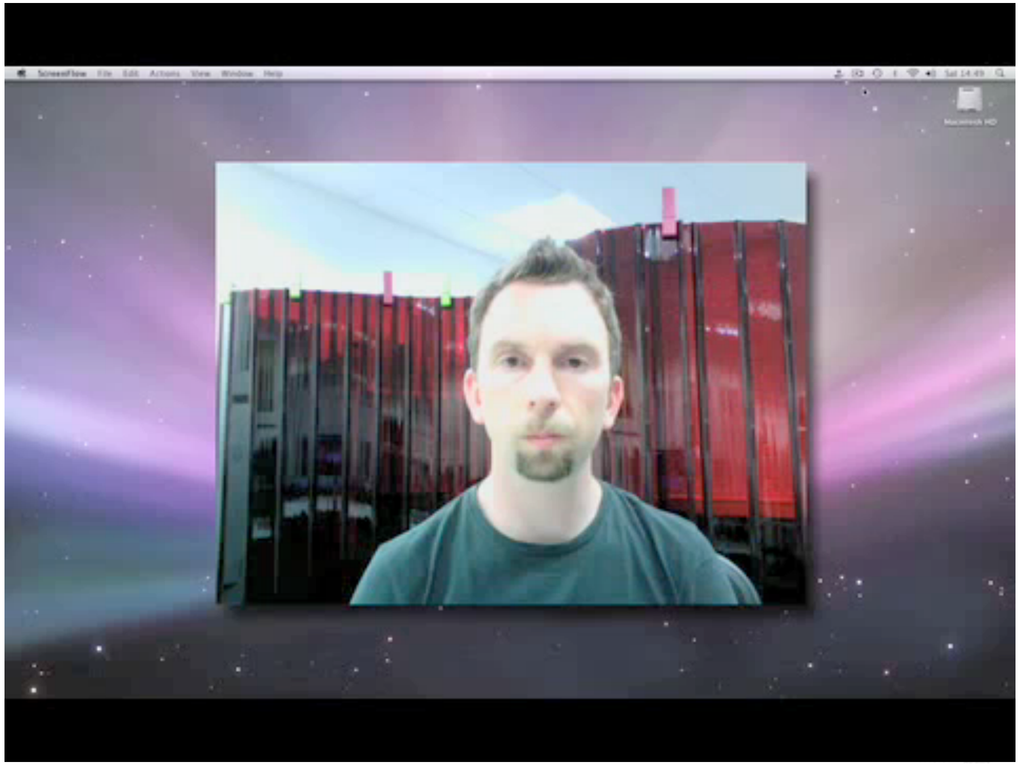
E8: Constructive Interaction

- Two people work on a task together
  - Normal conversation is observed (and recorded)
  - More comfortable than Think Aloud
- Variant of this: Different partners
  - Semi-expert as "trainer", newbie as "student"
  - Student uses UI and asks, trainer answers
  - Good: Gives insight into mental models of beginner and advanced users at the same time!

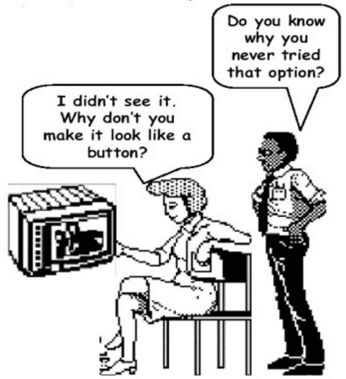
Recording Observations

- Paper + pencil
  - Evaluator notes events, interpretations, other observations
  - Cheap but hard with many details (writing is slow). Forms can help.
- Audio recording
  - Good for speech with Think Aloud and Constructive Interaction
  - But hard to connect to interface state
- Video
  - Ideal: two cameras (user + screen) in one picture
  - Best capture, but may be too intrusive initially

Silverback



E9: Retrospective Testing



- Additional activity after an observation
- Subject and evaluator look at video recordings together, user comments his actions retrospectively
- Good starting point for subsequent interview, avoids wrong memories
- Often results in concrete suggestions for improvement

E10: Controlled Experiments

- Quantitative, empirical method
- Steps:
  - Formulate hypothesis
  - Design experiment, pick variable and fixed parameters
  - Choose subjects
  - Run experiment
  - Interpret results to accept or reject hypothesis

More details: next lecture

Other Evaluation Methods

- Before and during the design, with users:
  - Questionnaires
  - Personal interviews
- After completing a project:
  - Email bug report forms
  - Hotlines
  - Retrospective interviews and questionnaires
  - Field observations (observe running system in real use)

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Next lecture

\+ Interviews, questionnaires,...

Dealing with Testers

- Tests are uncomfortable for the tester
  - Pressure to perform, mistakes, competitive thinking
- So treat testers with respect at all times!
  - Before, during, and after the test

Before the Session

- Do not waste the tester's time
  - Run pilot tests before
  - Have everything ready when testers arrive
- Make sure testers feel comfortable
  - Stress that the system is being tested, not them
  - Confirm that the system may still have bugs
  - Let testers know they can stop at any time
- Guarantee privacy
  - Individual test results will be handled as private
- Inform tester
  - Explain what is being recorded
  - Answer any other questions (but do not bias)
- Only use volunteers (consent form)

During the Session

- Do not waste the testers' time
  - Do not let them complete unnecessary tasks
- Make sure testers are comfortable
  - Early success in the task possible
  - Relaxed atmosphere
  - Breaks, coffee, …
  - Hand out test tasks one by one
  - Never show you are unsatisfied with what the tester does
  - Avoid interruptions (cell phones, …)
  - Abort the test if it becomes too uncomfortable
- Guarantee privacy
  - Never let testers' boss (or others) watch

After the Session

- Make sure testers are comfortable
  - Stress that tester has helped finding ways to improve the system
- Inform
  - Answer any questions that could have changed the experiment if answered before the test
- Guarantee privacy
  - Never publish results that can be associated with specific individuals
  - Show recordings outside your own group only with written consent from testers

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