Computergrafik

Matthias Zwicker
Universität Bern
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Today

• Virtual reality
• “a computer technology that replicates an environment, real or imagined, and simulates a user's physical presence”, including interaction with the environment
https://en.wikipedia.org/wiki/Virtual_reality

• Presence: feeling of being there
History

1950s
Sensorama
https://en.wikipedia.org/wiki/Sensorama

1980s

1990s: Cave
https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment

2000s: HTC Vive, Oculus
Google Cardboard
https://en.wikipedia.org/wiki/Virtual_reality
Applications

• Education, training (medical, military, etc.)

• Entertainment (games, film, theme parks, concerts, theater, etc.)

• Design (consumer products, engineering, architecture, city planning)

• Virtual heritage, archeology

• Shopping
Why is VR hard?

- **Input:**
  - Body pose of user (hands, head, etc.); current status of virtual world

- **Output:**
  - Rendering of virtual world, other sensory outputs (audio, haptics); status of virtual world in next time step

- "Motion-to-photon" latency (input-to-output latency) must be < 20ms
  - Otherwise, "VR sickness"

- Challenging to obtain in a system with many components
  - [Link](http://oculusrift-blog.com/john-carmacks-message-of-latency/)

- **Requirements**
  - Fast 3D motion tracking
  - Fast rendering, GPUs
  - High-resolution displays
First head mounted display

• With mechanical head tracking (Ivan Sutherland, 1968)

https://en.wikipedia.org/wiki/Ivan_Sutherland

• See-through (“augmented reality”)

![Image of early head mounted display](image-url)
Consumer VR system (2016)

- Head mounted display, tracked (HMD)
- 3D tracking hardware
- Hand-held controller (tracked)
- Sound input/output
- GPU
Technical challenges

• Head-mounted displays
  - Resolution
  - Binocular depth perception, also called stereopsis (vergence-accommodation conflict)

• Integration of additional input and output devices
  - 3D tracking of head, hands, body
  - 3D audio
  - Haptics (sense of touch)
Head mounted display

Pre-distorted binocular stereo images

http://www.osvr.org/hardware.html

Shows two separate, slightly different images to each eye
Stereopsis

• Perception of depth (3D structure) through binocular vision

• Binocular depth cues
  https://en.wikipedia.org/wiki/Depth_perception#Binocular_cues
  - Vergence
  - Disparity

• Allow distance estimation based on binocular vision
Vergence

• Both eyes rotate ("vergence"), such that fixation point is in center of visual field (fovea) for both eyes.
Binocular disparity

- (Angular) disparity: difference in image location (angle) of object seen by left and right eye

Disparity: difference between left eye view and right eye view
Accommodation

https://en.wikipedia.org/wiki/Accommodation_(eye)

- Lens in eye changes optical power (by deforming) to focus at certain distance
Accommodation

- Head mounted display includes additional lens to allow focus (accommodation) at a comfortable distance
Vergence-accommodation conflict

- Vergence: to perceived point in space
- Accommodation: to virtual display surface
Vergence accommodation conflict

- Can lead to “VR sickness”
- Currently unsolved
- Related: retinal blur
  - Out-of-focus blur of objects at distances away from fixation point
  - Perceivable in real world, but not replicated in current HMDs
- Research ideas exist
  - “Light field stereoscope”
    http://www.computationalimaging.org/publications/the-light-field-st
3D tracking

- Goal: determine position and orientation of real-world objects relative to a reference coordinate system.
Triangulation

- Assume known “lighthouse” coordinate systems
- Measure directions from lighthouses to tracking point
- Intersection gives 3D position (triangulation) of tracking point relative to lighthouses
- Triangulating 3 or more points determines orientation
HTC Vive/SteamVR tracking tech

https://partner.steamgames.com/vrtracking/

- Lighthouses emit optical timing signals and sweeps room (left-right and top-bottom) with laser beam, 60 times per second
- Tracking point has light sensor
- When tracking point detects laser beam, can recover laser beam direction from timing information, then perform triangulation from two beams
Calibration: establish relation between lighthouses and world coordinates

Moving tracking objects around and recording multiple beam directions from both lighthouses allows to reconstruct relation of light houses

Set world coordinates at center of user space, user defined
HTC Vive/SteamVR tracking tech

- Track several objects, like hand controllers
- 1000Hz refresh rate (using additional inertial sensors in tracked devices)
3D tracking demo

• Juggling

• Many other 3D tracking technologies exist
• Often via triangulation
VR in practice

• GPU-based rendering (almost) as usual (OpenGL, DirectX)

• Interface to VR hardware via OpenVR

https://en.wikipedia.org/wiki/OpenVR
OpenVR

- **Main functionality**
  - Provide 3D tracking information (hand controllers, head, etc.)
  - Provide VR camera parameters (two eyes)
  - Display rendered images on HMD

- **Source and documentation**
  [https://github.com/ValveSoftware/openvr](https://github.com/ValveSoftware/openvr)

- **Java binding via JNA**
OpenVR

• Basic setup

While running

**WaitGetPoses** to get 3D tracking information

Render left camera using OpenGL

**Submit** to compositor

Render right camera using OpenGL

**Submit** to compositor

Update application logic

OpenVR API calls in red
OpenGL rendering

- Using camera and projection matrices provided by OpenVR

- Render into OpenGL frame buffer object
  
  - Will not be displayed directly on screen

- Pass rendered image to OpenVR compositor via submit
  
  - OpenVR automatically performs lens pre-distortion

- Optionally, mirror rendered image to screen (OpenGL glBlitFrameBuffer)
OpenVR in jrtr

- Encapsulated in
  jrtr.OpenVRRenderPanel, jrtr.OpenVRRenderContext

- Some messiness because of JNA access to native functions and data structures

- Base code provided for VR programming exercise
  - Virtual squash game
  - Demo during exercise session