Overview of Human Cognition
and its Impact on User Interface Design
Stepping Back, Big Picture Recap

• Output
  – Output hardware (CRTs, LCDs, etc)
  – Pixel level operations (frame buffer, bitblt, color models)
  – Stroke level operations (line props, polylines, path model)
  – Component level operations (widgets, interactor tree)
  – Window level operations (damage / redraw)

• Input
  – Input hardware (mouse, keyboard, etc)
  – Event devices and sampled devices modeled as events
  – Higher-level events modeled as well (enter / exit)
  – Event Queue and Dispatch strategies
A Whirlwind Overview of Cognition

- Mental Models
- Affordances
- Color
- Performance characteristics of people
- Errors

- How these affect design and implementation of GUIs
- Afterwards, advanced interaction techniques
Design of Everyday Things

- By Don Norman (UCSD, Apple, HP, NN Group)
- Design of everyday objects illustrates problems faced by designers of systems
- Explains conceptual models
  - doors, washing machines, digital watches, telephones, ...
- Resulting design guides

→ Highly recommend this book
The “Interface Cycle”

I want to add a thin black box around the title
The “Interface Cycle”

SYSTEM

• Updates display

Display
The “Interface Cycle”

**USER**
- Evaluates and understands display

**DISPLAY**

**SYSTEM**
- Updates display
The “Interface Cycle”

USER
- Evaluates and understands display
- Formulates goals and actions

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**USER**
- Evaluates and understands display
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- Acts to produce inputs

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Input Devices

Display

SYSTEM
- Updates display
- Interprets input events
The “Interface Cycle”

**USER**
- Evaluates and understands display
- Formulates goals and actions
- Acts to produce inputs

**Display**

**SYSTEM**
- Updates display
- Updates internal state
- Interprets input events

**Input Devices**
Norman’s “Gulfs”

- Norman describes two user activities bridging users and systems
- **The Gulf of Evaluation**
  - User perceives and interprets state of system
  - What is the state of the system?
Norman’s “Gulfs”

- Norman describes two user activities bridging users and systems
  - The Gulf of Evaluation
    - User perceives and interprets state of system
  - The Gulf of execution
    - User formulates inputs to achieve goals

- Making these “gulfs” small makes the interface much easier to use
Example Gulfs of Evaluation?

I want to add a thin black box around the title.
Example Gulfs of Evaluation?

- User understands and evaluates display
  - In this case pretty easy to see no black box around text yet
  - Compare editing web page in text editor
Example Gulfs of Evaluation?

- User understands and evaluates display
  - In this case pretty easy to see no black box around text yet
  - Compare editing web page in text editor
- Formulates goals and actions
  - Add a black box
- Acts to produce inputs
  - This is the hard part here
  - Too many buttons?
  - Too many menus?
  - What’s the dog on the side for?
Example Gulfs of Execution?
Gulfs of Evaluation and Execution

• Some causes of Gulf of Evaluation
  – Poor use of colors
  – Bad layout, poor grouping
  – Important information looks same as unimportant
  – Forcing people to remember lots of things
  – Lack of feedback in response to inputs

• Some causes of Gulf of Execution
  – Don’t know what is possible
  – Widgets might not have meaning (solvable with experience)
  – Interaction patterns might not have meaning (see above)
    • Example patterns: Dialogs, Shopping Carts
How to Address These Gulfs?

• Simple answer: Good Design
• More complex answer:
  – Mental Models
  – Affordances
  – Feedback
  – Mappings
  – Metaphor
  – Color
  – Visual Grouping / Separation
  – Layout

• Note: rapid coverage of cognitive science topics
Mental Models

• Mental representation of how object works & how interface controls affect it

• People may have preconceived models that are hard to change
  – (4 + 5) vs. (4 5 +)
  – dragging to trash?
    • delete file but eject disk

• Interface must communicate model
  – visually
  – online help and documentation can help, but shouldn’t be necessary
Mental Models Example: Refrigerator

**Problem:** freezer too cold, but fresh food just right
What is a typical conceptual model?

Normal Settings: C and 5
Colder Fresh Food: C and 6-7
Coldest Fresh Food: B and 8-9
Colder Freezer: D and 7-8
Warmer Fresh Food: C and 4-1
OFF (both): 0
A Common Conceptual Model

independent controls
Now can you fix the problem?

Possible solutions
  – make controls map to user’s model
  – make controls map to actual system
Design Model & User Model

- Users get model from experience & usage
  - through system image
Mental models

• People inevitably build models of how a system works
  – can’t help but do it
  – may be highly detailed and functional
  – may be quite naïve

• Generally not complete, not necessarily “logical”
  – Ex. children and computers
  – Ex. you and your car
  – Ex. your mental map of Funchal
Conceptual Model Mismatch

• What if design model and user model don’t match?

• Mismatch can lead to...
  – Slow performance
  – Errors and inability to recover
  – Frustration
  – ...
### Notorious Example

#### Confusion over Palm Beach County ballot

Although the Democrats are listed second in the column on the left, they are the third hole on the ballot.

| (REPUBLICAN)                | 2.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.5.
Key points about mental models

- The system designer has too good a mental model
  - Nearly perfect mental model
  - Really good prediction of what system does
  - Real users won’t ever have that good a model

- Design Implication #1
  - HCI Mantra: “You are not the user”
  - System implementer knows too much and can’t forget

- Design Implication #2
  - Try to design for a clear mental model and foster that model
Outline

• Mental Models
• Affordances
• Feedback
• Mappings
• Metaphor
• Color
• Visual Grouping / Separation
• Layout
Affordances

• Well-designed objects have *affordances*
  – clues to their operation that are readily apparent
  – often visual, but not always (e.g., speech)
  – Allows and promotes certain actions
    • Door knobs afford turning
    • Handle of hammer affords grasping in a particular way
Affordances as Perceptual Clues

Siemens Pocket PC Phone
Pen input, no keypad

Hanspring Treo
Pen input/keypad input
Affordances as Perceptual Clues

- Poorly-designed objects
  - no clues or misleading clues

*French artist Jacques Carelman*

Crazy design for a screw punch!
“Virtual affordances”

• Visual appearance can suggest function
  – Example: Knurling
  – Small ridges typically found on knobs
  – Increases friction → Affords grip

• Leveraging real-world knowledge
  – Don’t have to know about knurling for this to afford “grip” with the mouse
“Virtual affordances”
Design Implications

- **Design Implication**
  - Make sure objects that users can manipulate have affordances that suggest how they work
- **Standard GUI widgets have “standard” affordances**

![Diagram showing standard GUI widgets]

- **New GUI widgets (or web apps) will need well-designed visual affordances**
Administrivia

• P3 Progress?

• 3 minutes break
Outline

• Mental Models
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Feedback

• Response by the system to the actions of the user
  – Cause and effect
  – Essential for forming mental models

• Making “system state” visible
  – The system did “the right thing”
    • Immediate – Button goes down
    • Intermediate – Thin black box appears on screen
    • Delayed – Amazon “Thank you for shopping” + email
  – Sometimes just to let you know the system is still alive
Feedforward

- Feedforward
  - What will happen if you execute the action
  - Ex. web page mouseover, word processing i-bar
  - Useful for helping people predict what will happen
Performance properties of people

- Feedback depends on properties of people
- How much can people remember?
- How fast are things perceived?
How much can a person remember?

- Short term (working) memory
  - small capacity (7 ± 2 “chunks”)
    - 6174591765 vs. (617) 459-1765
    - EDCMBIMGC vs. DEC IBM GMC
  - rapid access & decay
  - for us just: “very limited”

- Long-term memory
  - huge (if not “unlimited”)
  - slower access time
  - but requires effort and may not always work on cue
Simple Experiment

- Need a volunteer
- Start saying the **color** you see in list of words
  - when slide comes up
  - as fast as you can
- Say “done” when finished
- Everyone else time it…

Alice ➔ You say “Black”

Bob ➔ You say “Blue”
<table>
<thead>
<tr>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
</tr>
<tr>
<td>Black</td>
</tr>
<tr>
<td>Yellow</td>
</tr>
<tr>
<td>Blue</td>
</tr>
</tbody>
</table>
Design Implications

• Be careful of interference
  – two strong cues in working memory
  – link to different chunks in long term memory

• Design for recognition over recall
  – Recall
    • info reproduced from memory
    • e.g., command name & semantics
  – Recognition
    • presentation of info provides knowledge that info has been seen before
    • e.g., command in menu reminds you of semantics
    • Retrieval cues, e.g., icons, labels, menu names, etc.
How fast are things perceived?

• < ~20ms (1/50 sec) discrete flashes merge into continuous perception
  – CRTs and LCDs refresh 60 times per second
  – Below 50 times per second can start seeing flicker

• Differences in peripheral vision
  – Peripheral vision highly motion sensitive
  – Good for seeing saber tooth tigers
  – Bad for banners ads
How fast are things perceived?

- Fact #1: < ~20ms (1/50 sec)
- Fact #2: Displays update at 50-75hz

- So? Don’t ever have to be faster for user response!
  - People can’t distinguish
  - Get ~1140 million instructions (@3Ghz)
    - You can do a lot with that
    - (First GUIs had ~20K)
    - Not enough? Apply Moore’s law…
How fast are things perceived?

• But don’t have to be this strict, \( \sim 100\text{ms} \) seems like “instant response”
  – Hard to tell response times below this apart
  – Upper range of eye saccades

• Except for animation, most GUI responses don’t need to be faster than this
  – \( \sim 100\text{ms} \) typical human “cycle time” in Model Human Processor
  – \( \sim 2.2\text{k million} \) machine instructions

• Experiments suggest a little slower still ok
  – Window dragging \( \sim 1/5 \) second to be acceptable
How fast are things perceived?

- < 1-2 seconds typically “good response time”
  - Similar times in conversational turn taking protocols
  - Longer delays ~5 sec have to say something to keep conversation alive
How fast are things perceived?

- > 10-15 sec is typically “bad response time”
  - STM decay effects
  - Need to use progress meters here for feedback

- Web has sort of trained us for slow response times
  - Though lots of times I forgot what I wanted to do by the time a page loaded
Perceptual Causality

• How soon must red ball move after cue ball collides with it?
A little about response times

• Good vs. bad response time depends on expectations
  – If you can’t meet the goals, manipulate user expectations!
  – Web did this well
  – “This will take 5 minutes to install”
  – Minimum hardware requirements

• Consistency of response is very important
  – Can be more important than time
  – Predictability
A little about response times

• Caveat #1
  – “Premature optimization is the root of all evil (or at least most of it) in programming.” – Donald Knuth
  – Programmer intuitions often wrong
  – Use a profiler, see where time is spent
  – Typically follows Pareto distribution (80/20)

• Caveat #2 – Perceived response times important too!
  – Waiting for elevator
  – Amazon book purchase
1 minute break
Outline

• Mental Models
• Affordances
• Feedback
• Mappings
• Metaphor
• Color
• Visual Grouping / Separation
• Layout
Map Interface Controls

- Controls should mirror real-world
- Which is better for dashboard speaker front / back control?
Map Interface Controls
Metaphor

- **Definition**
  - “The transference of the relation between one set of objects to another set for the purpose of brief explanation.”
Metaphor

• Lakoff & Johnson, *Metaphors We Live By*
  – “...the way we think, what we experience, and what we do every day is very much a matter of metaphor.”

• In our language & thinking - “argument is war”
  – he attacked every weak point
  – criticisms right on target
  – if you use that strategy

• Relationships and navigation
  – going in the wrong direction
  – took a u-turn
  – our marriage is at a crossroads
Desktop Metaphor

• We can use metaphors to leverage existing conceptual models
• Suggests a conceptual model
  – Not really an attempt to simulate a real desktop
  – Leverages existing knowledge about files, folders, trash
  – A way to explain why some windows seemed blocked
Example Metaphors

• Data & function
  – rolodex, to-do list, calendar, applications documents, find, assist

• Collections
  – drawers, files, books, newspapers, photo albums

• Actions
  – Cut, copy, paste
  – When was the last time you actually did this for real?
Metaphors Aren’t Always Effective

• Mac desktop inconsistent
  – Dragging disk to trash
    • should delete it, *not* eject it
Metaphors Aren’t Always Effective

- Magic Cap
  - Somewhat unwieldy, not good use of screen real estate
Metaphors Aren’t Always Effective

- Microsoft Bob
  - Set expectations too high
Summary

- Gulf of Evaluation and Execution
- Mental Models
- Affordances
- Feedback
- Mappings
- Metaphor

- Next time:
  - Color
  - Visual Grouping / Separation
  - Layout