LECTURE 11: INTERACTION

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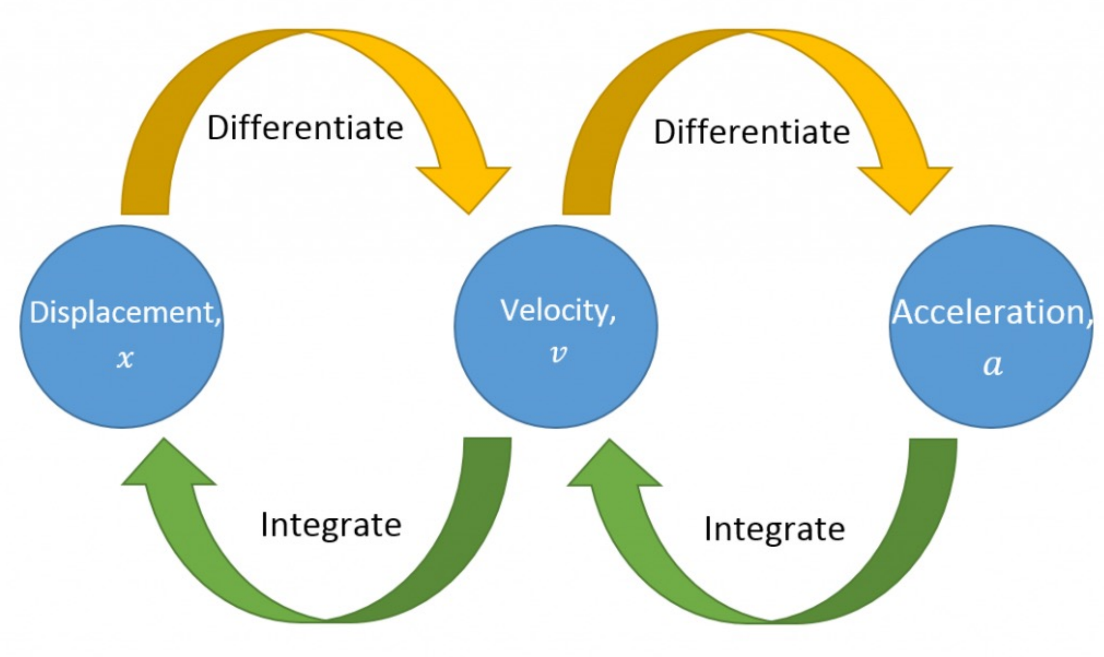
Recall: Four Problems to Solve For Effective Tracking

- Calibration: Assume access to a high quality sensor and a few low quality sensors. The output of the low quality sensors could be calibrated to mimic the high quality sensor.
- Integration: Sensors output their measurement in discrete times, so their outputs need to be integrated over time
  - Recall Euler integration
- Registration: The initial orientation must be determined through an additional sensor or a startup procedure
- Drift Error: As the error grows over time, other sensory data may be needed to compensate for it

Recall: Common Base: Dead Reckoning

- Orientation is solved leveraging IMUs
- Position: The base solution is to position is to use accelerometers in IMUs
  - Typically run at 1000 Hz
  - Take twice integration to derive position
  - Infeasible if you rely only on double integration



From moment to moment it's how every VR headset and controller tracks itself.

Recall: SLAM / Inside Out Operation

This Lecture: Interaction

- How should the users interact with the virtual world?
- How should they move or be moved?
- How should they interact with representations of each other?

- Recall that the goal is not necessarily increased realism
  - Put aside the engineering hat (more frame rate, better graphics)
  - At the end, what matters is the human subject!
  - You can potentially make the interaction better than reality, how?
  - VR interaction mechanisms may not have counterparts in the physical world

Outline

- Motor learning and control concepts
  - Remapping: motion in the real world may be mapped into a substantially different motion in the virtual world
  - Need to develop remapping solutions that are easy to learn, easy to use, effective, and comfortable for the user
- Locomotion: motion in the VR world not matched in the physical world
- Different methods a user may interact with other objects in the virtual world
- Social interaction mechanisms (allow users to interact directly with each other)

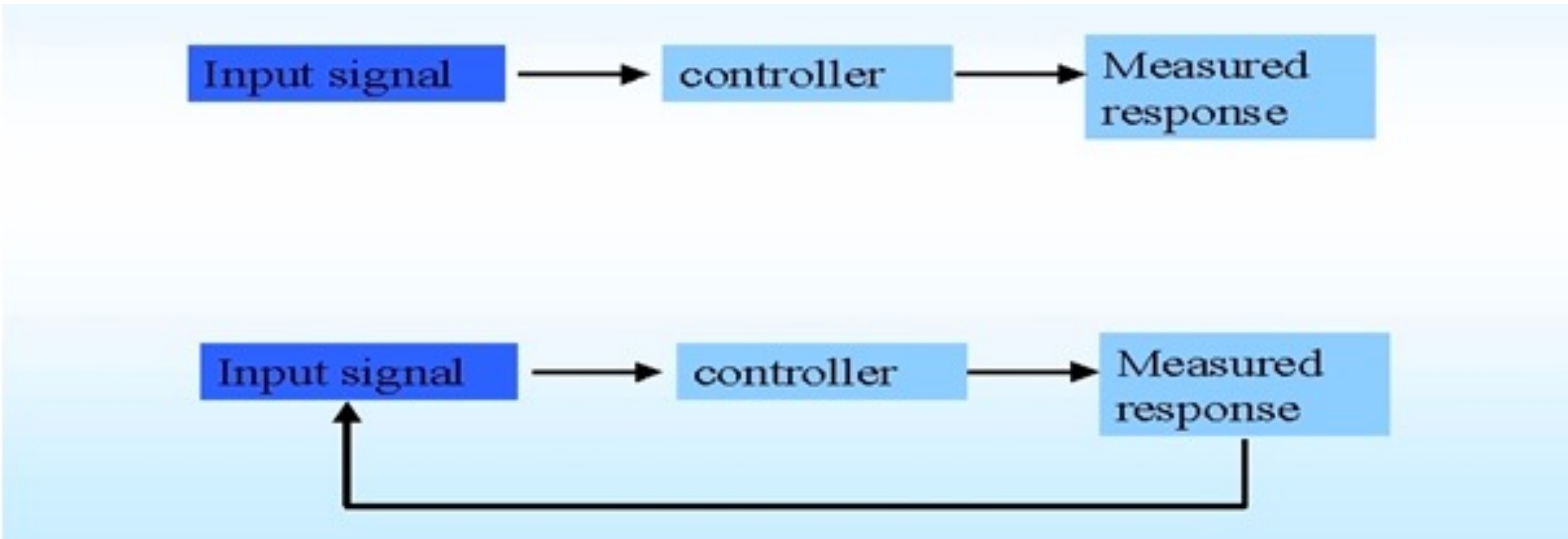
Motor Programs

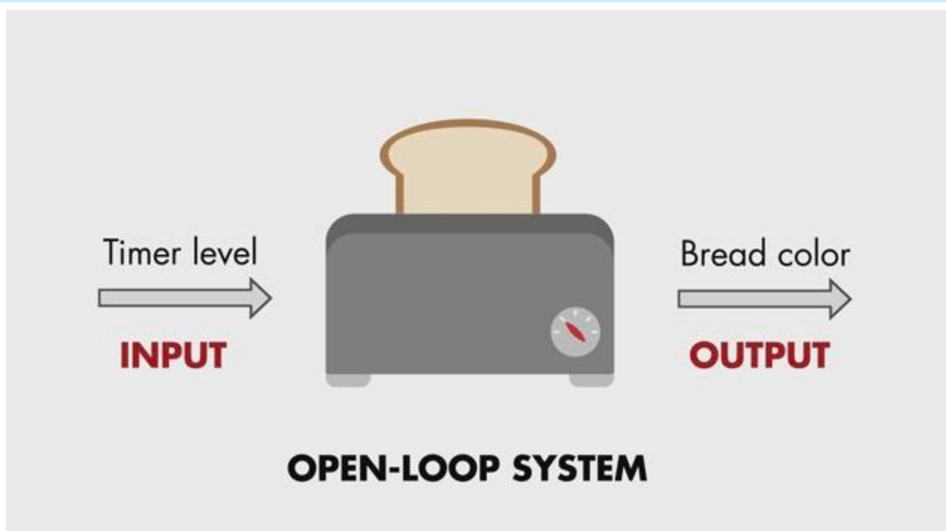
- Motor programs: throughput our lives we learn motor skills for different tasks
  - Text writing, throwing a ball, riding a bicycle
  - Eventually get to do it without even having to think about it
- Similar manner to learn about computer interface, e.g., mouse control
  - **Fast keyboard typing can take years!**
- We have potential to learn new motor programs or unlearn previous motor programs
  - Some motor programs may need to eliminate others, e.g., riding a bicycle with steering wheels in the opposite direction of tires takes six months to learn and you lose ability to ride a normal bicycle!

Development of Interaction Mechanisms for VR

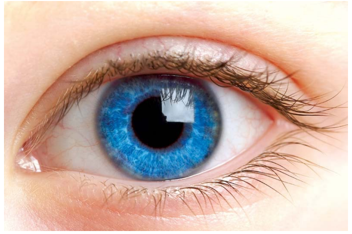
- Main considerations:
  - Effectiveness for the task in terms of speed, accuracy and motion range
  - Difficulty of learning new motor programs
  - Ease of use in terms of cognitive load
  - Overall comfort over extended periods

Closed Loop vs Open loop Systems





Closed Loop Operation in Brain



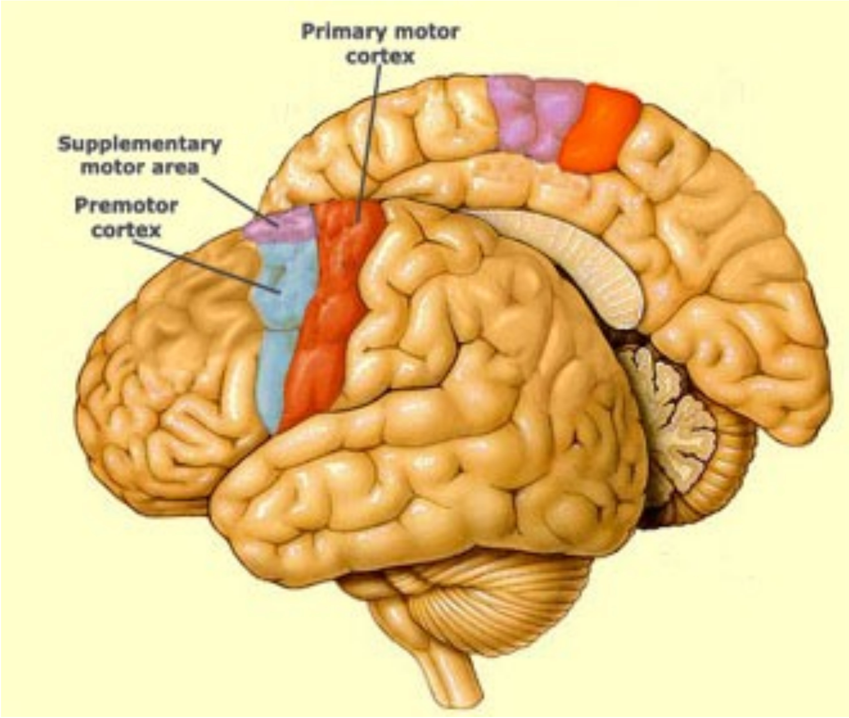
Sensory Input

Perceptual Experience

Output motor body motion

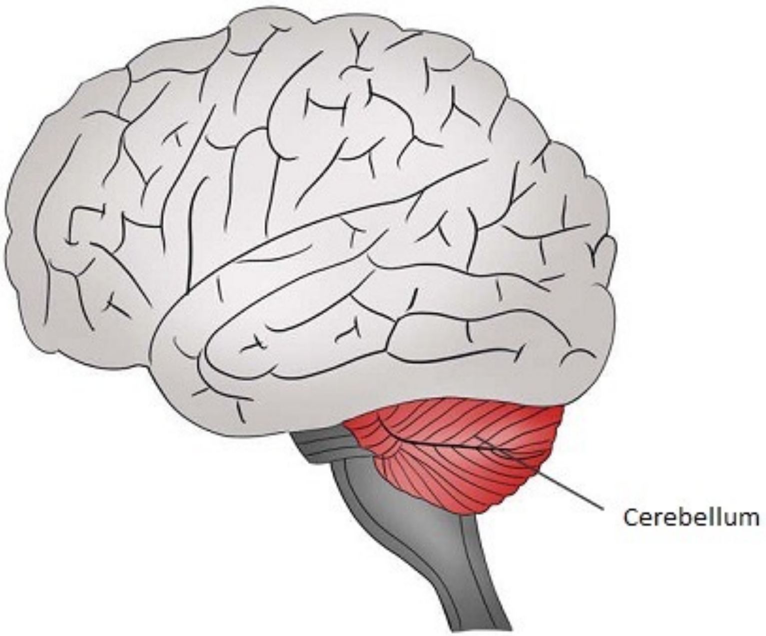
Neurophysiology of Movement

- The primary motor cortex is the main source of neural signals that control movement, whereas the premotor cortex and supplementary motor area appear to be involved in the preparation and planning of movement.



Neurophysiology of Movement

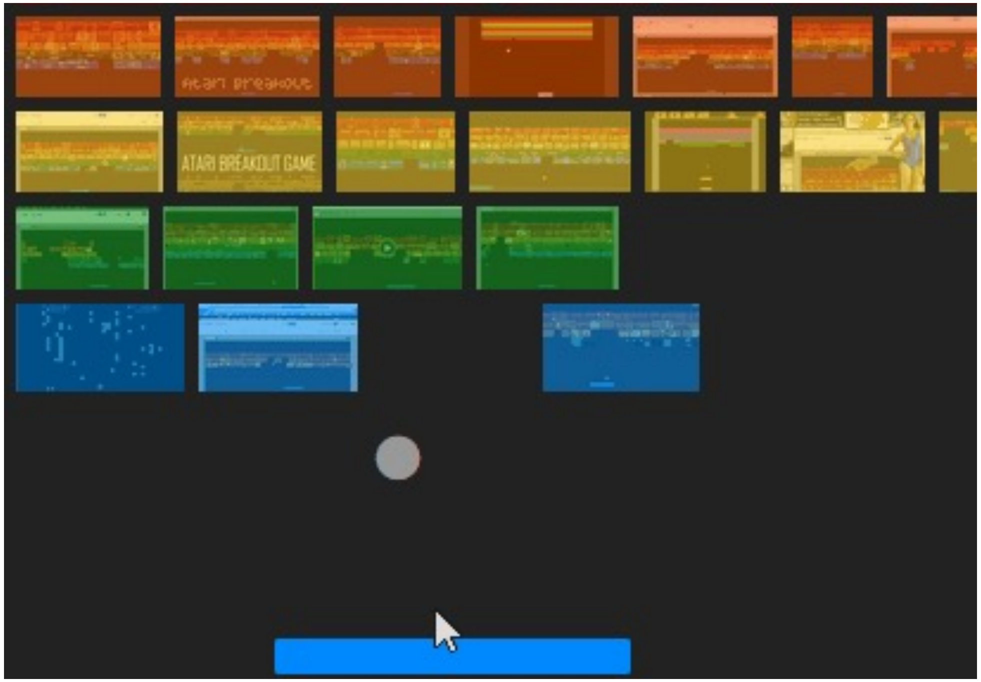
- Many more parts are involved in motion and communicate through neural signals
- Important part: cerebellum, meaning “little brain”, at the back of the skull.
- It seems to be a special processing unit that is mostly devoted to motion, but is also involved in functions such as attention and language.
- Damage to the cerebellum has been widely seen to affect fine motor control and learning of new motor programs.
- It has been estimated to contain around 101 billion neurons (highly densely packed cells)



How Long it Takes to Learn a New Motor Program?

- Great variation across humans
- Neuroplasticity: potential of the brain to reorganize its neural structures and form new pathways to adapt to new stimuli
- Toddlers have a high level of neuroplasticity
  - It reduces over time through synaptic pruning
  - Healthy adults have about half the synapses per neuron than a 2 or 3 year old child
  - Adults would have a harder time learning new skills
  - Neuroplasticity greatly varies among people of the same age

Learning Motor Programs



- The learning process: taking information from visual perception of turning the knob and determining the sensorimotor relationships.
- Much better than moving a small tray in the real world. An example where the virtual world version allows better performance than reality.
- Sensorimotor: having or involving both sensory and motor functions

Alternatives to Turning a Knob

- Goals: accuracy, fast placement, and long-term comfort
- Press a key (arrow on keyboard) left and right
  - Time the key pressed correspond to movement
  - Velocity controlled by program than user
- Use the computer mouse
  - 2D position of the mouse mapped to a 2D position on the screen

Motor Programs for VR

- The examples are closely related to VR
- A perceptual experience is controlled by body movement that is sensed through a hardware device
- Universal simulation principle: any interaction mechanism from the real world can be simulated in VR
- In the Atari example, the physical interaction could be literally controlled by holding the paddle or simulated through another controller

Remapping

- Learning a sensorimotor mapping that produces different results in a virtual world than one may expect from the real world
- Remapping is natural in VR
- Strive for simplicity
- Open a virtual door: reach out to a door knob or press a button
- Remapping for natural walking in virtual world
  - Locomotion
    - A scaling parameter can be used, 1 cm in real world mapped to 10 cm in virtual world
  - Object interaction methods also achieved by remapping

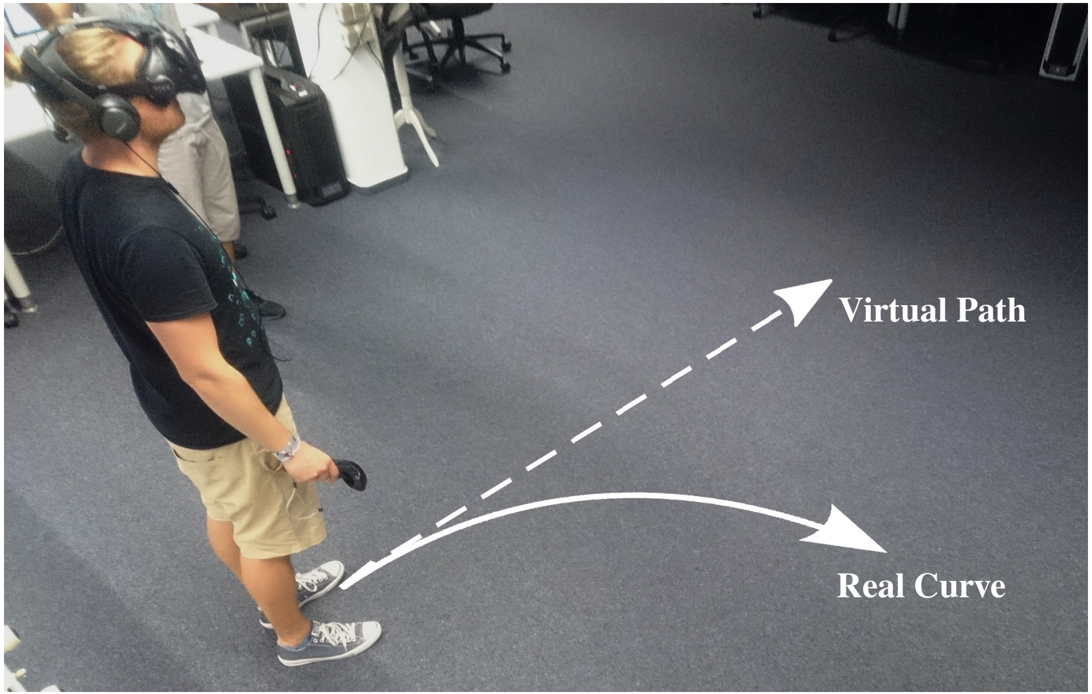
Motion Support in VR

- Real walking with headset
  - Best experience with less mismatch/vection
  - Examples:
    - CAVE systems
    - Omni threadmill

- What if matched zone is much smaller than the virtual world?
- Need to have locomotion solution

Redirected Walking

- If the tracked area is 30 meters on each side, it is possible to make the user believe she is walking a straight line for kilometers, when she is in fact walking in circles!
- Impossible for humans to walk a straight line without visual cues
  - User viewpoint could be gradually varied, by having a small mismatch between real and virtual worlds



Other Solutions

- An omnidirectional treadmill used in a CAVE system by the US Army for training.
- A home-brew bicycle riding system connected to a VRheadset.

Locomotion Spectrum

LOCOMOTION SPECTRUM

All matched motions ⟵⟶ All remapped motions

Real walking with headset	Seated in swivel chair with headset	Seated in fixed chair with headset	Seated in fixed chair and viewing a screen
		Yaw and translation handled by controller	Entire lookat handled by controller

HTC Vive
CAVE systems

Gear VR
Google Daydream
Oculus Rift

FPS game on screen
Nintendo Virtual Boy

Teleportation

- So far, we covered experiences that are familiar in the real world
- VR allows us to come up with solutions that are physically implausible
- Teleportation: immediately transport the user to a new location
- How to determine the desired location?
  - Virtual laser pointer
    - Point the laser and press a key to be instantly teleported
    - Easy to experiment with Google cardboard
    - Places that are not visible can be selected by using a pop-up map

Teleportation: Pros and Cons

- Teleportation reduces vection and VR sickness
- Cost: reduced learning of the spatial arrangement of the environment
  - Similar to people who rely on phone map or GPS for driving rather than their own wayfinding

Manipulation: Interaction with Objects

- Manipulation involves complex sensorimotor relationships which, through evolution and experience, enable us to manipulate objects under a wide variety of settings.
  - Objects different in size, weight, temperature, etc.
  - Examples: pick a cup of tea and drink
  - Pick up a rock and throw
  - Extremely hard to get robots to do these things
- In VR we do not need to follow the complexities of manipulation in the physical world
  - Make operations (carrying, selecting, grasping) as fast and as easy as possible

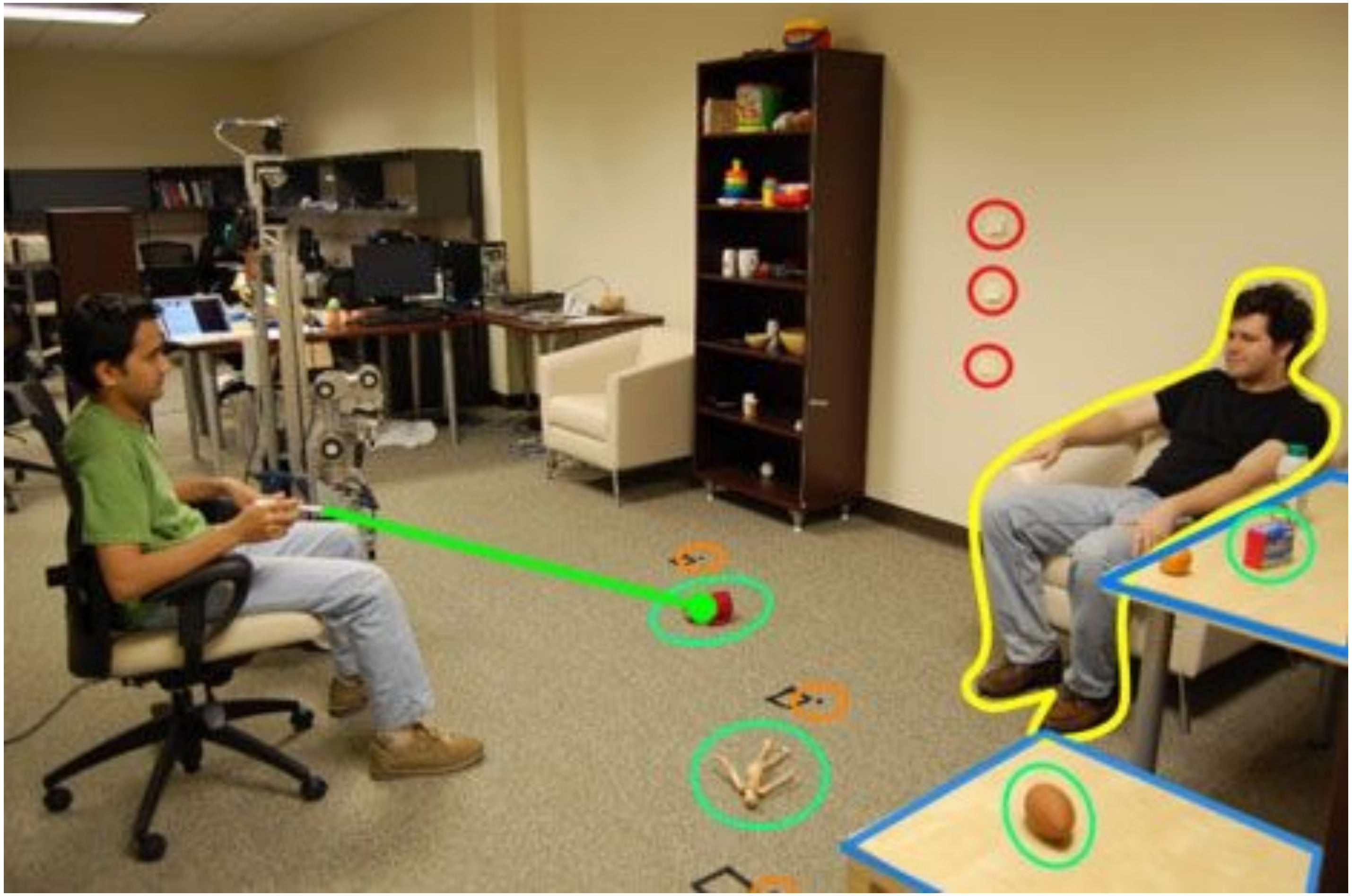
Gorilla Arms

- Moving windows on a holographic display with extended arms
- Quickly causes fatigue
- Need to avoid them

Selection

- A simple way to select an object in the virtual world is to use a virtual laser pointer
  - Illuminate the object of interest and press a button
  - If the goal is to retrieve, the object can be immediately placed in user’s hand or bag
  - If the goal is to manipulate, pressing a button could cause a virtual program to be executed
- As a developer you could put a limit on the laser depth
  - May not be good to open a door from very far away

Retrieve Objects with a Virtual Laser Pointer in AR

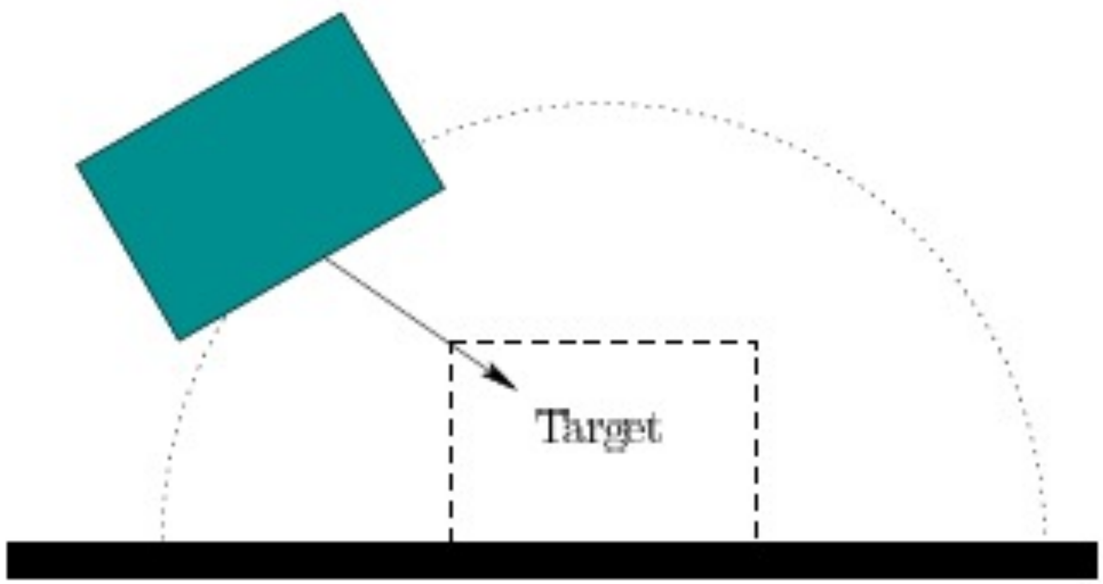


Manipulation

- Example: carefully inspect an object while having it in possession
  - Move around the object to determine its 3D structure
  - Object orientation could follow the 3D orientation of a controller that the user holds
  - The user could even hold a real object (different from virtual object), which is tracked by cameras and provides force/touch feedback

Placement

- Consider placing an object in the virtual world
- Define a basin of attraction
  - User enters the object in the basin and releases it
  - After the object is released, it falls directly onto the target pose



Minecraft sandbox game by Markus Persson (Notch)

- Example convenient object placement, in which building blocks simply fall into place

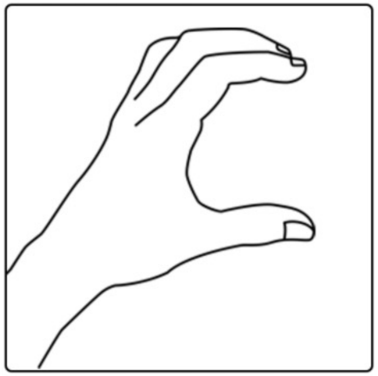
Current Interaction Systems

- Development of interaction mechanisms is one of the greatest challenges in VR
  - Use game controllers
  - Assume large hand motions are the norm
  - Goggles and gloves
  - Gesture systems that involve no hardware in hand, e.g., Magic Leap

Xbox 360 Wireless Controller

HTC Vice

Gloves



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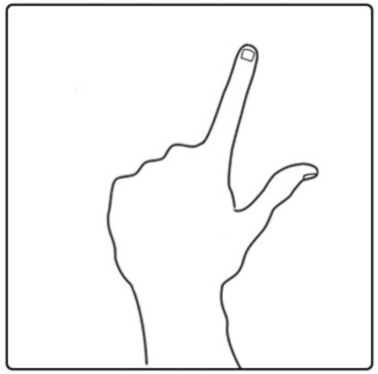

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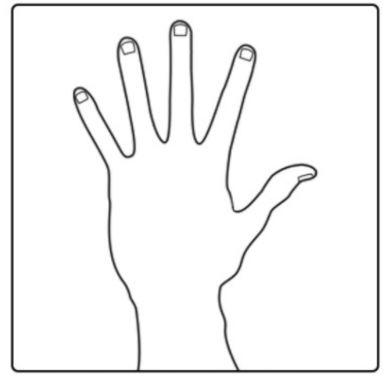
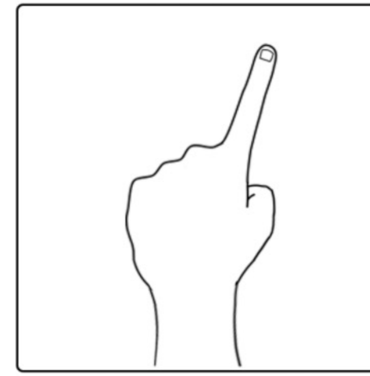
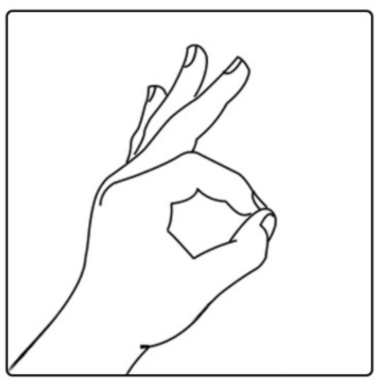


Back of the Hand



Point

Fist



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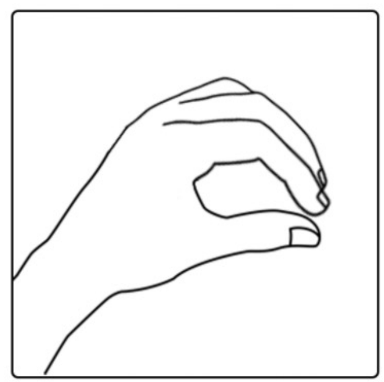
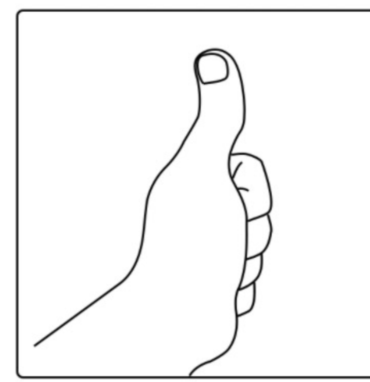


Pinch



Thumbs Up

Social Interactions in VR

- Still in a stage on infancy
- Extreme interest in metaverse at the moment

- Our focus: how should others see you in VR

Your Digital Twin

- A spectrum of possibilities
  - One extreme: represent yourself through an avatar
    - Offers anonymity
    - People change their behavior
  - Another extreme: A user captured through imaging technology (or synthetic matching) and reproduced in the virtual world with a highly accurate 3D representation
    - How close is the appearance to the actual person
    - How close is the sound
    - Behavioral appearance: avatar’s motion match the body language, facial expressions, and other motions of the person

Synthetic Matching for Appearance

- Make a kinematic model in the virtual world that corresponds in size and mobility to the actual person
  - Hair and eye color matching can be performed
  - Texture mapping on the avatar face using a photo of the real person
  - More accurate matching might be possible by combining information from both imaging and synthetic sources
  - Avoid looking like zombies!


A
B
C

Voice Reproduction in VR

- Recording and reproducing voice is simple in VR
  - Can better match auditory appearance
  - Render audio with proper localization, so it appears to others to be coming from the mouth of the avatar
  - Anonymity can be achieved by using real-time voice changing software such as MorphVOX and Voxal Voice Changer

Behavioral Experience Matching

- Main motivation behind motion capture systems
  - Motions of a real actor recorded and then used to animate an avatar in motion picture
  - Move production is a long, offline process
  - Capturing the user's face (facial expressions) is harder if wearing a VR headset

Oculus Social

- Multiple people can meet in a virtual world and socialize, e.g., watching a move theater. Head movement is provided by head tracking data. They also talk to each other with localized audio.