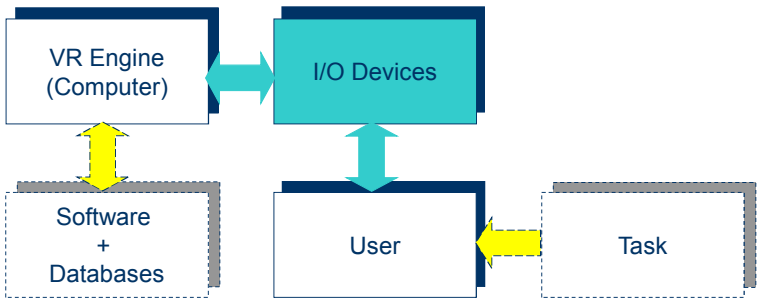
ENSF 545
Introduction to Virtual Reality

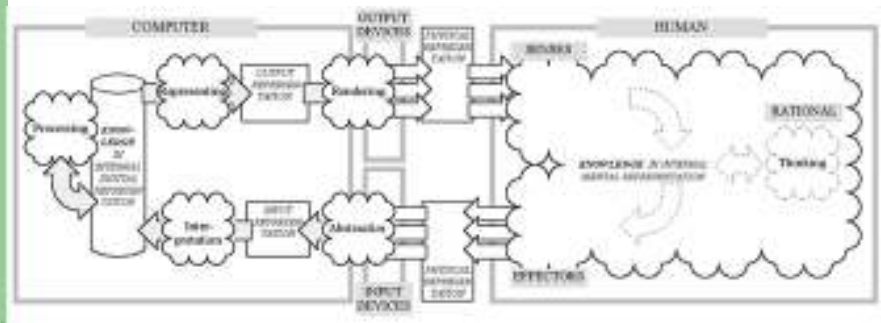
Output Devices

A VR System



Human-Computer Interaction

- Computer outputs ➔ human input (Senses)
- Computer inputs ➔ human output



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Output Devices for VR

- Graphics displays
  - visual feedback
- Haptic interfaces
  - force and touch feedback
- 3D audio hardware
  - localized sound
- Smell and taste feedback ???

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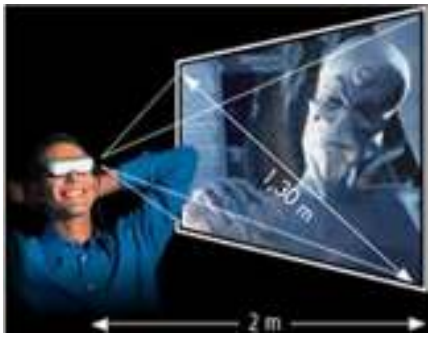
Graphics Displays

Graphics Displays – Definition

- A computer interface presents synthetic world images to one or several users interacting with the virtual world.

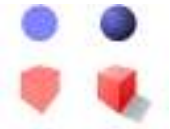


Olympus Eye Trek Face Mounted Display Optics

Depth Cues in Human Vision

Relative size

Lighting, shadows



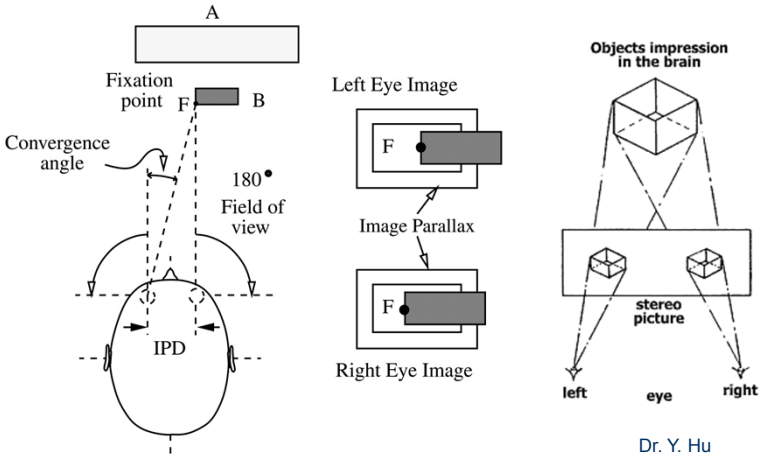
Linear perspective

Camera focus, depth of field

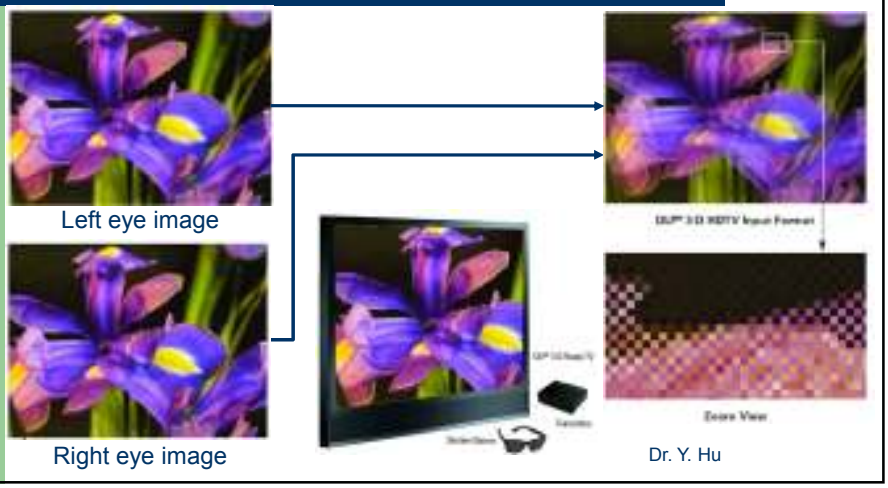
Overlaying

Speed

Human Visual System



Stereoscopy ←→ 3D HDTV



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Consideration - Stereo Displays

- For what purposes is a stereoscopic display suitable?
- How to present 2 images of the same VR environment?
- How to deal with image discontinuity?
- What are the cost and availability?
- How does a stereo display differ from another in quality and performance?

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Graphics Displays – Types

- Images
  - Stereoscopic, monoscopic
- Display technology
  - LCD- and CRT-based, projector-based
- Volume
  - Personal displays
  - Large volume displays

Personal Displays

- Definition:
  - A graphics display that outputs a virtual scene destined to be viewed by a single user
- Types (stereoscopic):
  - Head-mounted displays (HMD)
  - Hand-supported displays (HSD)
  - Floor-supported displays
  - Autostereoscopic displays

Head Mounted Displays (HMD)

- Project images floating some 1~ 5 m in front of the user (one)
- Display technology
  - LCD
  - CRT
  - Organic LEDs
- Resolution
  - 800 x 600, 2400x 1729

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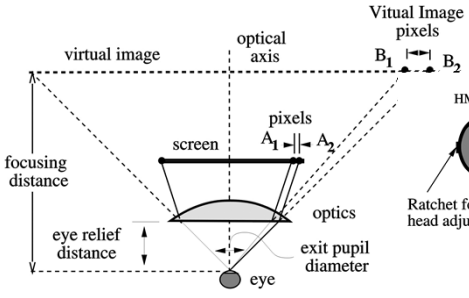
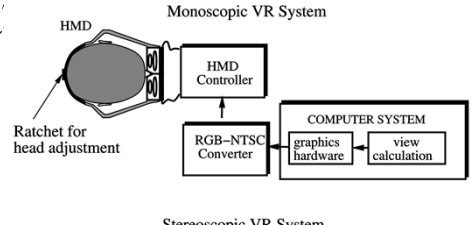
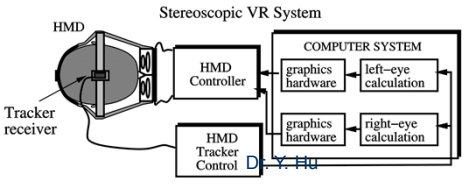
HMD: How to present 2 images for stereoscopy ??

HMD in a VR System



Simplified HMD Optics Model





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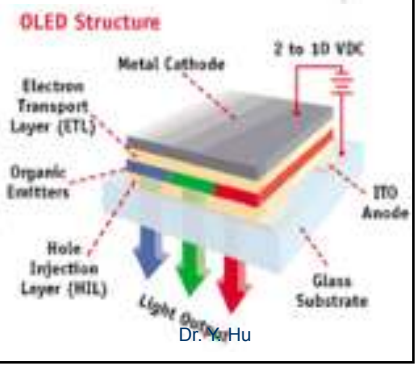
Organic LEDs (OLED)

- Light emitting polymer
- No need of a backlight
- Pixel-wise on/off
- No intrinsic limitations to the pixel resolution
- Low power consumption
- Paper thin and bendable
- Effective manufacturing
- Degradable



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OLED HMDs

- 5DT
  - 800x600, stereo
  - 40^0 diagonal view
  - 600 grams, $4k
- Samsung Emagin z800
  - 800x600, stereo
  - 360^0 pan + 60^0 pitch (tracking)
  - 8 oz, $1.2k
- Sensics *piSight* panoramic
  - 2400x1729, binocular overlap 82^0
  - 179^0 horizontal + 58^0 vertical
  - 1 kg, $???

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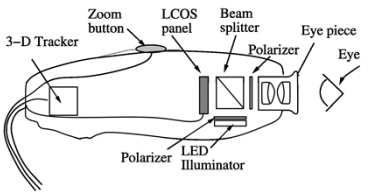
Supported Displays



- Virtual binocular
- Floor supported displays

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Autostereoscopic Displays

- Not need of special glasses or other viewing aids
  - Passive displays
  - Active displays
- Display technologies
  - Parallax barrier
  - Lenticular sheets
- Resolution
  - 640x1024 to 1600x1200

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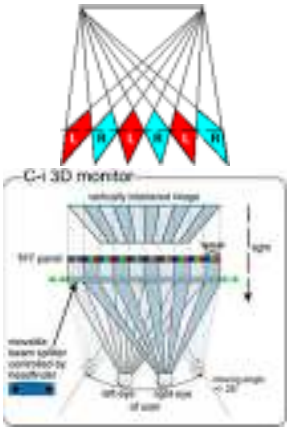
Types - Autostereoscopic Displays

- Passive display
  - Not track the user's head
  - The user's eyes in a small area to perceive 3D effect
- Active display
  - Track the user's head and performs a real-time adaptation of the column interlaced images



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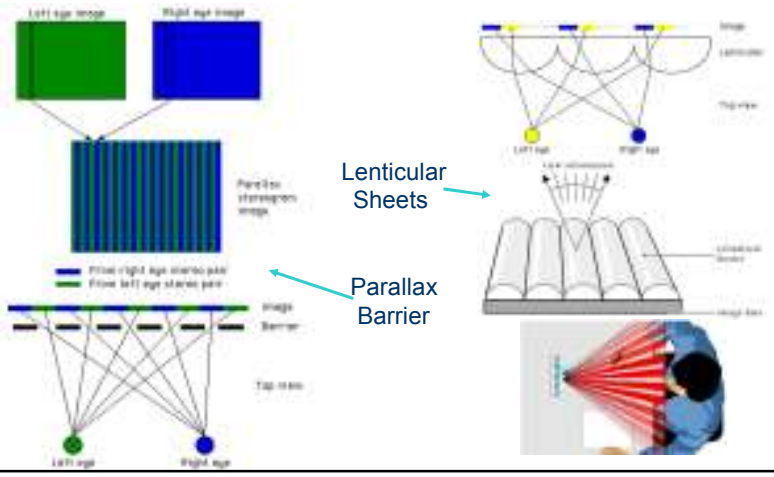
Autostereoscopic displays:
How to present 2 images for stereoscopy ??

Parallax Barrier + Lenticular Sheets



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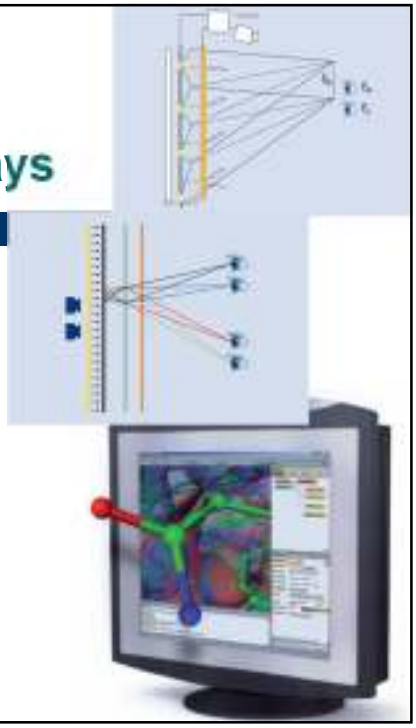
Multi-user Auto-stereoscopic Displays

- Tracking pupils of multiple users
- Good resolution but showing some flicker
  - OLED might help to eliminate flicker
  - Higher display frequency (100 ~ 120 Hz)



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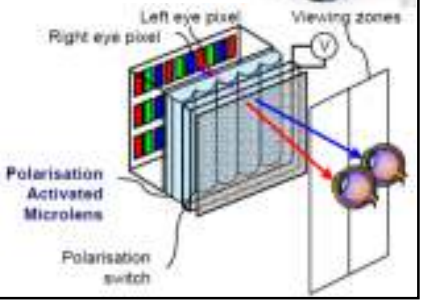
Autostereoscopic Cell Phone!

- TTPCom Technologies → InTouch
  - 2.1” transflective 2D/3D TFT-LCD
  - RGB displaying 132x176 pixel
  - Automatic switching 2D/3D
  - Running TTPCom WGE 3D stereo game demos



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Holographic Displays

- Objects appears to float in space via a 9 optical layer glass panel
- Bare-hand 3D interaction
- Incorporation of IR cameras and image processing board

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Comparison of Displays

Table 3.1 Performance comparison of various personal graphics displays

Display name	Type	Resolution (pixels)	FOV (H × V)	Weight (grams)	Price 10^3
Olympus "Eye-treck"	AMLCD FMD200	267×225	30°× 23°	100	.5
Daeyang "Cy-visor"	LCOS LCD FMD	800×600	60°× 43°	160	1
Keiser "ProView XL35"	AMLCD HMD	1024×768	28°×21°	992	20
n-vision "Datavisor"	CRT HMD	1280×1024	78°×39°	1,587	35
n-vision "V. Binoculars"	CRT HSD	1280×1024	42° diagonal	907	13.5
Fakespace Labs "Boom3C"	CRT FSD	1280×1024	85°×	N/A	up to 100
Virtual Research "WindowVR"	Flat panel FSD	1280×1024	21" diagonal	N/A	13.9
DTI "Virtual Window"	TFT LCD autostereo	1280×1024 2D 640×1024 3D	18.1" diagonal	11,250	7
Elsa "Ecomo4D"	TFT LCD autostereo	1280×1024 2D 640×1024 3D	18" diagonal	17,000	15

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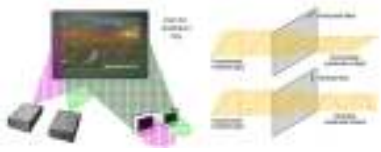
Large Volume Displays

- Definition
  - Graphics displays that allow several users located in close proximity to simultaneously view an image of the virtual world
- Active or passive glasses
- Classifications
  - Monitor-based
  - Projector-based (predominant)

3D Glasses – Passive and Active

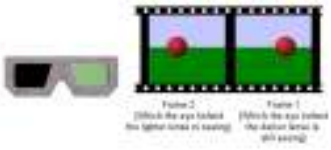
- Anaglyph glasses

- Polarized 3D glasses



- Shutter glasses (active)

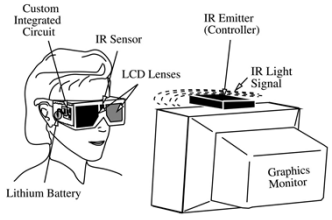
- Pulfrich 3D Glasses



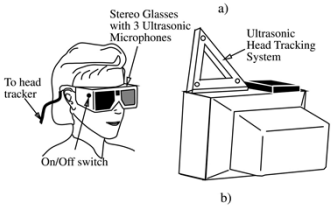
Displays using active glasses:
How to present 2 images for stereoscopy ??

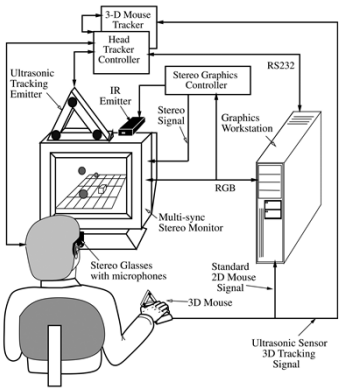
Monitor-based Displays

Untracked Wireless



Tracked Wireless





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Side-by-Side Monitors

Panoram PV 290

Resolution:
3840 x 1024
Dimension:
1,11 m x 0.29 m

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Image Synchronization

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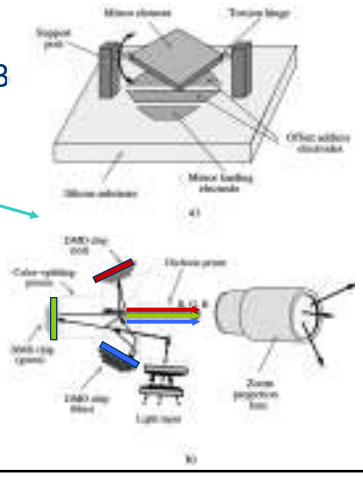
Projector-based Displays

- Old technology
  - ➔ CRT-based 3 tubes (R, G, B
- Recent technology
  - ➔ *Digital Micro-mirror Device*
    - Workbench-type displays
    - Cave-type display
    - Wall-type displays
    - Domes



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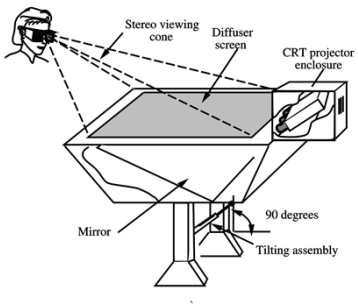
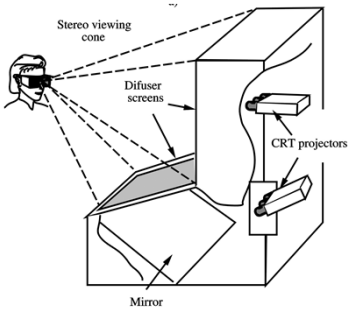
Workbench-type Displays

Fakespace “ImmersaDesk”

BARCO “Baron”

Workbench Geometries





New Types of Displays

BARCO trace

Microsoft SURFACE

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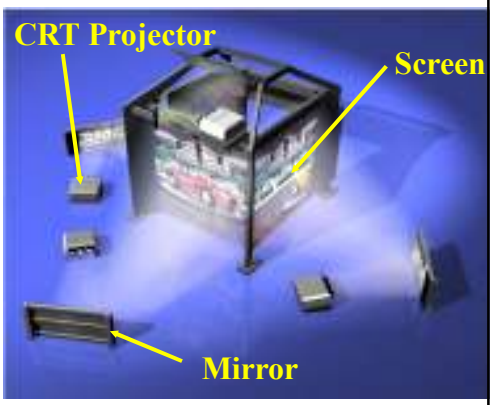
Cave-type Displays - CAVE

- CAVE (Computer-automated Virtual Environment)
- Invented at the Electronic Visualization Laboratory, the University of Illinois



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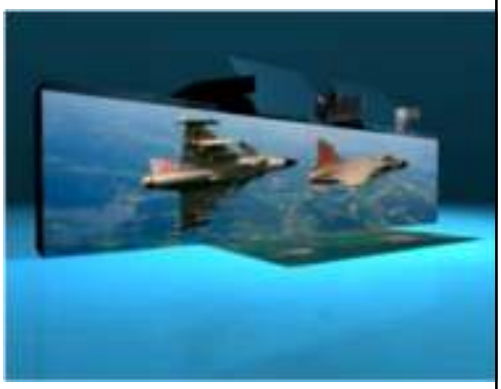
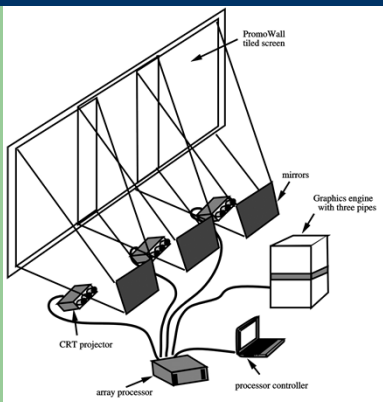
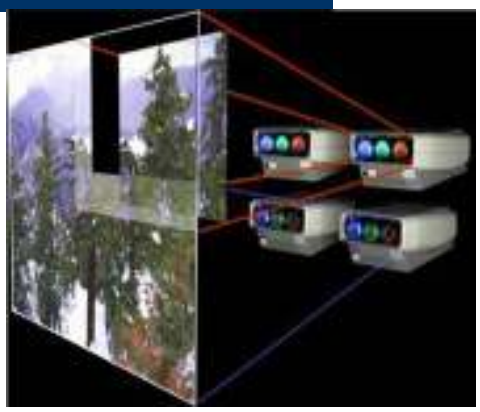
Cave-type Displays - RAVE

- RAVE (Re-configurable Virtual Environment)
- Various viewing
  - flat wall
  - angled theater
  - CAVE
- Several minutes to reconfigure



Wall-type Display





Pros and Cons of Wall-type Displays

- Advantages:
  - Accommodate more users
  - Give users more freedom of motion
- Disadvantages:
  - Large cost
  - Much lower resolution than for CRTs
  - More projects for more numbers of pixels/unit

Comparison of Displays

Table 3.2 Comparison of various large-volume graphics displays

Display name	Type	Resolution (10^6 pixels/m^2)	Image size (m^2)	Number of users	Price $\times 10^3$$
StereoGraphics "CrystalEyes"	active glasses	18.2	0.36× 0.2	4 approx.	2.6
Panoram PV280	3-panel monitor	12.2	1.11× 0.29	3 approx.	25
Barco Baron	tilt workbench	1.9	1.36× 0.71	4 approx.	80
Trimension L-shaped V-Desks	L-shaped workbench	1.0	1.36× 1.73	4 approx.	173
Fakespace Workroom	4-wall CAVE	0.1	3.0 × 3.0×4	12	300
Fakespace RAVE	modular CAVE	0.2	2.3× 2.4×4	var.	500
Panoram PanoWall	Wall (3 proj.)	0.2	7.11× 2.13	var.	300
Trimension V-Dome	Dome (7 proj.)	0.009	21 diameter	400	2,172

Note: Price does not include the computer driving the simulation

Consideration - Stereo Displays

- How to present 2 images of the same VR environment?
- How to deal with image discontinuity?
- For what purposes is a stereoscopic display suitable?
- What are the cost and availability?
- How does a stereo display differ from another in quality and performance?

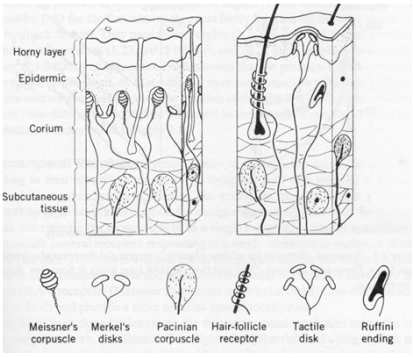
Haptic Displays

Haptic Displays

- Haptics:
  - the sense of touch (from Greek Hapthai)
- Tactile feedback:
  - conveys real-time information on surface geometry, surface roughness, slippage, and temperature
- Force feedback:
  - provides real-time information on surface compliance, object weight, and inertia

Human Touch

- The hand:
  - Most touch sensors
- Four primary sensors:
  - Meissner's corpuscles
  - Merkel's disks
  - Pacinian corpuscles
  - Rufini corpuscles



Skin Sensors

Table 3.3 Comparison of various skin mechanoreceptorss

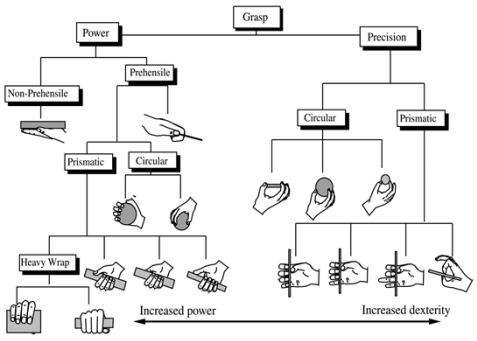
Receptor Type	Rate of Adaptation	Stimulus frequency (Hz)	Receptive Field	Function
Merkel Disks	SA-I	0–10	Small, well defined	Edges, intensity
Ruffini Corpuscles	SA-II	0–10	Large, indistinct	Static force, skin stretch
Meissner Corpuscles	FA-I	20–50	Small, well defined	Velocity, edges
Pacinian Corpuscles	FA-II	100–300	Large, indistinct	Acceleration, vibration

Based on Seow [1988], Cholewiak and Collins [1991], and Kalawsky [1993]

SA-I: Slow adaptation, high spatial resolution; SA-II: Slow adaptation, low spatial resolution
FA-I: Fast adaptation, high spatial resolution; FA-II: Fast adaptation, low spatial resolution

Maximum and Sustained Force

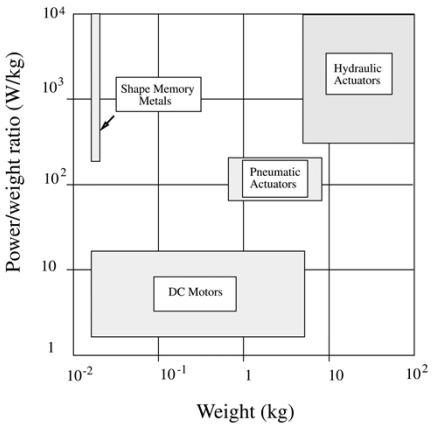
- Maximum force
  - in “power” grasp
  - 400 N (male), 225 N (female)
  - 50 N (finger joint), 100 N (shoulder)
- Sustained force
  - much smaller than maximum



Haptic Feedback Actuators

- Good power/weight ratio;
- High power/volume ratio;
- High bandwidth;
- High dynamic range (fidelity);
- Safe for the user

➔ None actuator technology satisfies all requirements



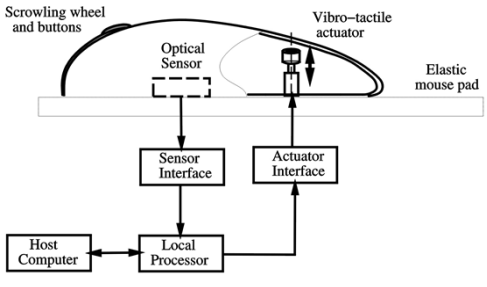
Consideration – Haptic Displays

- How to differentiate tactile feedback from force feedback?
- For what purposes is a haptic display suitable?
- What are the cost and availability?
- How does a haptic display differ from another in quality and performance?

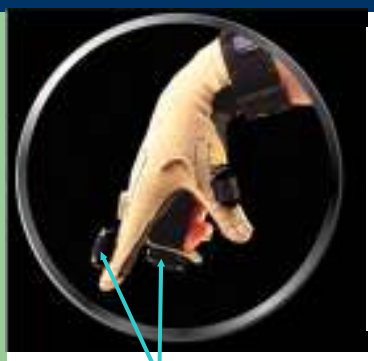
Tactile Feedback Interfaces

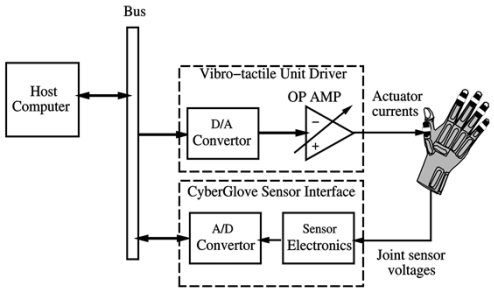
- Desk-top or wearable (gloves);
  - Touch feedback mouse;
  - CyberTouch glove;
  - Temperature feedback actuators;

Tactile Feedback - iFeel Mouse



Tactile Feedback - CyberTouch Glove

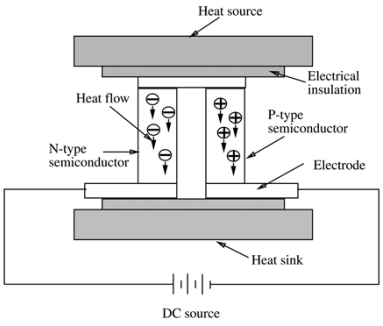


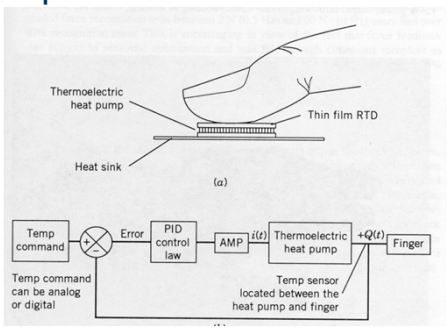


Vibrotactile actuators, 0-125 Hz frequency, 1.2 N at 125 Hz

Tactile Feedback - Temperature

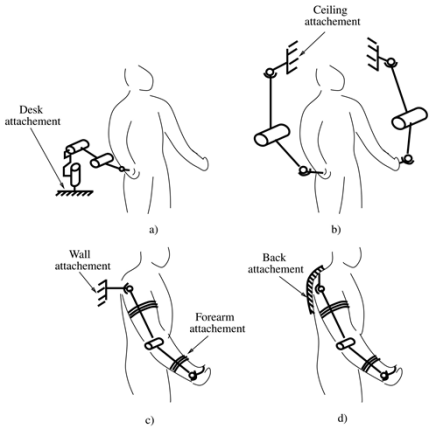
- Simulate surface thermal “feel”
- Use thermoelectric pumps





Force Feedback Interfaces

- Mechanical grounding to resist user motion
  - Force joystick
  - Stylus-style
  - Exoskeleton



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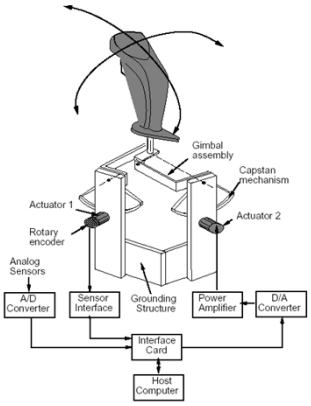
Force Feedback - Joystick



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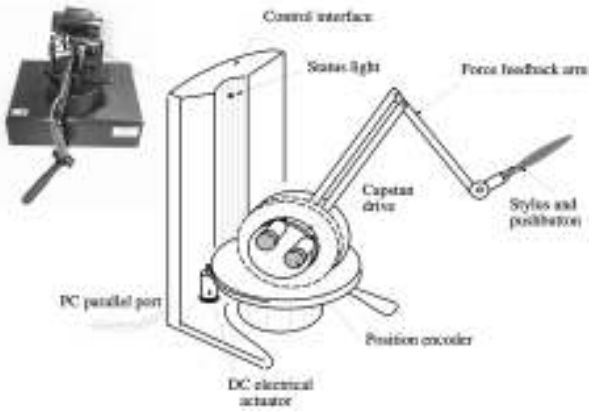
Force Feedback - Stylus-style (Serial)



SensAble PHANToM

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Comparison of PHANToMs

Model	The PHANTOM Desktop Device	The PHANTOM Omni Device
		
Force feedback workspace	~6.4 W x 4.8 H x 4.8 D in. ~ 160 W x 120 H x 120 D mm	~6.4 W x 4.8 H x 2.8 D in. ~ 160 W x 120 H x 70 D mm
Footprint (Physical area the base of device occupies on the desk)	9 5/8 W x 7 1/4 D in. ~245 W x 184 D mm	8 5/8 W x 8 D in. ~168 W x 203 D mm
Weight (device only)	6 lb 5oz	3 lb 15 oz
Range of motion	Hand movement pivoting at wrist	Hand movement pivoting at wrist
Nominal position resolution	> 1100 dpi ~ 0.023 mm	> 450 dpi ~ 0.055 mm
Backdrive friction	< 0.23 oz (0.06 N)	<1 oz (0.26 N)
Maximum available force at nominal (orthogonal arms) position	1.8 lbf. (7.9 N)	0.75 lbf. (3.3 N)
Continuous available force (24 hrs.)	0.4 lbf. (1.75 N)	> 0.2 lbf. (0.88 N)
Stiffness	X axis > 10.8 lb/in (1.86 N/mm) Y axis > 13.6 lb/in (2.35 N/mm) Z axis > 8.6 lb/in (1.48 N/mm)	X axis > 7.3 lb/in (1.26 N/mm) Y axis > 13.4 lb/in (2.31 N/mm) Z axis > 5.9 lb/in (1.02 N/mm)
Inertia (apparent mass at tip)	~0.101 lbm. (45 g)	~0.101 lbm. (45 g)
Force feedback	x, y, z	x, y, z

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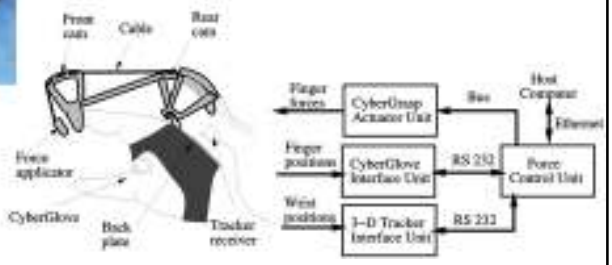
Force Feedback - Stylus-style (Parallel)

Omega 3DOF

Delta 6DOF

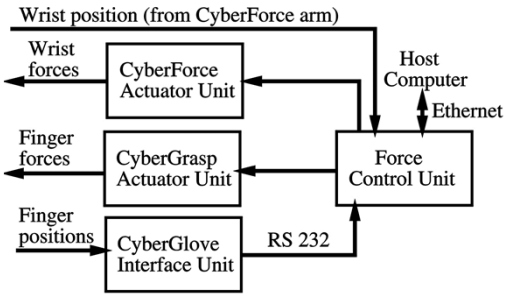
Novint Falcon 3DOF

Force Feedback - Exoskeleton



CyberGrasp

Force Feedback - Exoskeleton



CyberForce

Comparison of Haptic Displays

Table 3.5 Haptic interfaces for the hand

Product Name	Type of feedback	Number actuators	Maximum Force (N)	Weight (grams)	Bandw. (Hz)	Price ($10^3$$)
iFeel Mouse	vibro-tactile	one	1.1N @30 Hz	132	0–500	0.04
CyberTouch glove	vibro-tactile	six	1.2N @125 Hz	142	0–125	15
DTSS X10	tempe-rature	up to eight	NA	340	na	20
WingMan 3D joystick	force	two	3.3	na	0–333	0.06
PHANToM Desktop	force	three	6.4	75	7	16
PHANToM 1.5/6.0	force	six	8.5	90–188	15 (est)	57
Haptic Master	force	three	250	na	10	34
CyberGrasp glove	force	five	16	539	40	39
CyberForce arm	force	eight	8.8 (transl.)	na	7	56

Consideration – Haptic Displays

- How to differentiate tactile feedback from force feedback?
- For what purposes is a haptic display suitable?
- What are the cost and availability?
- How does a haptic display differ from another in quality and performance?

Sound Displays

Sound Displays

- Synthetic sound feedback to users interacting with the virtual world
- Sound types
  - Monoraural
  - Binaural → Stereo
- Increase the simulation realism

➔ Reading

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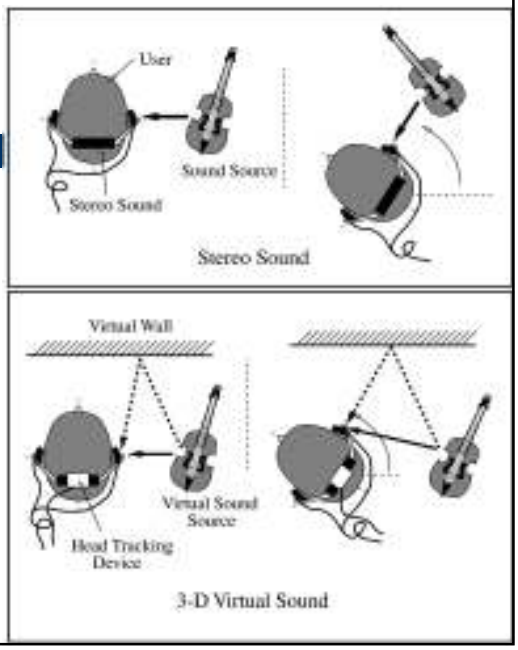
Stereo vs. 3D sound



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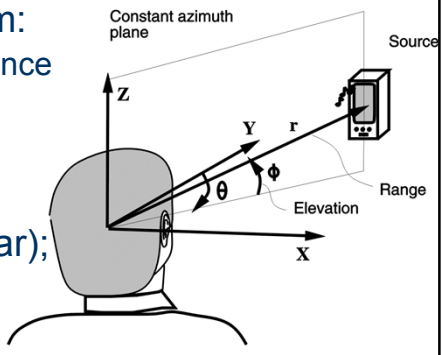
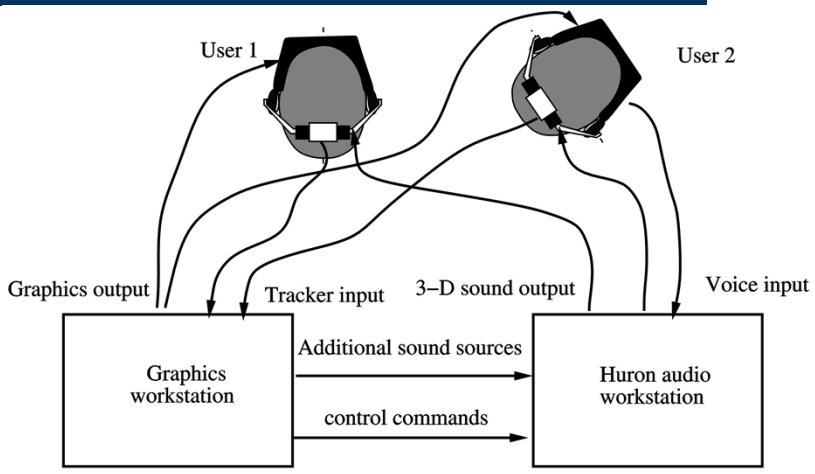
Human Hearing Model

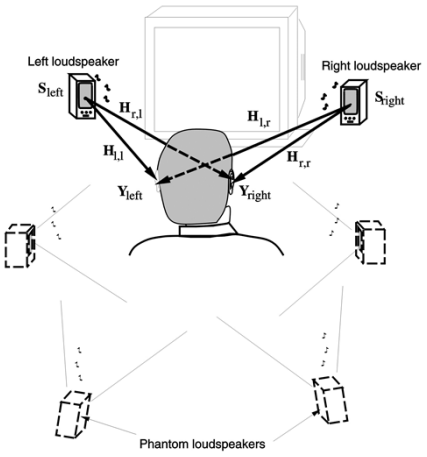
- Polar coordinate system:
  - azimuth, elevation, distance (range);
- Azimuth cues;
- Elevation cues;
- Effect of pinna (outer ear);
- HRTFs (head related transfer functions)



The Huron Workstation



3-D Audio Displays



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Commercial 3D Sound Cards

- What they have to offer:
  - Digital output
  - Multi-speaker compatibility → 7.1 channel format allows for 8 speakers
  - Positional audio → offers 3D dimensions of sound
- Two main audio APIs
  - DirectSound 3D (DS3D) → Microsoft 's DirectX component
  - Aureal 3D (A3D) →An extension of DS3D

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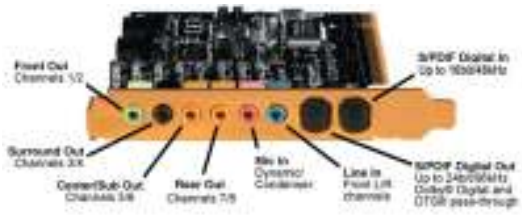
Creative Labs Sound Blaster Audigy 4 Pro

- Creative Labs Sound Blaster Audigy 4 Pro

- Turtle Beach Montego DDL 7.1 Sound Card



Comparison of 3D Sound Cards

Name	Chip/3Dsound engine/API	In/Out	SR
Creative Sound Blaster Audigy 4 Pro	CA10200 ICT DSP/CreativeWare/A3D 1.0, EAX Advanced HD 4	7.1-analog out; 5.1-digital out (DIN) ; 2-digital in/out (coaxial); 2-digital in/out optical ac3/dts pass-thru	$299
Philips Acoustic Edge	ThunderBird Avenger/QSound/ A3D 1.0/EAX 2.0	5.1-analog out; 2-digital in/out (coaxial); ac3/dtz pass-thru	$100
Turtle Beach Montego DDL 7.1	EAX 1 and 2, A3D, I3DL2 and DirectSound 3D	7.1-analog out; Optical S/PDIF In/Out; audio resolutions 24 bit (out) 16 (in); sample rates 96kHz (out) and 48kHz (in).	$80

Conclusion + Recap

- All output devices aim at stimulating the user's senses in real time.

- Graphics displays
- Haptic feedback
- 3D audio feedback (reading)
- No smell and taste feedback