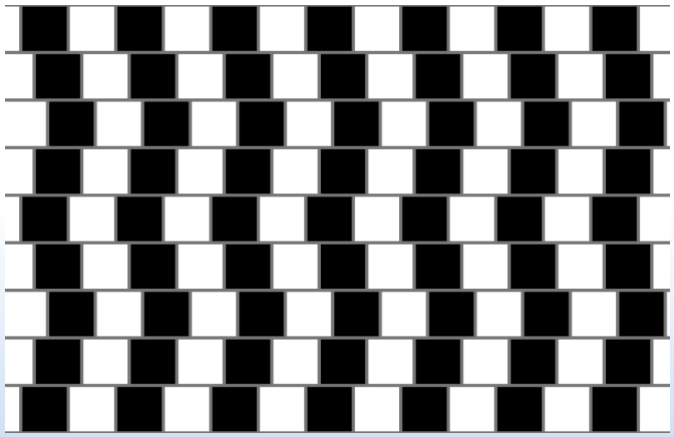
Displays

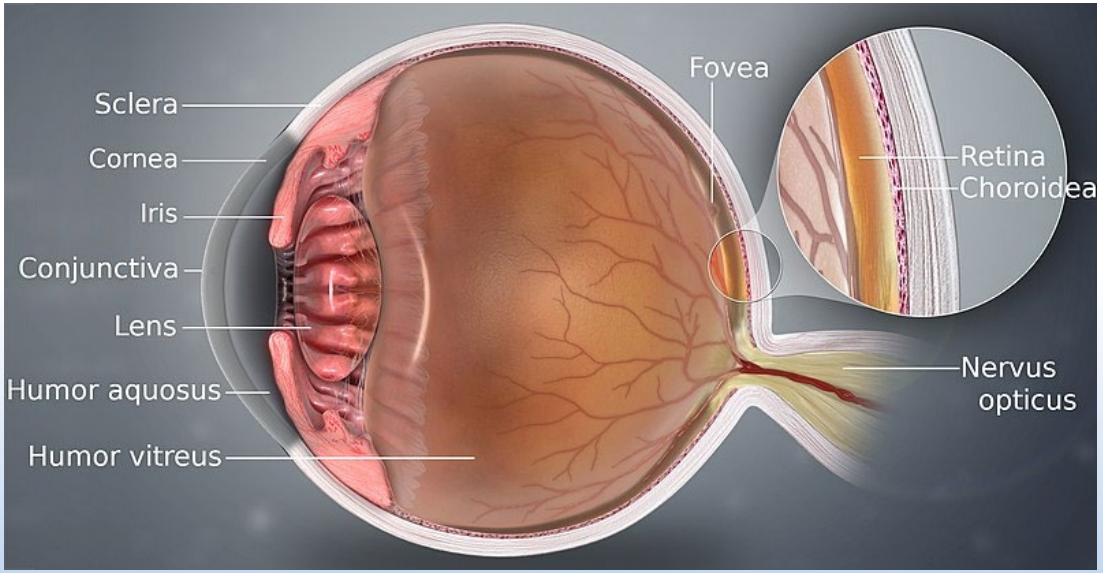
The Mechanics of Sight

- 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

- Human visual perception
  - Ability to perceive what we see
  - Light that enters the eye and focuses on the retina
  - Visual perception occurs in the brain's cerebral cortex



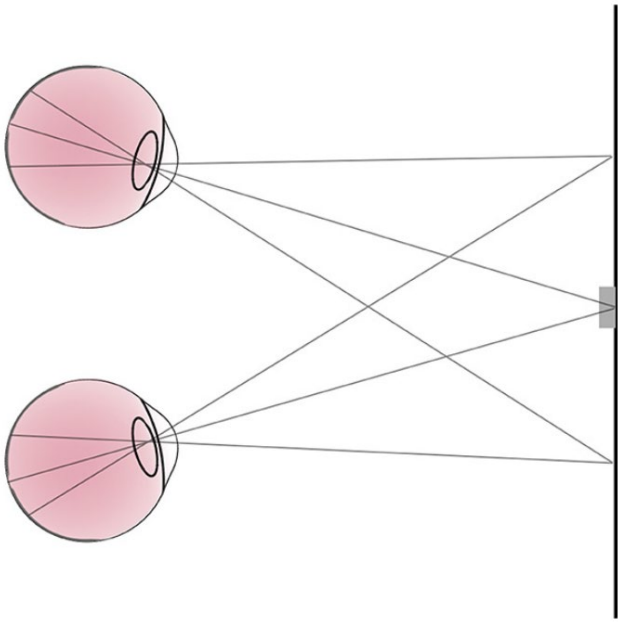


Visual Perception

- Field of view
  - Usually span between 200-220^{o} horizontally (both eyes combined)
  - The fovea
    - Highest visual acuity (ability to see small details) only 1-2^{o}
      - Peaks in the centre 0.5-1^{o}
    - Outside the fovea
      - Visual acuity falls off quickly with increasing viewing angle
      - Humans compensate for this by moving their eyes, up to 50^{o}, and head
    - High-quality displays must present sufficient resolutions in the areas of high acuity

Visual Perception

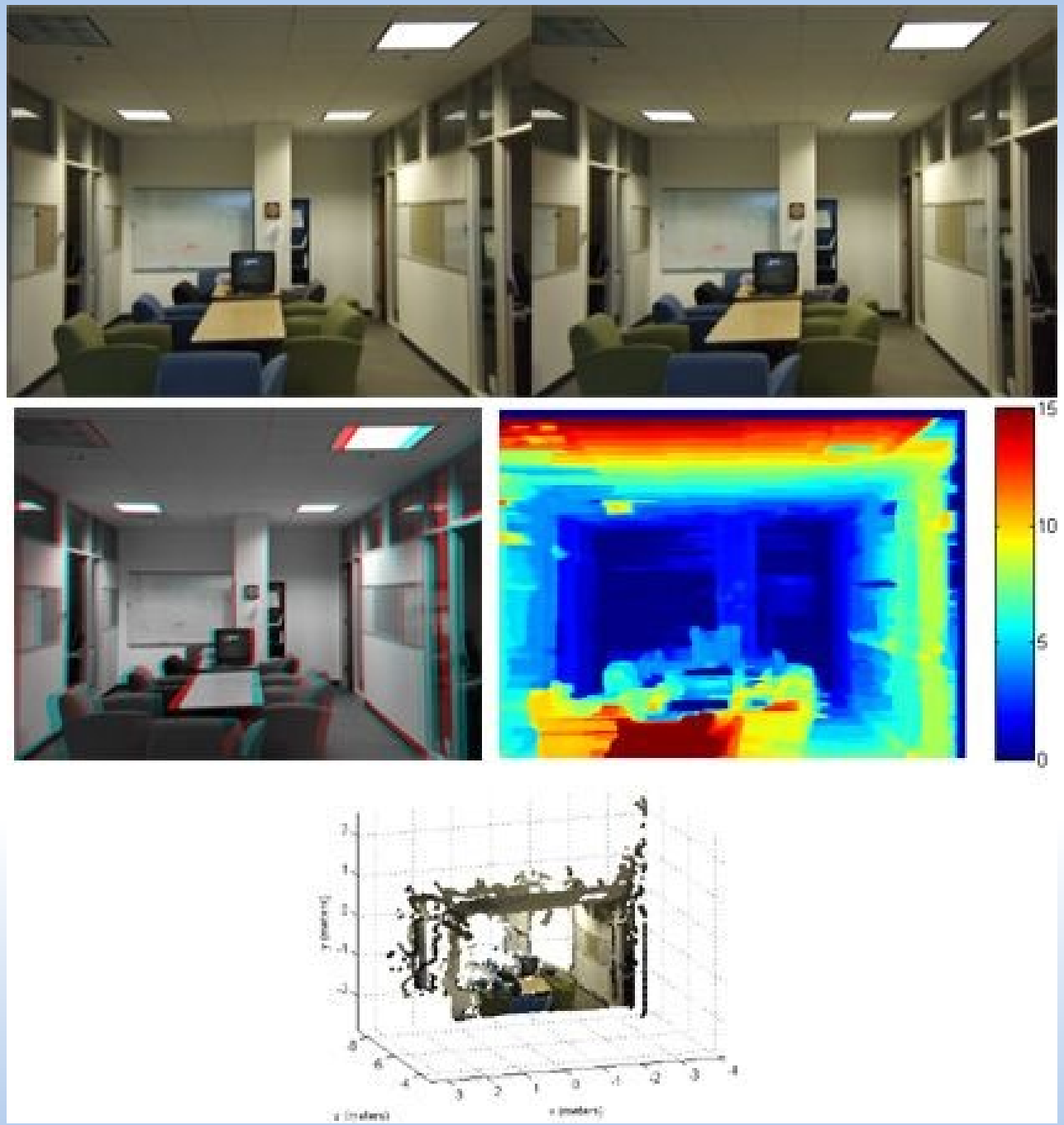
- Stereopsis
  - Perception of depth by the brain based on visual information from both eyes
  - Most prominent **binocular depth cue**
  - Binocular vision
    - Sight with two eyes
    - Each eye is at a slightly different position, ~63mm apart, and captures the scene from a slightly different angle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



Credit: Illustration by S. Aukstakalnis

Visual Perception

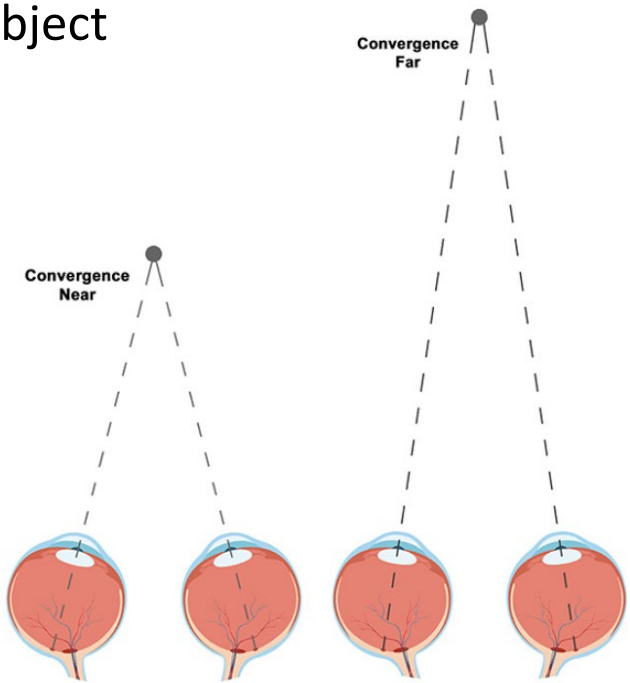
- Stereopsis
  - **Binocular disparity**
    - The difference in image location of an object seen by the left and right eyes
    - The closer an object is to the eyes, the bigger the angular offset, or parallax
    - The brain uses this to extract depth information from the retinal images
  - Stereoscopy
    - Method of artificially presenting two different 2D images separately to each eye



https://www.mathworks.com/discovery/stereo-vision.html

Visual Perception

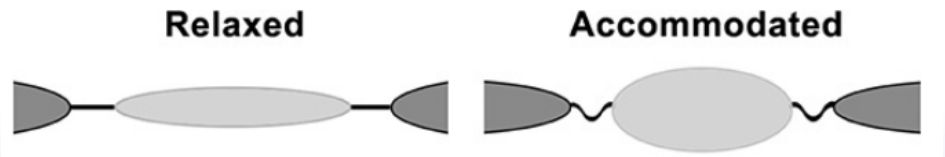
- Vergence
  - ➢ Simultaneous rotation of both eyes around their vertical axis in opposite directions for binocular vision
    - Pointing of the fovea of both eyes at an object
  - ➢ To look at an object
    - In the near field, eyes rotate toward each other or **converge**
    - In the far field, eyes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

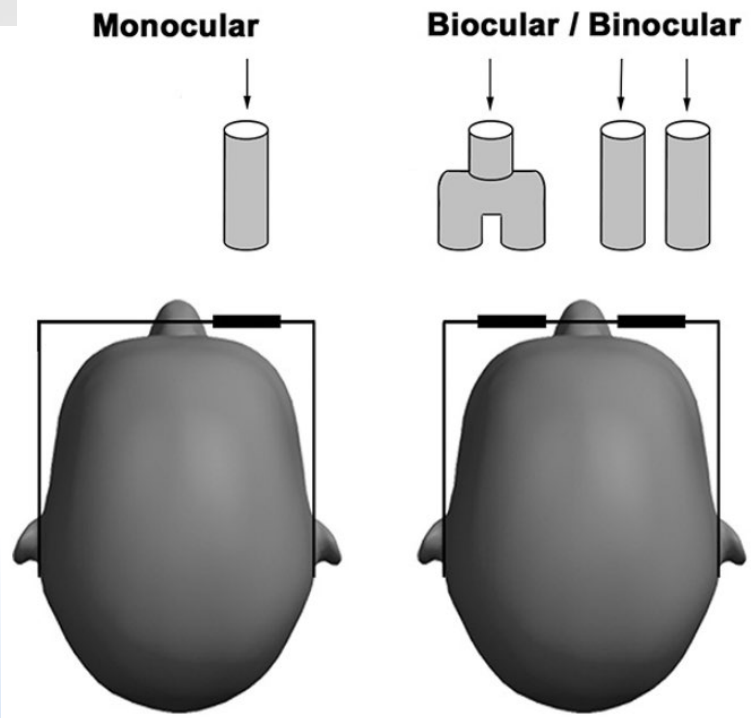
https://developer.nvidia.com/sites/all/modules/custom/gpugems/books/GPUGems/gpugems_ch23.html

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/

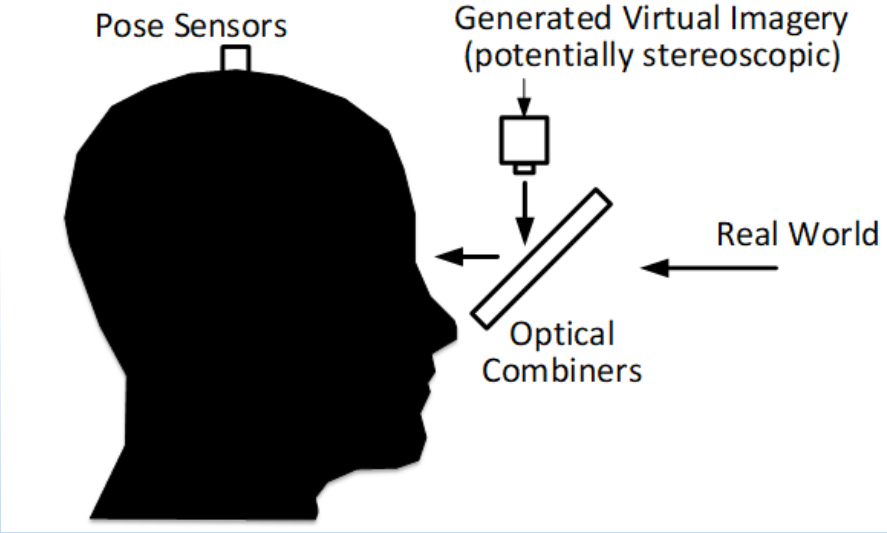
Display Fundamentals

- Ocularity

Ocularity	Advantages	Disadvantages
Monocular	Low weight, small form factor, least distracting, easiest integration, least computational overhead, easiest alignment.	Possibility of binocular rivalry and eye-dominance issues, small field of view (FOV), no stereo depth cues, asymmetric mass loading, reduced perception of low-contrast objects, no immersion.
Biocular	Less weight than binocular, no visual rivalry, useful for close proximity training tasks requiring immersion, symmetric mass loading.	Increased weight, limited FOV and peripheral cues, no stereo depth cues, often lens is larger to accommodate larger eye box.
Binocular	Stereo images, binocular overlap, larger FOV, most depth cues, sense of immersion	Heaviest, most complex, most expensive, sensitive to alignment, computationally intensive operation.

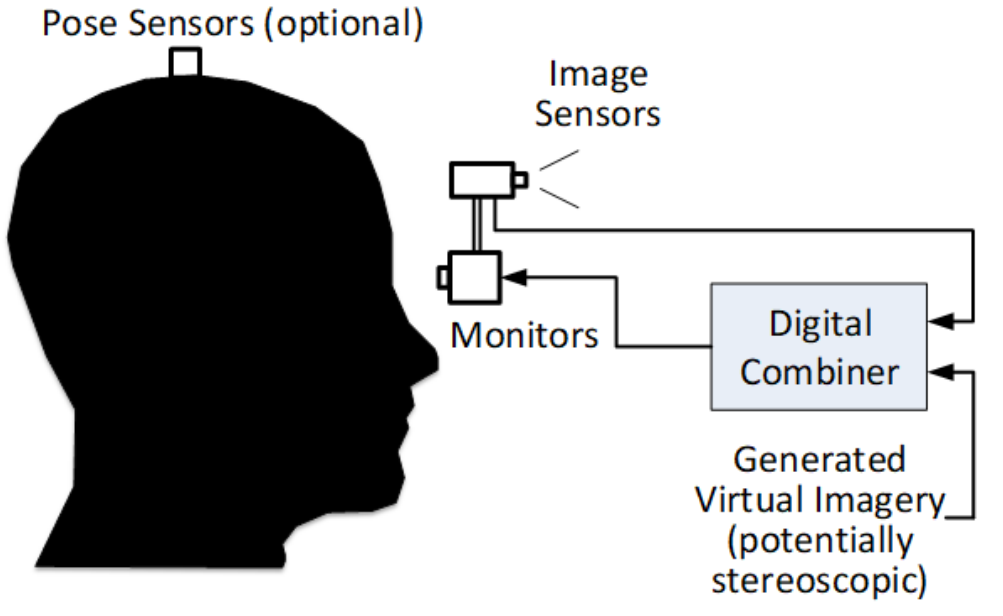
Display Fundamentals

- 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

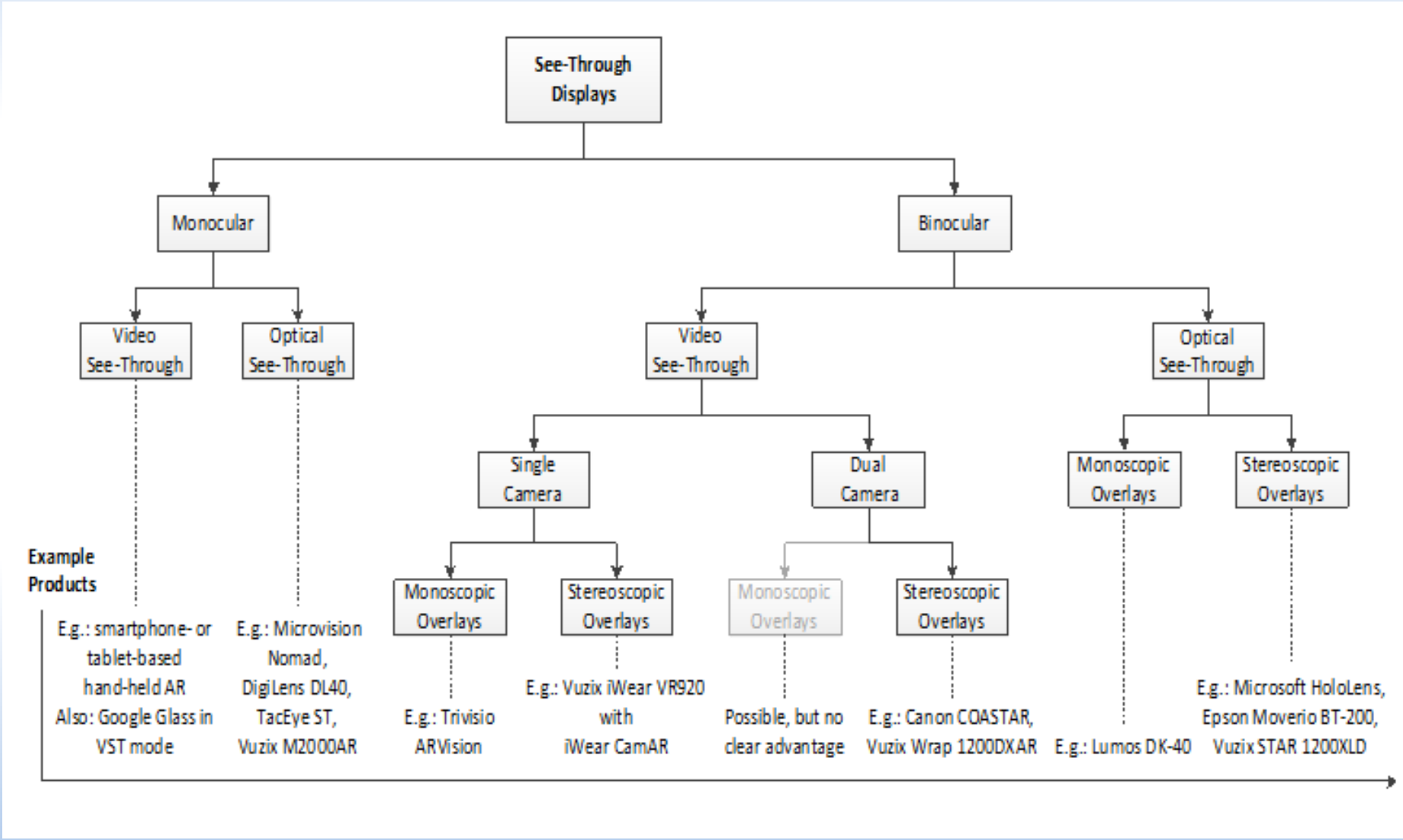


Display Fundamentals

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

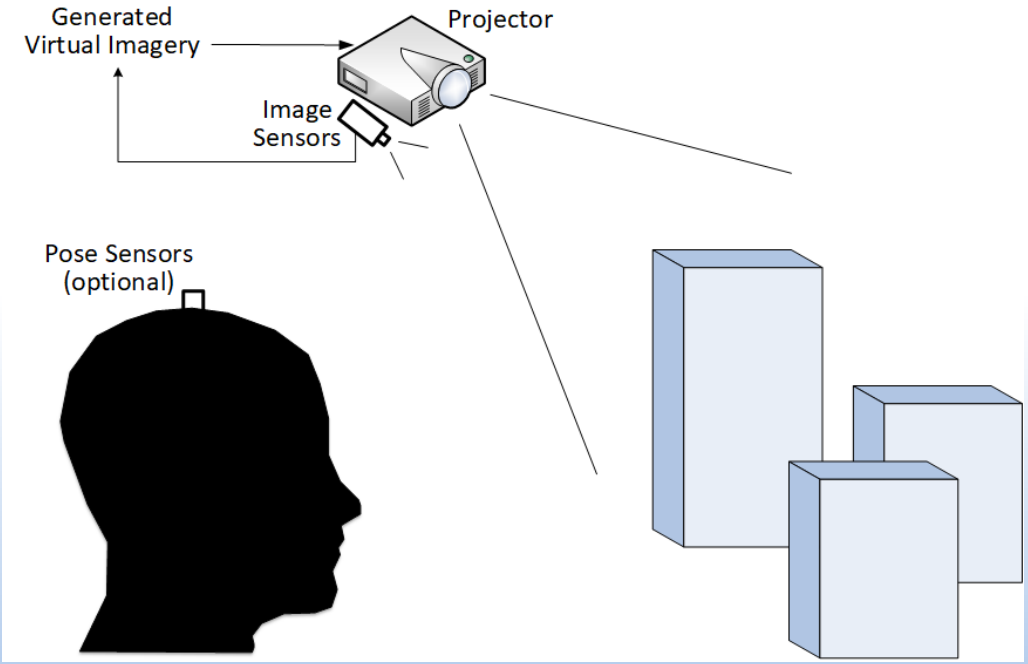


See-Through Display Taxonomy



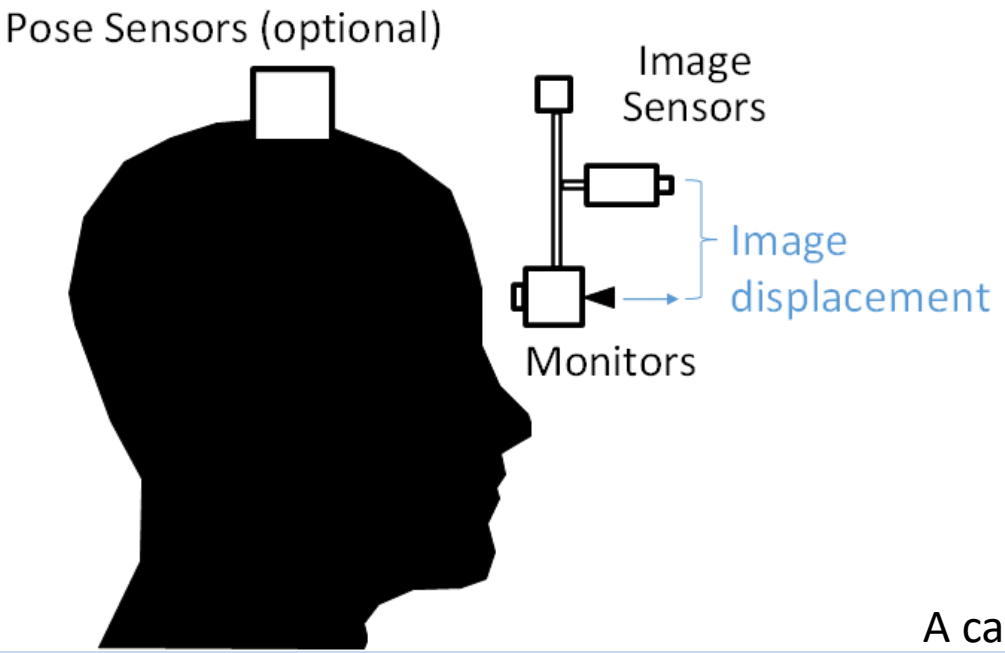
Display Fundamentals

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



Display Fundamentals

- Image displacement
  - Offset between the user's viewing direction and the camera's optical axis is not desirable

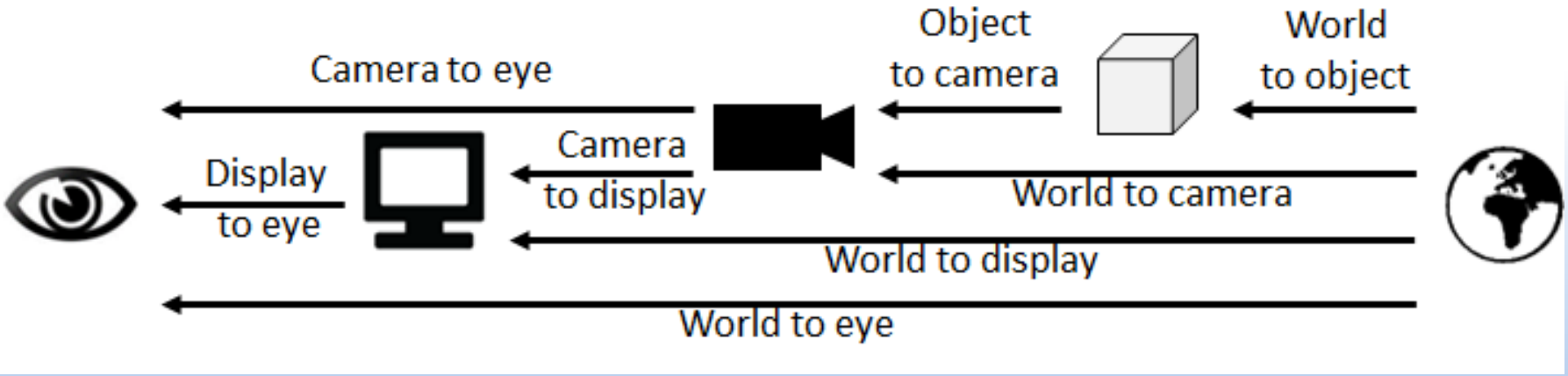


A camera pointing diagonally downward from behind the display captures an AR interaction space centred on the user's hands

Image: Morten Fjeld

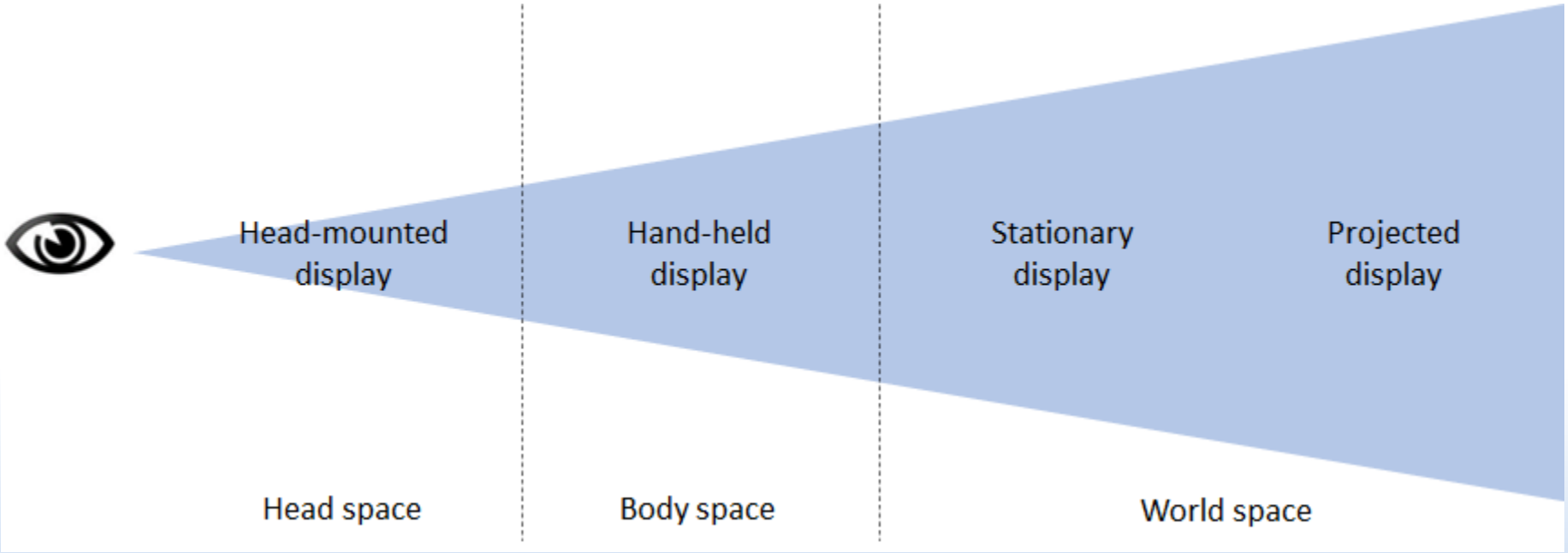
Display Fundamentals

- 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 Fundamentals

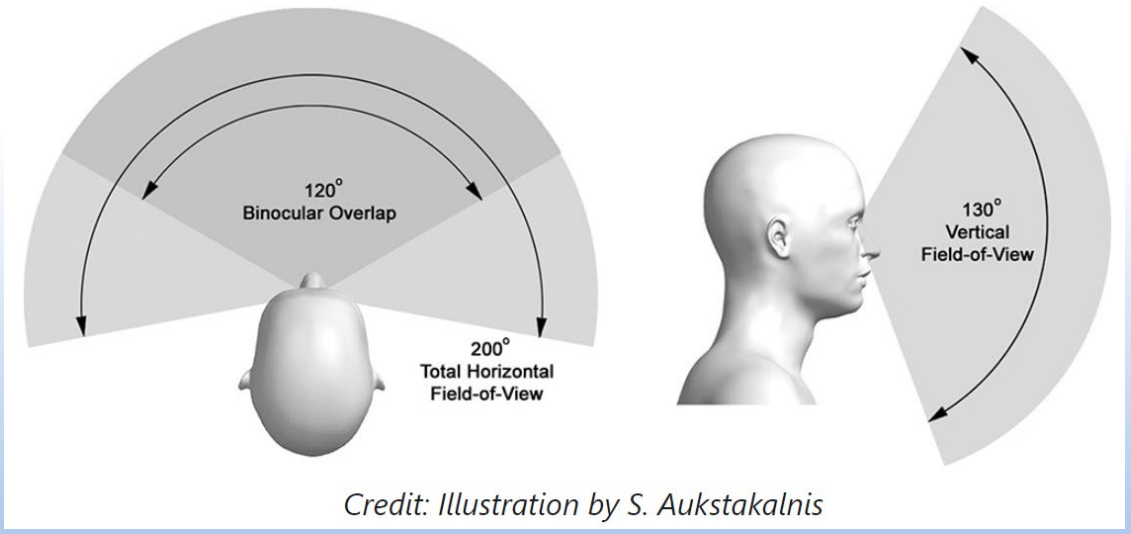
- Display space taxonomy
  - AR displays categorised according to the distance from eye to display



Feature	Specification
Ocularity	Binocular
Image Source	AMOLED
Resolution	1080 × 1200 per eye (2160 × 1200 combined)
Refresh Rate	90 Hz
Display Optics	Hybrid Fresnel
Field of View	~110°
Eye Relief	Not adjustable
Interpupillary Dist.	58–72 mm (adjustable)
Head Tracking	IMU (compass/ accel/ gyro) Optical tracking of IR LED "Constellation" on headset
Tracking Area	5 × 11 feet
Built-In Camera	No
Microphone	Integrated microphone
Audio	Integrated stereo supra-aural headphones
Connections	(1) HDMI port (2) USB 3.0 ports
Phone Integration	No
Weight	470 g (1 lb, .57 oz.)
	Recommended PC Specifications
GPU	NVIDIA GeForce GTX 970 equiv or better AMD Radeon R9 290 equiv or better

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



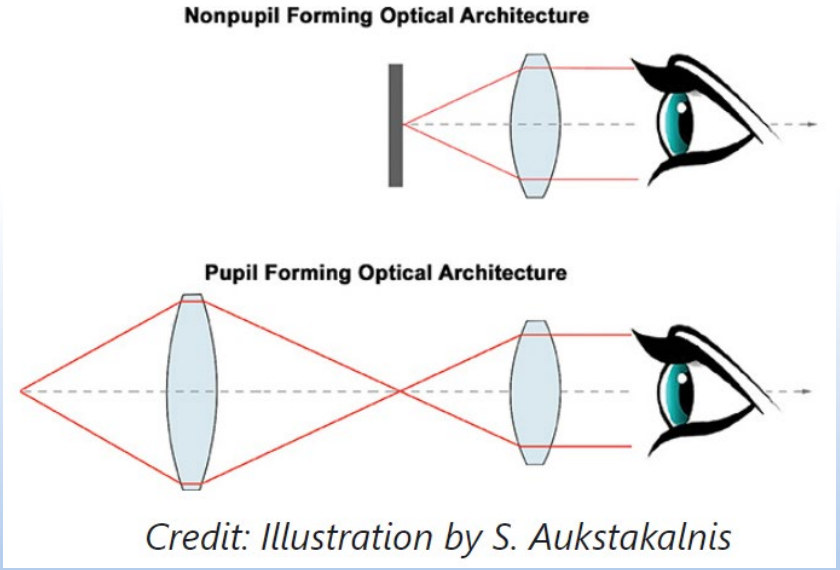
Credit: Illustration by S. Aukstakalnis

Display Fundamentals

- Interpupillary distance (IPD)
  - Distance between centres of the pupils of the eyes
    - Poor eye-lens alignment can result in image distortion
      - » Resulting in eye strain, headaches, nausea
    - Incorrect setting can impact convergence and incorrect perception
- Eye relief
  - Distance from the cornea of the eye to the surface of the first optical element
  - Defines the distance at which the user can obtain the full viewing angle of the display device
    - Affects the user's perceived FOV
  - Especially important for individuals who wear glasses

Display Fundamentals

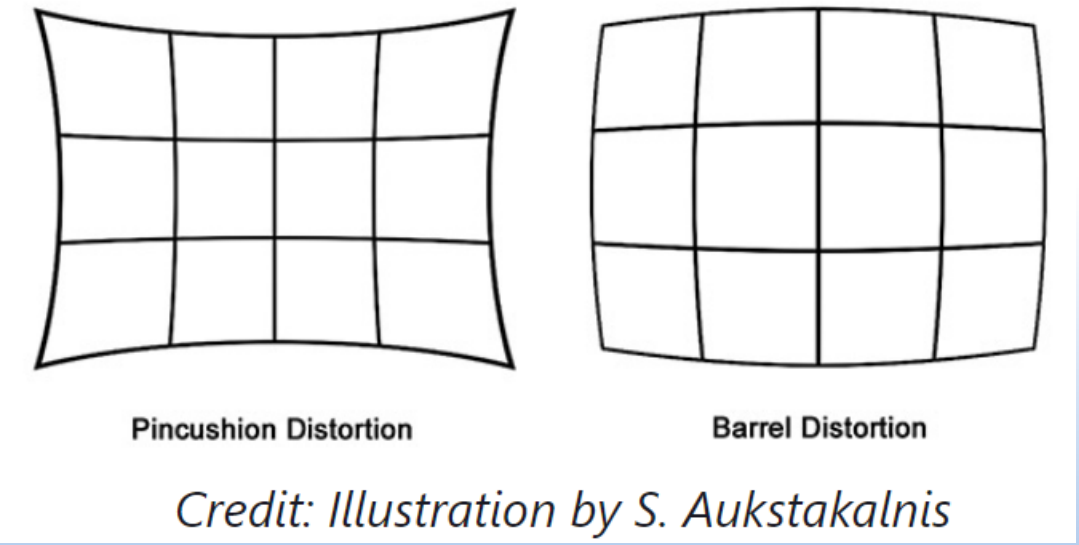
- Exit pupil
  - The diameter of light transmitted to your eye by an optical system
- Eye box
  - The volume within which users can place their pupils and experience the full performance of the device
- Pupil forming and nonpupil forming optics
  - Nonpupil forming
    - Single magnifier
      - » E.g., HTC Vive, Oculus Rift, Sony PSVR
    - Lighter, more compact, large eye box
    - Imposes significant pincushion distortion



Credit: Illustration by S. Aukstakalnis

Display Fundamentals

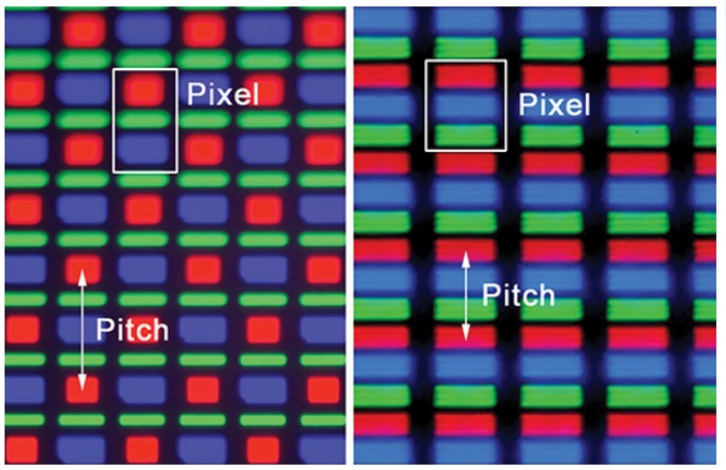
- Pupil forming and nonpupil forming optics
  - Need to render with barrel distortion to cancel out
  - Pupil forming
    - Usually heavier
    - Greater flexibility in design
      - » Can manipulate optical tracks to accommodate different designs



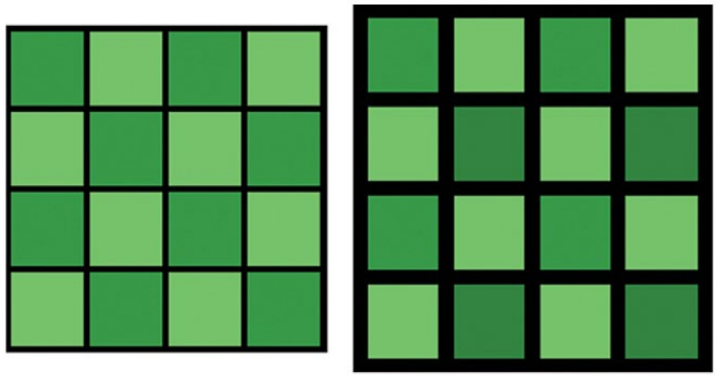
Credit: Illustration by S. Aukstakalnis

Display Fundamentals

- Resolution
  - The number of individual pixels of a display
- Pixel pitch
  - The distance between the centre of adjacent pixels
- Fill factor
  - The amount of black space between individual pixels
- Refresh rate
  - Rate at which the display refreshes with a new image
- Response time
  - Time required for a pixel to change



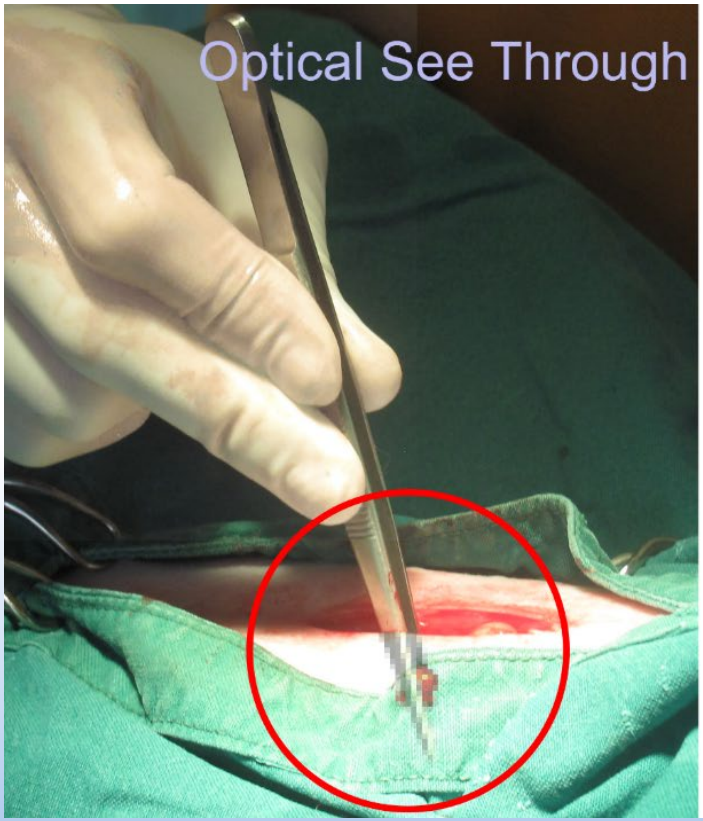
Credit: Illustration by S. Aukstakalnis

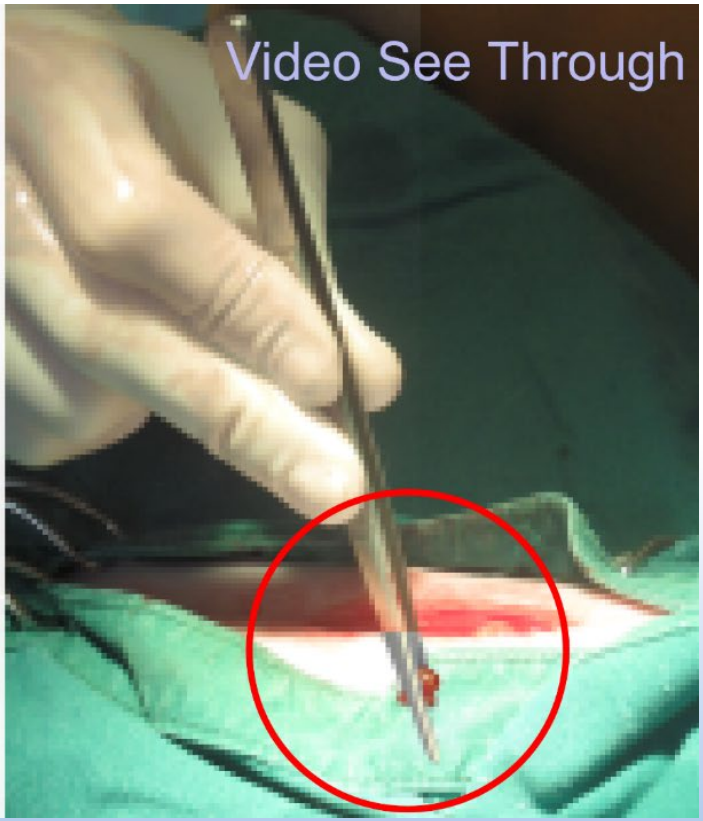


Credit: Illustration by S. Aukstakalnis

Display Fundamentals

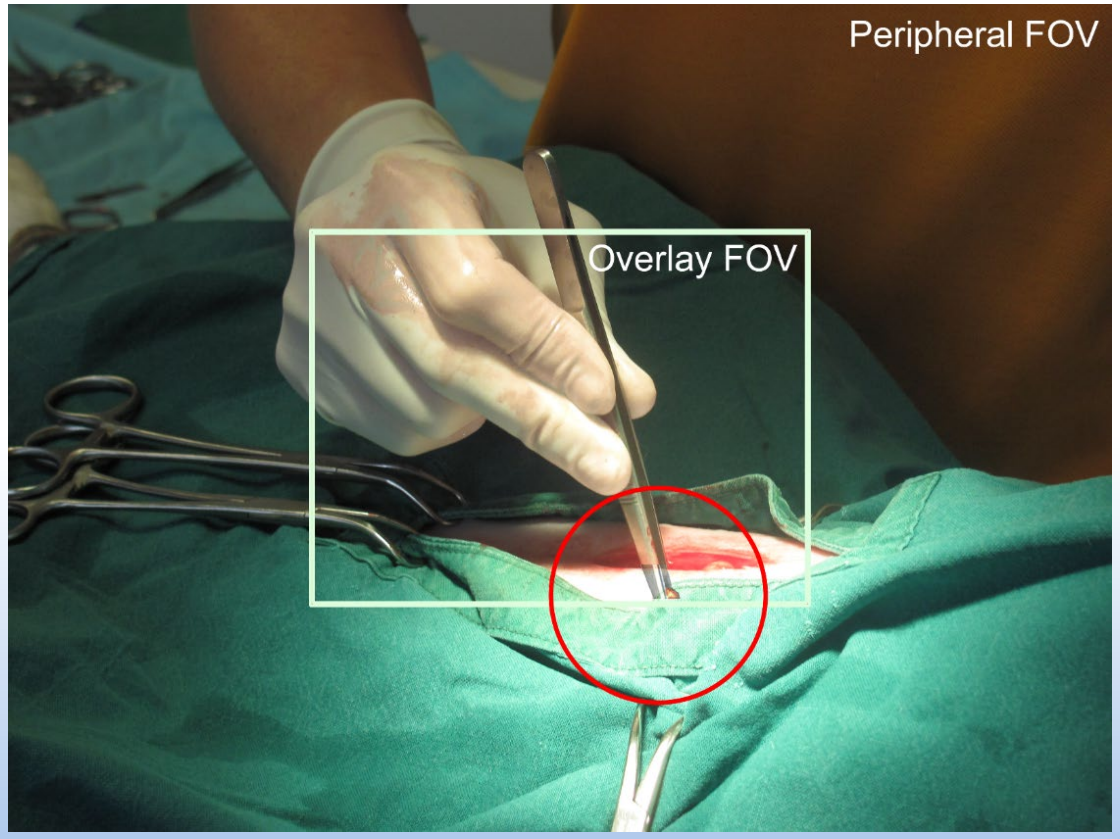
- Resolution and refresh rate
  - Impacts the fidelity of the resulting image
  - The example below shows exaggerated resolution artifacts





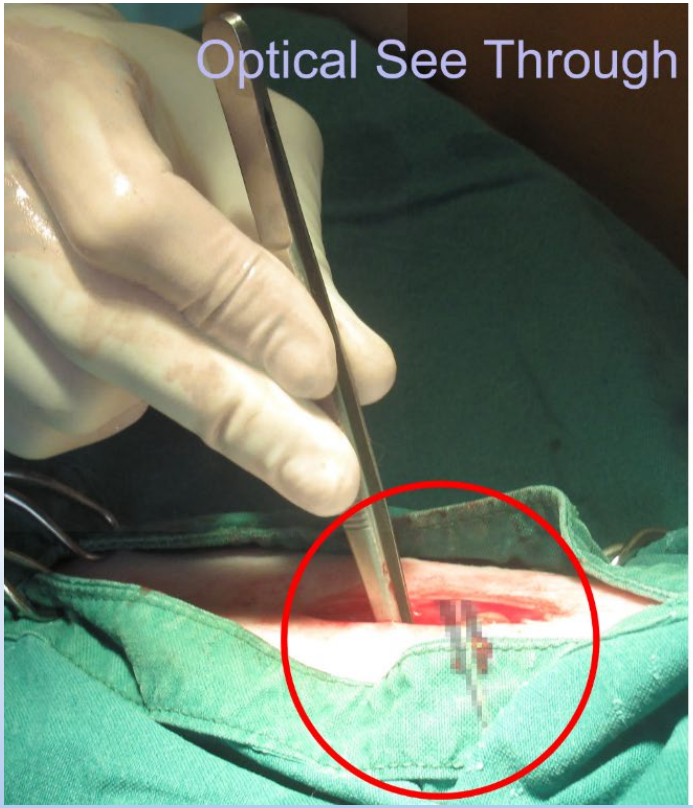
Display Fundamentals

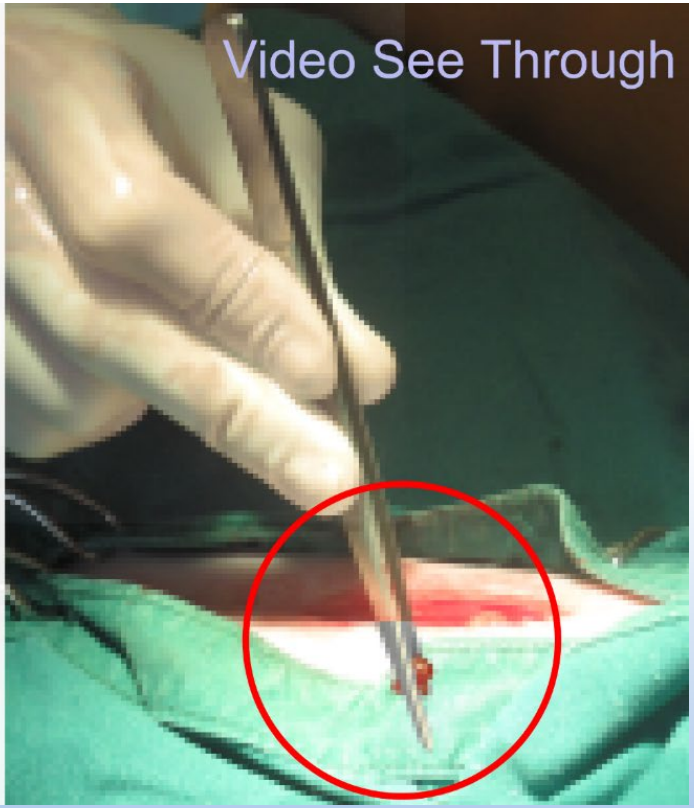
- Limited field of view
  - Resulting in an “overlay FOV” area where augmentations are visible, and a “peripheral FOV” area where they are not



Display Fundamentals

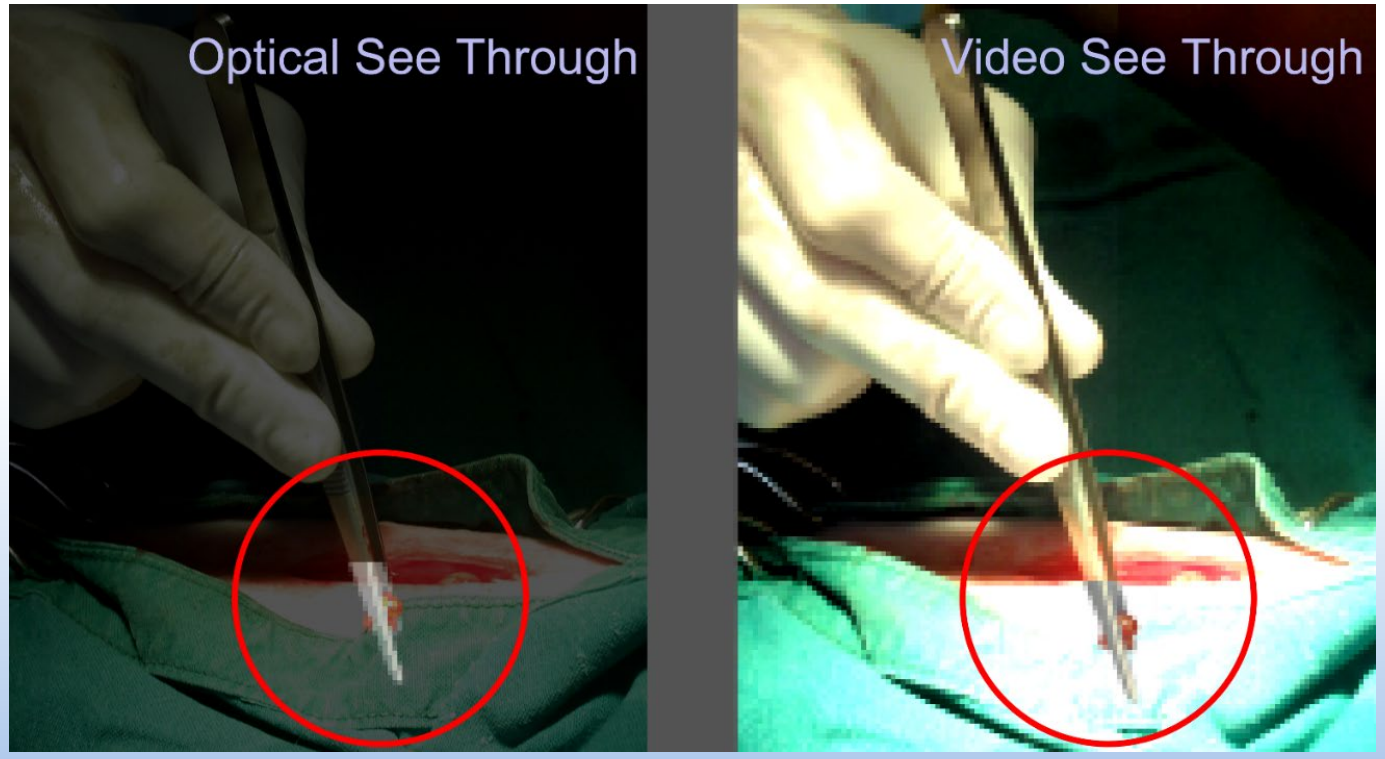
- Registration comparison
  - Insufficient eye-to-display calibration can lead to distracting offsets
  - In VST displays, pixel-accurate registration is easier to achieve





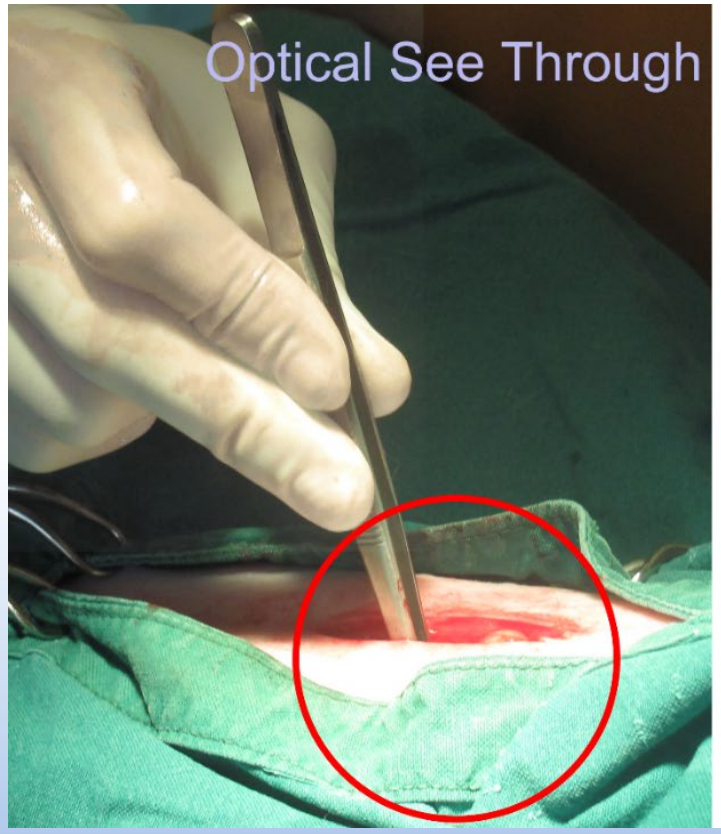
Display Fundamentals

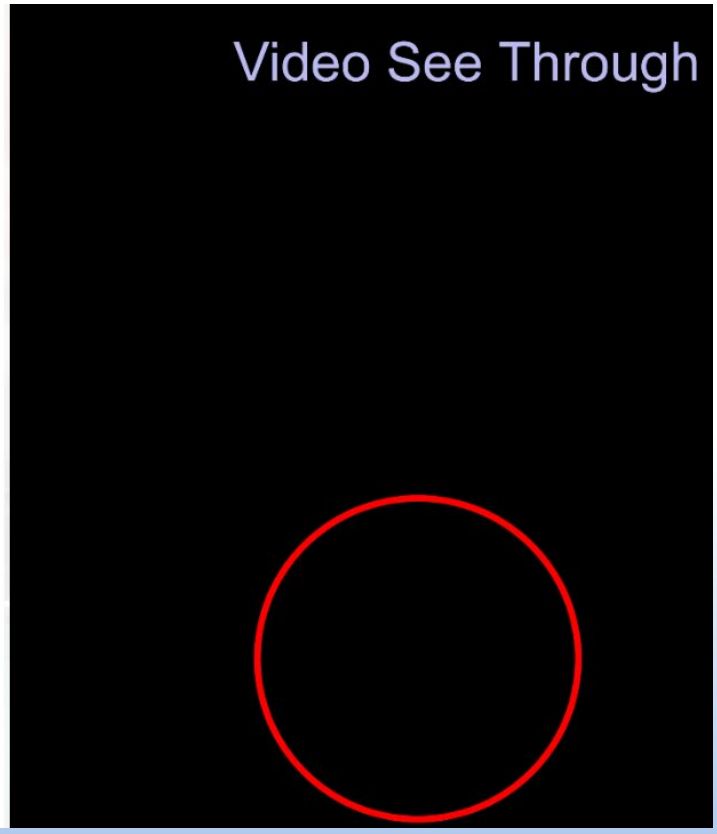
- Brightness comparison
  - OST displays depend on the transparency of the optical combiner
  - VST displays can change brightness and contrast arbitrarily as long as the display itself can delivery sufficient contrast
    - Losses real-world detail if contrast limit reached



Display Fundamentals

- Failure comparison
  - If the display fails, VST will not allow the user to see anything
    - Dangerous in critical situations, e.g., surgery or piloting an aircraft



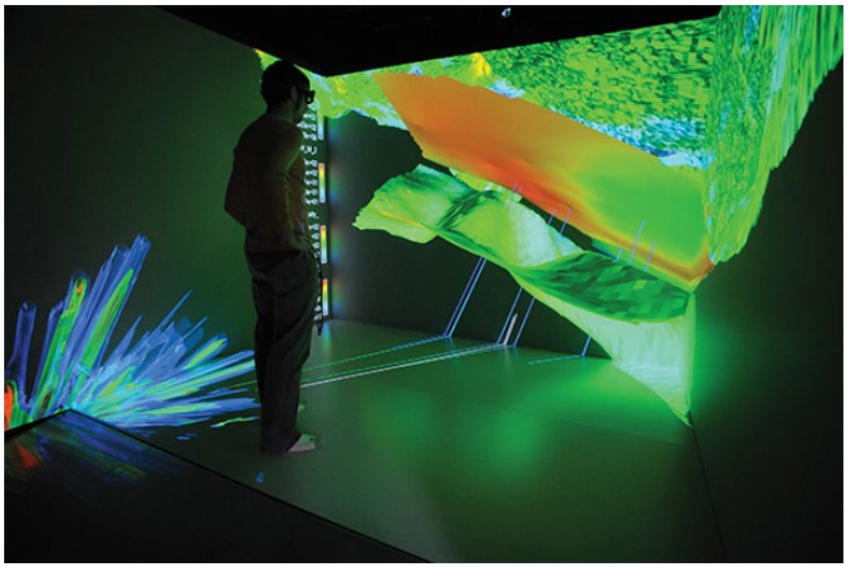


Displays

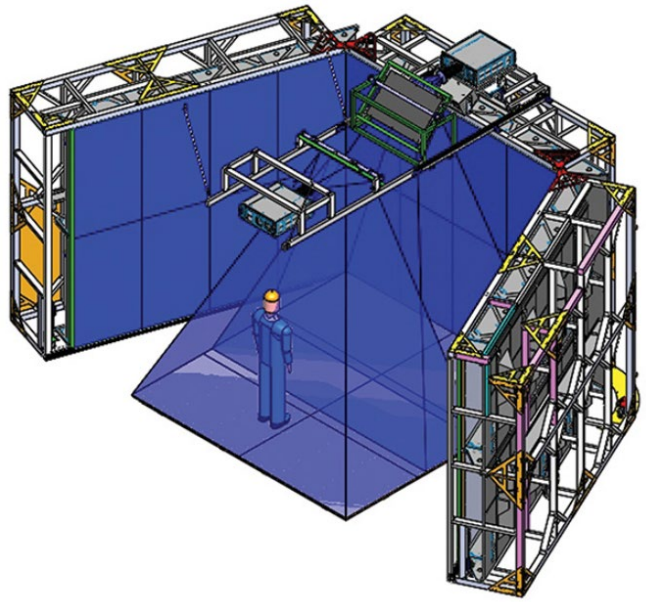
- Head-Mounted Displays (HMDs)
  - Meta Quest 2 and Quest Pro
  - HTC Vive
  - Valve Index
  - Microsoft HoloLens 2
  - Google Glass
  - Vuzix Blade
  - Magic Leap One
- Handheld devices
  - Tablets and smartphones

Displays

- CAVE
  - Computer-Assisted Virtual Environment (CAVE)
  - Most designed to accommodate multiple users
    - User typically wear shutter glasses with some method of tracking



Credit: Image courtesy of Idaho National Laboratory



Credit: Image courtesy of Mechdyne and UALR

Displays

- Hemispheres and domes
  - Large format displays
  - May not have stereoscopic imagery
  - Wide FOV highly compelling visual sensation of presence and immersion

Credit: Image courtesy of DoD

https://fulldome.pro/blog/first-vr-dome/

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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  - http://en.wikipedia.org/wiki/