The Human Controller
Class 2. From Perception …

"If the doors of perception were cleansed, everything would appear to man as it is: infinite." - William Blake

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Take Home Message Lecture 1

In Lecture 1 you have learned:

1. Learning goals of this class (to reproduce and apply concepts, to be critical of human-machine interaction design)

2. That this class is about humans controlling devices, and how to engineer better human-machine interaction,
   - which is difficult (due to human variability, imprecise predictions, adaptation) but necessary (to deal with future challenge)

1. The outline and planning of the coming lectures and assignments

2. That the human controller is adaptive and has strengths, limitations, preferences in: Perception, Cognition, Action

Learning Goals Lecture 2

After this lecture, you will be able to:

1. Reproduce the human sensors
    1. Basics of anatomy, functionality of the eye, ear and vestibular organ

2. Reproduce important theories of perception

1. Reproduce the observation window, and apply it to different sensory perception

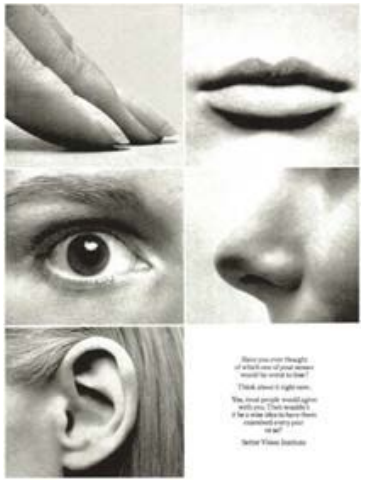
2. Apply methods to determine limitations in perception

3. Be critical of the limitations in applying fundamental perception research in understanding dynamic perception-action couplings & multi-sensory integration

Our human sensors

The ‘traditional’ five senses:

- Eyes (see)
- Ears (hear)
- Skin (touch=tactile)
- Nose (smell)
- Tongue (taste)



Less-known (but important) senses:

- Vestibular senses (motion/acceleration)
- Proprioceptive senses (muscle stretch, muscle force)

Human senses (by function)

Internal

- Propriocepsis (sensors in muscles)

Direct contact

- Taste (tongue)
- Tactile (skin receptors)
  - Pressure, temperature, vibration

External

- Smell (nose)
- Auditory (ears)
- Visual (eyes)
- Vestibulary (vestibulary organs)

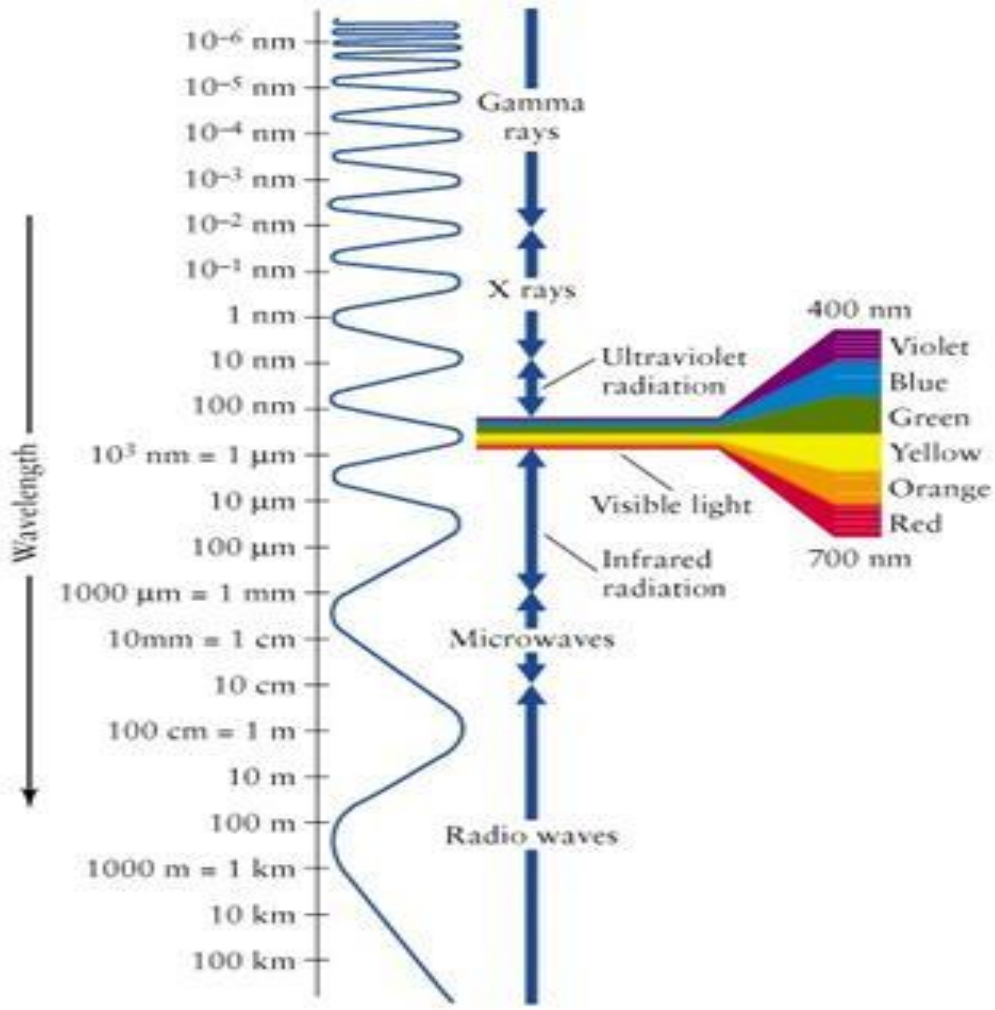
How do we perceive the world?

1. What is there?
2. What is it like?

Philosophical Questions!

- Metaphysics
- Ontology
- Phenomenology

Modern insight shows us we can only perceive a very small portion of reality, e.g. with our visual sensors, only a tiny portion of the electromagnetic spectrum



Brief history: thinking about perception

Natural Philosophy

- Thales of Milete (500 BC)

Descartes (1596 – 1650)

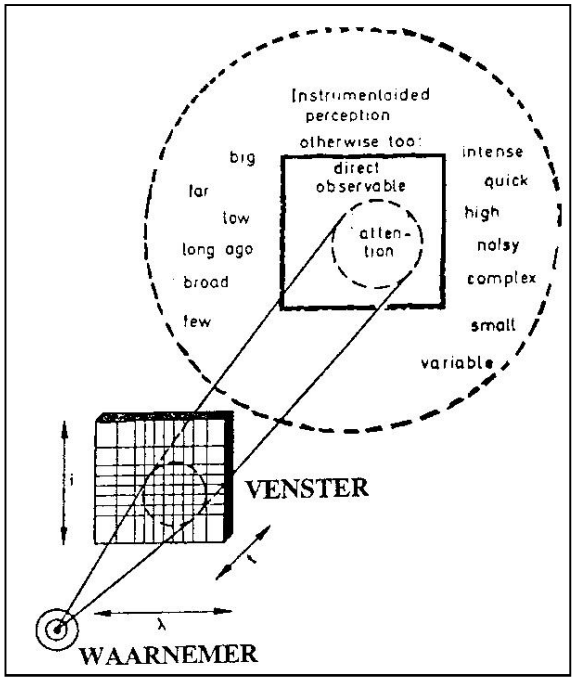
Cartesian: subjective vs objective

Kant (1724-1804)

The external world, he writes, provides those things that we sense. It is our mind that processes this information about the world and gives it order

Scientific Method

Emperical findings – experiments!



Ernst Weber (founder of experimental psychology

Measuring sensory perception

How good is perception?

Human sensory perception is not perfect

Not all information can be perceived
- Sensor limitations

Not all information can be processed
- Cognitive limitations

Making sense: illusions and mix-ups
- Within one sense, between conflicting senses

How good is perception?

Acuity of sensory organs is different between persons

Perception can also change within a person, as a result of:

- Context
- Expectation, Experience, Attention
- Age, Disease, Accidents
- Deprivation of sleep, food,
- Drugs

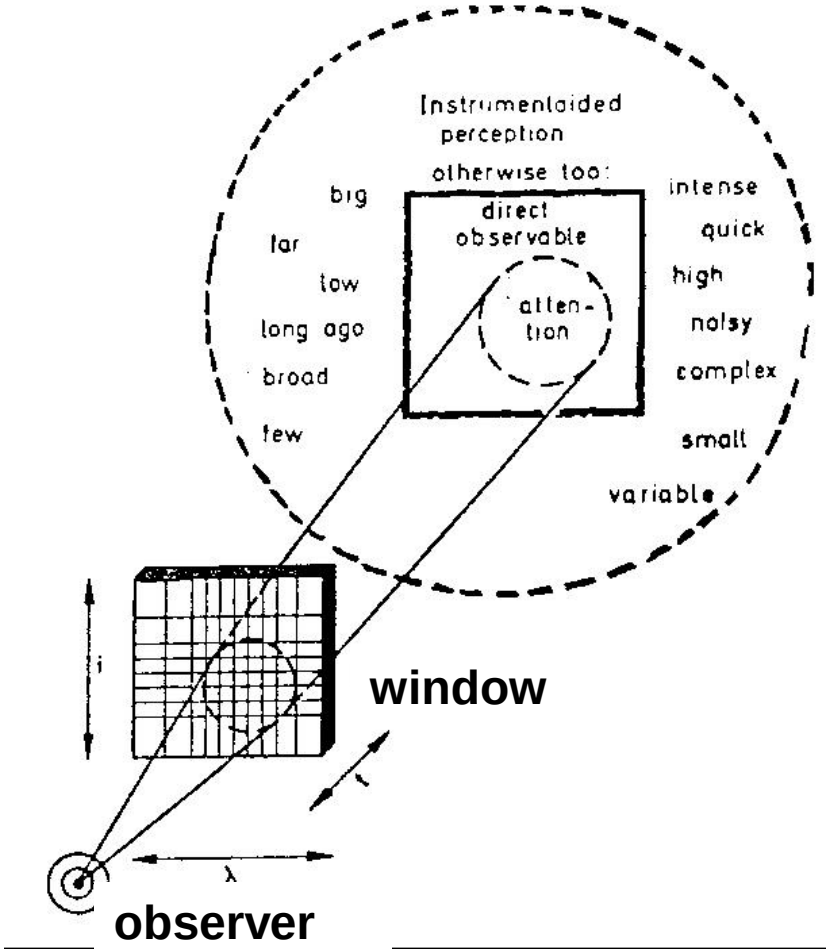
Measuring Human senses

Psychophysics

Sensation		Stimuli
Psychological domain		Physical domain
Subjective		*Objective*

Focus of Psychophysics:
Measuring perception limits of human sensory organs

Observation Window



Observation Window

Frequency vs Amplitude of a stimulus signal

- Lower boundary: Sensitivity
- Upper boundary: Damage
- Optimal region: Most detail, least effort

- Window area depends on person, and can change by:
  - Ageing
  - Disease
  - Trauma

- Technology provides:
  - Extension of observation window (microscope)
  - New observation windows (infrared sensor)

Time is a factor in perception

Time characteristics of a signal

- Latention time
  - Time needed before stimulus results in nerve signal
- Reaction time
  - Time to action on sensor stimulus
- Adaptation time
  - Time span in which sensor adapts to signal
- Fusion time
  - Time span in which two signals are perceived as one

Two kinds of Perception Limits

Perception Threshold

- Smallest amplitude of a signal, that can just be perceived

Just noticeable difference (JND)

- Smallest difference between two signals (in frequency or amplitude) that just can be perceived

Both depend on

- Alertness
- Training
- Attention
- Previous stimuli
- Central or peripheral (vision)

Weber's law

Ernst Heinrich Weber (1795-1878):

"the perceivable difference between one stimuli and the next, depends on the magnitude of the stimulus itself. The ratio between these is constant"

$$k = \frac{\Delta I}{I}$$

Issues with measuring perception

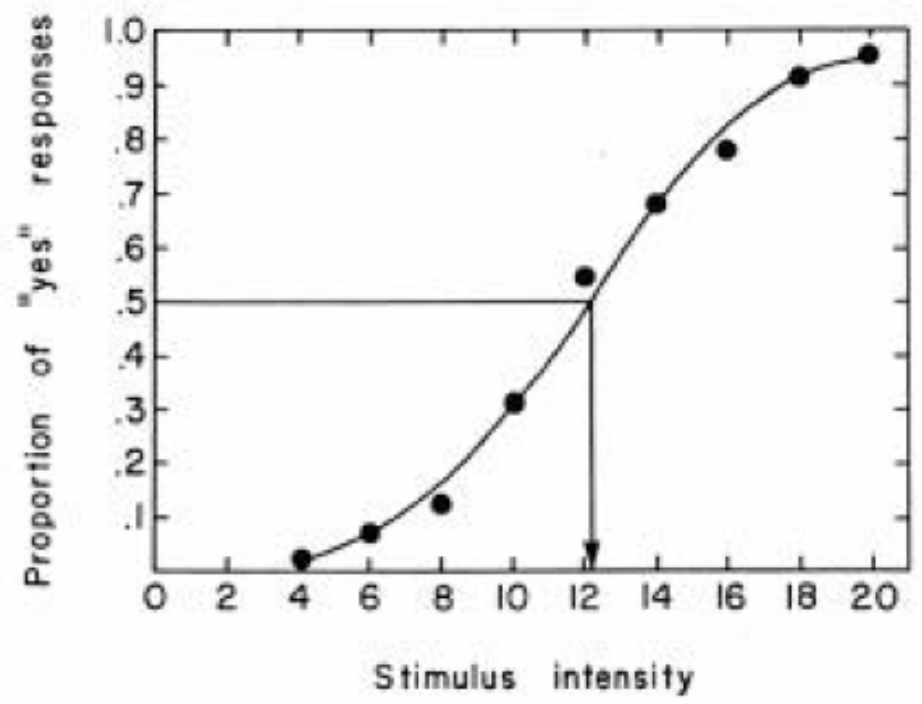
A given stimulus near the perception threshold is sometimes perceived, and sometimes not...

Perception thresholds are not fixed, not even for the same subject!

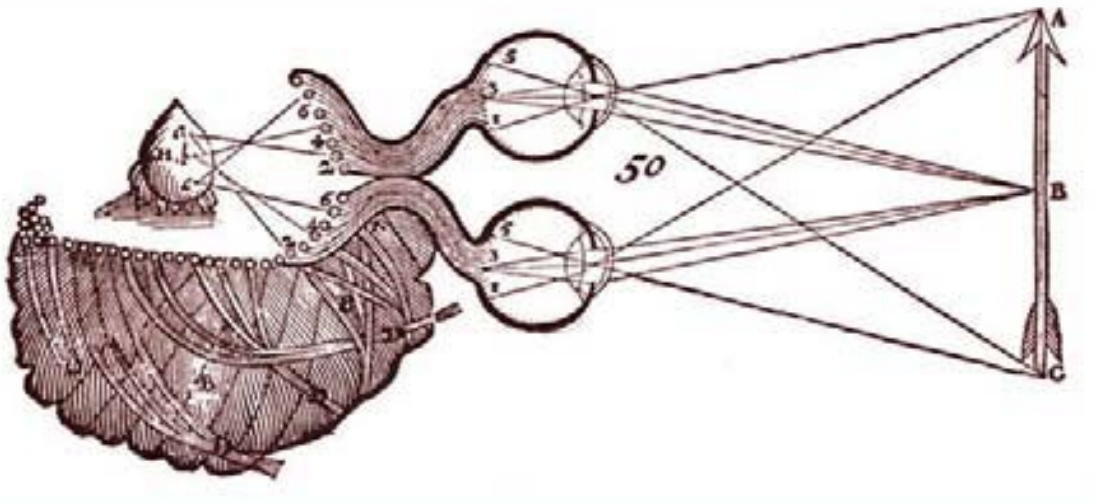
- Why?
  - Noise in sensors (e.g. sometimes firing without stimulus)
  - Subjective issues in answering (e.g. mood, personality)
- As a result, more trials leads to more reliable data

Determining Perception Limits: Method of Constant Stimuli

1. Stimulus presented
2. Subject indicates detection
3. Number of trials at each stimulus intensity
4. Proportion detected stimuli at each stimulus intensity



Millman, 1995



Visual Sensory System

The visual system

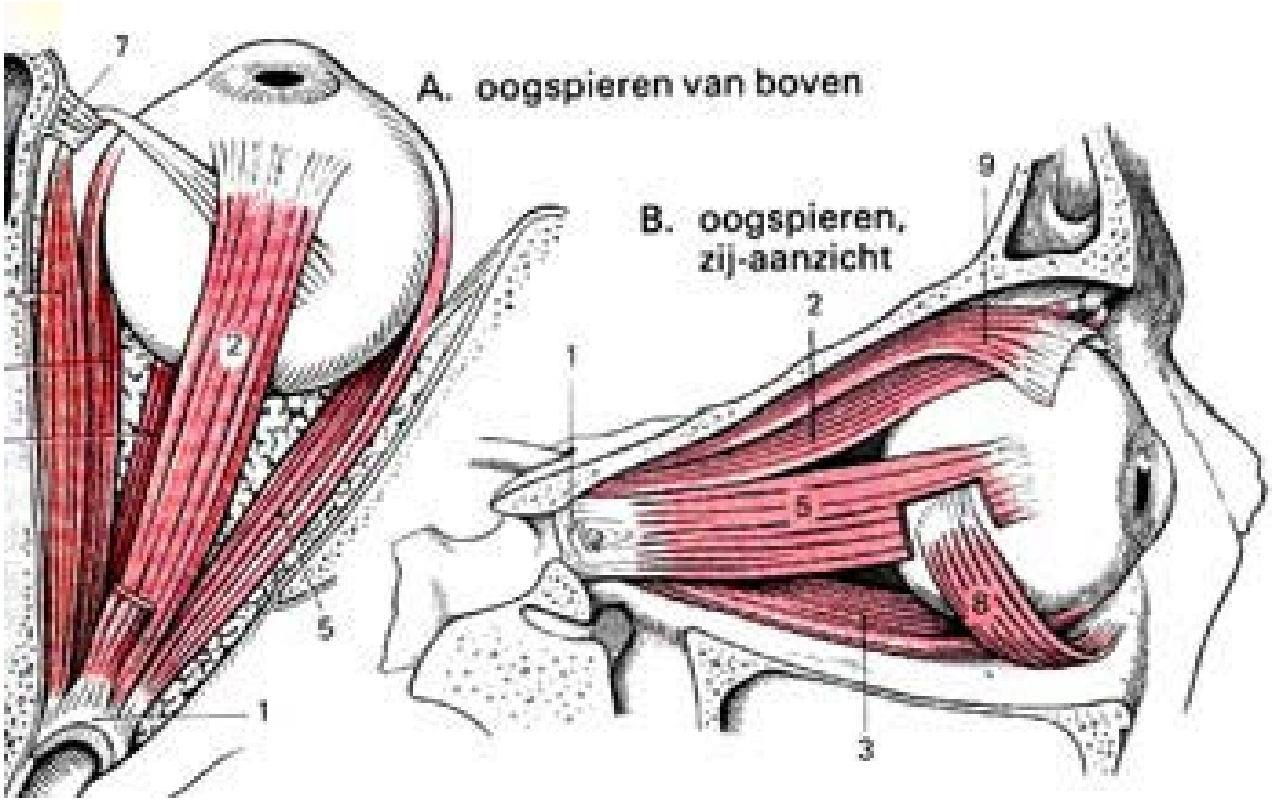
- One of the most powerful senses
- A versatile sense
- Active observations
- Fast tracking
- Reference for other senses

Some functions of the visual system

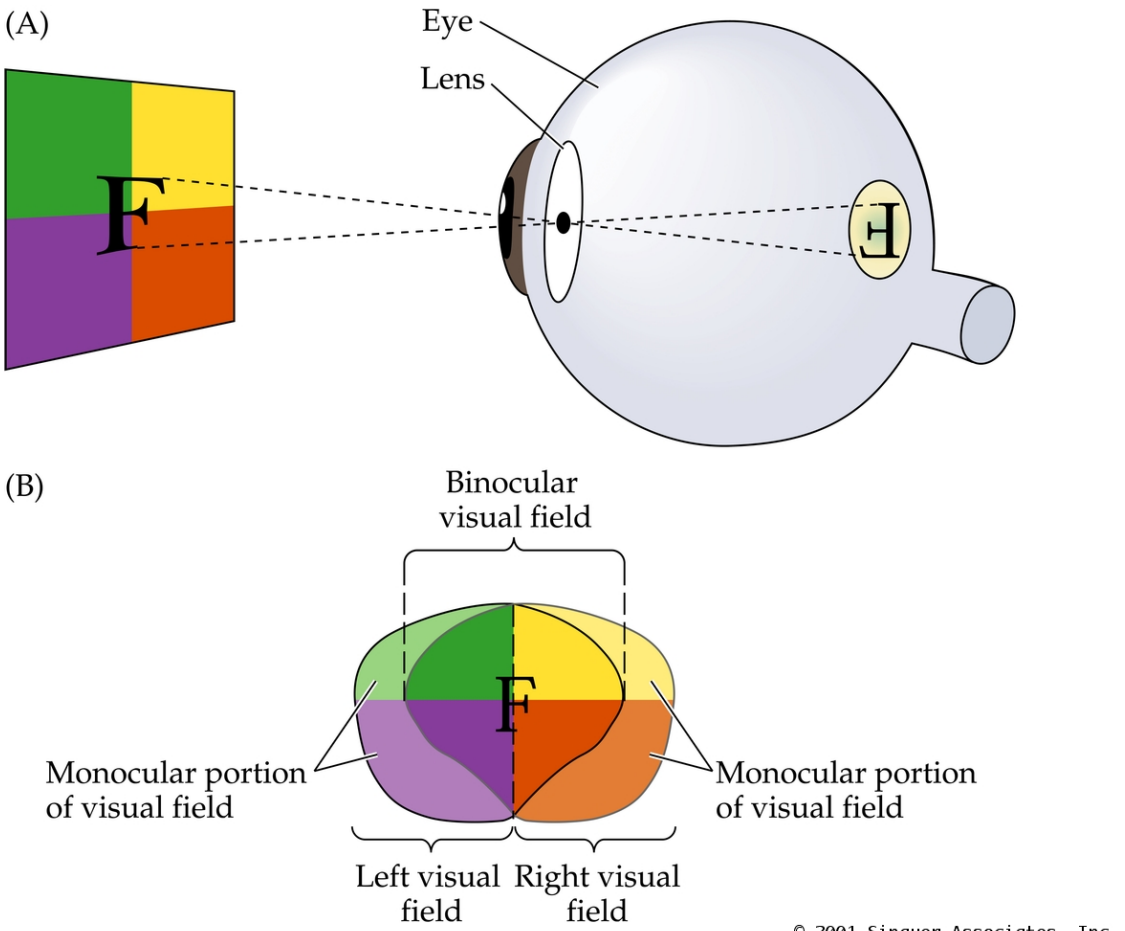
Gathering information

- Relative position, orientation, movement to environment
  - Distinguish static or moving objects (tracking)
  - Own orientation and self-motion
- Light / dark
- Colour

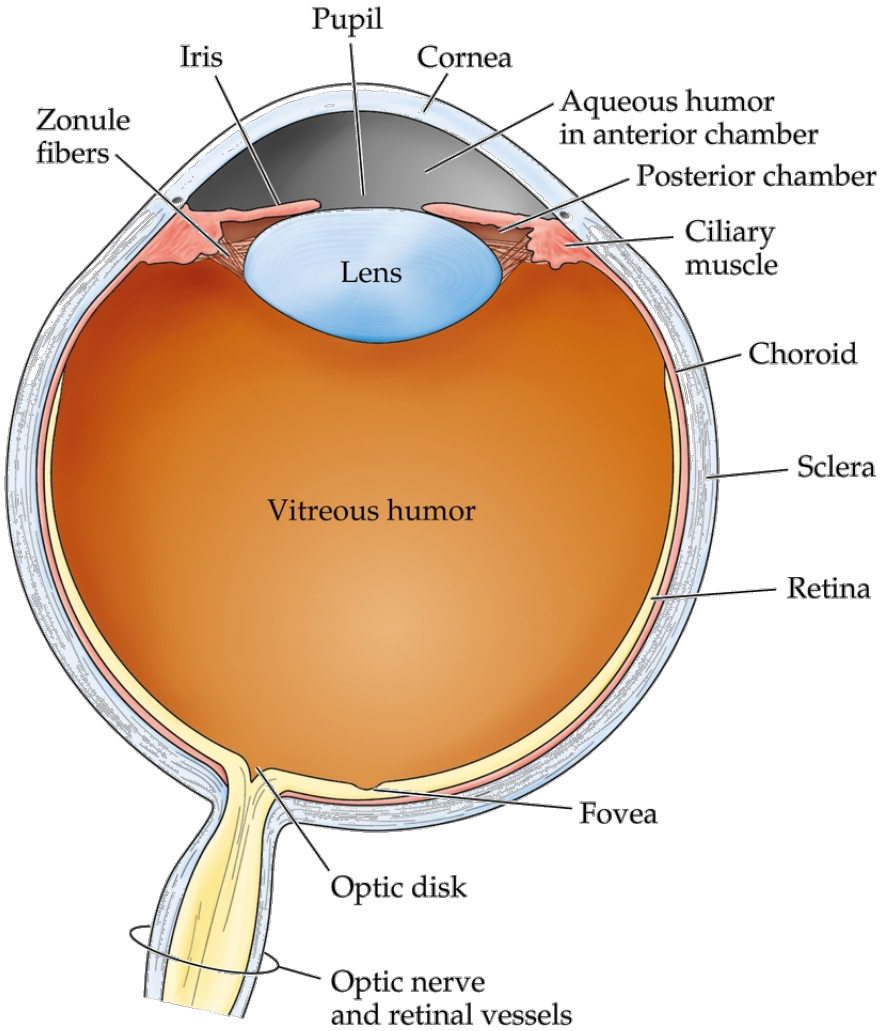
Anatomy of Eye Movement Control



Projection of visual field on retina



Focussing: Anatomy



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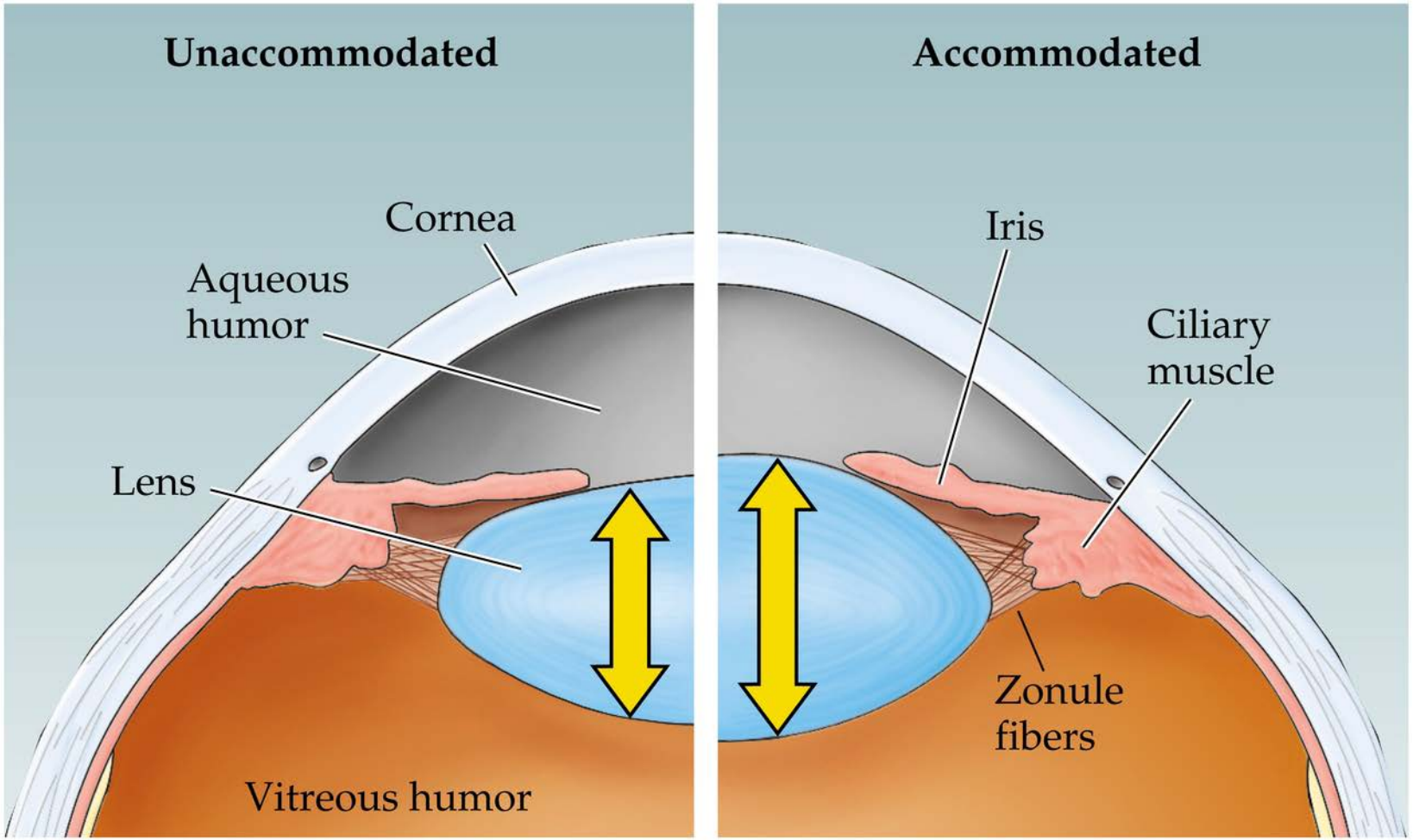
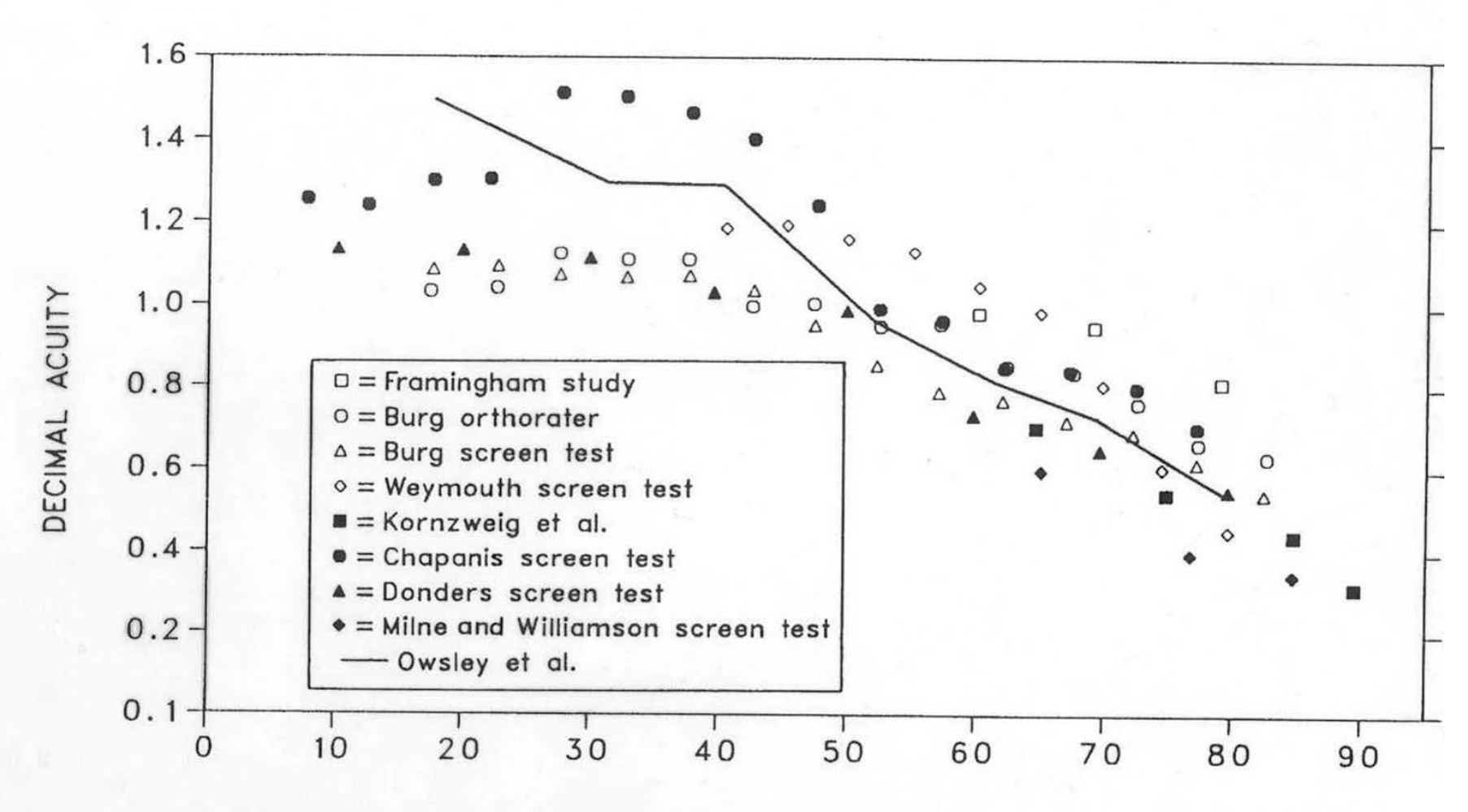


Age and visual acuity

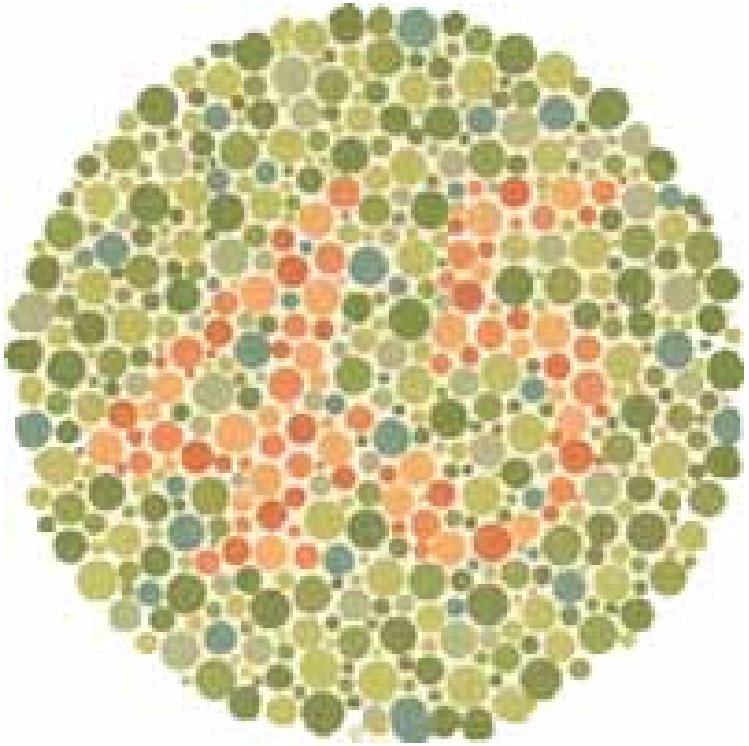


Photoreceptors: Rods and cones

Rods
- highly sensitive to light (dim light or night vision)
- capture more light
- do not respond well to moving stimuli (response time)

Cones
- not as sensitive to dim light (daytime vision)
- respond quickly
- transduce moving stimuli
- detect color (three different photopigments)
- cones are more concentrated in the fovea of the retina.

Are you color blind?



Relatively Large Prevalence: 8% males, 0.4% females

Applications for HMI

Application for Human-machine Interaction

- Design of simulators (perception of speed, example from lecture 1)
  - Be aware of richness of natural visual flow
  - Static and dynamic depth perception
- Design of Visual Displays
  - Dials, meters, screens
  - Augmented Displays (overlaying information on natural visuals)
    - Head up displays

Cues for depth and distance – Object Centred

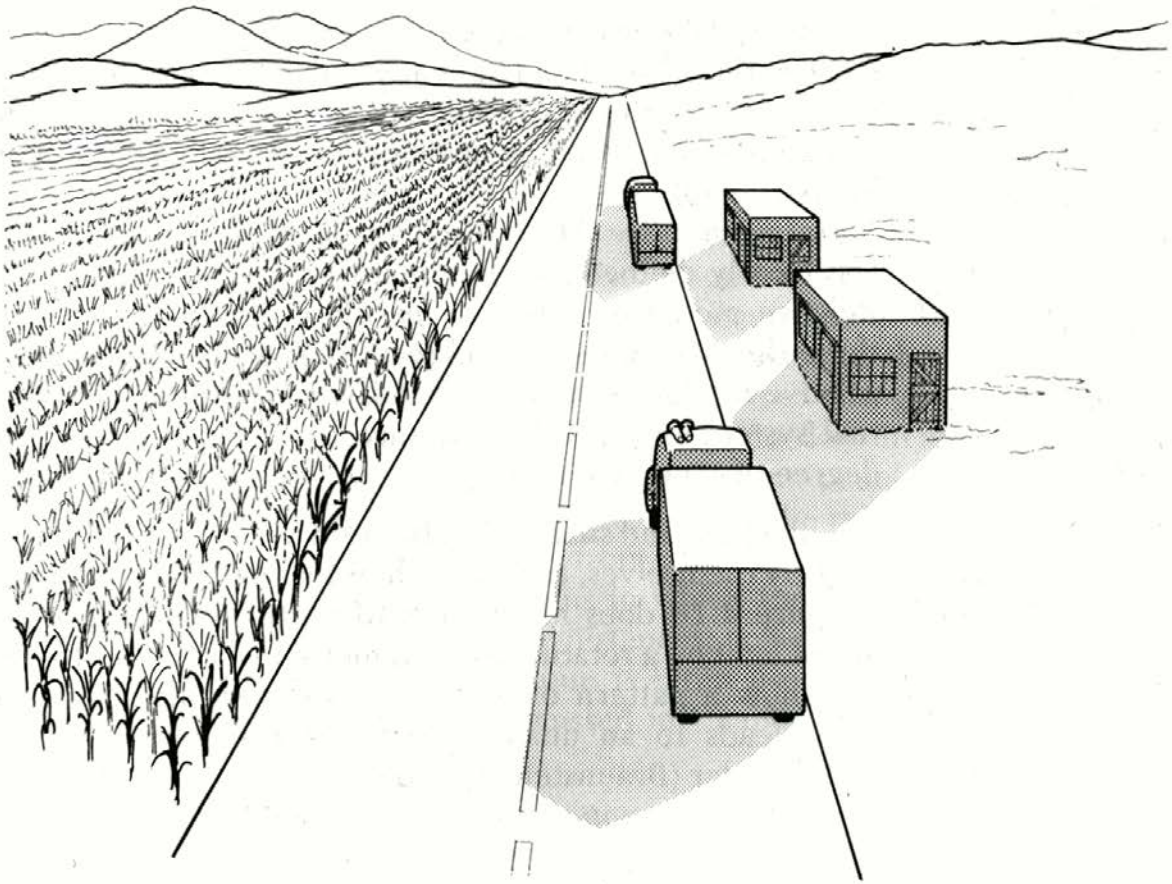
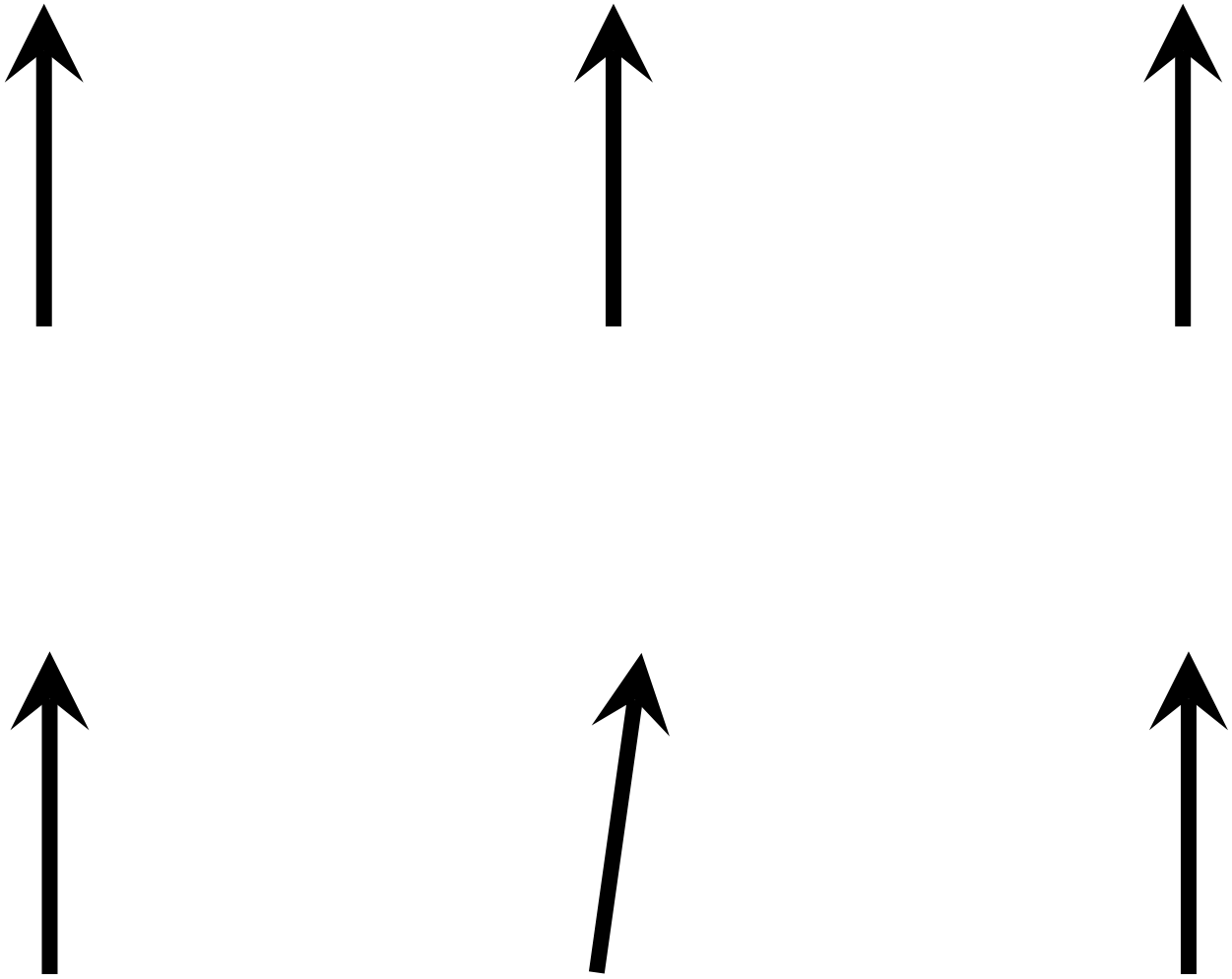


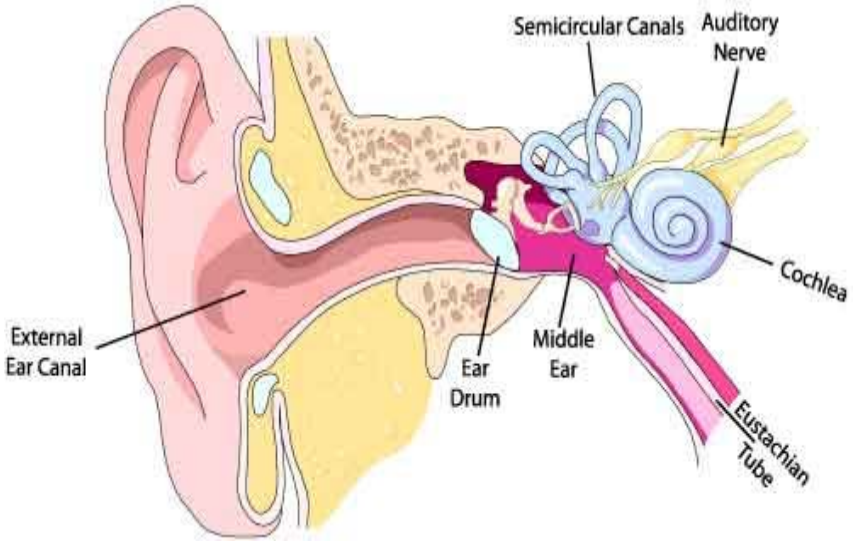
Figure 4.9 Illustrates several object-centered cues for depth as described in the text.

- Linear perspective
- Interposition
- Height in the plane
- Light and shadow
- Relative size
- Textural gradients
- Relative motion gradient

8254 8254 8254

8254 8254 8284





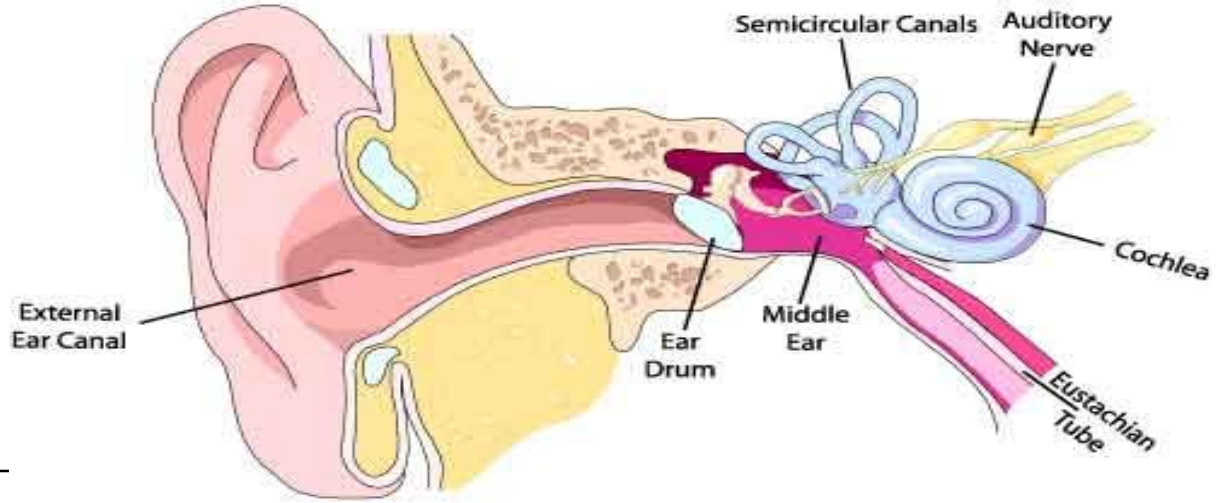
The Auditory Sense

Function of Auditory System

- Social communication
- Warning for danger
- Orientation
- Man-machine communication
  - Alarm: Horns and bells
  - Unintended noise
    - Positive: Shifting gears
    - Negative: Noise nuisance, deafness
  - Speech recognition
  - Speech generation

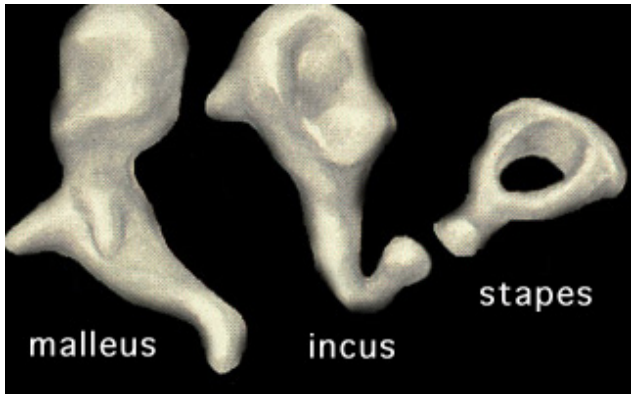
Anatomy and function

- **Pinna:** collecting device that funnels the sound waves into the ear canal.
- **Ear canal:** increases the intensity of the sound by reducing the area.
- **Tympanic membrane:** vibrates through sounds
- **Ossicles** (the three small bones): vibrations induced by tympanic membrane
- **Oval window** of the **cochlea:** vibrations induced by ossicles
- **Cochlea:** Nerve cells detect the vibrations to convert it into electrical impulses for processing by the brain.

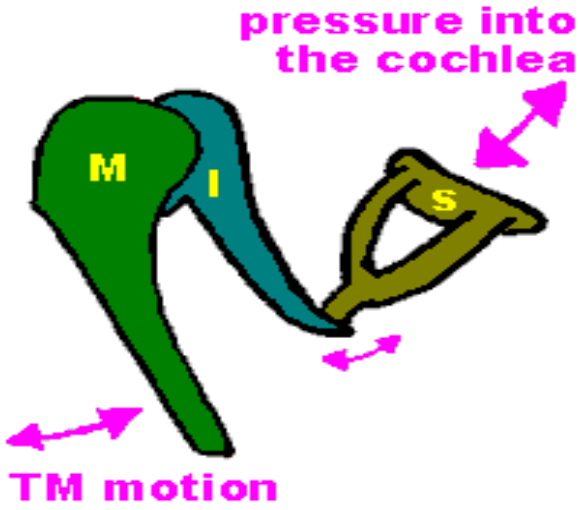


From air vibration to neural impulse

- Pinna – middle ear – inner ear – auditory nerve – CNS
- Air vibration – mechanic vibration – hydraulic vibration – chemo-electric signal



Ossicles:
Malleus (hammer)
Incus (anvil)
Stapes (styrrup)



From movement of the timpanic membrane to pressure into the cochlea

Observation Window - Audiogram

Specifications

Frequency:

- 20 Hz - 20 kHz (young) / 10 kHz (older)
- Optimal: 150 Hz - 8 kHz
- JND: 3 Hz

Amplitude:

- 1 - 10^{14} -> 0 - 140 dB
- Optimal: 40 - 80 dB
- JND: 0.5 dB

Communication: audio?

- **Pro**
  - Auditory channels can not be closed
  - Attention grabbing (warning signals)
  - Alerting for other signals, e.g. visual
  - Use
    - when visual signals not possible
    - when visual system is overloaded

- **Contra**
  - Noise is a nuisance (to yourself or other people)
  - Can cause startling / panic
  - Don't use
    - when already many auditory alarms
    - when information is not suited for sound coding
    - when already much noise at work station

Communication: audio possibilities

Possibilities to convey information through audio

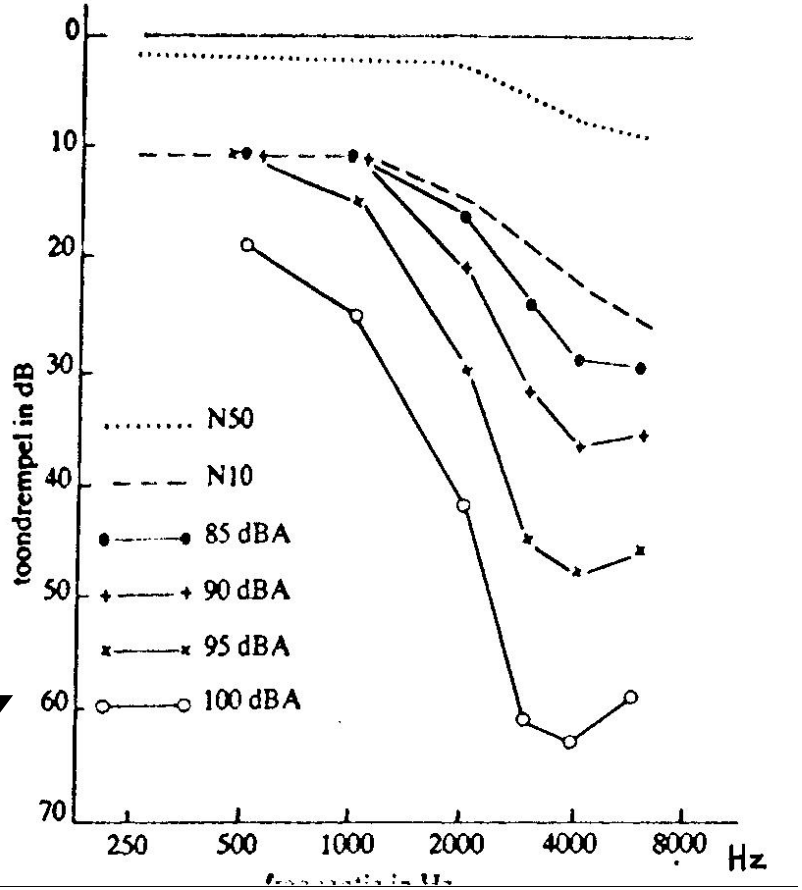
Warning / Attention Grabbing Sounds

- Frequency: high vs. low
- Amplitude: loud vs. soft
- Direction
- Timbre: Bell, gong, buzzer
- Repetition
- Pace of sequential tones
- Time pattern
- Melody / Harmony

- In its most complex form: speech and music

Hearing Damage

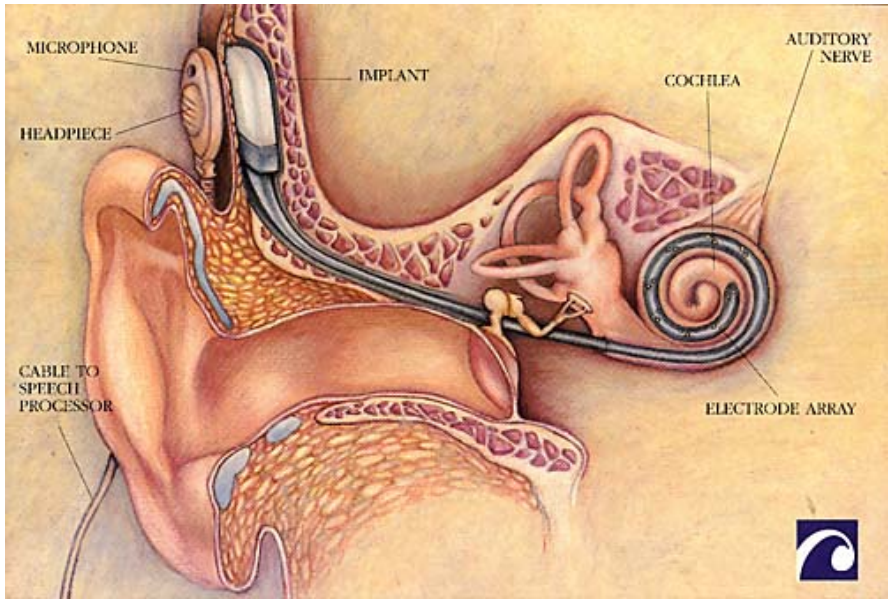
Decreased hearing (in dB)

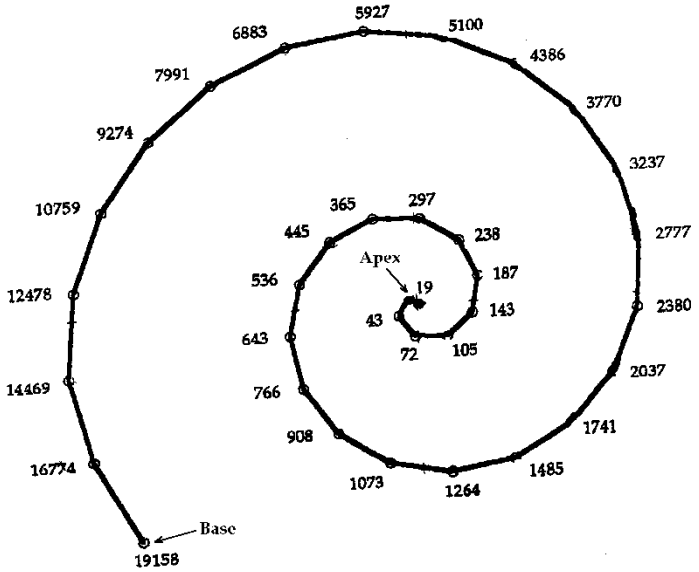


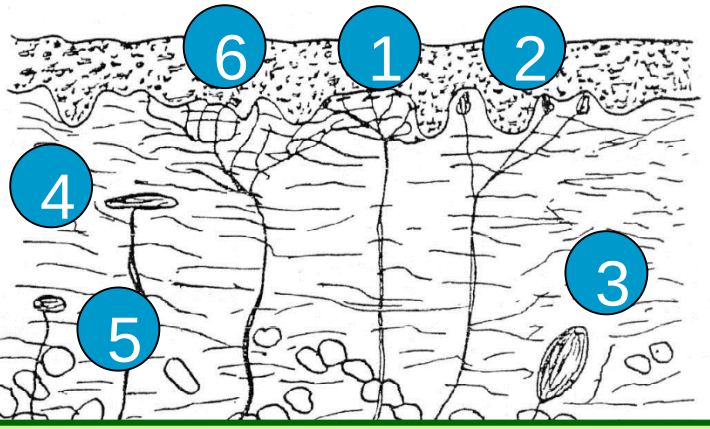
Exposure

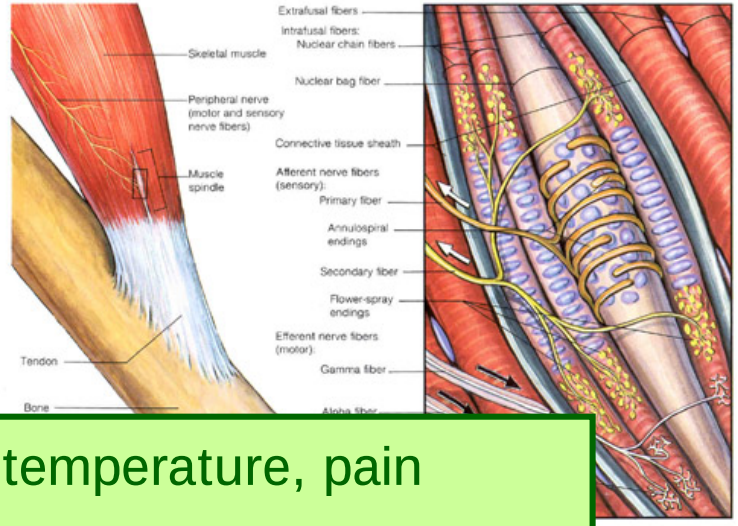
Frequency

Solving Hearing Damage: Cochlear Implants





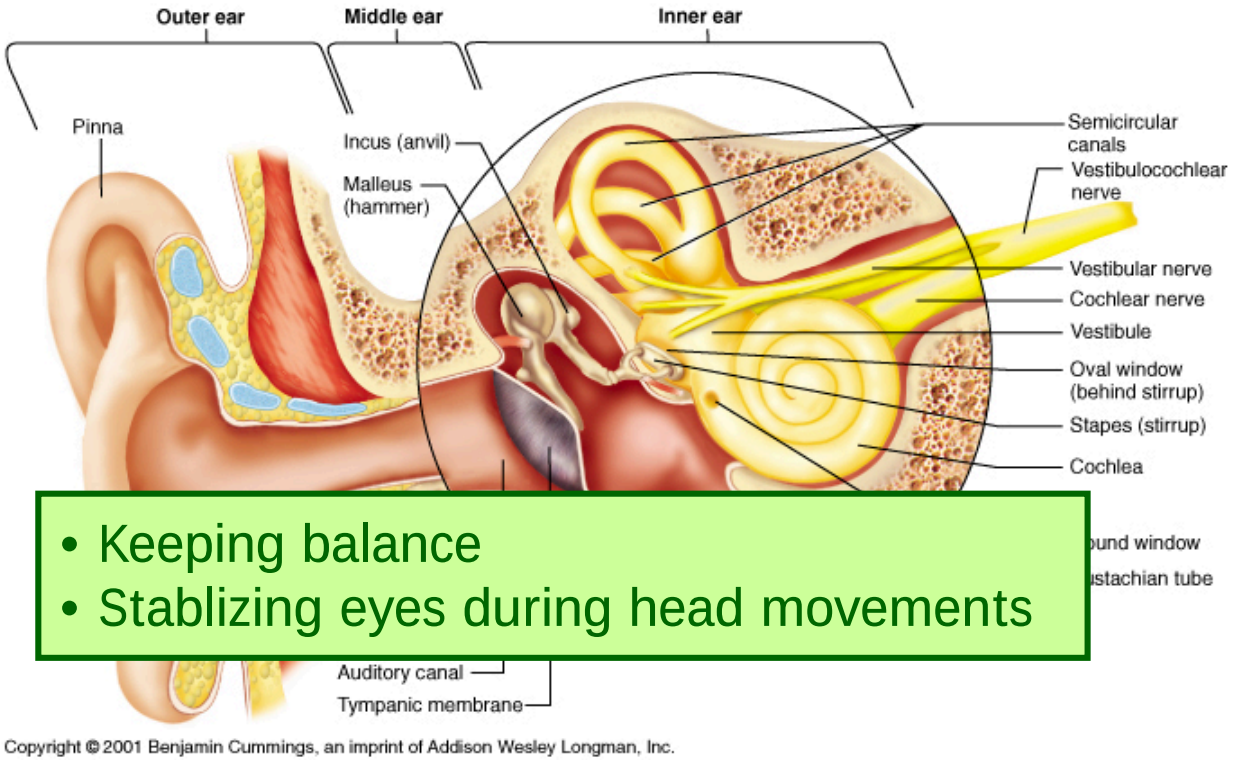




- Senses force, position, vibration, temperature, pain
- helps to control limbs

Tactile & Proprioceptive Senses

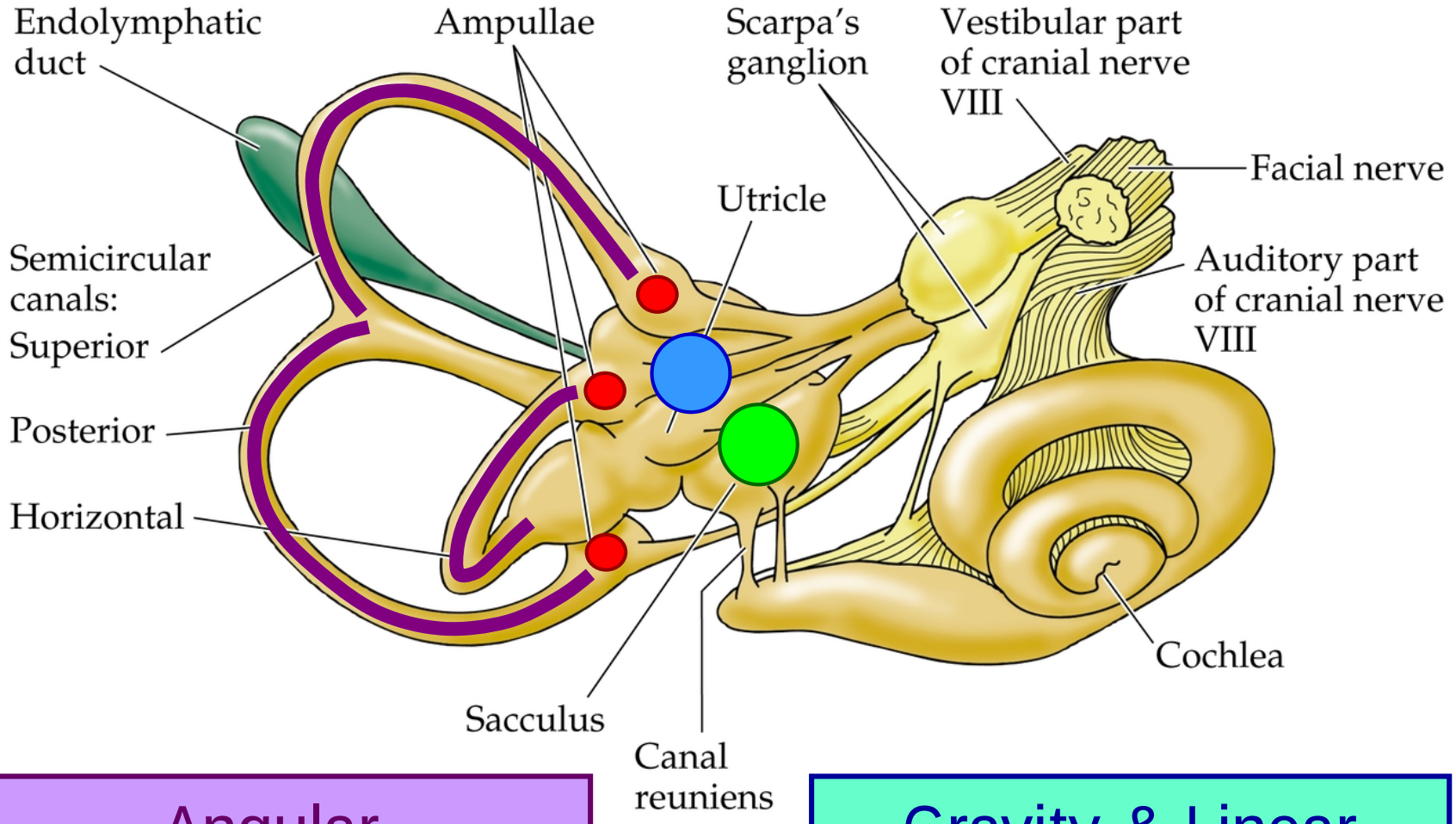
Class 3



- Keeping balance
- Stablizing eyes during head movements

Vestibular Senses

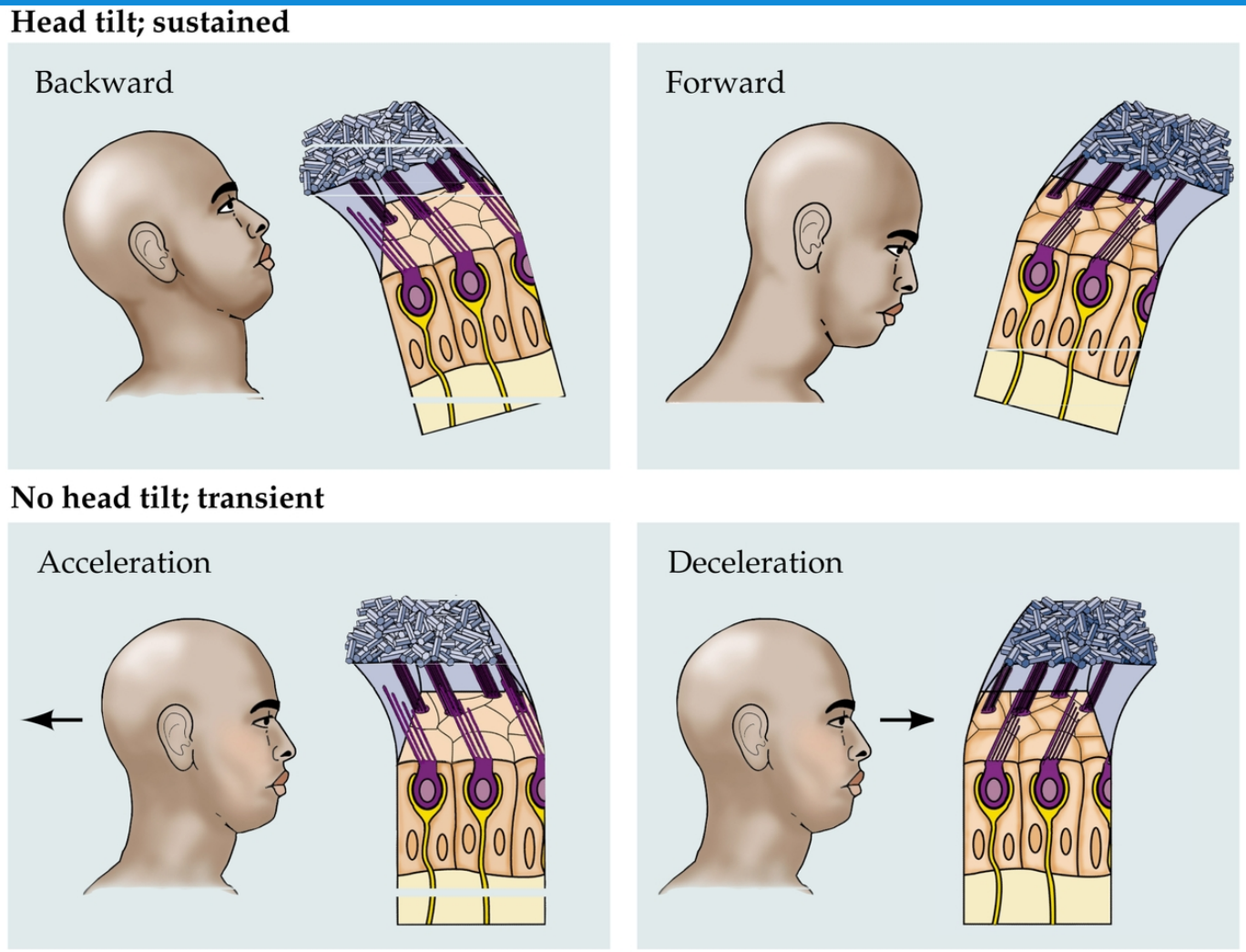
Anatomy



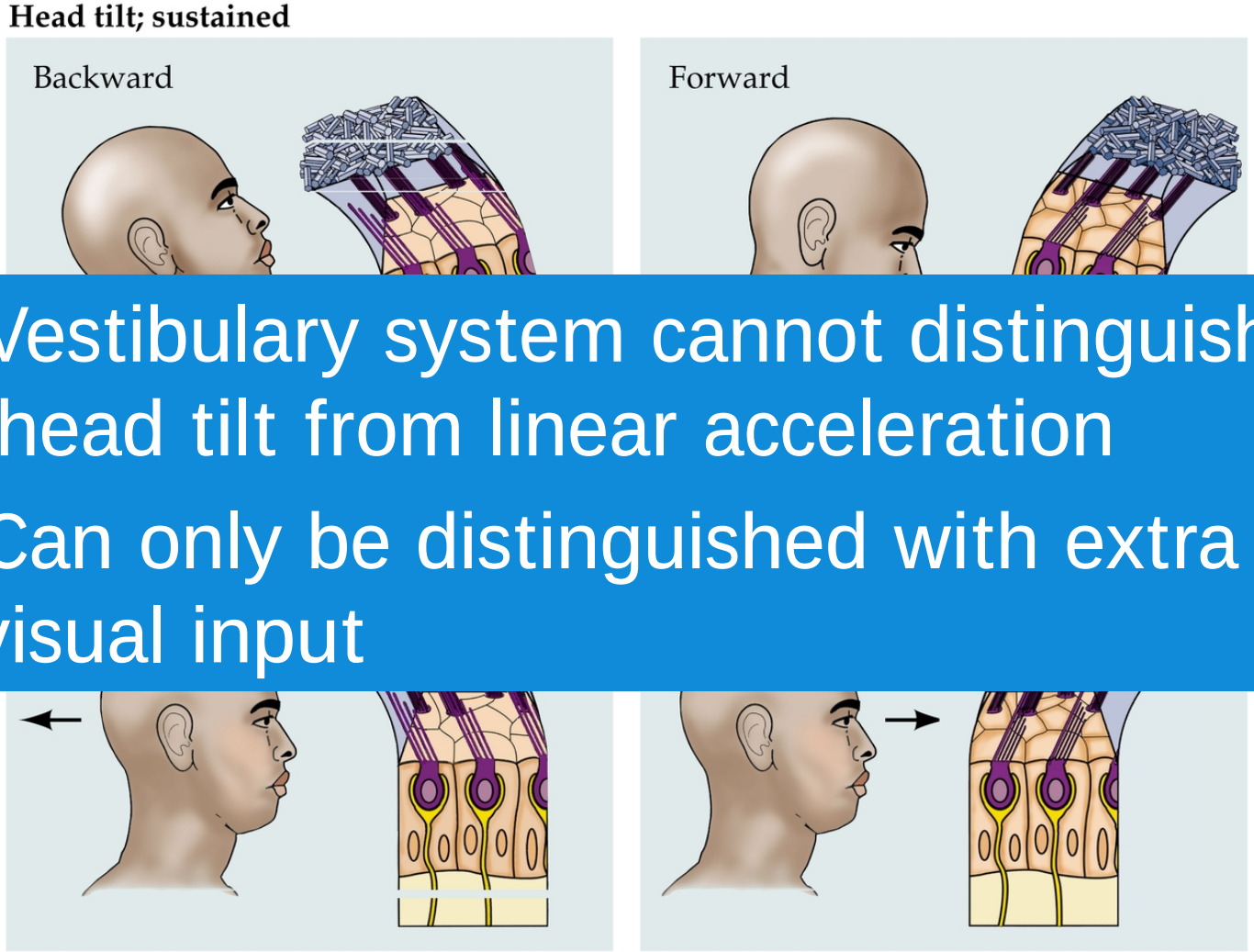
Angular Acceleration

Gravity & Linear Acceleration

Vestibular Sense: Accelerations

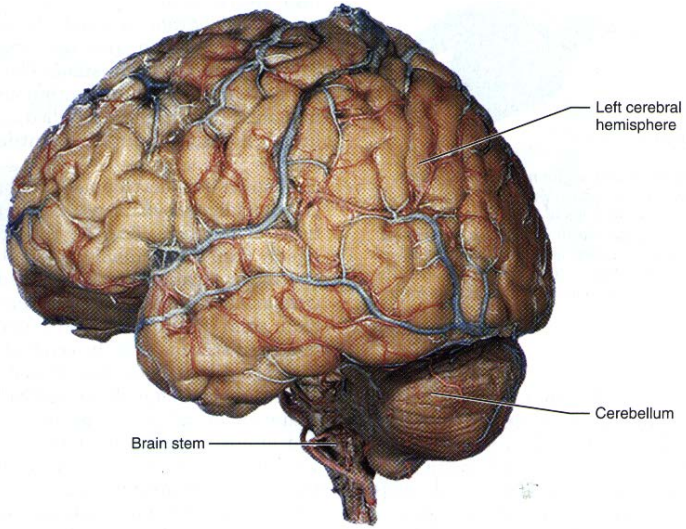


Working Principle



- Vestibulary system cannot distinguish head tilt from linear acceleration
- Can only be distinguished with extra visual input

More info about this topic: Human Movement Control A/B



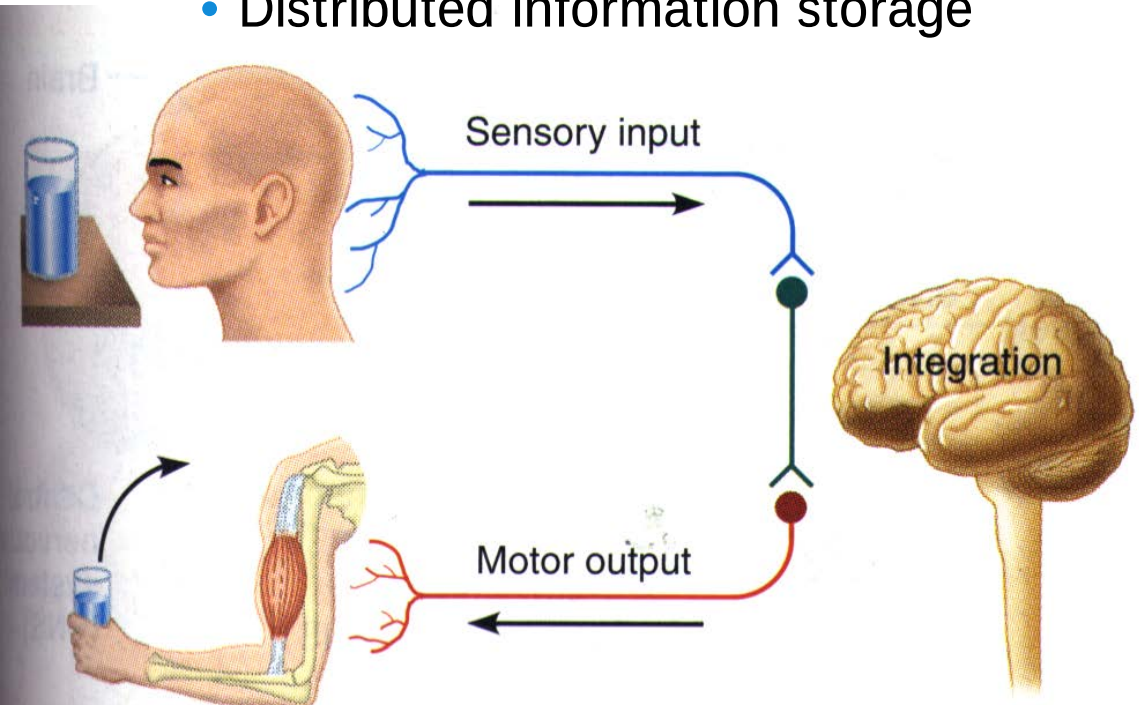
Processing information - the brain

Recommended Reading: “A portrait of the brain” Adam Zeman
Recommended Watching: TED X lecture by D. Wolpert
https://www.ted.com/talks/daniel_wolpert_the_real_reason_for_brains

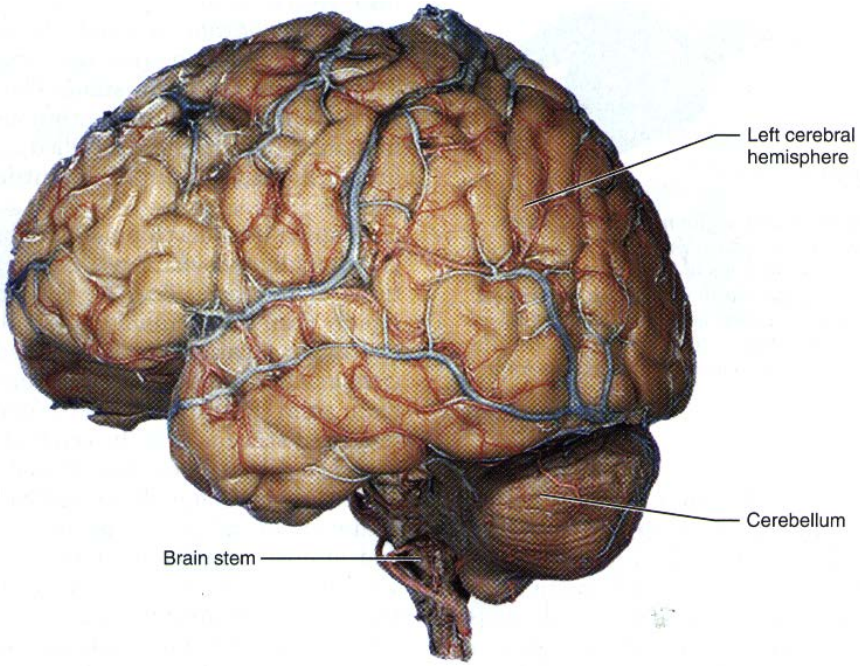
Central Nervous System

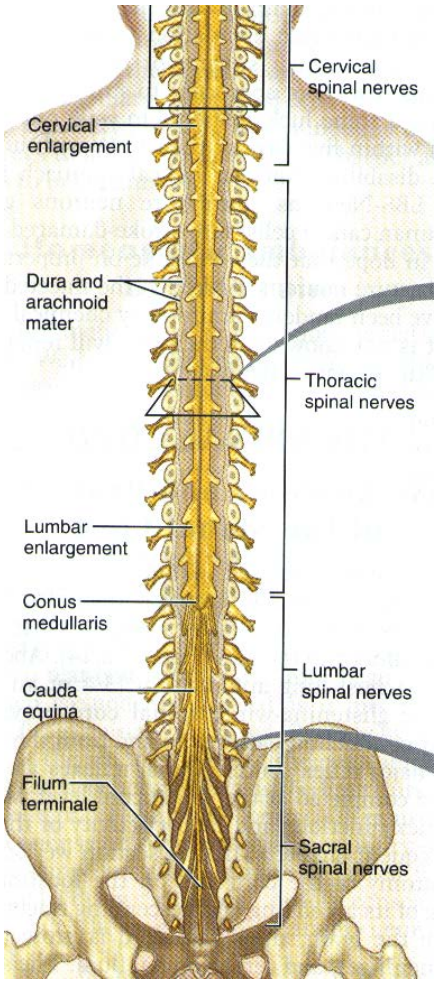
Very complex

- 10^{11} neurons
- 10^{4} synapses per neuron: 10^{15} synapses
- Synaptic strength changes due to frequent use: Learning & storage
- A-synchronous processing
- Distributed information storage



Cerebrum & Spinal Cord





Information Processing

cortical level

- Consciousness
- Abstract thinking
- Motor control

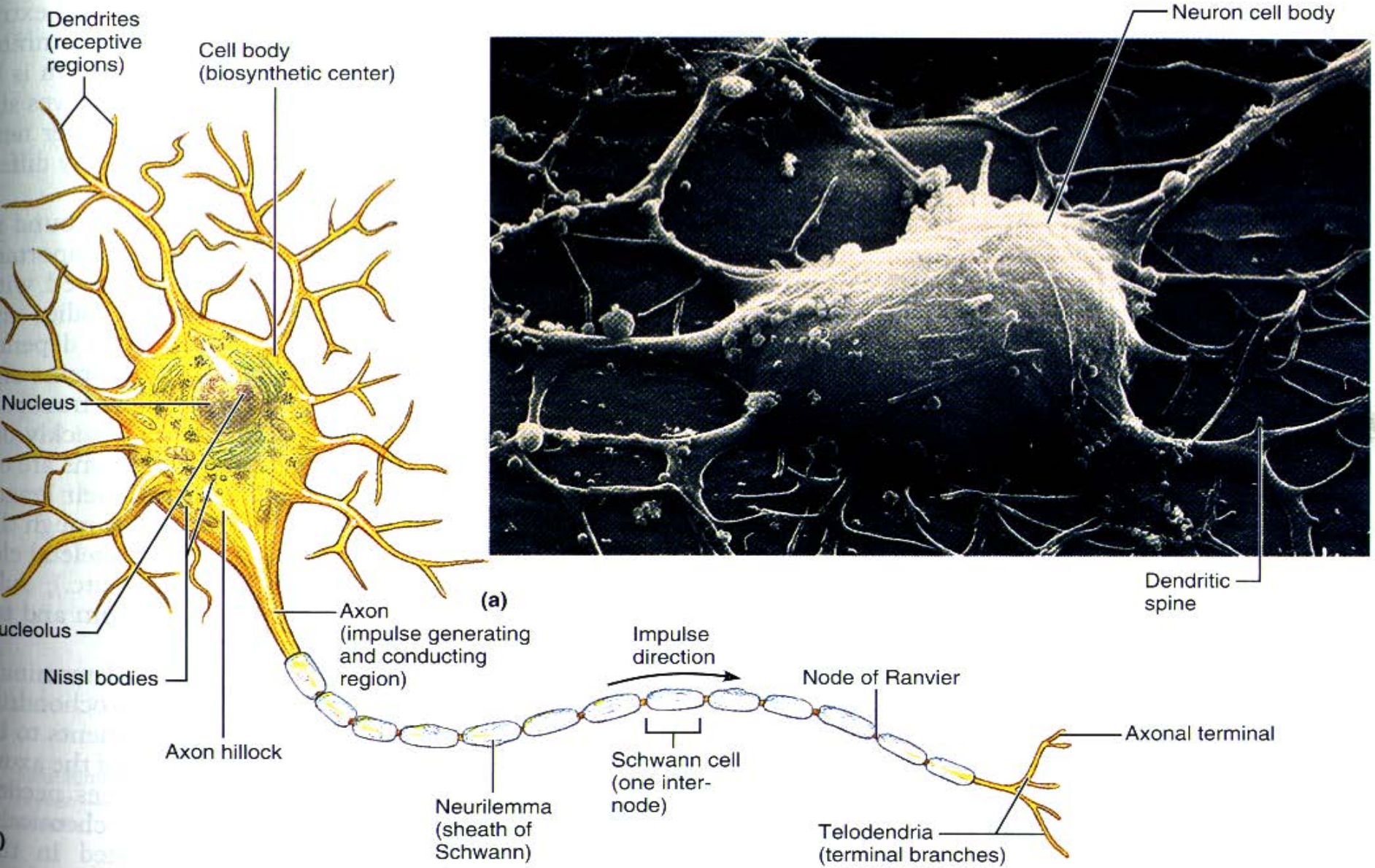
lower brain

- subconscious activities, coordinate functions
- cerebellum, basal ganglia

spinal cord

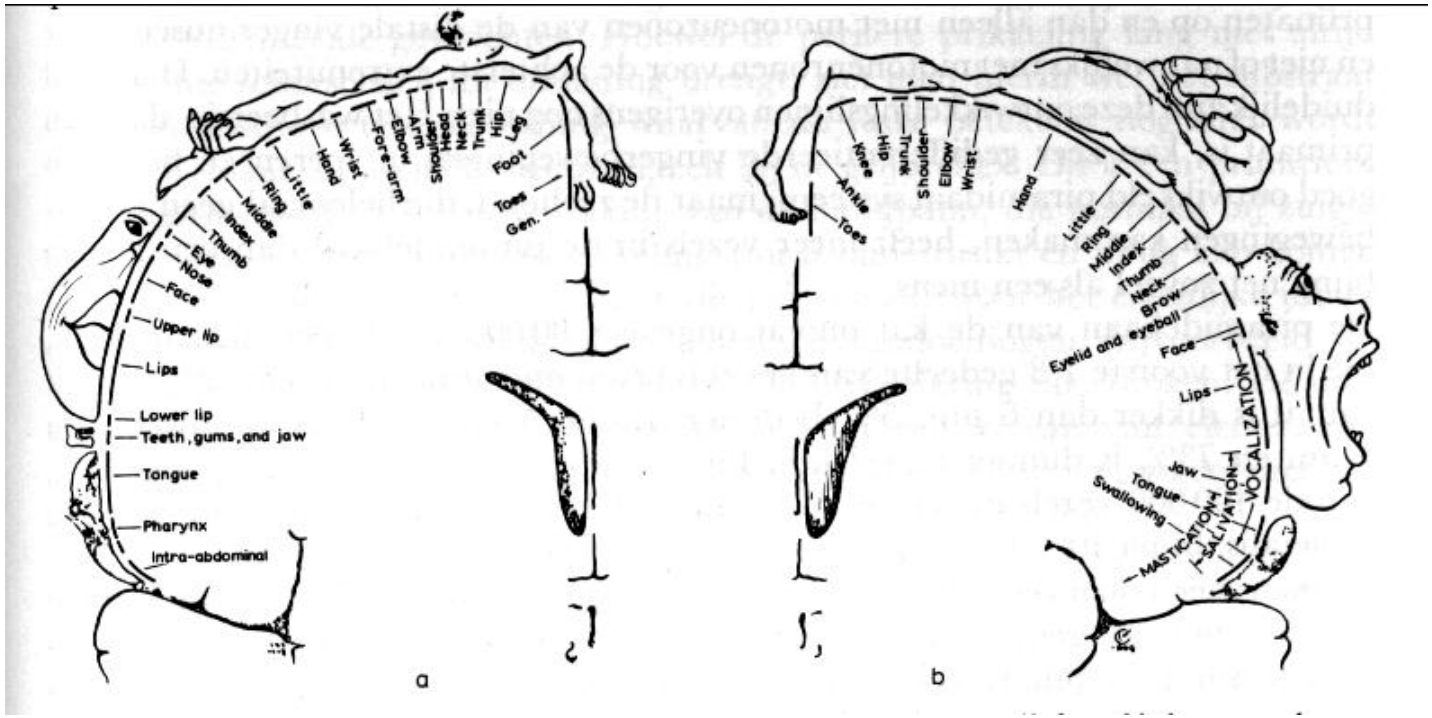
- reflexes

Connections: through Neurons

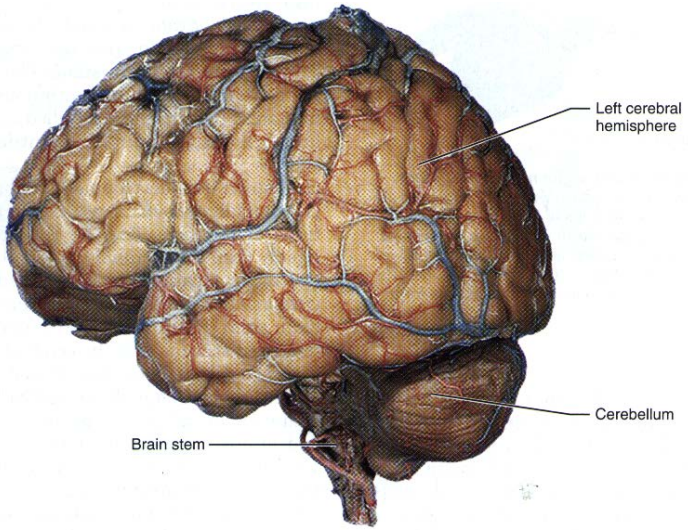


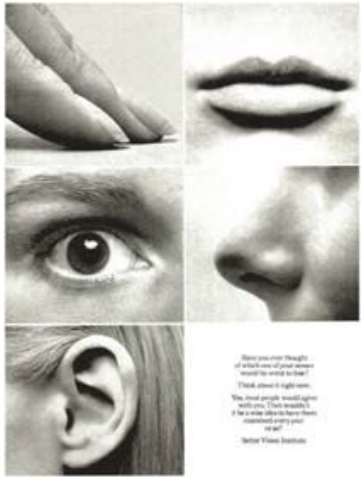
How many nerves per function?

Penfield's (1930) Homonculus



Sensory system **Motoric system**

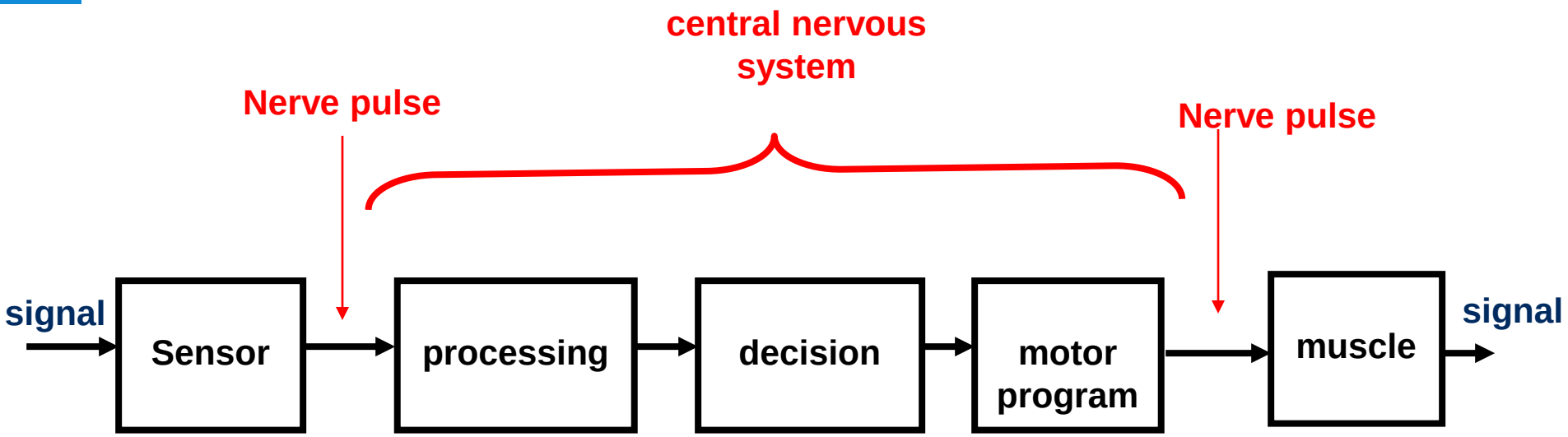




Making sense of signals

signal perception, sensory integration and meaning/experience

Perception theory: stimulus reponse

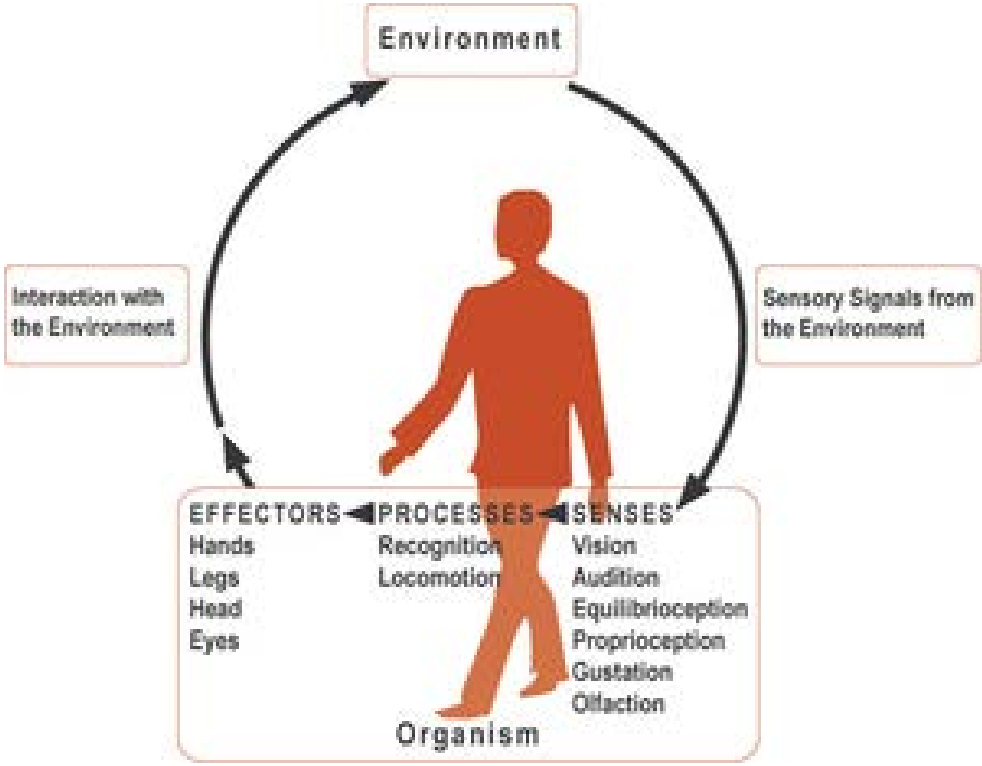


Perception in Action

Gibson (1950)

The Perception of the Visual World

- rejected the then fashionable theory of behaviorism
- proposed the idea that animals 'sampled' information from the 'ambient' outside world.



http://www.kyb.tuebingen.mpg.de/research/former-research-groups/ernstgroup.html

Perceiving and Understanding sensory input

- **Perception and interpretation**
  - Varies between persons
  - Varies within persons
- **Context is important**
  - Previous experience
  - Information from other senses
- **Altered perception can occur**
  - Illusions (harmful, beneficial, fun)
  - Age / disease / accident
    - Loss or enhancement

Name
the
colour
of
these
words

orange

purple

brown

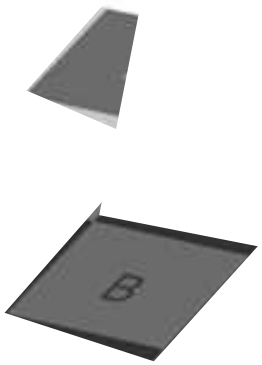
blue

green

black

Visual illusion: context matters!

Checker-shadow illusion:
The squares marked A and B
are the same shade of gray.



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Visual illusion – no depth cues

Which way is the dancer spinning, clockwise or counter-clockwise?
http://en.wikipedia.org/wiki/File:Spinning_Dancer.gif

Escher: what's wrong?

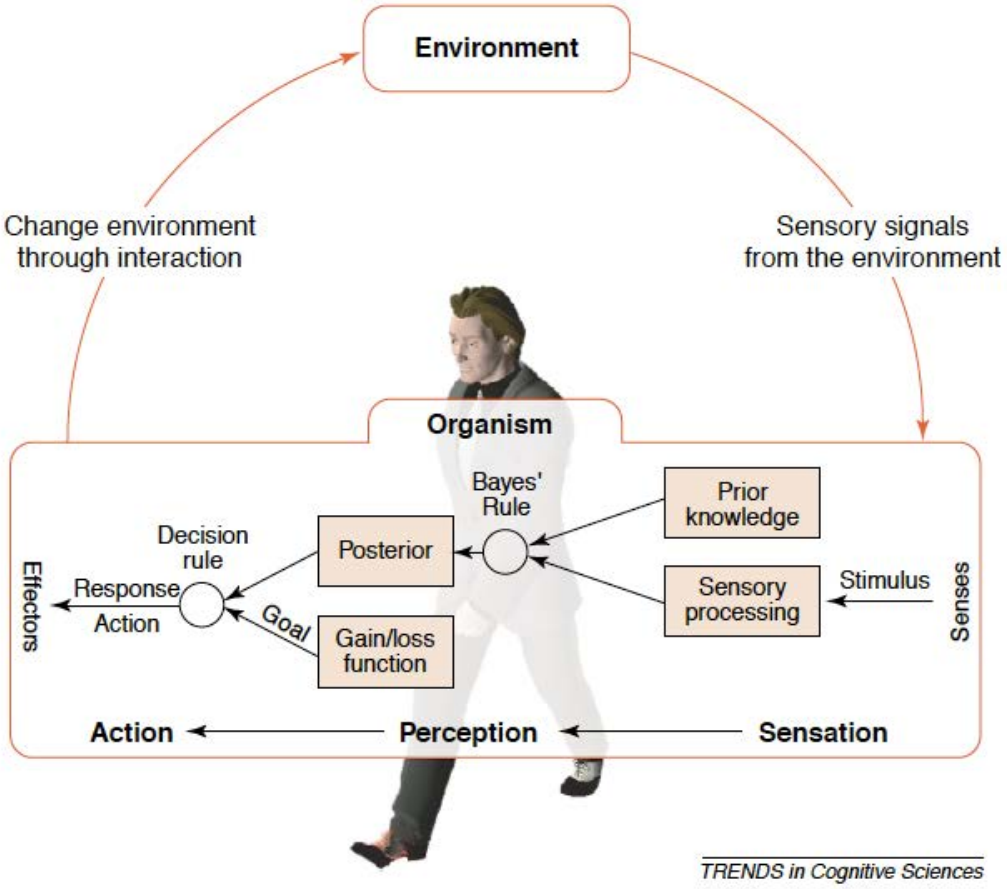
This is an identical twin (no photoshop ☺)

- How? Go to the Escher Museum in The Hague

Sensory Integration

- **Context is important**
  - Previous experience
  - Information from other sensors
- **We understand our interaction with the world by integration information from all our sensors**
  - Each having different ranges, noise levels, etc
  - These can amplify, replace, of contradict...!
- **Altered perception can occur when multiple sensors contradict!**
  - Illusions (harmful, beneficial, fun)

Sensory Integration



Hermann von Helmholtz

- human perception is a problem of inference, for which the sensory data are often not sufficient to uniquely determine the percept.
- Thus, prior knowledge has to be used to constrain the process of inference from ambiguous sensory signals.
- Bayesian Framework

http://www.uni-bielefeld.de/(en)/biologie/cns/

Sensory Integration

- **Comparison / coupling**
  - visual – vestibulary (e.g., perception of selfmotion)
  - propriocepsis – visual (e.g., reaching)
  - smell - taste (e.g., wine tasting)
  - tactile – propriocepsis (e.g., grasping)
  - propriocepsis – visual - vestibulary (e.g., balance)
- **Amplification / improvement**
  - visual – auditory (e.g., understanding speech)
- **Pattern recognition**
  - Words, letters
  - Color, Shape
- **Attention**

Visual-Vestibular Illusion

Belangrijke internationale onderscheiding

Efteling-attractie Villa Volta bekroond

Van een verslaggever

KAATSHEUVEL – Villa Volta, de nieuwste attractie van de Efteling, is dit jaar de enige Europese winnaar van de *THEA Award of Outstanding Achievement*. De Themed Entertainment Association, een internationaal comité uit de vakwereld van het entertainment, kende dit jaar in totaal elf prijzen toe voor bijzondere prestaties op het gebied van entertainment. De overige winnaars komen uit de Verenigde Staten (zes), Japan (drie) en Korea (één). De uitreiking van de onderscheidingen heeft plaats tijdens het jaarlijkse THEA Award Gala op 13 september in het Beverly Hills Hotel in Los Angeles.

Aan den lijve

Villa Volta vertelt het verhaal van Hugo van den Loonsche Duynen, die in de achttiende eeuw met zijn bende de Bokkenrijders een spoor van ellende trok door de omgeving. De villa zelf is een statig achttiende-eeuws herenhuis vol raadsels en geheimen, waarin de bezoekers aan den lijve ondervinden wat Hugo van den Loonsche Duynen heeft doen vluchten nadat hij door een mysterieuze vrouw in de ban is gedaan. Alle zintuiglijke waarnemingen worden in het huis op hun kop gezet.

Villa Volta is op een klassieke kermisattractie gebaseerd en werd vorig jaar geopend. Met de bouw was tien miljoen gulden gemoeid. De Efteling heeft de attractie in eigen huis ontwikkeld en gerealiseerd in samenwerking met het bedrijf Vekoma uit Vlodrop. Met de *THEA Award of Outstanding Achievement* heeft de Efteling zich naast prominente winnaars geschaard als de Universal Studios in Florida (voor de attractie Terminator 2/3D: the Battle Across Time), Disneyland Parijs (voor Space Mountain) en Disneyland-Anaheim C.A. (voor de Indiana Jones Adventure-ride).

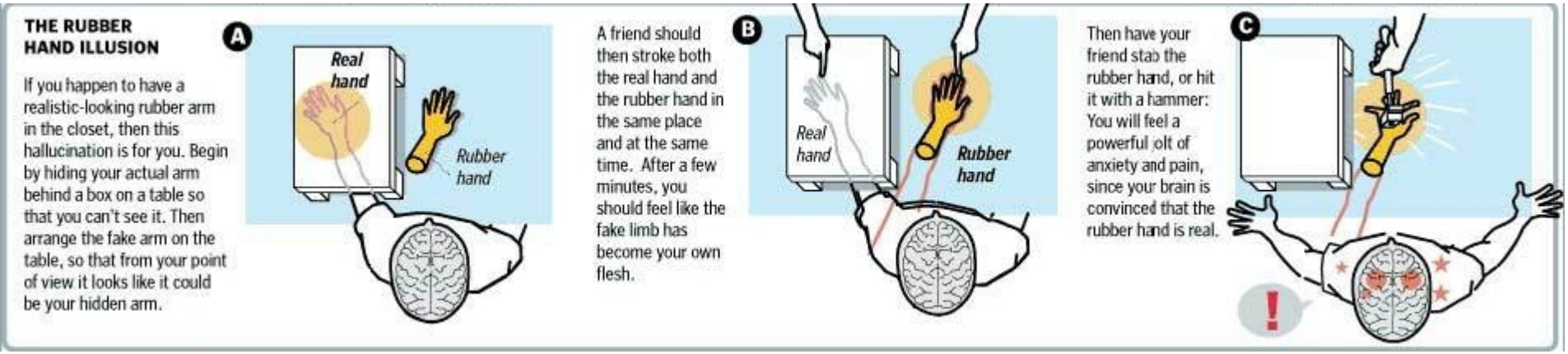
• *Villa Volta sleepte een belangrijke onderscheiding in de wereld van het internationaal entertainment in de wacht.*
Foto Frank Trommelen

Main Research Question

What are the perceptual processes that make us feel that we own our entire body?

- traditional textbook wisdom emphasizes that body perception is a direct result of bottom-up processing of afferent signals from muscles, joints and skin
- Is it possible that other processes dominate perception?

Haptic illusion: whose hand is this?



Botvinick & Cohen, 1999

The Body Illusion (Ehrsson)

- Experiment leader stroked the abdomen of both the mannequin and the body with a rod, for 2 minutes; synchronous and asynchronous, and then:
- Exp 2: threaten abdomen with a knife or a spoon

  (http://www.youtube.com/watch?v=M3iOROuTuMA)
- Exp 3: threaten abdomen with knife or spoon, after stimulating abdomen or hand
- Exp 4: substitute mannequin with an abstract rectangular object

Making sense of visual information:

Oliver Sacks "The man who mistook his wife for a hat"
>> on a patient who had problems seeing:

His visual acuity was good: he had no difficulty seeing a pin on the floor (...). He saw all right, but *what* did he see? I opened out a copy of the *National Geographic Magazine* and asked him to describe some pictures in it. His eyes would dart from one thing to another, picking up tiny features, individual features, — but in no case did he get the scene-as-a-whole. I showed him the cover, an unbroken expanse of Sahara dunes. 'I see a river,' he said. 'And a little guest-house with its terrace on the water.'

He decided that the examination was over and started to look around for his hat. He reached out his hand and took hold of his wife's head, tried to lift it off, to put it on. He had apparently mistaken his wife for a hat! His wife looked as if she was used to such things.

The power of proprioceptive information:

Oliver Sacks "The man who mistook his wife for a hat"
>> on a patient who lost proprioception:

- Standing was impossible—unless she looked down at her feet. She could hold nothing in her hands, and they 'wandered'—unless she kept an eye on them. When she reached out for something, or tried to feed herself, her hands would miss, or overshoot wildly, as if some essential control or coordination was gone. 'Something awful's happened,' she mouthed, in a ghostly flat voice. 'I can't feel my body. I feel weird—disembodied.'

The sense of the body, I told her, is given by three things: vision, balance organs (the vestibular system), and proprioception—which she'd lost. Normally all of these worked together. If one failed, others could compensate, or substitute—to a degree.

Altered Perception - couplings

Synesthesia

"a neurologically-based condition in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway"

- Rare
- Often reported as an enriching experience

Examples:

Tori Amos (musician) – mixes sound and light

"The song appears as light filament . In more than thirty-five years of composing, I've never seen a duplicate song structure: I've never seen the same light creature in my life. I try to imagine the best kaleidoscope ever."

Aphex Twin (musician) – mixes sound and color

Kandinsky (painter) – mixed color, hearing, touch and smell

Philosophical Intermezzo

- The philosopher Bergson on sensory perception:

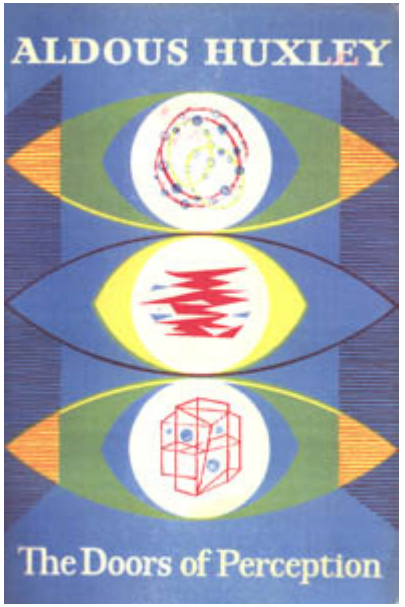
  "The function of the brain and nervous system and sense organs is in the main *eliminative* and not *productive*. Each person is at each moment capable of remembering all that has ever happened to him and of perceiving everything that is happening everywhere in the universe. The function of the brain and nervous system is to protect us from being overwhelmed and confused by this mass of largely useless and irrelevant knowledge."

  C.D. Broad: "According to such a theory, each one of us is potentially a Mind at Large. But in so far as we are animals, our business is at all costs to survive. To make biological survival possible, Mind at Large has to be funneled through the **reducing valve** of the brain and nervous system. What comes out at the other end is a measly trickle of the kind of consciousness which will help us to stay alive on the surface of this particular planet."

Altered Perception - vision

Aldous Huxley on perception when using mescaline:

“ ‘What about spatial relationships?’ the investigator inquired, as I was looking at the books. It was difficult to answer. True, the perspective looked rather odd, and the walls of the room no longer seemed to meet in right angles. At ordinary times the eye concerns itself with such problems as Where?—How far?—How situated in relation to what? In the mescalin experience (...) place and distance cease to be of much interest: the mind does its perceiving in terms of intensity of existence, profundity of significance (...). In this context position and the three dimensions were beside the point. Not, of course, that the category of space had been abolished. When I got up and walked about, I could do so quite normally, without misjudging the whereabouts of objects. Space was still there; but it had lost its predominance. The mind was primarily concerned, not with measures and locations, but with being and meaning. “



Altered Perception – vision/haptic

Study at Johns Hopkins University:

Griffiths et al. (2006). “Psilocybin can occasion mystical-type experiences, having substantial and sustained personal meaning and spiritual significance.” Psychopharmacology (2006) 187:268–283

“after psilocybin, the participants experienced alterations in mood, affect, and cognition (...) including perceptual changes (e.g., visual pseudo-hallucinations, illusions, and synesthesias)”

Altered Perception - smell

Oliver Sacks "The man who mistook his wife for a hat"
>> on a student, who took amphetamines:

- "Stephen D., aged 22, vividly dreamt he was a dog, in a world unimaginably rich and significant in smells. Waking, he found himself in just such a world. 'As if I had been totally color-blind before, and suddenly found myself in a world full of color.' He did, in fact, have an enhancement of color vision ('I could distinguish dozens of browns where I'd just seen one brown before')

  But it was the exaltation of *smell* which really transformed his world: 'I had dreamt I was a dog—it was an olfactory dream—and now I awoke to an infinitely redolent world—a world in which all other sensations, enhanced as they were, paled before smell.'

Learning Goals Lecture 2

After this lecture, you should be able to:

1. Reproduce the human sensors
    1. Basics of anatomy, functionality of the eye, ear and vestibular organ

2. Reproduce important theories of perception

1. Reproduce the observation window, and apply it to different sensory perception

2. Apply methods to determine limitations in perception

3. Be critical of the limitations in applying fundamental perception research in understanding dynamic perception-action couplings & multi-sensory integration & **the complexity of making sense of perceptual information**

Questions?