Binocular Cues

- **Stereopsis**
  - **Vergence–accommodation mismatch** can be caused by using fixed distance displays to present stereo imagery
Binocular Cues

- Binocular rivalry

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Visual Display Characteristics

- Field of Regard (FOR)
  - Visual angle within which imagery can be presented by a display
  - Often measured in horizontal, vertical (or diagonal) degrees
  - Depends on location of user relative to display

- Field of View (FOV)
  - Portion of the FOR that can be seen by a user at a given point in time

FOR

FOV

User
Visual Display Characteristics

- Resolution
  - Absolute: Pixels per linear inch
  - Relative: Pixels per degree
  - May vary across display
    - Absolute variance caused by unequal pixel distribution
      - E.g., Higher pixel density at center of display in world coordinates
    - Relative variance caused by user position relative to display
      - E.g., Higher pixel density at periphery in projection on retina

Visual Display Characteristics

- Surface geometry
  - Planar
  - Curved
  - Hemispheric

CAVE (Cave Automatic Virtual Environment)
Visual Display Characteristics

- Surface geometry
  - Multiple surfaces
    - KAUST Immersive Cube
      - 24 4096×2160 pixel projectors (4 per wall)
      - 100M pixels @ 10K lumens, stereo

- Surface orientation
  - Absolute
    - Vertical
    - Slanted
    - Horizontal

Images courtesy Tom DeFanti

https://vimeo.com/122661332
Visual Display Characteristics

- Surface orientation
  - Relative
    - Held/worn by user (how and with what is it held/mounted/worn)
      - Hand
      - Head
      - Wrist

- Tiling
  - Multiple panels
  - Multiple projectors
Visual Display Characteristics

- Light transfer approach
  - Example: surface in environment
    - Emissive / transmissive
      - E.g., rear projection, or flat panel
      - Scene can be obscured by user
    - Reflective
      - E.g., front projection
      - Projection can be obscured by user (shadows)
  - Consequences differ depending on form factor

Visual Display Characteristics

- Refresh rate
  - Number of times per second (Hz) displayed image is refreshed from memory
- Frame rate
  - Number of times per second (Hz) image is generated from representation
- Refresh rate is limiting factor
  - However, if frame rate >> refresh rate, multiple different frames can be accumulated for each refresh to improve quality (e.g., antialiasing)
Visual Display Characteristics

- Brightness
- Black level
- Dynamic range
- Transfer function
- Duty cycle
- Persistence
- Color gamut

Stereoscopic Viewing
Passive

- Spatial multiplexing
  - “Free viewing”
  - Stereoscope
    - Present each eye with its own view

Stereoscopic Viewing
Passive

- Spatial multiplexing
  - “Free viewing”
  - Stereoscope presents each eye with its own view

What’s wrong with these pictures?
Stereoscopic Viewing
Passive

- Spatial multiplexing
  - Stereoscopic viewer for smartphone/tablet
  - Separate left/right stereoscopic views of virtual objects combined with shifted copies of a monoscopic camera view

Stereo viewer for Nokia Lumia 800 courtesy of USC ICT MxR Lab
Build your own: http://projects.ict.usc.edu/mxr/diy/fov2go-viewer/

Commercial versions (w/o camera support):
- www.amazon.com/Hasbro-Viewer-touch-iPhone-Black/dp/B0047TVV2Y
- www.samsung.com/GearVR
- www.google.com/get/cardboard/

Autostereoscopic Viewing
Passive

- Spatial multiplexing
  - Parallax barrier approaches
    - Parallax stereogram
  - Viewer’s eyes need to be positioned properly

http://paulbourke.net/stereographics/lenticular/


**Autostereoscopic Viewing**

**Passive**

- Spatial multiplexing
  - Parallax barrier approaches
    - Parallax panoramagram
      - Presents different stereo pairs at different locations
  - Can use physically moving mechanical or virtually moving liquid crystal barrier to create active display for tracked user

  - [mfl.nyu.edu/~perlin/demos/autostereo.html](http://mfl.nyu.edu/~perlin/demos/autostereo.html)

- Lenticular approach
  - Array of cylindrical lenses
  - Brighter than barrier

  - [http://paulbourke.net/stereographics/lenticular/](http://paulbourke.net/stereographics/lenticular/)
Autostereoscopic Viewing
Reconfigurable from mono to stereo

- Goal: Display that can switch from autostereoscopic 3D to 2D
- Solution: Parallax barrier made from switching LC panel that can be turned on or off

![Diagram of autostereoscopic display with switching LC panel]

Solution:
Parallax barrier made from switching LC panel that can be turned on or off

Stereoscopic Viewing
Passive

- Spectral multiplexing
  - "Red–cyan" (earlier "red-blue") anaglyph stereo
    - Display overlapped left/right images in red/cyan
    - Can create by combining red channel of left image with green/blue channels of right image

![Diagram of anaglyph stereo with red-cyan images]

http://www.stereoscopy.com/3d-images/photography.html
Stereoscopic Viewing
Passive

- Spectral multiplexing
  - ColorCode 3-D
    - Display overlapped left/right images in amber/blue
      - Left eye provides color (mostly)
      - Right eye provides second eye's geometry (mostly)
    - Better color rendition than red/cyan anaglyph
    - Imagery looks better without eyewear
    - www.colorcode3d.com
    - Other color pairs used by other vendors

- Infitec
  - Display overlapped left/right images using different RGB primaries for each eye
    - Special narrow bandpass filters used on projector and in eyewear
  - Passive eyewear (expensive)
  - Metallized screen not needed
  - Very low crosstalk
  - Slight L–R color shift
  - www.infitec.net
  - http://www.infitec.net
Stereoscopic Viewing
Passive (single image)

- Spectral multiplexing
  - Chromostereoscopy
  - Different colors focus at slightly different points on retina (red closer to temple than blue)
  - Chromatic aberration

Spectral multiplexing

Chromostereoscopy

Different colors focus at slightly different points on retina (red closer to temple than blue)

Chromatic aberration

- Actual position of object (black) and optically shifted positions due to red and blue focusing at different offsets on retina.
- Fovea is off center relative to eye's optical axis. Index of refraction varies with wavelength

Perceived fused depth (blue)

Perceived fused depth (red)

Optical axis

Fovea is off center relative to eye's optical axis. Index of refraction varies with wavelength

- Effect is more extreme if optics are used for both eyes

Stereoscopic Viewing
Passive (single image)

- Spectral multiplexing
  - ChromaDepth™ stereo
    - Inspired by chromostereoscopy
  - Refractive/diffractive optics over right eye shift colors differentially to the left (red > blue)

ChromaDepth™ stereo

- Actual position (black) and optically shifted positions
- Perceived fused depth (blue)
- Perceived fused depth (red)

Optics

Effect is more extreme if optics are used for both eyes