Methods for Design, Prototyping, and Evaluating User Interaction

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In this lecture, we will discuss different models used to understand human performance in HCI. These models help us design better interfaces by predicting how users perceive, process, and act on information.

The key topics for this lecture are:

1. The role of models in HCI
2. The Human Visual System
3. The Model Human Processor
4. Fitts's Law
5. Gestalt Principles of Perception

Let's start with the importance of models in HCI.

Models

Models

Models describe phenomena, isolating components and allowing a closer look

- Capture Essential Pieces
  - Model should have what it needs, but no more.
  - Avoid underfitting or overfitting
- Allow us to measure
  - Collect data, put in model, compare model terms
- Allow us to predict
  - The better the model, the better the predictions

Models are simplified representations of real-world phenomena. They help us:

- Capture essential pieces of a system while avoiding unnecessary complexity.
- Measure and collect data for comparison and improvement.
- Predict human behavior, which is essential for designing effective user interfaces.

Creating Models

One approach:

1. Observe
2. Collect data
3. Find patterns
4. Draw analogies
5. Devise model
6. Test fit to data
7. Test predictions
8. Revise

Fundamentally an inductive process
From specific observations to broader generalizations

One approach to creating models follows these steps:

1. Observe human behavior
2. Collect data
3. Identify patterns
4. Draw analogies
5. Devise a model
6. Test fit to data
7. Test predictions
8. Revise based on results

This is an inductive process where we start from specific observations and then move to broader generalizations.

Models of Human Performance

Model of Human Performance	Type of Model
Visual System	Biological Model
Model of Human Processor	Higher-level model
Fitt's Law	Model by analogy
Gestalt Principles	Prediction interpretation

We are going to consider 4 models (read each model) and we can think of them from a different perspective we call the "type of model" (read each type).

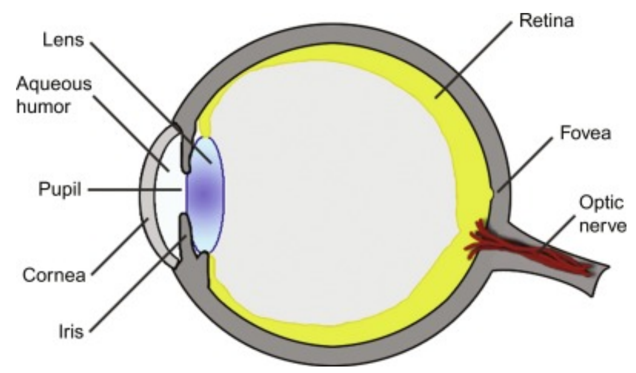
Visual System

Biological Model

Understanding how humans see and process visual information is key to UI/UX design.

Human Visual System

Light passes through lens, focused on retina, goes to the brain where it gets processed.



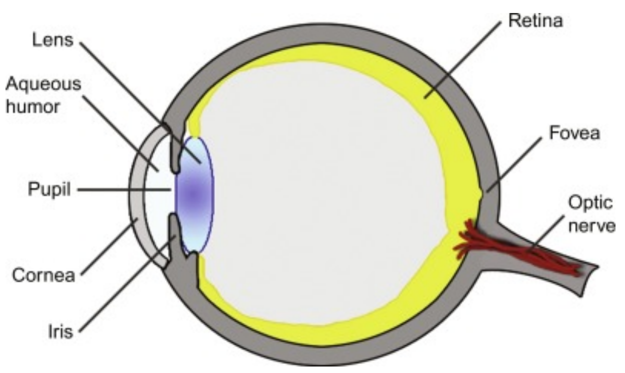
Briefly, the eye works like this:

- Light passes through the lens, gets focused on the retina, and then transmits signals to the brain.
- The retina contains rods (light-sensitive, for night vision) and cones (for color perception).
- Most cones are in the center of the retina (fovea), enabling high detail in the center of vision.
- The periphery of the retina contains mostly rods, helping detect movement but with low detail.

Notice that the optic nerve is passing *through* the retina!

Human Visual System

If the light is captured by the retina, and optic nerves have to pass through it, shouldn't we have a blind spot?



(read slide), let's try and experiment!

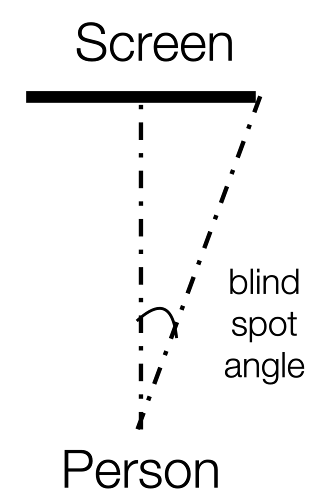
Human Visual System

1. Close your right eye
2. Using your left eye read each number 0 through 9
3. The star on the left should disappear at some point

⭐ 0 1 2 3 4 5 6 7 8 9

(read slide)
Take a minute or two to try this out!
(wait 2 minutes)
Pretty cool, right!? But, what implications does this have?

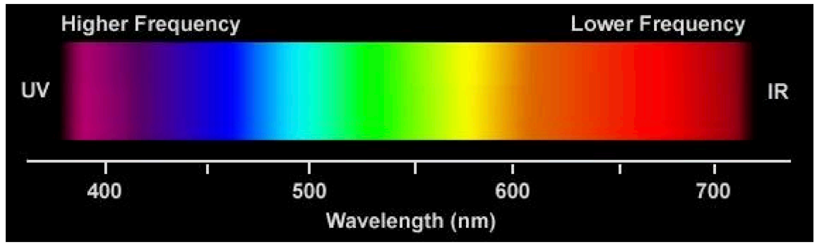
Human Visual System



If design elements are within the users blind spot, then they will not see it. Think, if something was important like a warning or notification. It would go unnoticed!

Human Visual System

Visible Spectrum



This image shows the visual spectrum for humans with sight and color sensitivity.

Human Visual System

Retina

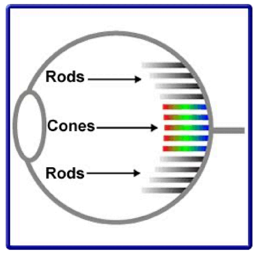
- Covered with light-sensitive receptors
  - Rods (120 million)
    - Sensitive to broad spectrum of light
    - Sensitive to small amounts of light
    - Cannot discriminate between colors
    - Sense intensity or shades of gray
    - Primarily for night vision & perceiving movement
  - Cones (6 million)
    - Used to sense color

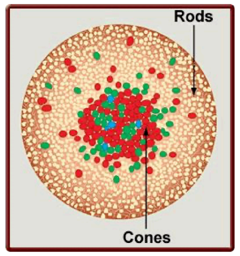
The retina has cones that are used to sense color.
Rods are for detecting movement and intensity.
Cones are used to sense color.
There are around 6 million rods in the retina.

Human Visual System

Retina

- Center of retina has most of the cones
  - Allows for high acuity of objects focused at center
- Edge of retina is dominated by rods
  - Allows detecting motion of threats in periphery





Color is perceived at the center of the retina where the cones are most dense.
The edge of the retina are covered with rods and are used to detect movement in the periphery (detecting threats)

Human Visual System

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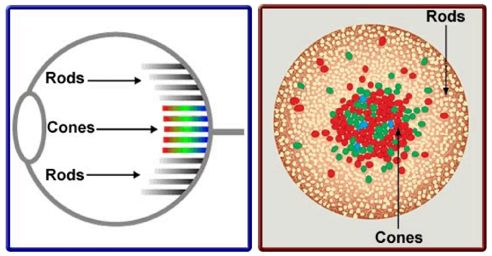

What does that mean for you?

Human Visual System

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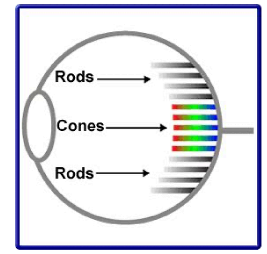

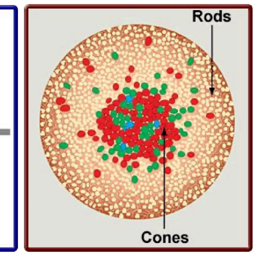

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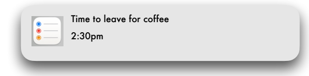
Human Visual System



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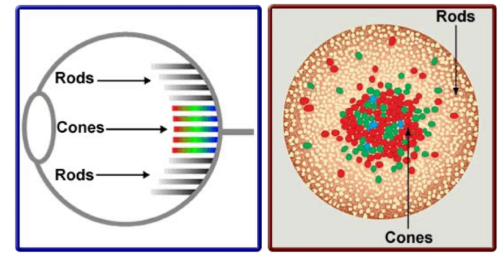


What does that mean for you?

Peripheral movement is easily distracting

I’m willing to bet no one missed the fake notification that popped up. That’s because it’s in the periphery. Any movement there is distracting and should be limited in interfaces to only important elements.

Human Visual System

Color Perception via Cones

- Photopigments used to sense color
  - 3 types: blue, green, “red” (actually yellow)
- Each sensitive to different band of spectrum
- Ratio of neural activity stimulation for the three types gives us a continuous perception of color

The cones allow us to detect three different types of color: blue, green, and red (which is actually yellow). These sensitivities are due to the size of the wavelengths of light that cones are sensitive to.

Human Visual System

Distribution of Photopigments

- Not distributed evenly
  - Mainly reds (64%), Very few blues (4%)
  - Insensitivity to short wavelengths (e.g., blue)
  - Highly sensitive to long wavelengths (e.g., orange and yellow)
- No blue cones in retina center (high acuity)
  - Fixation on small blue object yields “disappearance”
- Lens yellows with age, absorbs short wavelengths
  - Sensitivity to blue is reduced even further
    - (Don’t rely on blue for text and small objects!)

Humans have three types of cones, each sensitive to different wavelengths of light:

- S-cones (Blue-sensitive) – Peak sensitivity around 430 nm (short wavelengths).
- M-cones (Green-sensitive) – Peak sensitivity around 530 nm (medium wavelengths).
- L-cones (Red-sensitive) – Peak sensitivity around 560 nm (long wavelengths).

However, the L-cones, which are often called “red cones,” are actually most sensitive to yellowish light (around 560 nm) rather than deep red. This means they respond more strongly to yellow-green wavelengths than to true red.

Human Visual System

Color Sensitivity & Image Detection

- Most sensitive to center of spectrum
  - To be perceived as the same, blues and reds must be brighter than greens and yellows
- Brightness determined mainly by red and green
  - Y = 0.3 Red + 0.59 Green + 0.11 Blue (To calculate grayscales and balance colors!)
- Shapes detected by finding edges
  - We use brightness and color difference
- Implication
  - Blue edges and shapes are hard to detect

All this means we must be careful with the colors we choose in our designs! If we miss choose colors, then interface elements may go complete unnoticed!

Human Visual System

Focus

- Different wavelengths of light focused at different distances behind eye's lens
  - Constant refocusing causes fatigue
- Saturated colors (i.e., pure colors) require more focusing than desaturated (i.e., pastels)

This is why it hurts to read this message!

Color choices can also cause fatigue, I mean, just read this message. Annoying, right?

Human Visual System

Color Vision Deficiency

- Trouble discriminating colors
  - Affects about 9% of population
- Two main types
  - Different photopigment response most common
    - Reduces capability to discern small color differences
  - Red-Green deficiency is best known (color blindness)
    - Cannot discriminate colors dependent on red and green

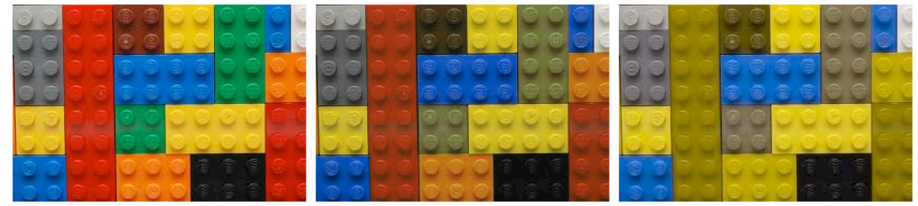
There is a sizable portion of the population that have trouble discriminating colors.

There are two main types of this:

1. Reduces the ability to discern small color differences.
2. Cannot discriminate colors dependent on red and green.

Human Visual System

Living with Color Vision Deficiencies



David R. Flatla and Carl Gutwin. 2012. "So that's what you see": building understanding with personalized simulations of colour vision deficiency. In Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility (ASSETS '12). Association for Computing Machinery, New York, NY, USA, 167–174.

Here is a great example from the paper “So that’s what you see: building understanding with personalized simulations of color vision deficiency”

Notice what people see when they can’t see red or green. Green looks just like gray. And red looks like yellow.

Human Visual System

Color Vision Deficiency

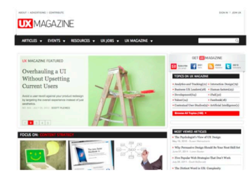
- 52% of the population is unable to differentiate 10% of the colors in an average website or infographic.
- 10% of the population is unable to differentiate 60% of the colors in an average website.

David R. Flatla and Carl Gutwin. 2012. "So that's what you see": building understanding with personalized simulations of colour vision deficiency. In Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility (ASSETS '12). Association for Computing Machinery, New York, NY, USA, 167–174.

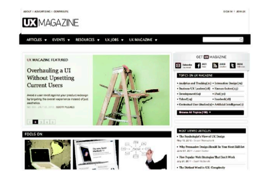
Here are two major things we need to keep in mind when we design interfaces.
(read slide)

Human Visual System

So what do they see?

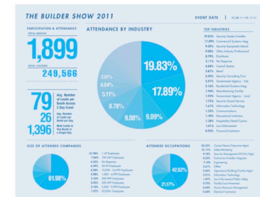


(a) Original website

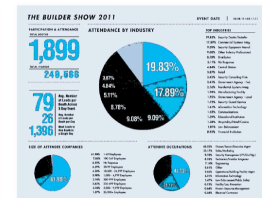


(b) Colors pairs that are not differentiable by 20% of the population have been set to black.

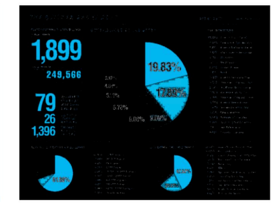
(c) Colors pairs that are not differentiable by 10% of the population have been set to black.



(d) Original infographic



(e) Colors pairs that are not differentiable by 20% of the population have been set to black.



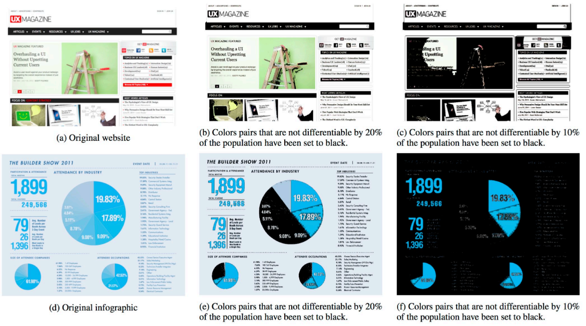
(f) Colors pairs that are not differentiable by 10% of the population have been set to black.

Take a second and compare from left (original) to the two on the right. Incredibly, right? Color matters!

Human Visual System

Color Vision Deficiency

- Usability issues
  - can’t perceive color-coded cues in an interface
- Obstacles in information uptake
  - e.g., if color-coded charts hinders data interpretation
- Reduction of perceived appeal
  - e.g., if an image is perceived with a different color palette than intended



(a) Original website

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Bad color use can cause a range of problems, from misinterpretation of the design to the design just not being usable any more. So….

Human Visual System

Color Vision Deficiency

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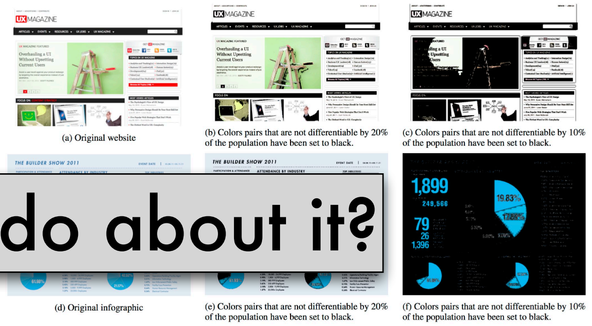


What can we do about it?

(read slide)
There are design tools to help us!

Human Visual System

Dual / Redundant Encoding

Multiple Sensory Channels:
Information is presented in different formats (e.g., text, audio, haptic feedback) to accommodate users with varying abilities, such as those with visual or hearing impairments.

The first is called dual encoding. This is where we use text or symbols or a combination of that allow users to different elements in our design without using color.

Human Visual System

Dual / Redundant Encoding

Color-Independent Design:
Important cues are not solely reliant on color (e.g., using symbols, patterns, or text alongside colors) to support users with color blindness.

Symbols, text, and patterns can support color bind people in differentiating design elements.

Human Visual System

Dual / Redundant Encoding

Alternative Text & Captions:
Redundant encoding ensures that images, icons, and audio content have text descriptions, closed captions, or transcripts for screen readers and deaf users.

Another example is using text and caption to support the hearing impaired.

Human Visual System

Dual / Redundant Encoding

Tactile & Auditory Feedback:
Haptic (vibration) or sound cues reinforce visual elements for users with low vision or those in situations where looking at the screen is difficult.

Tactile or auditory feedback can be useful when the screen is hard to see or look at.

Human Visual System

Dual / Redundant Encoding

Clear & Consistent Redundancy:
Key information is conveyed in multiple ways without causing cognitive overload (e.g., using both icons and labels for navigation buttons).

It's important to not overload the user though! Cognitive overload can make a system hard to use.

Human Visual System

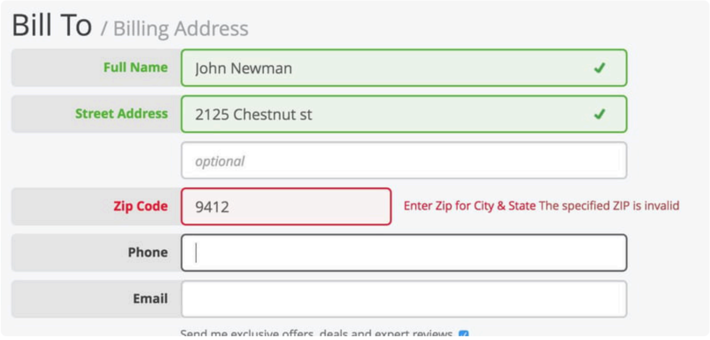
Dual / Redundant Encoding

Customizable Redundant Inputs:
Users can adjust how information is encoded based on their needs (e.g., enabling spoken feedback, enlarging text, or using high-contrast mode).

Customization can help a lot! It allows the users to fine tune the interfaces design so it’s most useable for them.

Human Visual System

Dual / Redundant Encoding



Here is an example of dual encoding using color, symbols, and text.

Human Visual System

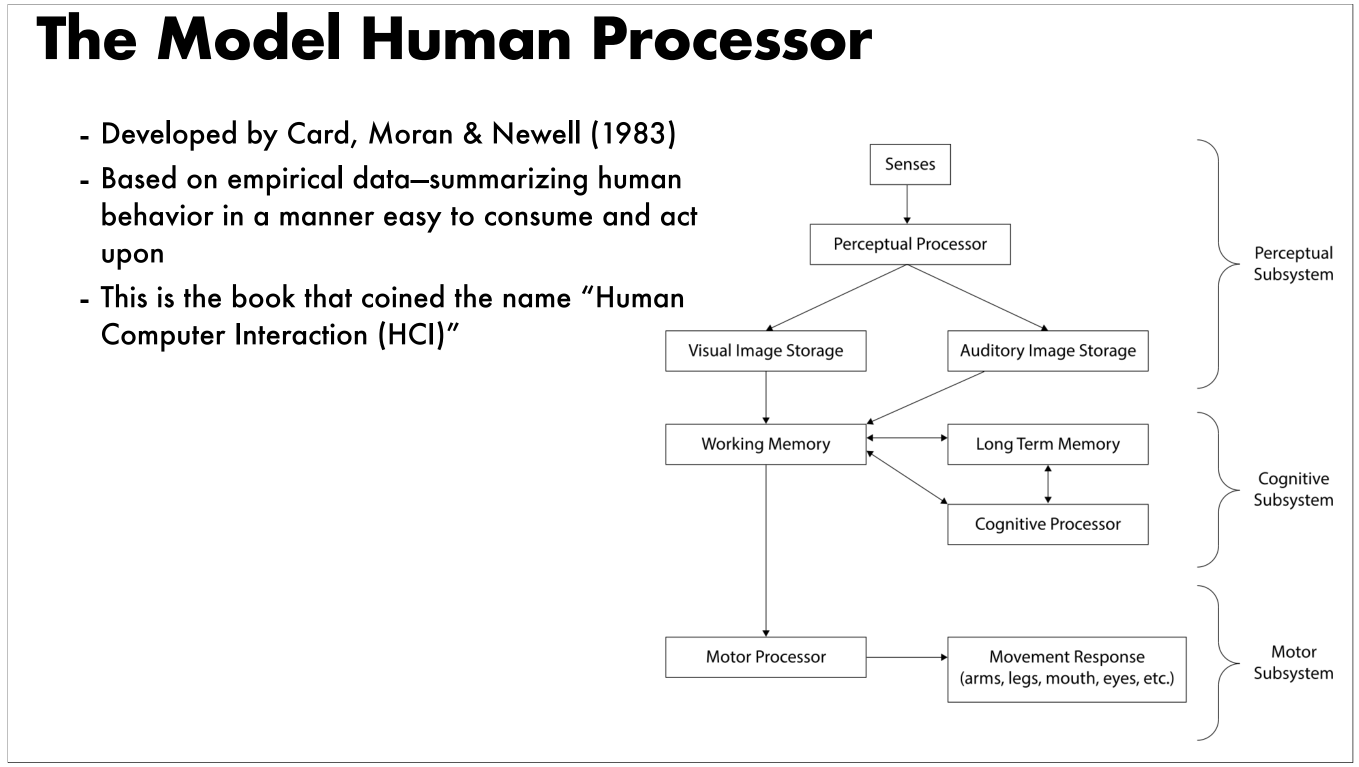
Dual / Redundant Encoding

Loracana Deck

Card games are usually very good at using dual encodings. This Loracana deck uses icons in the corners to differentiate the cards.

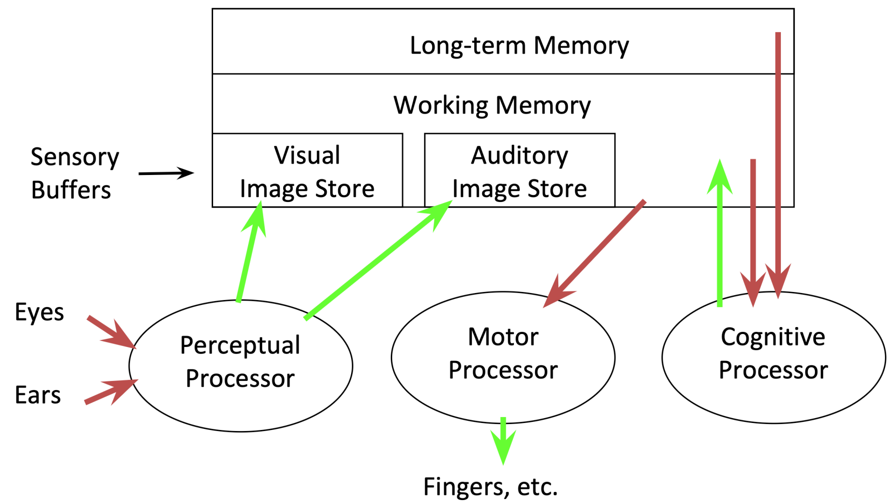
Model of Human Processor

We now move onto the model of human processor.



The model human processor models a human abstractly as a computer breaking down their processing into three subsystems called perceptual, cognitive, and motor. The perceptual subsystem consists of the senses and both visual and auditory image storage which are then stored in working memory due to the cognitive subsystem which contains working memory, long-term memory, and cognitive processing. Finally, a humans actions are controlled by the motor subsystem which contains a motor processor and movement response.

The Model Human Processor



Here we can see how this model would work. What the user is looking at is input into the perceptual processor which is then stored in working memory in the visual and auditory image stores. Then actions are moved from working memory into the motor processor resulting in movement. In parallel, information is written to working and long-term memory due to these actions.

The Model Human Processor

- Sometimes serial, sometimes parallel
  - Serial in action and parallel in recognition
- Parameters:
  - Processing speed
  - Memory capacity, type, etc.

Humans general work in both serial and parallel modes. For example, pressing a key in response to light is serial, but reading signs and hearing while driving a car happens in parallel. Depending on the person and types of action and which subsystem is being used there might be different notions of processing speeds, memory capacity, etc.

Memory

- Working memory (also known as short-term)
  - Small capacity (7 ± 2 "chunks")
    - 6174591765 vs. (617) 459-1765
    - IBMCIACSE vs. IBM CIA CSE
- Rapid access (70ms) and decay (~200 ms)
- Pass to long-term memory after a few seconds of continued storage

- Long-term memory
  - Huge (if not "unlimited")
  - Slower access time (~100 ms) with little decay

Humans have both working memory or short-term memory and long-term memory. Working memory has a rather small capacity. This is why it's easier to remember a phone number if it's written in the style of one, and how it's easier to remember certain expressions if they are relatable like IBM CIA CSE. One good thing about working memory is recall is fast, but it doesn't stick around for long if it isn't written to long-term memory. Now, long-term memory is huge and has little decay! But, is slow to access!

Model Human Processor Operation

- **Recognize-Act Cycle** of the Cognitive Processor
  - Contents in working memory initiate cognitive processes
  - Actions modify the contents of working memory
- **Discrimination Principle**
  - Retrieval is determined by candidates that exist in memory relative to retrieval cues
  - Interference created by strongly activated chunks

Working memory initiate cognitive processes, and actions can modify the contents of working memory. These drive the recognize-act cycle of the cognitive processor.

The discrimination principle, from cognitive psychology, is often referred to as "Interference Effects" in memory retrieval. It states that retrieval success depends on how well the retrieval cues can uniquely specify the target memory relative to other competing memories. If multiple memory "chunks" (units of information) are strongly activated, they can interfere with one another, making retrieval more difficult. This is linked to proactive and retroactive interference, where old memories interfere with new ones (proactive) or new memories interfere with old ones (retroactive).

This principle is particularly relevant in Human-Computer Interaction (HCI) for designing interfaces that minimize cognitive overload, ensuring that cues are distinct enough to avoid interference when retrieving information.

Fitts’ Law
Model by Analogy

The next model is the model of Analogy or Fitts’ Law.

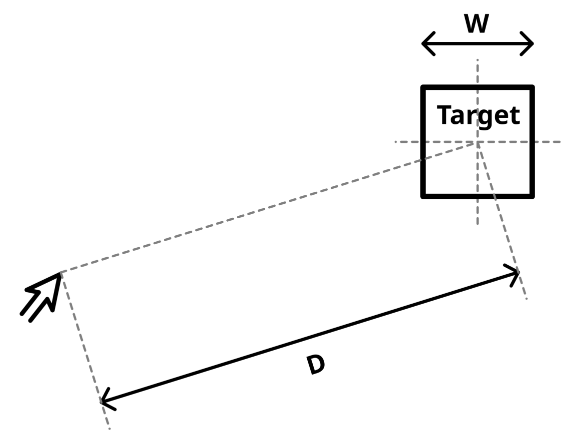
Fitts' Law (1954)

- Models time to acquire targets in aimed movement
  - Reaching for a control in a cockpit
  - Moving across a dashboard
  - Pulling defective items from a conveyor belt
  - Clicking on icons using a mouse

- Very powerful, widely used
  - Holds for many circumstances (e.g., under water)
  - Allows for comparison among different experiments
  - Used both to measure and to predict

Paul Morris Fitts did a study to see how long it takes the average user find and identify various targets in a field. This was done in 1954! It turns out that he found a rather important principle that has sense been used in a variety of ways in HCI. For example, reaching for a control in a cockpit, moving across a dashboard, clicking icons with a mouse, etc.

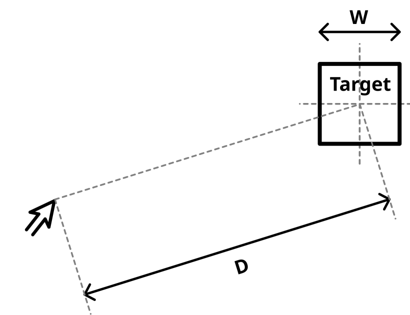
Reciprocal Point-Select Task



Fitts showed that the time it takes to rapidly move to a target area is a function of the ratio between distance to the target and the width of the target. Here the target is the center of the box and the user needs to find it with the pointer. So we can see that the target itself has a width, and there is a distance between the pointer and the target.

Reciprocal Point-Select Task

- $\mathrm{ID} = \log_2(D/W + 1)$
  - The difficulty to hit a target varies with the log of the ratio of the movement distance (D) to target width (W)
- Why is it significant that it is a ratio?
  - Units of D and W don't matter
  - Allows comparison across experiments
  - (Typically reported in "bits")



Fitts used an information analogy. He thought of the distance to the center of the target as a signal and the width (or tolerance) of the target as noise. This is why we call it a “model by analogy”. He then proposed the “index of index of difficulty” indicated here by ID. Fitts dropped the units abstracting to a unit he called “bits”. Thus, we need to take the ratio so they drop, and then this allows us to compare across experiments more easily.

Much later, Fitts law was generalized to touch screens like mobile and tablets as well!

Fitts' Law Related Techniques

- Put targets closer together
- Make targets bigger
- Make cursor bigger
  - Area cursors
  - Bubble cursor
- Use impenetrable edges

Fitts' Law has several important implications for HCI. For example, (read slide).

Fitts’ Law Related Techniques

- Gravity Fields
  - Pointer gets close, gets “sucked in” to target
- Sticky Icons
  - When within target, pointer “sticks”
- Constrained Motion
  - Snapping, holding Shift to limit degrees of movement
- Target Prediction
  - Determine likely target, move it nearer or expand it

Some more techniques for helping people find targets are (read slide).

Gestalt Principles

The Gestalt principles is our last model and has to do with how we perceive information based on layout.

Gestalt ("pattern" or “configuration”) Psychology

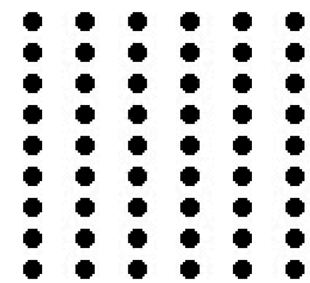
- Described loosely in the context of this lecture and associated work, not a real definition
  - Perception is neither bottom-up nor top-down, rather both inform the other as a whole!
  - "The whole is greater than the sum of its parts”

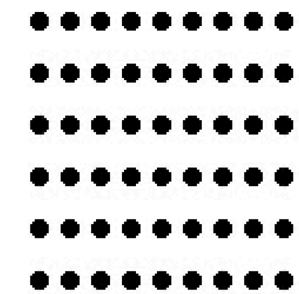
We now take a brief look at gestalt psychology. This is where the phrase “the whole is greater than the sum of its parts” and it deals with the idea that we as people perceive information as a whole rather than the accumulation of its parts. We look at five principles within gestalt psychology relevant to HCI.

https://en.wikipedia.org/wiki/Gestalt_psychology

Principle: Proximity

Objects close to each other
form a group

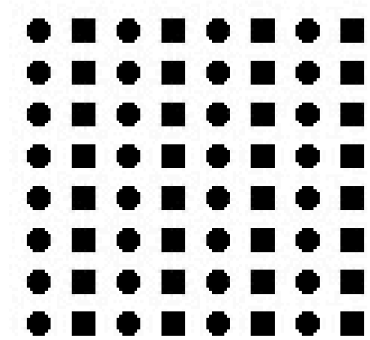




First, the principle of proximity which states that objects laid out close together appear to form a group. For example, the left square appears as six columns, but the right most square appears as six rows.

Principle: Similarity

Objects that are similar form a group

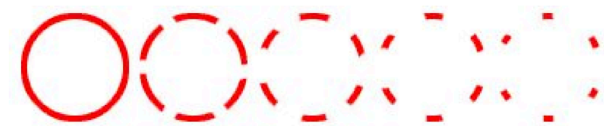


Next the principle of similarity which states that similar objects form groups. So here we naturally see the columns of circles and squares.

Principle: Closure

Even incomplete objects are perceived as whole;

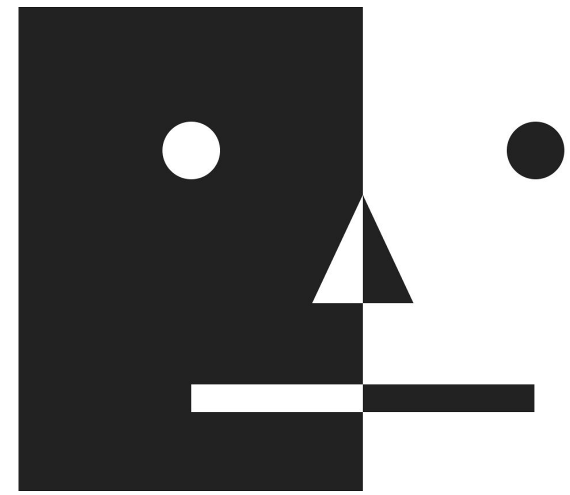
Increases regularity of stimuli



The third principle is closure which states that incomplete objects are perceived as whole. For example, we perceive each object to the left as a circle even though some of them are broken up.

Principle: Symmetry

Objects are perceived as symmetrical
and forming around a center point



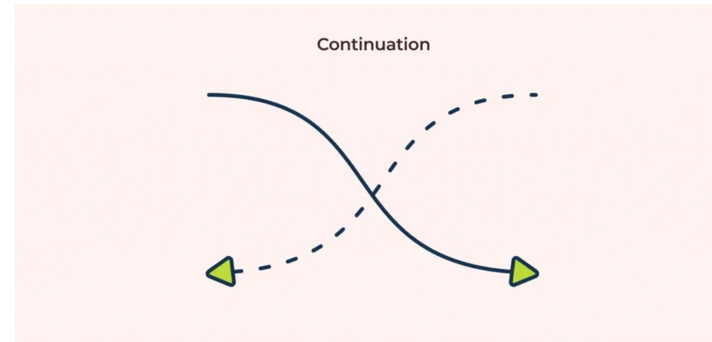
Then we have the principle of symmetry which states that objects can appear symmetrical and grouping around a center. We can see this results in the perception of a face rather than separate objects.

Principle: Continuity

Objects are perceived as grouped when they align

Remain distinct even with overlap

Preferred over abrupt directional changes



Last, we have the principle of continuity. We perceive the image on the left as two lines intersecting each other, rather than two cup shapes placed back to back.

Models from Different Perspectives

Model of Human Performance	Type of Model
Visual System	Biological Model
Model of Human Processor	Higher-level model
Fitt’s Law	Model by analogy
Gestalt Principles	Prediction interpretation

In this lecture, we have gone over each type of model that is important for HCI and how it relates to design. To make it a bit easier, I have also created a….slide change

- **Visual System**
  - The human visual system processes **color, depth, motion, and patterns** to interpret UI elements.
  - **Foveal vision** (sharp, detailed) vs. **peripheral vision** (broad, less detailed).
  - Design implications: Use **contrast**, **hierarchy**, and **grouping** for clear UI
- **Model Human Processor (MHP)**
  - Describes human cognition as an information processing system with:
    - **Perceptual** processor (sensory input)
    - **Cognitive** processor (decision-making)
    - **Motor** processor (action execution)
  - Helps predict user response times in UI interactions.
- **Fitts's Law**
  - Predicts movement time (MT) to a target:

$$MT = a + b\log_2\left(\frac{D}{W} + 1\right)$$

  - D = Distance to the target; W = Width of the target
  - Implication: Larger & closer buttons improve usability.
- **Gestalt Principles** (Perception & UI Design)
  - **Proximity**: Close objects are grouped together.
  - **Similarity**: Similar elements are perceived as a group.
  - **Continuity**: The eye follows smooth paths.
  - **Closure**: Users mentally "fill in" missing information.
  - **Figure-Ground**: Distinguishes objects from the background.
  - Used for intuitive layouts, icons, and visual grouping in UI.

One Slide Summary

Summary slide. Let me know if you have any questions.

Thank you!