Display systems

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Overview

- Display technologies
  - Current
  - In development

- Various VR display systems
  - Non-immersive, semi-immersive and immersive
Often a critical factor

- VEs engage visual senses above others
  - Quality of display may determine quality of system
- Projected or screen-based?
- Size
  - Related to immersive v not
- Speed
  - Will they respond to interaction?
- 2D or 3D?
  - Still mostly 2D pretending to be 3D
  - But new technologies very desirable
More display parameters

- Resolution
  - Size and distance-related
- Colour
  - Use differently-coloured pixels next to each other
- Brightness
- Contrast
- Refresh rate
  - Interactivity depends on this
- Sensitivity to viewing angle
Technologies

- Liquid crystal display - LCD
  - Active and passive
- CRT (Cathode Ray Tube)
- Digital Light Processor
- Auto-stereoscopic
- Virtual Retina Display
LCDs

■ Made of small flat chips
  – Transparency properties change when voltage applied
■ Elements in an $n \times m$ array
  – LCD matrix
■ Level of voltage controls gray levels
■ Elements do not emit light
  – LCD matrix is backlit
LCDs cont

- Colour via filters in front of each LCD element
  - Impacts brightness
  - Usually black space between pixels to separate filters

- Hard to make individual LCD pixels very small
  - Impacts resolution

- Image quality depends on viewing angle.
**LCD types**

- **Passive**
  - Cycle through LCD matrix applying required voltage to each element
  - Once aligned with the electric field the molecules in the LCD hold their alignment for a short time

- **Active**
  - Each element contains a small transistor that maintains the voltage until the next refresh cycle.
  - Higher contrast and much faster response than passive LCD
Resolution

- Often quoted as separate colour elements not number of RGB triads
  - Example: 320 horizontal by 240 vertical elements = 76,800 elements
  - Equivalent to $76,800 / 3 = 25,600$ RGB pixels
  - So "Pixel Resolution" is c 185 by 139 ($320/\sqrt{3}, 240/\sqrt{3}$)
Screen-based displays

- Limited in size
  - LCD max = 108 ins
  - Plasma max = 103 ins; non interactive
    - Problems with green phosphor latency limiting update rate
- Limited in resolution
- Thin & lightweight
  - Flexible displays in development
  
  http://en.wikipedia.org/wiki/Flexible_display
Projected displays

- Use bright CRT or LCD screens to generate an image
  - sent through an optical system to focus on (usually) large screen.

- Full colour obtained via separate monochromatic projector for each of R,G,& B colour channels
CRT projector
Front v Back projection

- **Front projection:**
  - Can cast awkward shadows, especially if you get too close
  - Projectors typically high up and hard to access
  - Makes best use of available light

- **Back projection:**
  - Expensive translucent screen
  - Needs more space
  - Loses light: brighter displays needed
Projector pros & cons

- **Very large screens**
  - Large FoV
  - Can be shared by many - supports cooperative working

- **BUT image quality can be fuzzy**
  - Light is lost: dimmer than monitor displays
  - Sensitive to ambient light.
  - Delicate optical alignment, at least with CRTs
CRT pros and cons

- Typically: 3CRT’s + lens per projector
  - Liquid cooled internally
  - Hot; Noisy (cooling); Consume a lot of power; Fragile

- Analogue devices
  - Need frequent calibration; Phosphor decays; Not particularly bright

- Good refresh rate (essential for stereo)

- Very good contrast (20,000:1)

- Can distort the image as necessary to get rectangular display
Dealing with distortion

- Flat display - rectangular image
- Curved display - distorts image
  - Needed on many large-scale displays
- Use CRT distortion to compensate
  - Use automatic hardware to control it
  - Complicates configuration
  - More frequent alignment problems
LCD projector
LCD projected systems

- Usually single projector
  - Brighter; Lower power; Less heat; Less noise
- BUT
  - Lower refresh rate
  - Low contrast (400:1 in typical projectors)
  - Produce polarized light: interferes with LCD shutter glasses
  - Harder to correct for curved screens
Digital projectors

- **Digital Micro-Mirror Device (DMD)**
  - Developed at T.I. Labs in 1994
  - Basis for digital cinema projection
  - 1.3 Million mirrors on a silicon chip
  - Each modulates reflected light, mapping pixel of video data to pixel on display
  - Digitally controlled: load data into memory cell located below the mirror.
  - Switching rate of thousands of Hz
DMD
Digital Light Processing (DLP)

- Electrostatic control of mirror tilt angle
  - +10 degrees (ON) or -10 degrees (OFF).
  - Light from ON mirrors passes through projection lens to screen.

- Digital Light Processing (DLP)
  - All digital display: completely digital except for A/D conversion at front end
  - Progressive display: displaying complete frames of video
  - Removes interlace artefacts such as flicker
DLP cont

- “Square” pixels, fixed display resolution
  - Resolution fixed by number of mirrors on DMD
  - 1:1 aspect ratio of the pixels
- Requires re-sampling of various input video formats to fit onto DMD array
- Digital colour creation
  - Spectral characteristics of colour filters and lamp coupled to digital colour processing in the system
Quality

With LCD projector

With DLP projector
Stereo

- Depends on supplying separate image for each eye
  - Time-parallel (passive stereo)
  - Time-multiplexed (active stereo)
Active stereo

- **One projector**
  - Projects L/R images alternately
  - Quad-buffered stereo - special graphics cards required!
  - Typical refresh rate of projectors 120 Hz (60Hz for each eye)
  - Ghosting problems with CRT projectors (green phosphor too slow)
  - Requires shutter glasses
Shutter glasses

- **LCD display technology**
  - Two crossed, polarized layers per eye
  - One permanently polarized
  - One switchable
  - Controlled by an IR signal
Pros and cons

- Expensive: > 100 GBP/pair
- Quite heavy - batteries and electronics inside
- Maintenance issues:
  - Batteries run out
  - Fragile
- Direct line-of-sight
- 50% light loss
  - could avoid with two active layers
- Single projector
  - Cheaper and easier to set up
  - But impact on frame rate
Passive stereo

- Two projectors
  - Polarize with each with different filter
- View with two lenses
  - Polarized in orthogonal directions
Pros and cons

- Cheap
- Light and comfortable
- More or less indestructible
- Continuous image in both eyes (2 projectors)
- Two projectors
  - Expensive
  - Alignment issues
  - Non-polarizing screen required
  - 50% light loss
  - Can’t tilt head more than a few degrees


Stereo rendering

- Two camera ports
  - Slightly separated
- Can be calculated in software
  - But can be done in hardware on some graphics cards
Displays classification - 1

- **Head-Mounted Displays (HMDs)**
  - The display and a position tracker are attached to the user’s head

- **Head-Tracker Displays (HTDs)**
  - Display is stationary, tracker tracks the user’s head relative to the display.
  - Example: CAVE, Workbench, Stereo monitor
Differences

■ HMD
  - Eyes are fixed distance and location from the display screen(s)
  - User line-of-perpendicular to display screen(s) OR at fixed, known angle to the display screen(s).

■ HTD
  - Distance to display screen(s) varies
  - Line-of-sight to display screen(s) almost never perpendicular
  - Usually much wider FoV than HMD
  - May combine virtual and real imagery
Displays Classification - 2

- Non-immersive (desk-top) VR
- Semi-immersive VR
- Immersive Systems
Non-immersive VR

- workstation screen
- navigation using a mouse/spaceball
- stereo glasses
Semi-immersive VR

- Large screen
- stereo glasses
- datagloves
- position tracking
Immersive Systems

- Head Mounted Displays - HMD’s
- Cubical projection systems - CAVE
- datagloves, position tracking.
HMDs

- Still identified with VR in popular mind
- Originally CRT based: one screen/eye
  - High-end systems still are
  - Expensive, bulky, but higher resolution
- Less expensive systems are LCD-based
  - resolution: varies from 320x240 up to 1700x1350, standard 800x600
- Limited FoV
  - 25-100 degrees diagonal
  - See http://www.stereo3d.com/hmd.htm
Head Mounted Displays
Occulus Rift

- HMD for games partly financed by crowdfunding: $2.4m out of $91m
  - See http://en.wikipedia.org/wiki/Oculus_Rift
- Developer version: 1280x800= 640x800/eye; consumer ?1920×1080
  - Developer cost $300; consumer version ?
    summer 2014
  - LCD 7” screen; 24 bit colour
  - Low latency tracker: 1000Hz
  - Adjustable eye distance; replaceable lenses
  - Inter-pupil adjustment in software
Resolution issues

- Number of pixels related to display area
- Pixel size also related to viewing distance
- Closer to a screen results in less resolution
Accommodation v convergence

- All projected images actually at same distance
  - On the screen
  - Thus *constant* accommodation: unlike real world
- But manipulated to create convergence for eyes
  - Thus variable convergence
- Can create eye strain
  - HMDs have screens very close to the eye
Issues with HMDs

- Inter-pupil distance (IPD) needs to be adjusted
  - Or it puts extra strain on the eyes
- Resolution and FoV not very good
  - OculusR remains to be seen
- Cannot see one’s own body
  - Impairs presence
- Not collaborative
  - Becomes expensive in multiples especially at high end
- Cumbersome to wear
  - Especially over spectacles: need replacable lenses
CAVE
Characteristics

- **4-6 active stereo surfaces**
  - Around 3m sq
  - Usually backprojected using mirrors
  - Floor sometimes front projected from ceiling

- **Enclosure**
  - Tracking system for ONE user
  - Can fit maybe 4 others into space
  - Often adds spatialised sound

- **Can ‘walk around’ displayed objects**
  - Can see own body - high presence
  - Occasionally people walk into a wall
Fully immersive
Large footprint!
Update rates

- Head turning not a problem
  - Unlike many HMDs
  - But much more computational power

- Fast head movement within space can be a problem
  - Tracking allows update
  - Sometimes with a bit of a lag
Computational requirement

- Originally large multi-graphic pipe rack system
  - One pipe per panel
  - SGI: contributed to high cost

- Current work
  - Use of PC cluster
  - x2 PCs per panel: one for each stereo channel

- Cluster issues
  - Software
  - Synchronisation
  - Large models
Workbench

- **Immersadesk**
  - Back-projected
  - Stereo
  - Objects float in front
  - Hand & head tracking

- **Good for object interaction**
  - Life-size (‘widgets’) or less-than-life-size (buildings in city models)

- **Can link for collaboration**
Semi-Immersive Display

- Reality Room
  - Three edge-blended front projectors
  - No tracking
  - 150 by 40 degree Horizontal and Vertical FoV
  - Engages peripheral vision
Characteristics

- **Very good for spatial engagement**
  - Very large FoV
  - Building interiors
  - City models

- **Good for collaborative work**
  - 20 people
  - Design reviews
  - Popular in oil industry
  - Public involvement in urban planning decisions
Issues

- **Interactively weak**
  - Driven by one person with a mouse (possibly 6 dof): no head tracking
  - Can produce cybersickness especially for fast movement

- **Projector ‘blending’ can be a problem**
  - Often visible
  - Projectors need frequent tuning to hide it

- **Must compensate for curved screen**
  - Usually best done with CRT displays: less bright
WorkWall

Features:
- flat screen
- two or more edge blended projectors
- rear projected
WorkWall

- Screen size: (two configurations)
  - 8.0’ h x 16.0’ w and 8.0’ h x 24.0’ w screens
    (2.1m h x 4.9m w and 2.4m h x 7.3m w)
- Size: Scaleable display setup is.
- Work Group Size: Ideal for two to forty viewers
- Maximum Resolution:
  - 3 Projector System 3456 x 1024 resolution
  - 2 Projector System 2304 x 1024 resolution
**Dome/sphere displays**

- **Multiple projector system**
  - Project onto domed surface above
  - 180 deg or more
    - e.g. Trimension V-dome: Hayden planetarium, American Museum of Natural History
    - 180x180; 21 m diameter; 7 projectors

- **ETH Zurich Visdome**
Solving the movement problem

- **Cybersphere**
  - Bearings at base
  - Rotates as walk
Factors in choosing displays

- Degree of immersiveness and presence needed
  - Relationship to virtual space
  - Objects life-size or not?
- Amount of interactivity needed
  - Balance between object interactivity and navigation
- Degree of cooperative working
- Space requirements and cost
Technologies under development

- **Auto-stereoscopic**
  - Commercially available but non-interactive

- **Virtual Retinal display**
  - Still being researched
Auto-stereoscopic

- **Stereo without glasses**
  - Both halves of stereo pair displayed simultaneously, directed to corresponding eyes
  - Uses special illumination plate behind the LCD: light from compact, intense light sources
  - Optically generates lattice of very thin, very bright, uniformly spaced vertical light lines
  - Lines are spaces with respect to pixel columns of the LCD
  - Left/right eye sees lines through odd/even columns
Lenticules

- **Lenticular sheet**
  - contains series of cylindrical lenses molded in plastic substrate.
  - lens focuses on image behind lenticular sheet.
  - Each eye's line of sight focused onto different strips.
Current state

- Laptop with auto-stereo screen available
- Non-interactive display for product display
  - Similar to plasma screen size
- Sensitive to head position
  - Too slow for interaction right now
Virtual Retinal Display (VRD)

- Scan light directly onto retina
  - No screen needed
- Idea from scanning laser ophthalmoscope
  - Used to acquire picture of retina
- Work at University of Washington
  http://www.hitl.washington.edu/research/vrd/
Laser-based

- VGA video source (640x480)
- Argon for blue and green
- Laser diode for red
- Control and drive circuits
  - Direct modulation of laser diode
  - Indirect modulation of argon source
VRD

- Scanned onto retina using
  - Horizontal: mechanical resonant scanner
  - Vertical: galvanometer
- 40 nsec on retina with no persistence
- Scan loops instead of flyback
  - 60 Hz interlaced
  - Final scanned beams exit through lens
- User puts eye at exit pupil of VRD to see image
  - Total: 307,200 spots of non-persistent lights
Characteristics

- Perceived without flicker
  - With vibrant colour
- Seen both in occluded and augmented viewing modes
- Extremely small exit pupil
  - Large depth of focus
Advantages

- Large colour range
- Theoretical resolution limits set by eye
- Luminance should be safe
  - 60-300 nW for perceived equivalent brightness
  - 3-4 times less power than CRT
- Better contrast ratio than CRT
- Better depth of focus
  - Like a pinhole camera
- Low power consumption (if using laser diodes)
- Theoretically very cheap
Issues

- Problem with head movement
  - Lose the image

- Needs an argon laser
  - Large and costly
  - But red, green, and blue laser diodes are coming

- Safety issues still not clear
  - Coherent light vs. non-coherent

- Need better resolution and larger FoV

- Want portable version (eye glasses)
FogScreen Inia

- Frameless walk-through screen by Inition
- Fog screen injected into a laminar airflow
  - Translucent / fully opaque images projection
  - 2 metres wide X 1.5 metres high
- Fog – ordinary water & ultrasonic waves
FogScreen Inia

- **Standard video projectors**
  - 2 projectors: different images on both sides of the screen
  - At least 3000 ANSI Lumens
  - Can use both back & front projection
  - Min 2 metres between projectors and screen
  - Better result with a darker background

- 25.6" (65cm) high x 35.4" (90cm) deep x 91" (2.31m) wide, Weight 150kg.

- Interactivity through pointer stick
Conclusions

- **Display technology still imperfect**
  - New technologies being developed
  - Still problems with resolution, brightness, FoV

- **A number of different display systems**
  - Different characteristics
  - Choose in relation to application