Overview

- Visual Displays
- Auditory Displays
- Haptic/Tactile Displays
- Level of Fidelity
- Running Case Studies
Visual Displays

- Present visual information to the user through visual system
- Most common display device in 3D Uis
- Requires computer system to generate digital content the display device transforms into perceptible form

Visual Display Characteristics

- Field of regard (FOR) and field of view (FOV)
  - FOR: the amount of the physical space surrounding the user in which visual images are displayed (measured in degrees of visual angle)
  - FOV: the maximum number of degrees of visual angle that can be seen instantaneously on a display
Visual Display Characteristics

- **Spatial Resolution**
  - Related to pixel size and is considered a measure of visual quality
  - Resolution depends on both the number of pixels and the size of the screen
  - Can be measured in absolute units such as dots per square inch (dpi)
  - Can also be measured in degrees of solid angle subtended relative to the viewer

Visual Display Characteristics

- **Screen geometry**
  - Variety of different shapes including rectangular, circular, L-shaped, hemispherical, and hybrids
  - Projection mapping supports displays on any shape or surface

- **Light Transfer**
  - Through a monitor or television, front projection, rear projection, laser light directly onto the retina, and through the use of special optics
  - Technologies include liquid crystals, light-emitting diodes, digital light processing, and organic light-emitting diodes
Visual Display Characteristics

- **Refresh rate**
  - Refers to the speed with which a visual display device refreshes the displayed image from the frame (usually expressed in Hertz)
  - Not the same as frame rate (speed with which images are generated and placed in the frame buffer)

- **Ergonomics**
  - Maintain user comfort
  - Unobtrusive as possible

Visual Display Characteristics

- **Depth cue support (see Chapter 3)**
  - Stereopsis (strong with objects in close proximity)
  - Motion parallax
  - Monocular depth cues
  - Deal with accommodation-vergence mismatch
    - “true 3D” displays
    - light-field displays
Visual Display Device Types

- Single screen displays
- Surround-screen and multiscreen displays
- Workbenches and tabletop displays
- Head-worn displays
- Arbitrary surface displays
- Autostereoscopic displays

Single Screen Displays

- Conventional monitors
- High-definition and higher resolution televisions
- Front- or rear-projection displays using a wall or screen material as the projection surface
- Smartphone and tablet displays
Single Screen Displays

- Relatively inexpensive compared to more complex displays
- Provide monocular and motion parallax depth cues
- Pair of stereo glasses is also needed to achieve stereoscopic viewing

- Stereoscopic viewing
  - Active (shutter glasses)
    - Synchronized to open and close their shutters at a rate equal to the refresh rate of the visual display (temporal multiplexing)
  - Passive
    - Filters two separate, overlaid images with oppositely polarized filters (polarization multiplexing)
    - Display two separate, overlaid images in different colors (spectral multiplexing)
Single Screen Displays

- Single screen display with stereo and head tracking (sometimes called fish-tank VR)

  **Advantages**
  - Simple yet effective for 3D spatial applications
  - Support any input device
  - Good spatial resolution

  **Disadvantages**
  - Not very immersive
  - Limited range of user movement
  - Accommodation-vergence mismatch
  - Physical objects used for interaction may occlude display

Surround-Screen and Multiscreen Displays

- Visual output device that increases the FOR for a user or group of users
  - set of display screens
  - large curved display screen
  - some combination of curved and planar screens

  **Goal is to “surround” the user**
Surround-Screen and Multiscreen Displays

Variation on the traditional, orthogonal surround-screen display system. This device uses 3 large planar screens where the angle between them is 120 degrees.

(Photograph courtesy of Joseph J. LaViola Jr.)

Surround-Screen and Multiscreen Displays

A surround-screen display using a collection of LCD display panels.

(Photograph courtesy of Chris North, Department of Computer Science, Virginia Tech)
Surround-Screen and Multiscreen Displays

Advantages
- High spatial resolution with high FOR and FOV
- Provide stereo and strong motion parallax depth cues
- Real and virtual objects mixed in the display

Disadvantages
- Expensive and require a lot of physical space
- Accommodation-vergence mismatch
- Typically only one user is tracked at a time
- Front projection can effect 3D UI techniques
Workbenches and Tabletop Displays

- Displays to simulate work and augment interaction that takes place on desks, tables, and workbenches.

Workbench style displays. (Photographs courtesy of Barco and Fakespace Systems)

- Personalized head tracked stereo workbench.

Photograph courtesy of Joseph J. LaViola Jr.
Workbenches and Tabletop Displays

- Advantages
  - Good spatial resolution
  - Intuitive display for select applications (e.g., medical simulation, 3D modeling)
  - Same depth cues as single and surround screen displays (assuming stereo and head tracking hardware)
  - Can easily support 2D and 3D UI

- Disadvantages
  - Limited movement around the device
  - Physical-based travel techniques not possible
  - Limited range of 3D viewpoints
  - Accommodation-vergence mismatch
Head-Worn Displays

- Displays in which the device is attached (coupled) to the user’s head
  - Also referred to as head mounted display (HMD)
  - Device is wearable
- Sophisticated device
  - Requires the complex integration of electronic, optical, mechanical, and even audio components
- Many different designs over the years

Main goal is to place images directly in front of the user’s eyes using one or two small screens

Combination of refractive lenses and/or mirrors (depending on the optical technique used) used to present and sometimes magnify the images shown on the screens
Head-Worn Displays

- Head Mounted Projective Display
  - Design variation of HWD
  - Hybrid between HWD and projection display
  - Small projectors attached to head-coupled device, these project the graphical images into the real environment
  - Uses retroreflective material
    - Deflects light back in the direction it came from, regardless of its incident angle with the screen surface
  - Ideally suited to collaborative mixed and augmented reality applications
Head-Worn Displays

- Augmented Reality HWDs
  - Supports seeing both real and virtual imagery
- Optical see-through
  - Place optical combiners in front of the user’s eyes
  - Combiners are partially transparent and partially reflective, so user can see the real world and virtual images reflected from small head-mounted screens
  - Provide direct view of real world with full resolution and no time delay
  - Much easier to see registration problems

Video see-through
- Stream real-time video from head-mounted cameras to the graphics subsystem
- Blends the virtual and real
- Make wide FOV easy to support
- Take advantage of compositing techniques
- Video has lower visual quality

HWPD
- Project imagery into real world
- Ensuring proper color correction and perspective critical
Head-Worn Displays

Advantages
- Complete visual immersion (360 FOR)
- Each user can have their own HWD
- No need for temporal multiplexing
- More portable and less expensive than other visual displays

Disadvantages
- Accommodation-vergence mismatch
- Must deal with weight and weigh distribution of device (potential ergonomic issues)
- Cannot see real world
- Physical objects need graphical representations (non AR HWD only)
Arbitrary Surface Displays

- Project imagery directly on arbitrary surfaces of any shape or size
  - Projection mapping
  - Spatial augmented reality
- Many technical challenges
  - Dependent on complexity of geometrical surface and its color and texture characteristics
  - 3D stereo
  - Shadows
  - Display area restrictions

Common approach is camera projector pairs
- Camera performs display surface estimation
  - Surface’s geometry
  - Color
  - Texture
- Multi-projector systems help with shadows and display size
- Calibration between projectors and camera required to ensure proper display

Other approaches include
- Optical overlays
- Transparent surfaces
Arbitrary Surface Displays

The Illumroom, an example of projection mapping to create an extended display in a living room. The projector-camera pair correctly projects onto the various surfaces in the room. (Photograph courtesy of Microsoft)

Arbitrary Surface Displays

The Virtual Showcase, an augmented surface display that projects virtual information onto a physical 3D artifact, presenting a seamless integration of the physical object and virtual content. (Photograph courtesy of Oliver Bimber)
Arbitrary Surface Displays

- Advantages
  - Good 3D stereo
    - Projecting onto objects supports appropriate depth
    - Will need view dependent stereo for images above or below an object surface
  - Display is anywhere

- Disadvantages
  - Front projection limits direct manipulation
  - Can be difficult to get right visually

Autostereoscopic Displays

- Generate 3D imagery without need for special shutters or polarized glasses
- Common examples
  - Lenticular
  - Volumetric
  - Holographic
- Other approaches
  - Compressive light fields, diffractive-optical elements, integral imaging, parallax illumination and barrier grids
Autostereoscopic Displays

- Parallax barrier: use a vertical grating
  - One eye sees odd pixels
  - Other eye sees even pixels
- Lenticular display: use a cylindrical lens array
  - Different 2D images into different subzones
  - Zones are projected out at different angles

A lenticular display.
(Photograph courtesy of Joseph J. LaViola Jr.)

Volumetric Displays
- Create “true” 3D images by actually illuminating points in 3D space
- Swept-volume approach – sweep a periodically time-varying 2D image through a 3D spatial volume at high frequencies
- Static-volume approach
  - Uses two intersecting invisible laser beams to create a single point of visible light (allows for voxel drawing)
  - Uses high speed projector with a stack of air-spaced liquid crystal scattering shutters
Autostereoscopic Displays

- Holographic displays – produce 3D imagery by recording and reproducing the properties of light waves from a 3D scene
  - Computational step
    - 3D description of a scene is converted into a holographic fringe pattern
  - Optical step
    - Modulates the fringe pattern and turns it into a 3D image
Autostereoscopic Displays

- Advantages
  - Number of viewers with correct perspective unlimited (volumetric and holographic)
  - No trackers needed to maintain motion parallax
  - No accommodation–vergence cue conflicts

- Disadvantages
  - Only small working volume (not appropriate for immersive AR or VR)
  - Cannot produce monocular depth cues (volumetric)
  - Lenticular displays require “sweet spot” for optimal viewing

Auditory Displays

- Generation and display of spatialized 3D sound
- Localization - is the psychoacoustic process of determining the location and direction from which a sound emanates
- Important benefits for 3D UI designer
- Requires
  - 3D sound generation
  - Sound system
3D Sound Generation and Synthesis

- 3D sound sampling: record sound the listener will hear in the 3D application by taking samples from a real environment
  - Can produce realistic results
  - Environmentally specific
- Binaural audio recording: place two small microphones are inside a person’s ears

Simulate binaural recording process
- Process monaural sound source with right and left head related transfer functions (HRTFs)
- Supports position specific listening (highly interactive)

Problems
- HRTF measurements need to be taken in echo-free environments
- Many HRTFs needed to cover an entire space
3D Sound Generation and Synthesis

- **Auralization** - process of rendering the sound field of a source in space using mathematical or physical models
  - Recreate listening environment with reflection patterns
  - Good for reverberation effects

3D Sound Generation and Synthesis

- **Auralization techniques**
  - **Wave-based modeling**
    - Solve wave equation to completely re-create a sound field
  - **Ray-based modeling**
    - Follow rays emitted from sound sources
  - **Ambisonics**
    - Directional recording approach that can capture a full sphere-based sound field with a minimum of four microphones
  - **Wave-field synthesis**
    - Virtual sound source can be approximated by overlapping sources originating from actual sources at other positions
### Sound System Configurations

#### Stereophonic Headphones
- Present different info to each ear
- HRTF coupling
  - High level of channel separation
- Isolate user from external sounds
- Multiple users can receive different 3D sounds
- Problem with inside-the-head localization
  - False impression sounds emanating from inside a user’s head
- Difficult to talk and listen to others outside the application

#### External Speakers
- Placed strategically in physical environment
- Often used with displays that are not head worn
- User does not need to wear any additional device
- Problem with crosstalk
  - Making sure left and right ear receive appropriate sounds
- Speaker placement can cause reduced sound quality
  - Sound partially blocked by display devices and other objects
Audio in 3D Interfaces

- Localization
  - Important 3D cue for wayfinding (Chapter 8)
- Sonification
  - Turning information into sound
- Ambient effects
  - Provide sense of realism
- Sensory substitution and feedback
  - Substituting one sense for another (i.e., sound for touch)
- Annotation and help
- Collaboration

Haptic Displays

- Provide user with sense of touch, force, vibration, temperature
- Force sensations – stimulated from joint and muscle nerve endings
- Touch sensations – stimulated from nerve endings in the skin
- Often coupled with input device tracking
- Requires haptic rendering
Haptic Display Characteristics

- **Perceptual dimensions**
  - Typically required direct physical contact with the body
  - Multiple parallel physiological and perceptual mechanisms required for good haptics
    - No best haptic display
- **Tactile cues**
  - Vibrations at different frequencies and amplitudes, static relief shapes, or direct electrical stimulation
- **Haptic cues**
  - Target different muscle groups in the limb
  - Actively modify forces that apply to the human body
- **Body location**
  - Density and distribution of nerve endings in different parts of the body effects actuation

**Resolution**

- **Spatial resolution**
  - The minimum spatial proximity of the stimuli that the device can present to the user
- **Temporal resolution**
  - Minimal temporal proximity of the tactile stimuli generated by haptic displays (refresh rate)
  - Needs to be high (> 1000 Hz)
Haptic Display Characteristics

- Ergonomics
  - Plays pivotal role
  - Need safety mechanisms in place
  - Do not want to cause pain
  - Want any user attachments to be comfortable and easy to put on

Haptic Display Device Types

- Ground-referenced
- Body-referenced
- Tactile
- In-air
- Combination
- Passive
Ground-Referenced Haptics

- Create a physical link between the user and a ground point in the environment
  - Desktop, wall, ceiling, floor
- Variety of different technologies
  - Force-reflecting joysticks
  - Pen-based force-feedback devices
  - Stringed devices
  - Motion platforms
  - Large articulated robotic arms
- User range is limited

A ground-referenced force-feedback device. (Photograph courtesy of SensAble Technologies)

Body-Referenced Haptics

- Places the haptic device part of the user’s body—the haptic display is “grounded” to the user
  - Provide user with much more freedom of motion
  - User must bear weight of device
- Promising approach to reduce weight is electrical muscle stimulation

A body-referenced force-feedback device. (Photograph reproduced by permission of Immersion Corporation, © 2004 Immersion Corporation. All rights reserved)
Tactile Displays

- Stimulate tactile sense
  - Apply physical stimuli on human skin
- Technologies
  - Mechanical displacement
  - Vibrotactile
  - Electrotactile
  - Electrovibration
  - Surface friction
  - Thermoelectric
- Generally much smaller and more lightweight than the force displays
In-Air Haptics

- Create tactile sensations in “mid-air” without need for direct physical contact with the haptic apparatus
- Techniques
  - Air
    - Concentrated air pressure fields is based on using air vortices
  - Ultrasonic waves
    - Two-dimensional array of hundreds of miniature ultrasonic transducers forms a beam of ultrasonic radiation pressure

Combination Haptics

- Combine more than one haptic/tactile technology
  - Increase realism
  - Increase hardware and software complexity

Combining ground-referenced and body-referenced force feedback (Photograph reproduced by permission of Immersion Corporation; © 2004 Immersion Corporation. All rights reserved)
Passive Haptics

- Use passive physical representations of virtual objects to communicate their physical qualities
  - Convey a constant force or tactile sensation based on the geometry and texture of the particular object
  - Very specific to a particular object
- Can be non-hand-held objects
  - Floors, tables, walls

Haptics in 3D UIs

- Improve realism in 3D UI
- Assist in object manipulation
  - Provide feedback
- Tactile feedback useful for identifying textures on surfaces
- Help determine weight of virtual objects
Displays and Level of Fidelity

- Fidelity: realism of the display
- Level of fidelity: is the degree to which the sensory stimuli produced by a display correspond to those that would be present in the real world

Importance
- Benchmarks compared to real world
- Significant effects on user experience
- No single number, made up of many components (e.g., FOV, FOR, spatial resolution)
- Can be useful in choosing an appropriate display

Case Studies

VR Gaming Case Study
- Want 360 FOR so choice is HWD
- Need to deal with ergonomics and safety
  - Lightweight and comfortable
  - Comfortable accommodation distance
  - Ideally have wireless HWD or backpack
  - Make sure users don’t hit physical objects
- Spatial sound for added realism (headphones)
- Rumble and vibration from hand held controllers
Case Studies

**VR Gaming Case Study**

- **Key concepts:**
  - Choose a visual display that will be both effective and practical for end users
  - Carefully consider human factors issues
  - Don’t forget to account for social aspects such as non-users viewing the VR experience

**Mobile AR Case Study**

- **Requirements**
  - Robust to withstand harsh conditions
  - Comfortable to hold for long periods of time
  - Compact to fit in a backpack
  - Handheld video-see-through AR display was only reasonable choice

HYDROSYS handheld AR device setup. (Image courtesy of Ernst Kruijff and Eduardo Veas)
Case Studies

Mobile AR Case Study

- Key concepts:
  - Support a comfortable power grip to hold the system firmly
  - Allow users to vary their poses and resting the arms against the body to extend usage duration
  - Closely analyze the relationship between display angle and pose
  - Cook closely at the balance of the setup
  - Try to limit the need for additional batteries for operation and compress additional cables

Conclusion

- Examined a variety of different output devices
  - Visual
  - Auditory
  - Haptic
- Looked at display fidelity
- Presented display choices for the two case studies
Next Class

- Input Devices
- Readings
  - LaViola - Chapter 5