3D User Interface Hardware

Lecture #7: Output Devices

Spring 2023

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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

Photograph courtesy of Joseph J. LaViola Jr.

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

Single Screen Displays

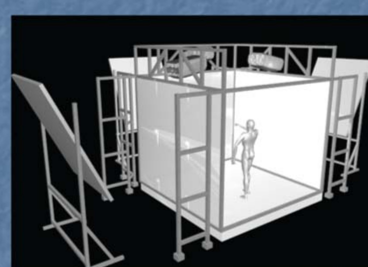
- Stereoscopic viewing
  - Active (shutter glasses)
    - Synchronized to open and close their shutters at a rate equal to the refresh rate of the visual display (temporal multiplexing)
  - Passive
    - Filters two separate, overlaid images with oppositely polarized filters (polarization multiplexing)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



Typical surround screen device with 4 orthogonal screens

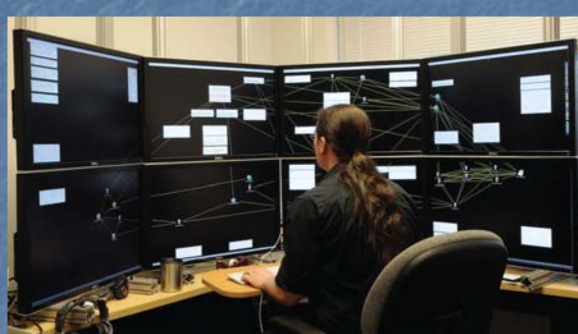
3D model courtesy of Mark Oribello, Brown University Graphics Group

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.)

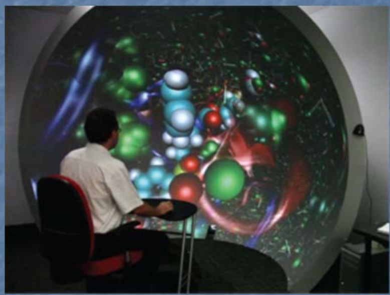
Surround-Screen and Multiscreen Displays



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



A hemispherical display used for interactive molecular visualization.
(Photograph courtesy of Paul Bourke)

A curved, rear-projected surround-screen display that combines both hemispherical and cylindrical geometry.
(Photograph courtesy of Digital Projection)

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

Rotatable display

Pressure sensitive

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

Workbenches and Tabletop Displays

- Personalized head tracked stereo workbench

Photograph courtesy of Joseph J. LaViola Jr.

Workbenches and Tabletop Displays

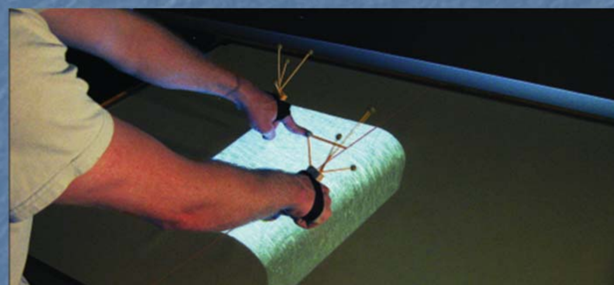


Table-based workbench style display that combines multi-touch and 3D spatial input (Photograph courtesy of Bret Jackson)

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

Head-Worn Displays

- 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 display for virtual reality (Photograph courtesy of Sony)

Head-Worn Displays

HWD that uses a smartphone's high-resolution screen as the display engine (Photograph courtesy of Samsung)

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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

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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

Head-Worn Displays

- 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

Examples of optical see through AR HWDs

Photographs courtesy of Epson and Microsoft

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

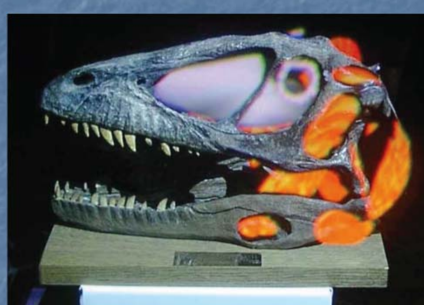
Arbitrary Surface Displays

- 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

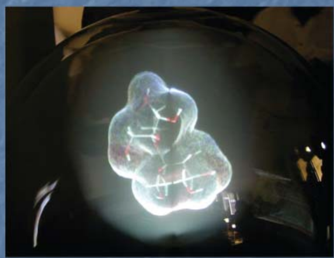
- Parallax barrier: use a vertical grating
  - One eye sees odd pixels
  - Other eye sees even pixels
- Lenticular display: use a cylindrical lens array
  - Different 2D images into different subzones
  - Zones are projected out at different angles

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

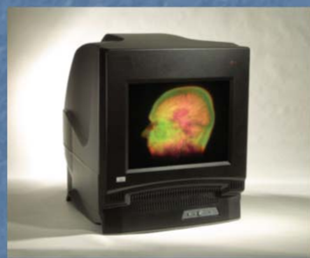
Autostereoscopic Displays

- 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



Swept-volume approach to generate 3D images. (Photographs courtesy of Actuality Systems)



Static-volume approach to generate 3D images. (Photograph courtesy of LightSpace Technologies)

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

3D Sound Generation and Synthesis

- 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 patters
  - 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

Sound System Configurations

- 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

Haptic Display Characteristics

- 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

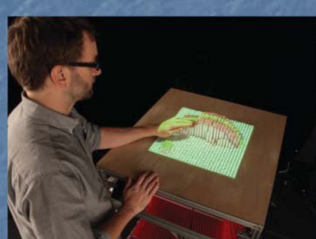
A body-referenced force-feedback device. (Photograph reproduced by permission of Immersion Corporation, © 2004 Immersion Corporation. All rights reserved)

Tactile Displays

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

A tactile device that puts vibrating actuators on the fingertips and the palm of the hand. (Photograph reproduced by permission of Immersion Corporation, © 2004 Immersion Corporation. All rights reserved)

Tactile Displays



InForm is a mechanical displacement display that is able to produce tactile haptic shapes.
(Photograph courtesy of MIT Media Lab)

Electrovibration displays allow the user to feel the bumps and ridges on the 3D rendering projected on the surface of the display. (Photograph courtesy of Ivan Poupyrev, copyright Disney, printed with permission)

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

Vortex-based in-air tactile display. (Photograph courtesy of Ivan Poupyrev, copyright Disney, printed with permission)

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 done 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

Case Studies

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