Chapter 2
Displays

Displays

- AR displays differ from normal displays in that they must combine virtual and real stimuli.
- In this chapter, we investigate the various options for such displays.
- There has been significant work in the area of augmentations via audio, whereas our other nonvisual senses—touch, smell, and taste—have received comparatively less attention with regard to AR.

- We will discuss desktop displays, head-mounted displays(HMD), handheld displays, projector-based displays, and stationary displays.

Multi-modal displays

- Audio displays
- Haptic displays
- Olfactory displays
- Gustatory displays

Visuo-Haptic Registration

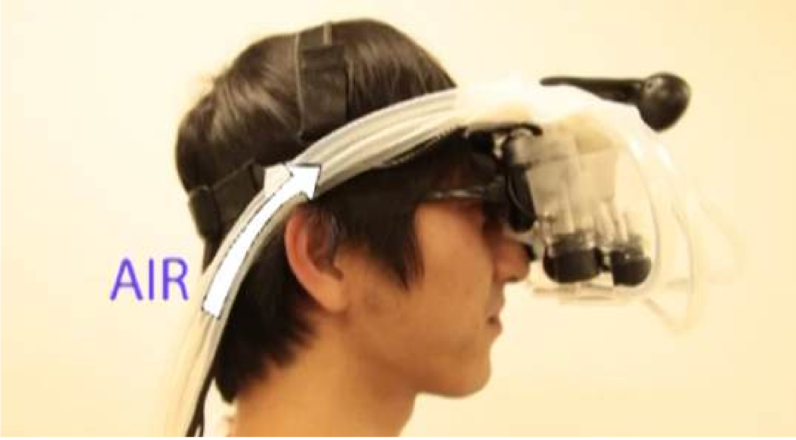
The stylus of a PHANToM haptic device is highlighted by visual AR

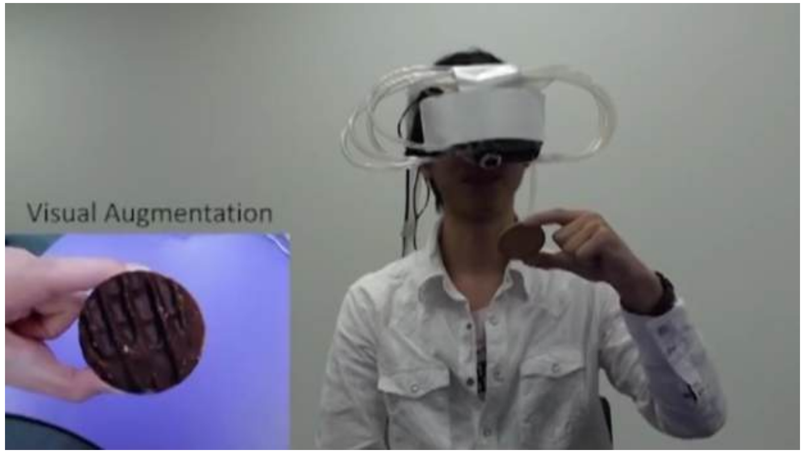
Image: Ulrich Eck and Christian Sandor

Olfactory Display

MetaCookie: An olfactory display is combined with visual augmentation of a plain cookie to provide the illusion of a flavored cookie (chocolate, in the inset).

Image: Takuji Narumi





Visual Displays

- See-through displays
  - Optical see-through
  - Video see-through
- Spatial Augmented Reality

Video-see through

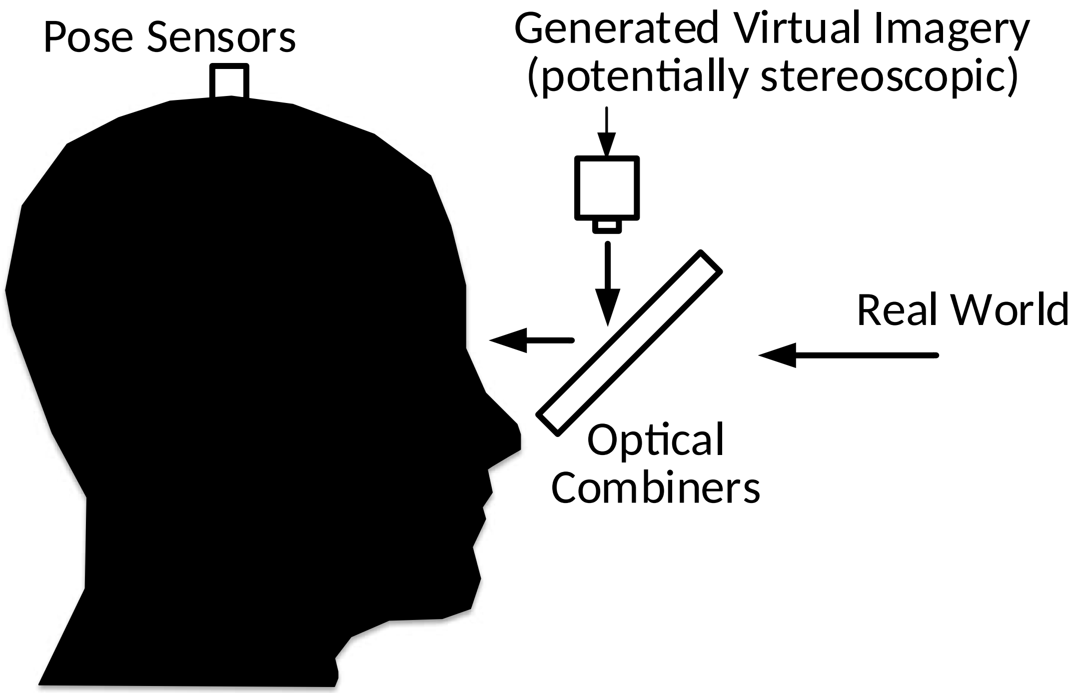
- Video-see through systems present video feeds from cameras inside head-mounted devices.
- This is the standard method that phones for example use AR with.
- This can be useful when you need to experience something remotely: a robot which you send to fix a leak inside a chemical plant; a vacation destination that you’re thinking about.
- This is also useful when using an image enhancement system: a thermal imagery, night-vision devices, etc.

Optical see-through

- Optical see-through systems combine computer-generated imagery with “through the glasses” image of the real world, usually through a slanted semi-transparent mirror.
- If you are in a mission-critical application and you’re concerned what happens should your power fail, an optical see-through solution will allow you to see something in that extreme situation.
- If you are concerned about the utmost image quality, portable cameras and fully-immersive head-mounted display can’t match the “direct view” experience.

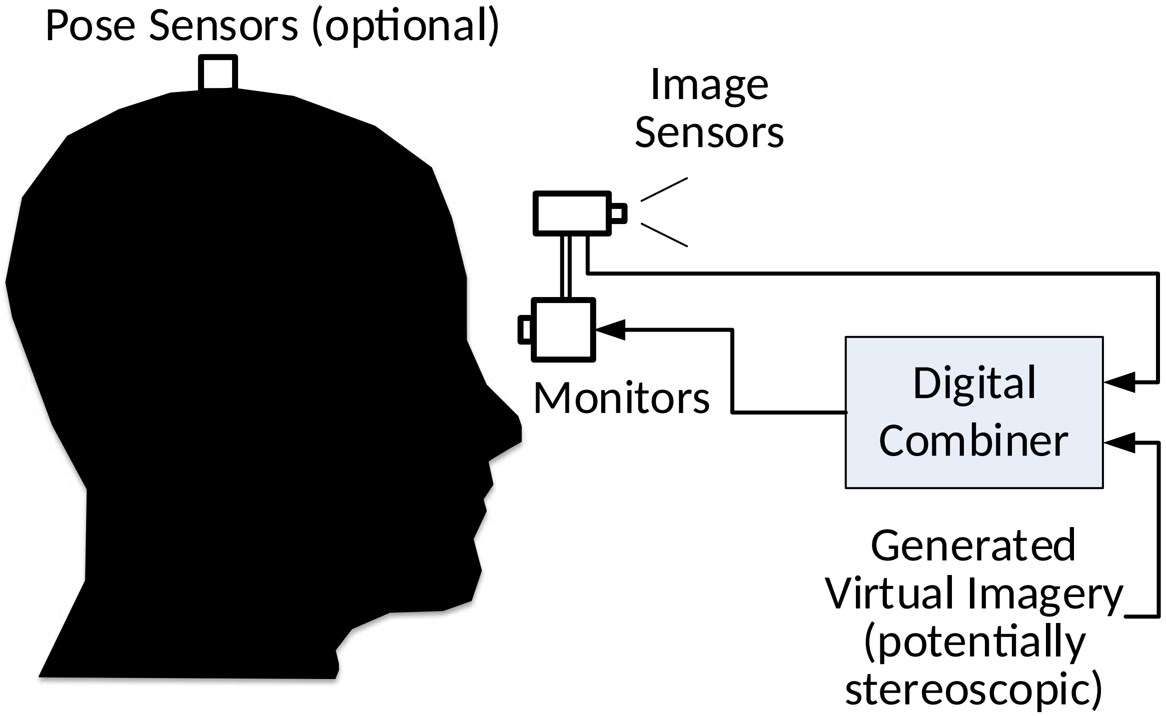
Optical See-Through Displays

An optical see-through display uses an optical element to combine a user's view of the real world with computer-generated images

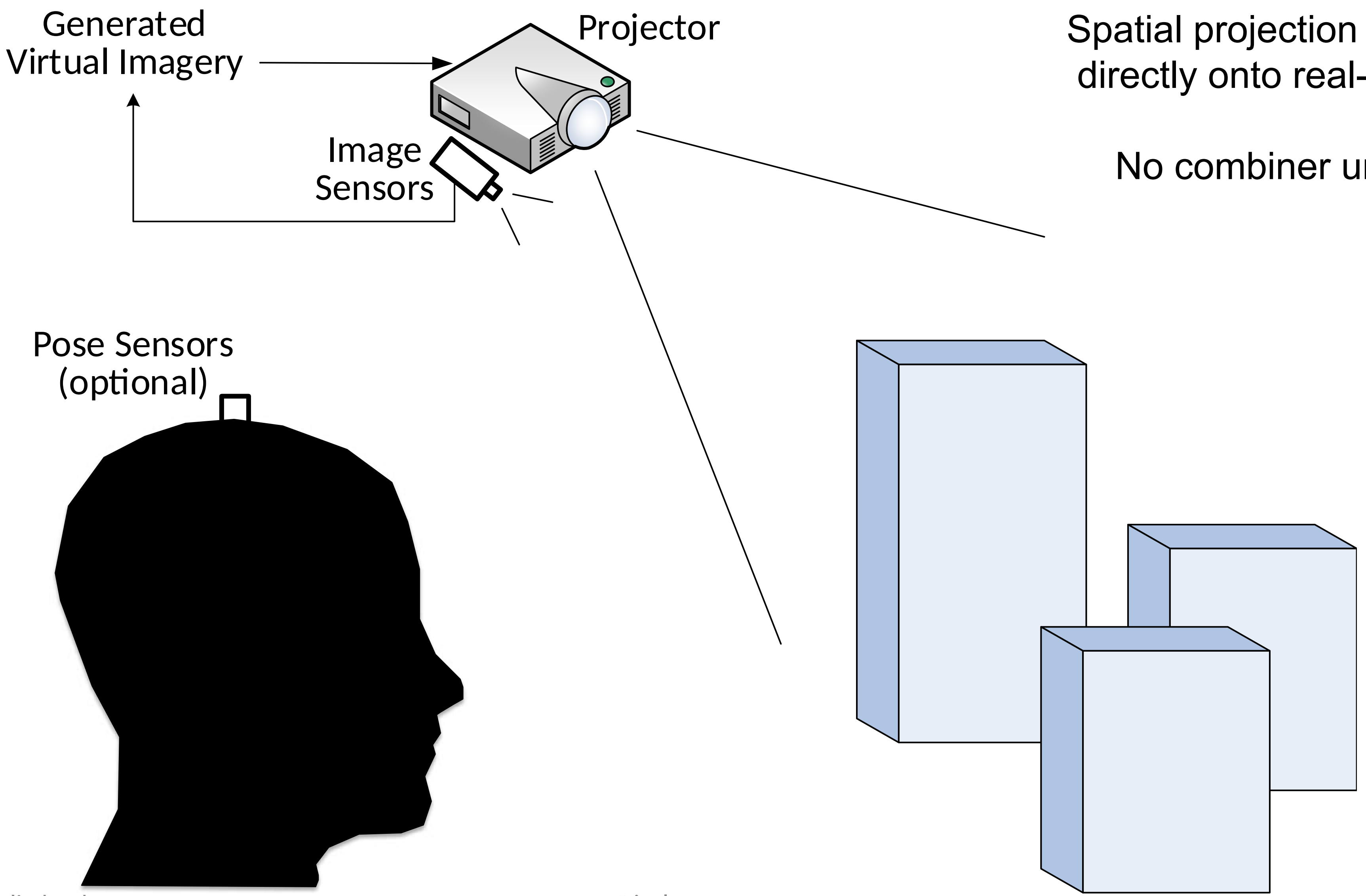


Video See-Through Displays

A video see-through display captures the real world with a video camera and electronically modifies the resulting image using a graphics processor to deliver a combined real + virtual image to the user



Spatial Augmented Reality



Spatial projection casts images directly onto real-world objects

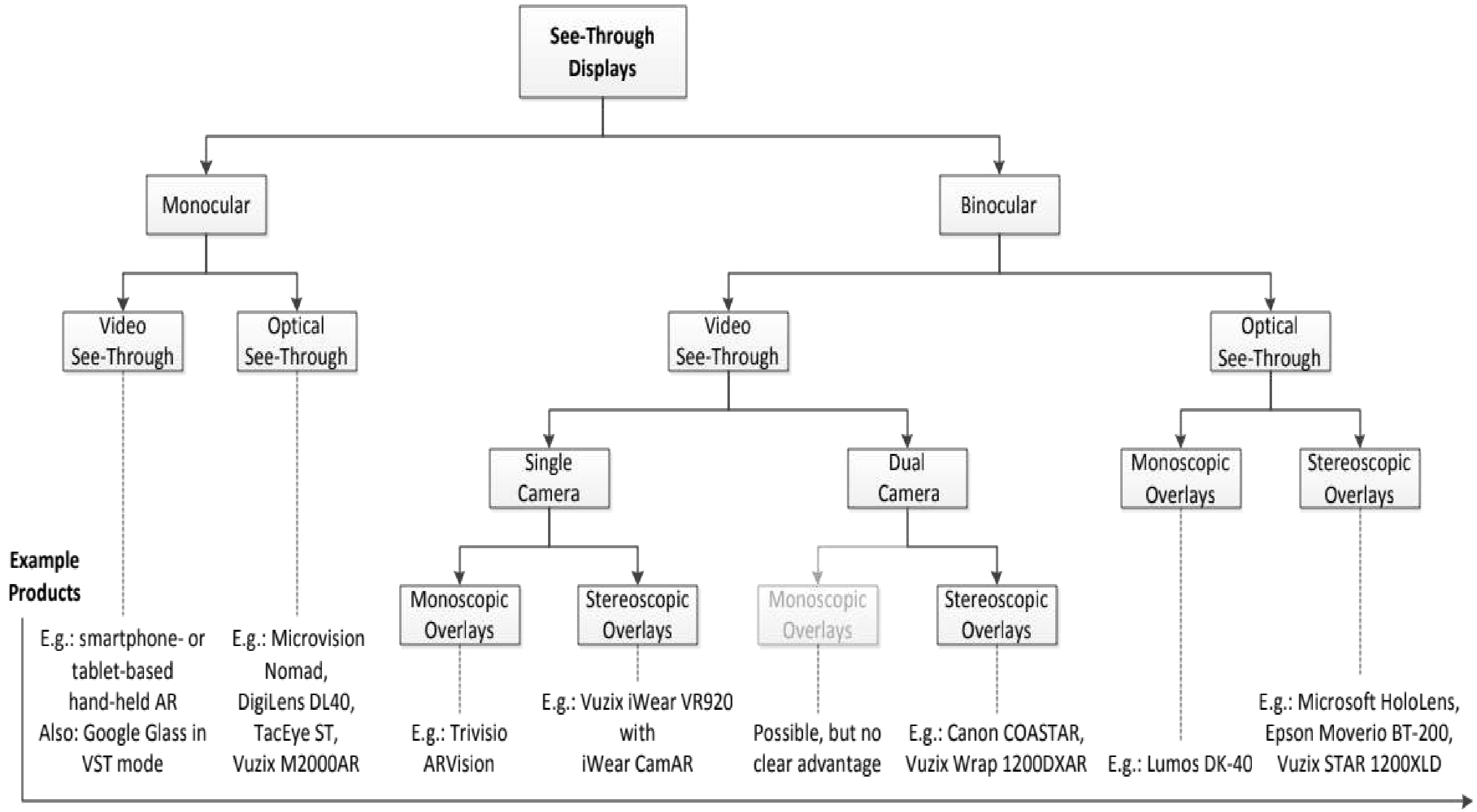
No combiner unit is required

Non-See-Through Displays

The Rift is a binocular HMD intended for immersive computer games. It is under development by Oculus, which was acquired by Facebook in 2014 for $2 billion, raising the interest in HMD technology worldwide

The Samsung Gear VR is an example of a head-mounted display that uses a smartphone (here: Galaxy S6) as the main I/O and computational engine

See-Through Display Taxonomy



- A monocular HMD presents images to only one eye.
- A monocular display can be used for AR, but this approach is not very popular, because it lacks immersion.
- A bi-ocular display presents the same image to both eyes, resulting in a monoscopic impression.
- This approach is sometimes used for VST HMD, because only a single camera stream is required and sensing and processing requirements are minimized.
- Finally, a binocular HMD presents a separate image to each eye, resulting in a stereoscopic effect.
- Binocular displays obviously deliver the highest-quality AR among these choices, but have a significantly increased technical cost.
- They require two displays or, alternatively, a wide-format single display that can be appropriately split using two optical elements

What is the difference between haptic vs tactile sensing?

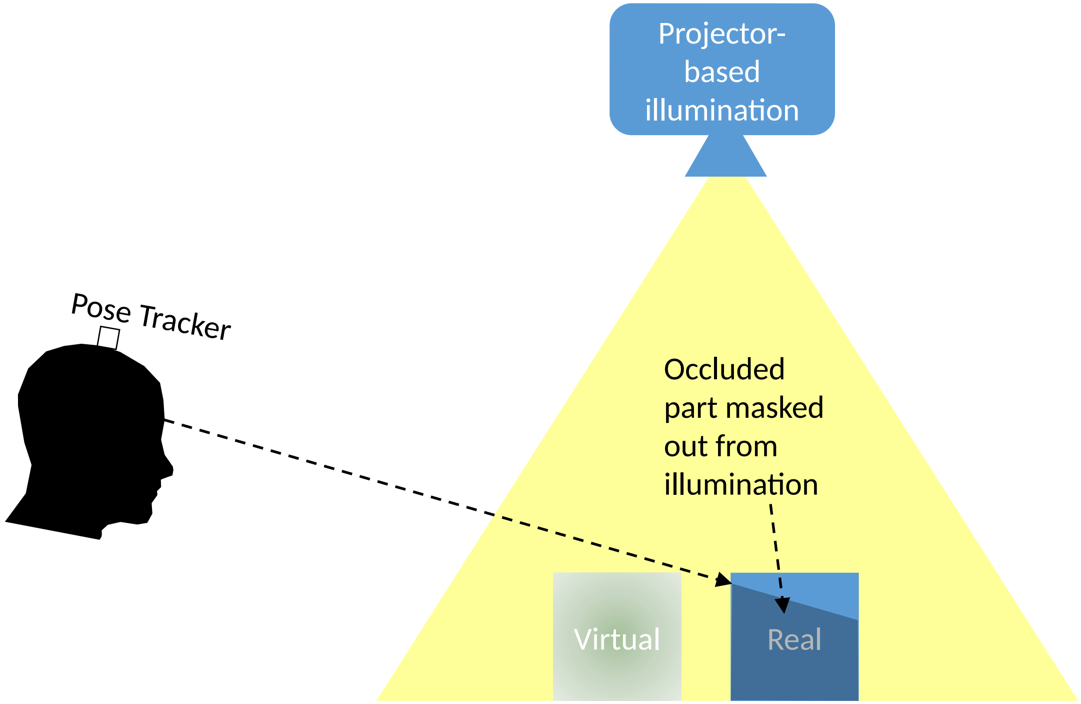
- Haptic sensing relates to any sense of touch and is a combination of two sensing abilities. One part of haptic sensing is tactile sensing, which is the detection of force on the skin surface, whereas the other part of haptic sensing is kinesthetic, meaning the sensing of body movement and muscle strength.
- Tactile sensing engages directly with an object in order identify object features like edges, holes, surface friction and overall ensuring a good grip of an object. This allows the avoidance of dropping, bruising or other means of damaging and object.

Occlusion

- Occlusion between virtual and real objects is an important cue to convey the scene structure.
- While correct occlusion among real objects is naturally given, and correct occlusion among virtual objects is easily achieved by means of a z-buffer.
- Achieving correct occlusion of virtual in front of real, or vice versa, requires special consideration.

Occluder Shadows

The occlusion shadows technique uses controlled illumination to blank out those portions of the real world where opaque graphics should be visible



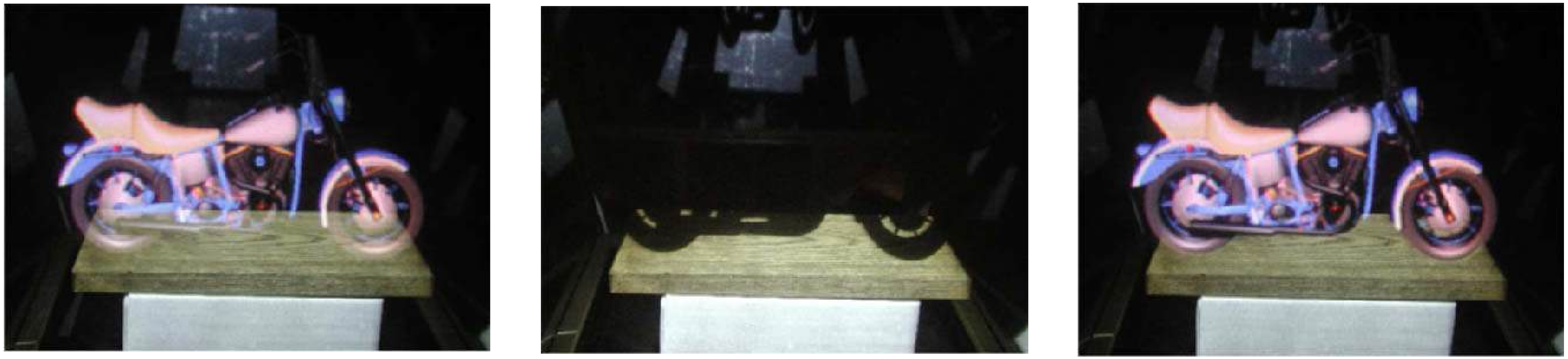
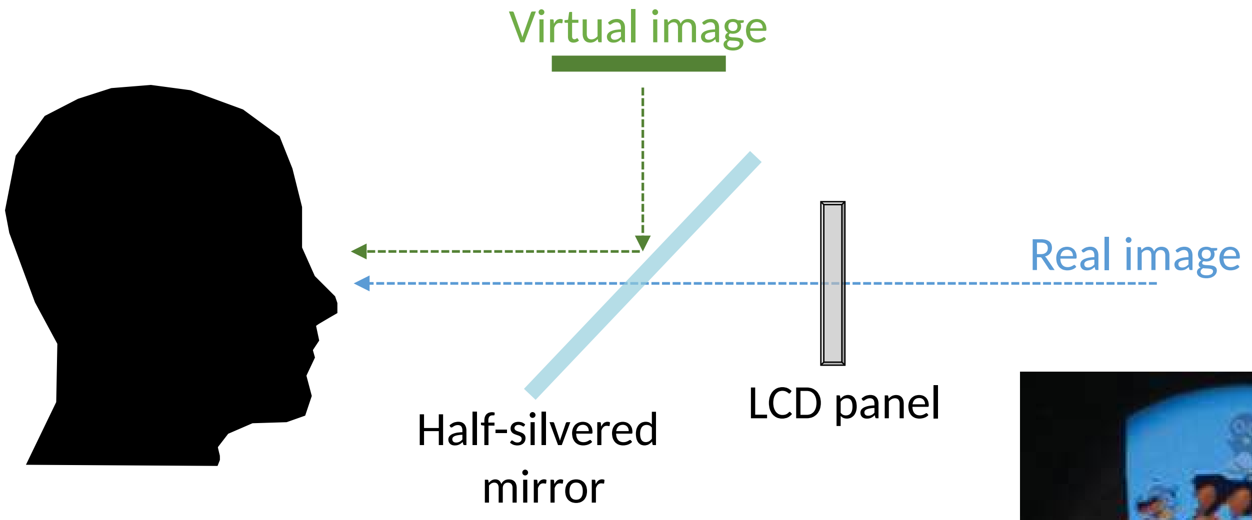


Image: Oliver Bimber

Optical See-Through with Real Occlusion



The ELMO HMD uses an additional LCD panel between display and optical combiner for pixel-wise blocking of occluded real-world objects

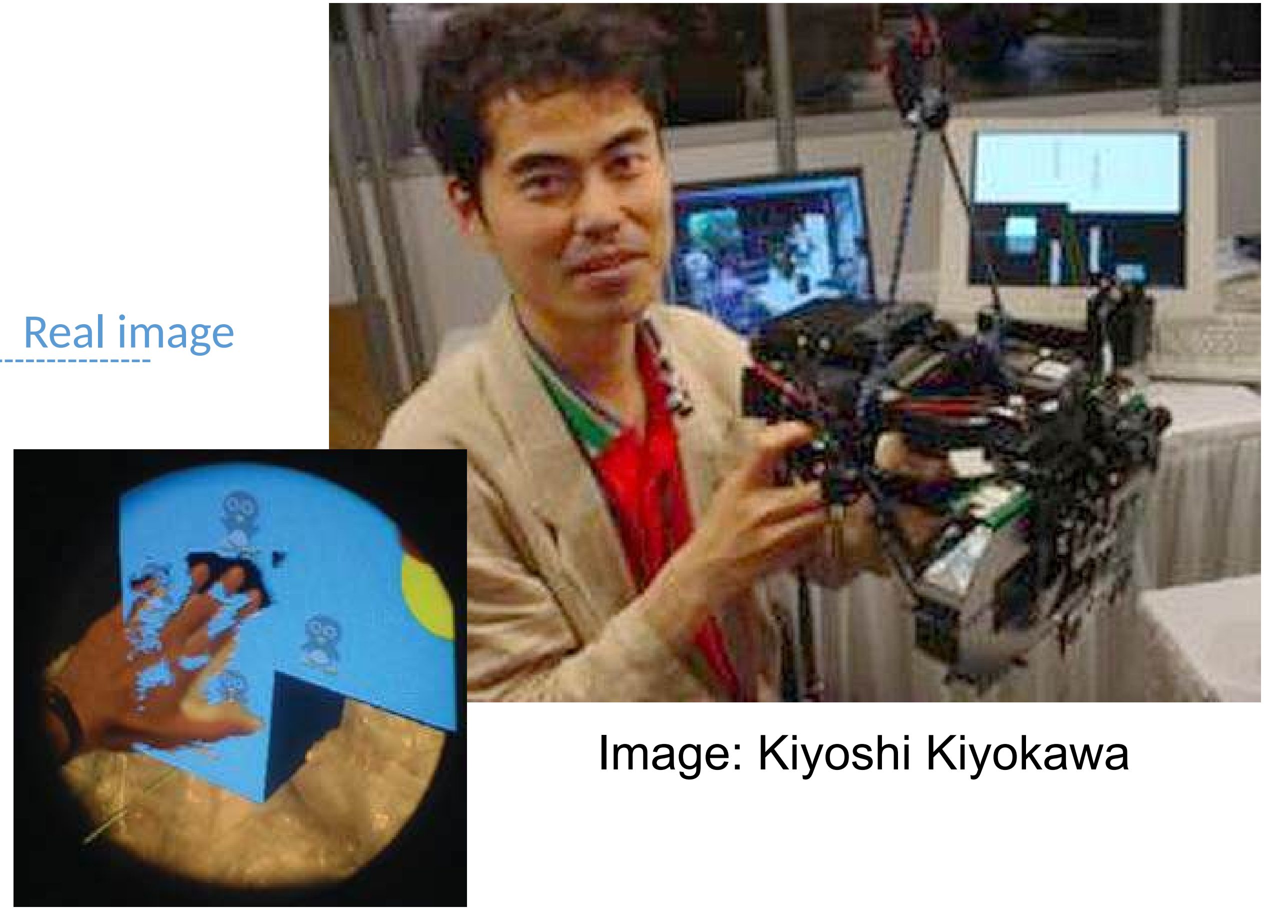


Image: Kiyoshi Kiyokawa

Image Quality Comparison

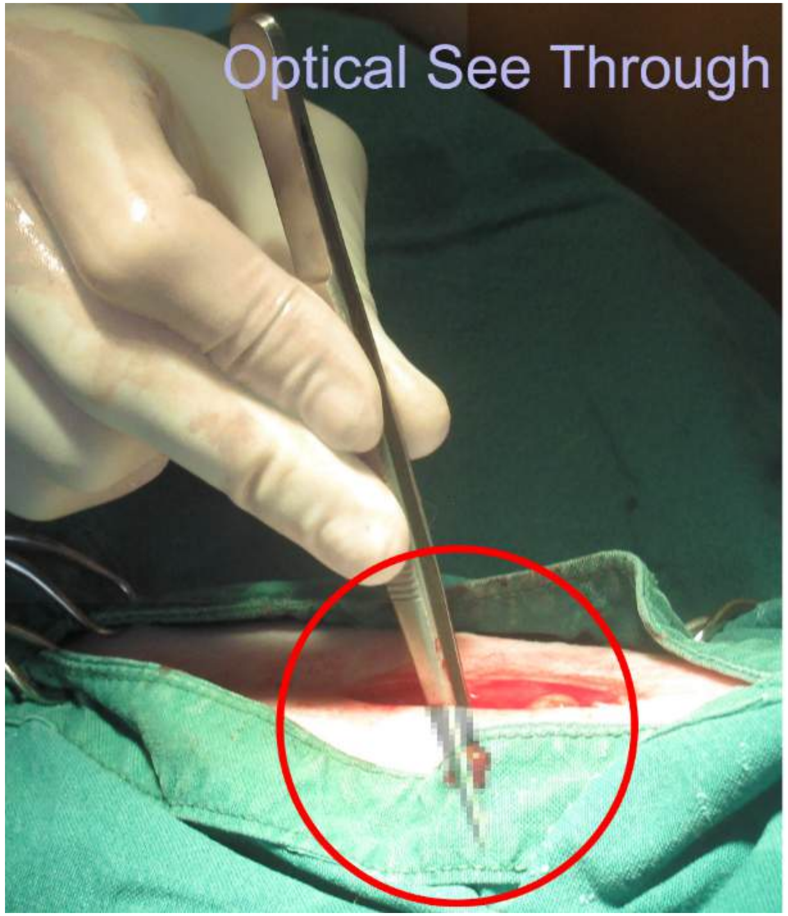
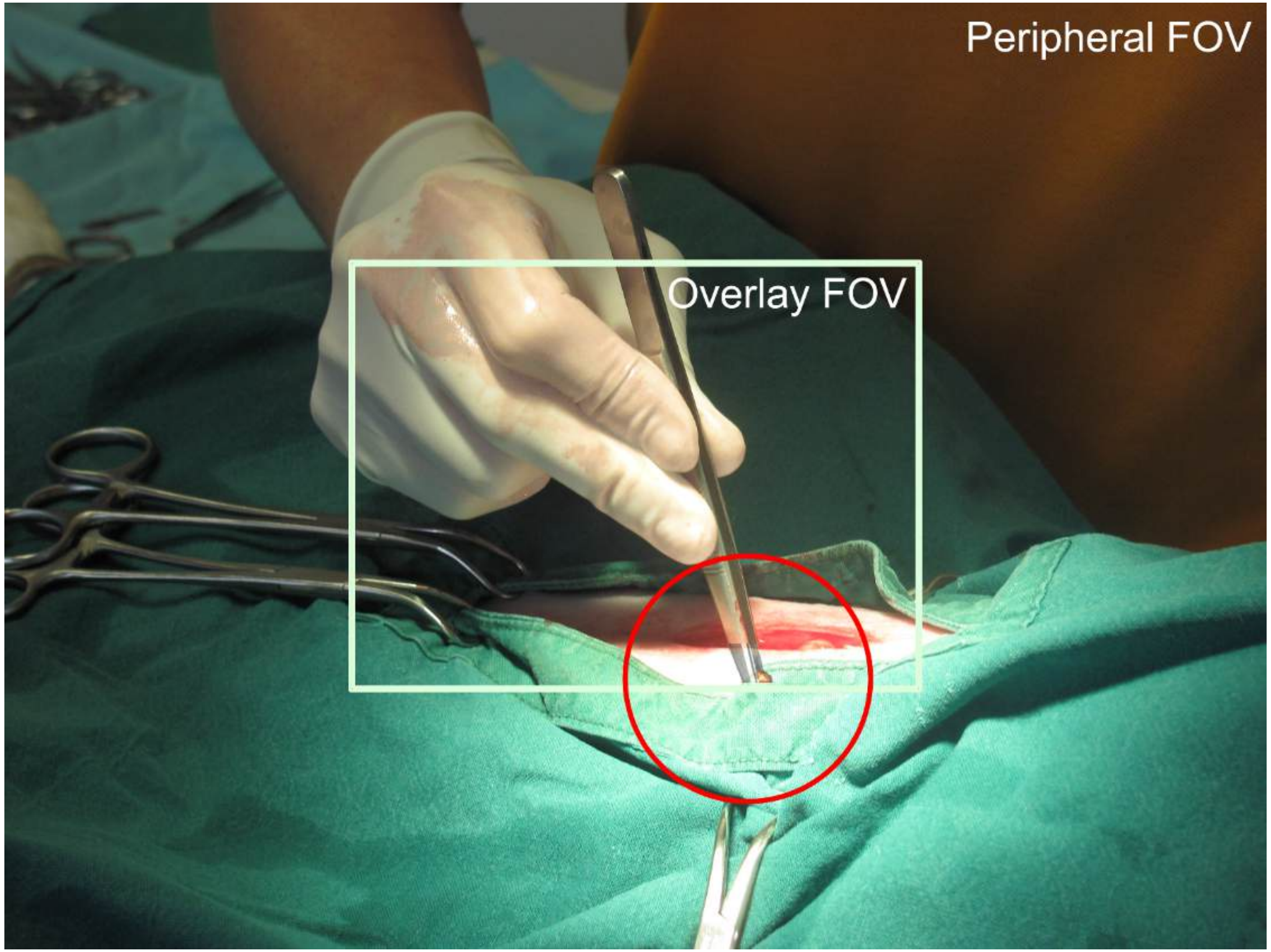


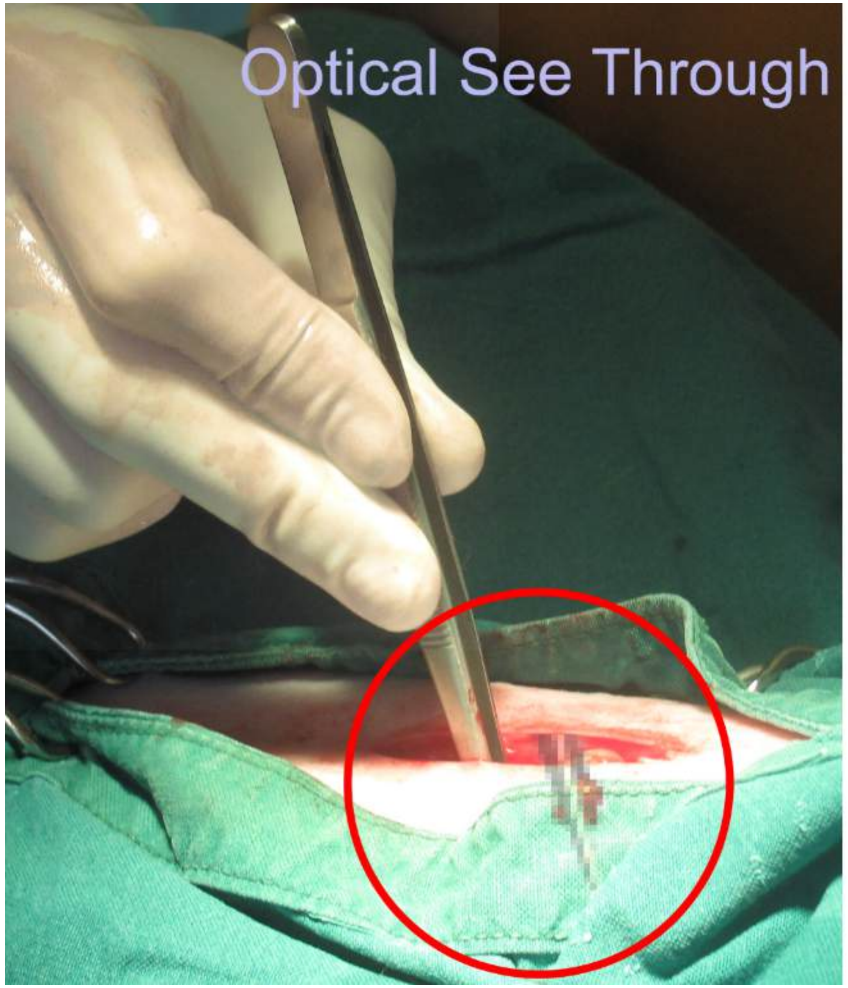
Image quality in optical see-through displays is higher for the real world, but generally inconsistent. The (normally occluded) tips of the pincers are rendered as augmentations. This illustrative mockup shows exaggerated resolution artifacts for the augmentation part on the left and the entire image on the right

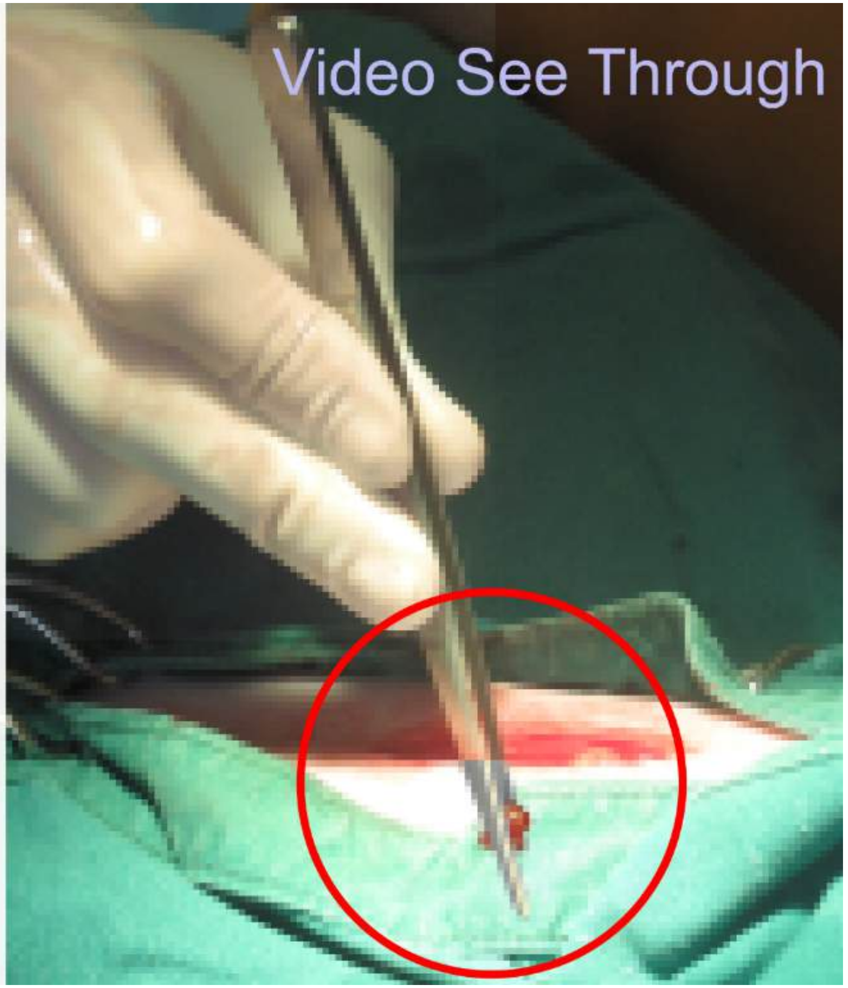
Field of View Comparison



AR systems typically have a limited field of view, resulting in an “overlay FOV” area, in which augmentations are visible, and a “peripheral FOV” area, in which they are not

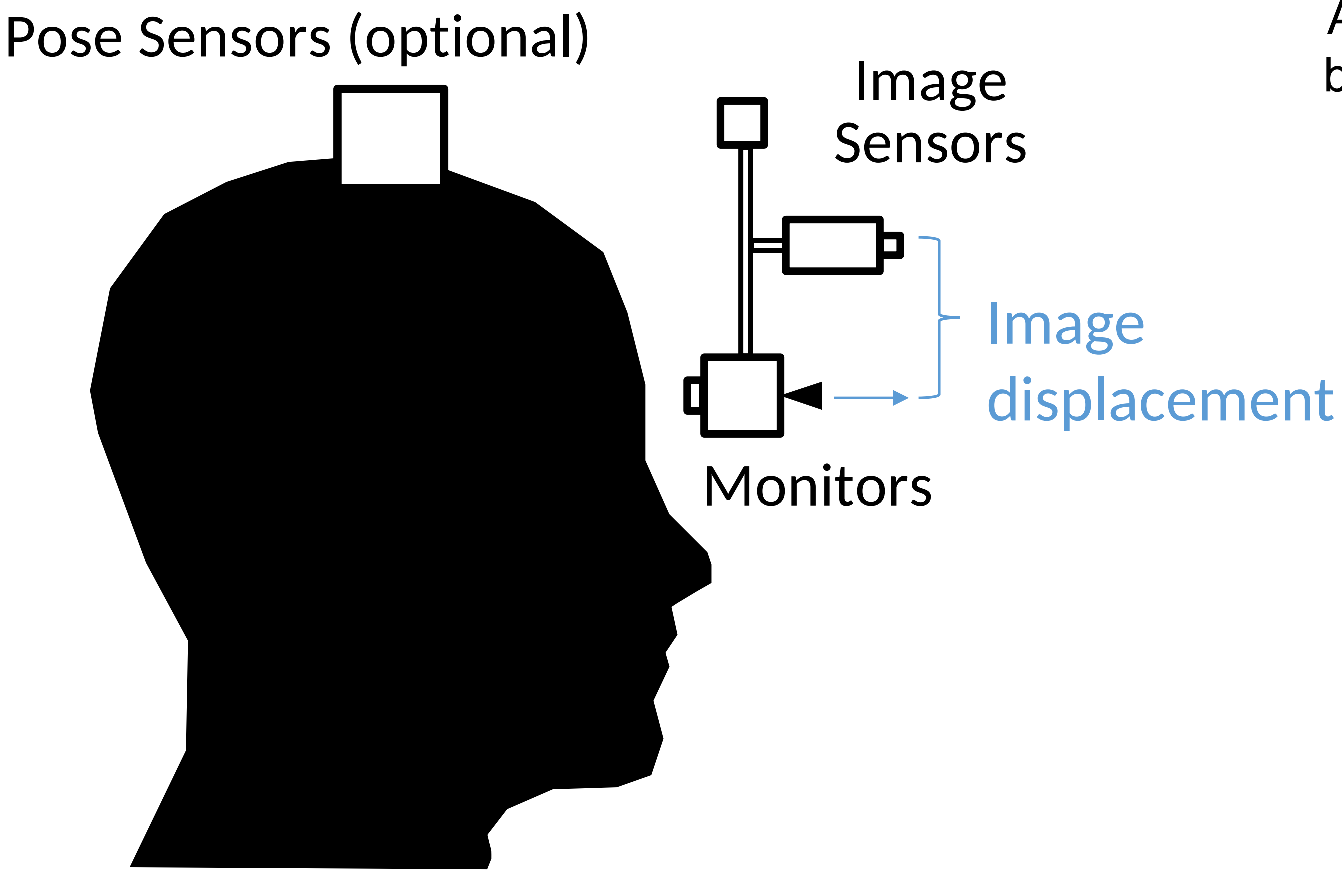
Registration Comparison





Insufficient eye-to-display calibration can lead to distracting offsets. In video see-through displays, pixel-accurate registration is easier to achieve

Image Displacement



In general, an offset between the user's viewing direction and the camera's optical axis is not desirable

A camera pointing diagonally downward from behind the display captures an AR interaction space centered on the user's hands

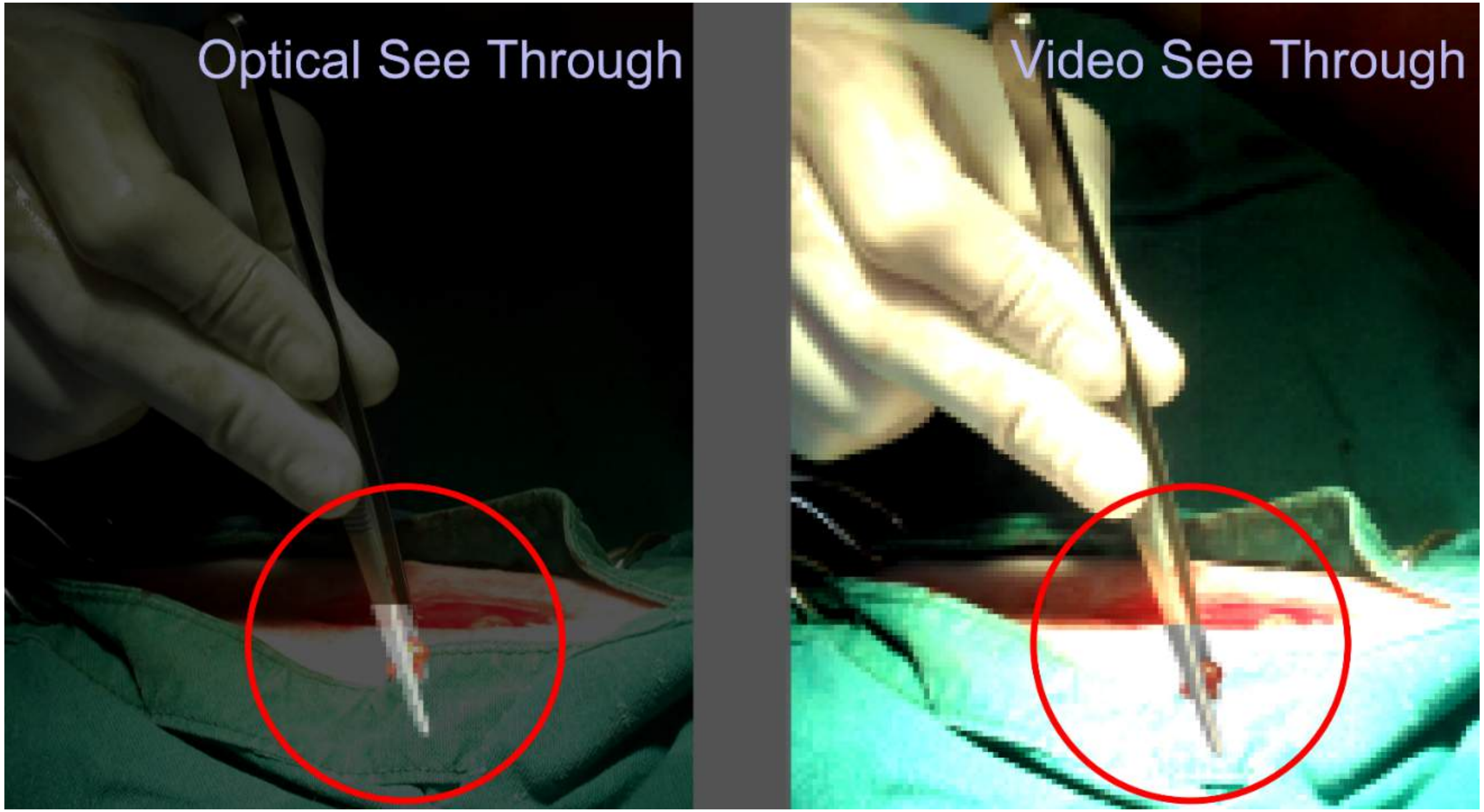
Image: Morten Fjeld

Stereo Video See-Through Display

COASTAR was the first commercial parallax-free video see-through HMD.

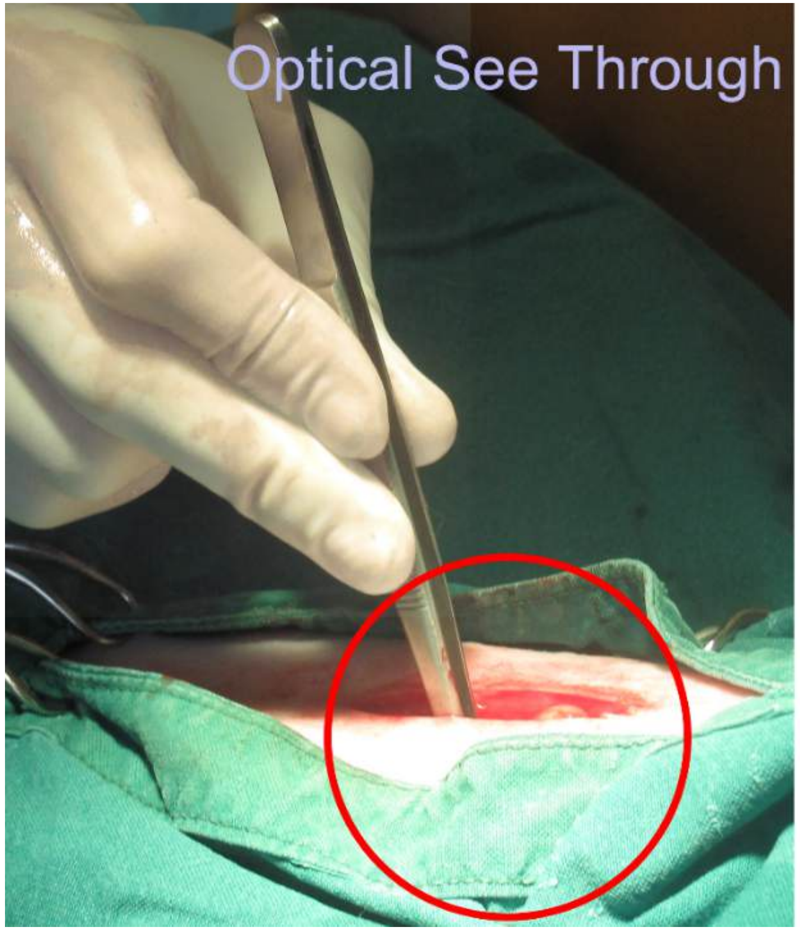
Image: Hiroyuki Yamamoto

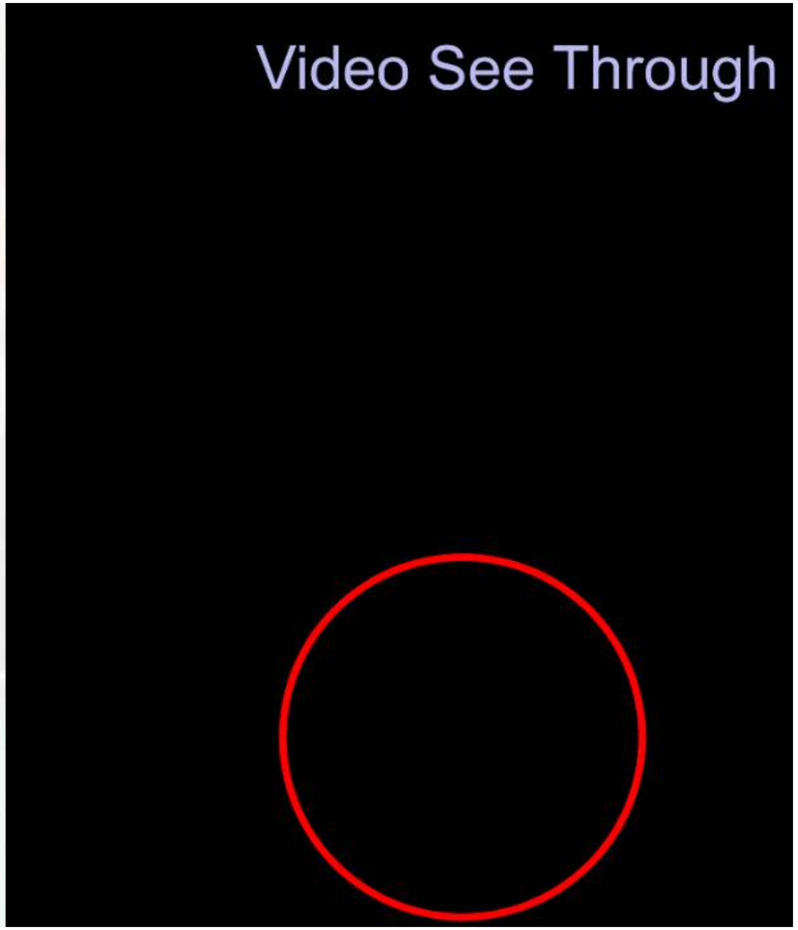
Brightness Comparison



Optical see-through displays depend on the transparency of the optical combiner, while video see-through displays can change brightness and contrast arbitrarily, as long as the display itself can deliver sufficient contrast. On the right, the contrast limit is reached, and some real-world detail is lost.

Failure Comparison



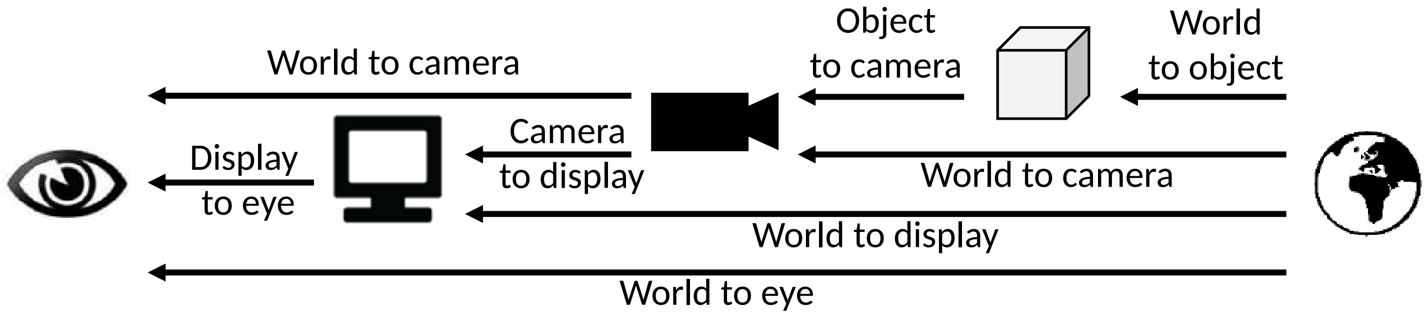


If the display fails, video see-through will not allow the user to see anything.

This can be dangerous in critical situations such as surgery or piloting an aircraft.

Display Coordinate Systems

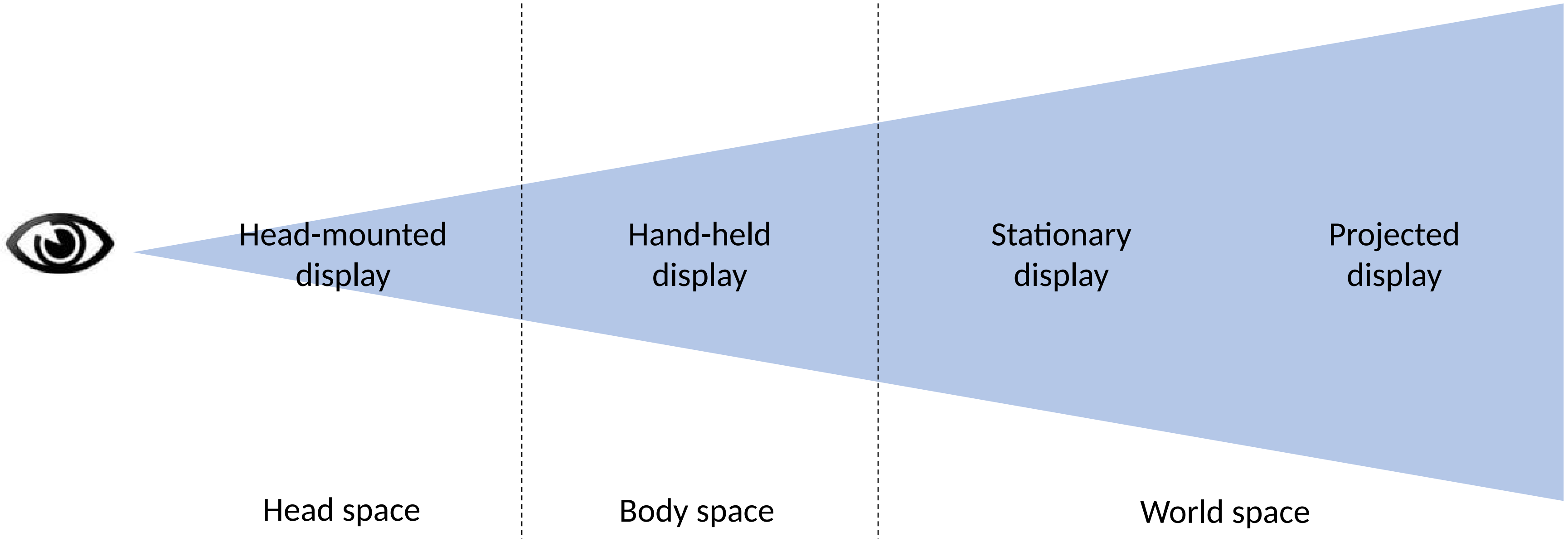
The spatial model of most AR displays can be defined as the spatial relationship of up to five components: the user's eye, the display, the camera, an object to be augmented, and the world.



Each coordinate transformation can be fixed and calibrated, tracked dynamically, or left unconstrained.

Display Space Taxonomy

AR displays can be categorized according to the distance from eye to display



Display Mounting

Helmet-mounted
Rockwell Collins SimEye

Clip-on
Google Glass

Visor Display
Epson Moverio

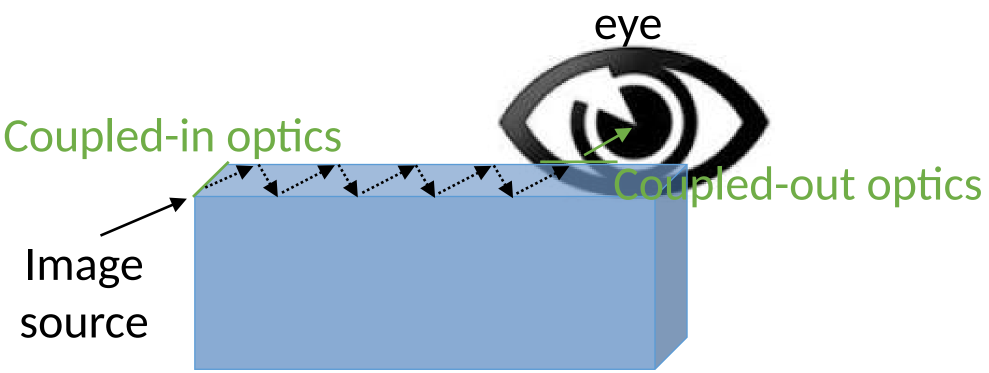
Optical See-Through Examples

Sony Glasstron LDI-D100B,
retrofit on a custom mount as part of the
Columbia MARS system

Image: Columbia University

See-Through Display with Optical Prism

Image: Jens Grubert

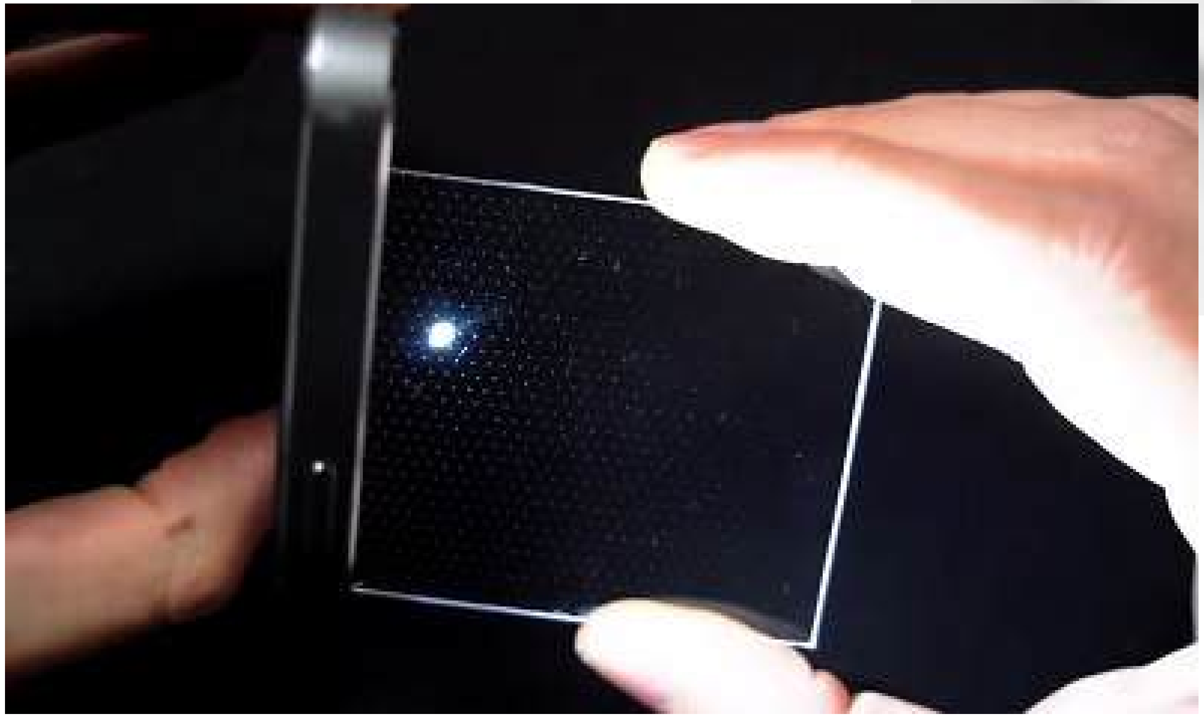


The Light-Guide optical element technology by Lumus propagates an image through a special optical prism

Pinlight Displa

Pinlight display prototype

Panel with a dense array of point light sources



View through
the display

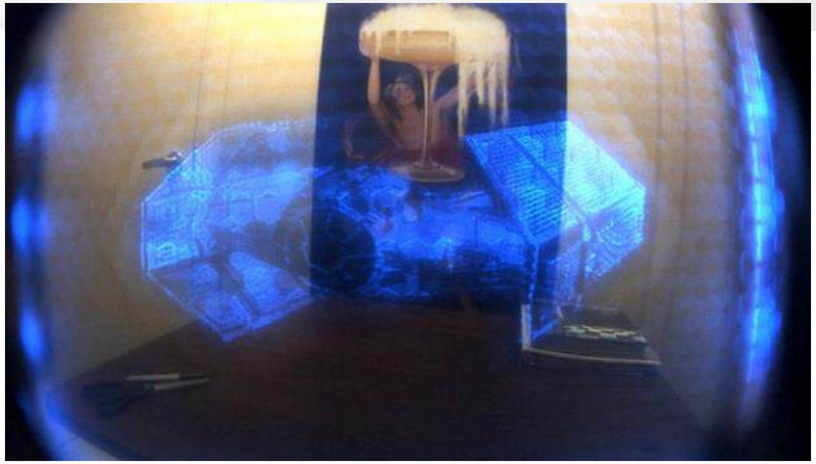
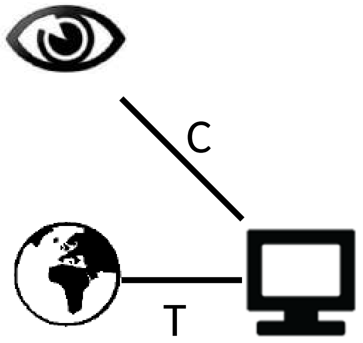
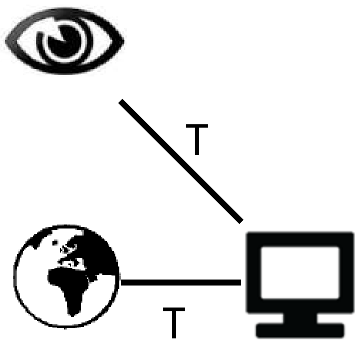


Image: Andrew Maimone, UNC Chapel Hill

Optical See-Though

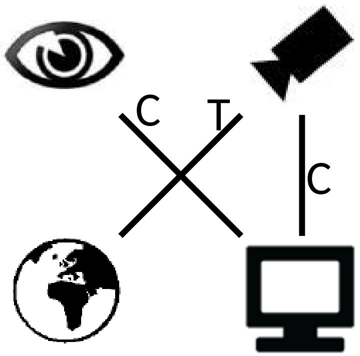


Without eye tracking

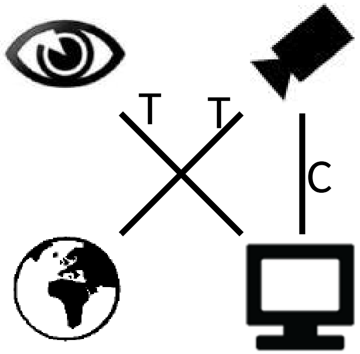


With eye tracking

Video See-Though



Without eye tracking



With eye tracking

Video See-Through with Half-Silvered Mirror

Example of VST HMD using cameras above the eyes with mirror optics.

Design by Andrei State, 2005.

Image: Andrei State, UNC Chapel Hill

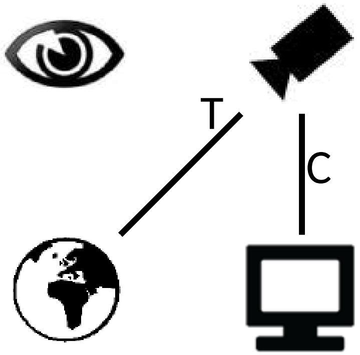
Oculus Rift with Stereo Video See-Through

The AR-Rift, a modified Oculus Rift with two video cameras

Image: William Steptoe

Hand-Held Display

Image: Daniel Wagner



A handheld AR display can be built from an unmodified smartphone or tablet computer

User-Perspective Hand-Held Display

Handheld display with device perspective

Handheld display with user perspective

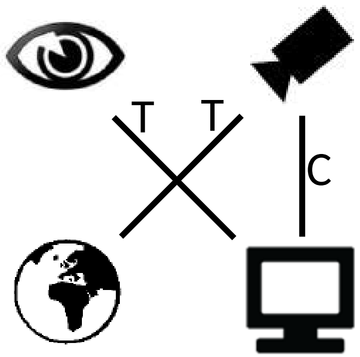
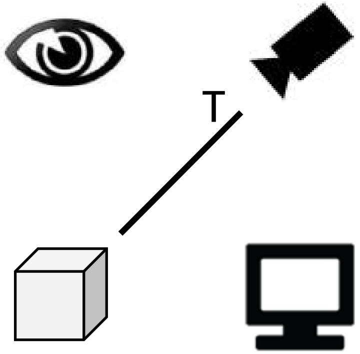
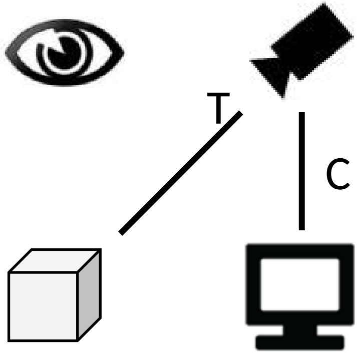


Image: Domagoj Baričević

Desktop AR



A desktop AR display can be built using the eyeball-in-hand metaphor, in which the camera is tracked and its recordings are fed to the display. In the application depicted here ([Lee and Höllerer 2007]), we are tracking the camera relative to an object (user’s hand), which is recognized as a marker and subsequently augmented.



Often, the camera is stationary, covering a working volume, in which augmentations can occur. Again, we are tracking the camera relative to a moving object (checkerboard pattern)

Video-See Through Magic Mirror

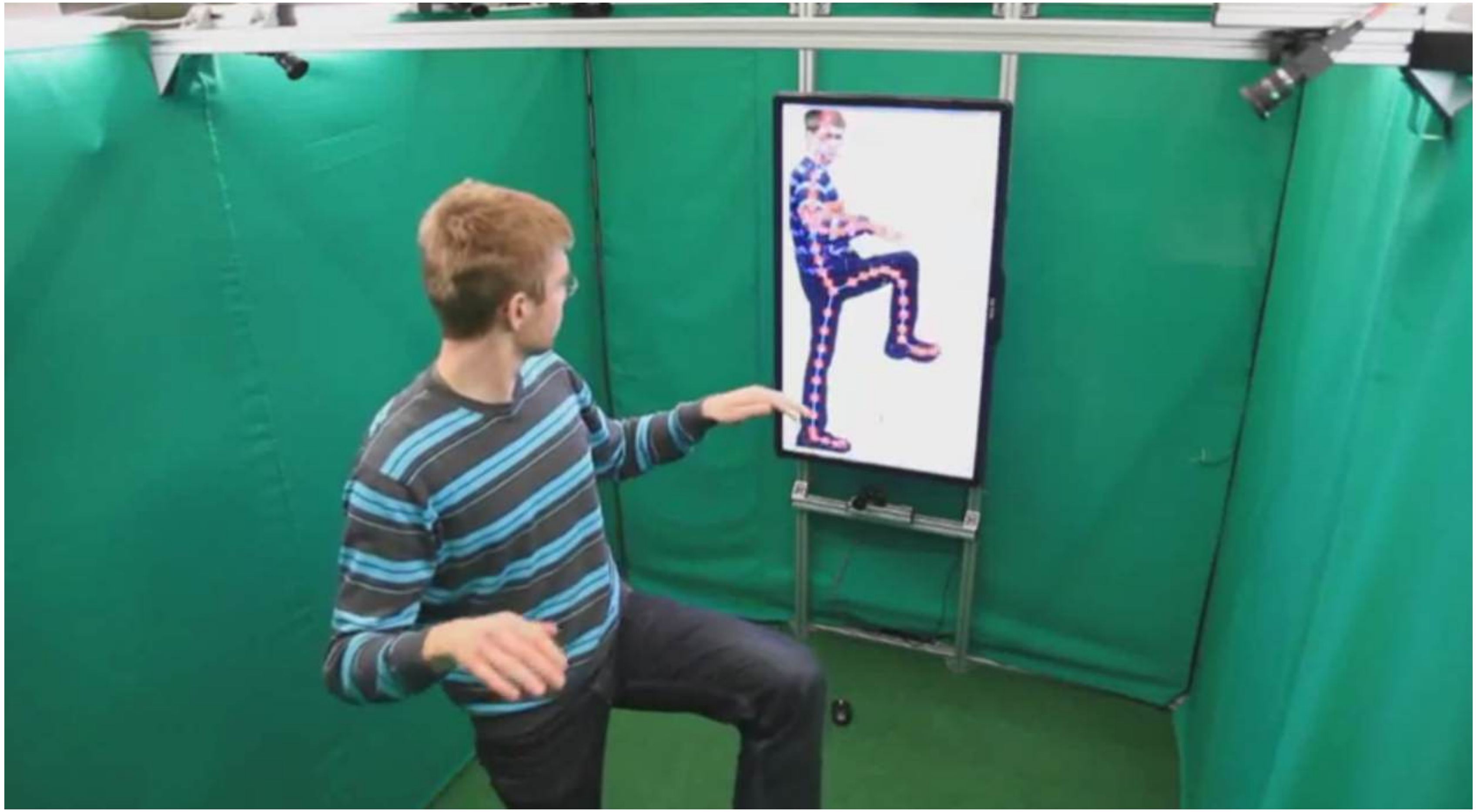
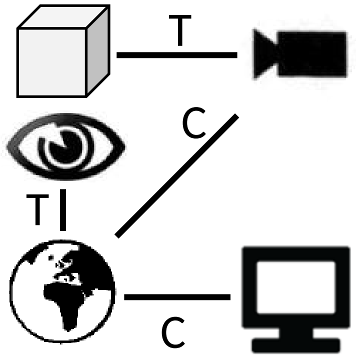
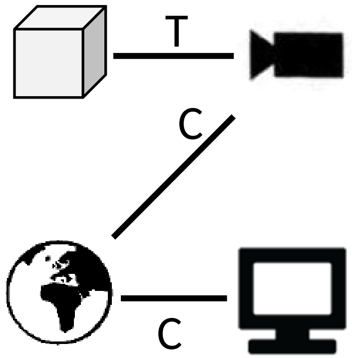


Image: Matthias Straka and Stefan Hauswiesner

The user (=box) must be tracked with respect to the camera.



Display always shows the user, independent of viewing angle.

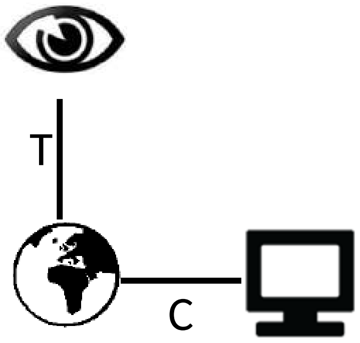


Display behaves like real mirror.

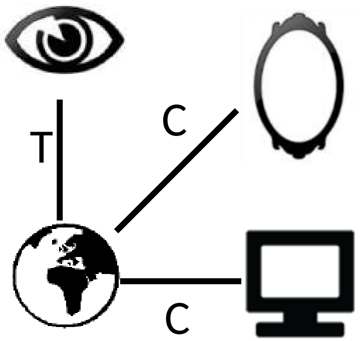
Optical See-Through Magic Mirror

Andy Wilson of Microsoft Research showing the HoloFlector

Image: Microsoft Research



Virtual Showcase



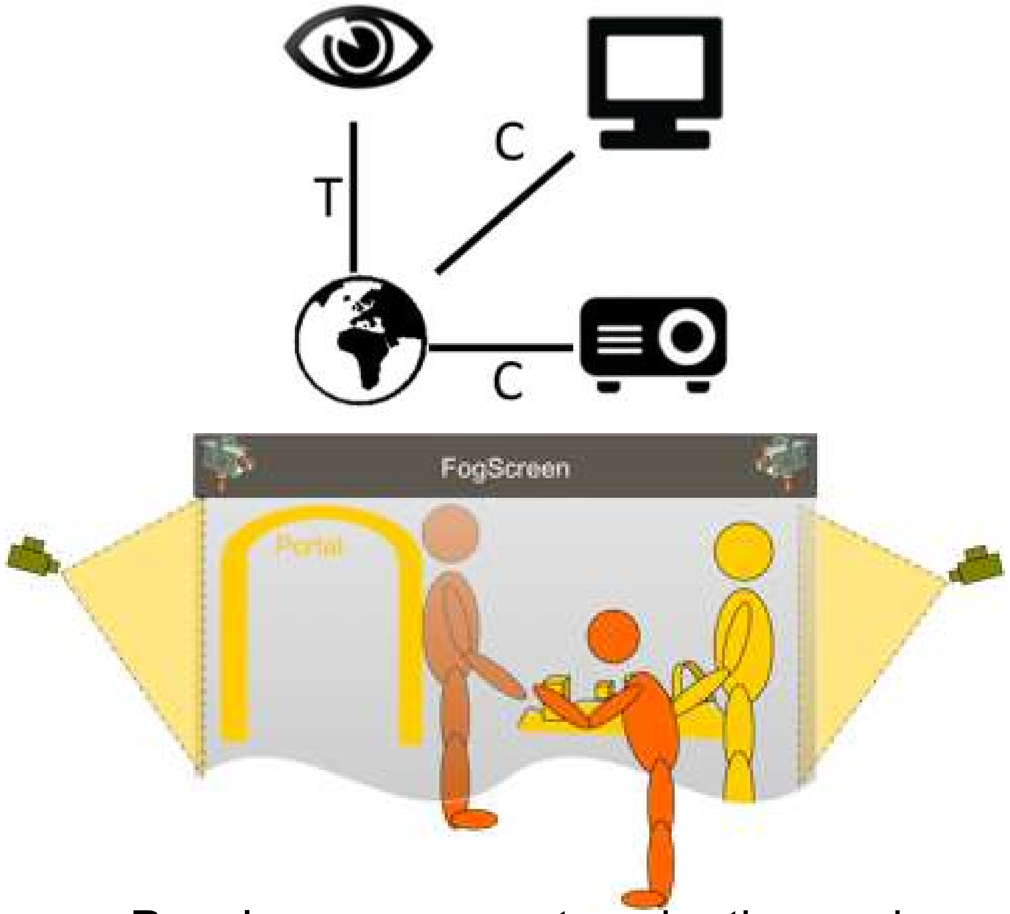
The Virtual Showcase is a stationary optical see-through display intended for exhibitions, museums, and showrooms

Image: Oliver Bimber

Transparent Display

Samsung Transparent Smart Window display, showcased at CES 2012

Immaterial Display



People can augment each other and interact through the FogSscreen

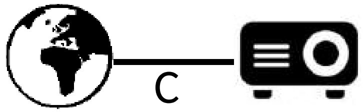
Dual-sided interactive FogScreen

Two FogScreens in an L-shaped configuration produce a depth-fused 3D rendering for a tracked observer

Spatial Augmented Reality

Spatial AR can be used to turn generic objects into textured models

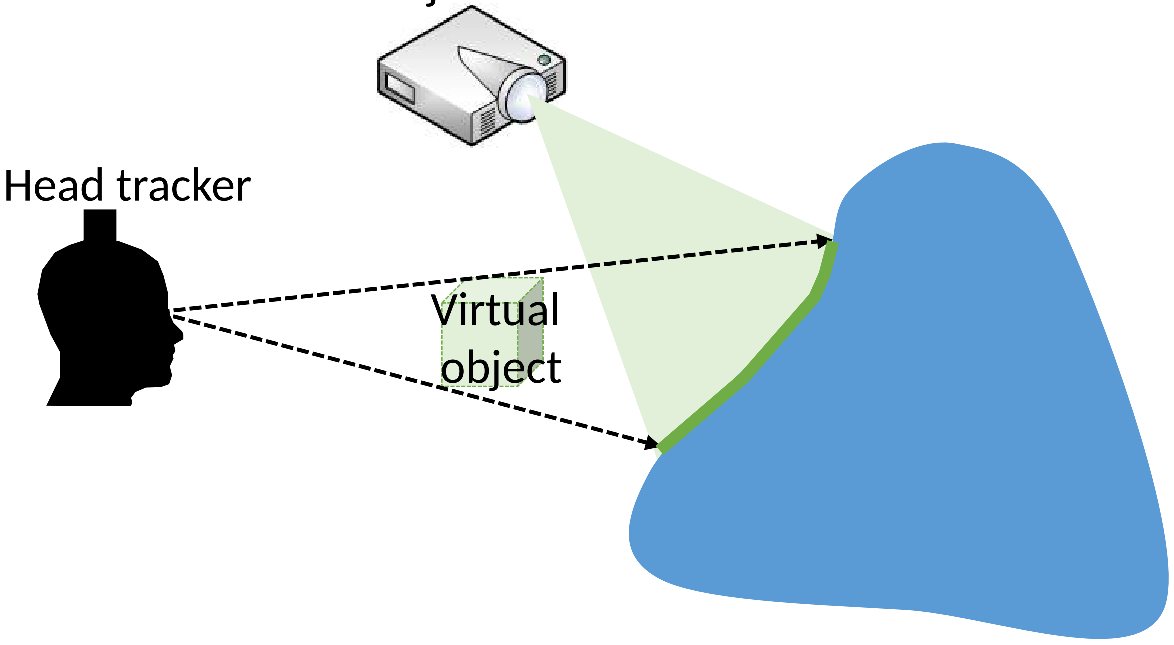
Image: Michael Marner

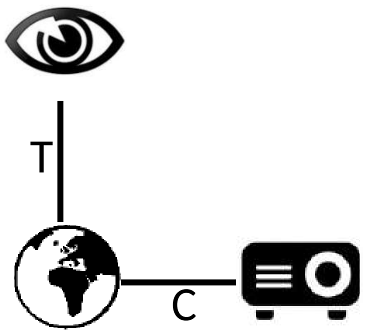


View-independent spatial AR

View-Dependent Spatial Augmented Reality

View-dependent spatial AR requires tracking the user, but can present free-space 3D objects





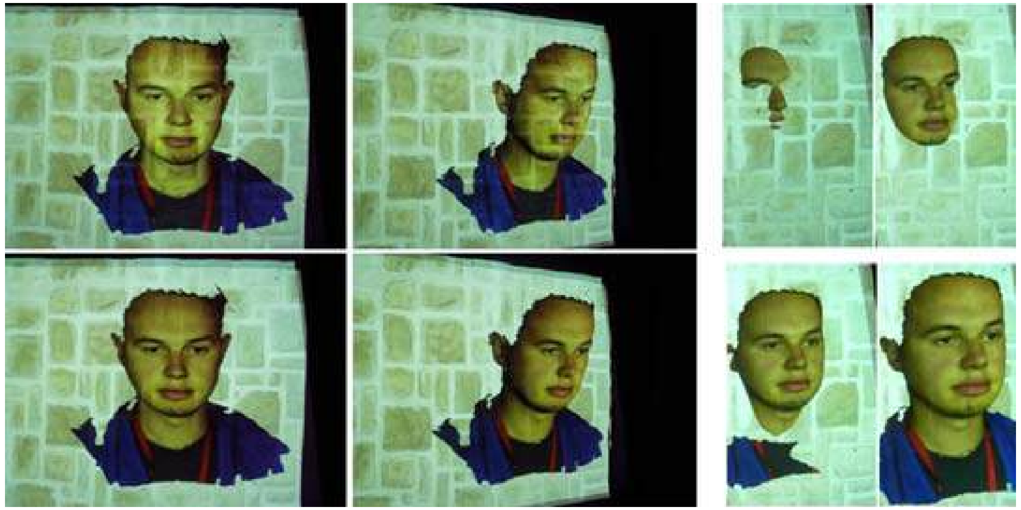
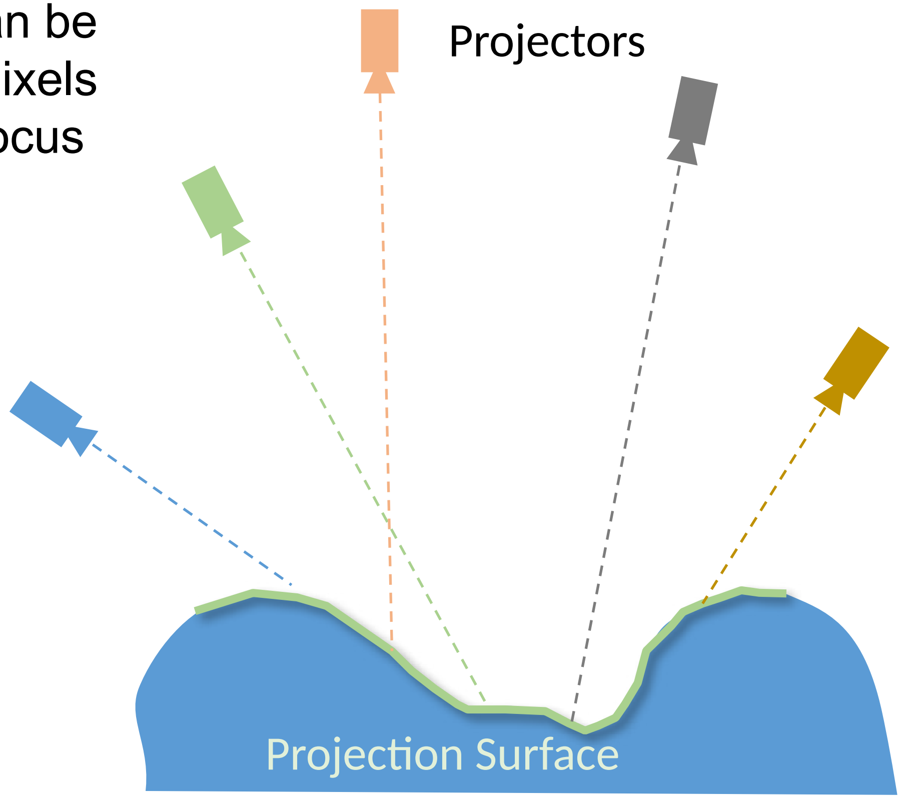
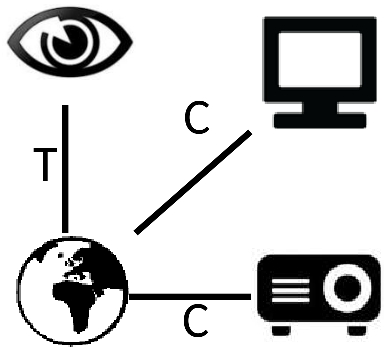


Image: Oliver Bimber

Spatial Augmented Reality with Projector Array

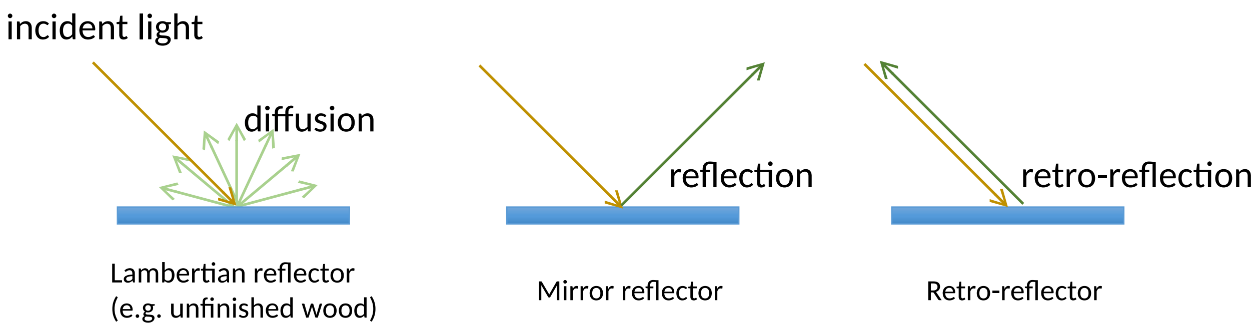
Multiple projectors can be combined to minimize pixels projected out of focus



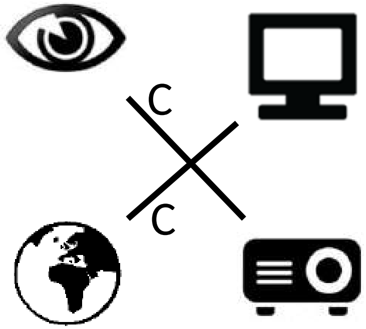


The geometry of the projection surface needs to be known (here: a display calibrated to the world)

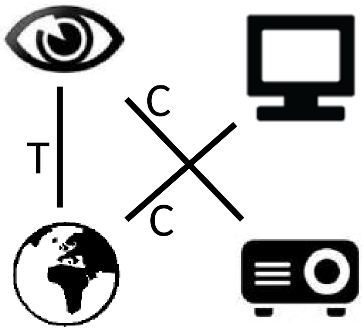
Head-Mounted Projective Display



Retro-reflective materials send incident rays back to the illuminating source, so they work well with head-mounted projector displays



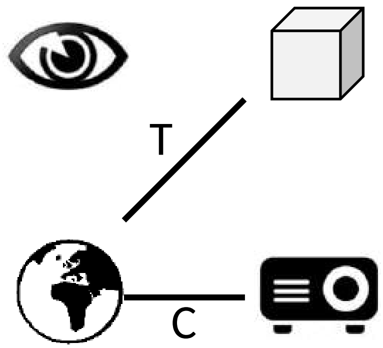
Spatial relationship schematics for HMPDs without head tracking



Spatial relationship schematics for HMPDs with head tracking - virtual objects are stable in space, while the viewer is moving

Dynamic Shader Lamps

Dynamic shader lamps deliver spatial AR on tracked objects



Painting with light on real surfaces

Image: Michael Marner

Animatronic character with animated facial projection

Image: Greg Welch, UNC Chapel Hill

Steerable Projector

Everywhere Projector Display

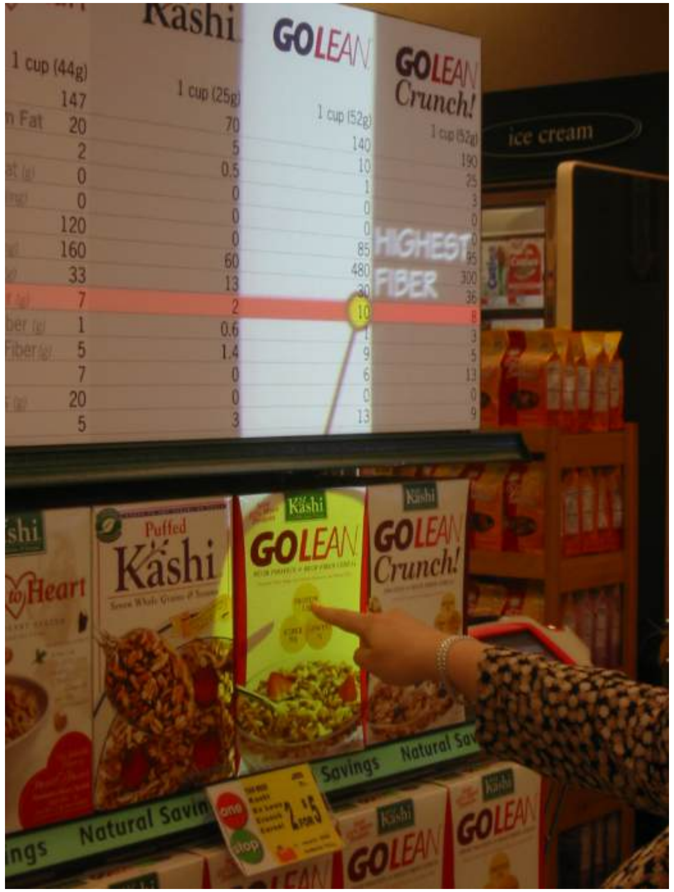
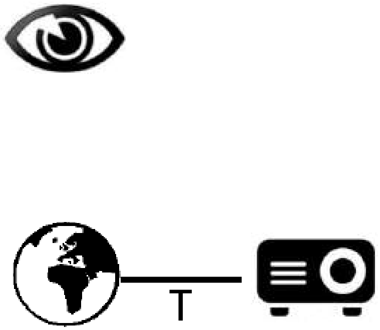


Image: Claudio Pinhanez, IBM Research



A steerable, tracked projector can display images anywhere