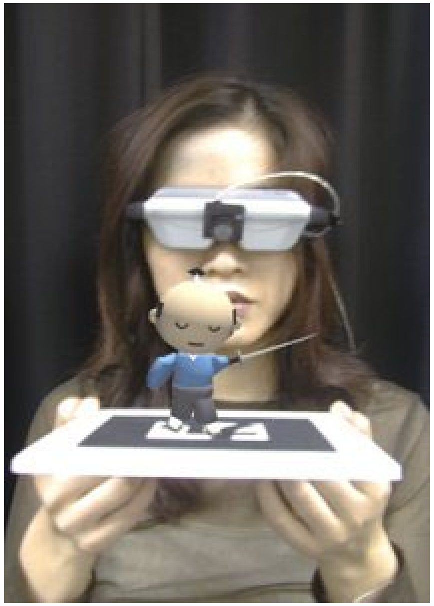
Revision

What is Virtual Reality?

- Virtual reality
  - Provides a user with the sensation of ***immersion*** and ***presence*** within a 3D computer-generated environment
    - Presence – the feeling of “being there”
    - Simulation of visual, auditory and other senses using computing devices
    - Immerse the user in an illusion of reality
  - Computer graphics currently capable of generating images that are indistinguishable from the real-world
    - Detached from real-world surroundings
    - Spatially restricting

What is Augmented Reality?

- Augmented reality
  - General term applied to various display technologies
    - Capable of overlaying or combining textual, symbolic or graphical information with a user's view of the real world
    - Must be aligned and correlated to the user's real-world view
  - Azuma's definition
    - Combines real and virtual
    - Interactive in real time
    - Registered in 3D



Ronald T. Azuma. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments* 1997, 6 (4): 355–385.

http://www.hitl.washington.edu/artoolkit.html

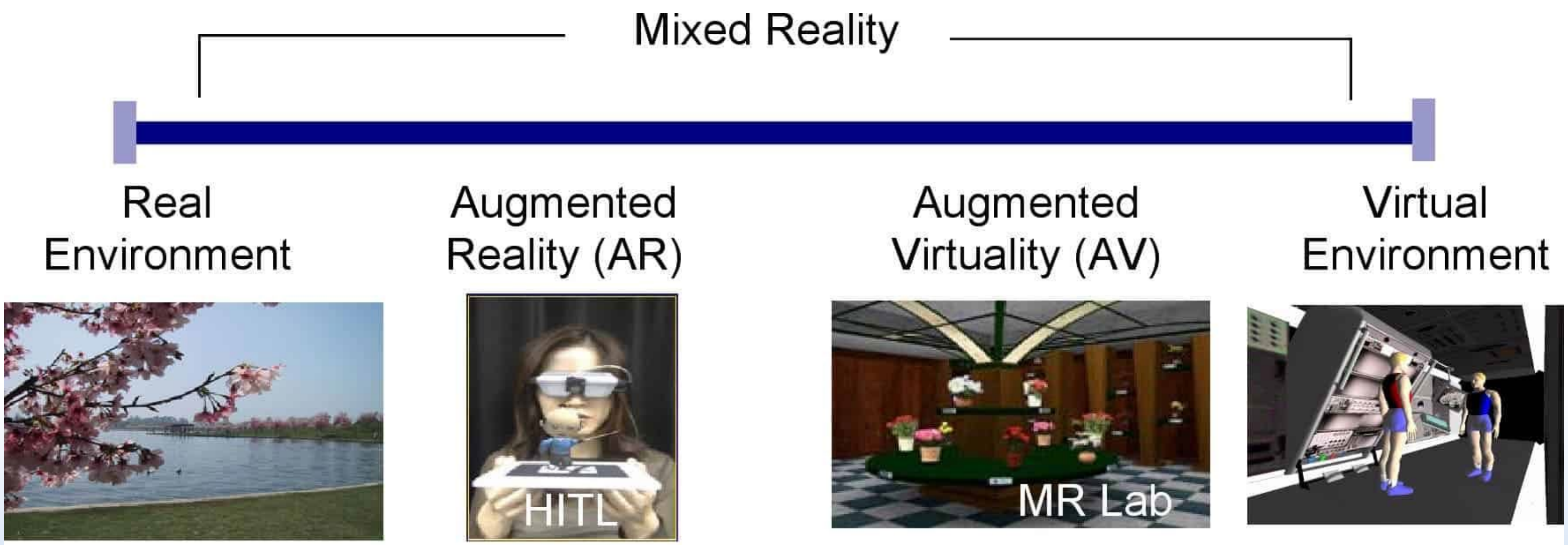
Virtual and Augmented Reality

- VR versus AR

Virtual Reality	Augmented Reality
Intent is to replace reality	Intent is to enhance reality
Users immersed in a completely virtual environment	Virtual content overlaid or combined with user’s real-world view
Fully immersive	Non-immersive
Large rendering load	Low rendering load
Requires wide field of view	Small field of view
Less accurate tracking not ideal, but acceptable	Highly accurate tracking required

Reality-Virtuality Continuum

- What is Mixed Reality (MR)?
  - Reality-virtuality continuum represents possible combinations of the real and virtual worlds



Reality - Virtuality (RV) Continuum [1]

Milgram, P. and Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems*, E77-D, 1321-1329.

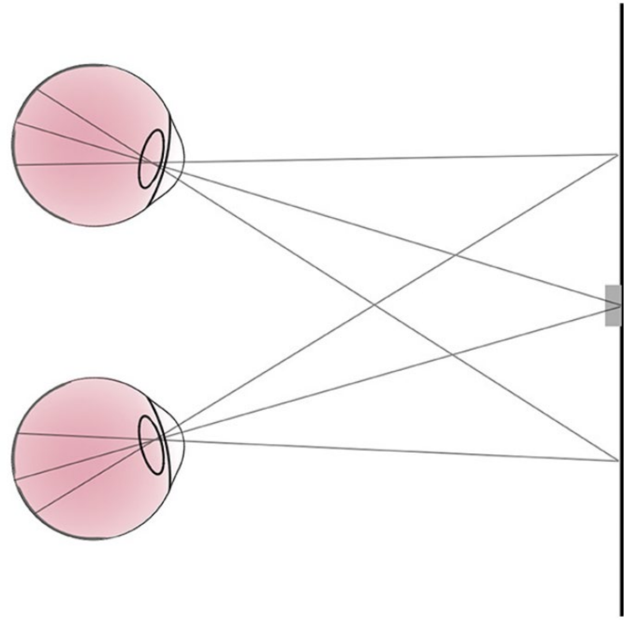
https://www.zmescience.com/other/did-you-know/difference-virtual-augmented-reality/

The Mechanics of Sight

- Human vision
  - Highly sophisticated
  - Responsible for delivering ~70% of overall sensory information to the brain
  - 40% of the cerebral cortex is thought to be involved in some aspect of processing visual information
- Virtual and augmented reality
  - Relies heavily on presenting information to the human **visual perception**
  - Important to understand this primary sensory mechanism

Visual Perception

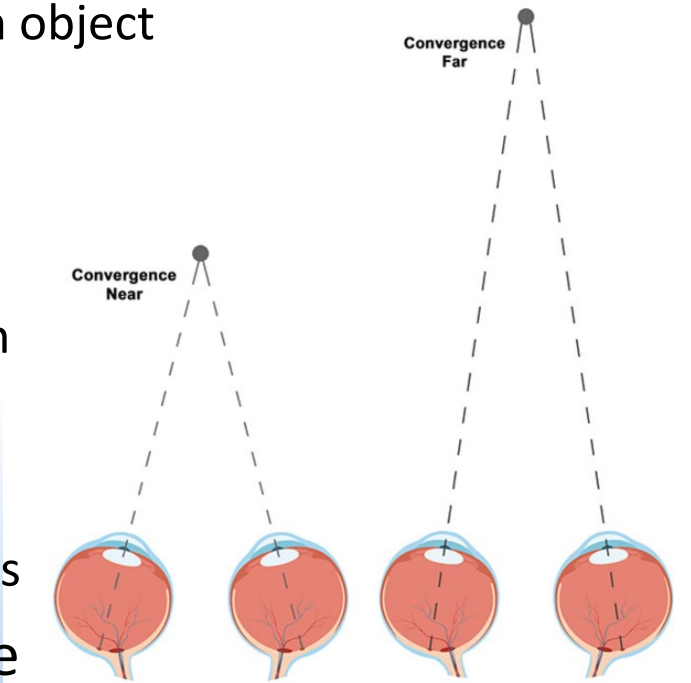
- Stereopsis
  - Perception of depth by the brain based on visual information from both eyes
  - Most prominent **binocular depth cue**
  - Binocular vision
    - Sight with two eyes
    - Each eye is at a slightly different position, ~63mm apart, and captures the scene from a slightly different angle
    - Perceive binocular depth cues



Credit: Illustration by S. Aukstakalnis

Visual Perception

- Vergence
  - Simultaneous rotation of both eyes around their vertical axis in opposite directions for binocular vision
    - Pointing of the fovea of both eyes at an object
  - To look at an object
    - In the near field, eyes rotate toward each other or **converge**
    - In the far field, eyes rotate toward each other or **diverge**
  - Disconjugate
    - When eyes rotate in opposite directions
  - Other eye movements are conjugate



Credit: *Eye illustration by Ginko / [Depositphotos.com]*

Visual Perception

- Accommodation
  - The process by which an observer's eye changes optical power to focus on an object on a different focal plane
    - Eye relaxes, lens flattens to focus at a distance
    - Eye constricts, lens becomes more rounded to focus on near-field

  - Limited depth of field
    - Only a certain range of objects will be focus, everything outside this range blurred

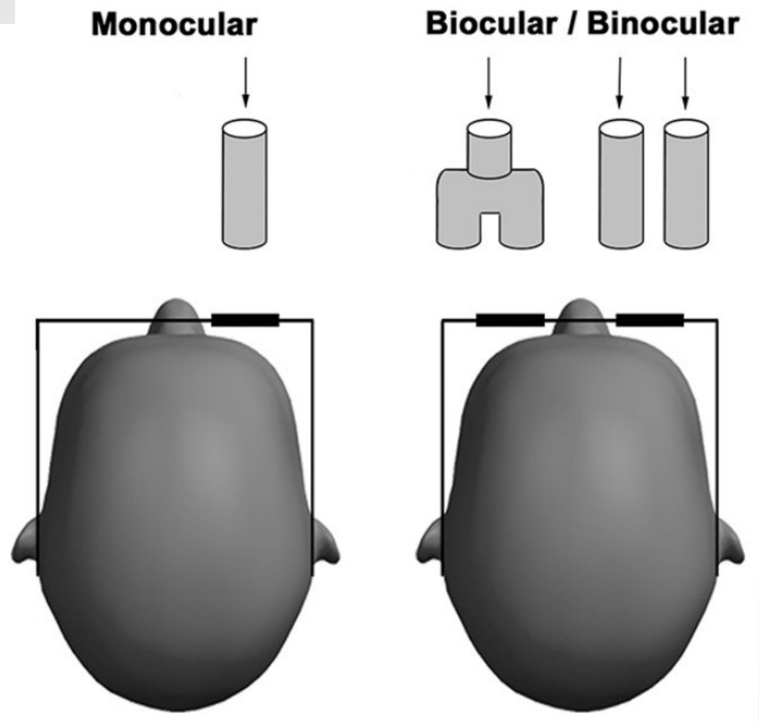
https://developer.nvidia.com/sites/all/modules/custom/gpugems/books/GPUGems/gpugems_ch23.html

Visual Perception

- Vergence and accommodation processes
  - Important to understand for virtual and augmented reality
  - Accommodation-vergence conflict
    - Visual fatigue, headaches and eye strain
      - Side effect caused by eyes having to remain focused on a flat display surface within inches of the eye
        - E.g., flat panel-based stereoscopic head-mounted displays
    - Depth of field is just simulated
      - Eyes focus on images presented to each eye displayed on a 2D surface
      - Constant focusing in the near-field
      - Mismatch in sensory cues provided to the brain by the vergence and accommodation processes

Display Fundamentals

- Ocularity
  - ➢ Monocular
    - Single viewing channel in front of one eye
  - ➢ Biocular
    - Single viewing channel to both eyes
    - No stereopsis
  - ➢ Binocular
    - Each eye receives its own separate viewing channel
    - Creates stereoscopic view

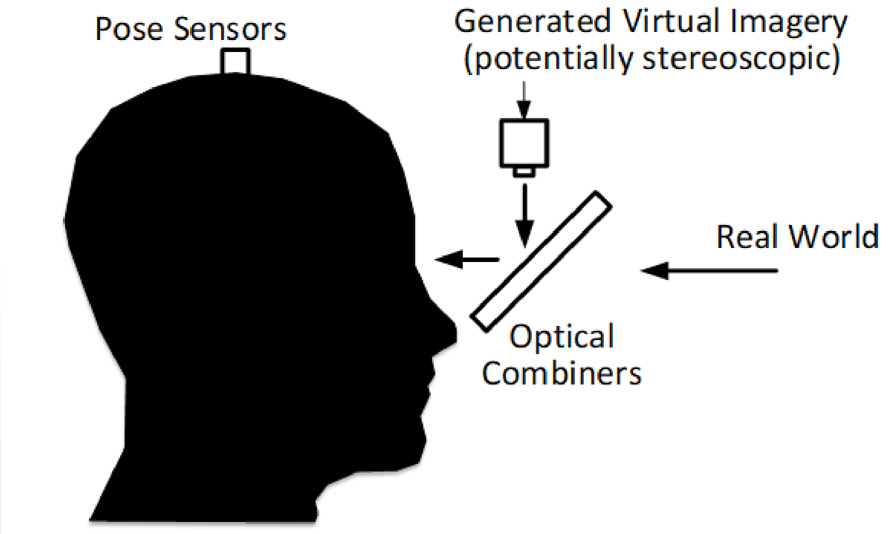


Credit: Illustration by S. Aukstakalnis

https://www.google.com.au/glass/start/

Display Fundamentals

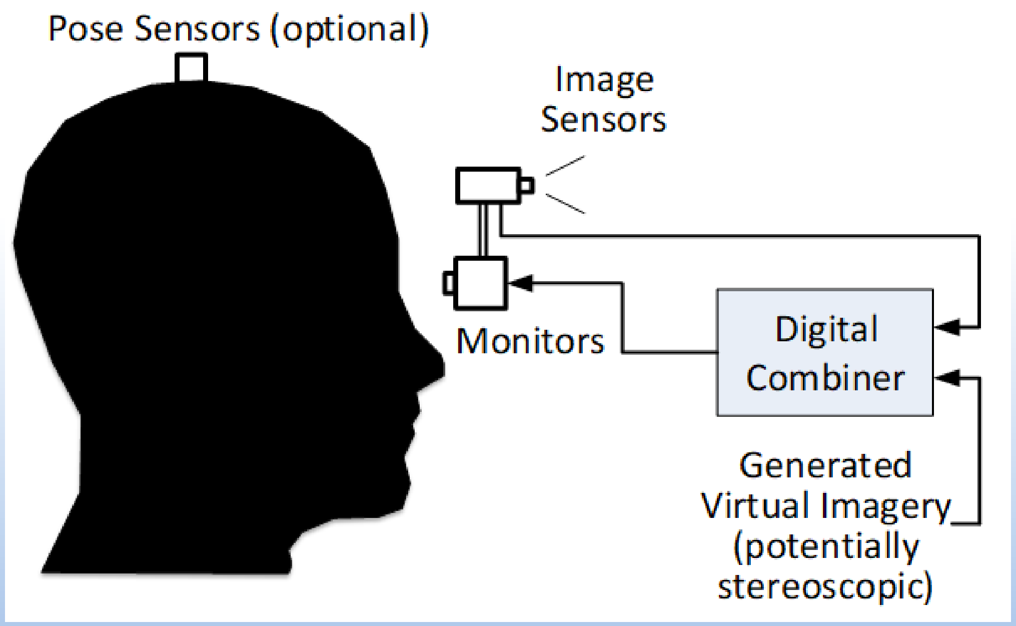
- Display types
  - ➢ Head-mounted display (HMD)
  - ➢ Fully immersive
    - Completely occlude the user's view of the outside world
  - ➢ Optical see-through (OST)
    - Commonly rely on an optical element that is partially transmissive and partially reflective



Evan-Amos, Public domain, via Wikimedia Commons

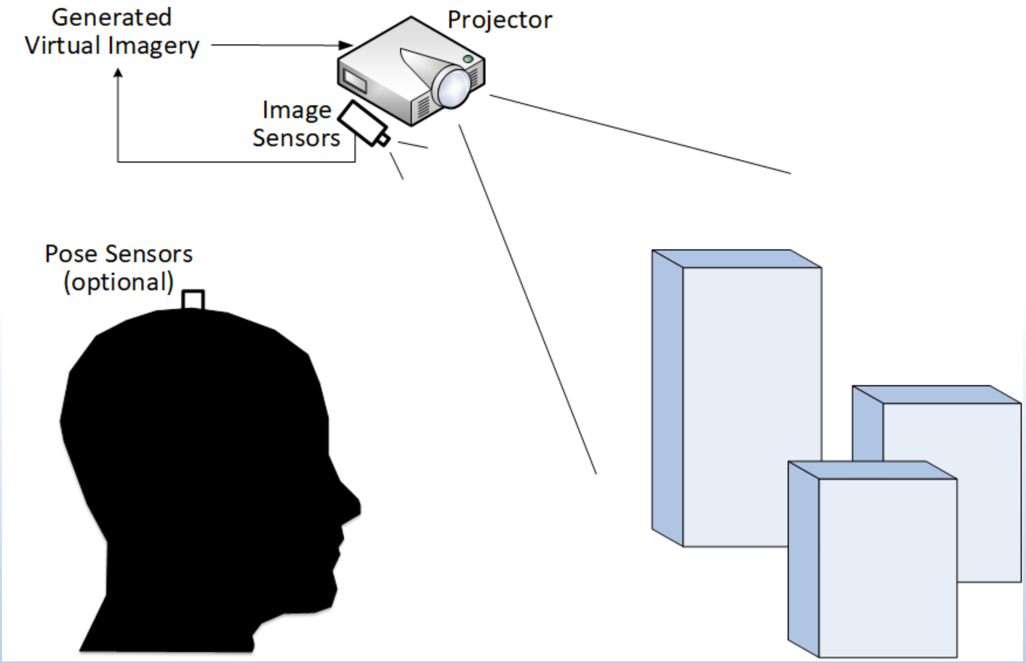
Display Fundamentals

- Display types
  - ➢ Video see-through (VST)
    - Combines real and virtual electronically
    - Real world captured via a video camera and transferred to graphics processor



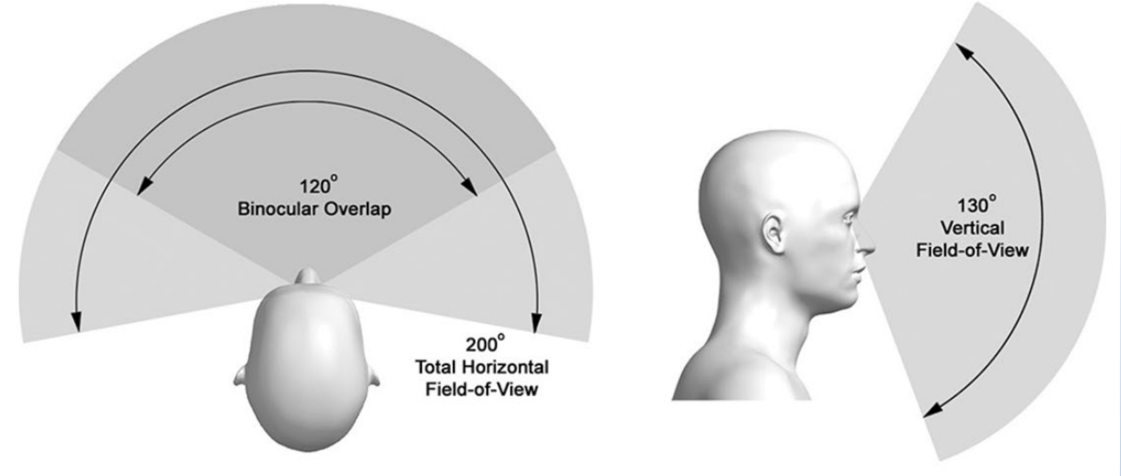
Display Fundamentals

- Display types
  - Spatial projection
    - Casts images directly onto real-world objects
    - No combiner unit is required, and no electronic screen



Display Fundamentals

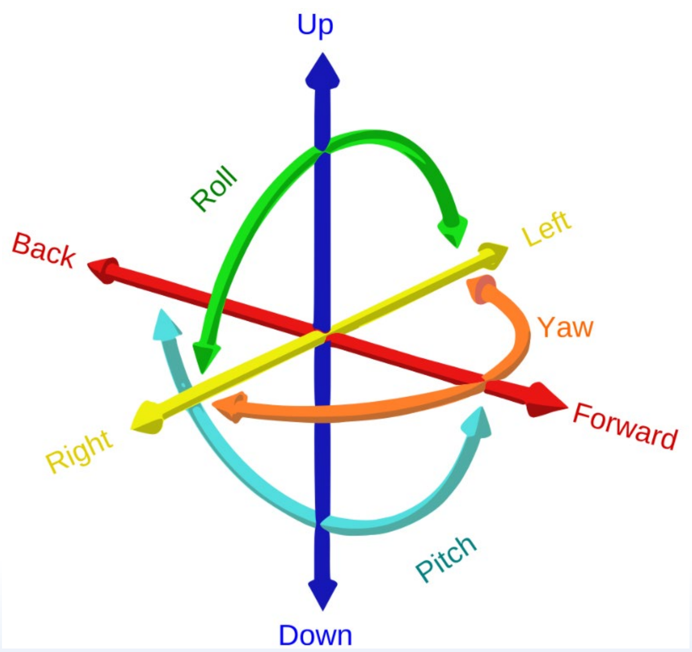
- Terms and concepts
  - Field of view (FOV)
    - Total angular size of the virtual image visible to both eyes
    - Binocular overlap
      - Part of the total visual field where the monocular FOV of the eyes overlap
      - Important for perception of depth



Credit: Illustration by S. Aukstakalnis

3D Objects

- Degrees of freedom (DOF)
  - ➢ Mechanical degrees of freedom of movement in 3D space
    - Tracking HMD or controllers
    - Movement of objects in 3D space
  - ➢ 6 DOF
    - Position
      - – x, y, z
    - Rotation
      - – yaw, pitch, roll
  - ➢ 3 DOF
    - In VR, typically refers to tracking rotational motion only

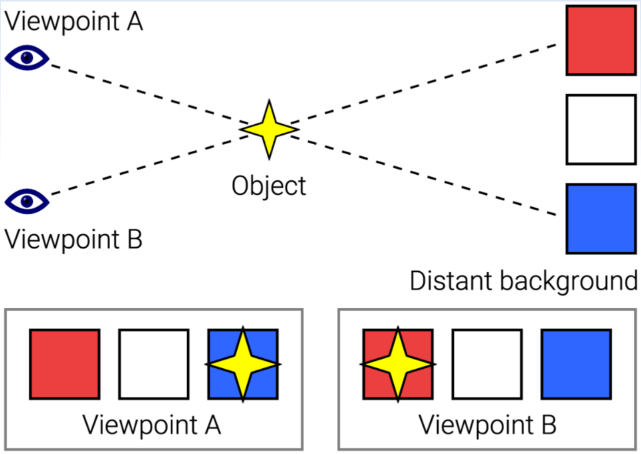


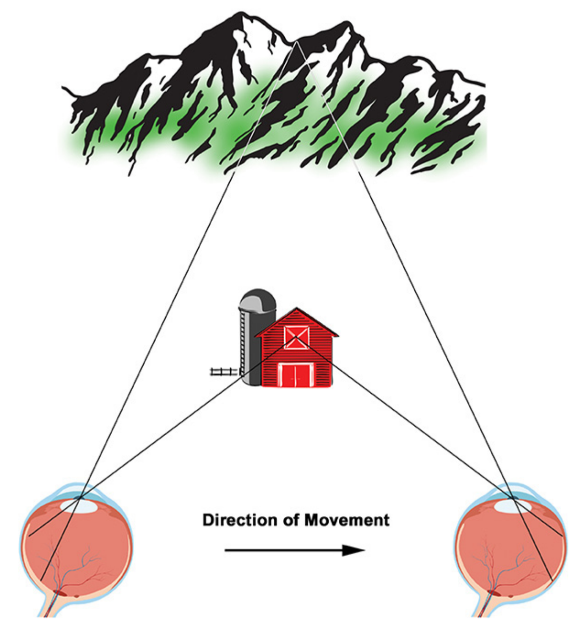
Visual Cues

- Sensory cues
  - ➢ A piece of information that is derived from sensory stimulation and is relevant to perception
- Monocular depth cues
  - ➢ Not dependent on both eyes
  - ➢ Monocular depth cues are strong
    - Misconception that depth perception enabled by stereo cues alone
  - ➢ Divided between
    - Viewer motion
      - – Requiring movement of light patterns across the retina
    - Fixed viewing position

Visual Cues

- Motion parallax
  - Objects closer to a moving observer appear to move faster than objects further away
  - Physiological perspective
    - The result of the speed at which an image moves across the retina
  - Strong relative motion cue
  - Important information on relative depth differences

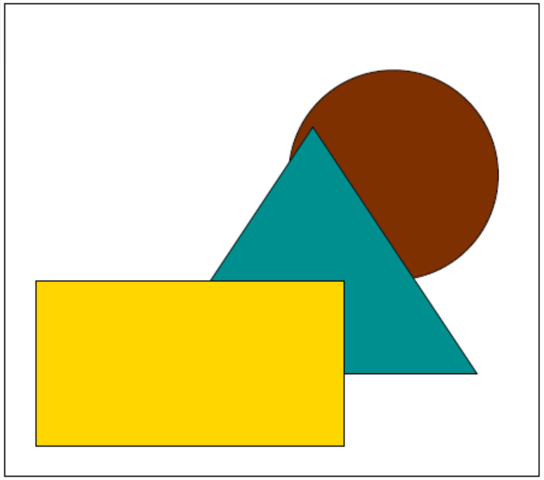




Credit: Illustration elements by sergeiminsk and Ginko © 123RF.com

Visual Cues

- Occlusion
  - Also known as interposition
  - Generated when one object blocks and observer's view of another object
    - Blocking object perceived as being closer to the observer
  - Indicates relative, as opposed to absolute, distance
  - Two components when moving
    - Deletion (hiding)
    - Accretion (revealing)



Credit: *Illustration by joyfull / Depositphotos.com*

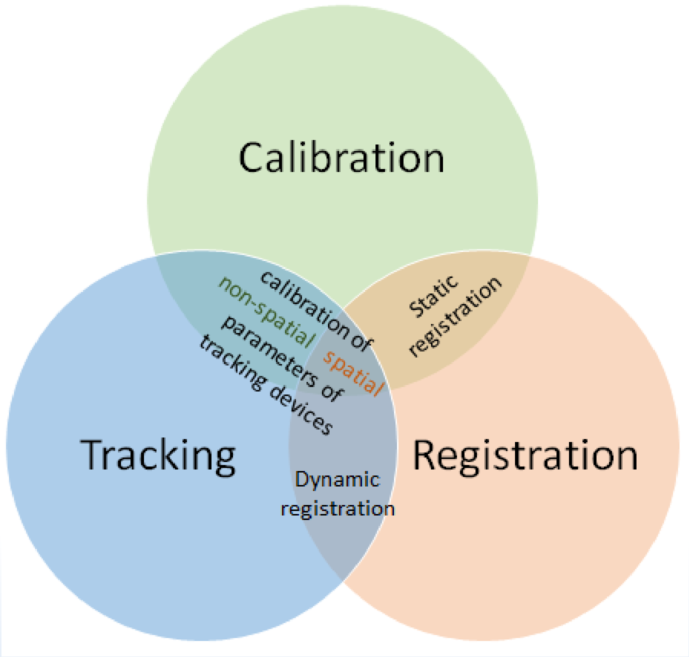
Visual Cues

- Texture gradient
  - Strong cue
  - Gradual change in appearance of textures and patterns of objects with distance
  - Less distinguishable with distance
  - Three key features
    - Perspective gradient
      - Decrease in separation of texture elements
    - Compression gradient
      - Decrease in apparent height of texture elements
    - Density gradient
      - Increase in number of elements per unit area

Credit: Image by Jeremy Keith via Flickr under a CC 2.0 license

Tracking

- Registration
  - ➢ Alignment of spatial properties
  - ➢ In AR, registered objects aligned to each other in a coordinate system
  - ➢ Goal
    - Accurate registration of virtual information with physical objects
  - ➢ Static registration
    - When the user/camera is not moving
    - Requires calibration of tracking system
  - ➢ Dynamic registration
    - When user/camera is moving
    - Requires tracking



Tracking

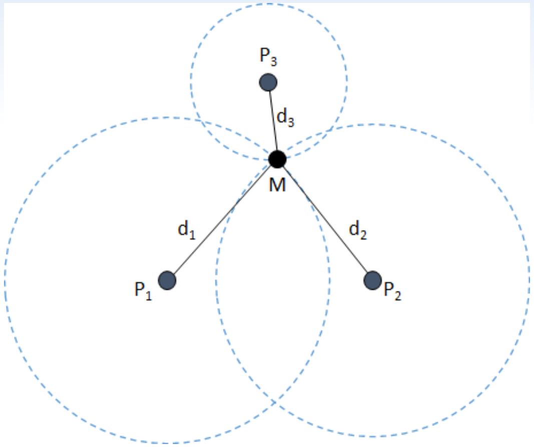
- Tracking
  - ➢ Dynamic sensing and measuring, continuous
  - ➢ Must know the relative pose
    - Position and orientation
- Calibration
  - ➢ Correlates sensor readings with a standard or a reference sensor
    - Device to be calibrated to a known scale
    - Check and adjust a sensor's accuracy
  - ➢ Usually only performed at discrete times
    - Once for the lifetime of the device (during manufacturing)
    - Before commencing an operation
    - Autocalibration – concurrently with tracking

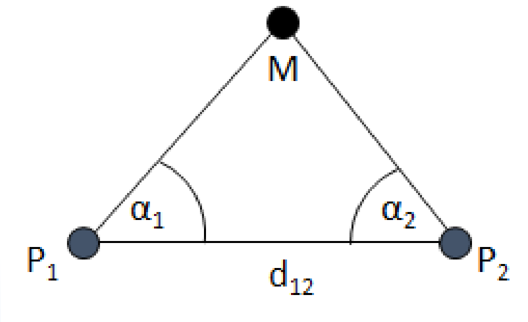
Characteristics of Tracking Technology

- Measurement coordinates
  - ➢ Global vs. local measurements
    - Global
      - Larger (or unlimited) workspace
      - More freedom of movement
    - Local
      - Smaller scale, better accuracy and precision
  - ➢ Absolute vs. relative measurements
    - Absolute
      - Coordinate system defined in advance
    - Relative
      - Reference coordinate system established dynamically
      - Incremental sensing
        - » E.g., mouse movement based on the last measurement

Characteristics of Tracking Technology

- Measured geometric property
  - ➢ Distances or angle
    - Trilateration
      – Geometric method of determining locations of points from at least three measurements
    - Triangulation
      – Determines locations of points from two or more measured angles
        » At least one known distance
    - Can recover position and orientation of a rigid object
      – From position of three or more points





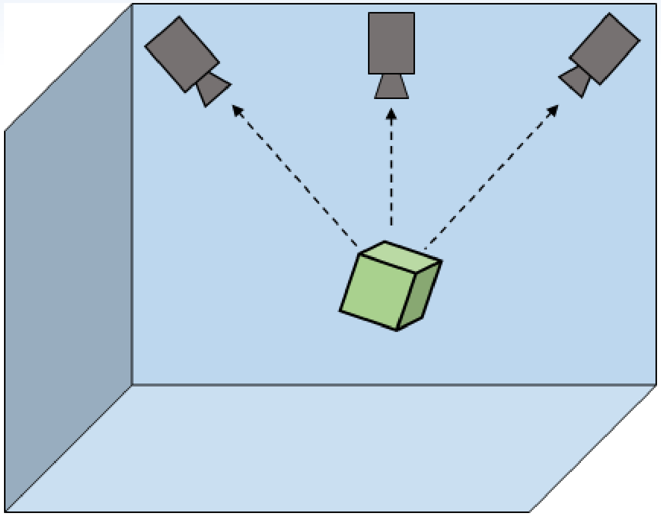
https://ar-tracking.com/en/product-program/targets

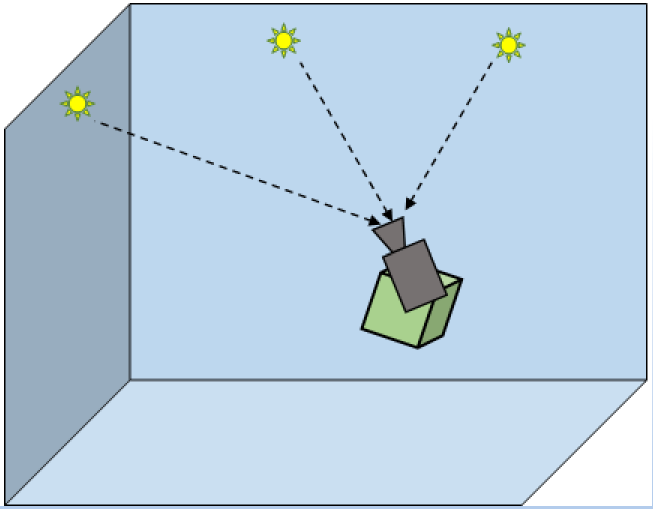
Characteristics of Tracking Technology

- Temporal characteristics
  - Update rate
    - Temporal resolution
    - Number of measurements in a given time interval
  - Measurement latency
    - Time it takes from occurrence of physical event to data becoming available
  - End-to-end latency
    - Time it takes from occurrence of physical event to presentation of a stimulus
    - 60Hz display requires updates within a time interval of less than 17ms

Characteristics of Tracking Technology

- Spatial sensor arrangement
  - ➢ Outside-in tracking
    - Stationary mounted sensors
      - Good position, poor orientation
      - User mostly unaffected by sensor properties, e.g, weight, power
      - Limited workspace
  - ➢ Inside-out tracking
    - Mobile sensor(s)
      - Good orientation, poor position
      - More independent of stationary structures
      - Disadvantage: weight, size, number of sensors

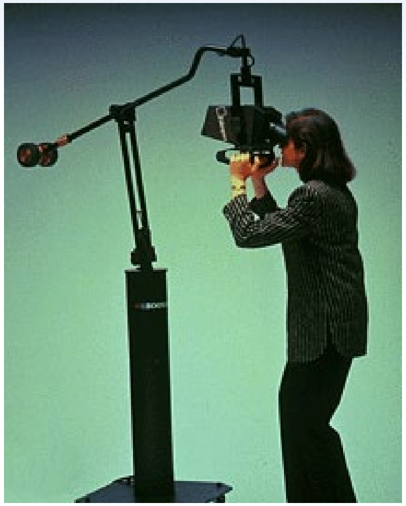




Tracking Systems

- Tracking systems
  - ➢ Choice depends on use case
  - ➢ Need to consider tradeoffs between
    - Performance and cost
    - Size, weight, power consumption
- Stationary Tracking Systems
  - ➢ Mechanical tracking
    - Track end-effector of articulated arm
    - Joints with 2/3 DOF, known lengths
      - – Rotary encoders or potentiometers
    - Fast, high precision
    - Limited freedom of operation

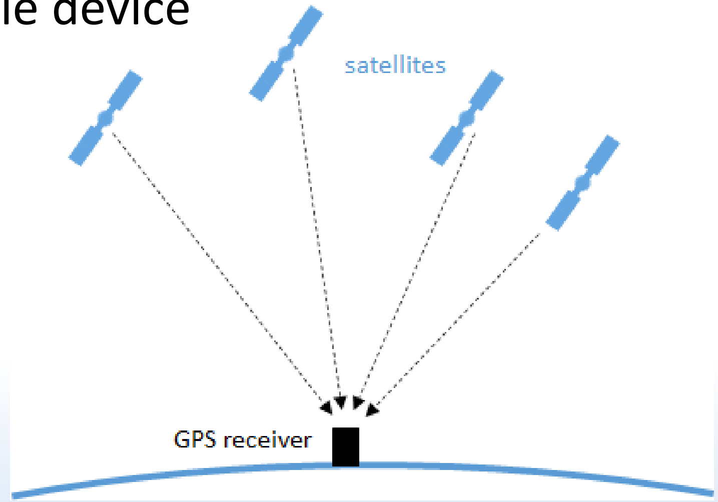
Fakespace BOOM



CyberGrask

Mobile Tracking Systems

- Mobile sensors
  - Can use outdoors
  - Sensing and computation for tracking
    - Must be performed locally on the mobile device
      - Limited processing power
      - Inexpensive sensors, usually
  - Global positioning system (GPS)
    - Planet-scale outside-in
      - Measures radiowave time-of-flight
    - Requires clock synchronization
    - Must receive signals from at least 4 satellites
      - Known current positions in orbit

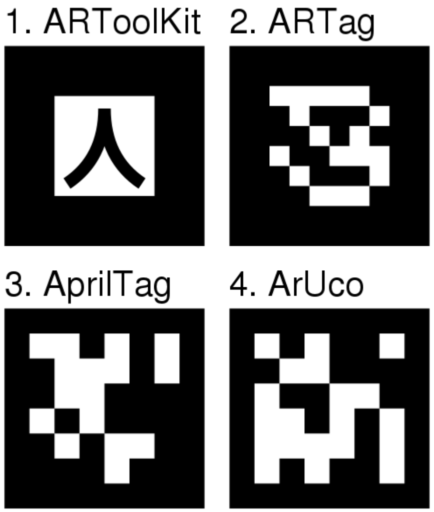


Optical Tracking Systems

- Optical tracking
  - One of the most important physical tracking principles used today
  - Optical sensors
    - Digital cameras are cheap and powerful
      - CCD (charge coupled devices)
        - » Professional photography
      - CMOS (complementary metal oxide semiconductor)
        - » Fast, cheap, low power consumption
    - Inexpensive cameras can provide rich measurements
      - Analysed with sophisticated computer vision techniques
    - Lenses are becoming the most limiting part

Optical Tracking Systems

- Model-based versus model-free tracking
  - Using images from a camera requires comparing with some reference model
  - Model-based
    - A tracking model is available
      - Reference model obtained before tracking
    - Compare the model to observations in the images
  - Model-free
    - At start-up, no tracking model is available
      - More flexible
    - Most build a temporary tracking model while tracking
    - Measurements only relative to starting point



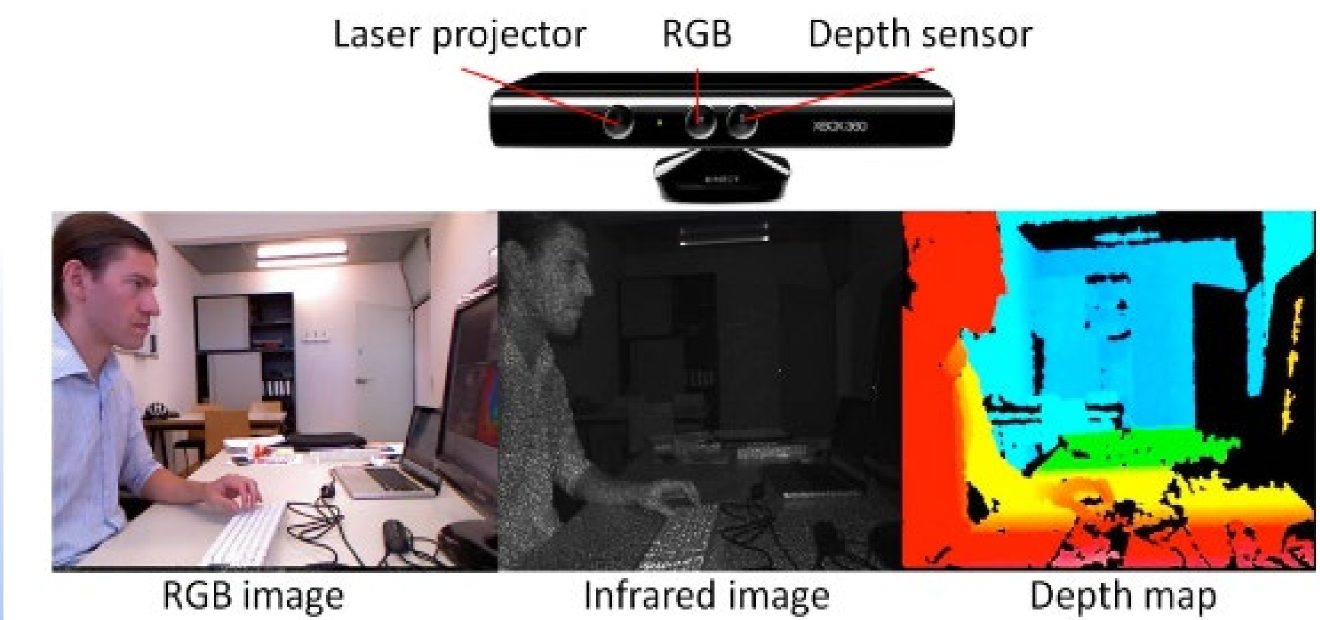
Optical Tracking Systems

- Illumination
  - Passive illumination
    - Natural light sources
      - Not part of the tracking system
    - Can use conventional digital camera
    - Requires sufficient contrast
      - Cannot track when it is too dark (mostly indoors)
  - Active illumination
    - Overcomes dependence on natural light sources
    - Often infrared spectrum
      - Outside human visible spectrum
    - LED beacons
    - Camera with infrared filter delivers high contrast
    - Not suitable with sunlight
      - Infrared frequencies

https://www.ign.com/articles/2006/11/29/making-sense-of-the-sensor-bar
Greyson Orlando, Public domain, via Wikimedia Commons

Optical Tracking Systems

- Structured light
  - Project a known pattern into the scene
  - Projector with regular light or laser
  - Laser ranging
    - » Measure time of flight taken by laser pulse
    - » LIDAR (light radar): long range laser used in surveying



Optical Tracking Systems

- Markers vs natural features
  - Fiducial markers
    - Artificial tracking targets
    - Square shapes yield 4 points (track pose)
    - Circular shapes yield only 1 point
    - Digital marker model exists first, marker manufactured second (e.g., printing)
  - Natural feature tracking
    - Existing visual features in the environment
    - Physical features exist first, tracking model reconstructed second

Image: Daniel Wagner
Image: Andrei State, UNC Chapel Hill

Interaction

- Interaction
  - Selection
    - User interacts by selecting a virtual object
  - Manipulation
    - User changes the virtual object in someway
  - Navigation
    - Control the position and viewing direction in the virtual environment
  - System control
    - User interacts with the system itself to perform functions outside the virtual environment
      - E.g., commands

System Control

- System control
  - ➢ Conventional GUI elements and techniques
    - Menus, buttons, toolbars
      - – E.g., drag-and-drop, double-click
  - ➢ Menus
    - Can be structured systematically
      - – Positioning, representation and selection technique
        - » E.g., can be fixed or linked to position of a virtual object, or user, or real object
  - ➢ 3D widgets
    - 3D objects coupled with interaction behaviour
      - – 3D geometry make their interactive functionality visible for the user
      - – Can be inspired by real objects
      - – Can be abstract objects, but functionality must be learned

Navigation

- Navigation
  - ➢ Two sub-areas
    - Wayfinding and traveling
- Wayfinding
  - ➢ Analysis, planning and decision about paths in the virtual world
  - ➢ Goal is to generate a cognitive map, i.e., simplified mental representation, of the virtual space
  - ➢ The process of wayfinding is unconscious
    - Resulting cognitive map different for each user
    - Support to enable user to acquire necessary spatial knowledge

Navigation

- Traveling
  - ➢ Motor component of navigation
    - Basic actions needed to change position and orientation of the virtual camera
  - ➢ Exploration
    - User does not have a concrete goal
  - ➢ Search
    - User has a goal of reaching a defined position
  - ➢ Maneuvering
    - Finding exact position in the immediate vicinity of the user
    - Characterised by short and precise movements

Navigation

- Locomotion methods
  - Room-scale movement
    - Manual interaction
    - Natural free real-world movement
  - Seated down
  - Continuous movement
    - Controller-based movement
    - Causes **vection** (illusion of movement)
      - Conflicting senses
      - Simulator sickness
  - Teleporting
    - Instantenously teleport to a location and/or face a certain direction

Selection

- Selection
  - ➢ More difficult in a 3D context than with 2D user interfaces
  - ➢ Pointing
    - Using index finger or input device
      - – Aim at target to be selected
    - Non-trivial to identify selected 3D entity
      - – Requires collision detection and/or ray-casting
    - Visual feedback
      - – Highlighting selected object
      - – Visually mark target point
        - » E.g., cursor, reticle
      - – Virtual hand

Selection

- Direct versus indirect
  - Direct pointing devices used to position 3D cursor directly
    - Can define absolute coordinates
    - May cover parts of the virtual world relevant to the selection task
  - Indirect devices (e.g., mouse)
    - Change cursor using direction vectors relative to previous position
    - User’s attention limited to one part of the overall space

Selection

- Selection techniques
  - ➢ Ray-casting
    - Most important and effective technique
    - Objects selected using a beam that points from a 3D cursor into the environment
    - Position and orientation of the beam are controlled by the user
    - All objects cut by the beam are candidates for selection
      - – Object closest to the user selected
    - Manageable accuracy decreases with distance
  - ➢ Flashlight
    - A selection cone instead of a beam
    - All intersected objects collected as candidates
      - – Distance can be an additional criterion

Selection

- Interaction
  - Visual feedback is an important interaction cue

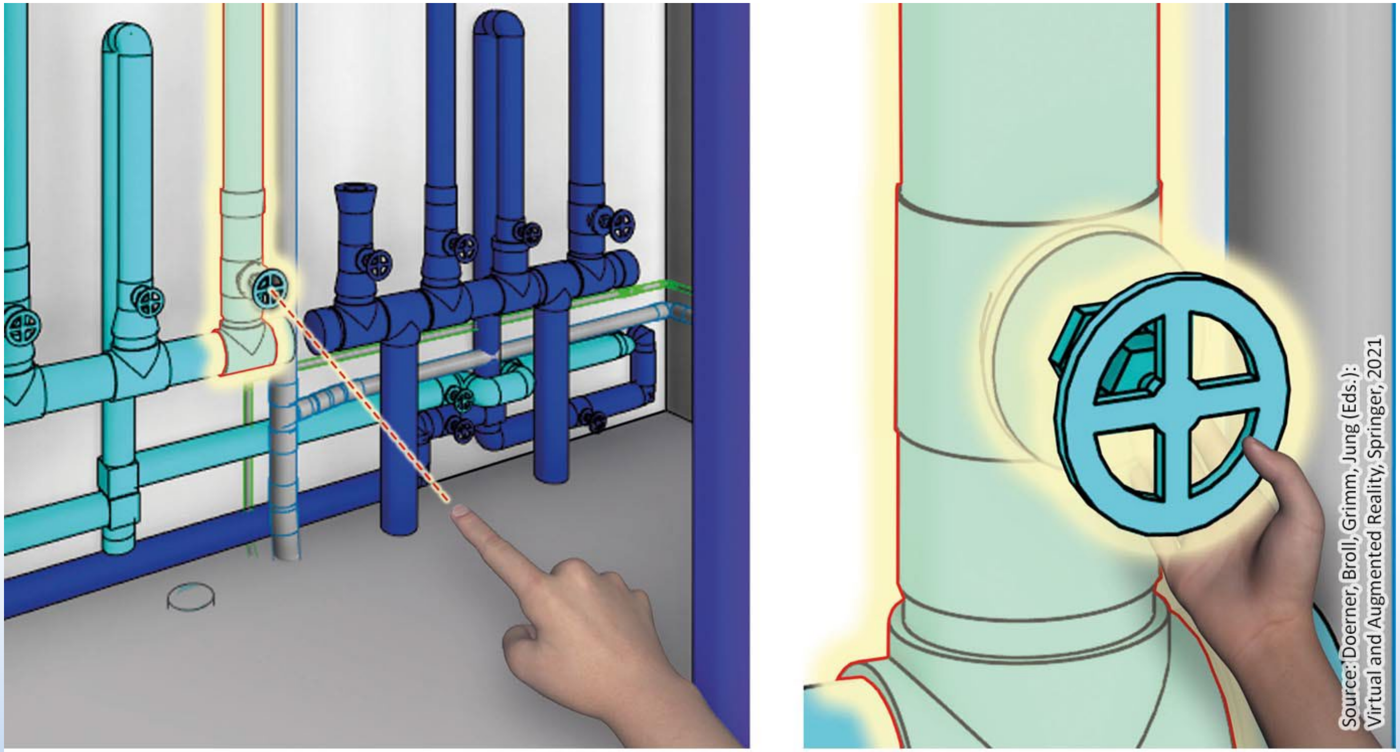


Fig. 6.1 Selection in VR and visual feedback. The selection process is realized (left) with a beam from the finger using ray-casting, or (right) by a virtual hand using collision detection.

Selection

- World-in-miniature

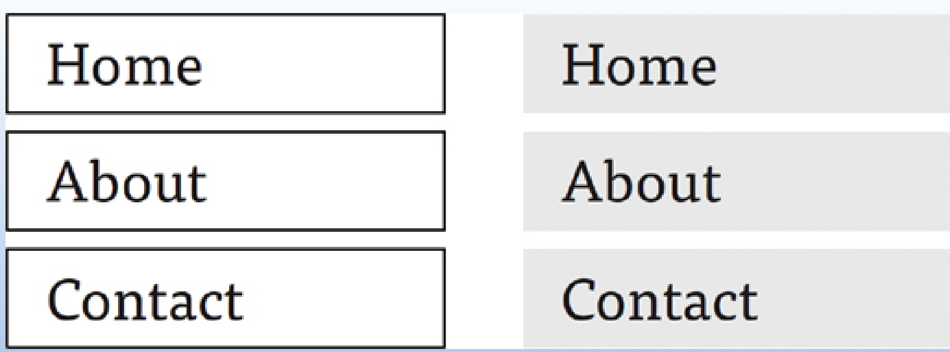
Fig. 6.2 Example of the selection of remote objects by a world-in-miniature. With this technique, users can select objects even if they are not in their field of view.

Manipulation

- Manipulation of objects
  - ➢ Follows on from selection
    - Selected object's properties changed by manipulation
      - – E.g., change an object's location, orientation, size, velocity, appearance
    - Selection and manipulation techniques designed together for interaction
  - ➢ May not have a direct equivalent in the real world
  - ➢ Can be exocentric or egocentric
  - ➢ Suitability of technique depends on
    - Desired functionality and concept underlying an application
      - – E.g., in simulation and training application desirable to reference reality using realistic interaction technique

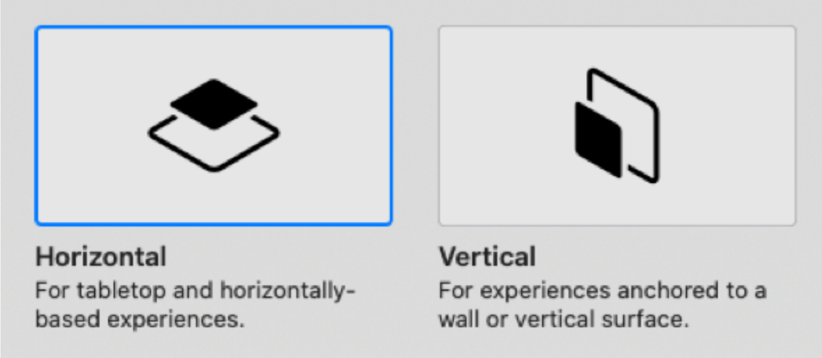
Uncontrollable Background

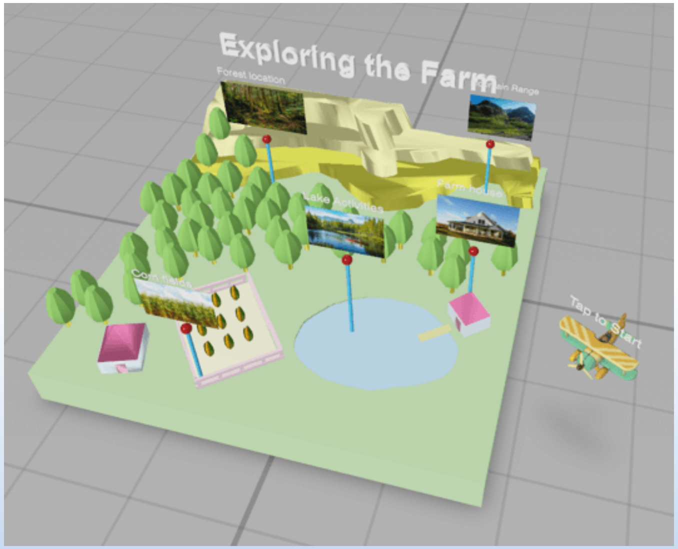
- Figure-ground
  - ➢ Visual relationship in which elements are perceived as either foreground or background
    - One element will fade to the back, another will stand out in front
  - ➢ Can be stable or unstable
    - For example
      - – Left, unstable: outlines and text at the same visual level makes distinction between figure and ground ambiguous
      - – Right, stable: clear that grey rectangles are the background



Uncontrollable Background

- Anchor types
  - Plane anchors
    - Flat surface, either vertical or horizontal
      - E.g., floor, table, walls
  - Face anchors
    - Use camera to scan facial features
    - Build experience around the face

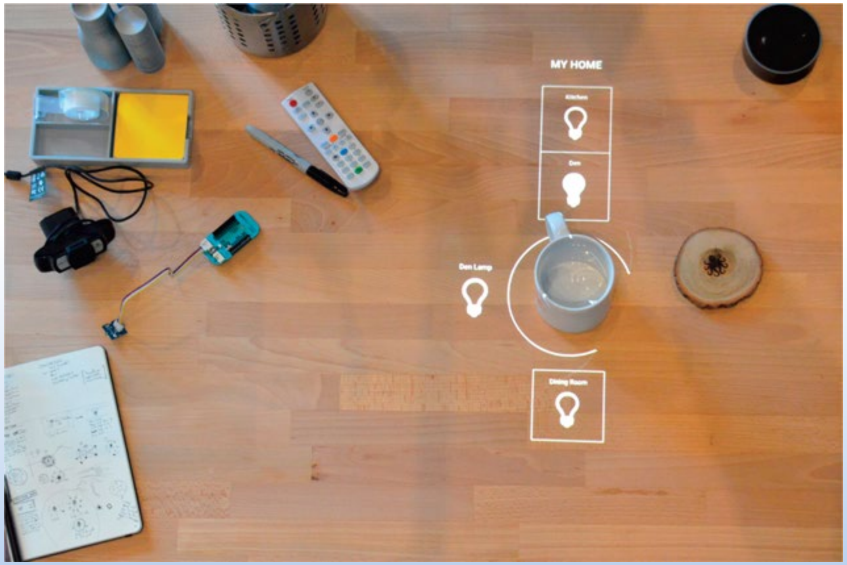




https://www.learningguild.com/articles/understanding-anchors-in-augmented-reality-experiences/
https://developers.google.com/ar/develop/augmented-faces

Uncontrollable Background

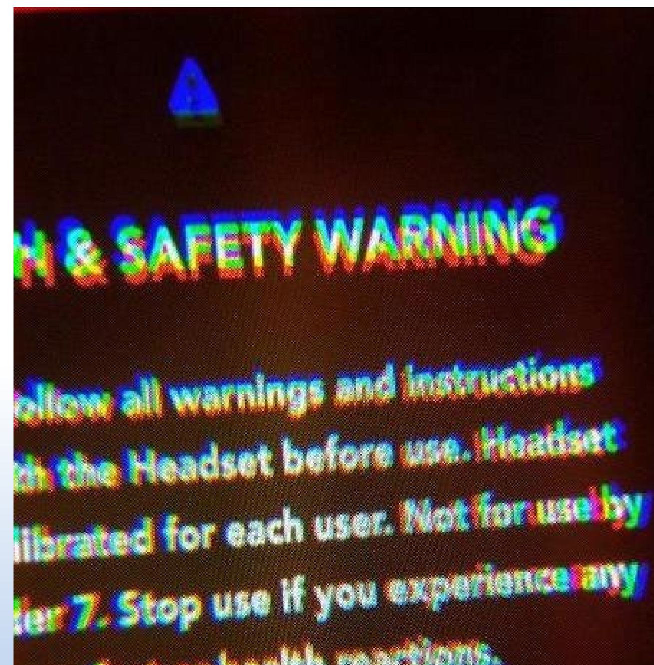
- Image anchors
  - Capture a static image
  - AR marker
- 3D anchors
  - Use a 3D object as an anchor
  - May need to scan a physical object



https://www.learningguild.com/articles/understanding-anchors-in-augmented-reality-experiences/

XR Typography

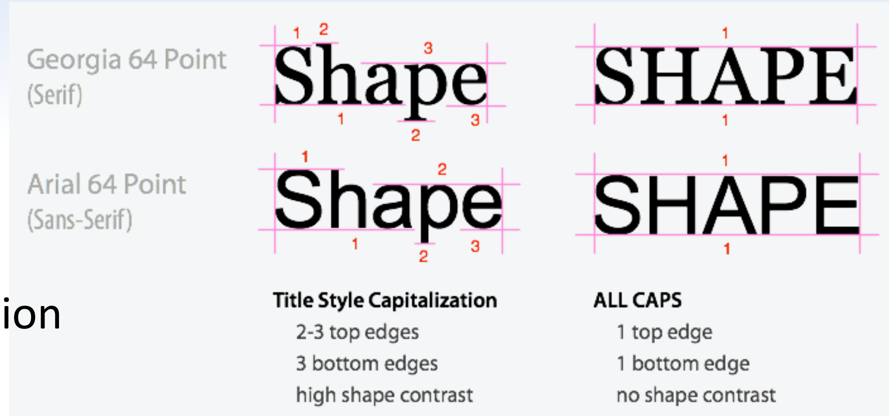
- Example aberrations
  - Halation
    - Spreading of light beyond proper boundaries
  - Chromatic aberrations
    - Inability of a lens to focus all colours at the same place
  - Screen doors effect
    - Visible fine lines between pixels, like looking out of a screen door

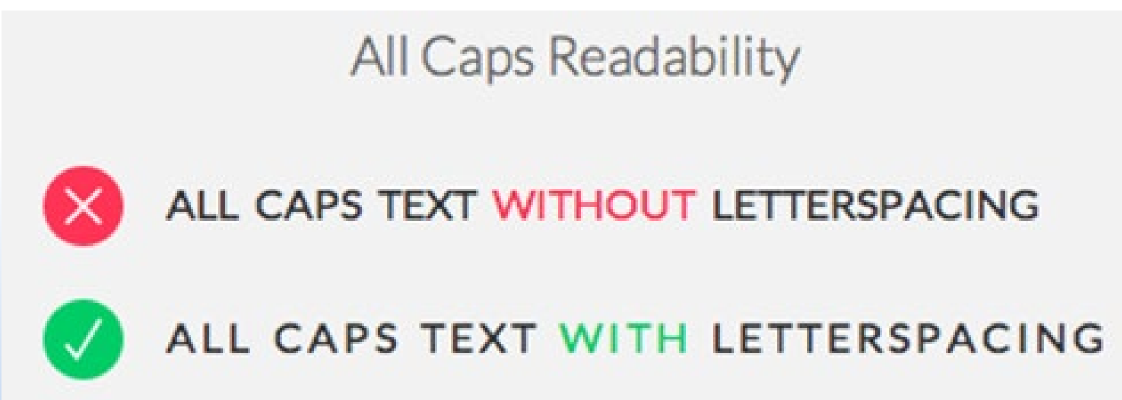


https://xr-typography.niteeshyadav.com/reading-experience/technical-aspects/aberrations

XR Typography

- Guidelines
  - Say more with less
    - Reduce the amount of text
    - Other forms of communication
      - Image, tooltips, audio
  - Casing
    - Uppercase is hard to read in large amounts, loses readability



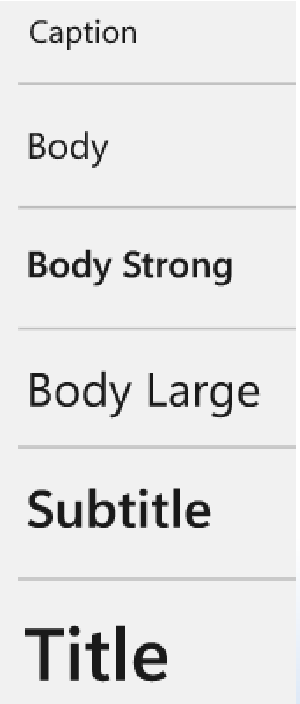


https://uxmovement.com/content/all-caps-hard-for-users-to-read/
https://uxmovement.com/content/how-letterspacing-can-make-all-caps-easier-to-read/

XR Typography

➢ Guidelines

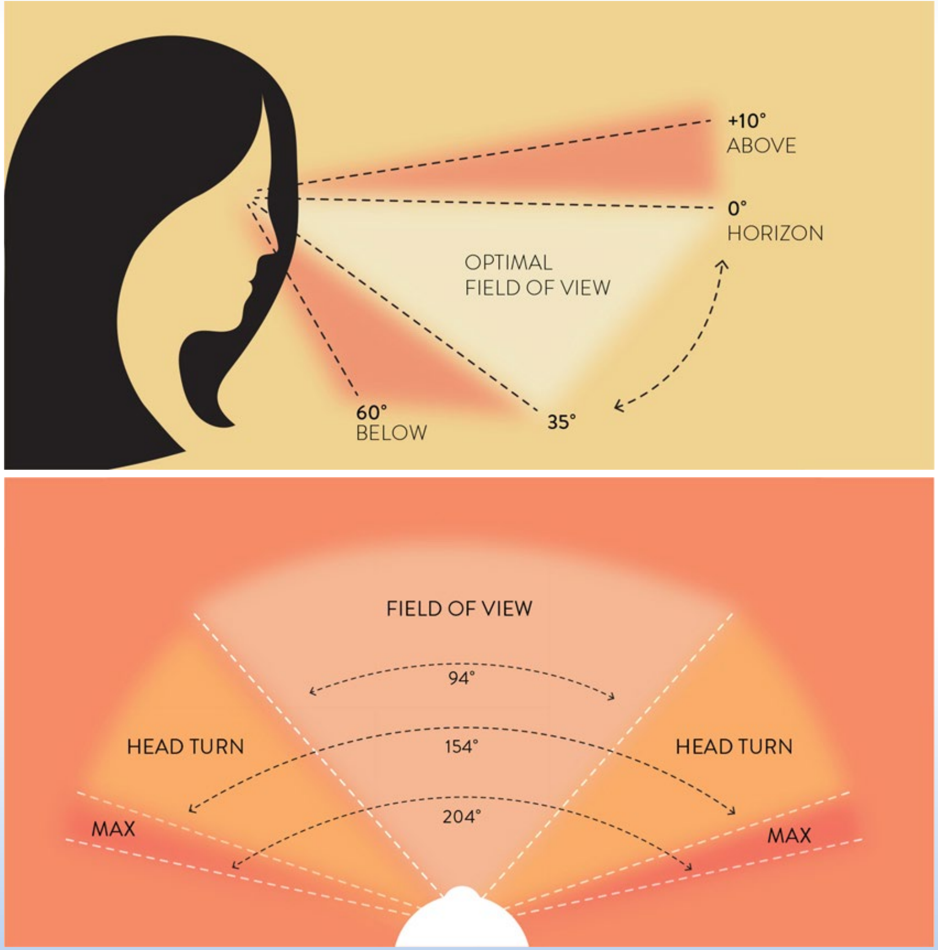
- Limit line length
  - To reduce eye strain, keep to 50 – 60 characters per line
- Weights
  - Varying weights adds hierarchy and guides the user's eye
  - Light and extra bold weights less legible than regular, medium or bold weights
- 2D type easier to read than 3D type
  - Extruded and volumetric types become harder to read
  - Logotypes are an exception



https://learn.microsoft.com/en-us/windows/apps/design/style/typography
https://wearetribu.com/2d-to-3d-graphic-design-and-3d-animation/

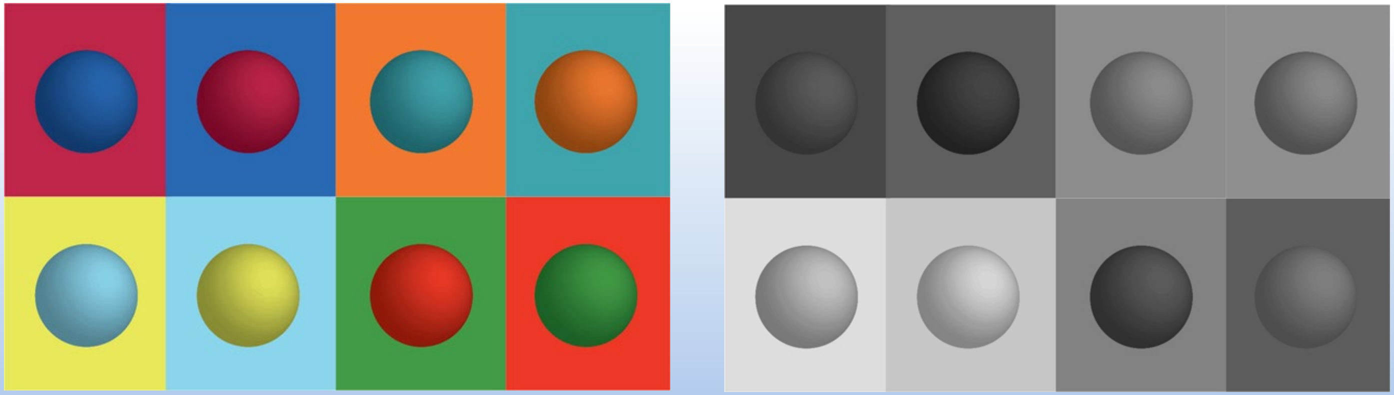
XR Typography

- Gaze
  - Up and down
    - Optimal FoV between 0º and 35º
    - Can cause neck and eye strain
  - Left and right
    - Keep type in the centre zone to avoid head turn or blurring for peripheral sight



Colour for XR

- Usability
  - ➢ Legibility and readability
    - Not only colour of the text but also of elements surrounding text
      - – Helps separate letters from the environmental background
    - White is the most common colour for text and icons in XR
  - ➢ Contrast
    - Colours close in shade or saturation vibrate off one another
    - Select colours with visual contrast



The UX of XR

- Elements to consider
  - Respect the user's personal space
    - Entry point
      - Reduce cognitive load by limiting the number of elements
      - Avoid extremes
      - Do not place content too close to the user
      - Avoid fast-moving (potentially alarming) elements
  - Agency
    - The ability for a user to control or change something in an experience
    - Designing how must power and control the user has
      - Too much and the user may be overwhelmed, distracted from the goal
      - Too limited, the user may feel constricted

The UX of XR

- Feedback
  - Every time the user communicates something, important to receive some type of response
  - Keep feedback natural and timely
  - User gains confidence
- Affordances
  - A property of an object that informs a user how they can interact with it to carry out an action
  - Within the first minute of an experience the user should have an understanding of
    - Where they are and how they fit into that space
    - Why they are there (what is their goal)
    - How they can interact with the elements within the experience to achieve the goal (most important)

The UX of XR

- Interactions
  - Types
    - *Direct interactions*: virtually touching an object, or physically touching an object on screen
    - *Indirect interactions*: joystick or scrolling a mouse
    - *Semi-direct actions*: mix of direct and indirect, e.g., world-in-miniature
  - Minimise the number of different types of interactions
    - Easier to remember
  - More natural gestures, easier learning curve
- Safety
  - Examples
    - Guardian boundary: establishes interaction space
    - Avoid situations like having to walk backwards

The UX of XR

- Things to consider
  - Introduce user agency
    - What can the user control or customise?
    - Balance between power and retaining control over baseline experience
      - Designed to maintain user comfort
  - Guide the user to start interacting
    - The first step is sometimes the hardest one
  - Identify any needed transitions between spaces
    - How does the user get from one to the next?
  - Allow for mistakes
    - Mistakes without consequences
      - E.g., undo, try again

The UX of XR

- Allow for a refresh
  - New technology may glitch or freeze
  - An option to refresh or reload may provide the user with the ability to resolve individual issues
- Provide an exit
  - Easy to find and perform
  - Helps user feel comfortable and instil trust
    - » They know they can always leave
- Provide a clear way to save the experience
  - Save/pause and resume later
  - Users will be more willing to try a different experience and return later

The UX of XR

- Questions to answer when planning user flow
  - What is the goal the user is trying to accomplish?
    - How do they learn about this goal?
  - What information is needed for the user to accomplish this goal?
    - Where is the information presented to them?
  - What pain points, or challenges, can prevent the user from achieving this goal?
    - What can help them overcome these challenges?
- Usability testing critical to get feedback and observe user behaviour
  - Needs to be part of the design process
  - Design improvements

The UI of XR

- 3D interface metaphors
  - ➢ Versatile and powerful visual communication tools
  - ➢ Interface metaphor
    - Commonly understood method/language based on cultural connection that informs a user how to interact with the UI
    - Refer to an idea, object, or concept using a parallel symbol
    - Knowledge user already has
    - Same concept may be used in 3D
      - – XR currently lacks accepted UI metaphors

Sound Design

- Sound in XR
  - ➢ Three main ways to use sound
    - Ambient sound
      - Background noises, creates a sense of space and mood
      - Not too noticeable, but adds a sense of realism
    - Feedback sound
      - Sound when interacting with an interactive element reinforces successful activation
      - Should be consistent, so users will start to associate the sound with their actions
      - Sound cues can guide interactions
        - » For example
          - Direct the user’s gaze
          - Alert a user they are close to the boundary

Augmented Reality

- Augmented Reality (AR)
  - ➢ The enrichment of reality by artificial virtual content
  - ➢ Not static
    - Augmentation is continuous and adaptive to the viewpoint of the viewer

Fusing a real environment (left) with a virtual object (right) to achieve Augmented Reality (center). (Single images: © Tobias Schwandt, TU Ilmenau 2018. All rights reserved.)

AR Types

- OST AR
  - Dark virtual objects may appear transparent
  - Darkened perceive reality
- VST AR
  - Real background same optical quality and brightness

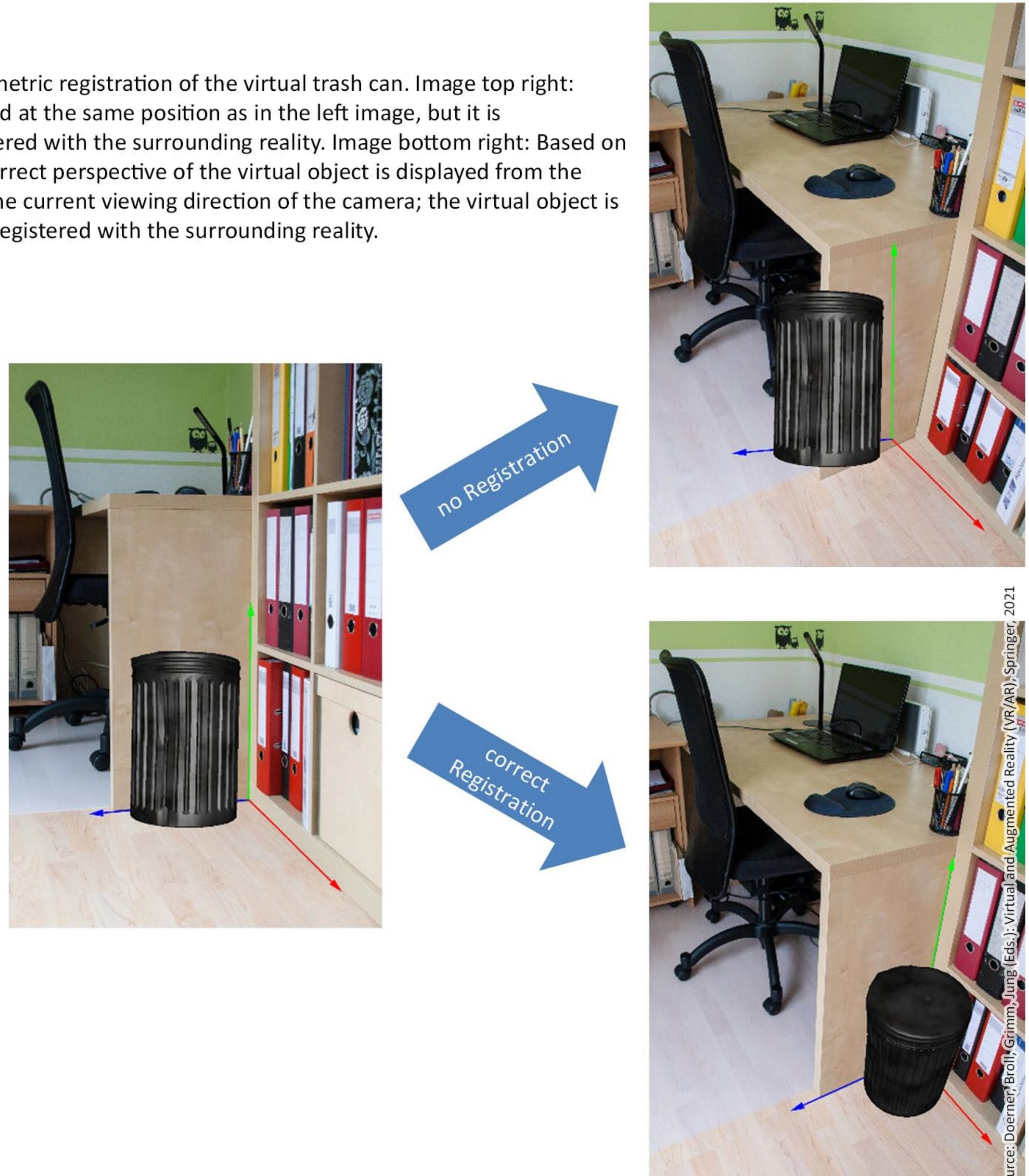
With the OST AR techniques, dark virtual objects sometimes appear transparent (here the less illuminated lower part of the red sphere).

Typical perception when using the optical see-through technique (left) compared to the video see-through technique (right)

Registration

- Geometric registration
  - ➢ Virtual object appears to be in the same place in reality even if the camera perspective changes
  - ➢ Tracking provides basis for geometric registration
    - Quality of the tracking is crucial for visual quality of registration
    - Affected by tracking
      - – Update rate
      - – Latency
  - ➢ Update rate
    - Should ideally match frame rate, i.e. at least 60 fps
    - Otherwise, virtual objects will move when camera/head moves
      - – Then, jump or jerk back to the correct position

Left image: Correct geometric registration of the virtual trash can. Image top right: Virtual object is displayed at the same position as in the left image, but it is geometrically not registered with the surrounding reality. Image bottom right: Based on the tracking data, the correct perspective of the virtual object is displayed from the current viewpoint and the current viewing direction of the camera; the virtual object is geometrically correctly registered with the surrounding reality.



Source: Doerner, Broll, Grimm, Jung (Eds.): Virtual and Augmented Reality (VR/AR), Springer, 2021

Registration

- Photometric registration
  - ➢ Geometric registration
    - A basic requirement of AR
  - ➢ Photometric registration of virtual objects
    - Only performed rudimentarily (if at all)
  - ➢ A correct adjustment of a virtual objects’ appearance to its real environment
  - ➢ Need to capture the real lighting conditions
    - Light probes – reflective spheres placed in the scene
    - Not always possible/desirable to have light probes
    - Affects the surrounding illumination

Visual Coherence

- Light probes
  - Can be used to effectively acquire a radiance map
  - Can be passive (reflective object) or active (camera)
  - Should be omnidirectional
    - Cameras require fish-eye lens

An omnidirectional camera can serve as an active light probe

A light probe in the form of a diffuse sphere and mirror sphere captures the real-world illumination

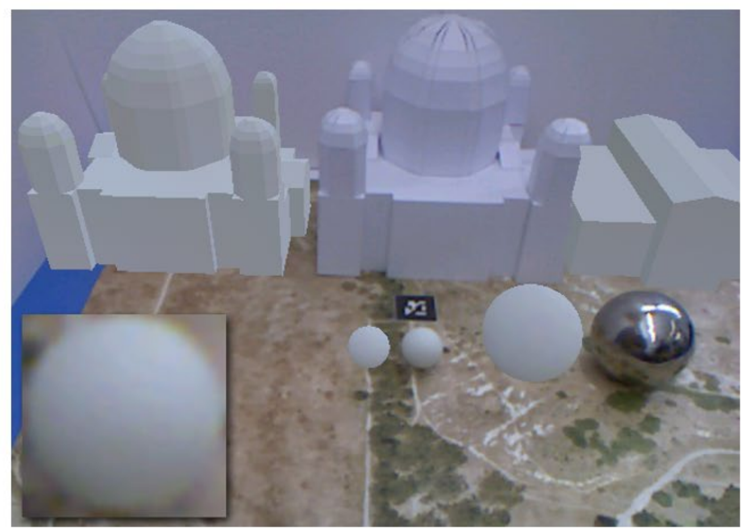
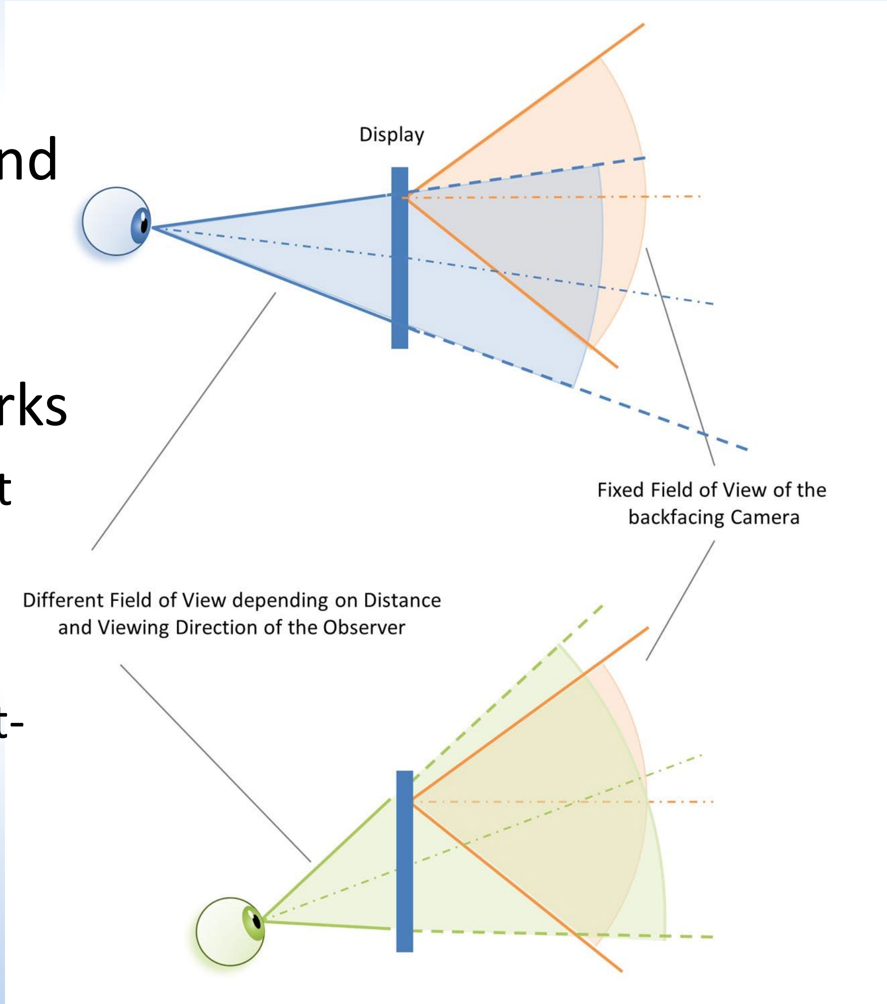


Image: Lukas Gruber

Visual Output

- Handheld devices
  - ➢ Currently most important and frequently used AR devices
  - ➢ Due to the availability of corresponding AR frameworks
    - ARCore for Android and ARKit for iOS
  - ➢ Analogous to VST
    - Augmentation usually correct-perspective, but not actual viewing point

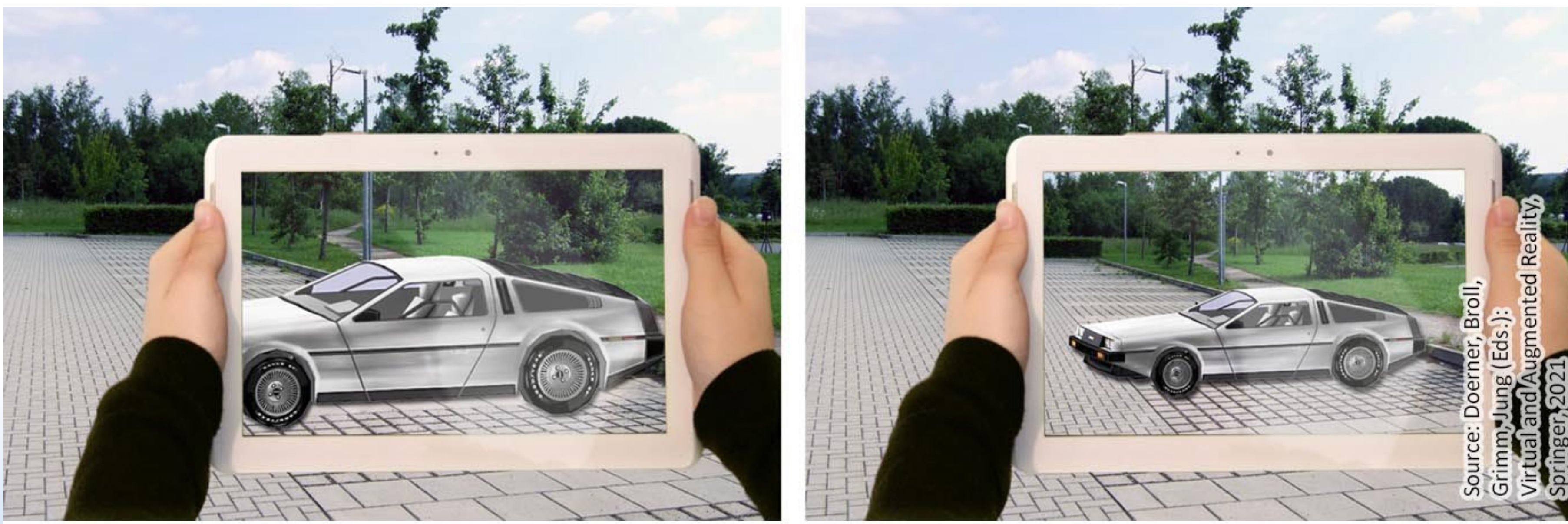


Different fields of view of viewer and camera in handheld AR.

Source: Doerner, Broll, Grimm, Jung (Eds.): Virtual and Augmented Reality (VR/AR), Springer, 2021

Visual Output

- FOV of camera is fixed in relation to the display
- The viewer’s FOV depends on the respective viewpoint and the viewing direction in relation to the display



Left: Matching perspective between reality and augmented image (Magic Lens effect).
Right: Camera image and reality are perceived with a deviating perspective.

Special AR Interaction Techniques

- Tangible user interfaces
  - Real objects linked with virtual objects
  - Real object (placeholder object or proxy) is mapped to the state of the virtual object
  - Physical properties of real object correspond to those of virtual object

Tangible User Interfaces: a real proxy object is used to interact with a virtual object.

Diminished Reality

- Diminished reality
  - Not AR
    - Removal of parts of reality
  - Two types
    - Attempt to reconstruct the actual real background
    - Merely create a plausible overall impression
      - i.e., showing some alternative content for removed object
  - Retrospective removal of persons from pictures has long tradition

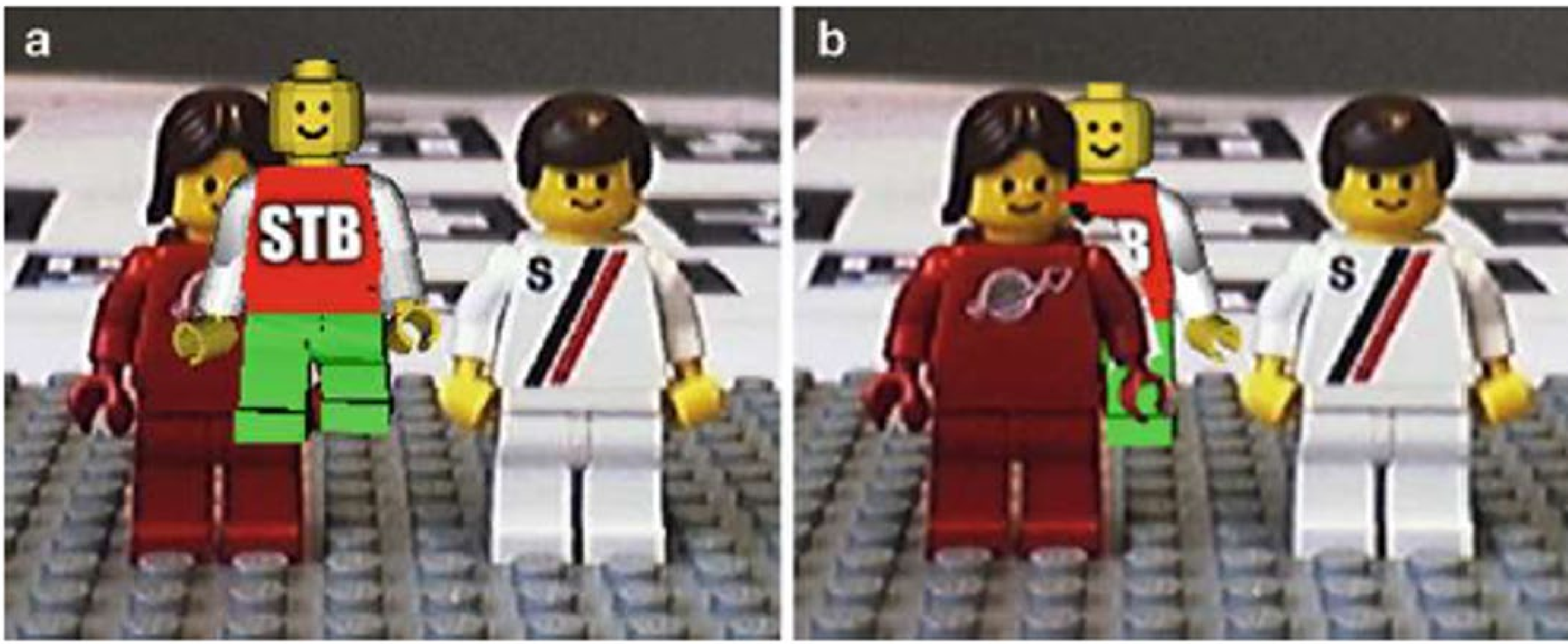
Example of Diminished Reality: The sink drain is removed from the live video stream in real time. (© TU Ilmenau 2018. All rights reserved.)

Visual Coherence

- Occlusion
  - One of the strongest depth cues
  - Simply drawing computer graphics objects on top of a video background with a registered camera
    - Not sufficient to create impression where real and virtual coexist
  - Virtual in front of real
    - Draw augmentation on top of video background
  - Virtual behind real
    - Need strategy to distinguish visible from occluded augmentations
    - Failure to consider occlusion
      - Leads to a composition that is irritating and not effective in conveying the 3D position of a virtual object

Visual Coherence

- Occlusion example
  - Lack of appropriate depth cues

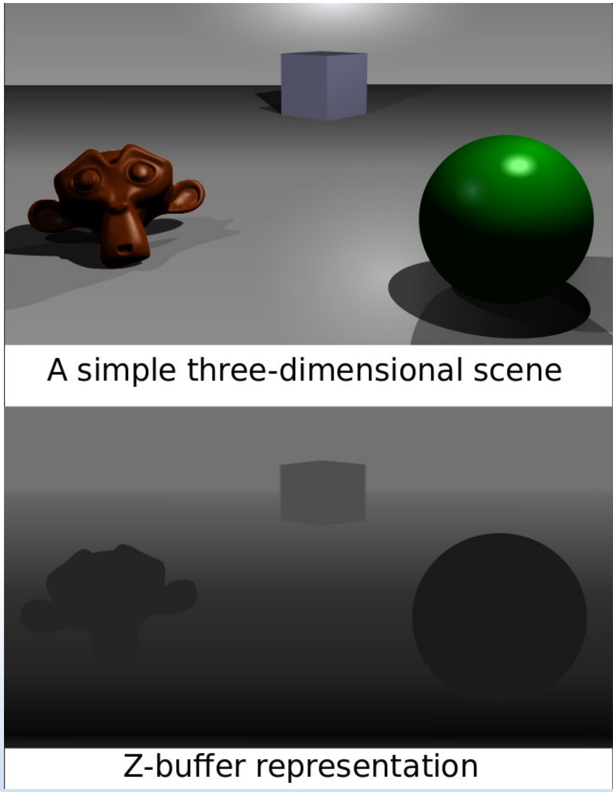


The virtual character is placed at the correct position, but occlusion by the physical character is not considered

Correct occlusion rendering creates a much more realistic impression without conflicting cues

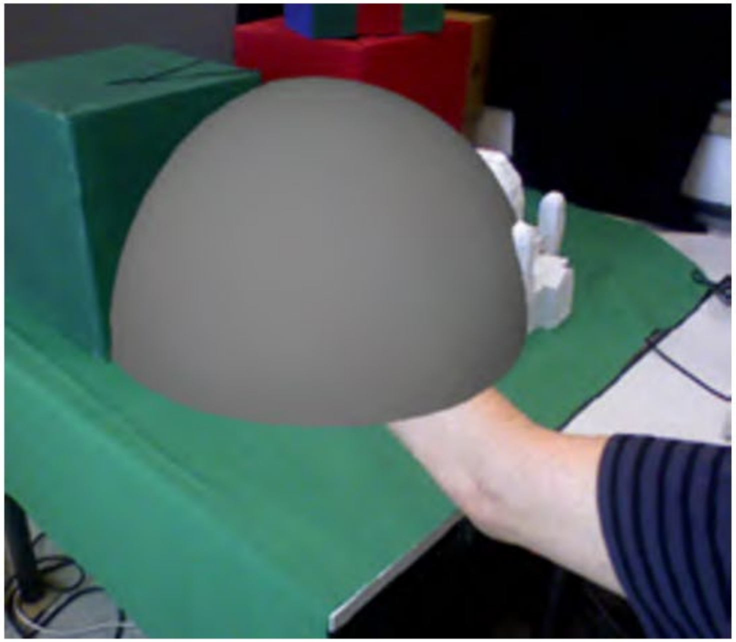
Visual Coherence

- Phantoms
  - ➢ Virtual representation of a real object, rendered invisibly
  - ➢ Occlusions handled by graphics hardware
    - Requires the z-buffer (depth buffer)
    - Phantom only rendered in the depth buffer
    - Establishes correct depth values for real object visible
    - Will occlude virtual objects

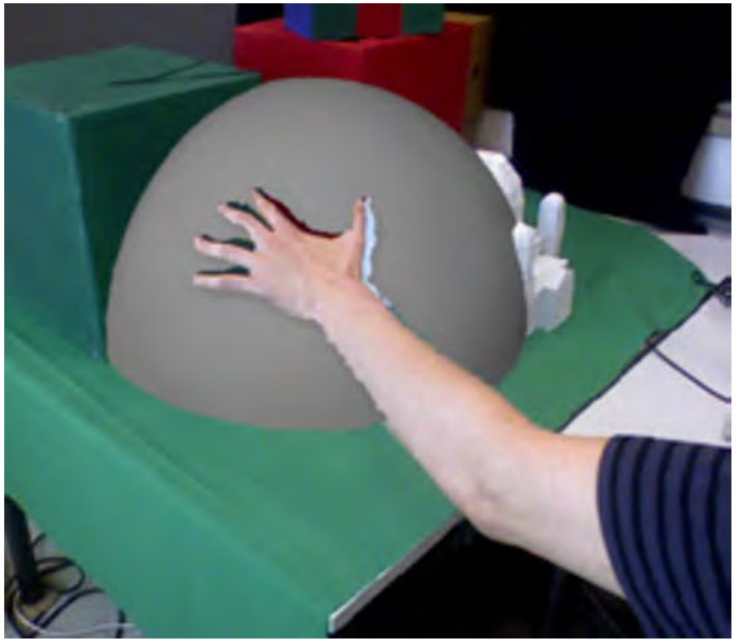


Visual Coherence

- Dedicated depth sensor
  - Depth maps obtained fully automatically in real-time
  - Depth image must be reprojected into camera's view space



The hand is incorrectly occluded by the virtual object



A depth sensor provides a simple way to resolve depth with real-world objects for every pixel at frame rate

Exam

- Question types
  - Multiple choice questions
  - Short answer questions

References

- Among others, material sourced from

  - S. Aukstakalnis, Practical Augmented Reality: A Guide to the Technologies, Applications, and Human Factors for AR and VR, Addison-Wesley
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  - R. Doerner, W. Broll, P. Grimm, B. Jung, Virtual and Augmented Reality: Foundations and Methods of Extended Realities, Springer
  - R. C. Stevens, Designing Immersive 3D Experiences, New Riders
  - http://en.wikipedia.org/wiki/