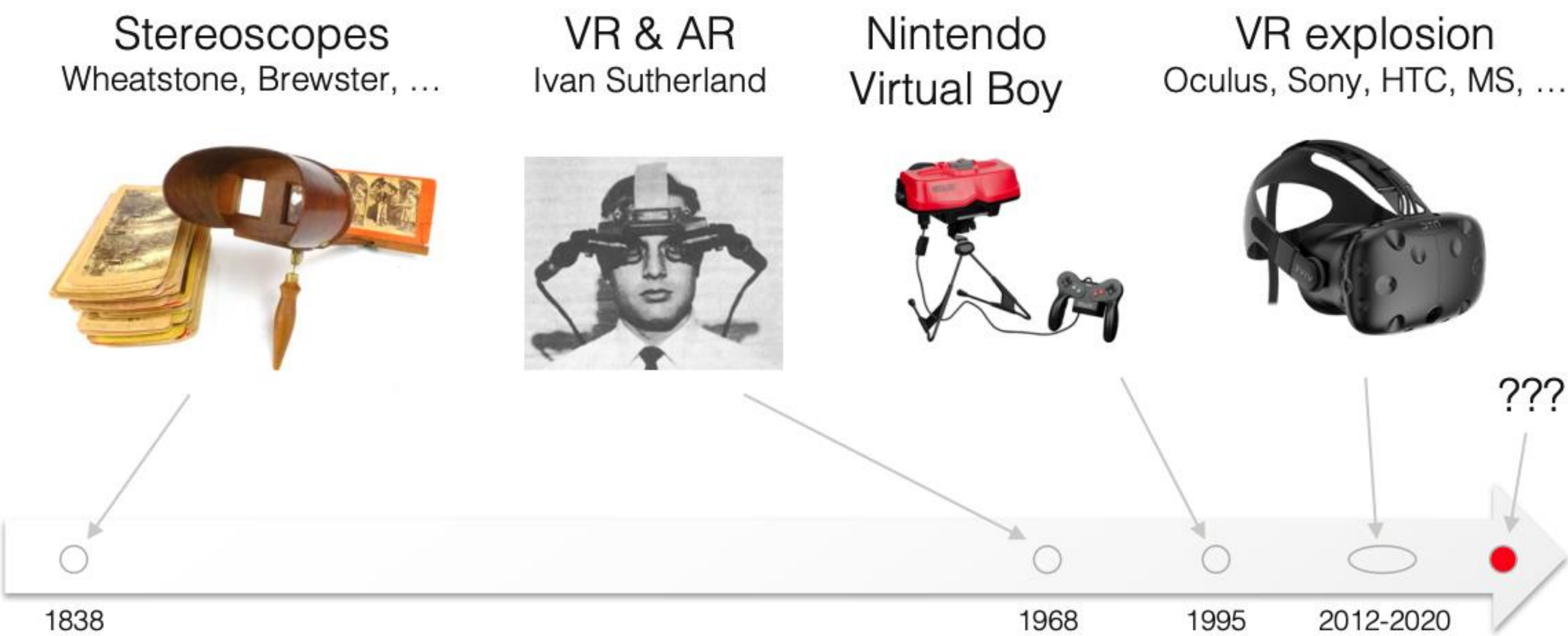
CS 410/510: VIRTUAL REALITY

Ehsan Aryafar
earyafar@pdx.edu
http://web.cecs.pdx.edu/~aryafare/VR.html

Recall: History of VR/AR

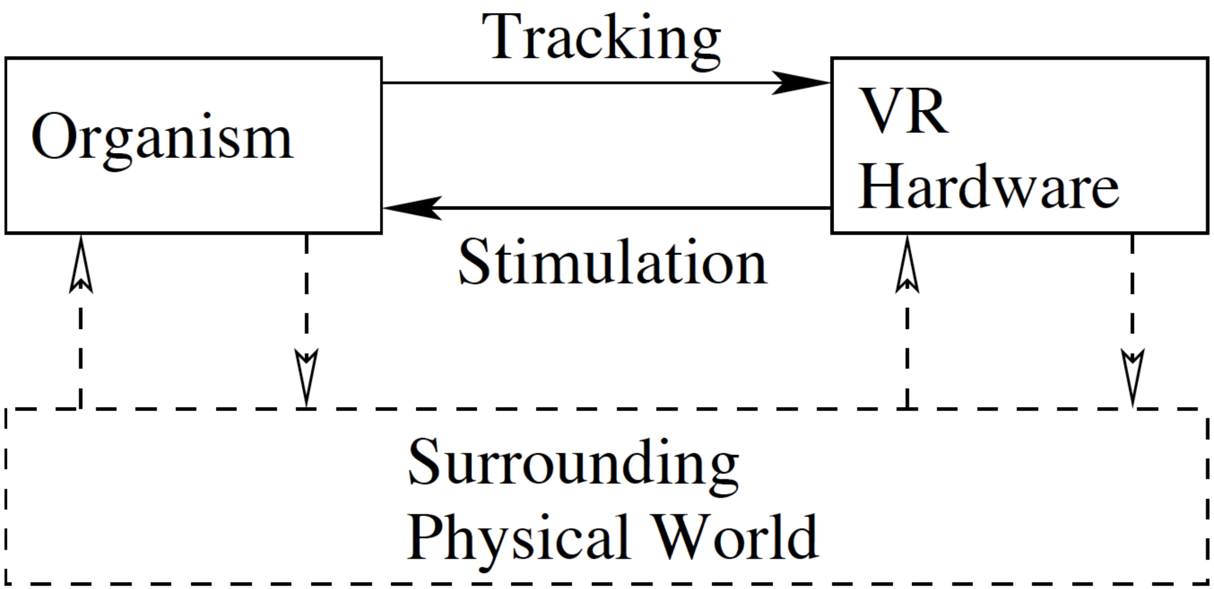


Outline

- Overview of VR systems
  - VR hardware
  - VR software
  - Human perception

Understanding VR Hardware

- VR is not just about computer, controllers, etc
  - Equally important is organism or human user as well as interactions with hardware and the surrounding world
  - VR hardware adjusts the stimulus based on human interaction
    - Achieves this through **myriad of sensors and tracking!**
    - What are some tracking examples?
    - Does surrounding environment play any role?



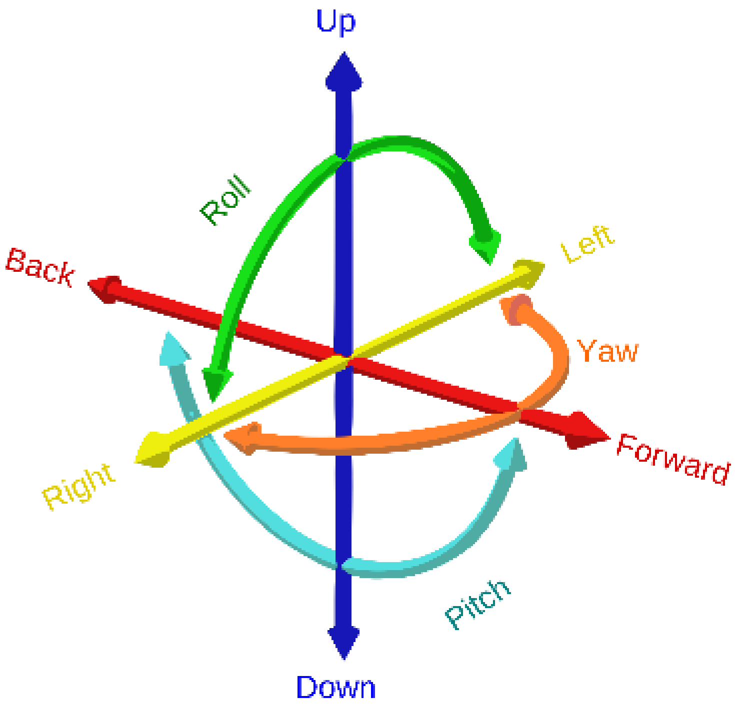
Interactions with the Surrounding Environment

- There is always stimuli from the surrounding environment to the user
  - VR system may track other objects in the environment
  - … especially if other objects are also in the VR world
  - Can the VR gear change the real world as well?

- VR hardware extracts information from the real world
  - **Transducer: transforms energy from one form to other**
  - Sensor: Special transducer that converts energy to an electric signal
  - Human brain works in a similar way: a sense organ (eye, ear) converts energy into neural impulses (**mostly electrical signals**)
    - **Nerual impulse is the way neurons communicate with each other**

Tracking sense organs

- VR hardware needs to track your sense organs (e.g., eye)
  - **Some sense organs are attached to body and move with it (ear)**
  - Some can also move relative to the body (eyes or hands)
- VR hardware track movement of a rigid body
- A rigid body has 6 degrees of freedom (DoF) to move in a 3D space
- **3 DoF for position and 3 for orientation**



ROLLING

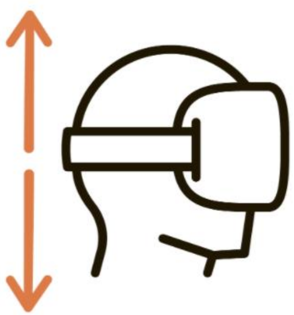
Roll is where the head **pivots side to side** (i.e. when peeking around a corner)

PITCHING

Pitch is where the head **tilts along a vertical axis** (i.e. when looking up or down).

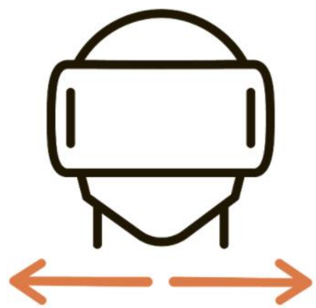
YAWING

Yaw is where the head **swivels along a horizontal axis** (i.e. when looking left or right)



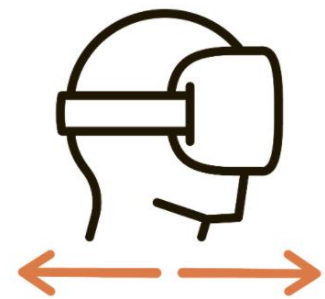
ELEVATING

Elevation is where a person **moves up or down** (i.e. when bending down or standing up)



STRAFING

Strafe is where a person **moves left or right** (i.e. when sidestepping)



SURGING

Surge is where a person moves **forwards or backwards** (i.e. when walking)

3 DoF vs 6 DoF Headsets

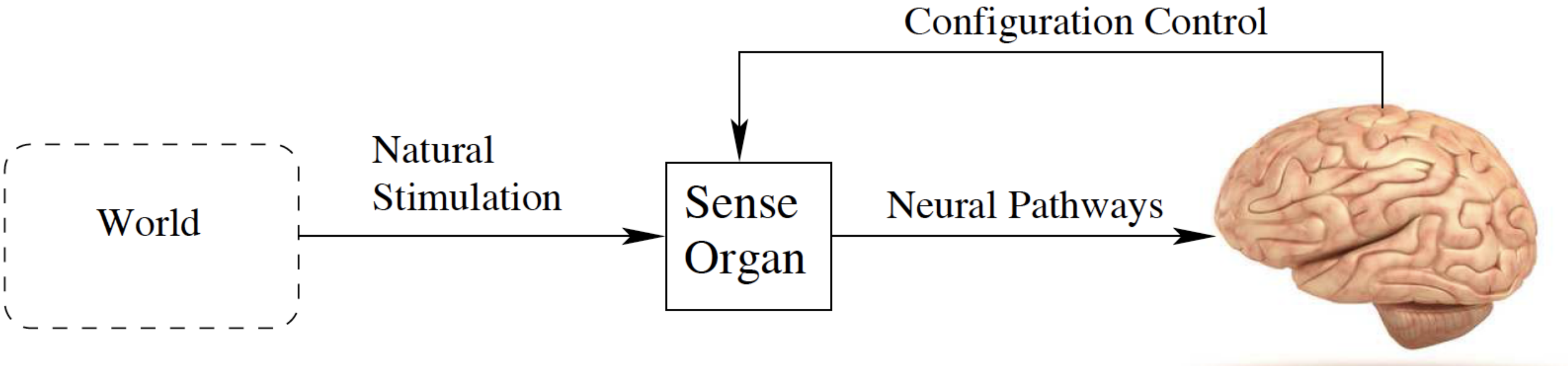
- Headsets with 3 DoF: **All phones based headsets:** Google cardboard, Samsung gear VR, google daydream and some standalone headsets such as Oculus Go
  - Simplest form of VR tracking build entirely on inbuilt sensors on the phone (accelerometer, gyroscope, magnetometer)
  - Gives you the perspective from a single standing point

- Headsets with 6 DoF: Oculus Rift, Windows Mixed Reality
  - You can also physically move in the VR world
  - Whole room VR experience, dodge VR bullets ☺
  - Leverage sensors in the outside world or attached to the user

VR systems need tracking tools to determine the position and orientation of each sense organ!

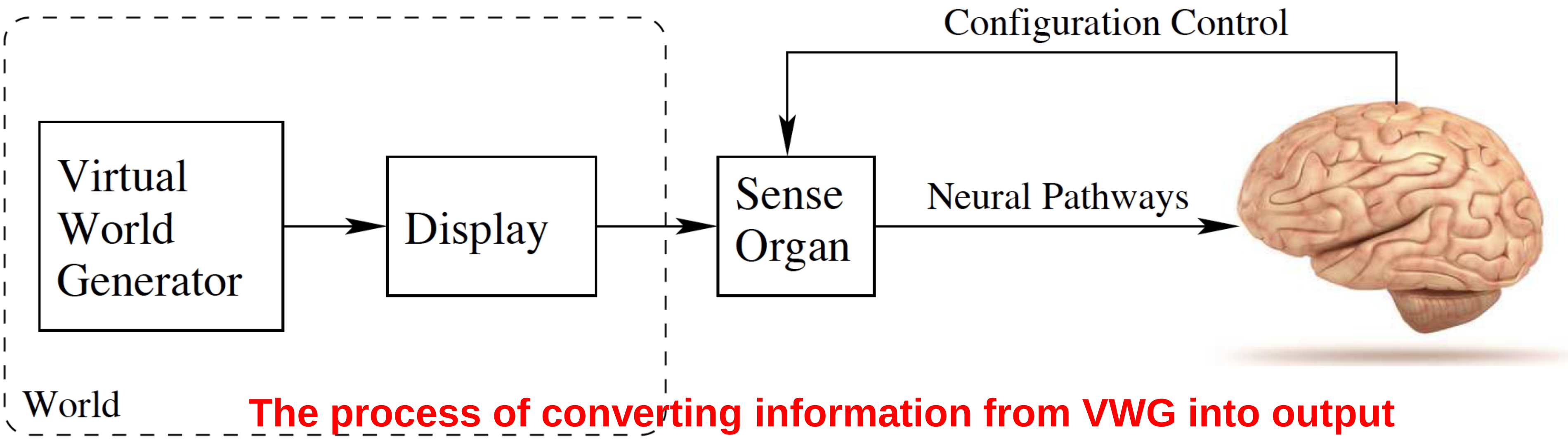
Abstract View of Brain Operation

- Brain controls configuration of sense organs
- Sense organ converts natural stimuli to neural impulses



Abstract View of VR Operation

- Virtual world generator (VWG) runs on a computer and generates another world
- Sense organ perceives the VR world through a display, which mimics the type of stimuli expected by the organ
    - Eye: smartphone screen; ear: display is called speaker



The process of converting information from VWG into output for display is called rendering!

If VR system is effective, brain is fooled into being in the VR generated world

Morpheus explains what is real!

Audio/Video Compensation/Tracking

- Suppose a user looking at a VR world through the display
- As the user head moves, the VR system need to show different views
  - i.e., assume the VR environment is fixed
  - Significant engineering challenge to estimate user head and eye movement and apply appropriate transformations to images and videos in a timely manner
  - If not handled well, will result in VR motion sickness
    - **Main reason VR systems lost popularity in 1990**

Components of VR Hardware

- Displays (outputs)
  - Devices that each stimulate a sense organ
- Sensors (input)
  - Devices that extract information from the real world
- Computers
  - Devices that process input and output

Display

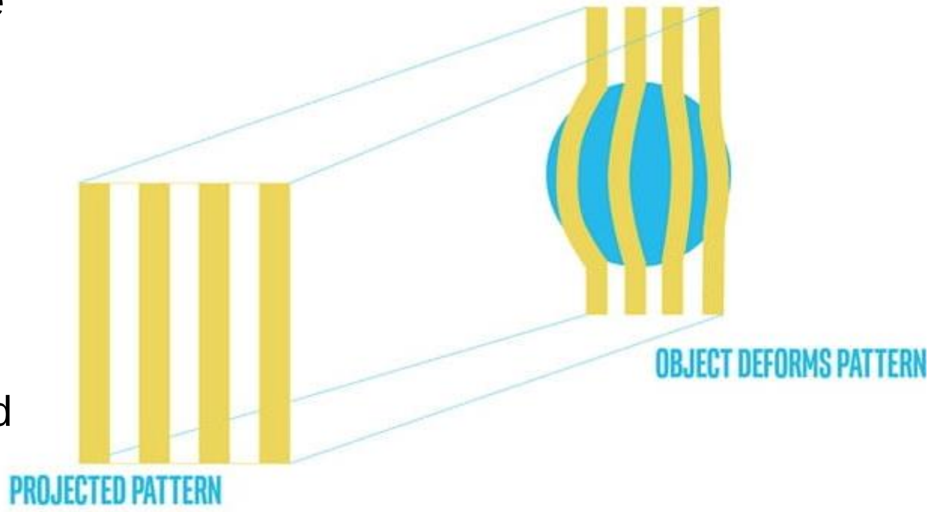
- Generates stimuli for a target sense organ
  - **Eye is the dominant sense organ**
    - CAVE systems: typically use a combination of projectors and mirrors
    - Headsets: a smartphone display can be placed close to eyes and brought into focus **using one magnifying lens for each eye**
    - VR Headsets using custom or latest display technology
      - May use one display for each eye with 90 Hz and higher frame rate
  - Ear is next in line
    - Speakers or methods to vibrate the skull and propagate to inner ears
  - Sense of touch
    - Haptic displays for vibration, pressure, or temperature
  - Other displays for taste and smell

Sensors

- The position and orientation of eyes and ears (or other sense organs) must be tracked by sensors
- Orientation is tracked by an IMU (Inertial Measurement Unit)
  - Detect linear acceleration using accelerometer
  - Detect rotational rate using gyroscope
  - Detect heading using a magnetometer
  - Typically each of the above per each axes (pitch, roll, yaw)

Sensors (Camera)

- Cameras can be used to track movement of humans or body parts (need to have a marker or a reference point)
- Cameras can also be used to **detect depth** (many technologies), e.g., structured light cameras
  - Project light with a known pattern (active method)
    - **Usually infrared (IR) so that humans would not observe**
    - Object deforms the pattern and IR sensor captures the image
    - Using disparity between the emitted and actual image, distance can be measured for every pixel



Computer

- Generates the virtual world
  - Separate PC
    - Wired or wireless connection to the head mount
    - **Microcontrollers on a headmount can be used to gather sensory data and send to PC**

Computer

- Generates the virtual world
  - Separate PC
    - Wired or wireless connection to the head mount
    - Microcontrollers on a headmount can be used to gather sensory data and send to PC
  - A smartphone can be dropped to a case with lenses

Google cardboard

Samsung VR gear

Computer

- Generates the virtual world
  - Separate PC
    - Wired or wireless connection to the head mount
    - Microcontrollers on a headmount can be used to gather sensory data and send to PC
  - A smartphone can be dropped to a case with lenses
  - The industry is moving towards **all-in-one VR systems**
      - **May use GPUs for quick graphics rendering**

Hardware

- Oculus Rift Development Kit 2 Teardown

Circuits that power IR LEDs

Circuit with microcontroller, IMU

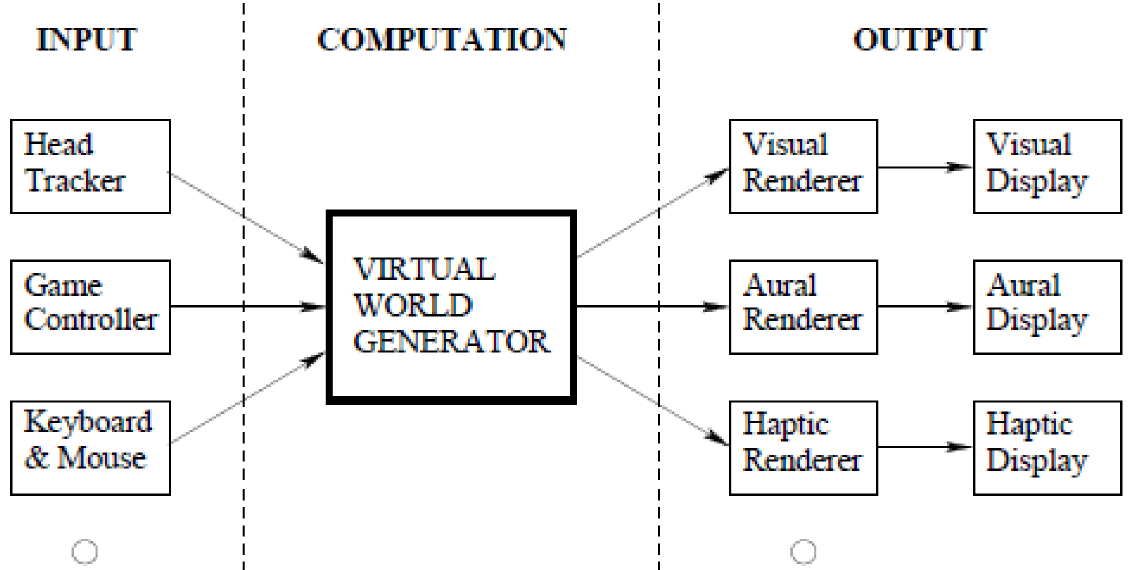
Lenses

Smartphone screen serves as display

Camera for tracking

Software

- Industry is moving towards full-fledged VR engines
  - Similar to game engines
    - Game engine: a software-development environment designed for people to create video games, which provides the following functionalities: 2D/3D rendering and management of memory, sound, networking, AI, threading, etc.
  - SDKs are being developed for particular headsets
    - Handle low level operations, e.g., device derivers, head tracking, and display



User Locomotion in the VR World

- Matched zone: Safe region in the real world where the user motions are confined to
  - Example: a VR arcade may have a region designated to each player
  - The VWG (Virtual World Generator) may detect if the user moves outside the matched zone, and would take steps to inform the user about it
- In many VR experiences, users wants to move well outside the matched zone (give an example?)
  - Locomotion: movement in the virtual world that is not matched by the real world
    - How can we potentially implement it?
    - Any problem associated with the mismatch?

Vection

- Vection: is the illusion of self-motion
  - Example: In the VR world you move by moving the cursor, but you are not moving in the actual world
  - Your brain gets conflicting sensory input
    - Your eyes say you are moving
    - Your balance says you are motionless
  - Can cause fatigue and VR sickness

Virtual World Physics

- Modeling physics appropriately in the VR is a discipline for itself
  - A ball dropped should accelerate
  - If you hit a ball, what should be the response?
  - What happens when two or more objects collide?
- In addition to handling motions of moving objects, the physics must also take into account how potential stimuli for displays are created and how they propagate in the VR world
  - Example: An ambulance that is moving away from the user
    - How should you hear the sound?

Networked VR Experience

- Users can be close to each other or distributed on earth!
- When close to each other, important to avoid collisions between them
- When users interact, they expect to see eye motions, facial expressions, and body language!

Developer Choice for VWGs

- Developer may use a ready made VWG (high level scripting). Two game engines adapted for VR are:
  - Unity 3D
  - Unreal engine by Epic Games
  - The game engines are easy to use but may lack to create experiences that were not imagined by the engine builders
- Alternatively, the developer may start from a basic SDK for a particular VR headset and build her own VWG from scratch
  - SDK needs to provide access to basic drivers and an interface to access tracking data and make calls to the graphical rendering libraries
  - Developer would be responsible for physics such as avatar movement, collision detections, modeling of audio and light!

Some News on Game Engines

Unity's IPO filing shows how big a threat it poses to Epic and the Unreal Engine

Two billion monthly active end users, 1.5 million creators

By Sean Hollister | @StarFire2258 | Aug 24, 2020, 3:17pm EDT

Apple terminates Epic Games' App Store account

Anthony Ha

@anthonyha / 5:40 pm EDT • August 28, 2020

Save

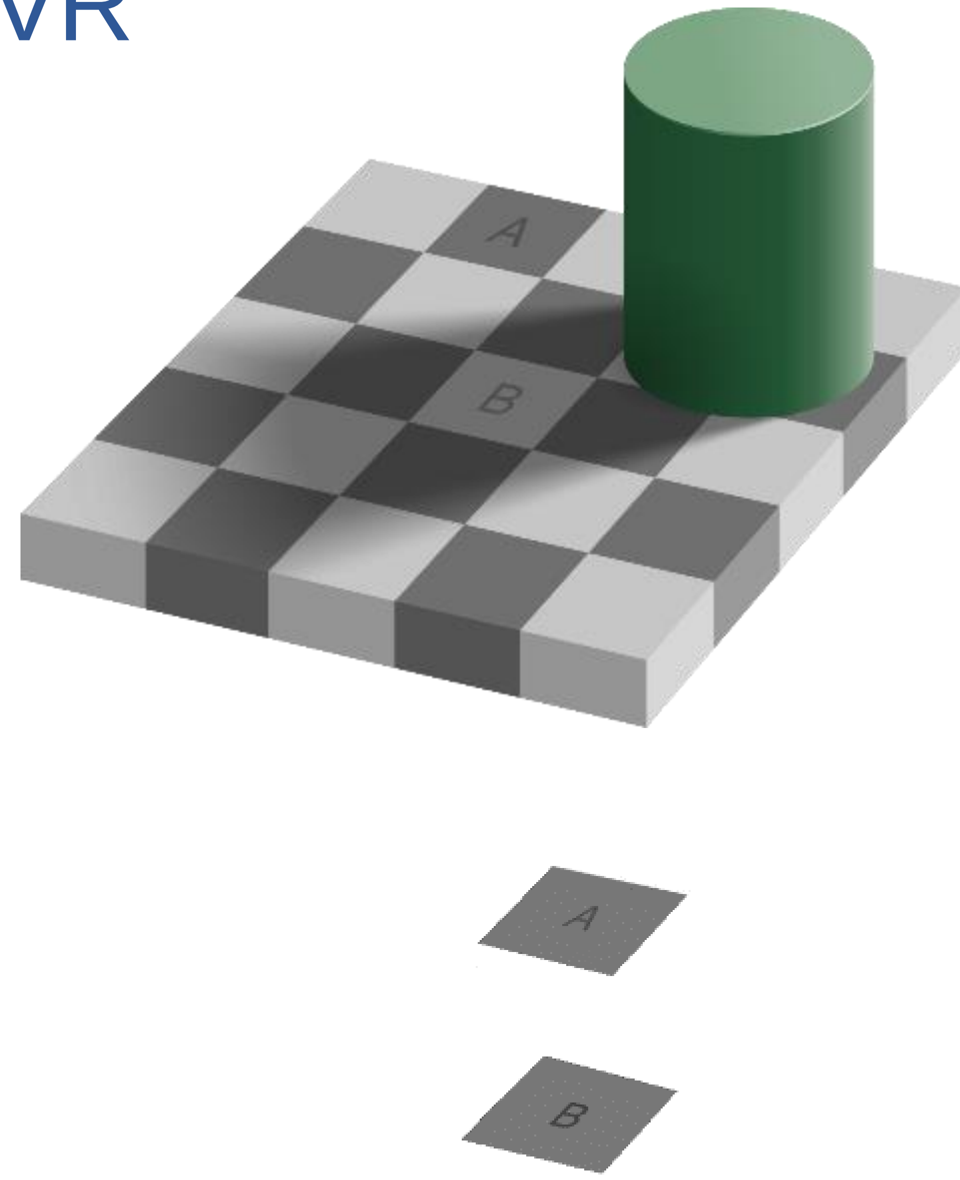
Comment

Human Physiology and Perception

- By providing artificial stimuli to our sense organs, we are disrupting the behavior of our body
  - **Perfect VR:** everything in the VR world is the same as the real world expectations
  - **VR is not exactly consistent, but you may quickly get used to it**
    - Some people who play video games frequently, for example, are already used to user locomotion, whereas for others it may be inconvenient
  - **VR may cause headache or increased fatigue**
    - Others may get VR sickness, involving dizziness and nausea

Perception side of VR

- **Perceptual psychology is the science of understanding how the brain converts sensory stimulation into perceived phenomena. It can help answer questions like:**
  - How much video resolution is needed to avoid seeing pixels
  - How many frames per second are needed to perceive motion as continuous
- The perception side of VR often is overlooked
  - A lot happens from when you see an image and recognize someone
  - **Our senses have limitations, e.g., optical illusions**

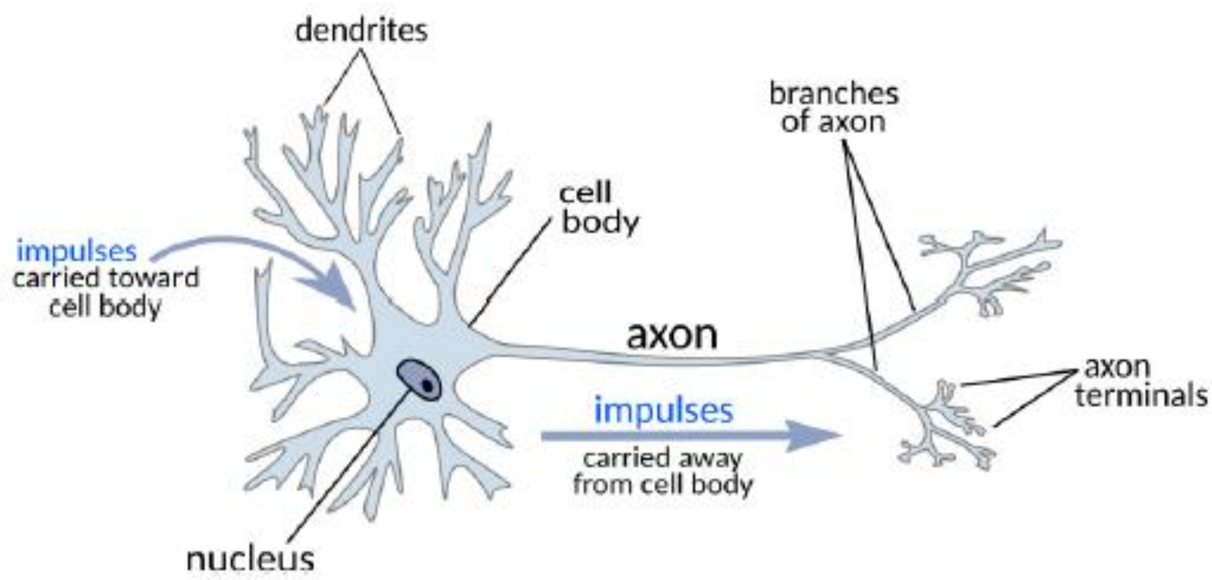


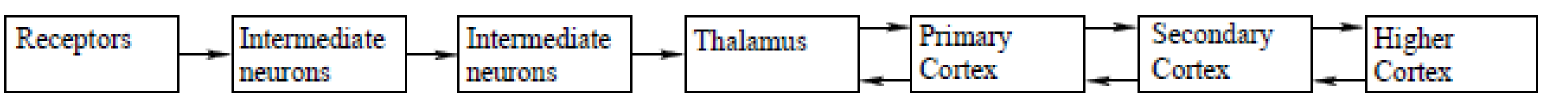
So How Does Perception Work?

- Sense organ receives stimulus
  - Example: eyes get electromagnetic energy
  - In eyes, 100s of millions of photoreceptors (sensors) exist, each respond differently to different parts of the visible light frequency and the intensity of it
  - Each photoreceptor converts the light signal into a neural impulse
    - Photoreceptor proteins in the cell absorb photons, triggering a change in the cell's membrane voltage
- Upon leaving sense organ receptors, signals propagate among the neurons to eventually reach the cerebral cortex in the brain
    - As signals pass through neurons in a hierarchical manner, increasingly complex patterns can be detected in the brain
      - Example: curves appear, which then turn into circles, then human, and eventually a familiar face

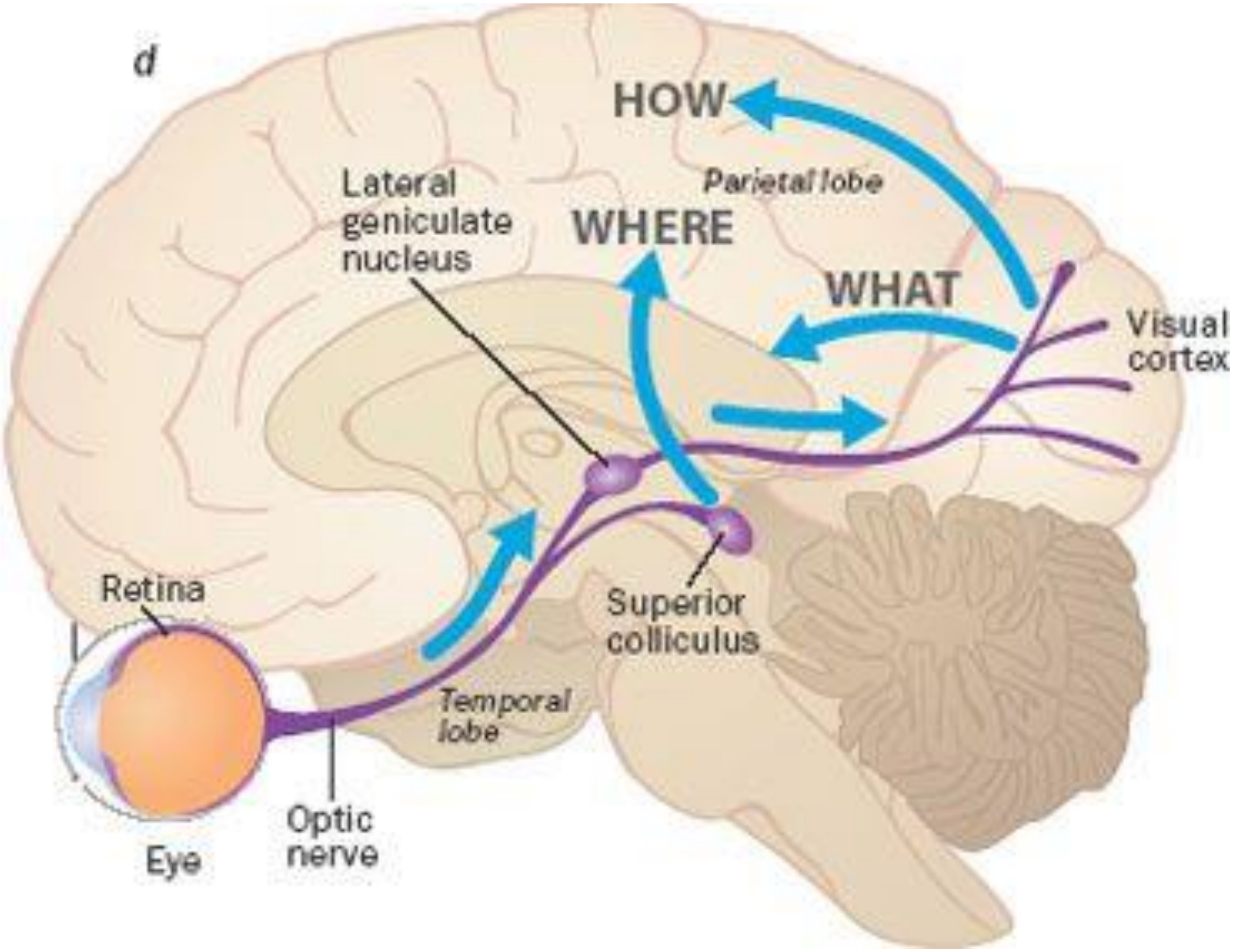
Neurons and Hierarchical Processing

- Human body has more than 86 billion neurons
  - **Around 20 billion are devoted to a part of brain called cerebral cortex (around 3 mm thick)**
    - Some animals have more neurons than humans, many less





From Eyes to Visual Cortex and Perception



Fusion of senses: signals from multiple senses are processed and combined with our prior experiences!

So Why Understanding Perception is Important?

- **VR systems need to be evaluated on users to see whether they are yielding the desired effects while avoiding unwanted side effects**
  - May need to conduct human subject experiments
    - How many subjects are enough?
    - **Make sure they do not adapt (get used to) to experiments**
      - Can give a bias when designing experiments
      - Gamers may have less of a vection problem
    - How does prior experience affect the experiment?