User Interfaces

EECS 3461 – Sections A & B
Fall 2021

Resource Pack: Humans (Users) III
Cognition, Attention, Perception

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Dependencies

This resource pack assumes that you are already familiar with:

- R-Humans-II
- R-Design-VIII (and all previous)
- R-Interaction-III (and all previous)

Key Questions

1. What is cognition? (0. Cognitivist model of users?)
2. What is attention?
3. What is perception?

   segue to R-Design-VII

4. How are Gestalt principles applied to visual perception in UX design?
5. What is inattentional blindness and change blindness? And why are these relevant to UX design?
6. Why is attention and perception relevant to UX design?

0. Cognitivist models of users?

First Paradigm [Harrison, 2007]

- The early days of computing (e.g., 1965-1980, prior to personal computing) saw interaction as a form of **man-machine coupling**
  - an amalgam of engineering and human factors, inspired by industrial engineering and ergonomics
- questions to be answered: what are the problems in the coupling? how can we developing pragmatic solutions to them?
- goal of design:
  - optimize the fit between humans and machines, deal with the concrete problems that arise in interaction and that cause disruption

Second Paradigm [Harrison, 2012]

- Next comes a revolution that that human minds are like information processors, and that interaction can be modeled as information exchange between humans and computers
  - the paradigm places "rationality and rational analysis [as] the most important mode of operation for human activity" (Flyvbjerg, 2001, p. 23)
- questions to be answered:
  - 'how does information get in', 'what transformations does it undergo', 'how does it go out again,' 'how can it be communicated efficiently'
- premise:
  - human information processing is deeply analogous to computational signal processing
  - the primary interaction task is enabling communication between the machine and the person

Model Human Processor (Card et al, 1983)

- One of the first HCI models to be used; based on information processing model
- Models the information processes of a user interacting with a computer
- Predicts which cognitive processes are involved when a user interacts with a computer
- Enables calculations to be made of how long a user will take to carry out a task

Second Paradigm [Harrison, 2012]

- premise and starting assumptions:
  - human information processing is deeply analogous to computational signal processing
  - the primary interaction task is enabling communication between the machine and the person
  - operations performed by one in pursuit of a goal affect the state of the other
  - If we modeling the state of the person as well as of the computer, then we can predict and optimize the relationship.

Human as an Information Processor

- a framework that explains how people think/do
- it uses metaphor of an (digital) information processor for the brain (and thus for cognition)
- the metaphor abstracts away the human body, the interactant is reduced to a brain

Information processing

- Conceptualizes human performance in metaphorical terms of information processing stages

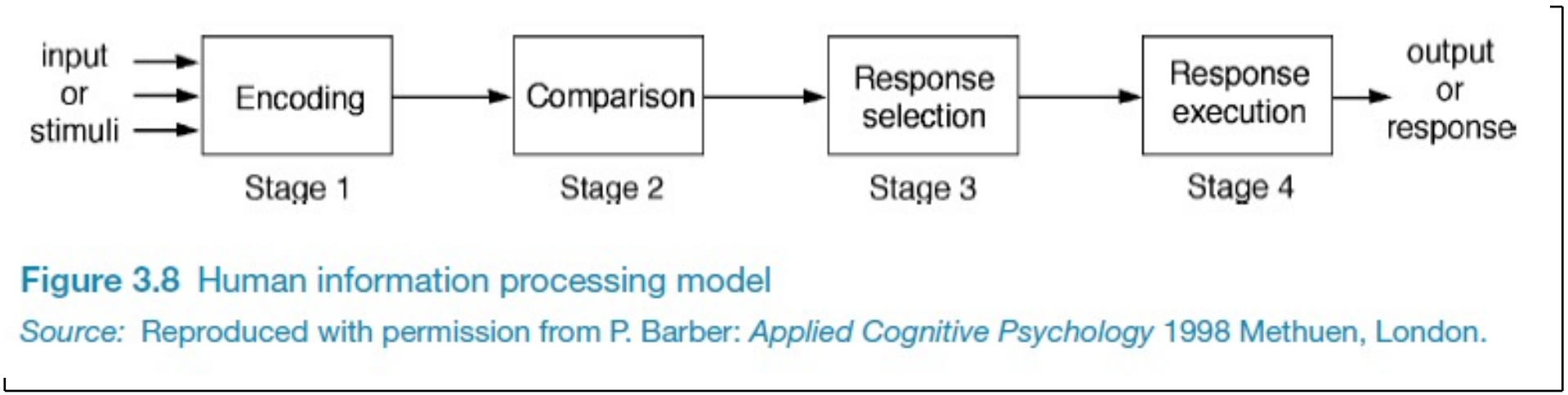


Figure 3.8 Human information processing model

Source: Reproduced with permission from P. Barber: *Applied Cognitive Psychology* 1998 Methuen, London.

What happens in the middle?

- In this model of the user:
  - there is an input stage
  - there is an output stage
  - In between receiving the input and producing the output, something is happening in the mind of the user
  - what is happening? this middle part is the cognitive processing

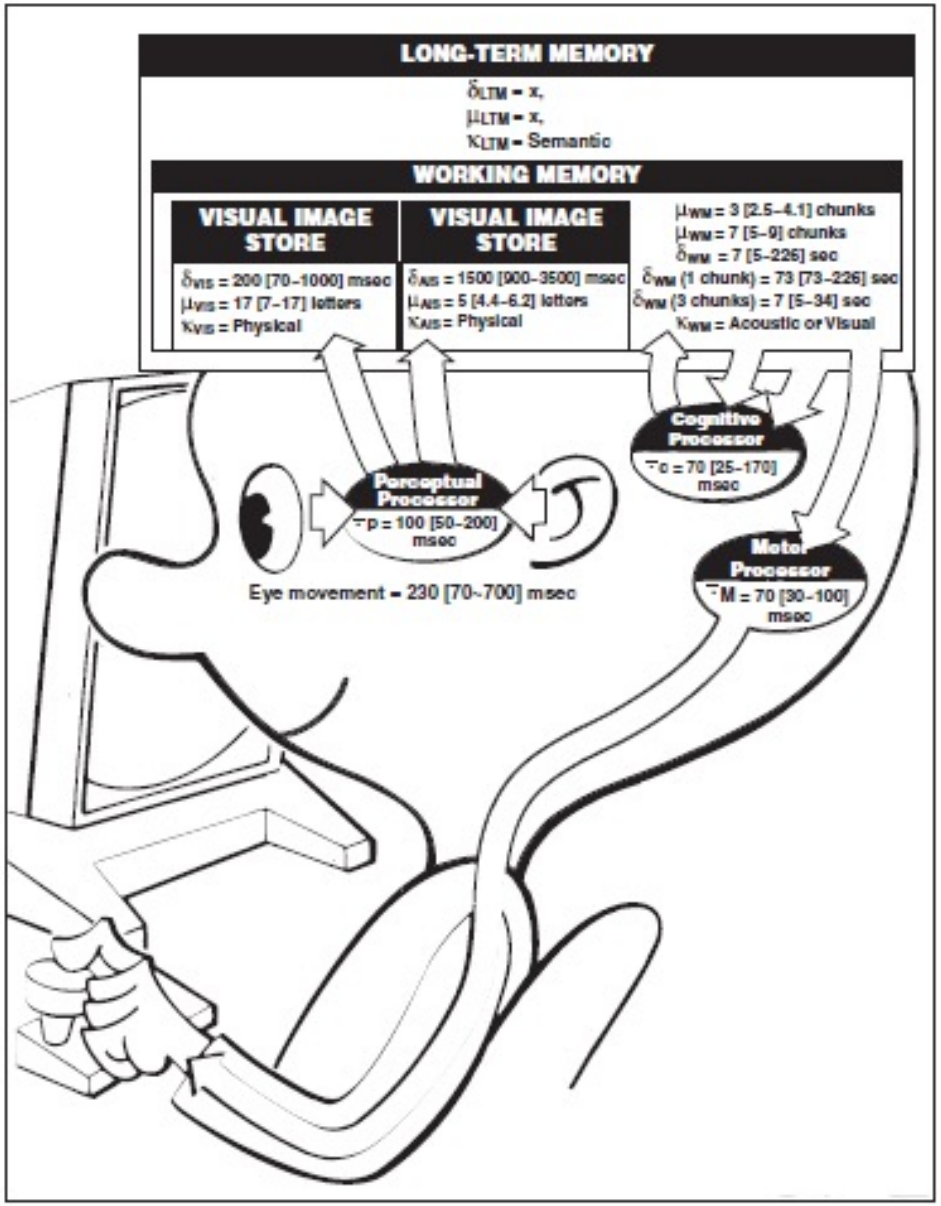


Figure 3.9 The human processor model

Source: The psychology of human-computer interaction by S. Card, T. Moran and A. Newell. Copyright 1983 by Taylor & Francis Group LLC - Books. Reproduced with permission of Taylor & Francis Group LLC.

Mental Models

- a framework that posits that people use mental models generally in cognition, for:
  - reasoning, making decisions
  - generating their next actions
  - generating explanations about what they observed
  - … many more
- There are two key points
  - a mental model is an internal construction
  - a mental model can be "run"
- There is plenty of evidence that people have mental models

Mental models: How do they work?

- Craik (1943) described mental models as:
  - internal constructions of some aspect of the external world
  - constructions that are manipulated somehow (processing)
  - this result of the processing is that predictions and inferences can be made
- Johnson-Laird (1983) and others
  - the process involves unconscious and conscious processes
  - the process involves 'fleshing out' the mental model
  - the process involves 'running' the mental model
  - the process involves activation of images and analogies

Deep vs Shallow Mental models

- Mental models can be formed in a deep or a shallow way
- Example of a deep model:
  - a model of how a car operates to the extent that you can trouble-shoot
  - how the combustion engine turns over, alternator, etc
  - how fuel lines/carberator/etc work
  - how braking systems operate
  - how steering systems operate
- Example of a shallow model:
  - a model of how a car operates to the extent that you can drive it
  - how to start the car
  - how to accelerate
  - how to brake
  - how to turn
- to drive, a shallow model suffices; to trouble-shoot malfunction, need a deeper model

How Do Mental Models Develop?

- Users develop an understanding of a system through learning about and using it
- Knowledge is sometimes described as a mental model:
  - How to use the system (what to do next)
  - What to do with unfamiliar systems or unexpected situations (how the system works)
- People make inferences using mental models of how to carry out tasks
  - they may start with incorrect assumptions
  - they may use inappropriate analogies
  - they may bring superstition into the process
  - they may use evidence to revise their mental models (towards or away from the correct model)

Shallow and Incorrect Mental Models

- there is plenty of evidence that the mental models are frequently erroneous
- Examples: thermostats, household plumbing, tailgating, elevator and crosswalk buttons, etc etc

0b. Norman's gulfs of execution and evaluation

Gulf Bridging

- not really a separate framework from mental models; rather an further component to explain how people behave

- the framework supposes there are two gulfs:
  - a gulf of **execution**
  - a gulf of **evaluation**

Bridging the gulfs

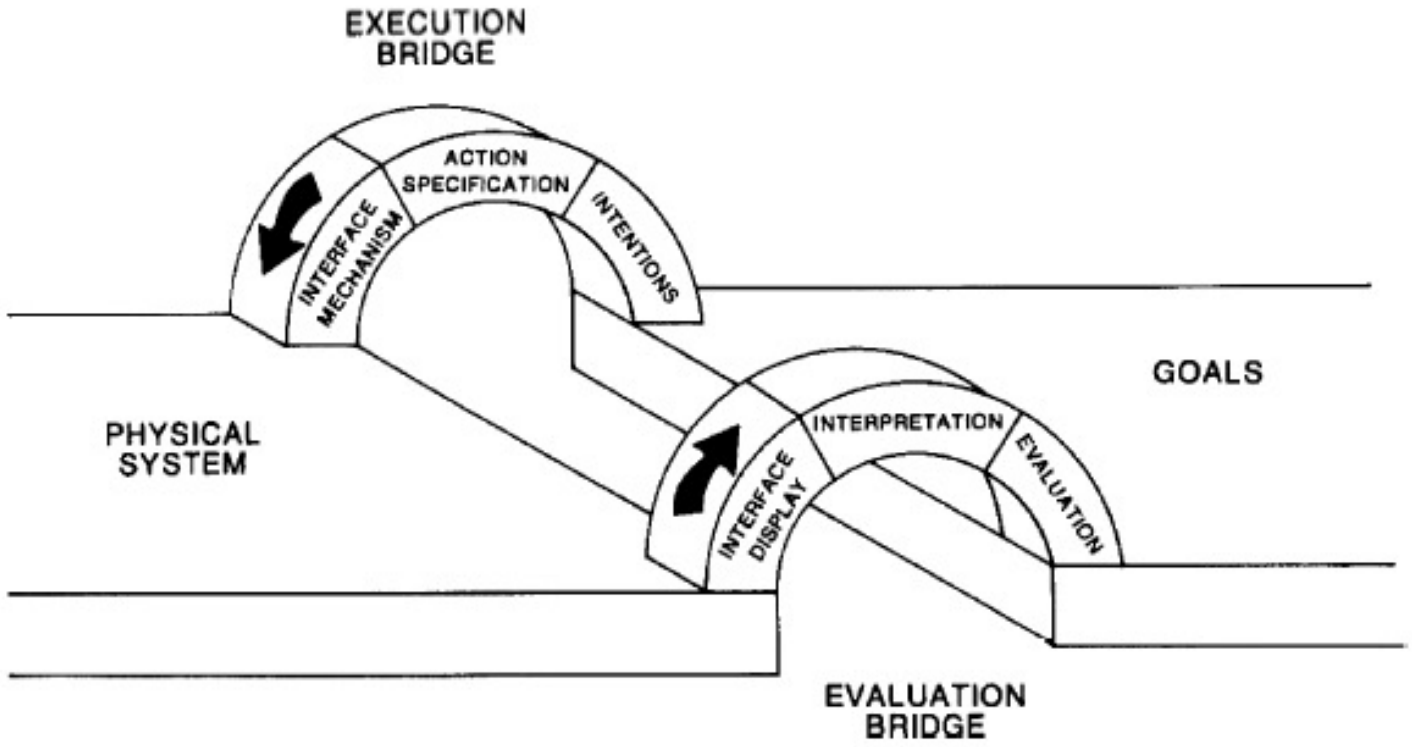


Figure 3.7 Bridging the gulfs of execution and evaluation

Source: User centered system design: new perspectives on human-computer interaction by D Norman. Copyright 1986 by Taylor & Francis Group LLC - Books. Reproduced with permission of Taylor & Francis Group LLC.

Gulf of Execution

- the **gulf of execution** is the difference between the following two things:
  - the user's model of what system is (and what the possible next actions are)
  - what is actually possible with the system
- each user will have their own version of this gulf

Gulf of Evaluation

- the **gulf of evaluation** is the difference between the following two things:
  - the user's model of the system state (what just happened, given action I just did?)
  - the system's actual state
- each user will have their own version of this gulf

Application of the Gulfs

- Norman's model of the gulfs of evaluation and execution have been applied to the design process (which we will cover in R-Design-II)

1. What is cognition?

Course Textbook Reference

- this resource pack draws upon sections 4.1, 4.2, and 4.3 of the course textbook

What is the Mind?

- *cognition* a term that has come to be associated with a scientific approach to the human *mind*
- the mind is understood as a set of "faculties" that includes:
  - cognition
  - other aspects generally considered non-cognitive, such as emotion, personality, motivation, sensory-perception, etc
- characterizing and understanding the human *mind* has been a focus of human activity for thousands of years
  - the study of the mind has been a focus of many other fields and disciplines: e.g., philosophy, religion, science, medicine, among many others
  - the history of the study of the mind is hugely complex
  - each of these fields and disciplines organize themselves around different paradigms, and the paradigms themselves have evolved over time (we will cover paradigms in R-Knowledge Practice-III)

What is the Mind?

- key questions have been and continue to be:
  - do non-humans have minds? what does it mean to have a mind?
  - what is the relationship between the body and the mind? (implies a Western tradition of mind-body dualism)
  - what is the relationship between cognition and the brain?
  - does cognition reside solely in the brain?

Theory of Mind

- the ability or capacity to attribute mental states to oneself and others and to understand that others have desires, intentions, and perspectives that are different from one's own
  - mental states include: beliefs, desires, intentions, perspectives, knowledges, emotions
- thought to be essential for empathy and understanding

What is cognition?

- There are a range of meanings of cognition [Allen, 2017], but generally:
  - cognition is ”the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses” [OED]
  - cognition is “the mental processes such as perception attention, memory, and so on, that are what the mind does” [Goldstein, 2011]
  - “Cognition refers to processes such as memory, attention, language, problem solving and planning” [Pessoa, 2008]
- “Should cognitive scientists be any more embarrassed about their lack of a discipline-fixing definition of cognition than biologists are about their inability to define “life”? [Allen, 2017]

Non-human cognition

- cognition is prototypically human [Allen, 2017]
- animal cognition emerged as a field of study in the 1960's, as researchers started to apply the emerging methods of cognitive science to non-human animals
  - mammals, primates, sea otters, dogs, etc
  - birds, corvids especially
  - fish
  - cetaceans, octopods
- 'the cognitive capacities of collectives (insect swarms, human group)" have been "assumed to be too different from prototypical human cognition" [p. 4234, Allen, 2017]
- "bacterial cognition, slime mold intelligence, and plant cognition, raise boundary questions about the scope of cognitive science" [p. 4237, Allen, 2017]
- see biosemiotics

What is considered cognition?

- memory
- reasoning
- planning
- problem solving
- learning
- language, writing, reading
- perception
  - there is a debate about whether perception is separate from cognition [Firestone and Scholl, 2015]

What is **not** considered to be cognition?

- "Non-cognitive skills are defined as the "patterns of thought, feelings and behaviours" (Borghans et al., 2008) that are socially determined and can be developed throughout the lifetime to produce value. Non-cognitive skills comprise personal traits, attitudes and motivations" (Zhou, 2016)
- traditionally, emotion has **not** been thought of as a cognitive process [Pessoa, 2008]
- social interaction:
  - cognitive: social cognition focuses on the how people process, store, and apply information about other people and social situations using cognitive processes
  - non-cognitive: empathy and social emotions are considered non-cognitive

Metacognition

- **Metacognition:** one's awareness of one's own strategies and methods of cognition

Cognition as the basis

- We will use this characterization of cognition as the basis for engaged with the topics of attention and perception

2. What is attention?

Attention is a cognitive mechanism

- The human mind is bombarded with millions of stimuli.
- The human mind is constrained; it can process only a fraction of this incoming information.
- The human mind must have a way of deciding which of this information to process.
- **Attention is a cognitive mechanism**
  - **it implements processes whereby this selection process is performed**
  - "a general term for selectivity in perception" [Int'l Encyclopedia of the Social & Behavioural Sciences]
  - also described as the 'allocation of limited cognitive processing resources' (Anderson, 2004)

Visual, Auditory, other Stimuli

- The human mind is bombarded with millions of stimuli, with respect to **each of the sensory pathways**
- Attention works differently for each of these pathways

Elaboration: auditory bombardment

- the auditory system can be bombarded with acoustic signals from multiple sources, and each ear can receive either slightly or completely different information
- why slightly different information?
  - because the ears are spatially distinct, thus the incoming signals will be subtly different
- why completely different information?
  - because dichotic listening scenarios can and do happen
  - dichotic listening: when each ear receives its own auditory stimuli (e.g., a person can be presented with two different auditory stimuli simultaneously)

The 'cocktail party' phenomenon

- "when person is selectively listening to one message among many yet hears his or her name or some other distinctive message such as "Fire!" that is not being attended" [Goldstein, 2011]

- e.g., You are in a crowded room with many people talking all at once. You are engaged in conversation talking to one person, paying close attention. Yet if someone is another conversation that is within earshot mentions your name, you immediately perk up and notice.

Elaboration: visual bombardment

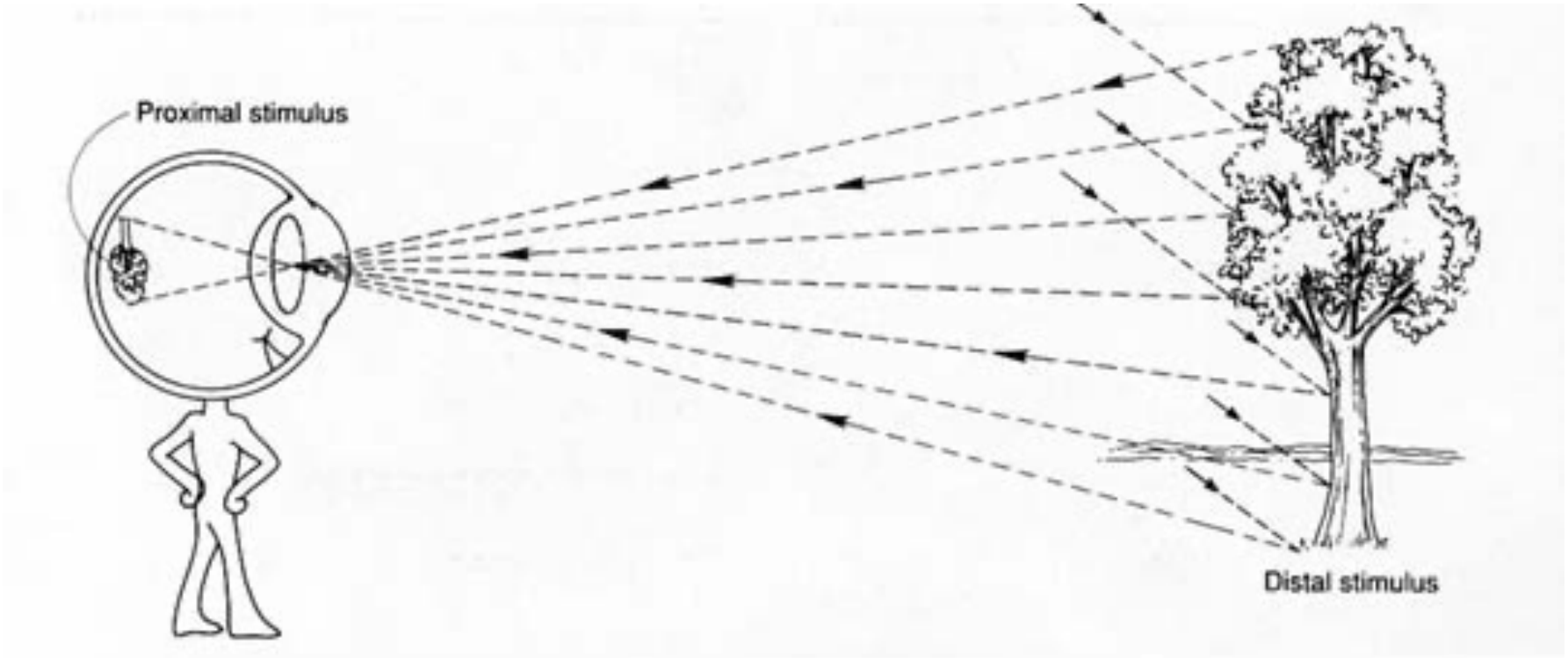
- the visual system receives information from the entire visual field but only a subset can be processed
- "Visual selection is also dramatic, since the raw data transduced by the retinal photoreceptors (Kelly, 1962) come at a rate of many megabytes per second. Note that several megabytes is more than that is needed to encode the text in a typical long novel. The data rate has to be reduced by more than 99% to about 102 bits per second (Sziklai, 1956), the capacity of the human attentional bottleneck." [Zhaoping, 2014]

The Visual Scene is an Illusion

- One has impression of perceiving entire visual scene in finely-grained detail all at once.
- This is an illusion created by the brain

ADDENDUM – VISION BASICS /start

Vision Basics



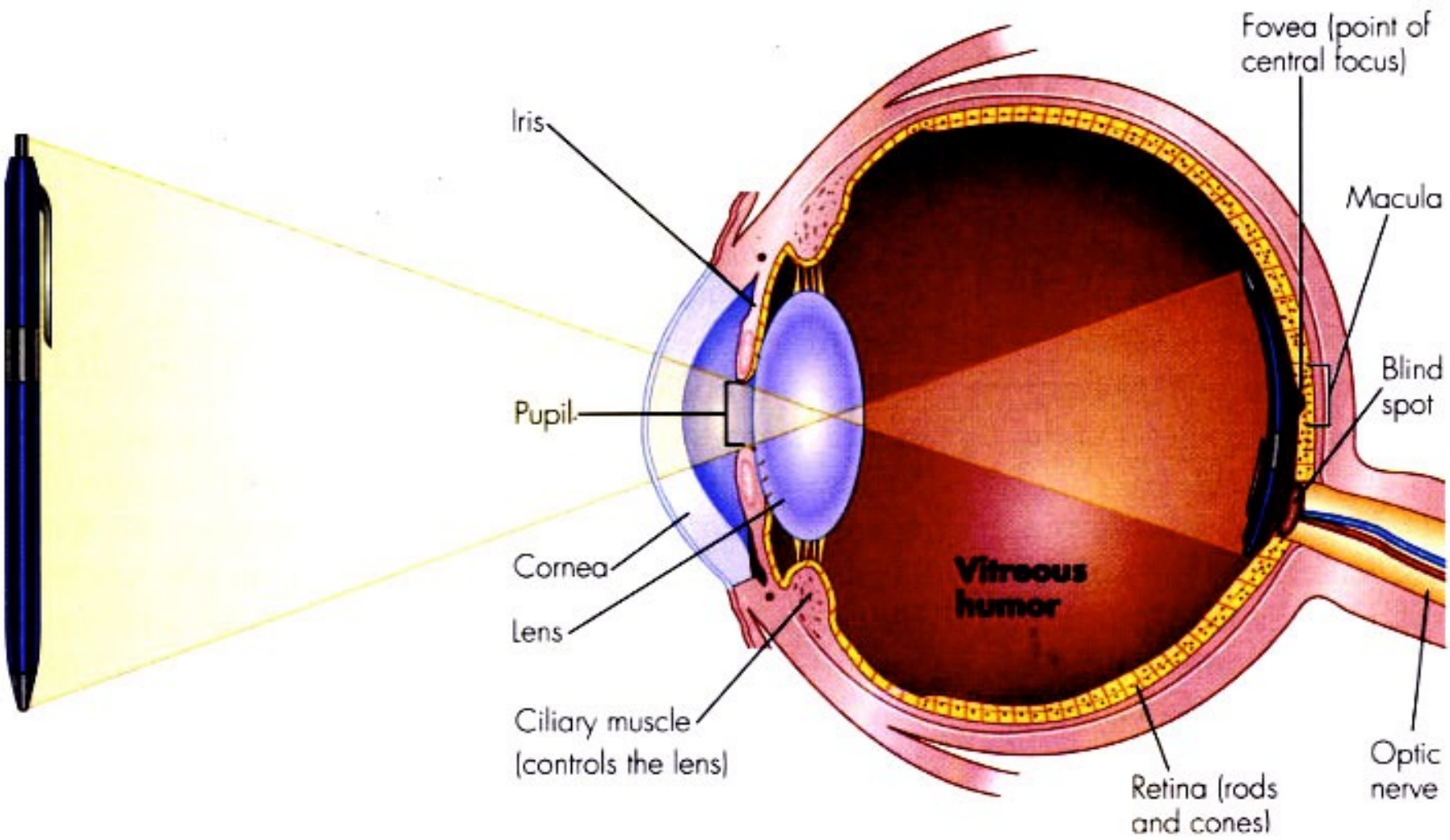
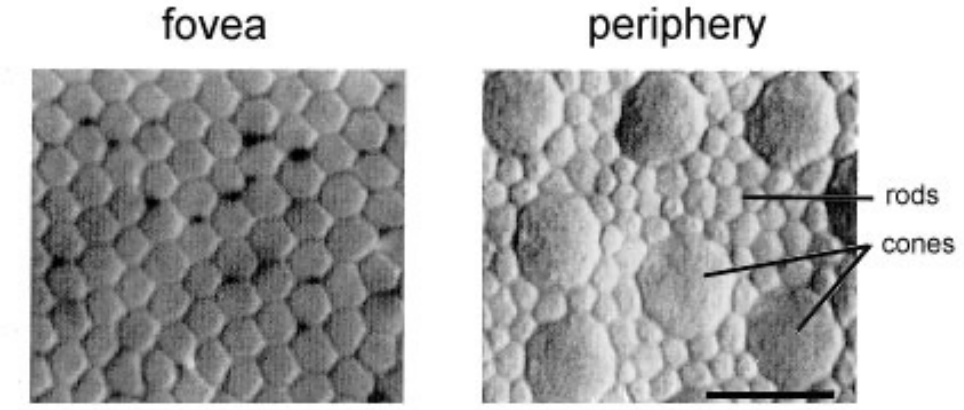


Figure 6.2 Cross section of the vertebrate eye
Note how an object in the visual field produces an inverted image on the retina.

Areas of the Retina

- photoreceptors are situated on the retina
  - two types: *rods* and *cones*
  - when light enters eye, it passes through these layers of cells before it hits the photoreceptors
- fovea: tight packing of receptors (cones, no rods)
  - in center of retina, specialized for acute detailed vision
- periphery of retina: proportion of rods to cones increase toward edge of retina



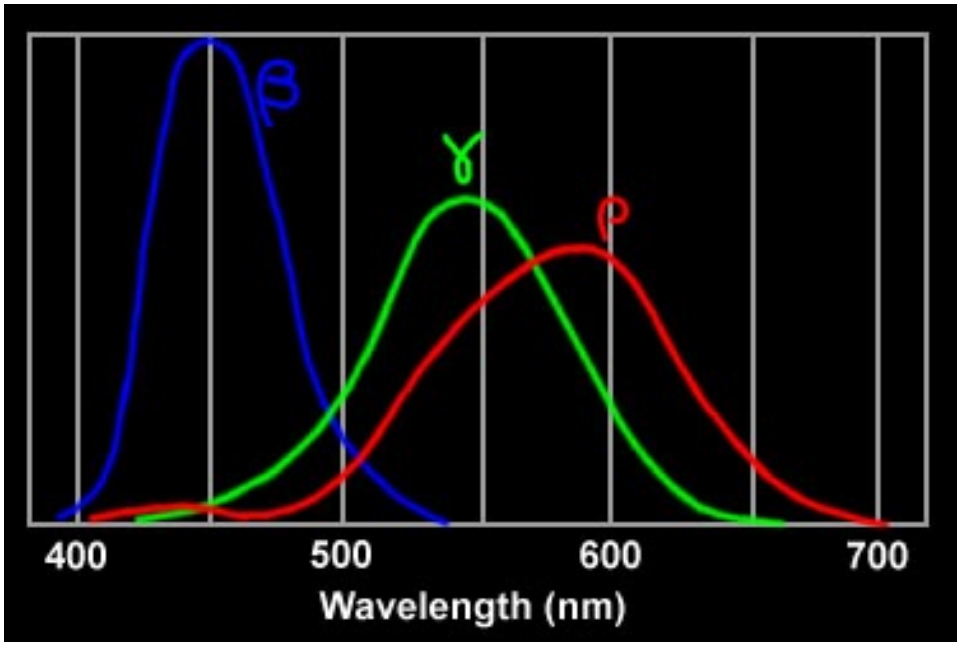
Colour Vision

- Cones: three types of cones: short-, medium-, and long-wavelength
- *Hue* is what we normally think of as colour
  - e.g., red vs. orange vs. yellow vs. green etc.

Red –
perceived by long-wavelength cones

Green –
perceived by medium-wavelength cones

Blue –
perceived by short-wavelength cones



Colour Vision

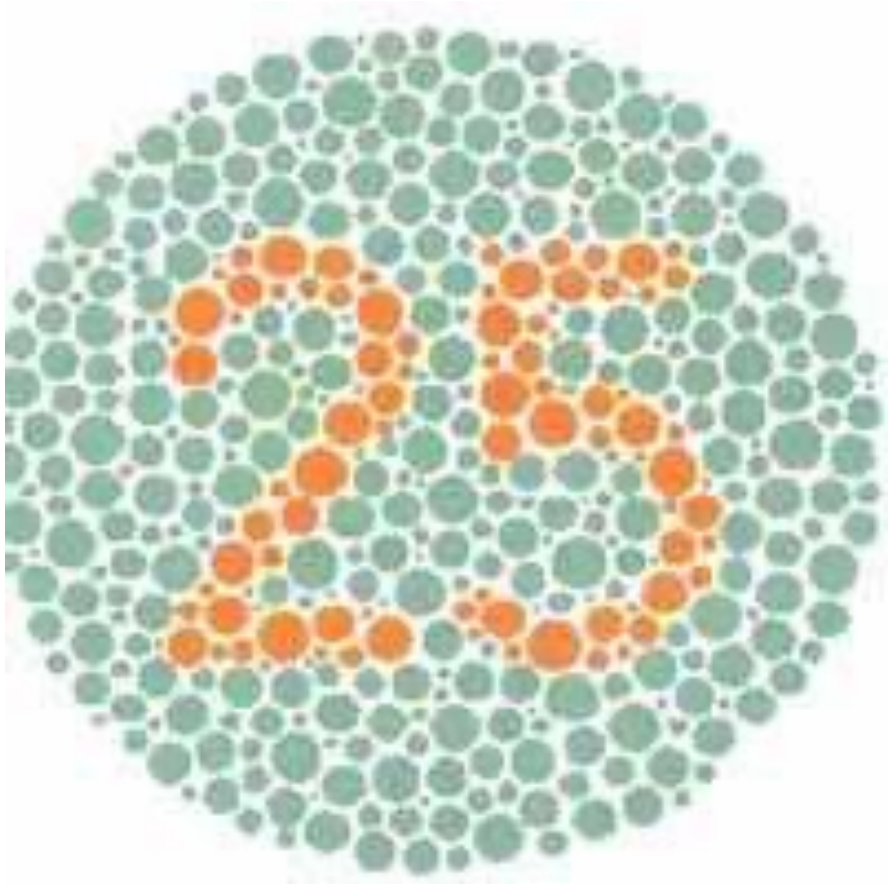
- Rods: *rods* are more sensitive to light than *cones*
  - are not specialized to particular wavelengths, instead attuned to a broad spectrum of light
- Intensity, also called *luminance* or *brightness*
  - how much light/dark
- The ratio of cones to rods in human retina is 1:10
  - what does this mean for relative sensitivity to variations in *hue* vs. *intensity*?

Colour Vision: Colour Blindness

- Dyschromatopsia
  - A condition in which the ability to perceive colours is not fully normal
    - 5-8% of males, 0.5% of women
    - red-green colour blindness most prevalent

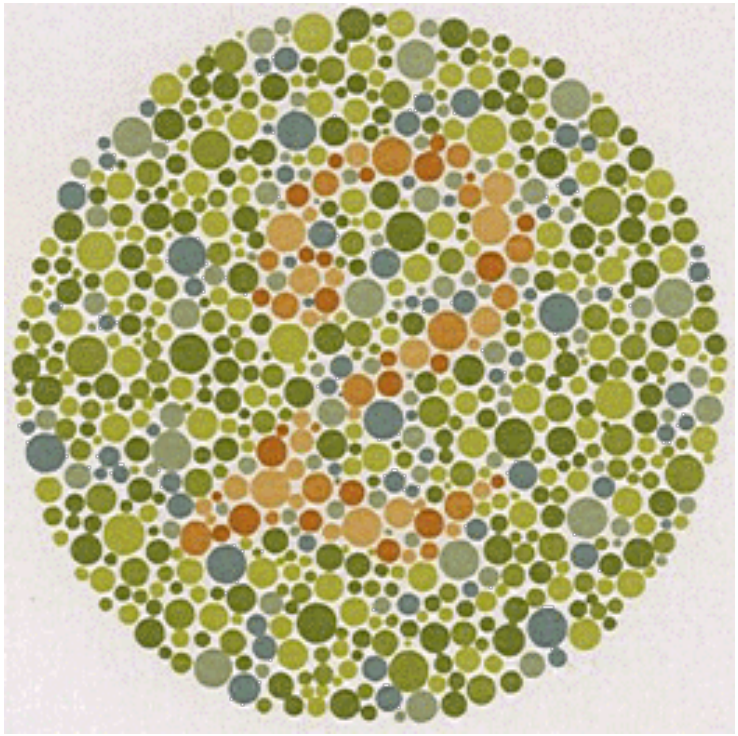
Testing Colour Blindness

"Ishihara plates" are used

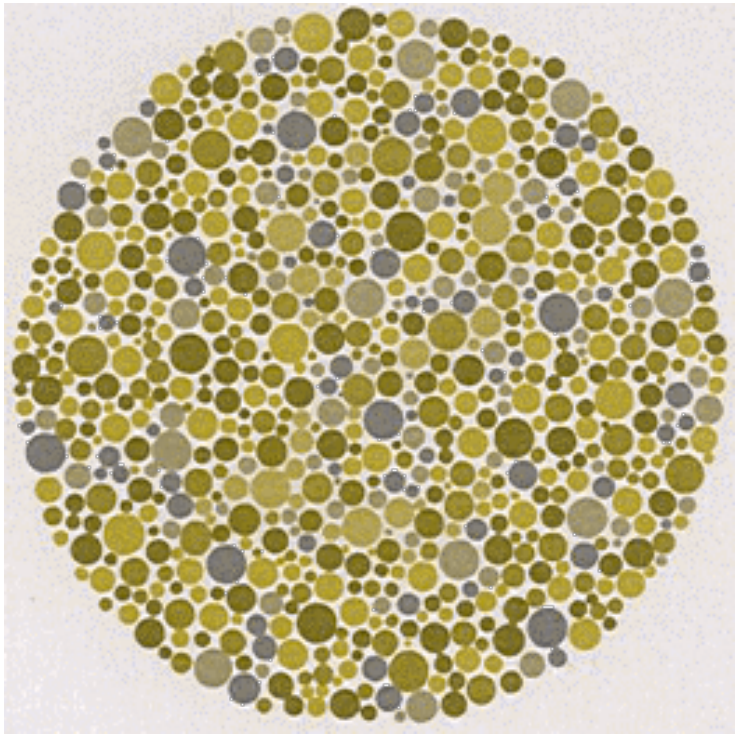


Simulation of Colour Blindness

stimulus image



perceived image



The Visual Scene is an Illusion

- The brain performs successive sampling of only small subsets of the visual scene via the fovea via various fixations
  - these eye movements are called *saccades:* rapid, ballistic movements of the eyes that abruptly change the point of fixation
- The brain makes use of specialized neurological processing to knit together all of these samples
  - this creates the illusion of the entire visual scene being seen in finely-grained detail all at once

ADDENDUM – VISION BASICS /end

Endogenous and Exogenous Attention

From Goldstein, 2011:

- **exogenous** attention refers to the automatic attraction of attention by a sudden visual or auditory stimulus
  - e.g., something moves off to the side and, without thinking, you automatically look toward it. A car backfires, and you turn your head to determine where the sound came from.
- **endogenous** attention refers to consciously determined attention
  - e.g., you consciously decide to scan the environment, perhaps to find a specific stimulus or just to keep track of what is going on.

Vision and attention; overt and covert attention

- there is a heavy focus on **vision** and **attention**, although attention is not specific to visual stimuli

[Goldstein, 2011]:

- **overt attention** refers to shifts of attention that are accompanied by eye movement
  - the movements of the eyes provide observable signals of how attention is changing over time
- **covert attention** refers to shifts of attention which occurs when attention is shifted without moving the eyes
  - commonly referred to as seeing something "out of the corner of the eye" (as you might do while trying to check someone out without looking directly at him or her)

Selective and Divided Attention

- attention is most often associated with **selective attention**—the focusing of attention on one specific location, object, or message

- **divided attention** refers to attending to two or more things at once

Selective Attentional Processes

- The first modern theory of selective attention was the filter theory of Broadbent (1958) (also called 'early selection model', 'bottleneck model')
- In this theory:
  - information flows from the senses through many parallel input channels and along the line there is a a selective filter which acts as an all-or-none switch that selects information from just one of the parallel input channels at a time
- "Broadbent's model provided testable predictions about selective attention, some of which turned out not to be correct" [Goldstein, 2011]
- The field of cognitive psychology then generated other models: attenuation-based and late selection models of attention

Inattentional Blindness

[Goldstein, 2011]:

- we may fail to perceive things that are clearly visible in our field of view
- experiments demonstrate that when observers are attending to one sequence of events, they can fail to notice another event, even when it is right in front of them

Activity

- You will watch a video
- You will see two teams of three players each.
- Count the number of times the players wearing white pass
- the basketball.
- Ready?
  - Watch the video for the “selective attention test” on the course website
  - https://www.youtube.com/watch?v=vJG698U2Mvo

What does this activity demonstrate?

- Did you notice the gorilla?
- In the experiment, nearly half—46 percent—of the observers failed to report having seen the event, even though it was clearly visible
- This demonstrates inattentional blindness

Change Blindness

- change blindness is an inability or difficulty in detecting changes in scenes
- Viewing Activity:
  - Change blindness demonstration
  - https://www.youtube.com/watch?v=bh_9XFzbWV8

Ambient Displays and Attention

- **Ambient displays** are defined as those that are "minimally attended" (e.g. just salient enough for conscious perception)
- **Alerting displays** are "maximally divided" (e.g. slightly less salient than focal tasks)
- Matthews et al (2004) categorize human attention (i.e., intent and expectation towards a stimulus) into three types:
  - **inattention**: stimulus is not directly available for conscious awareness but may still affect behavior (e.g., memory recall)
  - **divided attention**: distributing attention over several stimulus
  - **focused attention**: using all attentional resources to focus on one stimulus

Multitasking

- There has been much research on the effects of multitasking on memory and attention (Burgess, 2015).
- The general findings are
  - the ability to multitask depends on the nature of the tasks and how much attention each demands
  - the ability to multitask depends on the individual, and degree to which a person is distractable

Divided Attention

- divided attention refers to the distribution of attention among two or more tasks
- **automatic processing** is a type of task processing that occurs without intention and at a cost of only some of a person's cognitive resources
- **controlled processing** is the type of task processing that requires close attention

- Q: when we perform multiple tasks, what is the impact, if any on the task outcomes?
- In other words, are you better off doing one thing at a time in sequence or doing multiple things in parallel?
- e.g.
  - task 1: read a passage, task 2: have a text message conversation with a friend
  - sequential mode: task 1 takes 10 min, task 2 takes 3 min
  - parallel mode: task 1 and task 2 together takes… [will the time be > 13 min?]

Can divided attention be practiced?

- if many trials of practice can result in automatic processing, then divided attention can be achieved with practice
- if the task is difficult and controlled processing is required, then divided attention becomes very difficult

Are some people more distractable than others?

- [Sharp et al, 2019]:
  - a series of experiments comparing heavy with light multitaskers
  - the results showed that heavy media multitaskers were more prone to being distracted by the multiple streams of media they are viewing than those who infrequently multitask
- Infrequent multitaskers were found to be better at allocating their attention when faced with competing distractions (Ophir et al, 2009)

Being good vs bad at multitasking?

- A study of completion rates of coursework found that students who were involved in instant messaging took up to 50 percent longer to read a passage from a textbook compared with those who did not instant message while reading (Bowman et al., 2010).
- Multitasking can also result in people losing their train of thought, making errors, and needing to start over.

if you are interested in this topic, a suggested reading is:

Hayles, N. Katherine. "Hyper and Deep Attention: The Generational Divide in Cognitive Modes." Profession, 2007, pp. 187–199. JSTOR, www.jstor.org/stable/25595866

Hyper and Deep Attention: The Generational Divide in Cognitive Modes

N. KATHERINE HAYLES

Networked and programmable media are part of a rapidly developing mediascape transforming how citizens of developed countries do business, conduct their social lives, communicate with one another, and—perhaps most significant—think. This essay explores the hypothesis that we are in the midst of a generational shift in cognitive styles that poses challenges to education at all levels, including colleges and universities. The younger the age group, the more pronounced the shift; it is already apparent in present-day college students, but its full effects are likely to be realized only when youngsters who are now twelve years old reach our institutions of higher education. To prepare, we need to become aware of the shift, understand its causes, and think creatively and innovatively about new educational strategies appropriate to the coming changes.

The shift in cognitive styles can be seen in the contrast between deep attention and hyper attention. Deep attention, the cognitive style traditionally associated with the humanities, is characterized by concentrating on a single object for long periods (say, a novel by Dickens), ignoring outside stimuli while so engaged, preferring a single information stream, and having a high tolerance for long focus times. Hyper attention is character-

3. What is perception?

Sensation vs Perception

- Sensation and perception refer to an interleaved set of processes
- Sensation:
  - refers to the parts that involve the detection of a stimulus by the sensory receptors, which is initiated by an energy change in the environment (transduction)
- Perception:
  - refers to the parts that involve the selection, organization, and interpretation of sensory information that give an object or event its meaning

The Human Sensory System

The human sensory system consists of a number of different systems:

- **auditory**
- **visual**
- **somatosensory**: informs us about objects in our external environment through touch (i.e., physical contact with skin) and about the position and movement of our body parts (proprioception) through the stimulation of muscle and joints.
- **viscerosensory**: sensitive to mechanical, thermal and chemical stimulation of the viscera (i.e., internal body organs such as the heart and gastrointestinal tract)
- **olfactory** and **gustatory**: chemical senses of smell and taste
- **vestibular**: tells us about the orientation of the body with respect to gravity and the orientation of the body with respect to self generated movements

Sensory Pathways

A sensory pathway carries peripheral sensations from a sensory organ to the brain. [2]

A sensory pathways consist of the chain of neurons, from receptor organ to cerebral cortex, that are responsible for the perception of sensations. [1]

Sensory pathways are called *ascending* pathways

- in contrast with *descending* pathways, which carry motor output from the brain to control the musculature through motor neurons)

The various sensory modalities each follow specific pathways through the central nervous system.

Senses

Don't confuse a *human sense* with a *human sensory pathway*, which is only part of the sense.

Example

- the *human sense* of vision is active (not only 'input processing'). The visual system also involves action. For instance, the brain causes action of the eyes in order to scan the visual field in response to visual stimuli.
  - for the visual sense, there is a 'feedback loop' between the sensory 'input' and motor 'output'
- the *visual pathway* begins with the retina and the photoreceptors, which are in synaptic relationship with the second neurons of the visual pathway.
  - in the pathway, when light hits the eye, the photoreceptors produce a response that travels along neural pathways and results in brain activity.

Key Questions

1. how is information acquired from the environment via the different sense organs organs?

2. how is this information transformed into experiences of objects, events, sounds, and tastes?

Perceptual Processing

[pp. 50-52, Goldstein, 2011]:

- **bottom-up processing** is the first step in perception, the stimulation of receptors by stimuli from the environment
- perception involves more than bottom-up processing
- We are able to recognize different objects based on perceptual building blocks, and to give these objects names like “pail” or “cup,” because of knowledge we bring to the situation.
- processing that begins with a person’s prior knowledge or expectations is called **top-down processing**
- the knowledge that a person brings to the situation can influence perception
- attention has an impact on perceptual processing

Object Perception

[pp. 50-52, Goldstein, 2011]:

- how do we perceive objects? two approaches to explain:
  - Helmoltz's theory of unconscious inference
  - Gestalt processing

Helmholtz's Theory of Unconscious Inference

[pp. 57-52, Goldstein, 2011]:

- Helmholtz proposed a principle called the *theory of unconscious inference*, which states that some of our perceptions are the result of unconscious assumptions that we make about the environment

- The theory of unconscious inference includes the *likelihood principle*, which states that we perceive the object that is most likely to have caused the pattern of stimuli we have received.

Gestalt Principles of Form Perception

- Gestalt principles explain certain perceptual phenomena
- Law of Similarity
  - elements will be grouped perceptually if they are similar to each other; people perceive groupings on the basis of similarity
- Law of Proximity
  - when we perceive a collection of objects, we will see objects close to each other as forming a group
- Law of Prägnanz (figure-ground)
  - in perceiving a visual field, some objects take a prominent role (the figures) while others recede into the background (the ground)
- Law of Symmetry
  - when we perceive objects, we tend to perceive them as symmetrical shapes that form around their centre
- Law of Closure
  - we perceptually "close up" (i.e., complete) objects that are not, in fact, complete
  - people perceive single objects even when part of the object is obscured

4. How are Gestalt principles applied to visual perception in UX design?
5. What is inattentional blindness and change blindness? And why are these relevant to UX design?
6. Why is attention and perception relevant to UX design?

segue to R-Design-VII