EECE5512
Networked XR Systems

Lecture Outline for Today

- Tracking Fundamentals
  - Eyes
  - Face
  - Gestures
  - Hands
  - Head

- Sensors and algorithms

Tracking in XR

- What is Tracking?
  - The process of continuously determining the position and orientation (e.g., of a user's device or body parts) within a given space, such as hands, face, or eyes.

Tracking in XR

- Why do we need Tracking?
  - Essential for creating an immersive and interactive experience, as it allows the virtual environment to respond dynamically to the user’s movements.

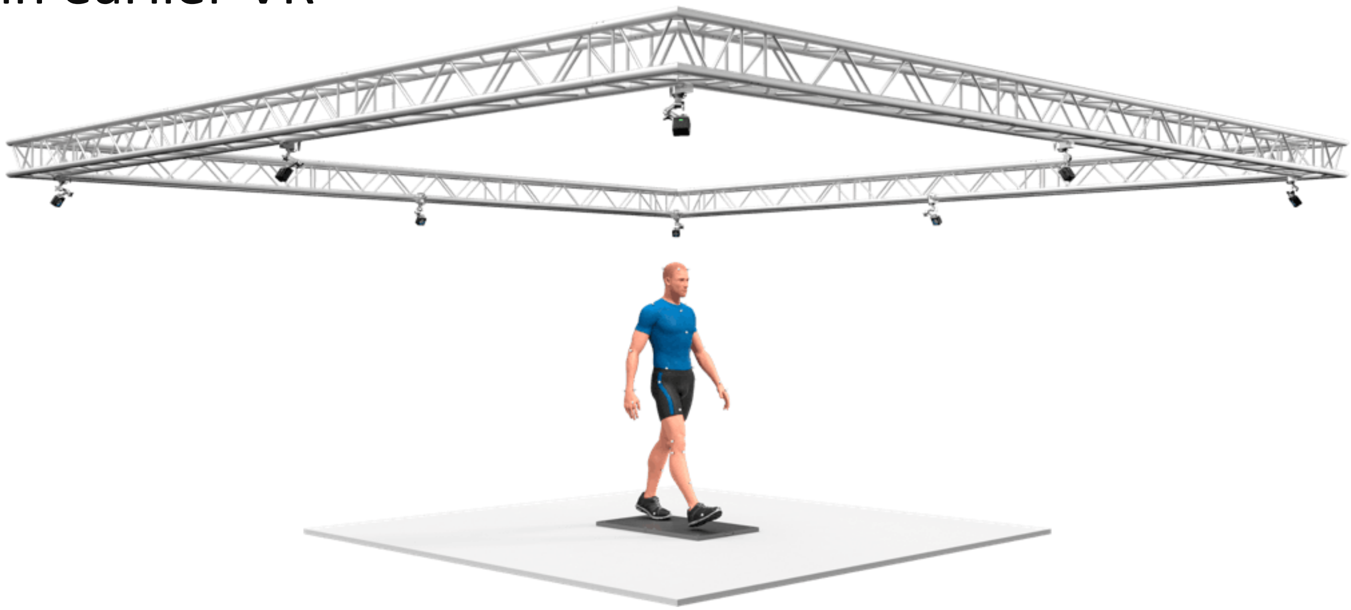
  - E.g., hand tracking in AVP eliminates the need for controllers

Tracking in XR

- Outside-in
  - Uses external sensors to track movements in space.
- Inside-out
  - Relies on sensors located on the device itself.

Tracking in XR

- Outside-in
  - Cameras or sensors are placed around the play area to track user movement.
  - Common in earlier VR systems.



Tracking in XR

- Inside-out
  - Uses cameras or sensors on the VR headset or AR device to track surroundings and determine position.

Tracking in XR

- Outside-in
  - High accuracy and low latency.
  - Requires a fixed setup; less portable.

- Inside-out
  - Greater freedom of movement, no external hardware setup.
  - May struggle with featureless environments.

Tracking in XR

- What kind of sensors are used for different types of tracking in XR?

Tracking in XR

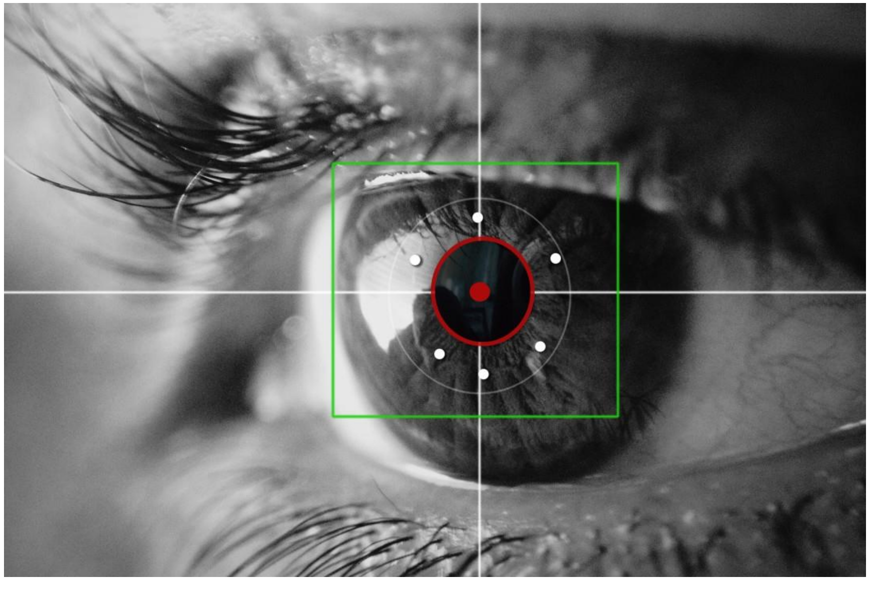
- What kind of sensors are used for different types of tracking in XR?
  - IMU (accelerometer, Gyro)
  - Color cameras
  - Depth cameras
  - IR cameras
  - Microphones, ultrasonic?
  - Magnetic?
  - Capacitive?

Tracking in XR

- What kind of tracking algorithms are used for XR?
  - Eyes
  - Face
  - Gestures
  - Hands
  - Head

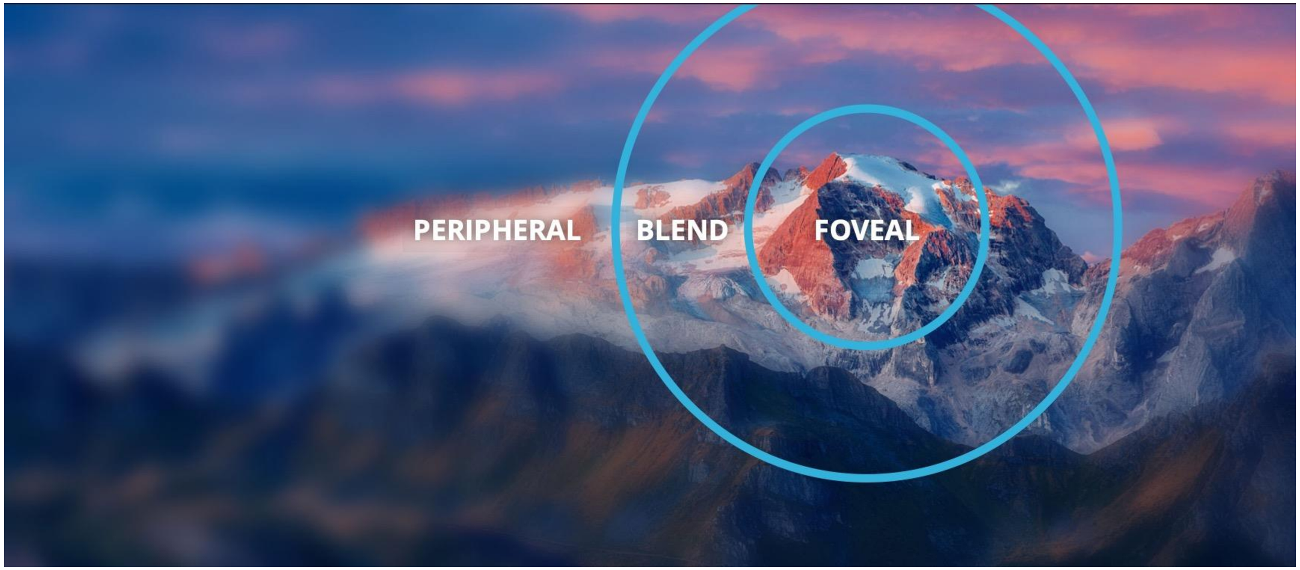
Eye Tracking

- Eye tracking is the process of measuring either the point of gaze or the motion of an eye relative to the head.



Eye Tracking

- Applications



Foveated rendering

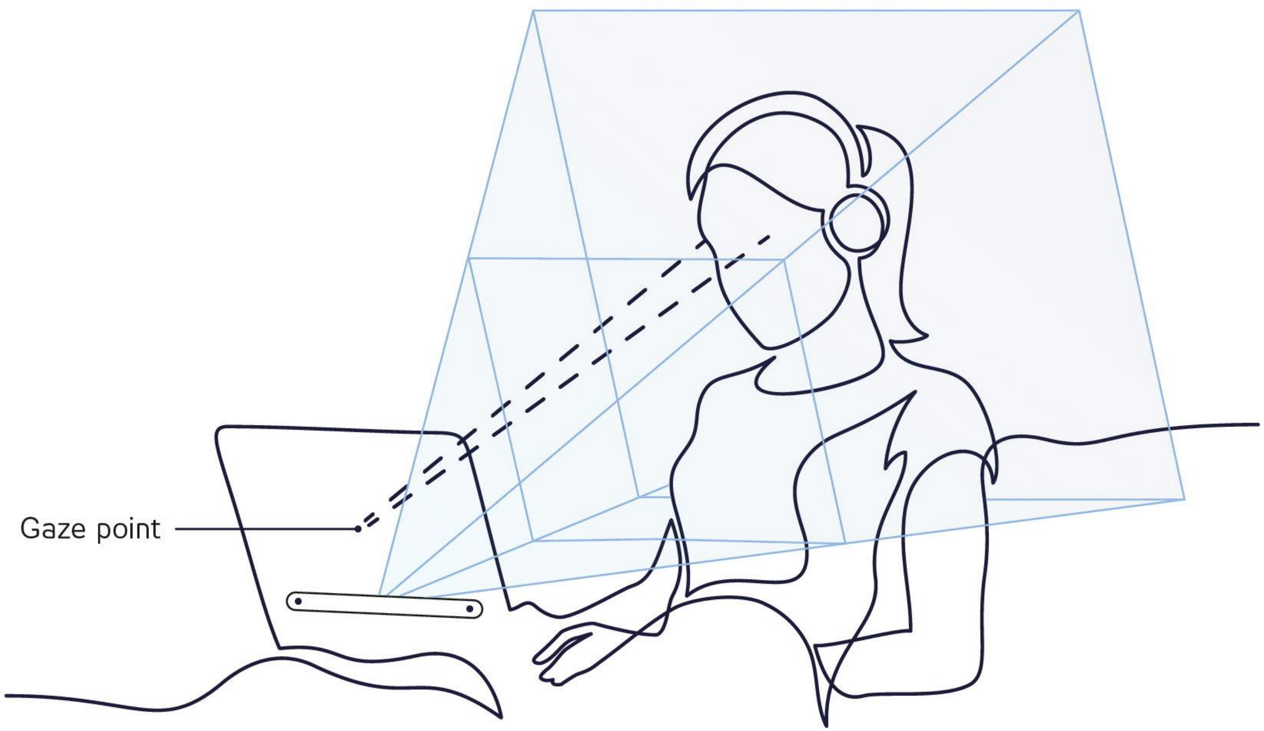
Eye Tracking

- Applications

Navigation

Eye Tracking

- So how does eye tracking work?
- Traditional settings

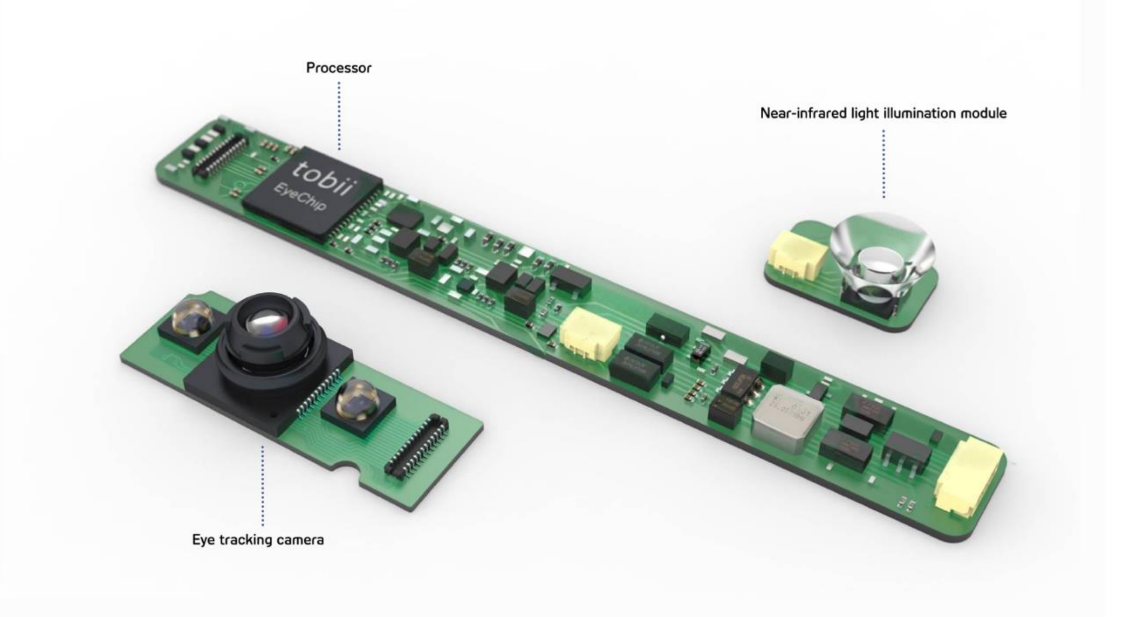


Eye Tracking

- So how does eye tracking work?
- Traditional settings

Video-based eye trackers, such as Tobii, typically consist of these key hardware components (Figure 1):

- Near-infrared light illumination modules
- Camera sensors
- Processor (image detection, 3D eye model, gaze mapping algorithm)



Tobii tracker

Eye Tracking

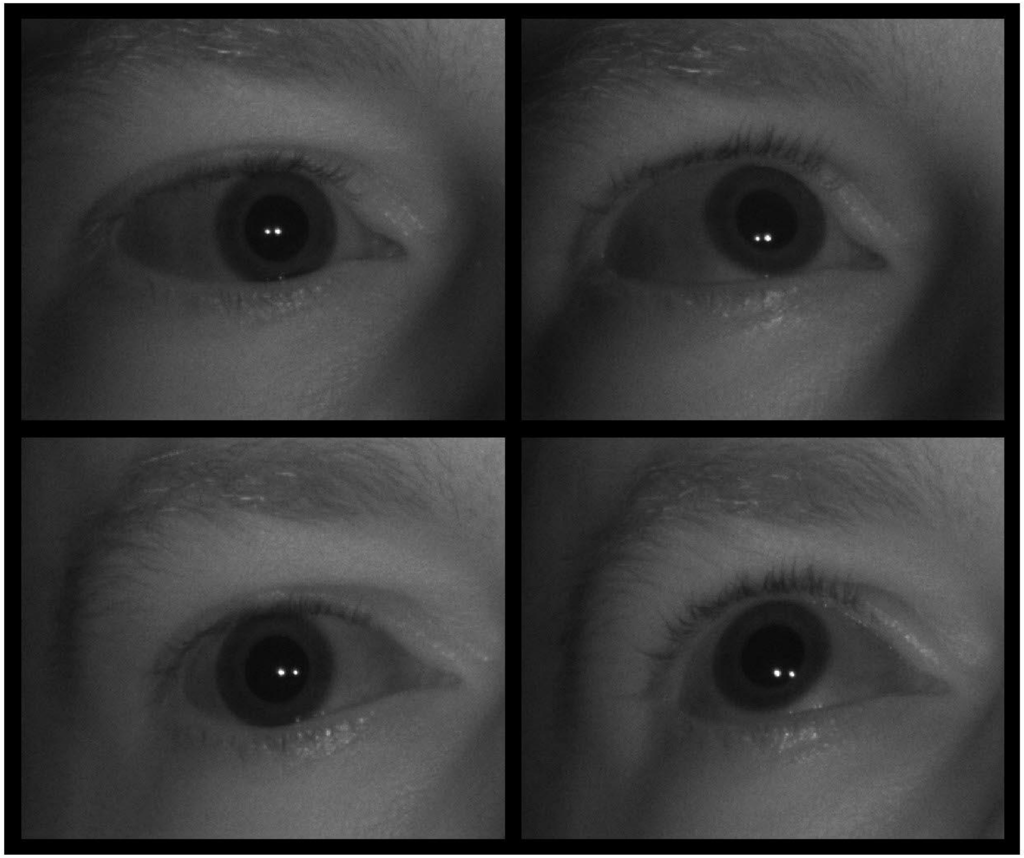
- Illumination of the eyes
- Reflection detection by sensors
- Image processing and analysis

Pupil-center corneal reflection (PCCR) method

Eye Tracking

- Key steps of the tracking algorithm
  - **Pupil Detection:** The algorithm identifies the darkest area in the image as the pupil.
  - **Glint Detection:** The brightest spots, typically near the pupil, are identified as glints.
  - **Vector Calculation:** A vector is drawn from the pupil center to the corneal reflection.
  - **Calibration:** The user looks at specific points on a screen to calibrate the system, establishing a mapping between the eye's position and points on the screen.
  - **Gaze Point:** The intersection of the vector with a plane (the screen or another surface) determines where the user is looking.

Eye Tracking



The position of the iris and the pupil changes with respect to the corneal reflection, which allows an accurate estimation of the point of gaze. Top images, from left to right: looking bottom left and top left. Bottom images, from left to right: looking bottom right and top right. Two glints are visible due to dual illumination. Tobii image.

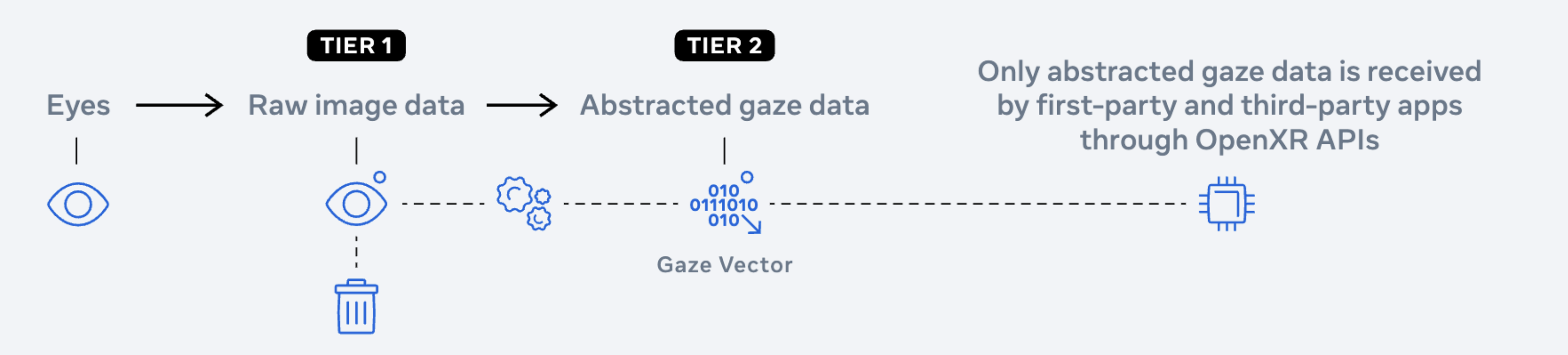
Eye Tracking

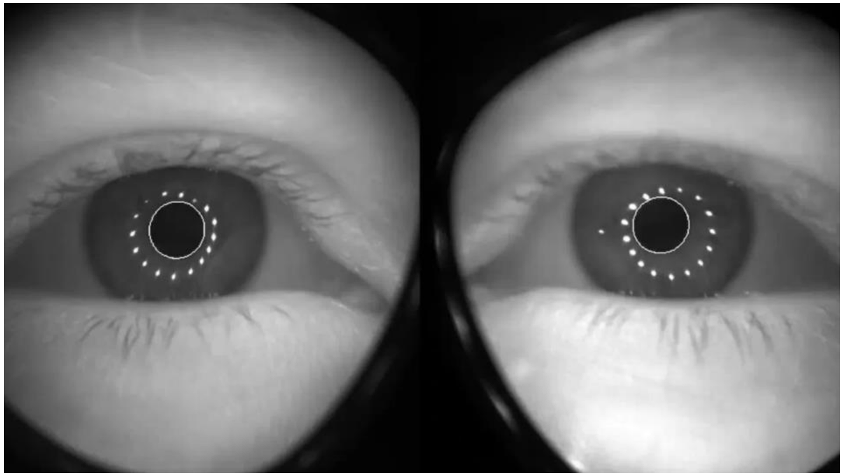
- Wearable eye tracker (Tobii glasses)

- 16 illuminators and four eye cameras integrated into scratch-resistant lenses
- Scene camera with a 106° field of view

Eye Tracking

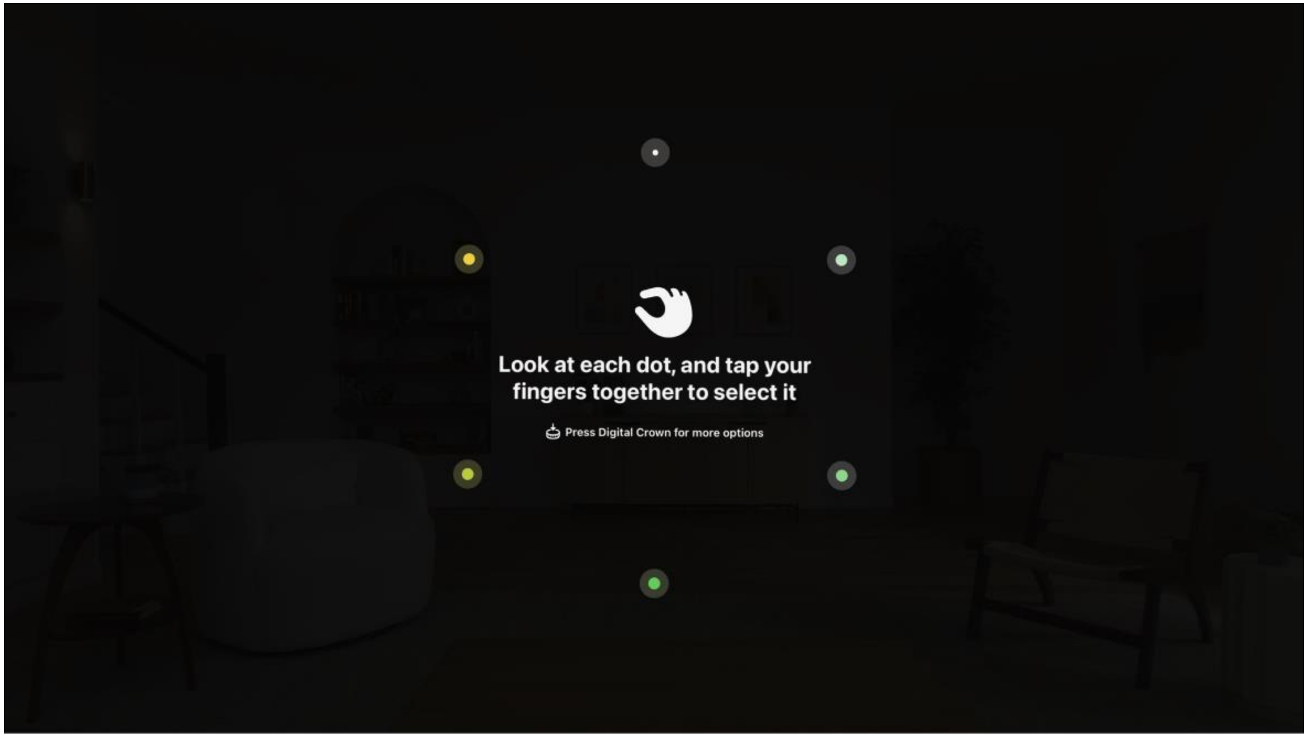
- Meta Quest Pro





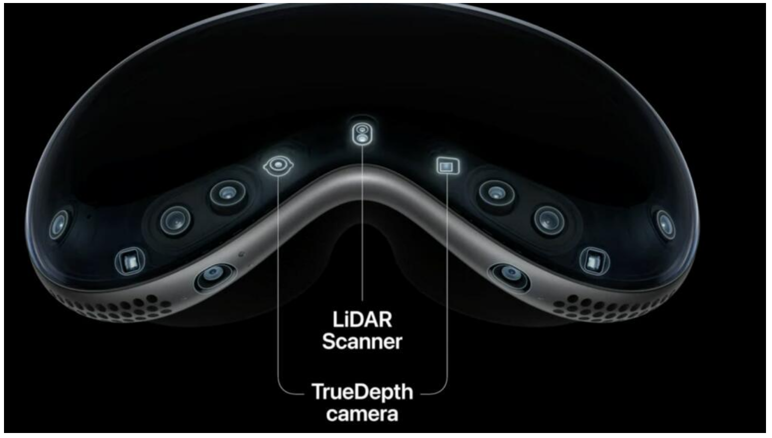
Eye Tracking

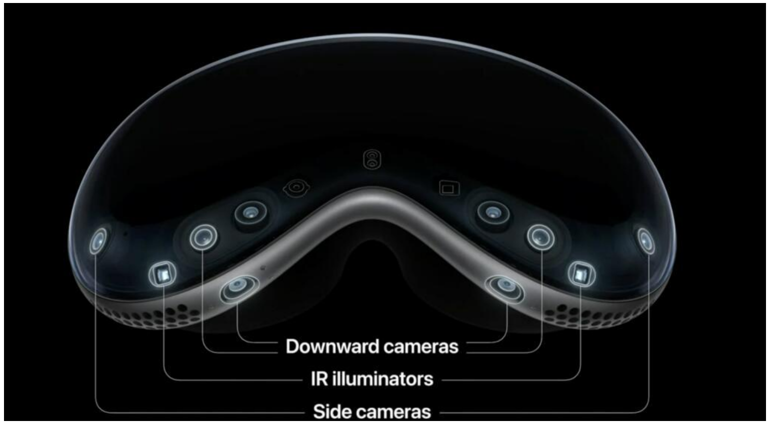
- Apple Vision Pro



Eye Tracking

- Apple Vision Pro





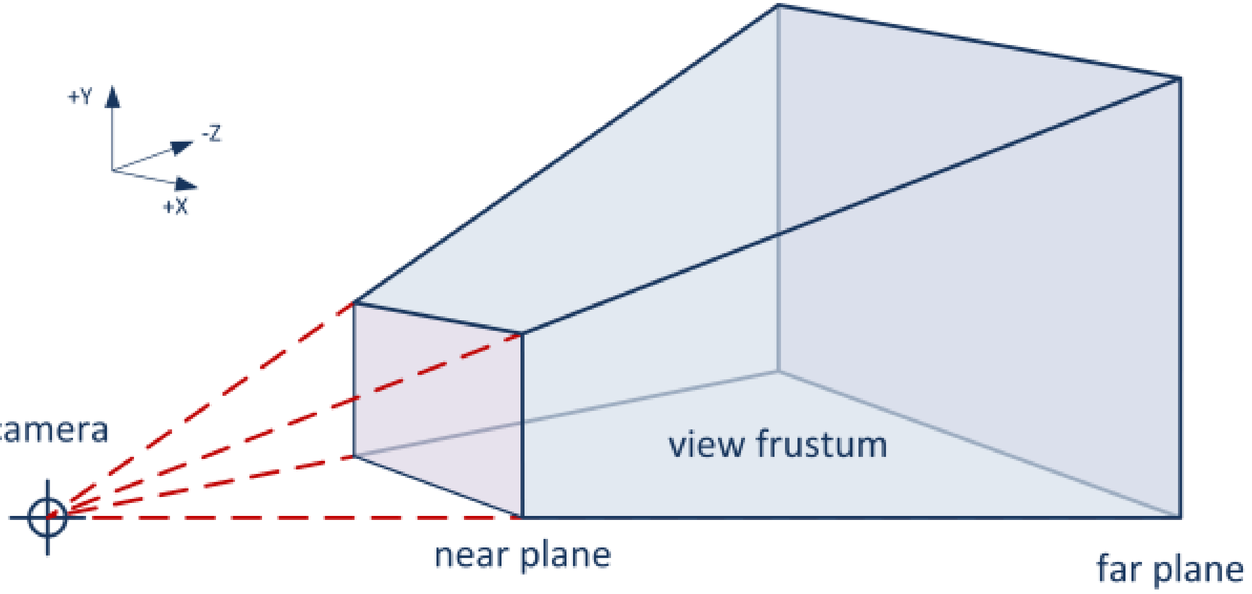
Head Tracking

- Detect the orientation and position of the user's head in three-dimensional space.

- Sensors: Accelerometers, gyroscopes, and magnetometers.

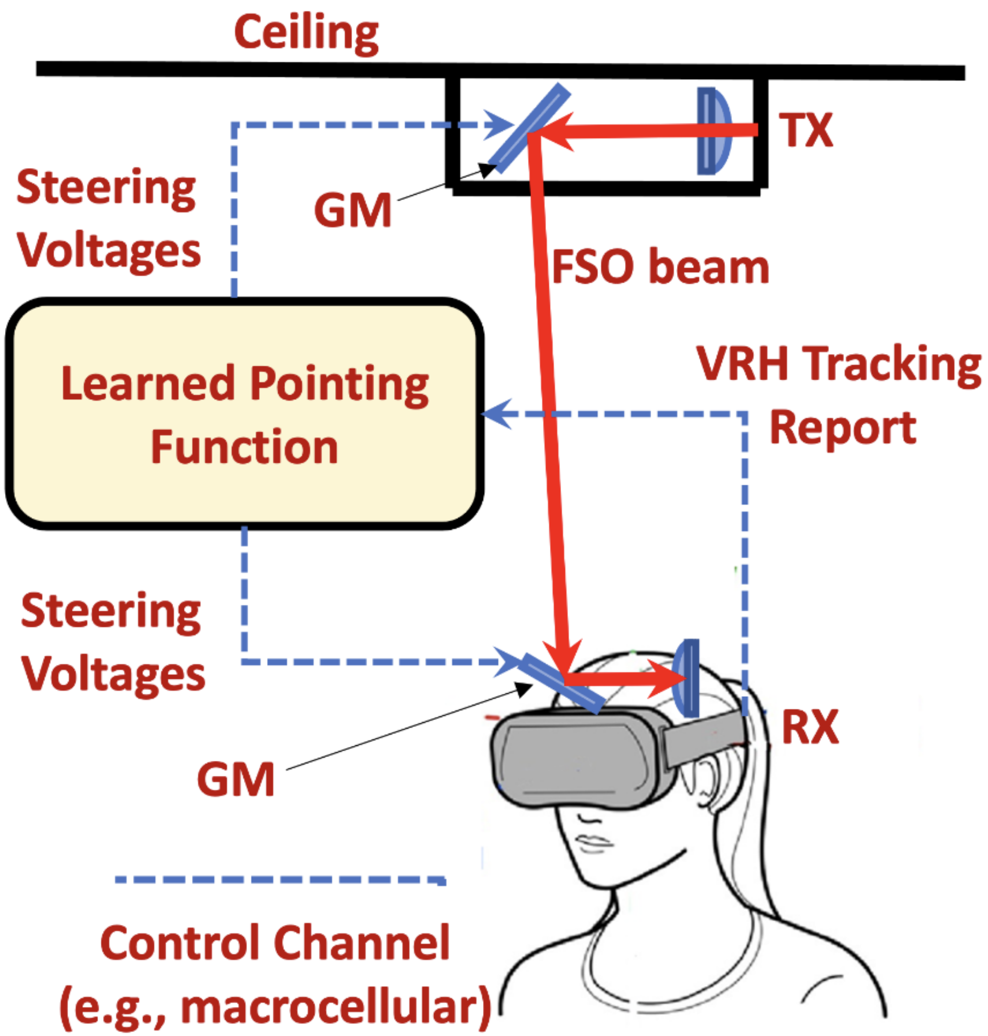
Head Tracking

- Applications
  - Viewport culling



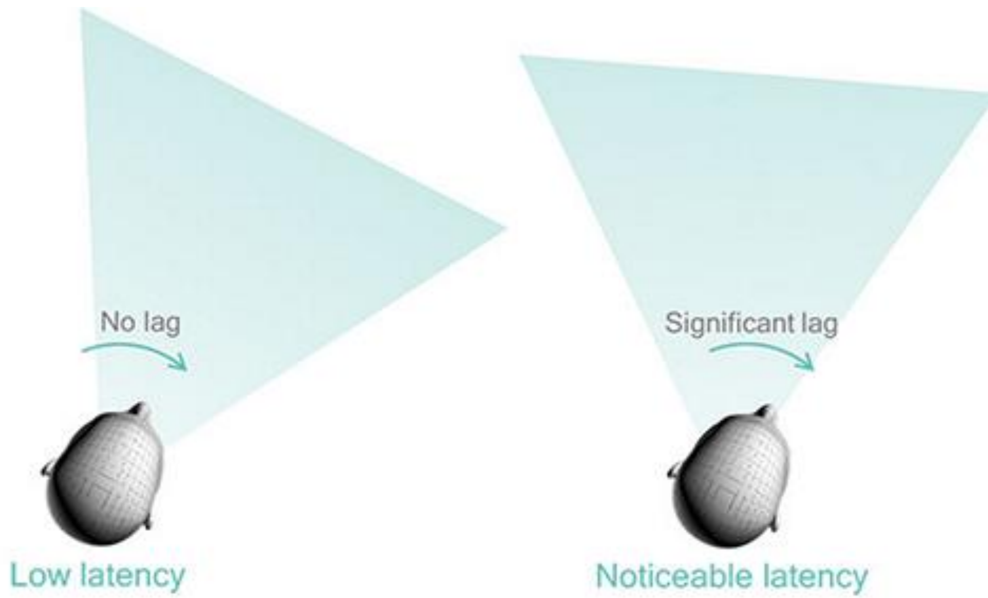
Head Tracking

- Applications
  - Streaming



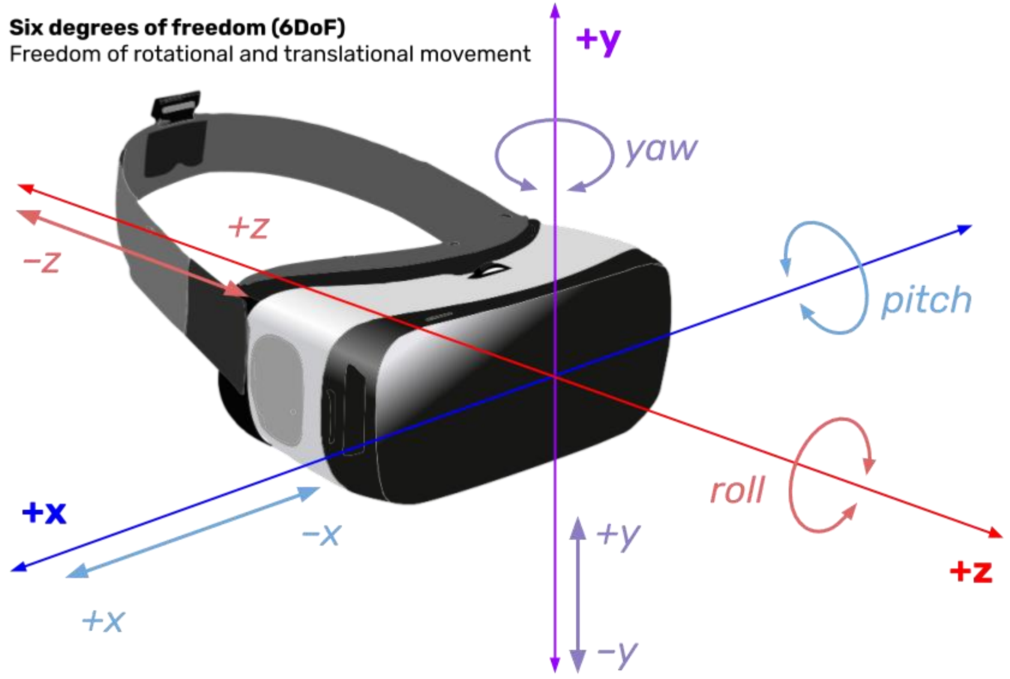
Head Tracking

- Challenges
  - The need for real-time response to head movements
  - Motion to photon latency



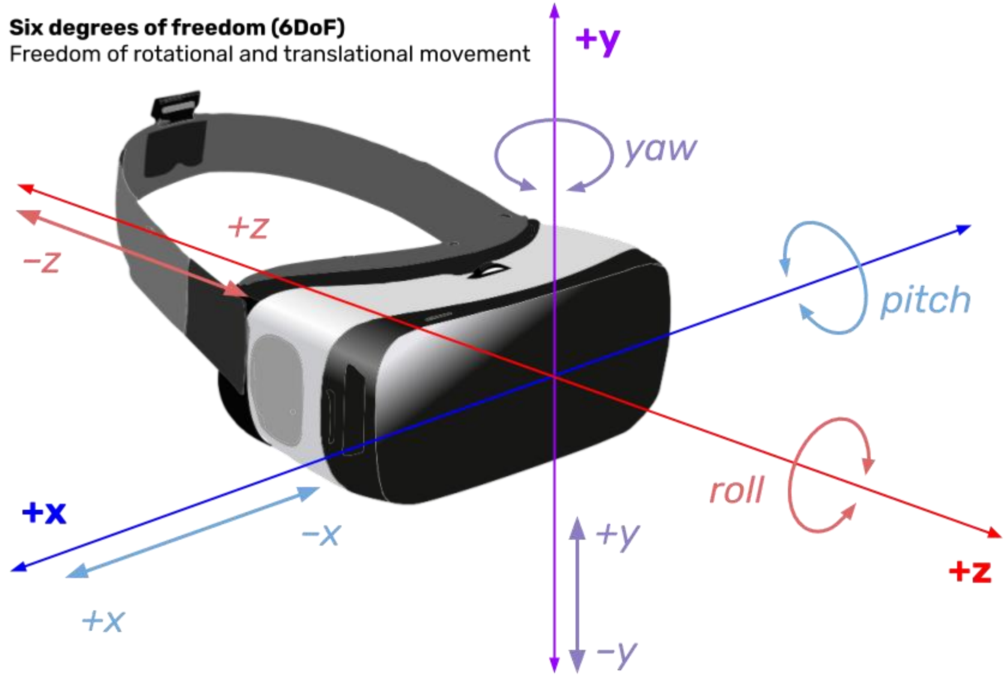
Head Tracking

- Types of head tracking
  - Rotational Tracking (3DOF): Measures orientation in terms of yaw, pitch, and roll.
  - Positional Tracking (6DOF): Measures both orientation and position in space.



Head Tracking

- Types of head tracking
  - **Infrared Sensors:** Used in outside-in tracking systems.
  - **Camera-based Tracking:** Employed in inside-out tracking systems.



Head Tracking

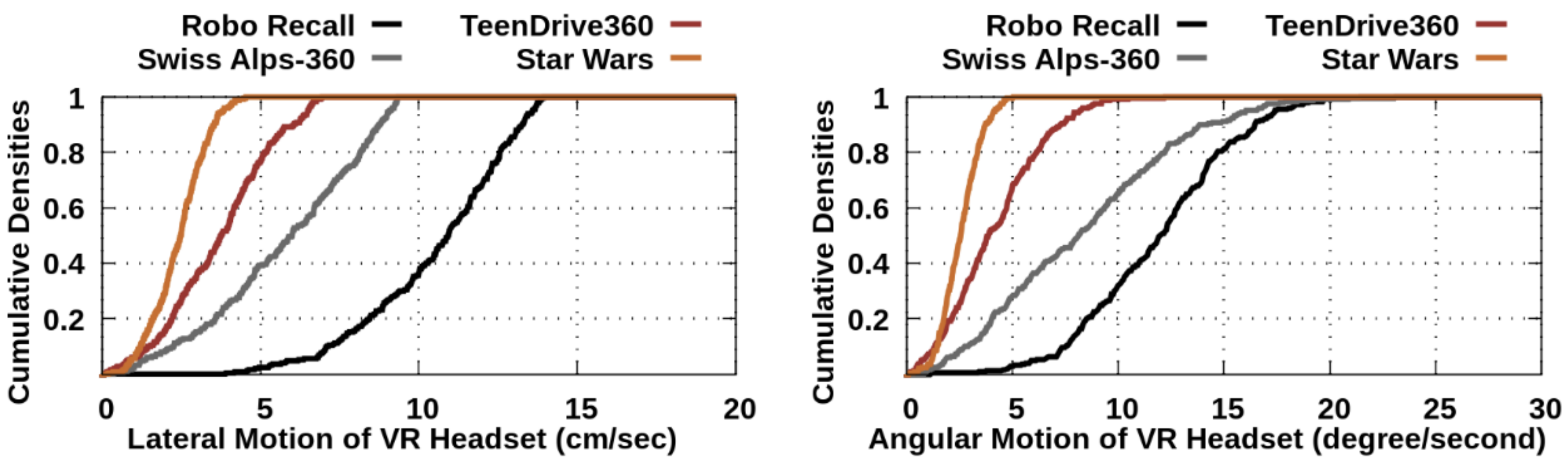
- Sensor fusion
  - Accelerometer: Measures linear acceleration
    - Detects changes in head position along x, y, and z axes.
  - Gyroscope: Measures rotational motion
    - Measures the rate of rotation around the head’s x, y, and z axes.
  - Magnetometer: Detects magnetic fields to determine orientation relative to the Earth's magnetic north.
    - Provides a reference direction (magnetic north) to stabilize orientation tracking.

Head Tracking

- Sensor Fusion
  - Kalman Filter: A statistical method that estimates the state of a dynamic system from a series of incomplete and noisy measurements.
    - Combines sensor data to predict and correct the head’s position and orientation over time.
    - E.g., Combines the quick response of the gyroscope data with the stable output of the accelerometer and magnetometer to improve tracking accuracy.

Head Tracking

- Typical head motion



Head Tracking

- Phone tracking for AR
    - Using phone's camera

Head Tracking

- Phone tracking for AR

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Summary of the Lecture

- Tracking fundamentals
- Eye tracking
- Head tracking

Next up: More tracking