

# Output Devices

Hannes Kaufmann

Interactive Media Systems Group (IMS)  
Institute of Visual Computing &  
Human-Centered Technology

Based on material by Dieter Schmalstieg, Oliver Bimber and Skip Rizzo

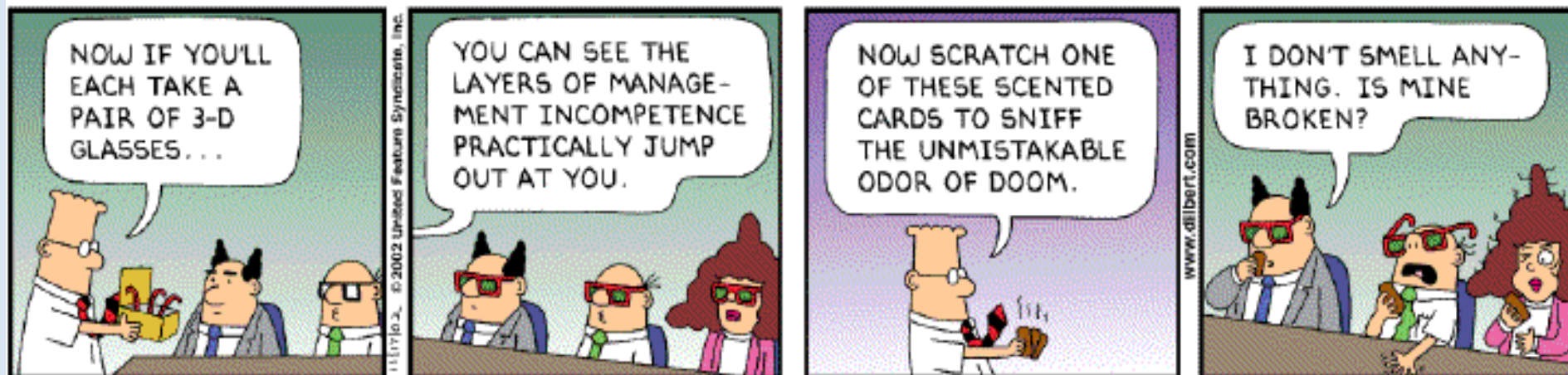
# Human Sensory Perception

- Vision ~ 70%
- Hearing ~ 20%
- Smelling ~ 5%
- Tasting ~ 4%
- Touch/haptic perception ~ 1%

In „The Cinema of the Future”, Morton Heilig, 1955, p. 247

# Display Hardware

- Visual Displays
- Auditory Displays
- Olfactory Displays
- „Taste Display“
- Haptic & Tactile Displays



# Immersion

## *“suspense of disbelief”*

Suspension of disbelief is a willingness of a reader or viewer to suspend his or her critical faculties to the extent of ignoring minor inconsistencies so as to enjoy a work of fiction.

- Immersion into a convincing simulation of reality
- Presentation of the artificial reality is done by stimulating human senses
- Stimulation through *Output Devices*



# Classification by Immersion

- Desktop Virtual Reality
  - = “Window on World” system
  - Conventional screen + 3D graphics
- Fishtank Virtual Reality
  - Tracking
  - Stereo (shutter glasses)
- Semi-immersive
  - CAVE, Workbench, large stereo screens
- Full Immersion
  - HMD, BOOM, VRD
  - options: audio, haptic interface

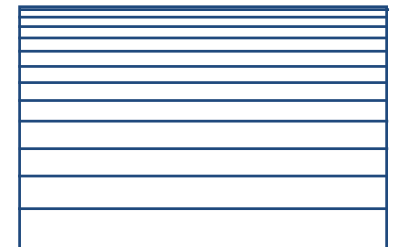
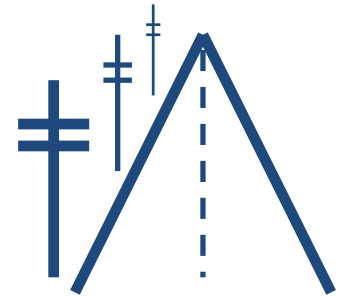
# Visual Displays

# Visual Display Characteristics

- Field of View (FOV), Field of Regard
  - Human FOV  $\sim 200^\circ$
- Spatial Resolution (dpi)
- Screen Geometry (rect., hemispherical...)
- Light Transfer Mechanism
  - Front/back projection, direct laser->retina
- Refresh Rate (Hz)
- Ergonomics

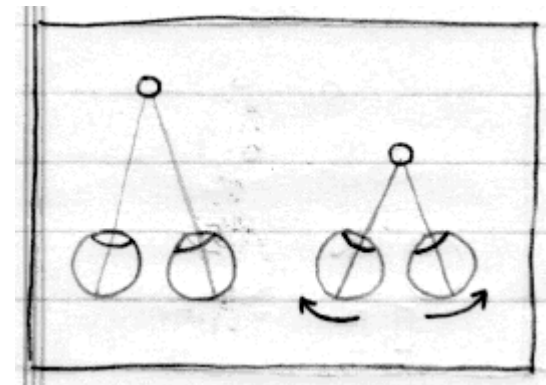
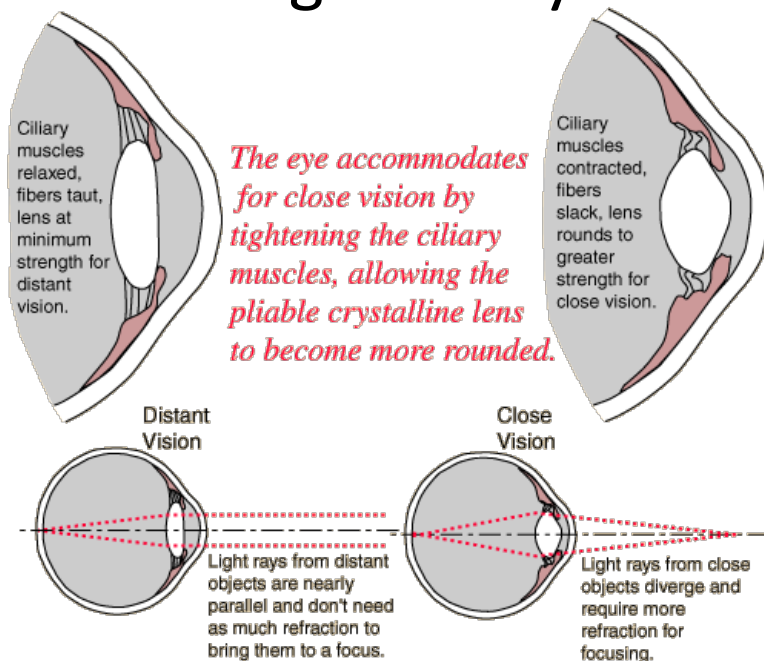
# Depth Cues: How to see in 3D (1)

- Monocular static cues
  - Relative size
  - Height relative to the horizon
  - Occlusion (strongest)
  - Linear perspective
  - Shadows
  - Lightning & Aerial perspective
    - Bluish and hazy -> further away
  - Texture gradient
    - More texture detail -> closer



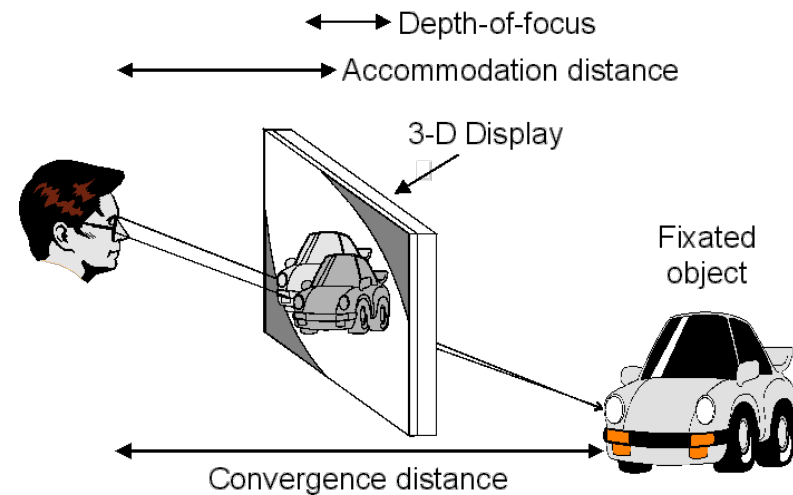
# Depth Cues: How to see in 3D (2)

- Oculomotor Cues
  - Derived from muscular tension
  - Accommodation: Change of eye focal length
  - Convergence: eyes looking inwards



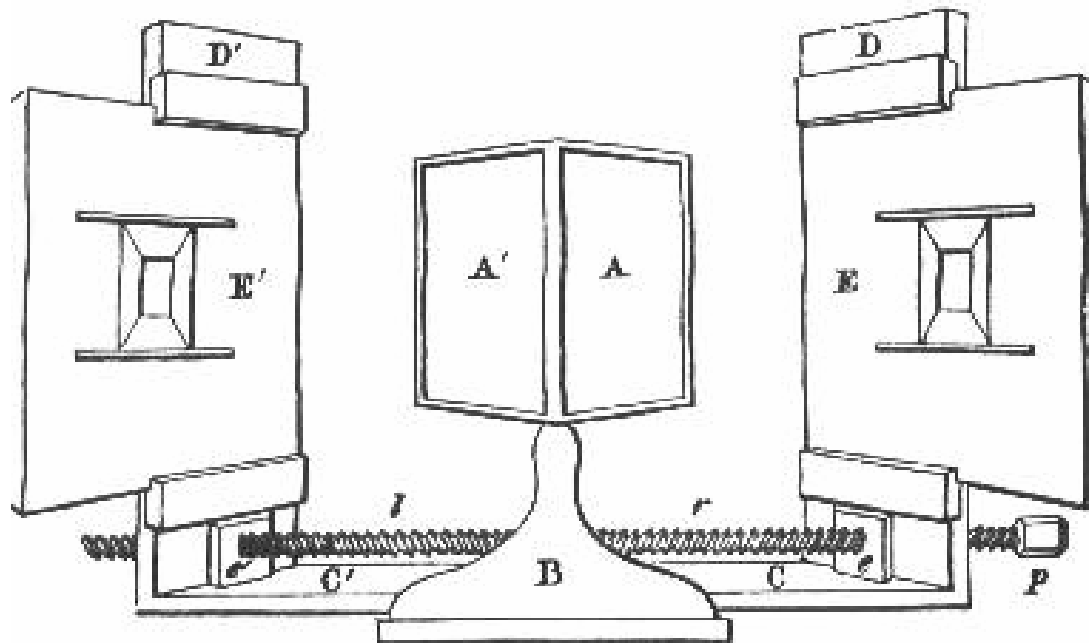
# Depth Cues: How to see in 3D (3)

- Motion parallax
  - Closer objects move faster
  - Very strong cue (esp. for far objects)
- Binocular Disparity/Parallax
  - “shift” in left/right images
- Problem with stereo displays: Cue mismatch



# 3D (stereo) viewing - Historical

- 1838 – Wheatstone stereoscope



The Wheatstone stereoscope used angled mirrors [A] to reflect the stereoscopic drawings [E] toward the viewer's eyes.

# Stereo Principles:

## Active vs. Passive Stereo

- **Active stereo:**  
active switching  
e.g. shutter glasses
- **Passive stereo:**  
e.g. anaglyph stereo  
(red/blue), polarized  
filters, infinitesc





# Active Stereo: Shuttering

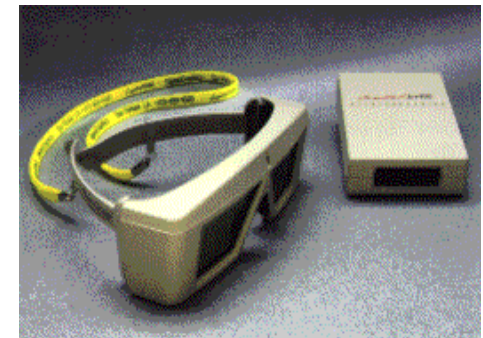


Shutter Glasses



# LCD Shutter Glasses

- Monitors with high refresh rate e.g. 120Hz - >60Hz per eye
- show stereo image pairs sequentially
- monitor and eye glass are synchronized
- every eye sees “its” image



Nvidia GeForce  
3D Vision glasses



NVIDIA 3D Vision Kit



3D Vision-Ready  
Display



Compatible NVIDIA  
Graphics Card



PC with Microsoft  
Windows Vista or Windows 7

# Stereo Monitor - Advantages

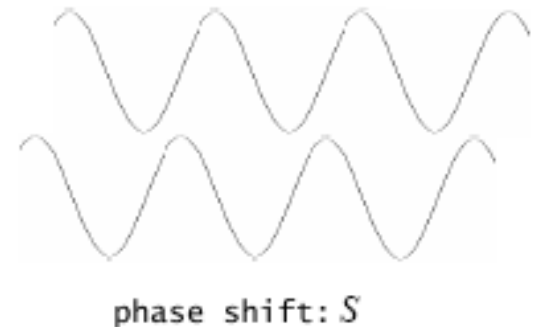
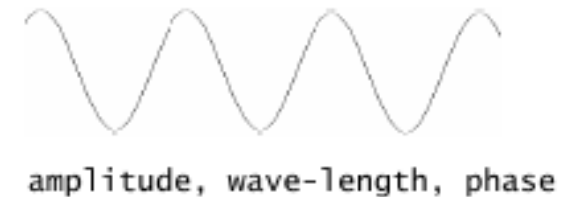
- Least expensive in terms of additional hardware over other output devices
- Allows usage of many input devices
- Good resolution
- User can take advantage of keyboard and mouse

# Stereo Monitor - Disadvantages

- Not very immersive
- Users cannot move around freely
- Does not take advantage of peripheral vision
- Ghosting
- Occlusions can avoid IR contact between emitter – glasses -> no shuttering

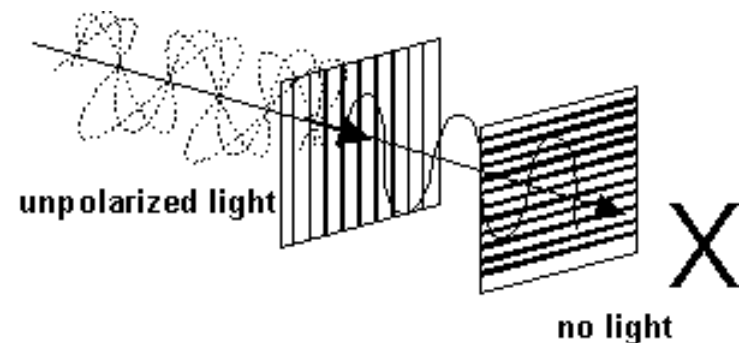
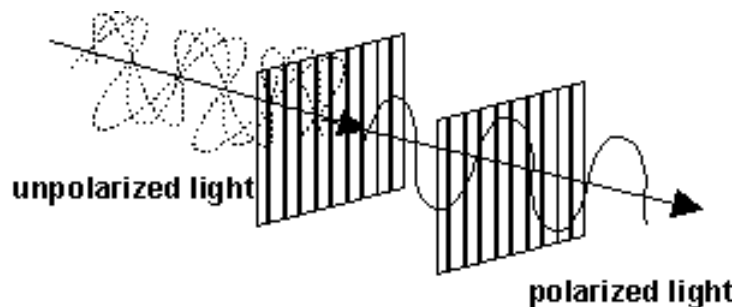
# Passive Stereo: Polarization

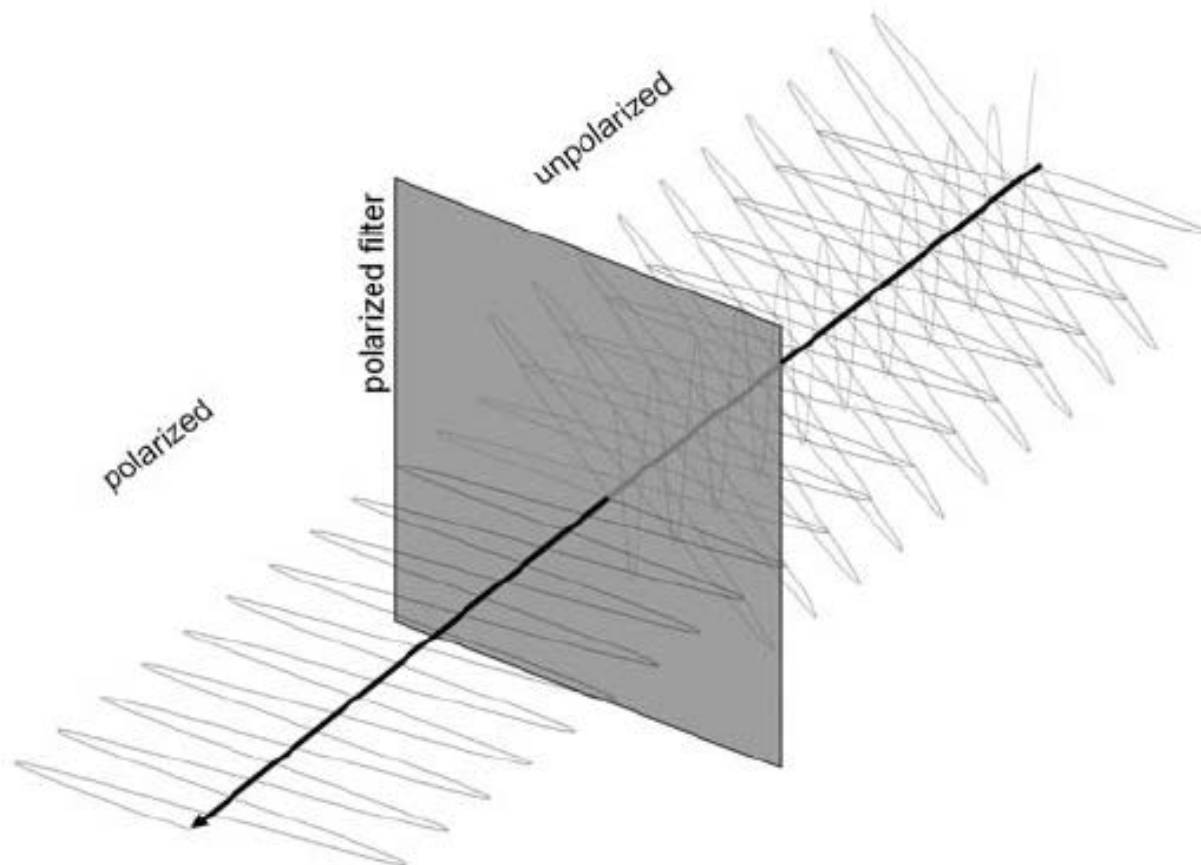
- Polarization filters create „different“ images for left and right eye
- Light is an electro-magnetic wave with
  - Amplitude (intensity)
  - Wave-length (color: visible light 380nm – 750nm)
  - Phase



# Polarization

- Use two projectors
  - Left: vertical filter in front of the lens
  - Right: horizontal filter in front of the lens
- Wear glasses with polarization filters
  - Left eye: vertical
  - Right eye: horizontal

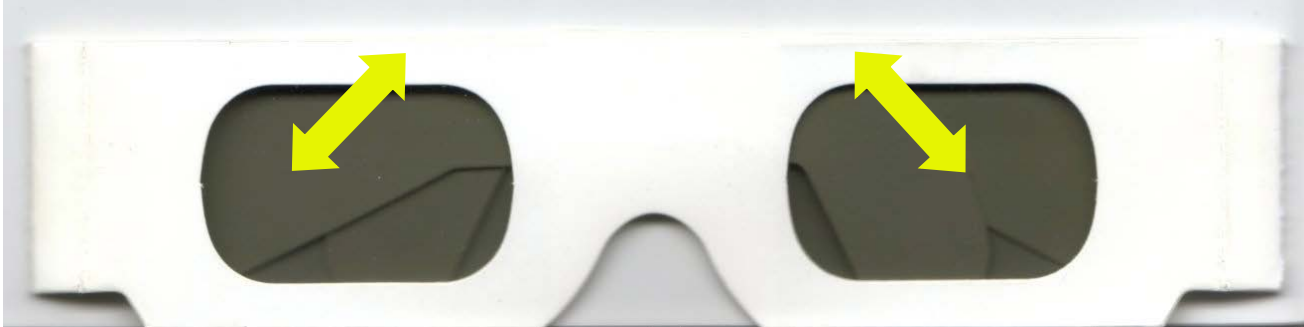




**Figure 2.4.** Polarization of light: only light waves with a specific orientation pass through the filter.

# Polarization glasses

- Very cheap, paper + plastic foil
- Trick: use  $\pm 45^\circ$  -> no wrong side wearing

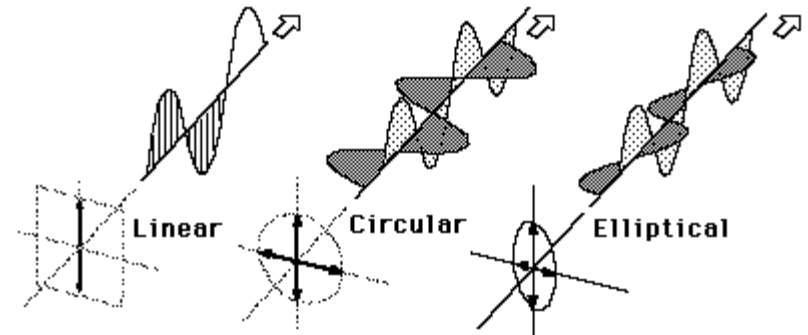


Polarization plane  $\pm 45^\circ$



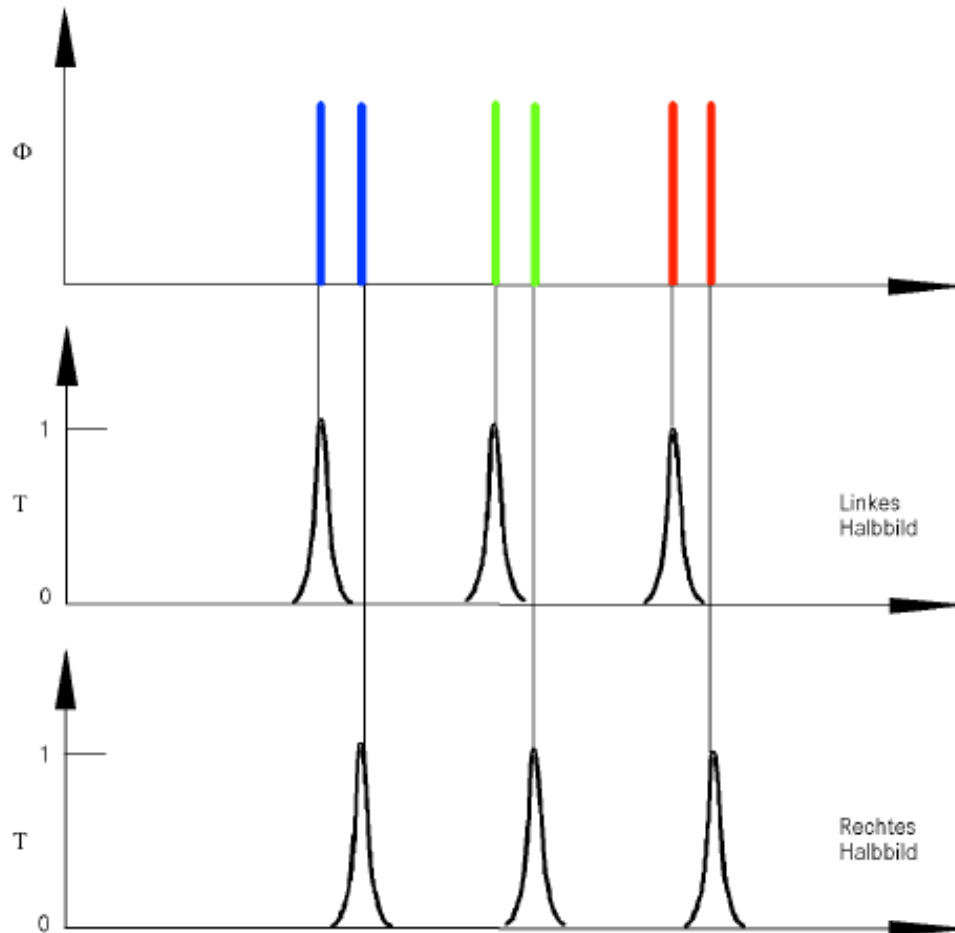
# Polarization

- Linear polarization
  - Can't tilt head
  - Little **ghosting**
- Circular polarization
  - More involved physics
  - Principle: counter clockwise / clockwise
  - Allows arbitrary head orientations
  - In general more ghosting than linear polarization

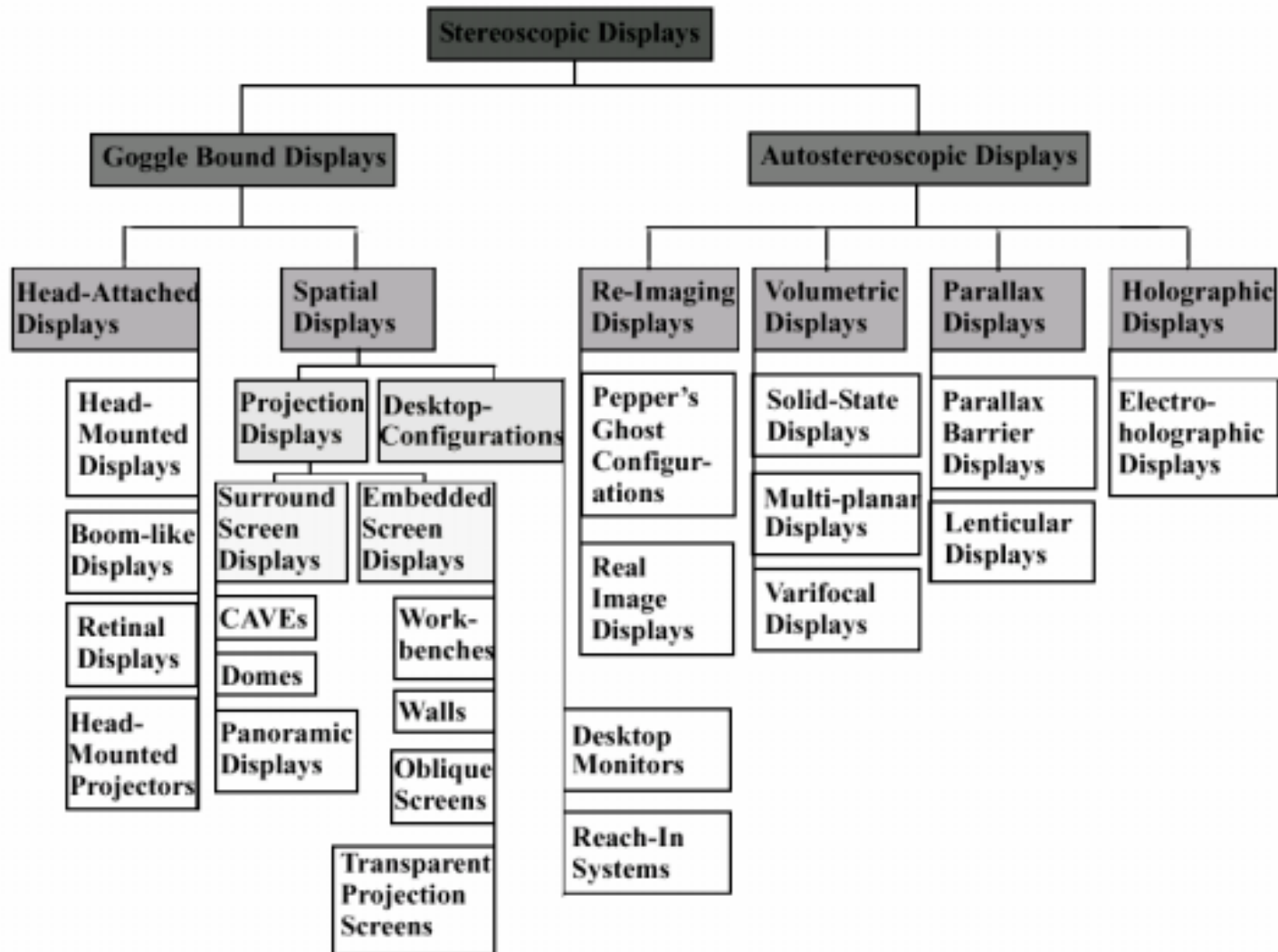


# Wellenlängenmultiplex Visualisierungssysteme

- Interferenzfiltertechnik (Infitec)



# Stereoscopic Displays Today - Overview



# Head Mounted Displays



Early prototype

# Head Mounted Displays (HMDs)



# 1968: Sutherland's 1st HMD



- Hidden-line graphics
- Mechanical tracking



- ❑ **See-through HMD**

# Head Mounted Display (HMD)

- Device has one or two screens (e.g. LCD, OLED) plus special optics in front of the users eyes
- Provides a stereoscopic view that moves relative to the user
- 2 versions:
  - See-through or
  - User cannot naturally see the real world

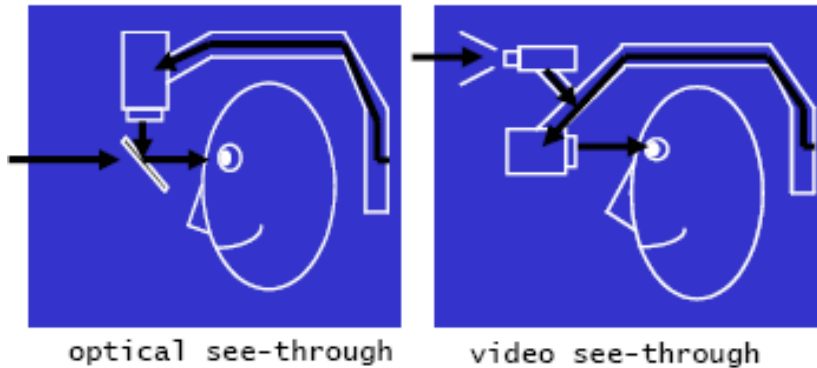


**Sony Glasstron (1997-2002):** LCD display,  
Resolution: SVGA  
(832×624 pixels)  
FOV: 30 × 22 degrees  
Weight: 120 grams

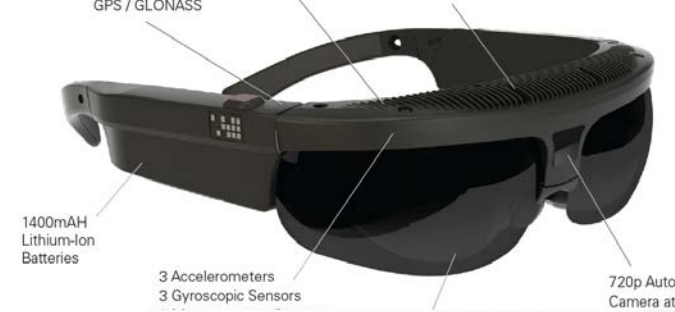


# See-through HMDs

- 2 Types:
  - Optical see-through
  - Video see-through



Azuma, R. T. A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, vol. 6, no. 4, pp. 355-385, 1997.



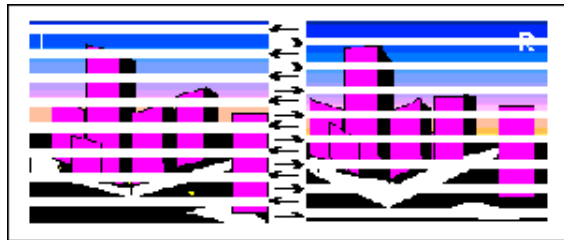
- Used in Augmented/Mixed Reality Applications



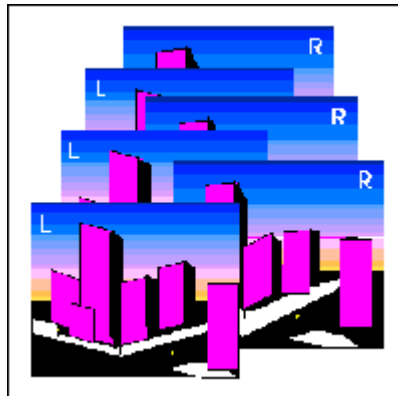
# HMD - Stereo Transmission Principle: 3 Types



**Line Interleaved Stereo**



**Field Sequential**

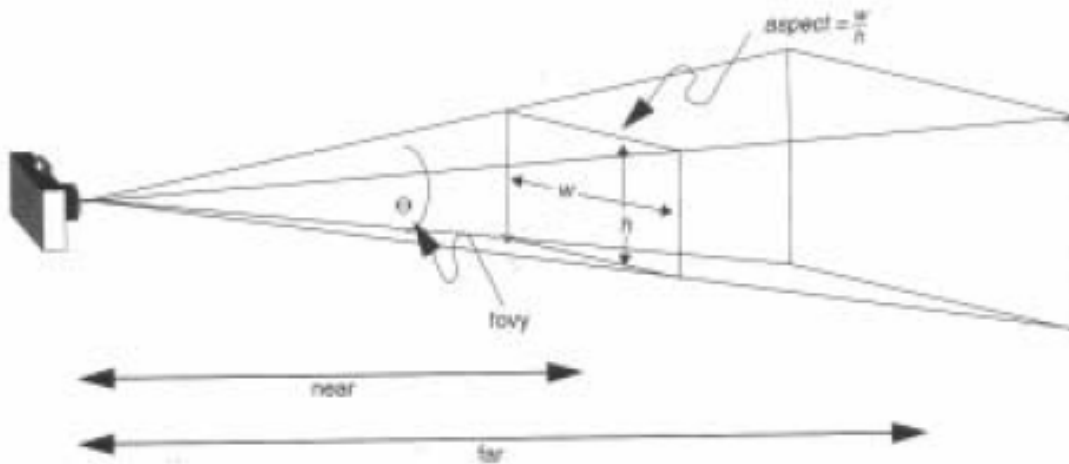


**Side-by-Side Stereo**

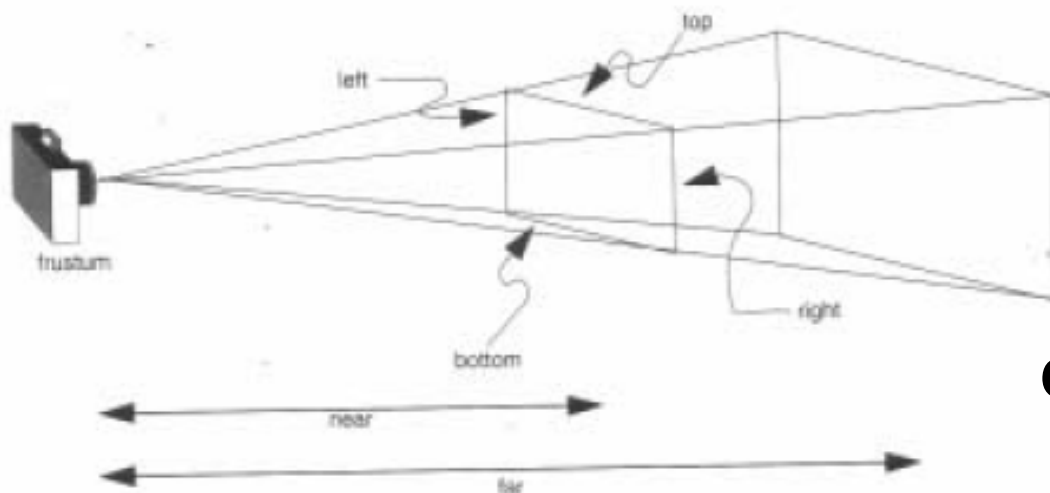


Sometimes: Top/Bottom

# On/Off-Axis Projection

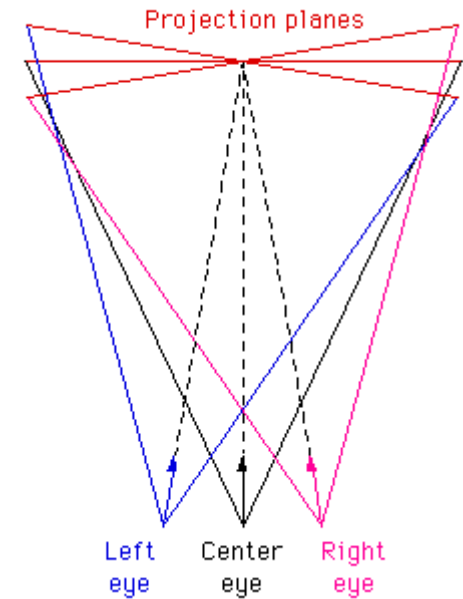


`glPerspective` → **On-Axis**

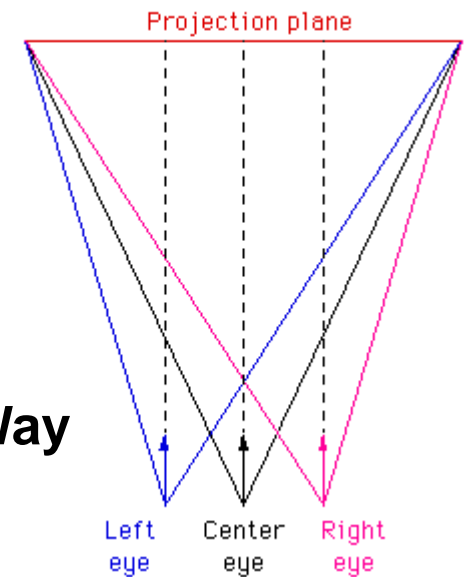


`glFrustum` → **off-Axis**

Toe-in projection (Top view)



Offaxis projection (Top view)



**Correct Way**

# HMD – Examples (1995-2008)



# Actual Costs (before 2012)

\$24,000



"Near Eye Immersive Display Systems"



\$1,800

\$20,000



\$10,000

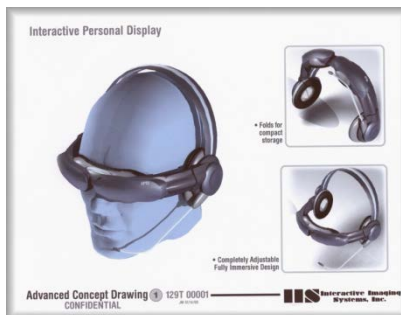
\$2,900



(Trivisio)



\$500-2,000



\$600

?





# Head Mounted Displays (2006-)

eMAGIN, Inc.



\$1500 w/3DOF  
Tracking



Sony HMD (HMZ T1/T2), 2011/12  
800 EUR; 1280x720 OLED

# Organic Light-Emitting Diodes (OLEDs)

- No backlight necessary -> very thin
- Deep black levels
- Very high contrast
- Low power consumption



# Oculus Rift

- Stereoscopic
- FOV: 100° diagonal
- Weight: 470 grams
- Resolution: 2 AMOLED  
1080x1200 per eye @ 90 Hz
- Price ~450 EUR
- Inertial Tracker built in
- Precise IR optical tracking
- Low-persistence display (2ms)
- Adjustable lens spacing from 58 to 72 millimeters



# HTC Vive Pro

- FOV: ~110° diagonal
- Weight: 555 grams
- Price ~1400 EUR
- Controllers included
- Inertial Tracker built in
- 2 cameras built in (see-through & depth)
- Resolution: 1440x1600 per eye @ 90 Hz
- Highly precise and fast Lighthouse Steam VR Tracking 2.0
  - Standard: Room scale tracking – max 10x10 meters
  - Theoretically large scale tracking up to 16 base stations
- Adjustable IPD; Lens distance adjustment
- Integrated Microphones & Headphones





# HTC Vive Pro Eye & Wireless



- Wireless module available
- Pro Eye includes eye tracker
  - 120Hz binocular
  - gaze dir., pupil size, pupil pos., eye openness

## Vive Cosmos (2019)

- Integrated SLAM Tracking (Lighthouse extension)
- 1440x1700 px per eye (LCD – higher px density)

# Valve Index

- 130° FOV
- 1440x1600 (per eye)
- 120 Hz (with experimental 144 Hz mode)
- LCD display with high pixel density
- Lighthouse 2.0 tracking
- Knuckles controllers



# Pimax

- 5K and 8K X versions
  - 8K X:  $3,840 \times 2,160$  per eye, 75Hz
  - 5K:  $2,560 \times 1,440$  per eye
- $\sim 200^\circ$  FOV
- Low persistence LCD (full RGB pixel matrix)
- Supports Lighthouse Tracking
- Integrated microphone



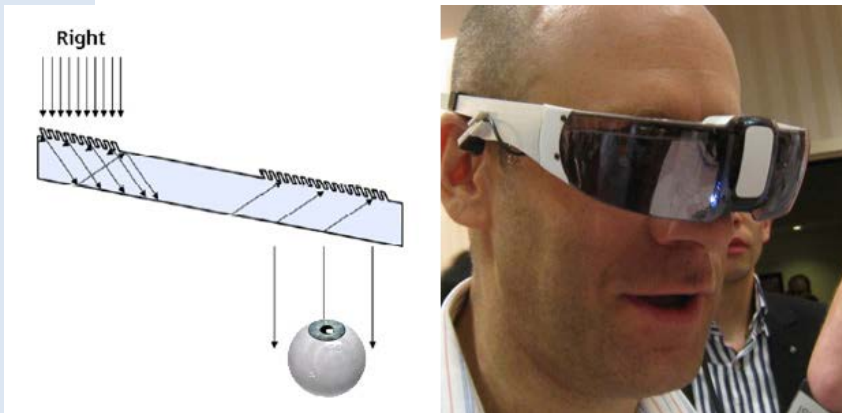
# Stand-alone HMDs

- Onboard 6DoF SLAM tracking
  - Typically 4-6 front/side cameras
- Onboard processing (ARM chip) -> Wireless
  - Less computational power compared to wired HMDs
- Examples:
  - Oculus Quest: 1440 x 1600, 72Hz
  - HTC Vive Focus: 1440×1600, 75Hz
  - Pico Neo: 1440 × 1600 px

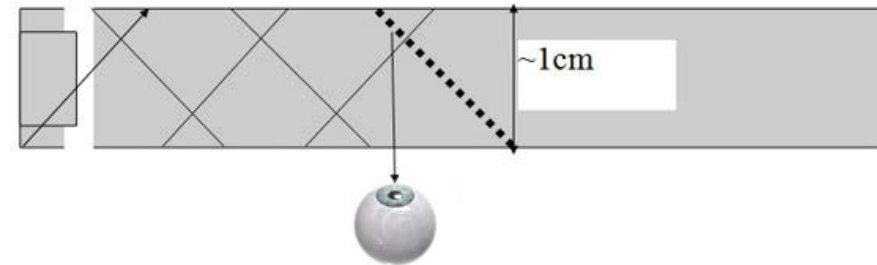


# AR See-Through Wearable Displays

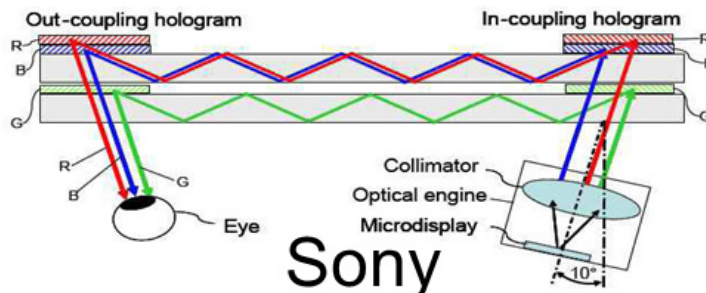
- Reflection on Curved Mirrors
- Waveguide-based



Reflective Waveguide (Google, Epson)



Diffractive Waveguide e.g. Nokia/Vuzix



Polarized Waveguide (Sony)



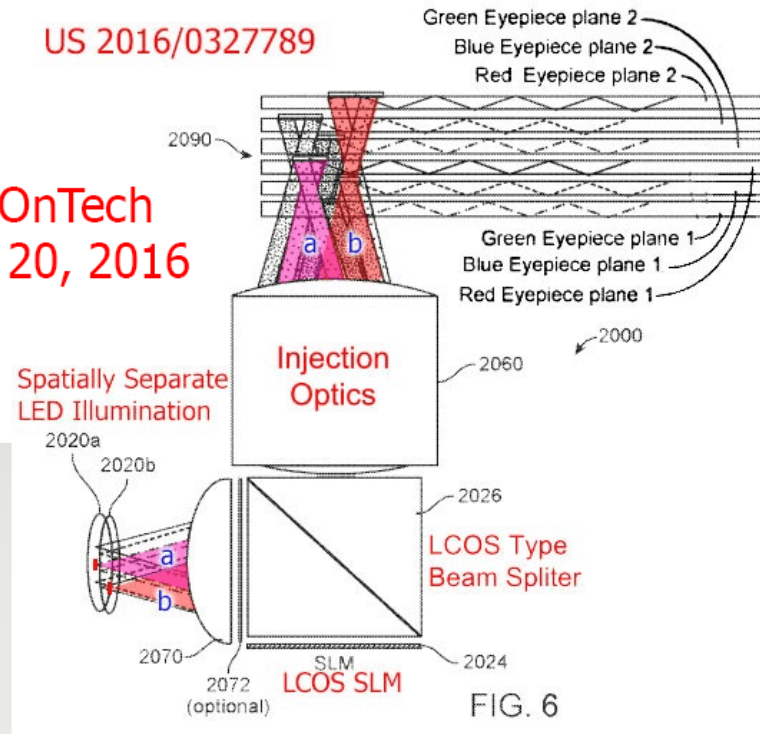
# Magic Leap Optics



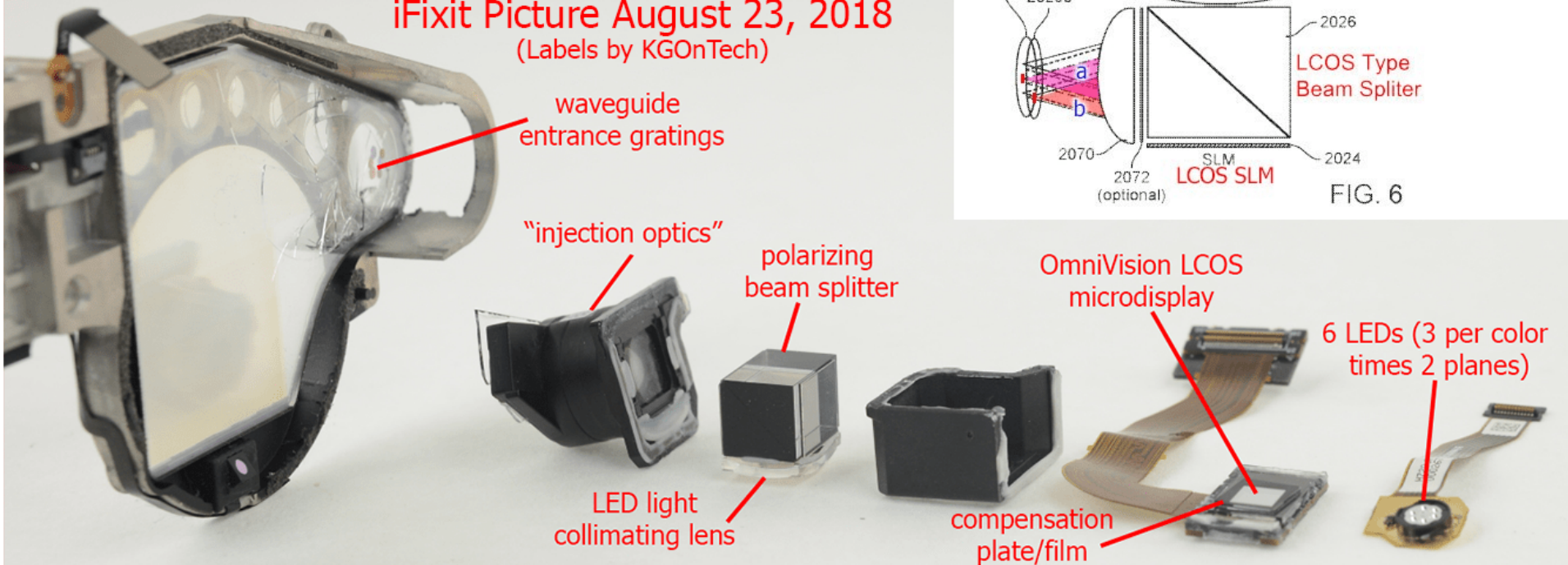
nTech's

US 2016/0327789

KGOnTech  
Nov. 20, 2016



iFixit Picture August 23, 2018  
(Labels by KGOnTech)



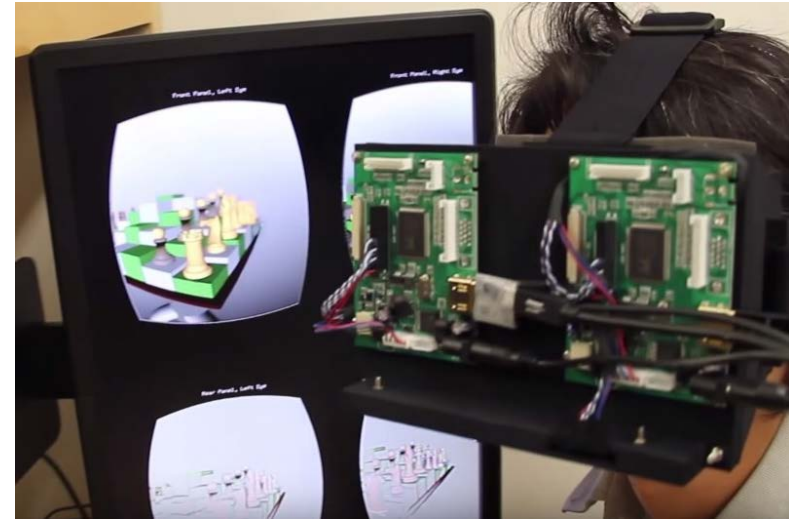
# MS Hololens 2

- Small screen,  $\sim 52^\circ$  FOV
- Resolution:  $\sim 2K$  per eye
- Ergonomics improved over Hololens 1
- Excellent SLAM tracking using 4 cameras
- Depth camera, IMU, HD video cam, 5 mics
- Stand alone unit
- Windows 10
- Eye-tracking included

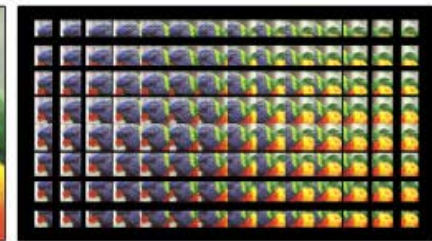


# Future: Near-Eye Light-Field Display

- Micro-Lenses (Nvidia) or Stacked LCDs
- Slim Design
- Focus change possible
- Small resolution in case of Micro-Lenses

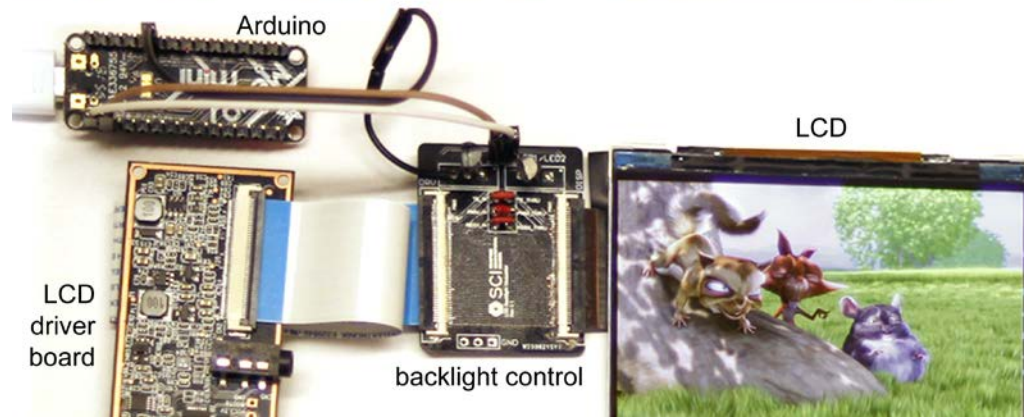
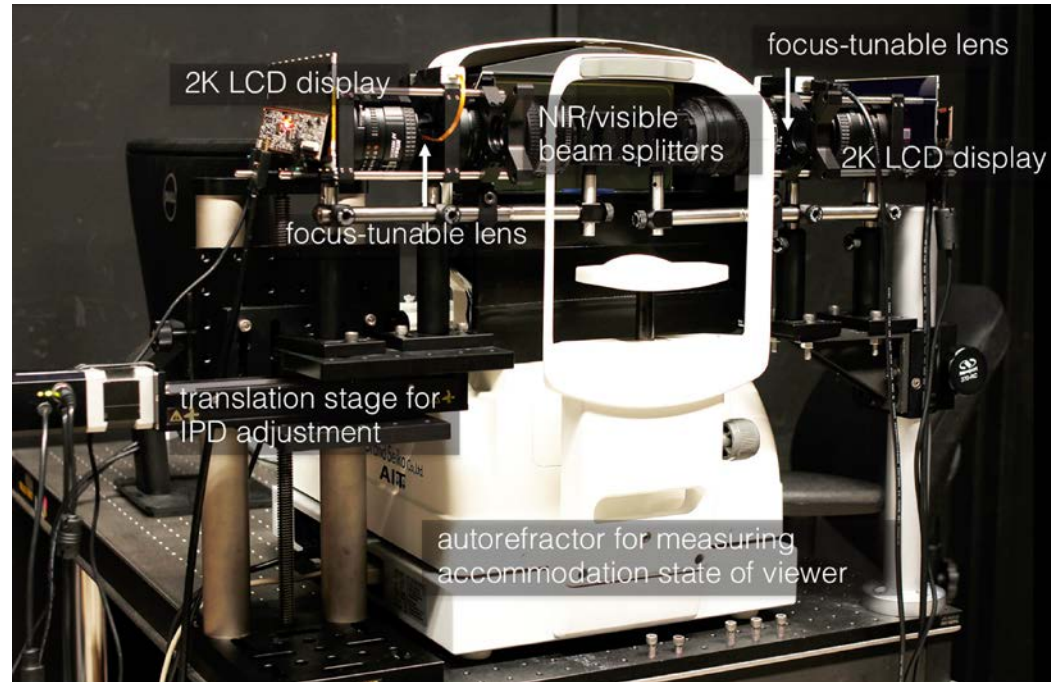


“Perceived” Image  
(Close-Up Photo)





# Accommodation-invariant Computational Near-eye Displays



# HMD - Properties

- Image:
  - FOV (Field of View)
  - Resolution
  - Fully immersive vs. see through
  - (Mono) vs. Stereo
- Ergonomics
  - Weight & Cables
  - Hygiene
  - Wearability
  - Ruggedness
- Cost
- Support (Repairing, ...)

# HMDs - Advantages

- Provides an **immersive** experience by blocking out the real world (non-see-through)
- Easy to set up
- Does not restrict user from moving around in the real world (...cable length)
- Good quality HMD is now affordable
- Achieves good stereo quality

# HMDs - Disadvantages

- Might have limited resolution and field of view (FOV)
  - Does not take advantage of peripheral vision
- Ergonomics: sometimes heavy, hot, uncomfortable
- No extended use: ~30-60min. Cybersickness (!!)
- AR HMDs have low FOV
- Non see-through:
  - Physical objects require graphical representation
  - Safety: Isolation and fear of real world events
- Hygiene

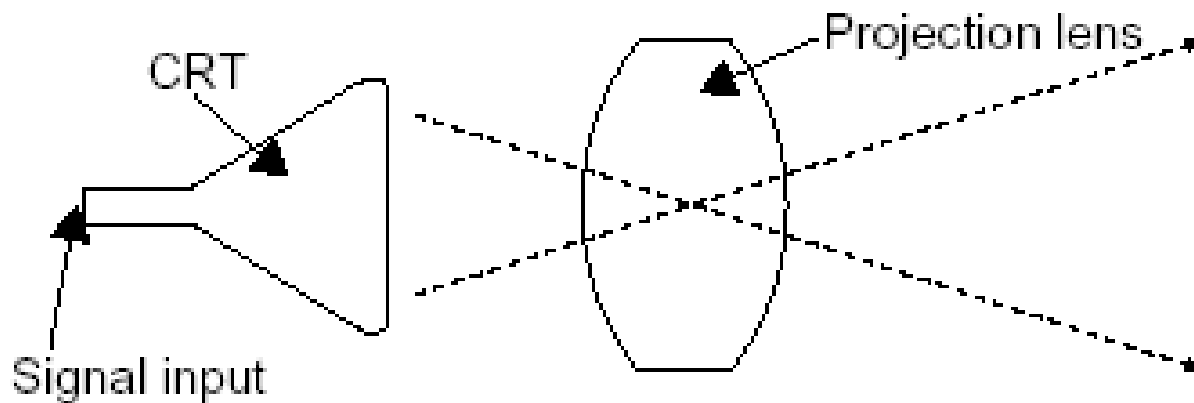
# Projection Displays

# Basic Display & Projection Technologies

- Vorlesung Display Technologien:
  - Display Technologien:  
[video.tu-clausthal.de/vorlesungen/ipp/visu-ws0304/flash/visu-10122003a.html](http://video.tu-clausthal.de/vorlesungen/ipp/visu-ws0304/flash/visu-10122003a.html)
  - <http://video.tu-clausthal.de/vorlesungen/ipp/visu-ws0304/>

# Projection Technologies: CRT

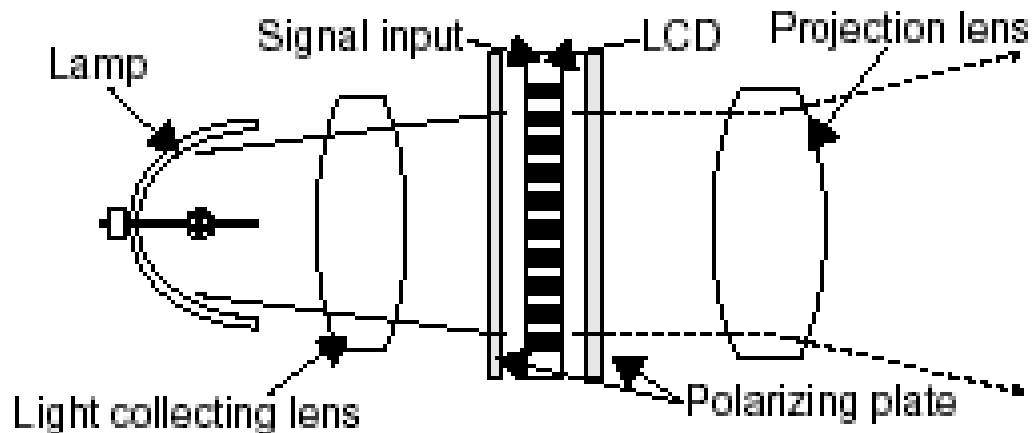
- CRT (Cathode Ray Tube) Projectors



- + High refresh rates ( $>100\text{Hz}$ ) – stereo capable
- + Relatively low cost
- Large and heavy devices, can implode
- Consume a lot of energy

# Projection Technologies : LCD

- Liquid Crystal Display (LCD) Projectors

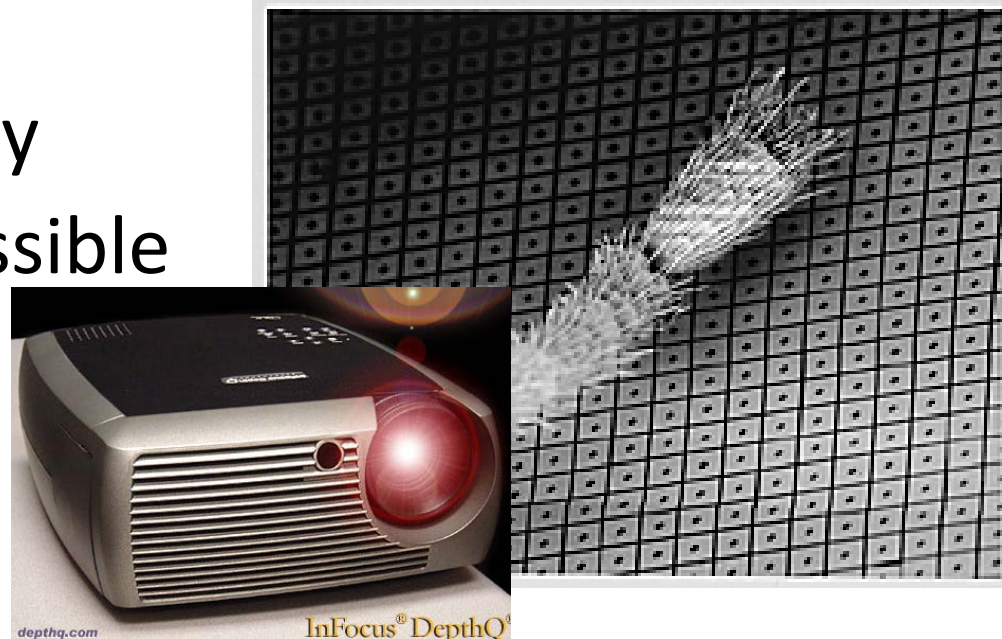
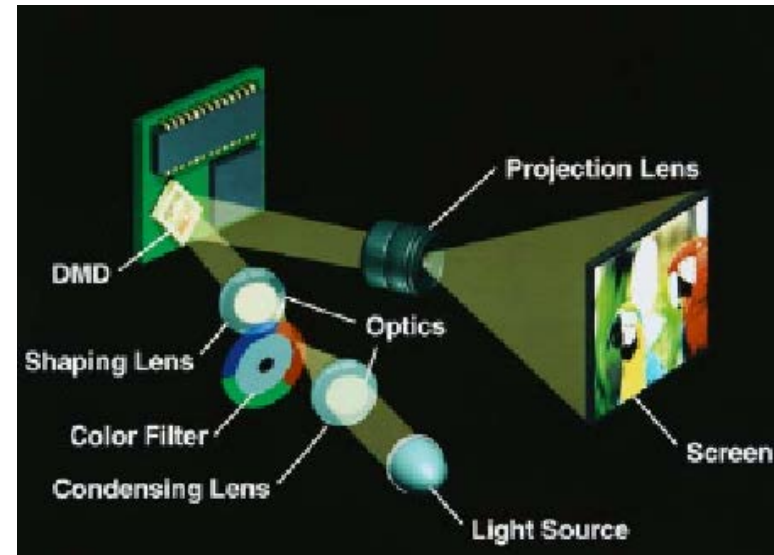


- Individual grayscale LCD for each color
- Pixel dimensions  $< 50\mu\text{m}$
- + Low cost
- Poor contrast and black level



# Projection Technologies: DLP

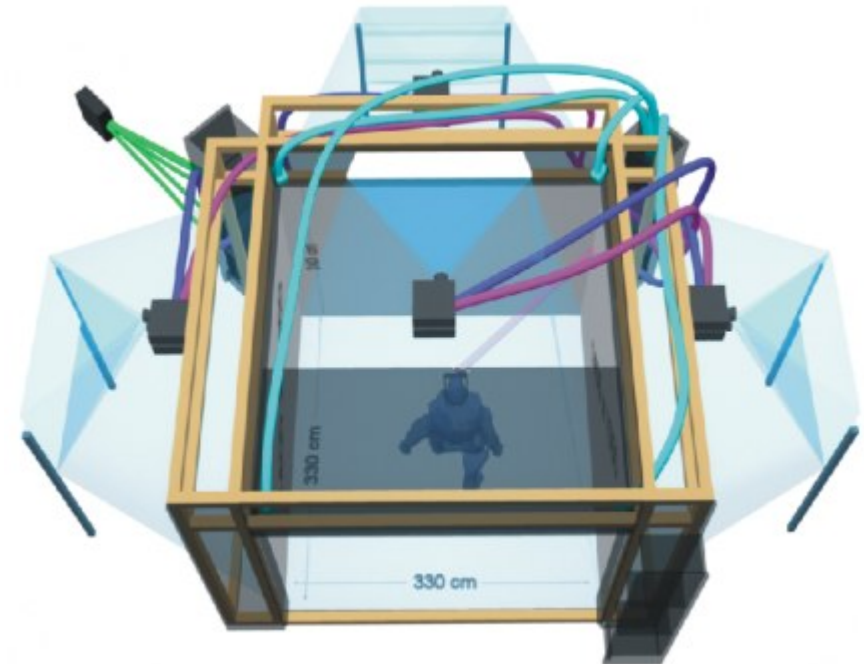
- Digital Light Processing (DLP)
- Fast switching of micro-mirrors (brightness, color)
- Uses information of several frames for artifact compensation -> delay
- High refresh rates possible (>120 Hz)
- Relatively low costs



# CAVE (1)

“Computer Assisted Virtual Environment” <sup>TM</sup>

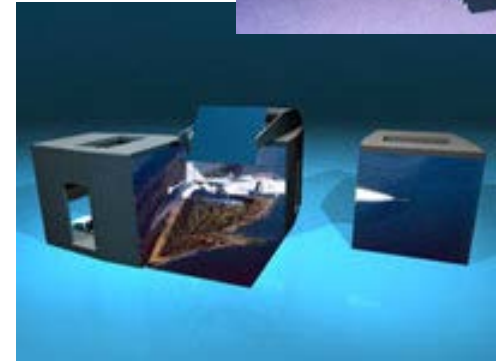
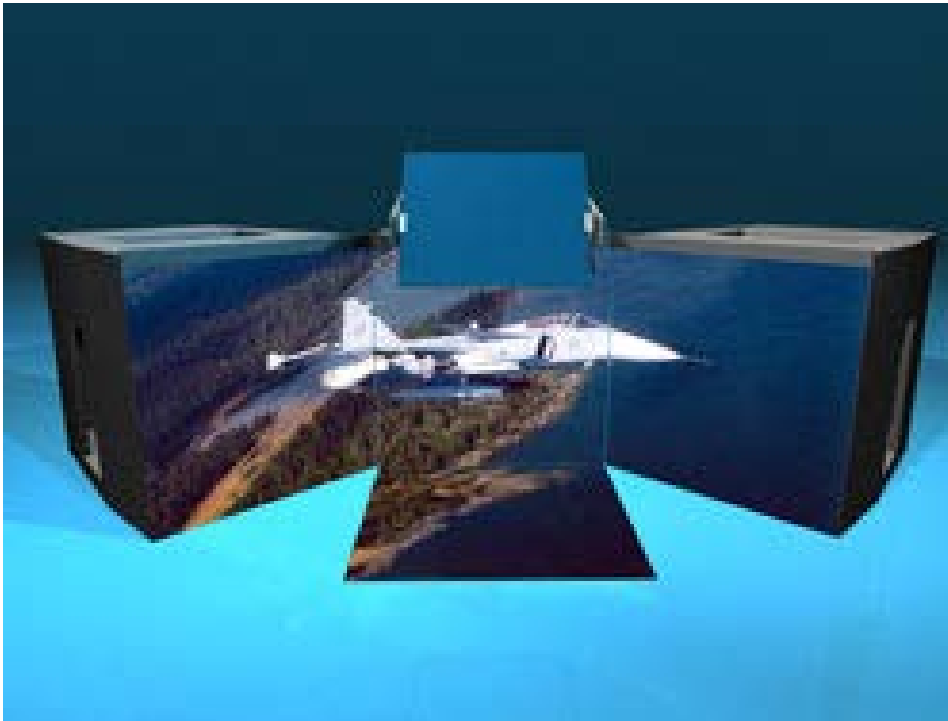
- Has 3 to 6 large screens
- Puts user in a room for visual immersion
- Usually driven by a single or group of powerful graphics engines – nowadays PC cluster



# CAVE (2)



# RAVE



“Reconfigurable Automatic Virtual Environment”

# CAVE - Advantages

- Provides high resolution and large FOV
- Uses peripheral vision
- User only needs a pair of light weight shutter glasses for stereo viewing
- User has freedom to move about the device
- Has space to place props (cockpit etc.)
- Environment is not evasive
- Real and virtual objects can be mixed in the environment
- A group of people can inhabit the space simultaneously (only tracked user sees correct stereo)

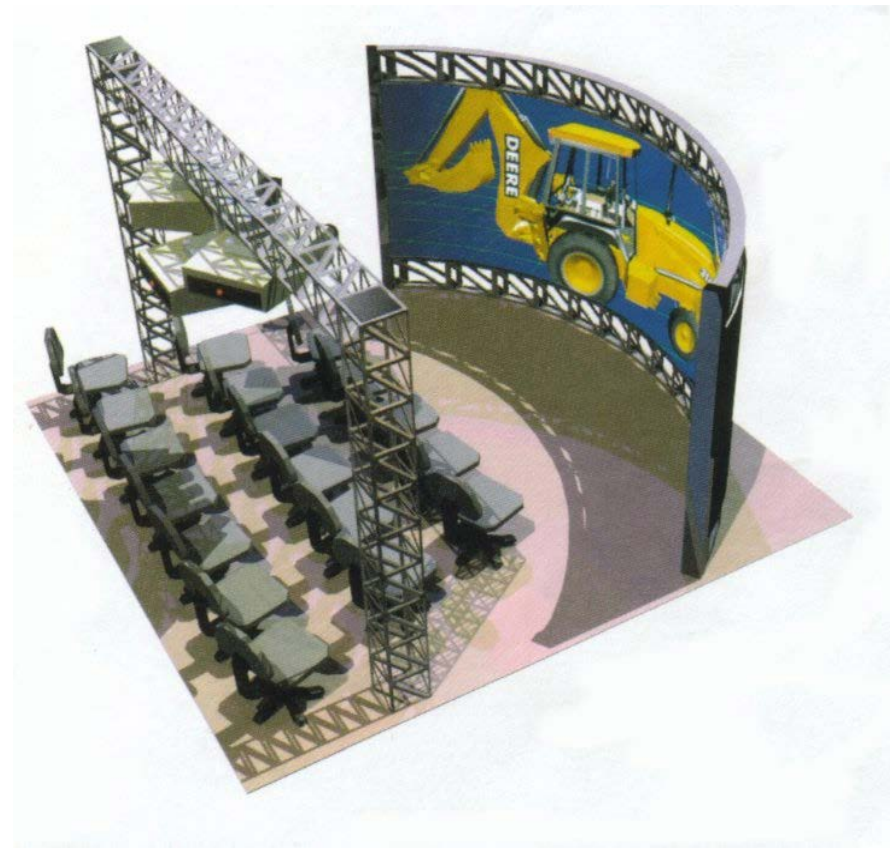
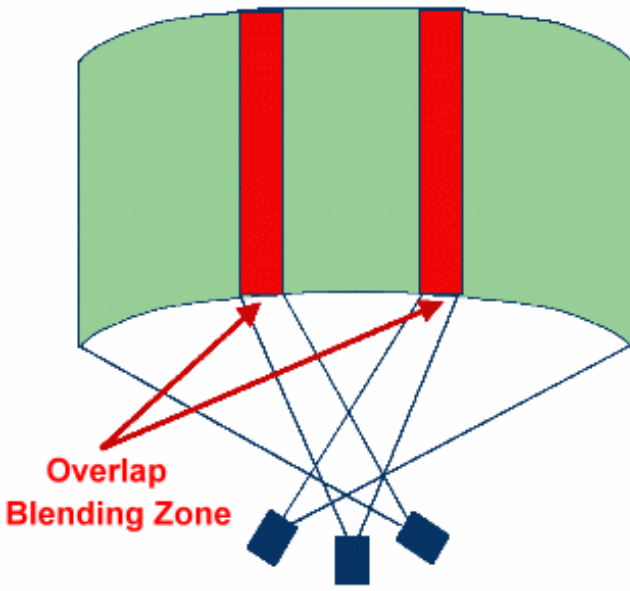
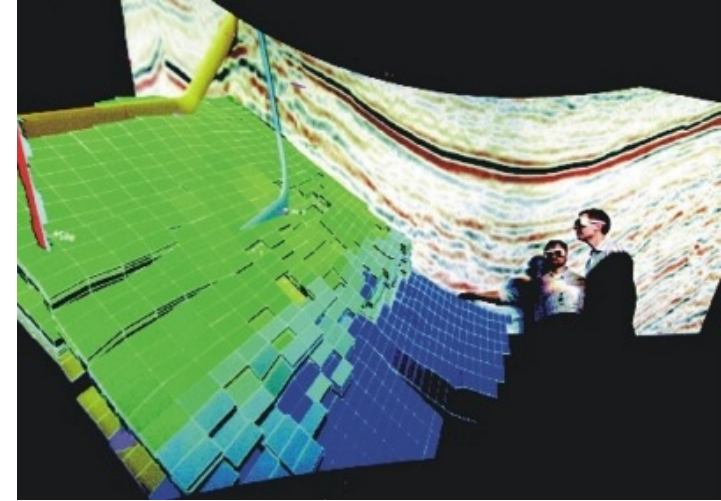
# CAVE - Disadvantages

- Very expensive (>200.000 EUR)
- Requires a large amount of physical space
- Projector calibration must be maintained
- Only 1-2 users can be head tracked
- Stereo viewing can be problematic
- No direct interaction possible
  - No “walking around” an object as with HMD
- Physical objects can get in the way of graphical objects

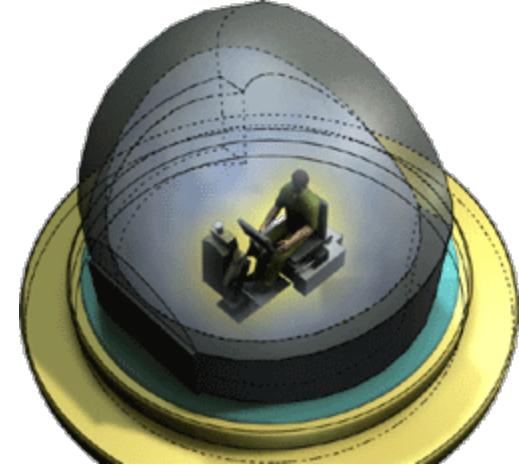


# Curved Displays

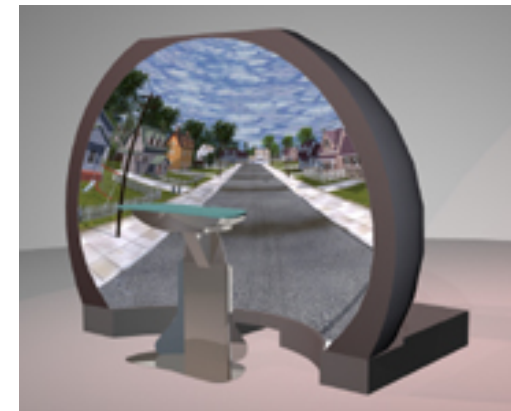
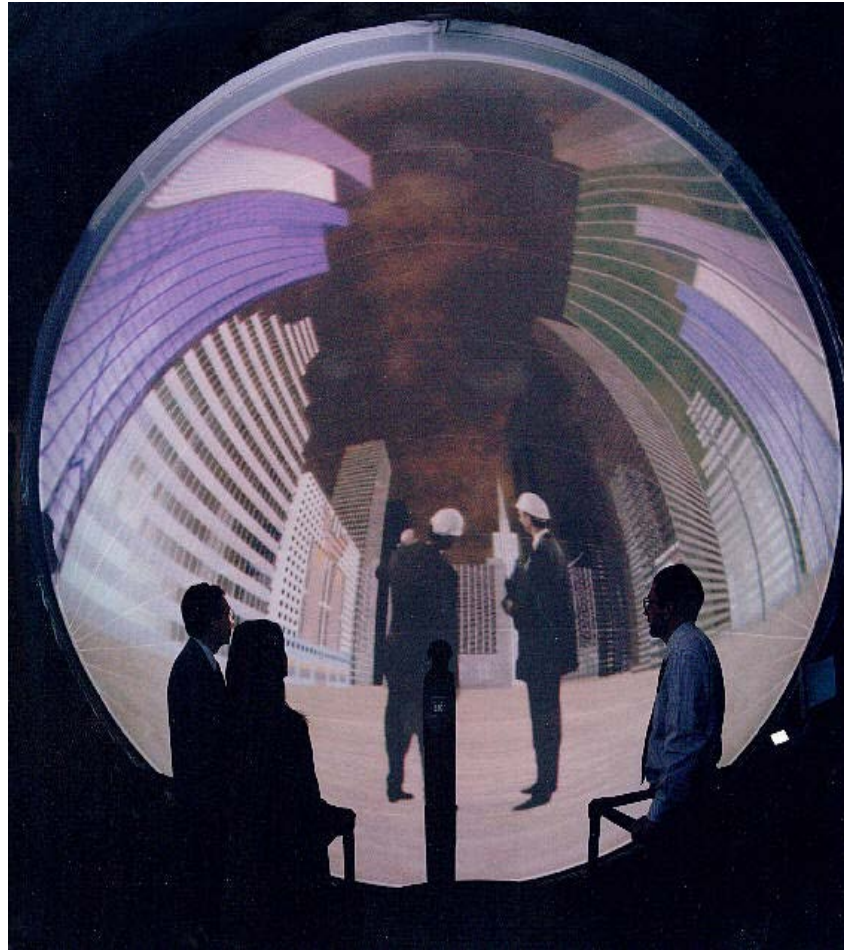
- Cylindrical or hemispherical screen
- Requires distortion correction
- Common in industry



# Vision Dome



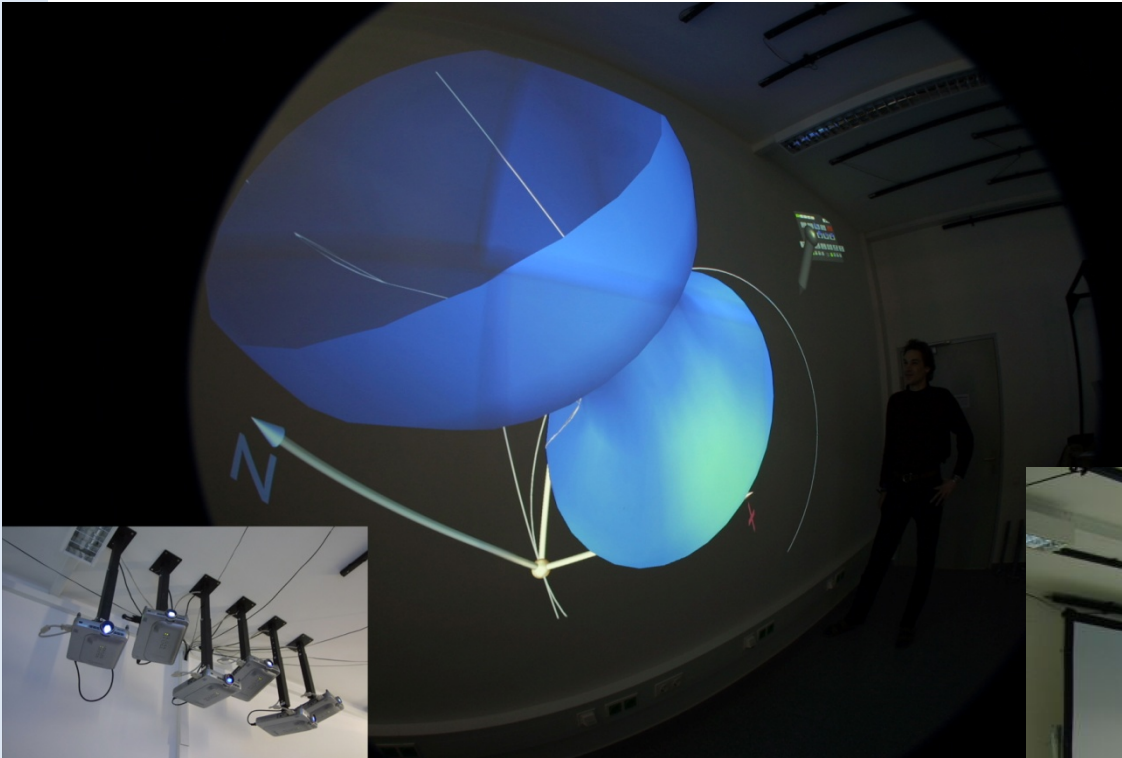
Spherical  
Display



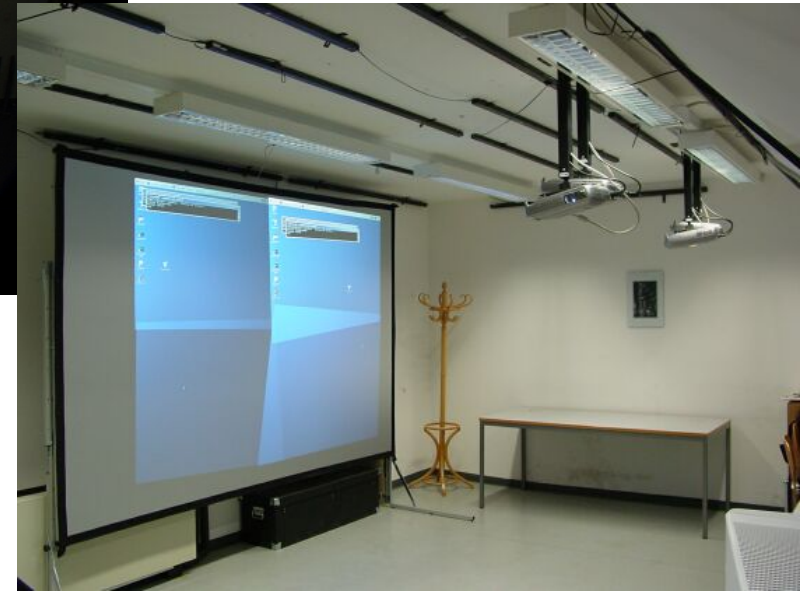
VisionStation



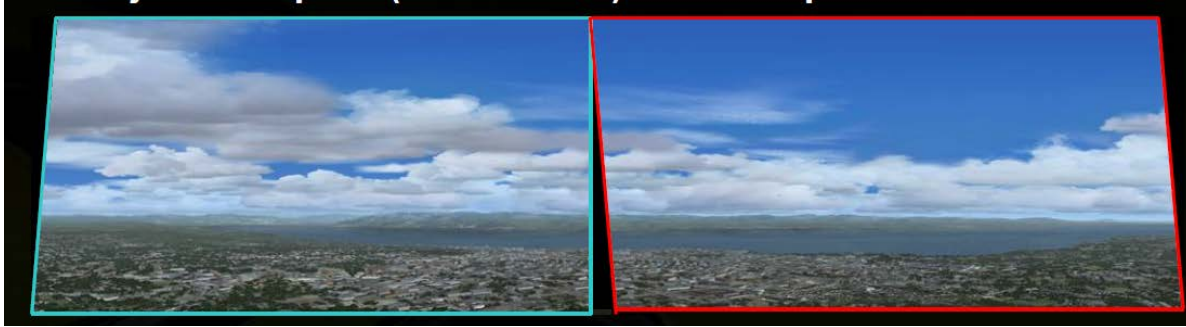
# Tiled Projector Display



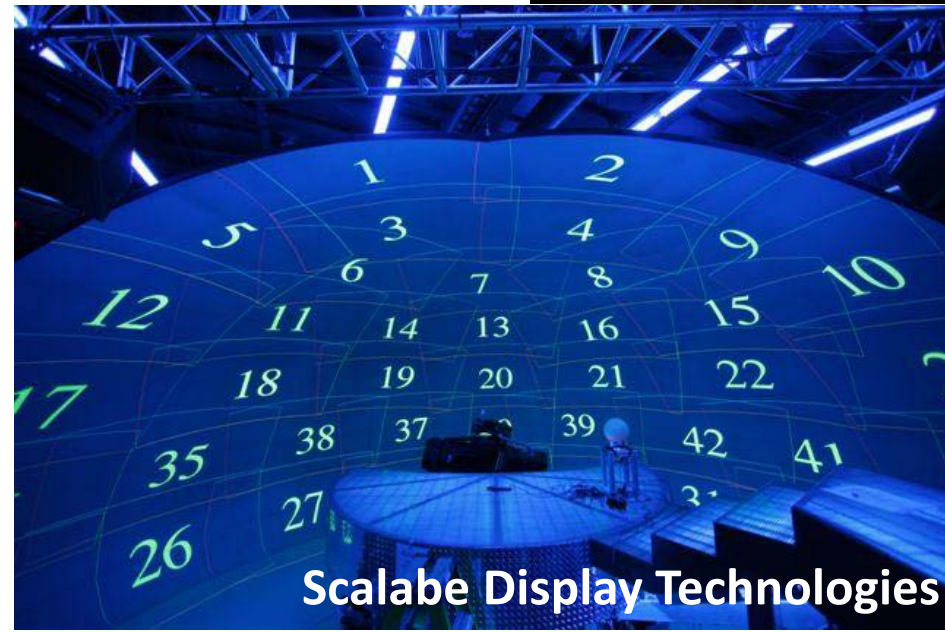
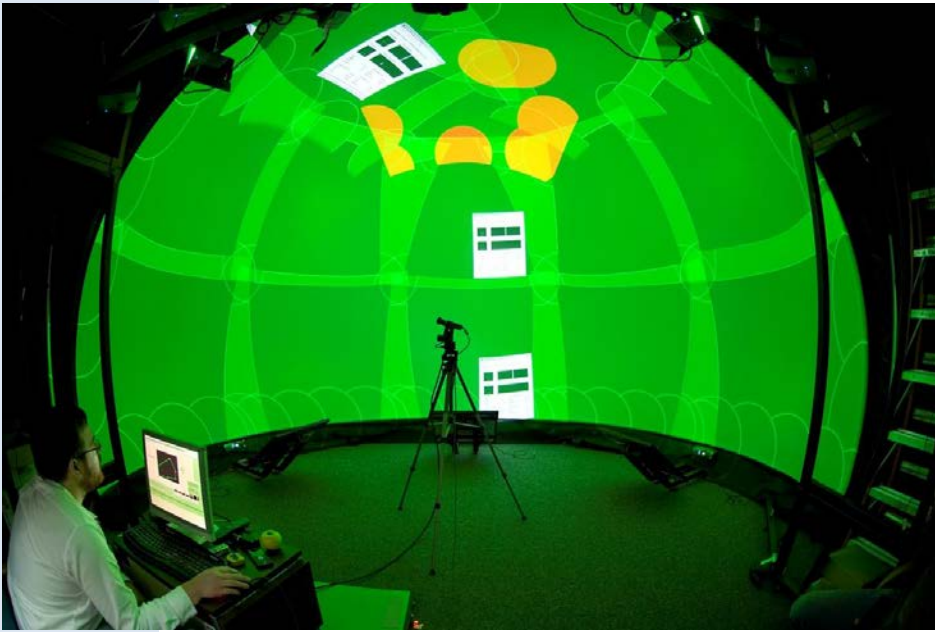
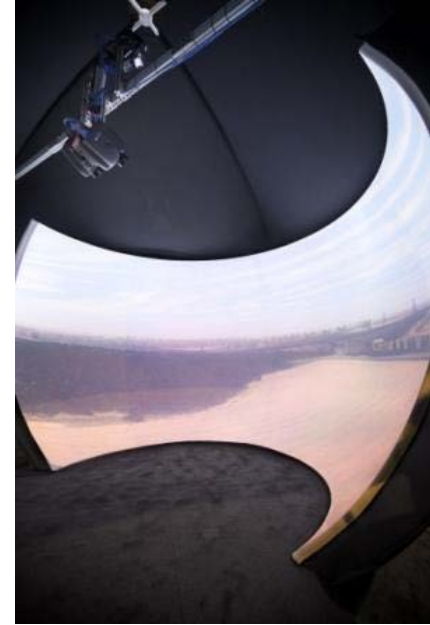
StubeRena  
Gottfried Eibner, 2003



# Multi-Projector Display



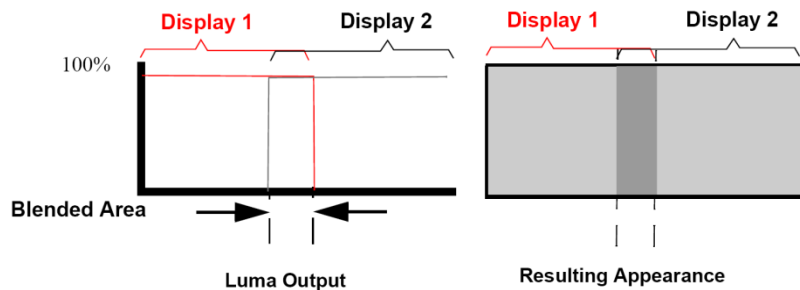
- Warp & Blend
  - Warp = Geometry Corrections
  - Blend = Intensity Adjustments



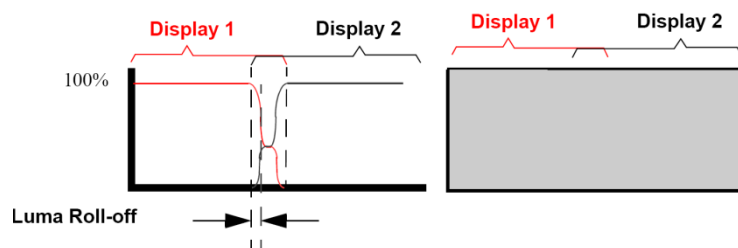
Scalabe Display Technologies

# Multi-Projector Walls

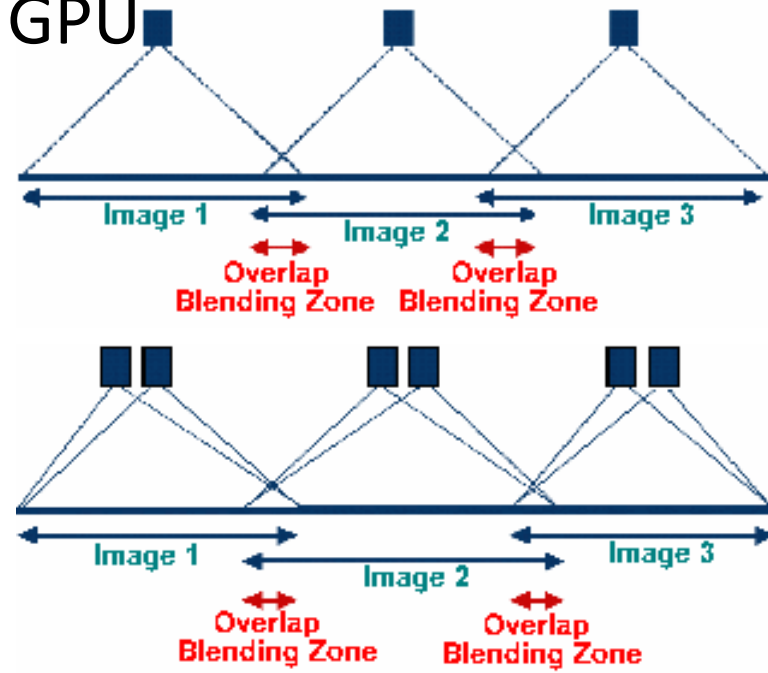
- Active or passive stereo
- Multi-projector setup
- Overlap, Edge Blending
  - Partly Nvidia driver support
  - Warp & Blend can be done on GPU



active



passive



# Multi Screen Displays

How to synchronize multiple displays?

(1) Multiheaded Graphics

(2) Multiple workstations: Genlock/ Framelock

## Genlock:

**Exact** synchronization of vertical synch (electron beam of CRT)

- Refreshes each pixel synchronously

## Framelock:

Synchronizing frame buffer swap

- Begins redrawing at the same time



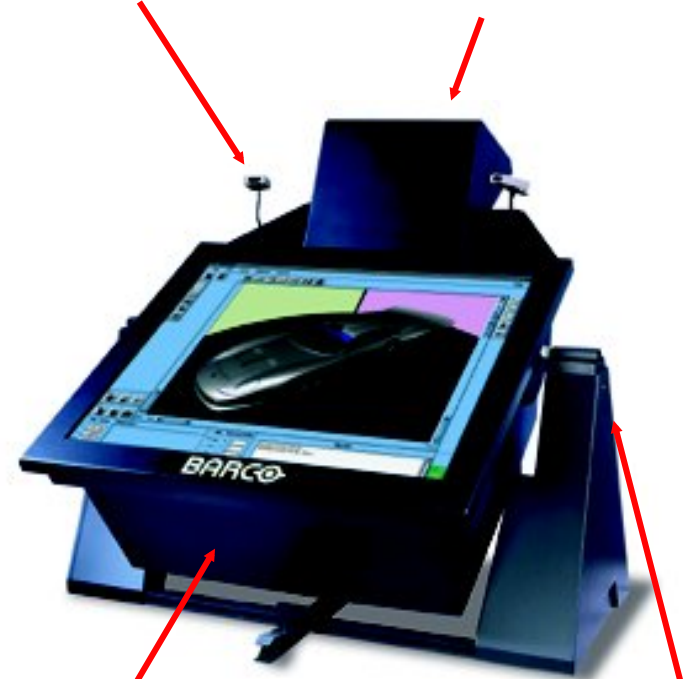
# Workbench / Projection / Touch - Table

Responsive Workbench,  
Holobench, Virtual Table...

- Technology similar to CAVE but one display (two at most)
- Can be a desk or a large single display (I.e. PowerWall)
- Traditionally a table top metaphor

IR Controllers

CRT Projector



Mirror

Tilting mechanism



# Workbench - Properties

- High resolution
- Intuitive display for certain apps.
- Allows table-top placement of props
- Can be shared by several users
- Pen-based / Touch input possible
- Large FOV

# Two User Workbench

- 4-way interleaving
- Problems
  - Reduced brightness
  - Cross talk
  - Refresh rates



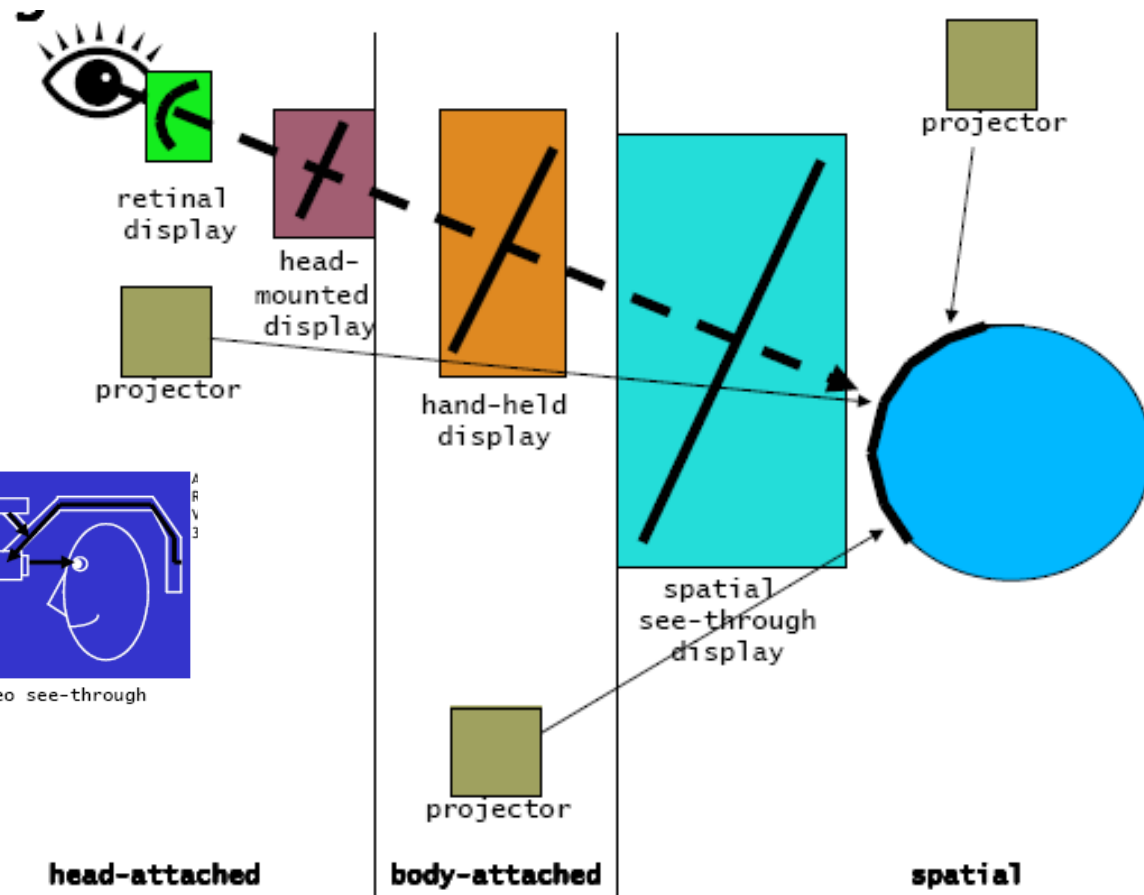
# Multi-user Approaches

- Private screens
  - Individual screen(s) / frame-buffer(s) per user / HMD for each
- Frame interleaving
  - Users share the same screen(s). Images rendered into individual frame-buffers displayed time-sequential. Special glasses separate images.
- Screen partitioning
  - Images are separated by additional optics.





# Current Augmented Reality Displays



# Pico Projectors

- Low brightness  
<800 lumens
- Max. 1280x800 resolution
- Image size max. 2.5m diagonal
- Projection distance max. 2.5m



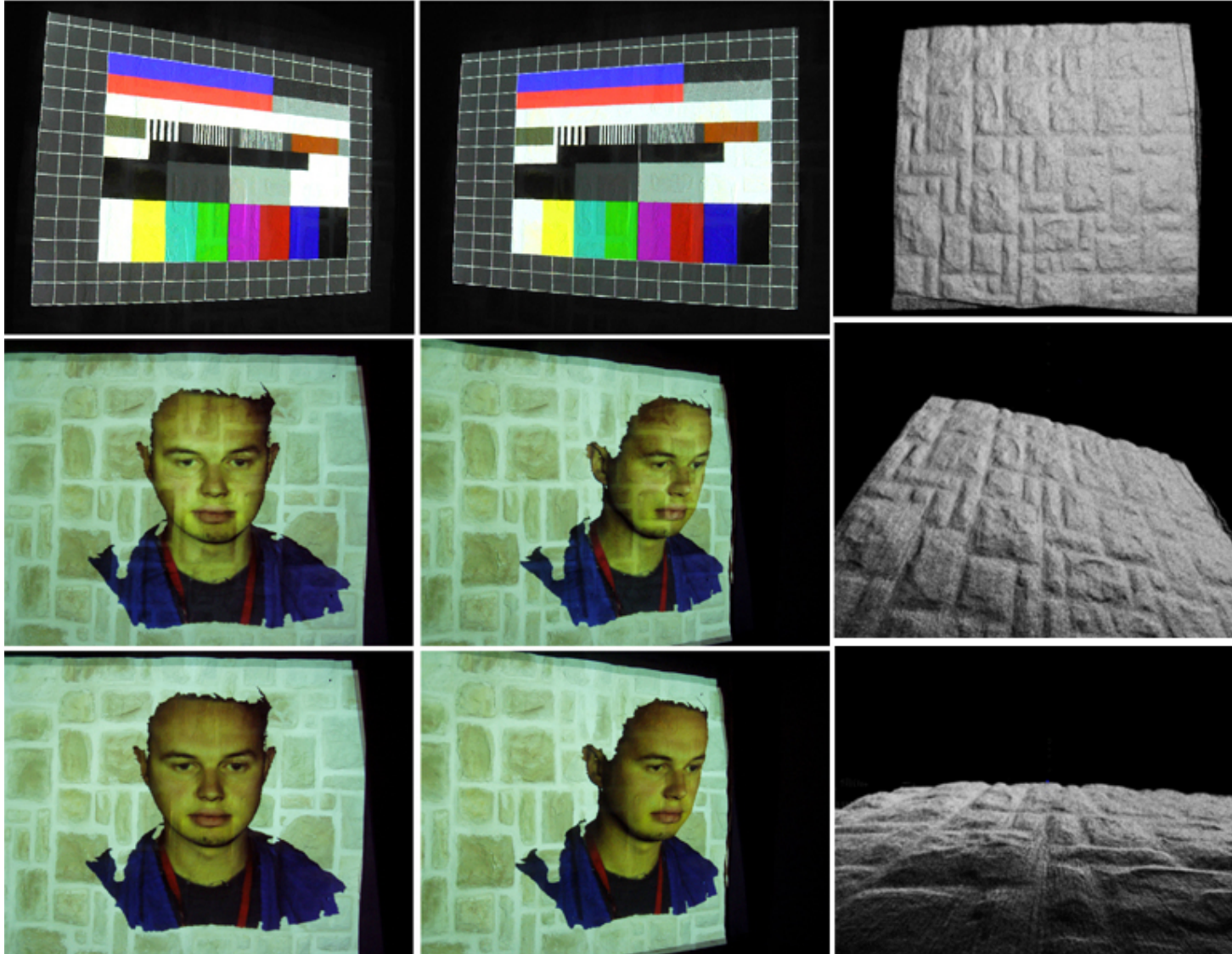
# Laser Projectors

- E.g. Extend3D Werklicht



# Projected Environments

Oliver Bimber, 2005



# Projected Environments



Bacardi Party Projection



Adidas 3D Mapping

# Mobile Devices

- Smartphones & Tablets
- Input device = Output device
- Output
  - Augmented Video Frames
    - Overlay real & virtual content
  - 2D (sometimes 3D)
- Input data
  - Video Frame (extract structures & information)
  - Touch & Device Orientation
  - Gyroscope, Accelerometer, GPS ...



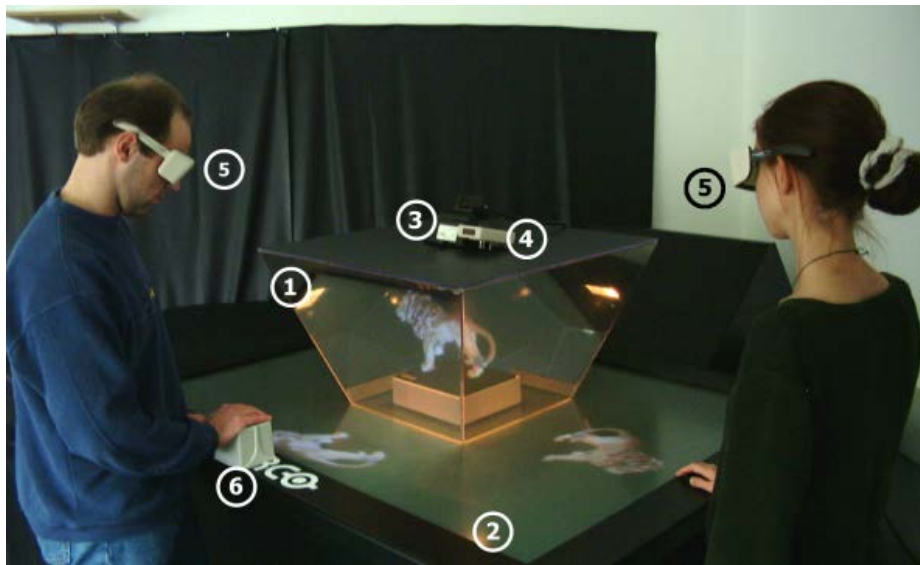


# Current Smartphone Specs

- Example: Samsung Galaxy S8 (Apr '17)
  - 2.3 GHz quad core CPU (Qualcomm Snapdragon 835)  
+ quad-core 1.7 Ghz
  - 4 GB RAM, 64 GB storage
  - GPU: Adreno 540
  - 2960 x 1440 pixels, 5.8" Super AMOLED display
  - 12MP rear cam, 8MP front, 4K video capture, HDR
  - Sensors: Accelerometer, gyroscope, proximity, compass, barometer, heart rate, SpO2, Fingerprint
  - LTE/HSPA, WiFi a/b/g/n/ac, NFC, Bluetooth 5.0
  - GPS, Galileo, Glonass, BeiDou
  - Android 7

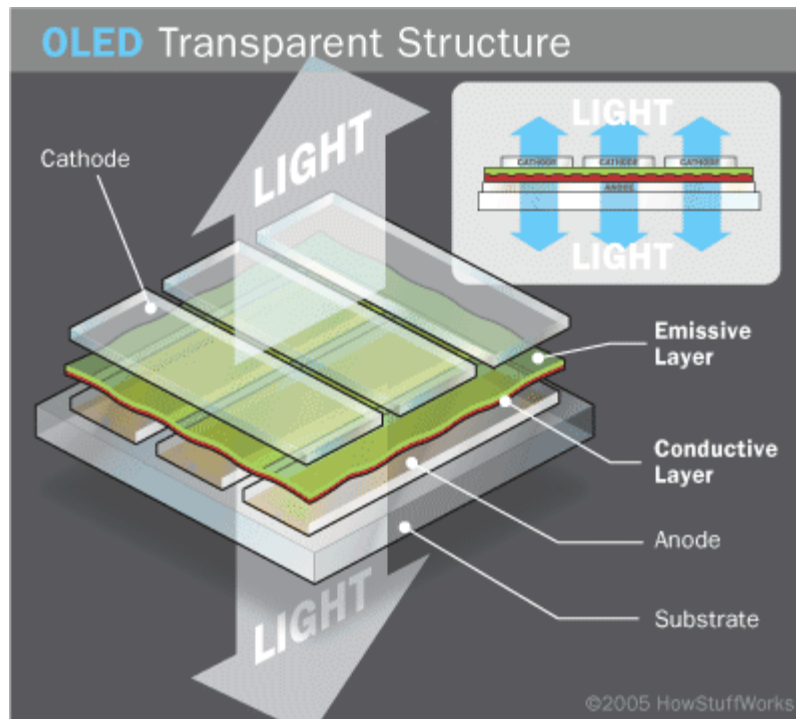
# Spatial See-through Displays: Virtual Showcase

- Projection-based AR
- Special purpose display for museums
- Real and virtual images or objects are merged
- Max. 3 users



# Transparent Displays

- Various Vendors
- Useful for AR applications



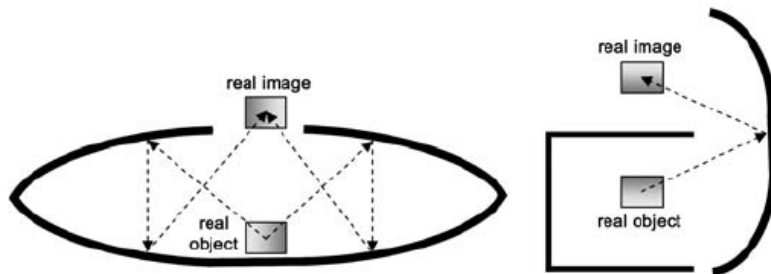


# Auto-stereoscopic Display Technologies

- Stereo without glasses
- Types
  - Re-Imaging
  - Lenticular
  - Volumetric
  - Holographic



Rotating volumetric display



**Figure 2.17.** Examples of common real-image display configurations using one or two concave mirrors.

# Lenticular 3D Displays



- Works without glasses!
- Various companies
- Some require/offer multiple views (up to 48)
- Others provide head tracking



# Looking Glass

8 inch or 15 inch; 4K at 60Hz  
only horizontal parallax, 45 views  
40-50° view cone

45 unique views of a 3D scene are captured on a computer at 60 FPS. These dozens of views are encoded into a video signal that is sent via HDMI to the Looking Glass®. The Looking Glass optics decode the video signal into a full-color, superstereoscopic three-dimensional scene that multiple people can view and interact with. All without the need for VR or AR headgear.

## Traces

*Provides front and back depth cues*

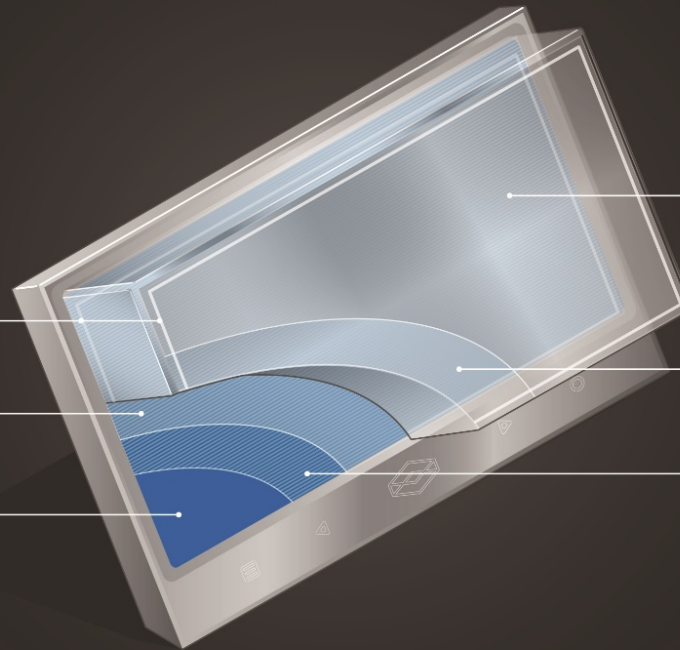
## Optical Film

*Sharpens subpixels*

## LCD

*Displays 45 unique interlaced views of a 3D scene at 60 fps*

**Dimensions** 8.2" x 3.7" x 6.1" (L x W x H)  
20.9cm x 9.3cm x 15.4cm (L x W x H)  
**Weight** 4.8 lb / 2.2kg



**Optical Films and Protective Layer**

**High Refractive Index Material**

*Shifts focal plane*

**Lenticular Lens**

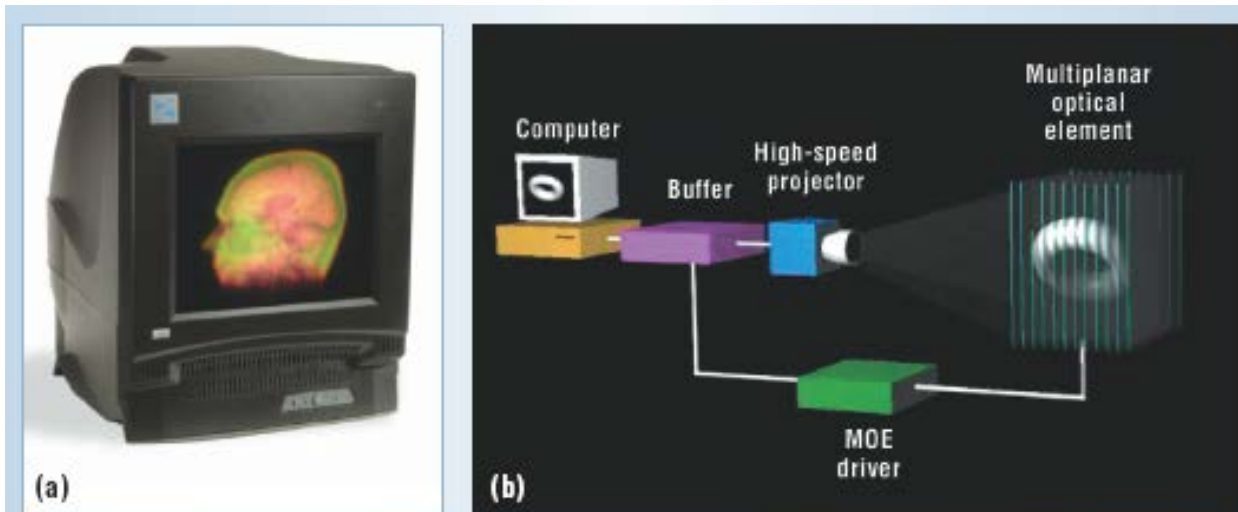
*Distributes 45 unique viewpoints to the viewer*

This equipment is manufactured by Looking Glass Factory Inc. (US). Patents pending around the world. Designed in Brooklyn and Hong Kong - Made in China. Looking Glass® is a registered trademark of Looking Glass Factory Inc.

Looking Glass Factory (US)  
95 Commercial St, Brooklyn NY, 11222 USA  
[www.lookingglassfactory.com](http://www.lookingglassfactory.com)

# Volumetric Displays

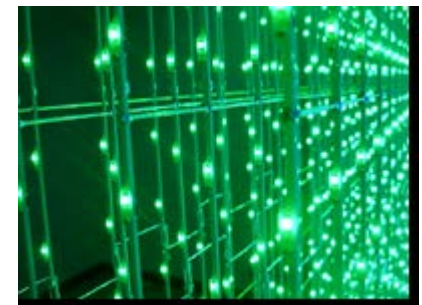
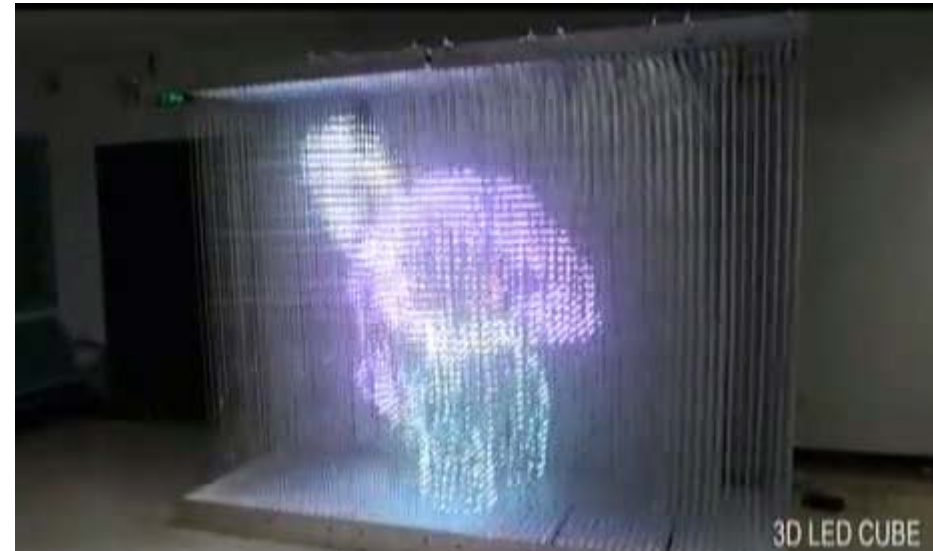
- 2 Types:
  - Swept volume: Plane or helical surface
  - Stack of planes
- LightSpace Technologies: DepthCube
  - 20 slices, 50fps, 1024x768x20



# Volumetric LED Displays

- 48\*96\*192cm
- 40 mm pixels pitch
- $12*24*48 =$   
13824 LEDs
- SD Card controller
- 200 – 4200 Watt

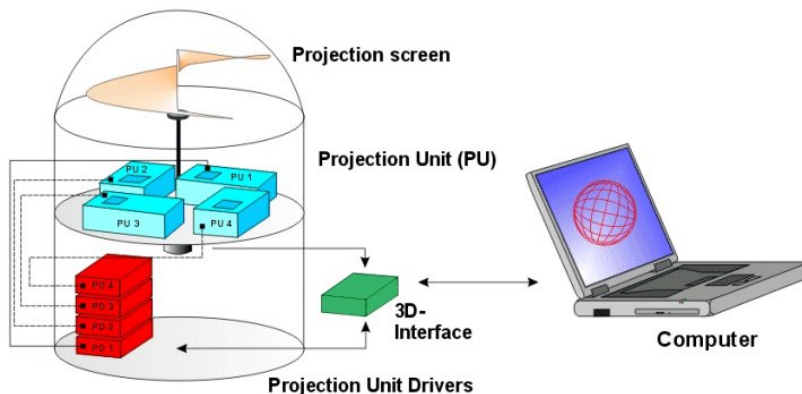
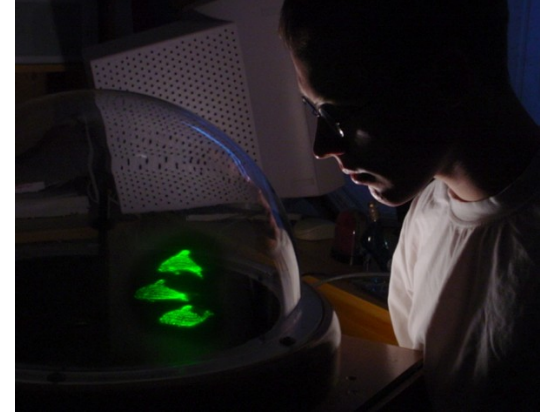
Seekway 3D LED Cube



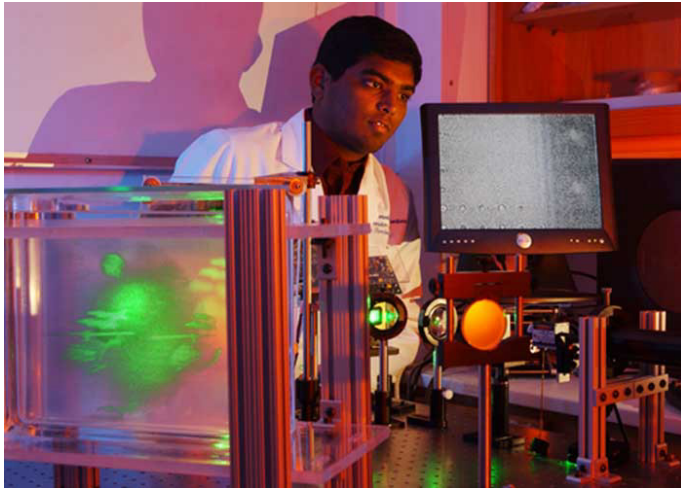


# Volumetric Displays

- Perspecta3D
  - 1024x768x3 digital projector, 198 images/slices, 900rpm
- Felix3D



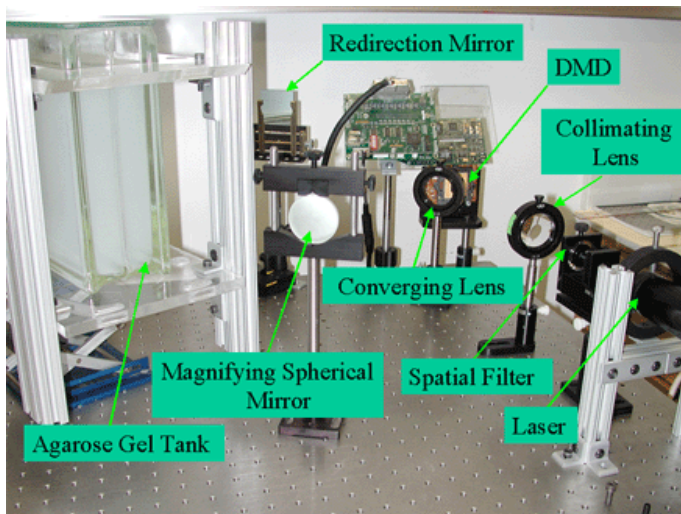
# Holographic Displays



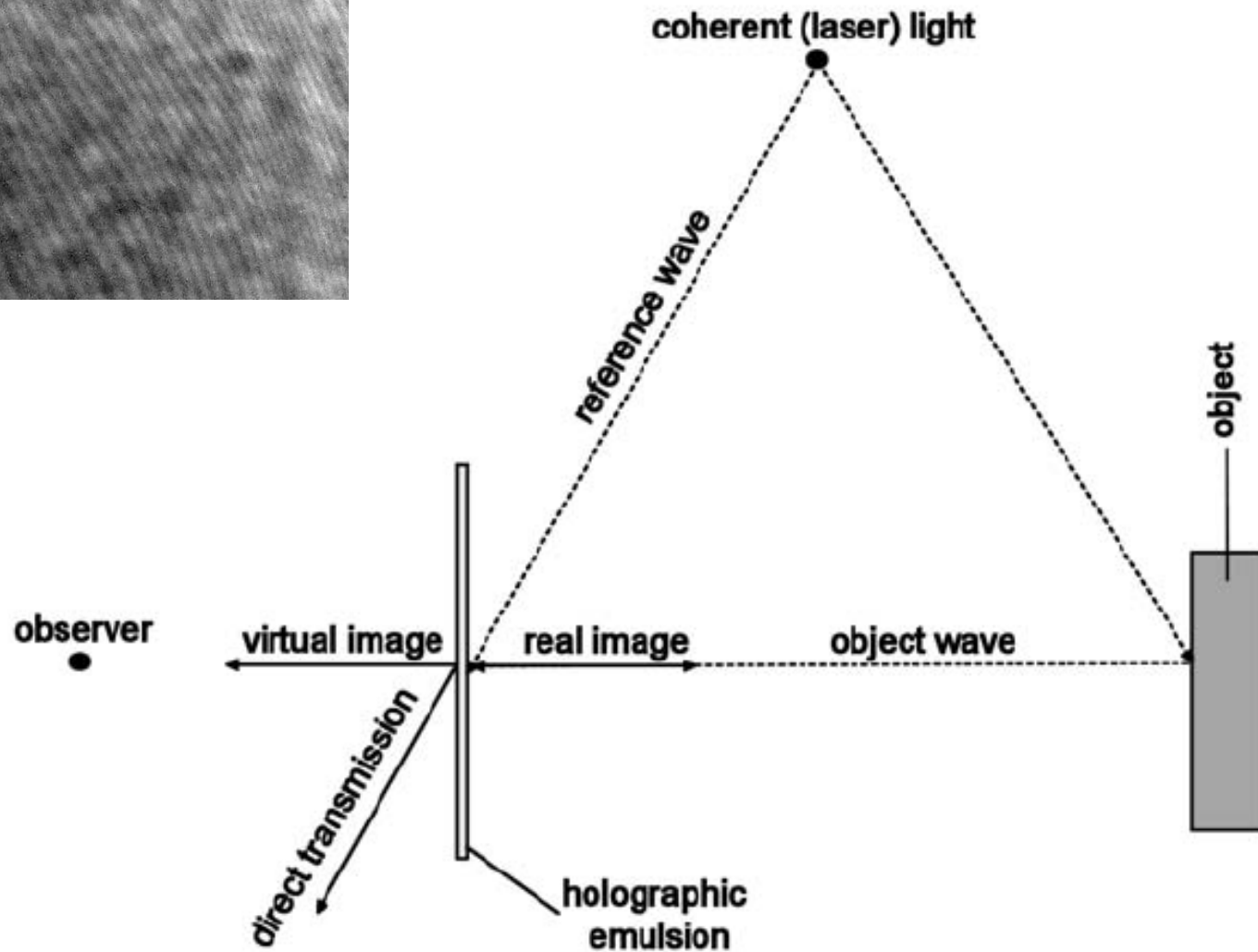
- Diffraction patterns encoding both amplitude and phase information of the light waves coming from a three dimensional object or scene
- Capable of reproducing these object light waves when illuminated with coherent light like lasers
- Up to now: photographic film emulsions and lasers used
- New development: Holografika
- Details on:

[http://innovation.swmed.edu/research/instrumentation/res\\_inst\\_dev3d.html](http://innovation.swmed.edu/research/instrumentation/res_inst_dev3d.html)

<http://www.holografika.com/>







**Figure 2.19.** Optical holographic recording and reconstruction (example of a transmission hologram). (Image reprinted from [18] © IEEE.)

# Holographic Displays

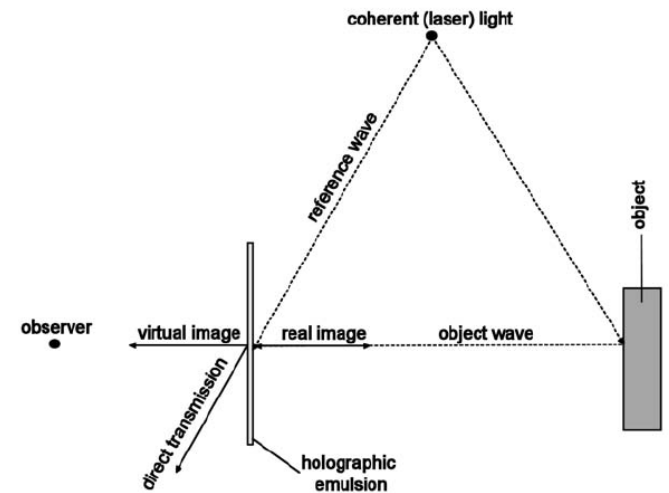


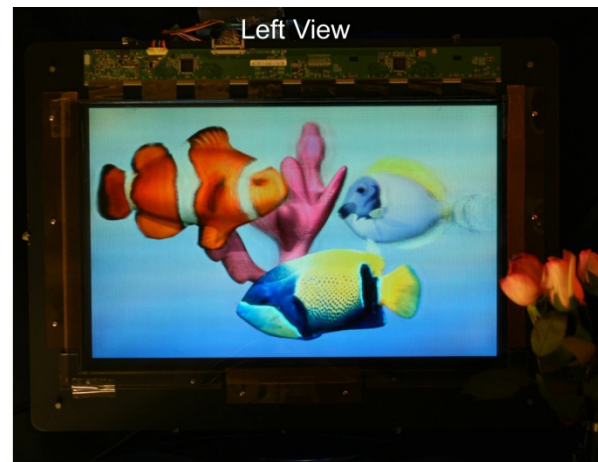
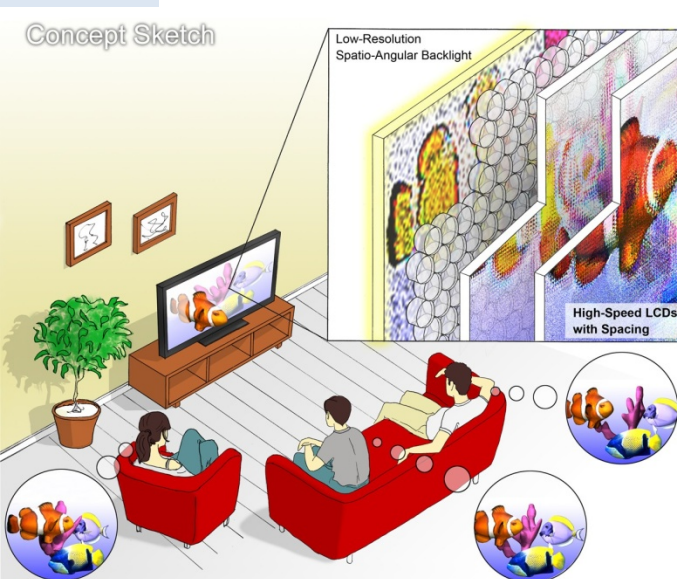
Figure 2.19. Optical holographic recording and reconstruction (example of a transmission hologram). (Image reprinted from [18] © IEEE.)



# Tensor Displays

## Compressive Light Field Synthesis using

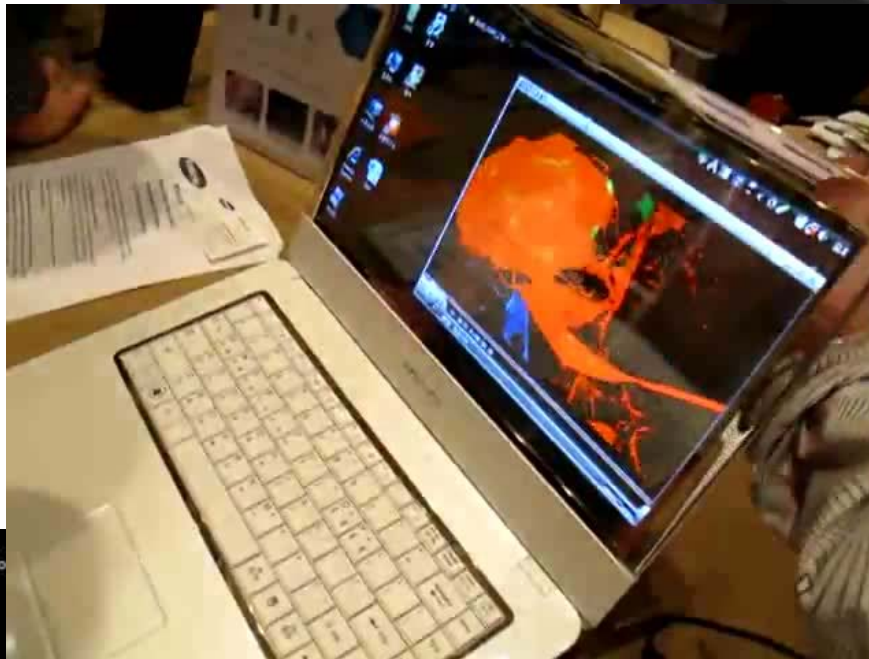
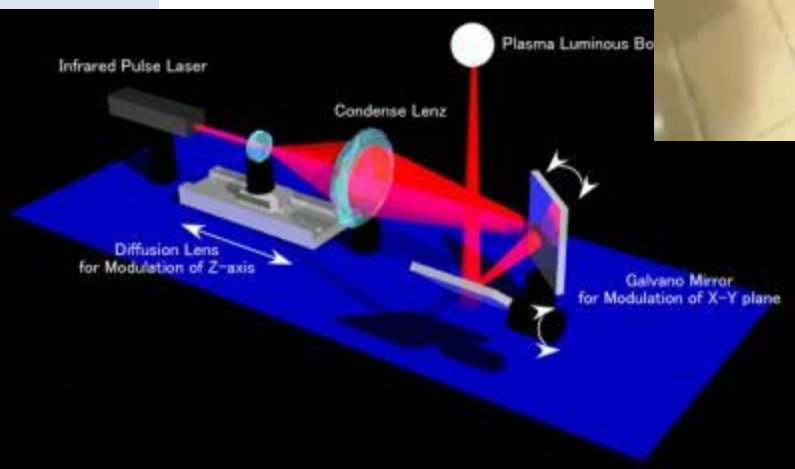
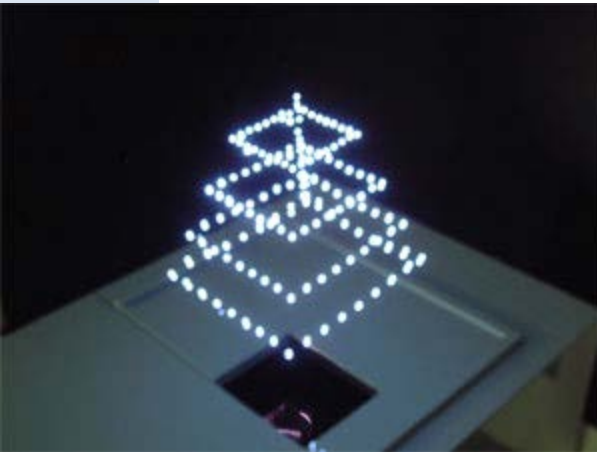
- Multilayer Displays with
- Directional Backlighting





# The Future... ?

## Laser Plasma



SolidFelix

Transparent  
Display

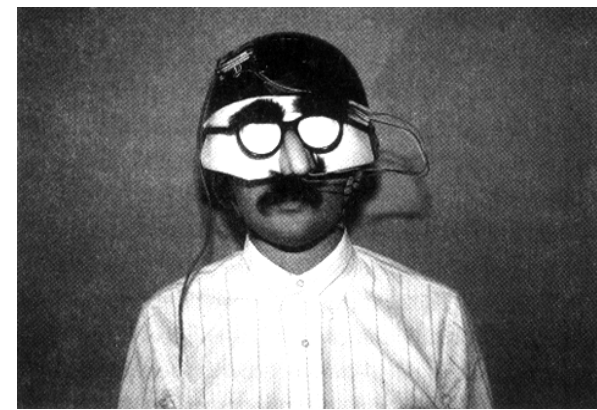
Foldable Displays



# Auditory Output

- Main Uses
  - Localization: how to create spatialized sound
    - 3D Sound Sampling; Auralization
  - Sonification: communicate information
  - Ambient effects: realism
  - Sensory Substitution
  - Annotation and help (speech)
- Many different types of setups
- If used properly can be a powerful tool
- Tells user where to look

# Olfactory Displays – Scent



- Sense of smell (or olfaction) is a primal chemical sense for humans. Impact on the central nervous system and hormone balance.
- Smell can influence mood, memory, emotions, social behavior, mate choice.
- Scents can e.g., reduce stress, enhance concentration or act as stimulants.
- Smell is more closely linked with memory than any other sense
- Smell cannot be synthesized by single components!
  - Typically 100s/1000s of smell molecules involved in one smell.

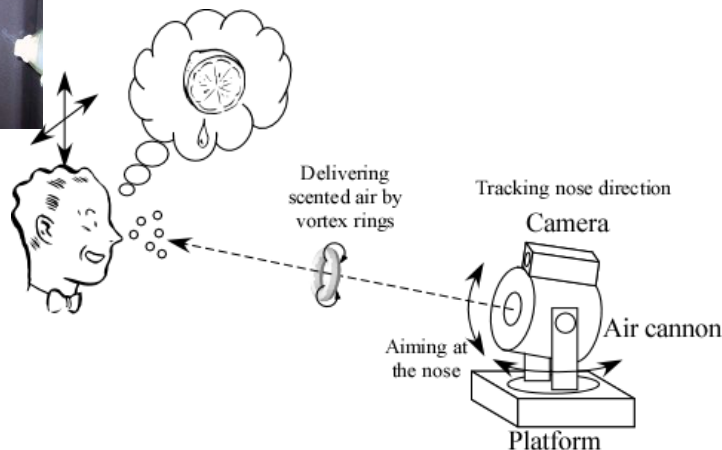
# Sniffman



Olorama  
12 smells wireless aromatizing device



# Scent Cannon





# Taste

- Research on taste perception started in 1500s
- Taste is 80% smell
- 5 basic tastes. The chemical sensation is synthesized from 5 elements of basic taste:
  - sweet, sour, bitter, salty, and umami
- Food Simulator: A Haptic Interface for Biting
  - Simulates biting force

Hiroo Iwata, University of Tsukuba, Japan

Hiroaki Yano, Takahiro Uemura, Tetsuro Moriya

<http://www.siggraph.org/s2003/conference/etech/food.htm>



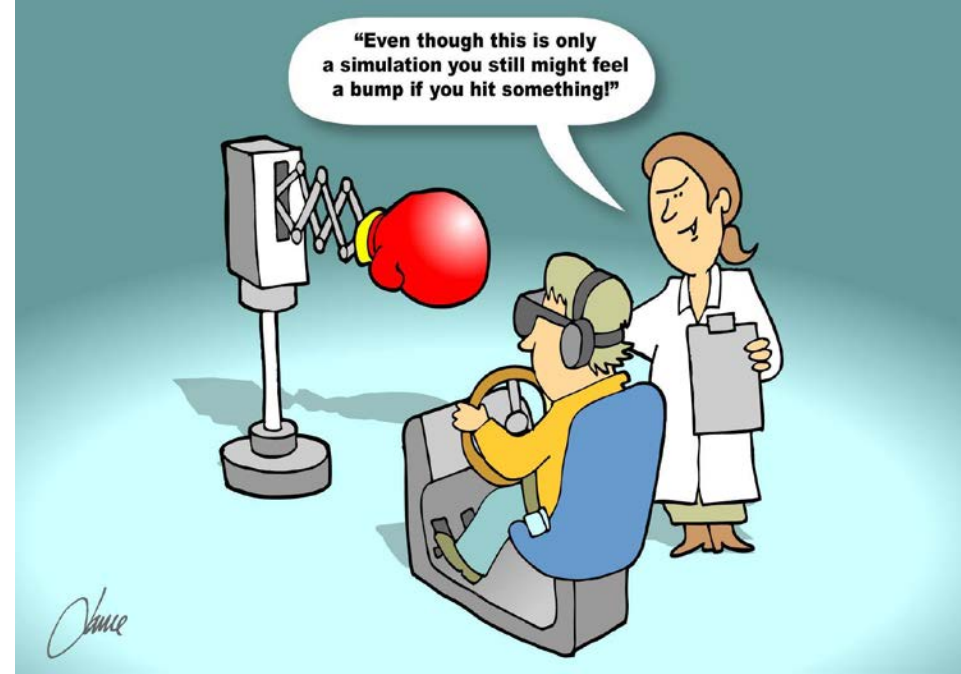
# Flavour

- Flavour does not travel well
  - Raki tastes GREAT in Crete
  - Not so good elsewhere!
- It's all about context
  - Where, with whom, preconditioning, etc



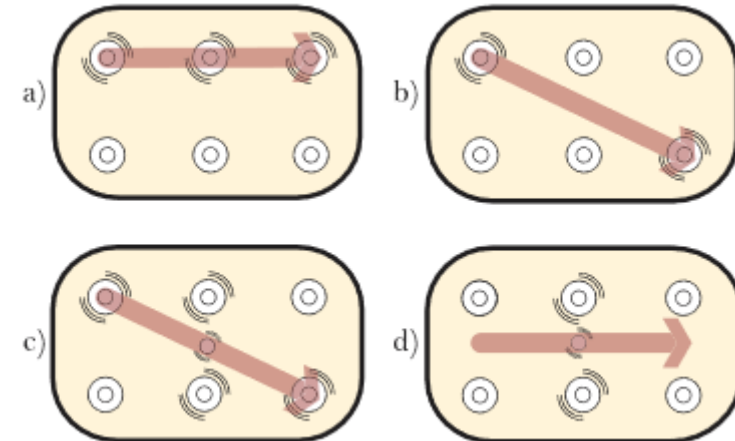
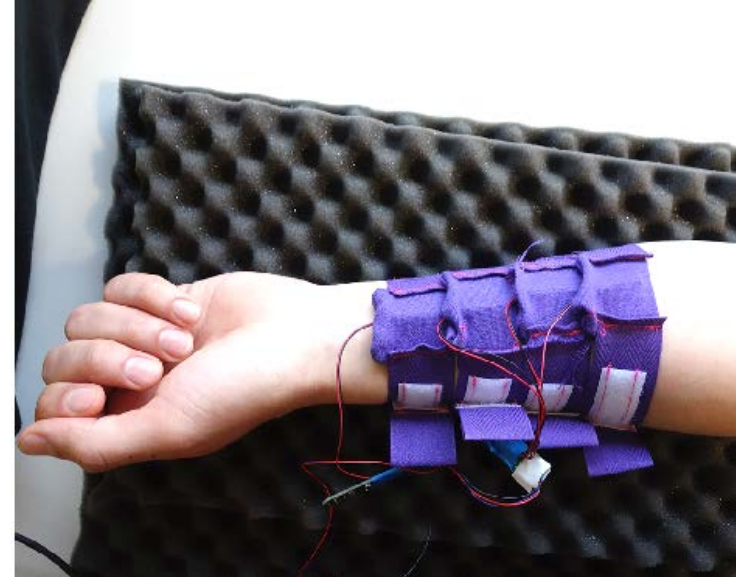
# Haptics

- Greek: Hapthai = sense of touch
- Haptics
  - Touch/tactile feedback
    - Relies on sensors in and close to the skin
    - Most sensors are on the hand
    - Conveys information about contact surface
      - Geometry
      - Roughness
      - Slippage
      - Temperature
    - Does not actively resist user contact motion
    - Easier to implement than force feedback
  - Force feedback



# Tactile Brush

- Stroking Sensations on skin
- Vibrotactile Array
  - velocity of between 1–10 cm/s
  - Produces feeling of linear motion



# State of the Art (1)

## Traditional Haptic Devices



1-Point Touch; Exoskeleton; Feeling Vibrations

# Force Feedback

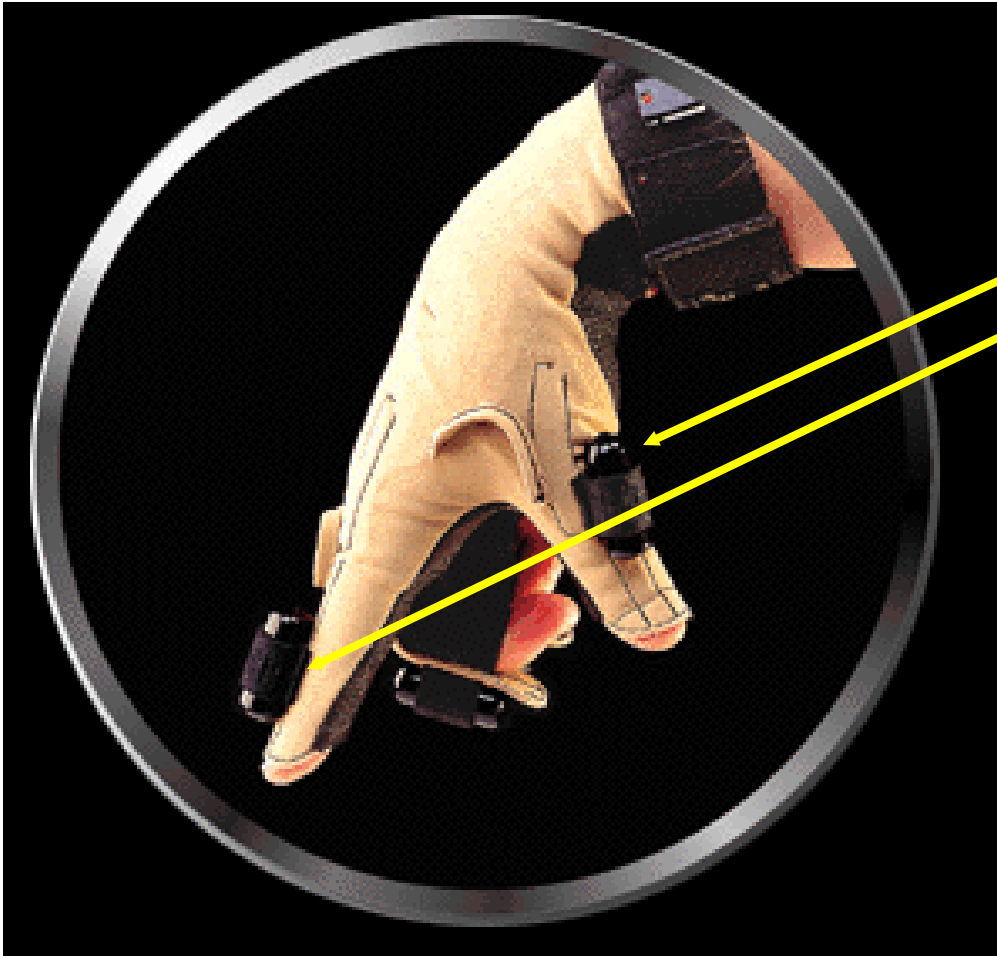


- Relies on human sensors on muscle tendons and bones/joints
- Conveys information
  - contact surface
  - Object weight
  - Inertia
- Actively resist user contact motion
- More difficult to implement than touch feedback
- No commercial products until mid 90s





# CyberTouch Glove

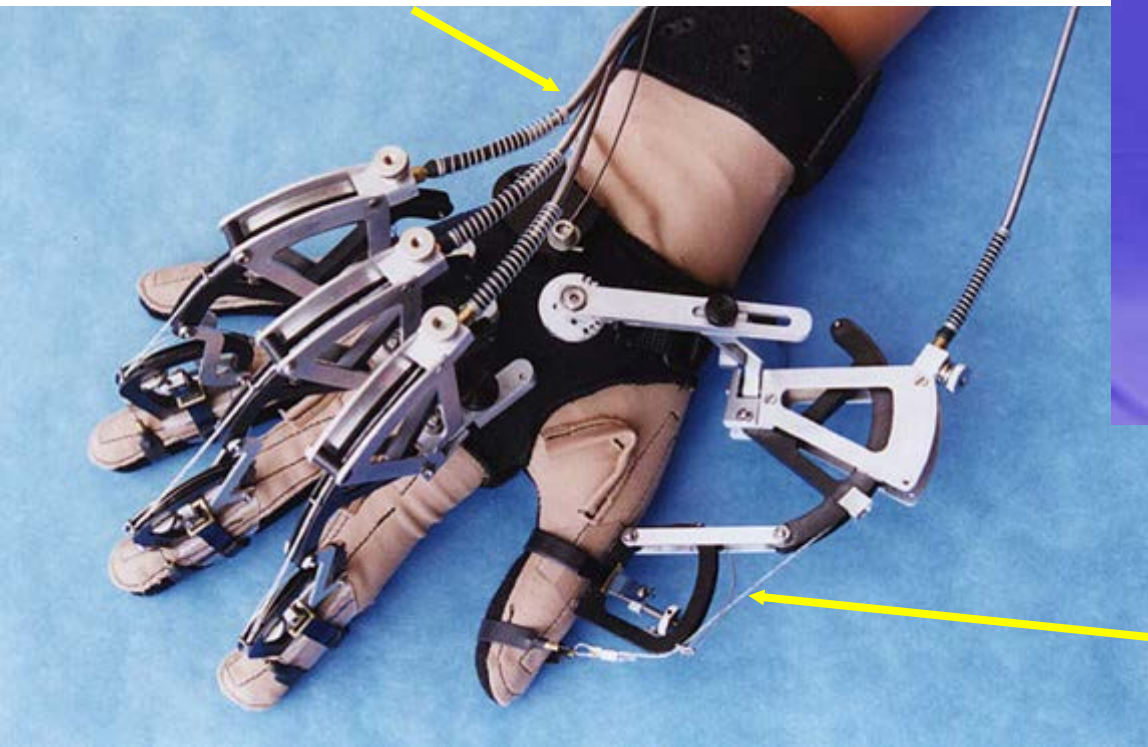


**6 individually  
controlled  
vibrotactile  
actuators**

**0-125 Hz  
frequency  
1.2 N amplitude at  
125 Hz**

# CyberGrasp Force Feedback Glove

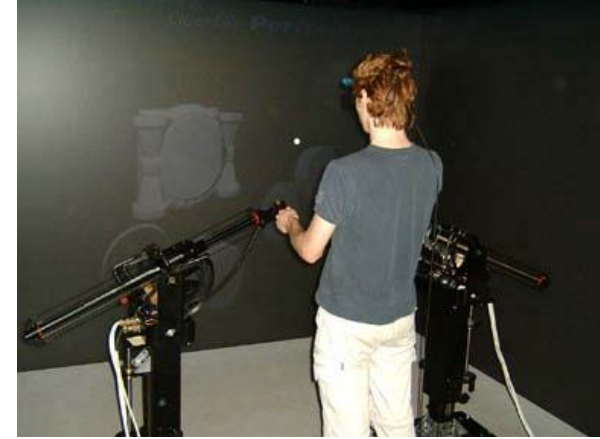
**Exoskeleton  
over CyberGlove)**



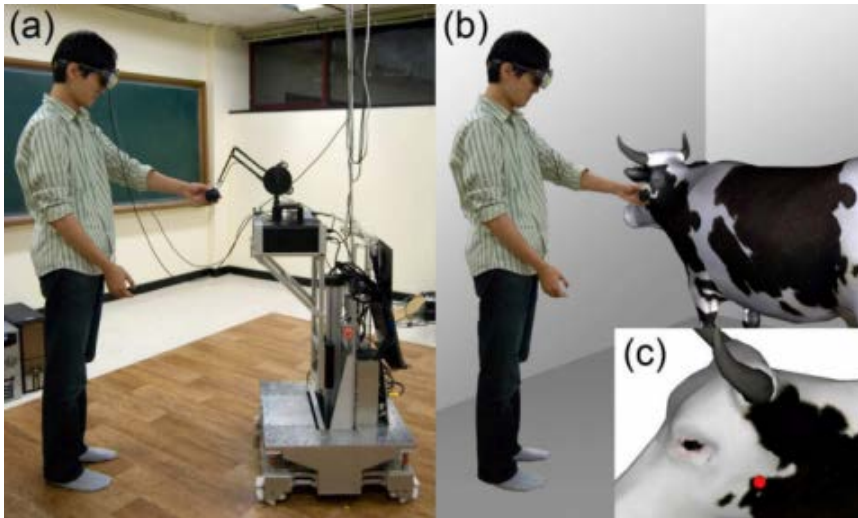
**Cables and pulleys**

**12 N/finger (continuous?); Weight 350 grams;  
remote electrical actuators in a control box.**

# State of the Art (2)

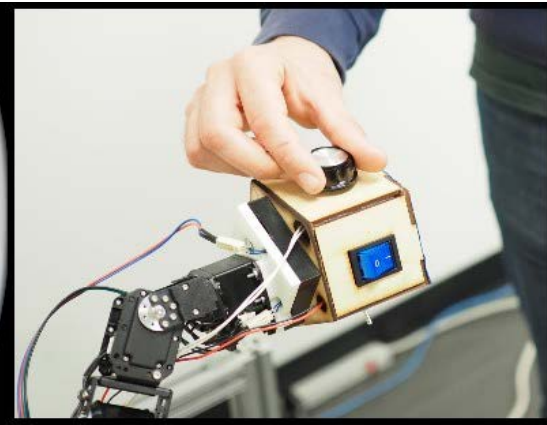
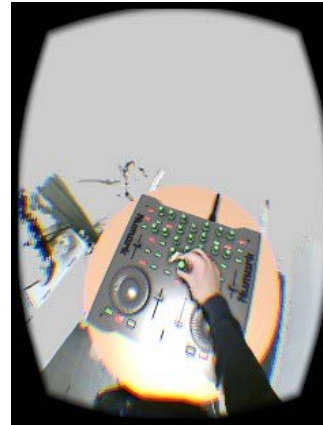


## Room-Scale Haptics – Traditional Devices on Mobile Platforms



# State of the Art (3)

## Haptics with Props





# State of the Art at TU Wien

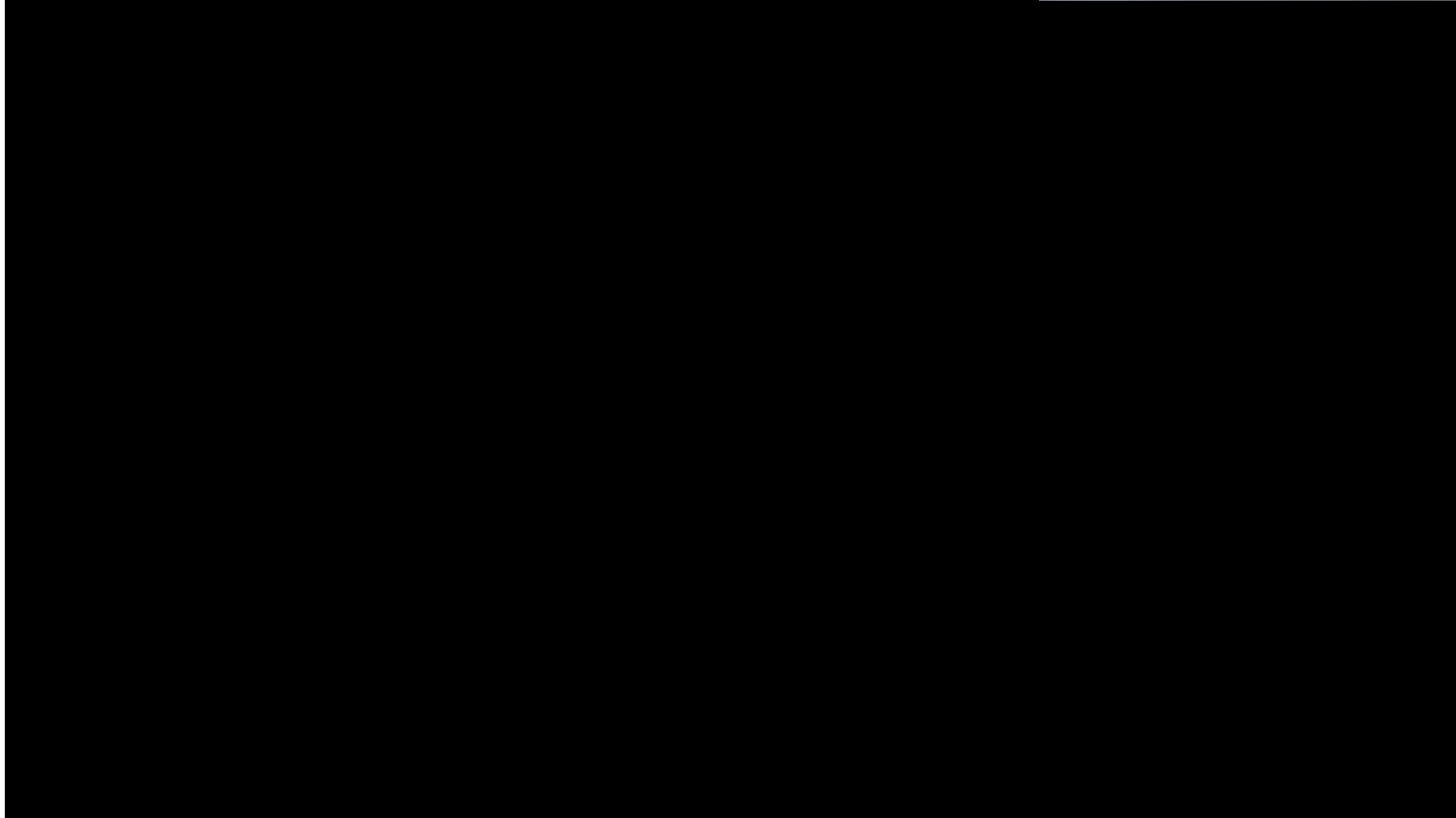


Hands-Free Haptic  
Interaction



Vonach E., Gatterer C., Kaufmann H.  
VRRobot: Robot Actuated Props in an Infinite Virtual Environment. IEEE Virtual Reality 2017.

# Next Step: Robotnik KAIROS Cobot







# VR Interface Problems

- No Moore's Law in the area of HMDs and other quality peripherals
- Need Cost/Benefit Proofs!
- Limited Awareness/Unrealistic Expectations
- (Aftereffects Lawsuit Potential)
- Ethical Challenges

# Cost-Benefit Analysis Summary

*Courtesy of Bob Stone*

Item	Number of Real Rounds Fired or Aircraft Hours at HMS CAMBRIDGE in a typical pre-closure year*	Costs per real round or per aircraft hour, inclusive of VAT	Totals SAVED Through Simulator Introduction
<b>30mm MSI</b>	13,320 rounds (111 students x 120 rounds each)	\$78 (£50)	\$1.03 million (£666,000)
<b>20mm GAM BO</b>	26,160 rounds (218 students x 120 rounds each)	\$50 (£32)	\$1.3 million (£837,120)
<b>Falcon 20 Aircraft</b>	384 hours	\$7666 (£4936)	\$2.95 million (£1.9 million )
			\$5.3 million (£3.4 million)

# The Interface Challenge



# The Interface Challenge

- **Naturalism:** make VE & interaction work exactly like real world.
- **Magic:** give user new abilities
  - Perceptual
  - Physical
  - Cognitive





# Interface Tools: Can we foster naturalistic interaction and do we need to?

© 1998 Randy Glasbergen. E-mail: [randy@glasbergen.com](mailto:randy@glasbergen.com) [www.glasbergen.com](http://www.glasbergen.com)



"I have a 300 MHz computer...with 10 MHz fingers."



# Japanese Karakuri Horse





# The Interface Challenge

- Will the target users be able to learn to **navigate** in and **interact** with the environment in an effective manner?

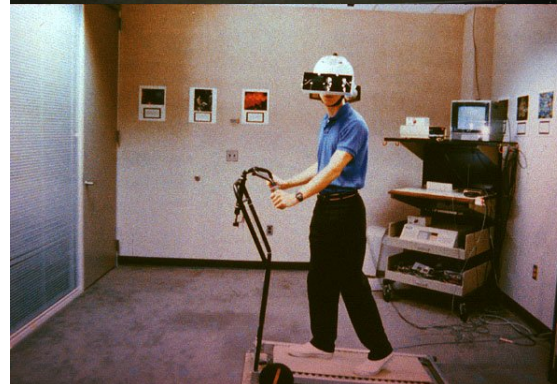
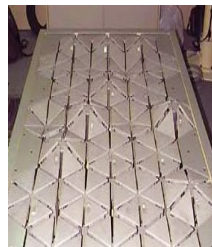
## Universal Interaction Tasks

- **Navigation**
  - Travel - motor component
  - Wayfinding - cognitive component
- **Selection**
- **Manipulation**
- **System control**



# The Interface Challenge

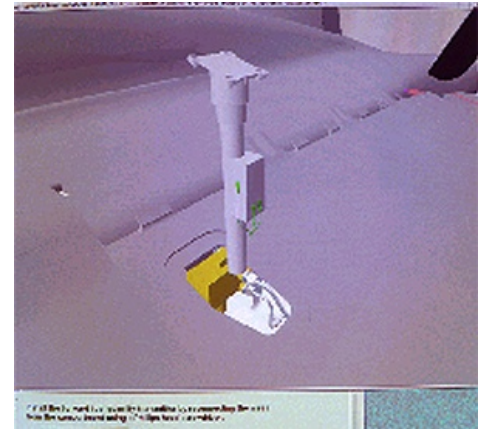
- Will the **cognitive overhead** required to use the interface distract users from the intended tasks and goals?



# The Interface Challenge

Industry Example with EXPERT users:

*(Courtesy of Bob Stone)*



Barnett *et al.* (Boeing; 2000): “As a result of these\* unique features of the VR, four of the participants commented that they **focused more on interfacing with the VR than with learning the task**”

\* Poor field of view, poor depth perception, object distortions, object manipulation

# The Interface Challenge

*Cost vs. Precision?*



VS.



*\$100 Gaming Glove?    \$5000 Wireless Glove?*



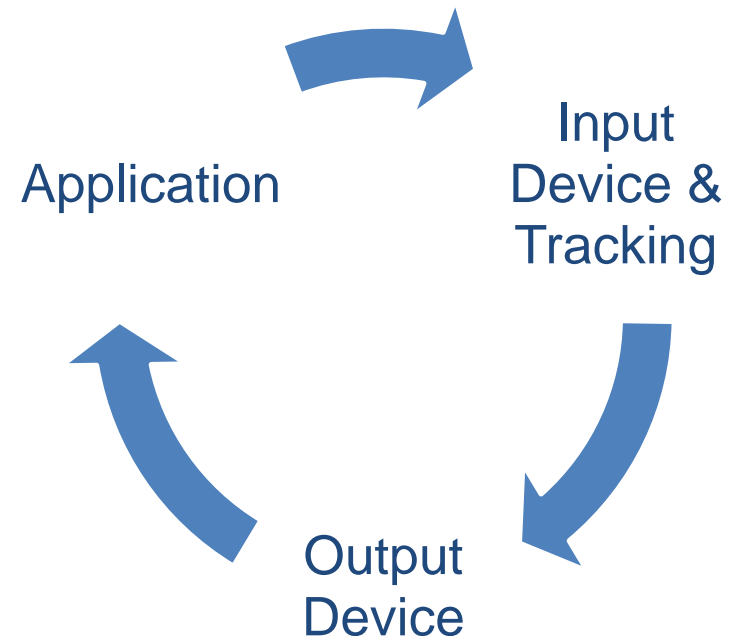
# Consider Human Factors!

Most people are not excited about HMDs & Foot-Mounted Trackers...



# General Guidelines for Choosing I/O

- Money is a big factor
- Think about what interaction techniques are required
- Choosing input device restricts the choice of output device
- Choosing output device restricts the choice of input device
- Application design depends on input+output devices and vice versa
- Creativity is important



There is **not** a single ideal solution for all applications!  
Know the possibilities!



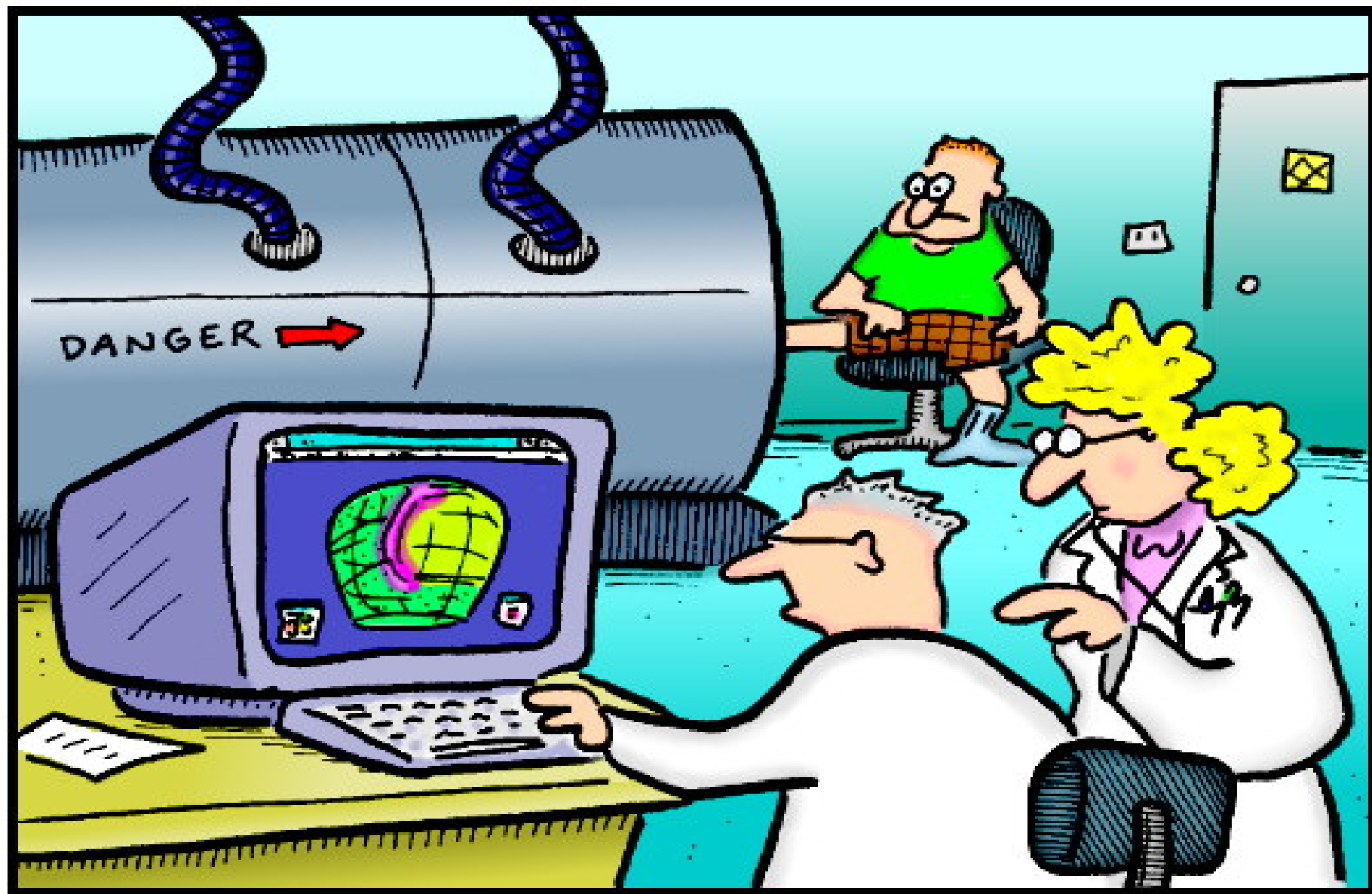
# When is a VE effective?

- Users' goals are realized
- User tasks done better, easier, or faster
- Users are not frustrated
- Users are not uncomfortable
- And there is some measurable gain in targeted real world performance

# Literature

- 3D User Interfaces – Theory and Practice (2nd edition)  
J. LaViola, Ernst Kruijff, Ryan P. McMahan, Doug Bowman, Ivan Poupyrev; Addison Wesley, 2017.
- 3D Depth cues:  
<https://web.archive.org/web/20130128090835/http://www.hitl.washington.edu/scivw/EVE/III.A.1.c.DepthCues.html>

# DOCTOR FUN



Using the latest in medical technology, modern podiatrists are able to study Phil's ingrown toenail in virtual reality.