Virtual and Mixed Reality

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DEFINITIONS

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Virtual Reality (VR) (1)

- The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment."

- "Virtual reality is an artificial environment that is created with software and presented to the user in such a way that the user suspends belief and accepts it as a real environment."

Virtual Reality (VR) (2)

- Traits:
  - Immersive
  - Artificial
  - Interactive

- Key Element:
  - VR technologies completely immerse a user inside a synthetic environment

Reality vs Virtuality

- Milgram’sReality-Virtuality Continuum (1994)

Mixed Reality

Real environment | Augmented reality | Augmented virtuality | Virtual environment




Augmented Virtuality

- Enhancing the virtual world by pictures / textures / models of the real world

Adapted from [Kau16]

Augmented Reality (AR) (1)

- Augmented Reality (AR) is a variation of VR that allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it

- Key characteristics:
  - Combines real and virtual world
  - Interactive in real time
  - Registered in 3-D (real and virtual objects are in a 3D relation to each other)

Augmented Reality (AR) (2)

- Combined imagery can be:
  - A simple information overlay
  - Depth-sorted and clipped fusion of real and synthetic image
- The second requires 3D information from the real environment and accurate registration to the virtual set
- Both require position and orientation tracking

Collaborative VR/AR

- Users share the same information space (virtual environment)
  - Potentially the same physical space, as well (AR or non-head-mounted VR projection)

Mixed Reality

- Any combination of real and virtual environment
- Implied:
  - Interaction with one or both
  - Impact on the virtual environment (must adapt to the physical)

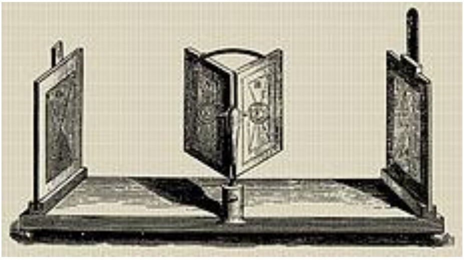
HISTORY OF VIRTUAL REALITY

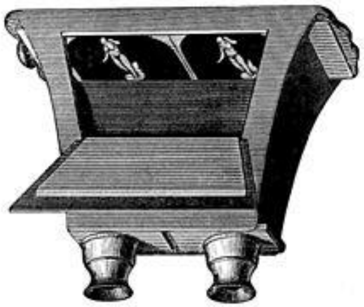
The Beginning – Concept of Virtual Space

- Plato, 360 BC (Book VII of “The Republic”)
  - First mention of alternate reality based on the limited view of the projected (real) world
- Descart, 1641 (“Meditations on First Philosophy”)
  - Hypothesized on complete, simulated illusions (“evil genius”) based on control of all our senses

The Stereoscope

- Sir Charles Wheatstone, 1838. Invented before practical photography!
- David Brewster, 1849. Use of lenses to make stereoscope compact
- Oliver Wendell Holmes, 1861. Low-cost, patent-free stereoscope





Multisensory Stimulus

- 1956: Sensorama
  - Augmented cinematic experience
  - Stereoscopic
  - Multi-sensory stimulus

The “Headsight”

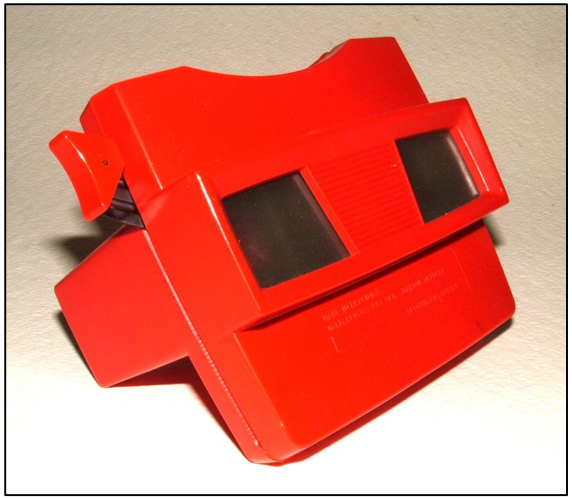
- 1961, Charles Comeau and James Bryan
- First Head-mounted display (HMD) as we know it today
- Two CRT elements, magnetic direction tracking system
- Intended use: remotely view and control the cameras for dangerous military situations

Sword of Damocles: the First AR Display

- 1968, Ivan Sutherland
- First superposition of graphics (wireframe) on real-world view
- Positional tracking
- The first AR system

The Viewmaster

- Hand-held stereoscopic slide projector for storybooks and documentaries
- Very affordable and widely used (60s-70s)



“Virtual Reality”

- Jaron Lanier, ~1980-82, first used the term Virtual Reality
- Founds the first company producing VR products (VPL Research)

The “Video Place” Installation

- Myron Krueger, 1985
- First vision-based system for tracking multiple fingers, hands and people
- Cable- and device-free interaction
- Rich gesture-based interaction!

VR Hype

… Hype was too early!

Immature and expensive technology

The CAVE

- Carolina Cruz-Neira, Daniel J. Sandin, and Thomas A. DeFanti, University of Illinois, 1992
- Immersive virtual reality environment where projectors are directed to 3-6 of the walls of a room-sized cube

- Head position and orientation tracking
- Stereo (interleaved) projection and active stereo glasses technology

2010 and On

- Advances in smartphone technology have provided the necessary components for VR to become commercially viable
  - Multi-core CPUs
  - Advanced mobile GPUs
  - High-density displays
  - Cheap, accurate tracking
  - RGB-D sensors

The "Rift"

- 2011, first prototype of what became next the "Oculus Rift" and subsequently the Oculus VR
- First consumer-level HMD
- Gradual integration of various technologies for latency minimization, tracking and lens distortion correction

Application Areas

- Games
- Industrial (real time simulation, ergonomics,…)
- Visualisation(scientific, medical, information vis.)
- Training & Education
- Rehabilitation & Therapy
- Modelling & Design
- Information layers

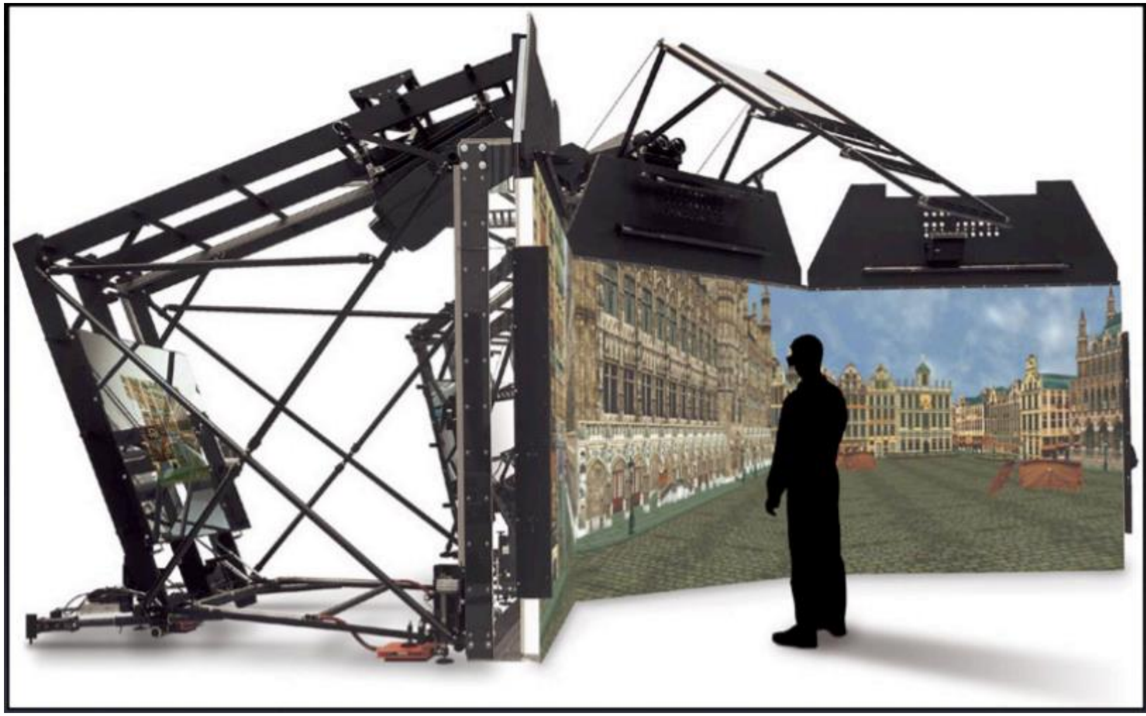
PRINCIPLES

Immersion Metaphors (1)

- Non-immersive: Flat/curved screen VR
  - Basic stereoscopic 3D

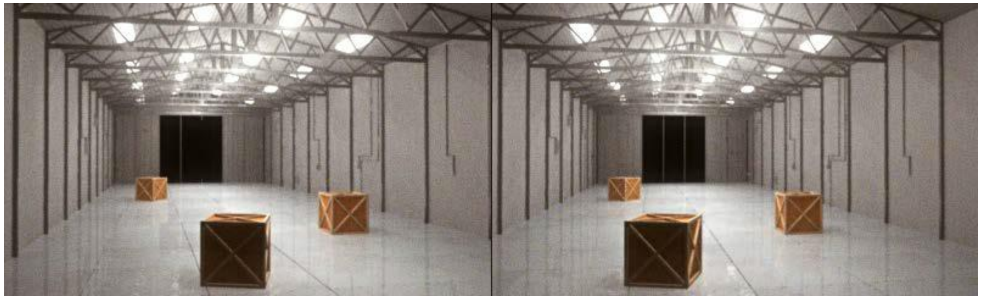
Immersion Metaphors (2)

- Immersive: Surround-projection: The CAVE system, VR domes
  - Shared experience: 1 tracked user, others share the view
  - Physical scale interaction and movement



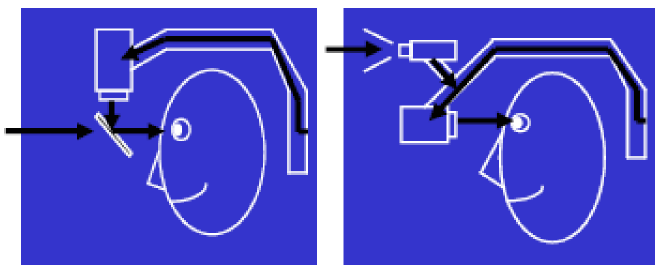
Immersion Metaphors (3)

- Immersive: HMDs
  - Personal/egocentric experience
  - Individualized single-/multi-user experience
  - Inconvenient/unnatural motion (navigation) metaphors



Mixed Reality Display Metaphors

- HMDs:
  - Optical see-through
  - Camera see-through



optical see-through   video see-through

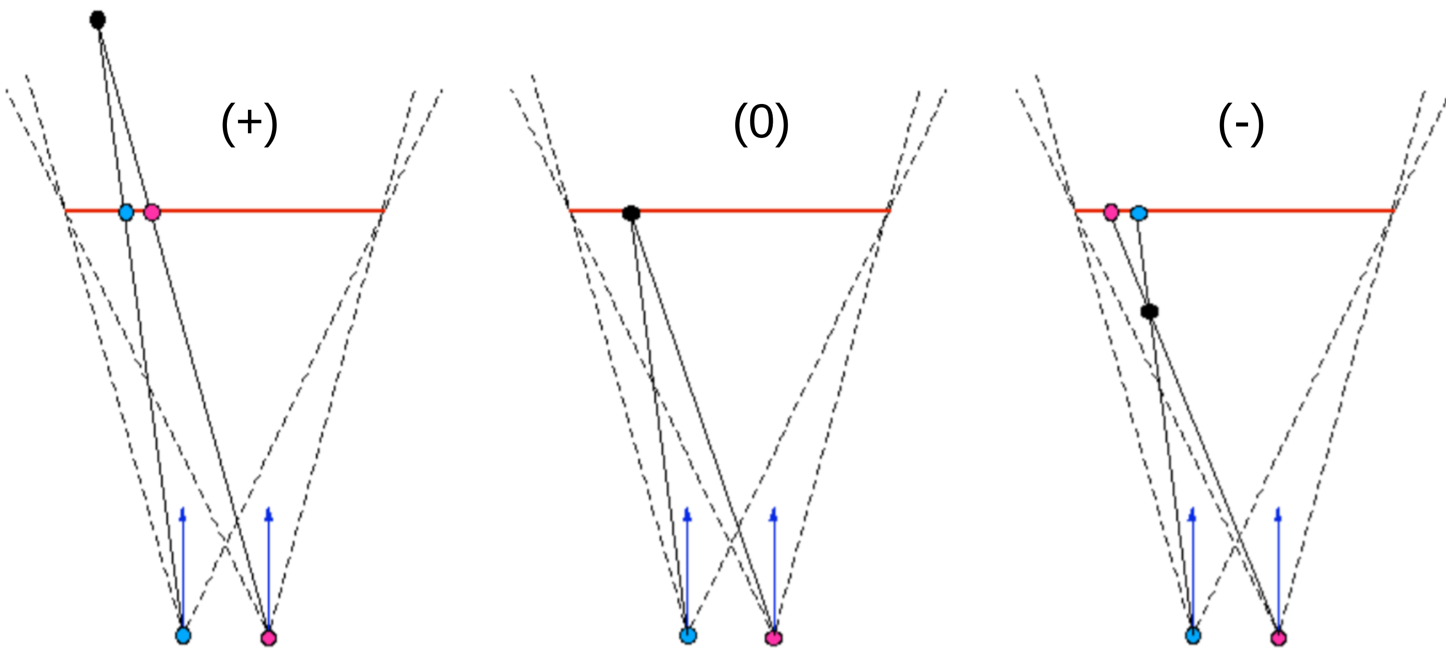
- Mobile AR:
  - Virtual “window” paradigm

Virtual Environment Rendering

- In VR, rendering does not only correspond to the image synthesis process
- Must encompass as many senses as possible to induce and immersive experience
  - Image synthesis
  - Audio rendering (spatial)
  - Tactile rendering and force feedback (both localized and full-body)
  - Smell simulation

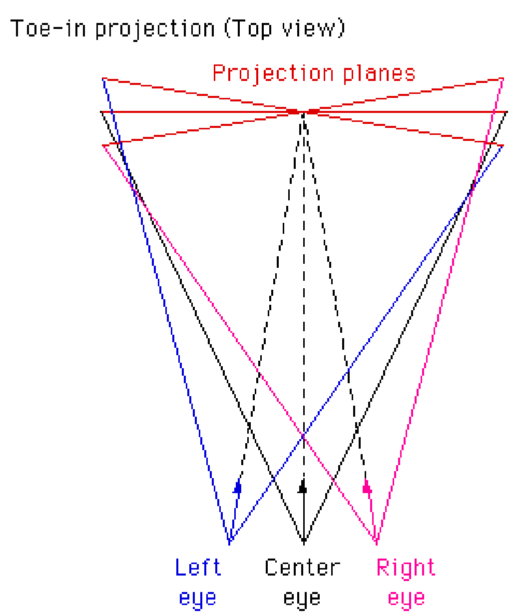
Parallax and Perceived Depth

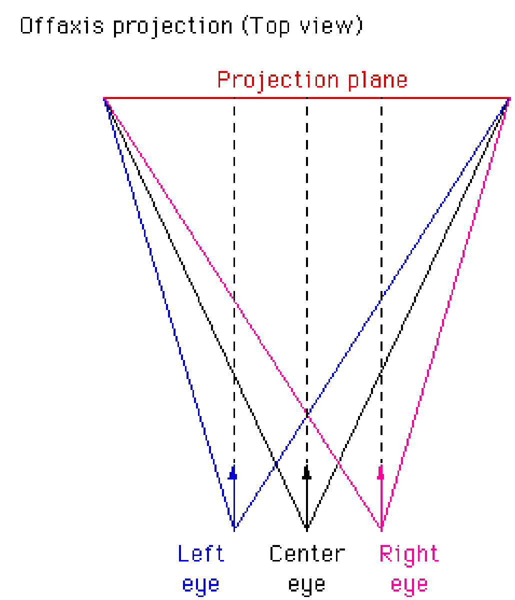
- Positive parallax (objects behind the screen)
- 0 parallax (objects appear at the screen)
- Negative parallax (objects appear in front of the screen)
- Positive parallax easier on the visual system than negative parallax



Stereoscopic Viewing

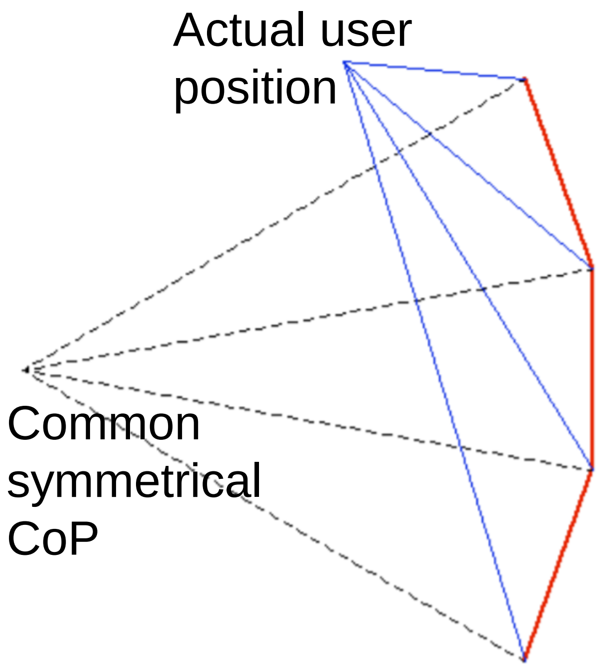
- Two styles of view frusta, depending on projection system:
  - HMDs: can display two independent eye views. The image edges do not have to coincide at zero plane → cross-eye or parallel
  - Projection/wall/screen systems: represent a “window” into the world. Seams must be consistent at surface bounds → off-axis





Off-axis Projection: Other Uses

- In fixed-display systems, the user moves and takes the center of projection along
- The formed view frusta are not symmetrical and therefore, off-axis projections must be individually calculated for each display tile



Stereo Rendering Calculations

$$d = a z_0 tan\frac{\theta}{2}$$

$$t = z_0 tan\frac{\theta}{2}$$

$$b = -z_0 tan\frac{\theta}{2}$$

Right eye

$$r = d - \frac{e_s}{2}$$

$$l = -d - \frac{e_s}{2}$$

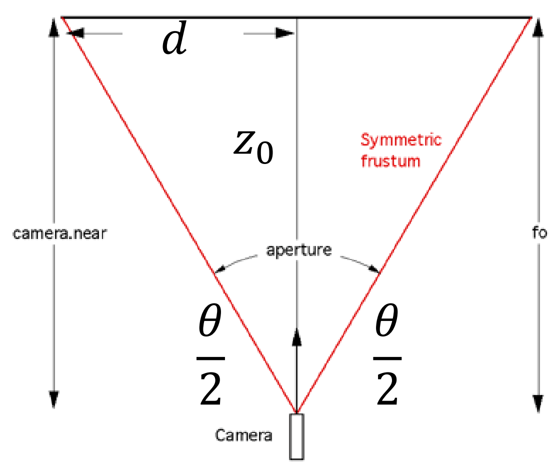
Left eye

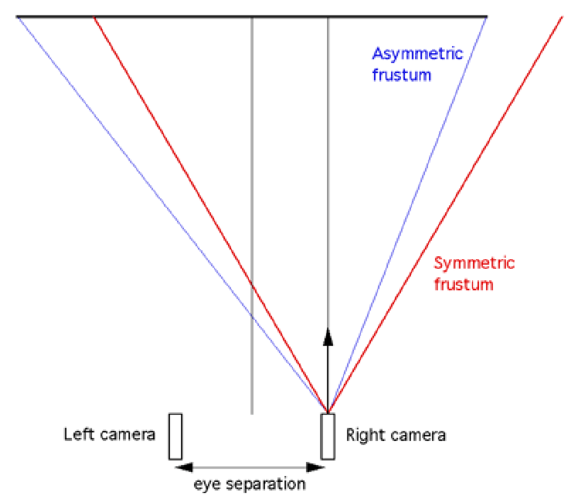
$$r = d + \frac{e_s}{2}$$

$$l = -d + \frac{e_s}{2}$$

- a: Aspect ratio
- θ: Vertical aperture
- z_0: (near) depth at zero parallax
- e_s: Eye separation

$$glm :: frustum(l, r, t, b, n, f)$$





Stereo Display Technology

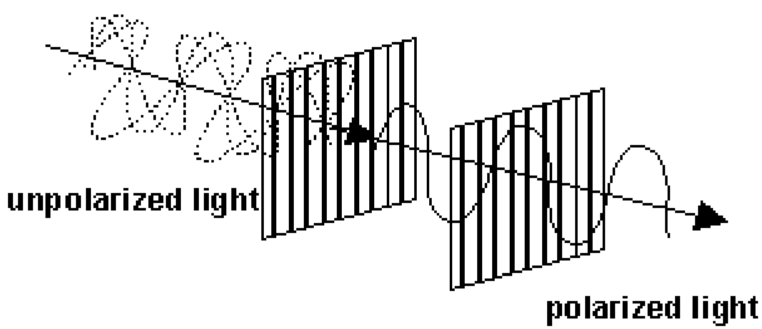
- Active stereo: active switching e.g. shutter glasses
- Passive stereo: e.g. anaglyph stereo (red/blue), polarized filters, infinitec

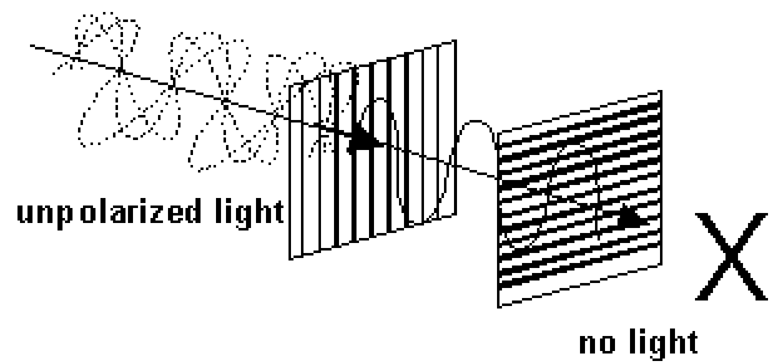
Active Stereo - Shuttering

- Shutter glasses use LCD panels to alternate the blocking of light to the left or right eye in sync with the alternating images on the display system
- Requires:
  - high frame-rate display or projector (2Xnormal speed)
  - Fast display element switching to avoid ghosting artefacts
  - Very good darkening of the LCD (100% is unattainable)

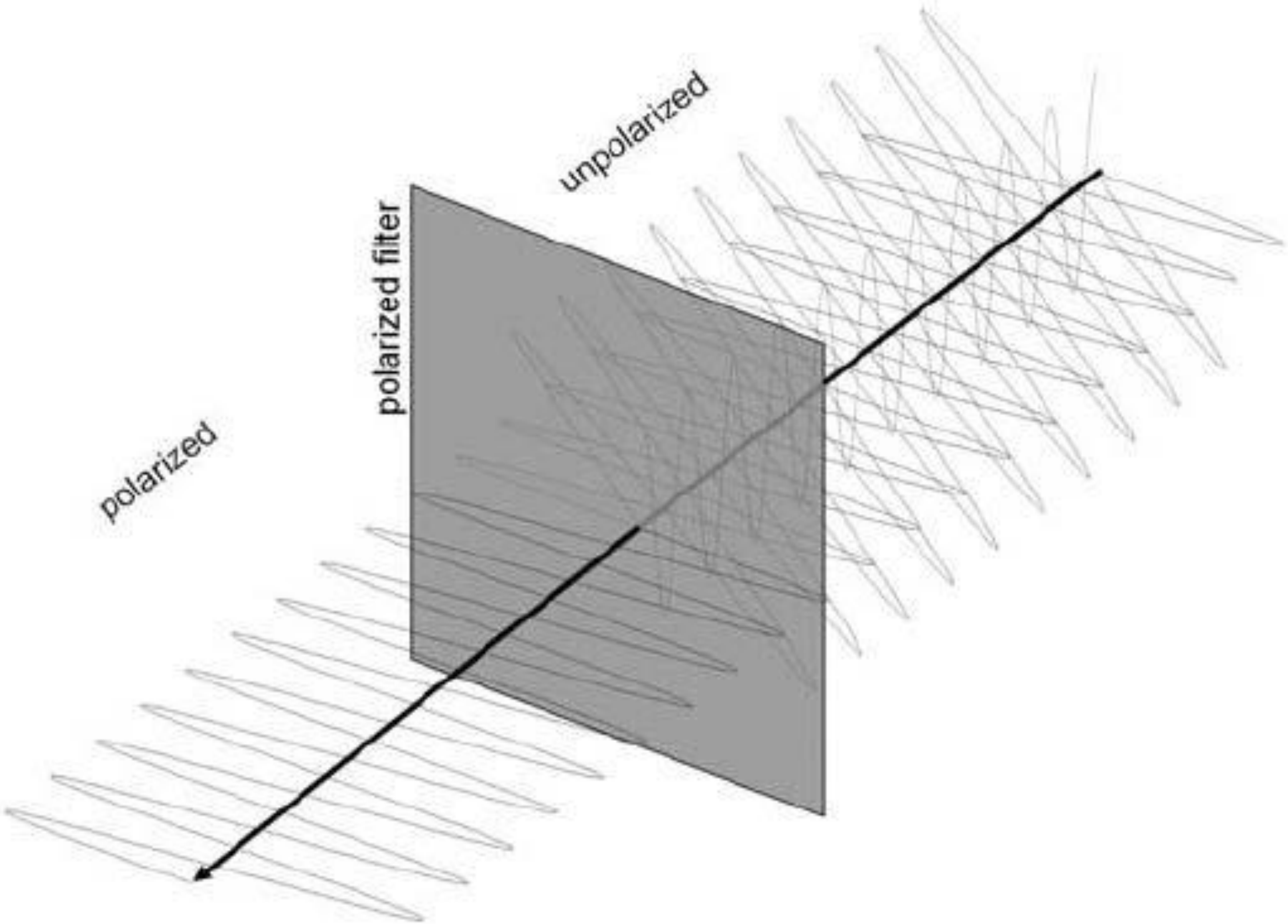
Passive Stereo – Polarization (1)

- Use two projectors
  - Left: vertical filter in front of the lens
  - Right: horizontal filter in front of the lens
- Wear glasses with polarization filters
  - Left eye: vertical
  - Right eye: horizontal

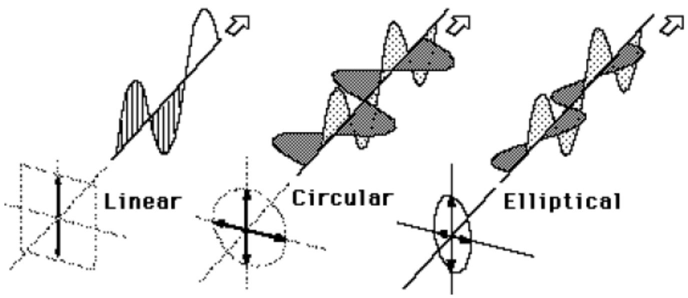




Passive Stereo – Polarization (2)



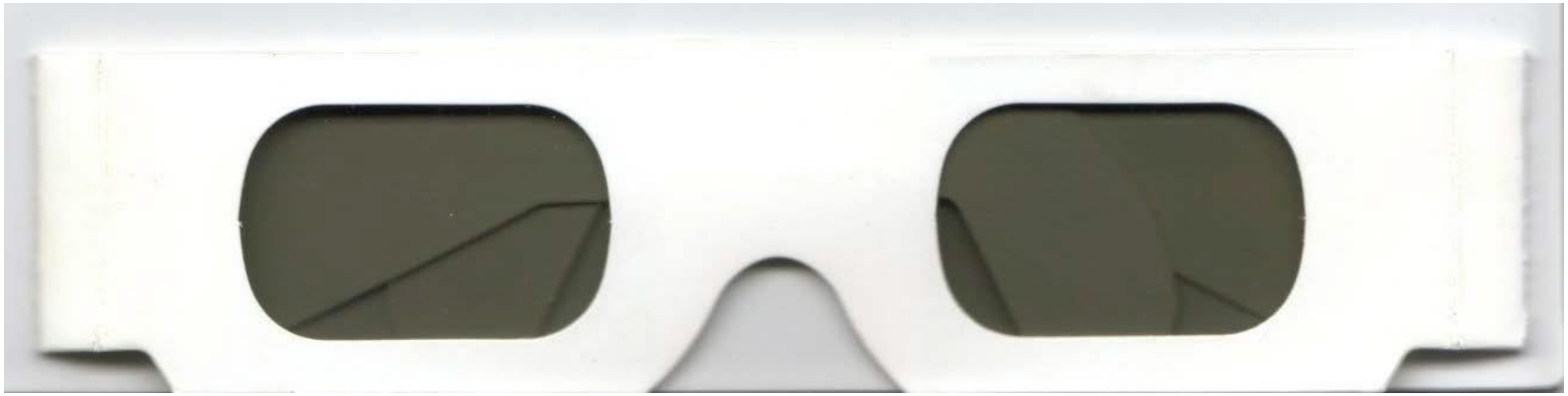
Passive Stereo – Polarization (3)



- Linear polarization
  - Can't tilt head
  - Little ghosting
- Circular polarization
  - More involved physics
  - Principle: counter clockwise / clockwise
  - Allows arbitrary head orientations
  - In general more ghosting than linear polarization

Passive Stereo - Polarized Glasses

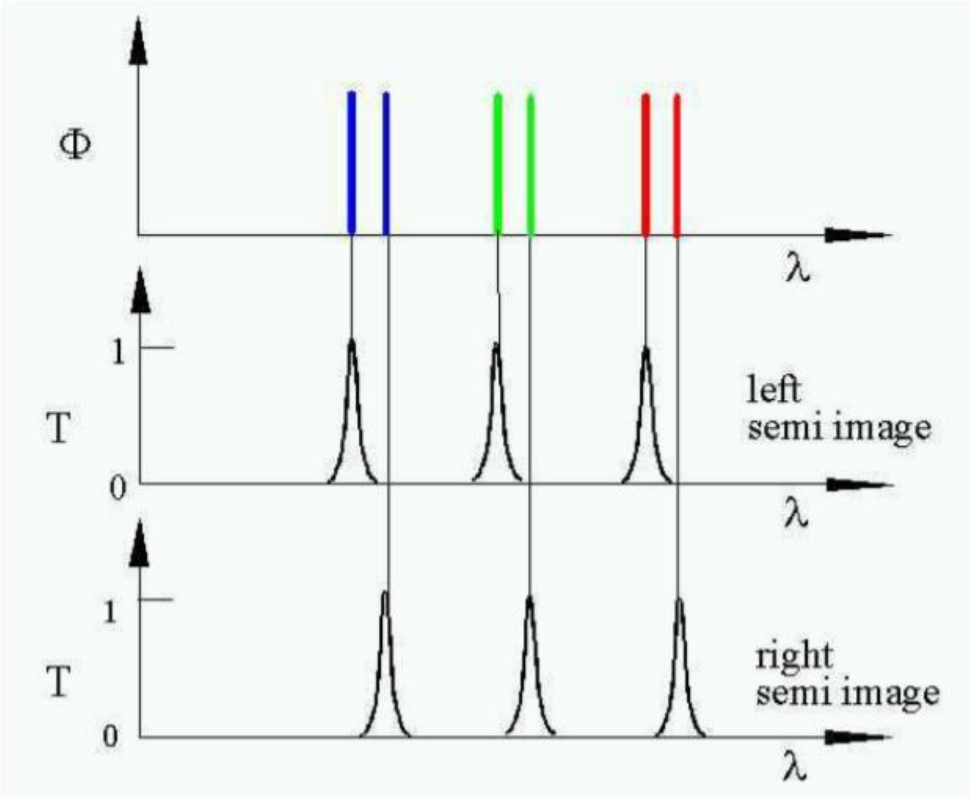
- Very cheap, paper + plastic foil
- Trick: use +/-45°-> no wrong side wearing



Source: [Kau16]

Passive Stereo – INFITEC (1)

- Interference Filter Technique
- Each projector/eye filter implements a series of band-pass filters
- Both eyes receive tri-color stimulus, but a slightly different part of each color
- Color compensation is performed by the brain



Passive Stereo – INFITEC (2)

User Experience - Immersion

- Immersion is of utmost importance for this “make believe” experience
- Hindering factors:
  - Field of view
  - Embodiment
  - Physical - virtual consistency

User Experience - Problems

- Motion sickness
  - Inconsistence between sensory input (aural, motor, visual) leads to disorientation and nausea
  - Display latency also contributes to this
  - Involuntary or/and unnatural motion conflicts with our motion prediction
- Natural interfacing with the VE is not easy to achieve
  - Sometimes it is preferable to avoid “natural” interfaces (and lose some immersion) to improve ergonomics
  - Many tasks harder than the desktop interaction paradigm (flat surface constraints more reassuring and precise, fewer DoF)

INTERACTION

Reminder: Interaction Design Goals

- Performance
  - efficiency
  - accuracy
  - productivity
- Usability
  - ease of use
  - ease of learning
  - user comfort
- Usefulness
  - users focus on tasks
  - interaction helps users meet system goals

The Interface Challenge

- Naturalism: make VE & interaction work exactly like real world
- Magic: give user new abilities
  - Perceptual
  - Physical
  - Cognitive

- Sometimes, the cognitive overhead required to use the interface distracts users from the intended tasks

What makes 3D Interaction Difficult?

- Spatial input
- Lack of constraints
- Lack of precision
- Layout more complex
- Fatigue
- Must map certain non-spatial universal tasks to spatial user interfaces (menu options, textual input, etc.)

Universal UI Tasks

- Selection
- Manipulation: modifying object properties (esp. position/orientation, shape, color,…)
- Navigation
- Travel – motor component
- Wayfinding – cognitive component; decision making
- System control: changing system state or mode
- Symbolic input (covered in Input Devices Part 1)
- Creative tasks

Selection and Manipulation

- Goals of Selection:
  - Indicate action on object
  - Make object active
  - Travel to object location
  - Set up manipulation
- Manipulation types:
  - Isomorphic: strict and natural, geometrical1:1 correspondence between physical – virtual world
  - Nonisomorphic: virtual tools extend working volume / arm length
  - Application-specific

Selection Techniques

- Pointing
- Touching with virtual hand/pointer
  - Non-linear distance coverage (Go-Go metaphor)
- Ray/cone casting
- Aperture
- Image plane interface
- Naming (speech rec.)

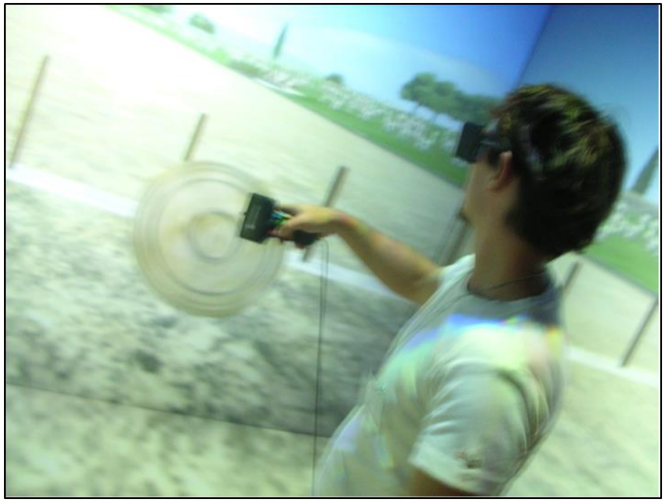
Selection – Task Decomposition

- Selection
  - Object indication
    - object touching
    - pointing
    - indirect selection
    - ….
  - Confirmation of selection
    - button
    - gesture
    - voice
  - Feedback
    - graphical
    - tactile
    - audio
    - text…

Selection – Performance Evaluation

- Ray-casting and image-plane generally more effective than Go-Go
  - Exception: selection of very small objects can be more difficult with pointing
- Ray-casting and image-plane techniques result in the same performance (2DOF)

Manipulation Metaphors



- Simple virtual hand
  - Natural, easy placement
  - Limited reach, fatiguing, overshoot
  - 1:1 position mapping
- Ray casting
  - Little effort required
  - Exact positioning and orienting very difficult
- Indirect depth control (e.g. mouse wheel)
  - Infinite reach, not tiring
  - Not natural, separates DOFs

HOMER Manipulation Technique

- Hand-Centered Object Manipulation Extending Ray-Casting
  - Select: ray-casting
  - Virtual hand moves to object
  - Manipulate: hand
  - Detach hand and return

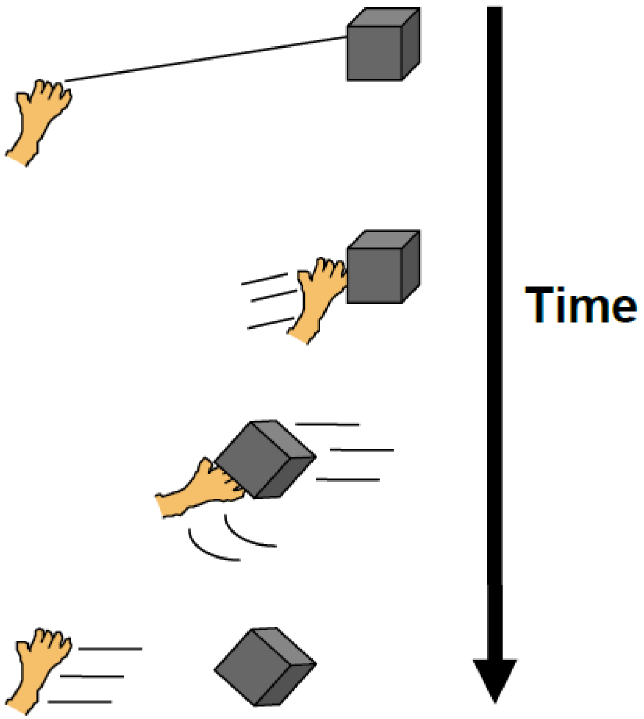
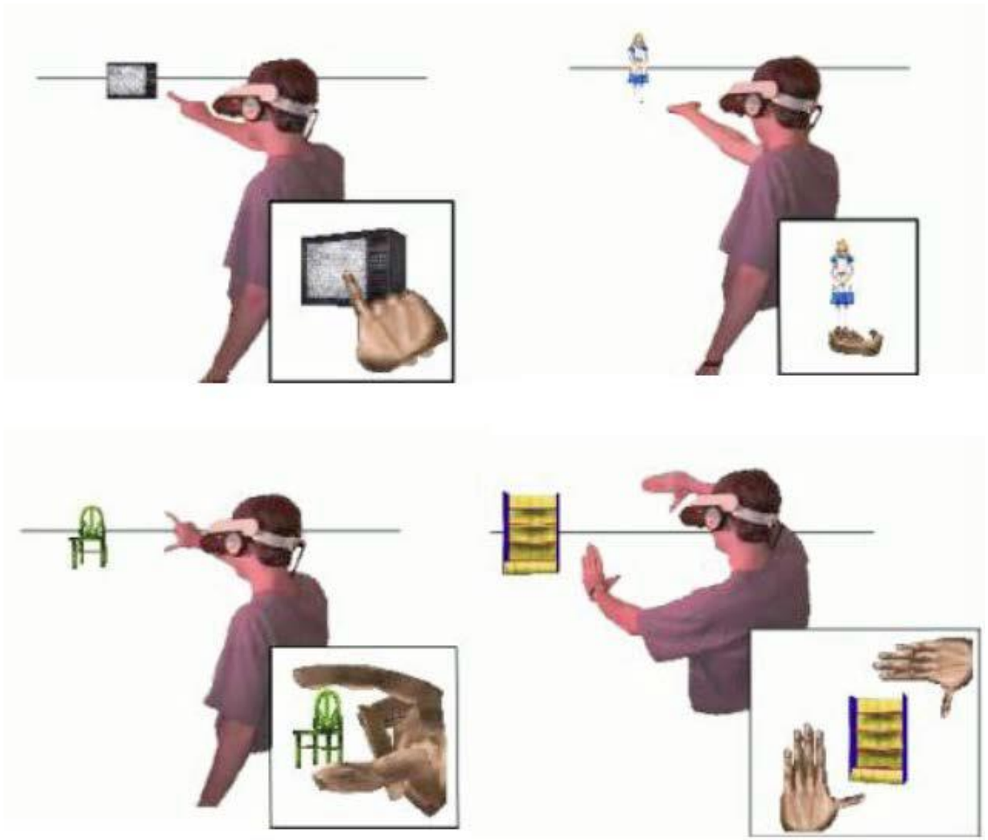


Image-plane Interaction

- Selection and manipulation
- Different gestures



Manipulation - Orientation

- Setting precise orientation is almost impossible
  - Must use smart snapping facilies → with or without visual aids and snap grids. Requires extra processing to calculate snaps
- Orienting at-a-distance harder than positioning at-a-distance
- Techniques should be <u>hand-centered:</u> Follow wrist motion and local object pivoting

Navigation – Travel (1)

- Motor component of navigation
  - Movement between 2 locations
  - Setting the position (and orientation) of the user's viewpoint
- Most basic and common VE interaction technique
  - Used in almost any large-scale VE
- AR: Travel often directly controlled (motion tracked, VE aligned to real world)
  - Viewpoint controlled by user

Travel Tasks

- Exploration
  - travel which has no specific target
  - build knowledge of environment
  - Search and discover target or layout
- Maneuvering
  - travel to position the viewpoint for a task (short, precise movements)
  - Relocate user near a point of interest

Traveling Metaphors (1)

- Steering metaphor: continuous specification of direction of motion
  - Gaze-directed
  - Pointing (the “fly” gesture)
  - physical device (steering wheel, joystick)
- Target-based metaphor: discrete specification of the goal location
  - Point at object
  - Choose from list
  - Enter coordinates

Traveling Metaphors (2)

- Manipulation metaphor: manual manipulation of viewpoint
  - “camera in hand”
  - fixed object manipulation – inspection (object-centered navigation)

Navigation Design Guidelines

- Make common travel tasks simple (target-based techniques for motion to an object, steering techniques for search)
- Provide multiple travel techniques to support different travel tasks in the same application
- Use transitional motions (not teleportation!) if overall environment context is important.

System Control

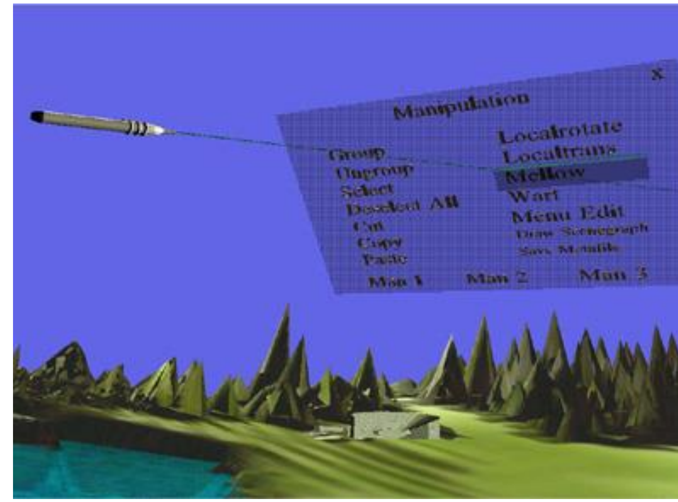
- Catch-all for other types of VE interaction
  - Issuing command
  - Changing mode
  - Choosing tool
- Often composed of other tasks

Common System Control Techniques

- Menu systems
- Voice commands
- Gestures/postures
- Implicit control (e.g. pick up new tool to switch modes)

Menus in 3D

- Floating menus in 3D
  - Very imprecise and hard to use with 3D interaction and selection metaphors → avoid



- Linear selectors (1 DoF)
  - Allow constrained selection → improved precision

2D Interfaces in 3D

- Physical surface (e.g. pen and tablet interaction)
  - Constrained and natural
  - Use of established metaphor
  - Can be used for various types of interaction, even text (handwriting) input and 3D manipulation

ADVANCED RENDERING TECHNIQUES

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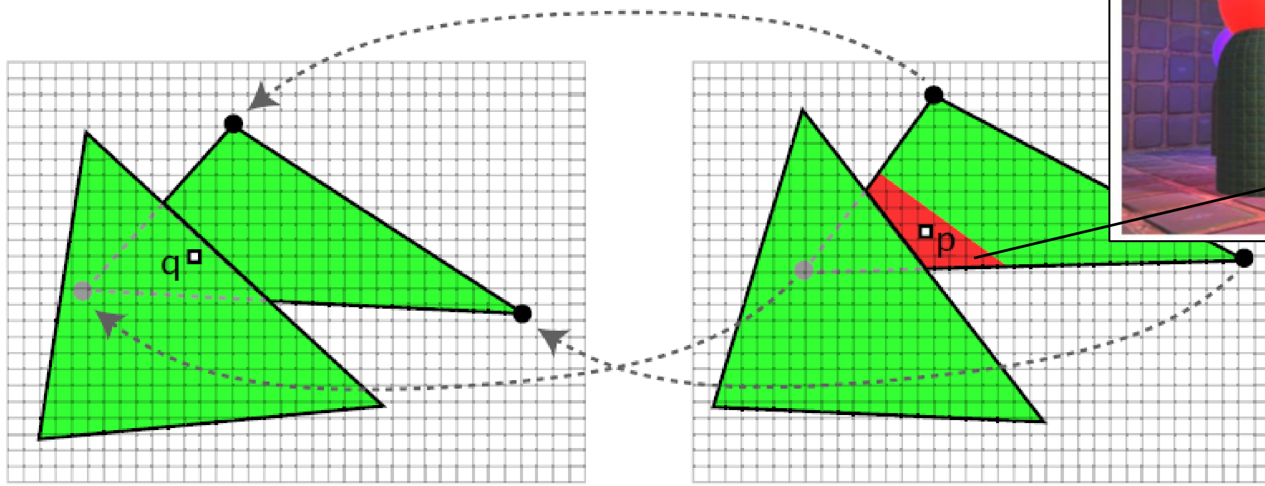
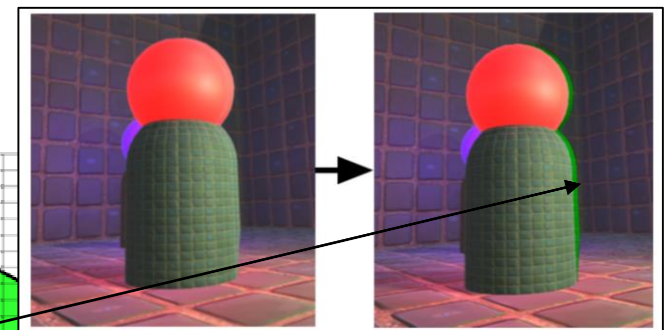
Reprojection (1)

- Stereo rendering effectively doubles the workload of the rendering pipeline
- We must seek ways to minimize the overhead
  - Faster frame rendering
  - Shorter latency in frame creation between stereo images
- Key observation: Much of the visible content in one eye is very similar to the other
- Can we reuse it?

Reprojection (2)

- The transformation between the two frames (L/R) is known
- Both images display consistent content (does not change across eyes – same time instance



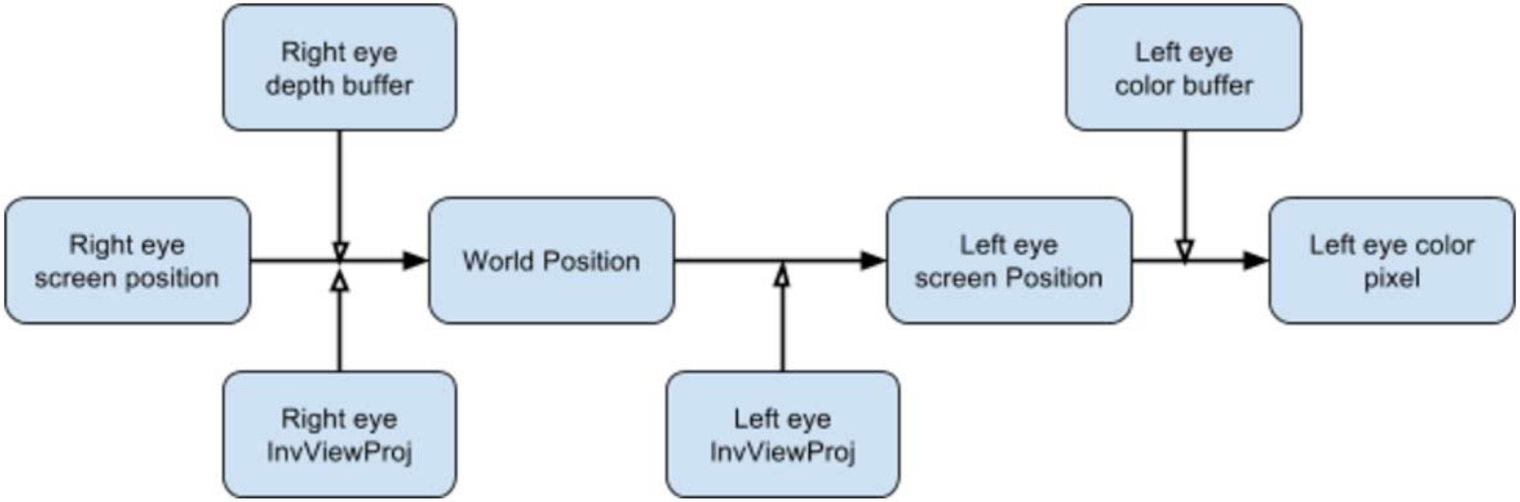


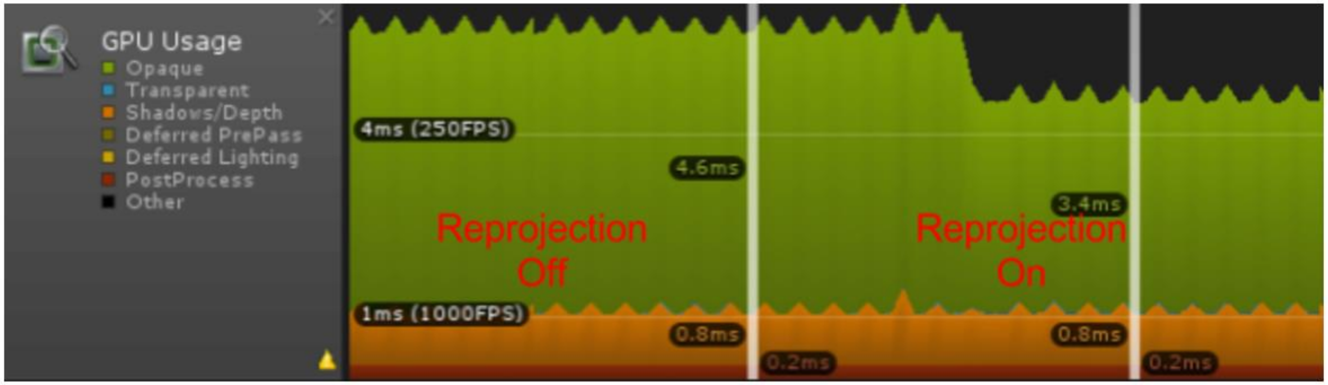
First view: fully rendered

Second view: render only depth and project samples on first view.
If compatible, “steal” shading (green area).
Otherwise, compute shading (occluded red area)

Reprojection (3)

- Example pipeline (Unity with Oculus VR):





Reprojection – Caveats

- The optimization requires both eyes to be rendered sequentially
  - Not compatible with optimizations that issue one draw call for both eyes (for example, Unity's Single-Pass stereo rendering or Multi-View in OpenGL).
- Not correct for highly view-dependent shading and effects using fake depth information like parallax occlusion mapping

Temporal Reprojection

- The same principle works for reprojection between time instances: Must know the relative (interpolated) transformation of each vertex (see image)
- This information can be used to generate a velocity field
  - Screen-space distance travelled by a fragment in the n frame relative to n frame (i.e. pixel correspondence)
  - Also useful for motion blurring

Geometry Proxies (1)

- The use of "impostor" geometry such as flat textured billboards that represent actual (complex) 3D shapes is common in interactive graphics
  - E.g. image-based rendered people, trees, smoke particles

Geometry Proxies (2)

- Geometry proxies must be used with caution in VR!
- Stereo perception and scale break the illusion!
- Only very distant image-based rendered props can be convincing due to insignificant depth parallax
- Completely avoid close, view-aligned billboards
- Use LODs with smooth transitions

Contributors and References

- Georgios Papaioannou

- Sources:

  - [Kau16] Hannes Kaufmann, Virtual and Augmented Reality, Lecture Slides, TU Wien, 2016.
  - [LaV16] Steven M. LaValle, Virtual Reality, online book, University of Illinois (http://msl.cs.uiuc.edu/vr/).
  - [Vil14] Hannes Högni Vilhjálmsson, The Ultimate Display: Imagining and Inventing Computer Graphics Polygon by Polygon, Pearls of Computation talk, 2014