Hannes
Kaufmann

Output Devices

Hannes Kaufmann

Interactive Media Systems Group (IMS)
Institute of Software Technology and Interactive Systems

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

Human Sensory Perception

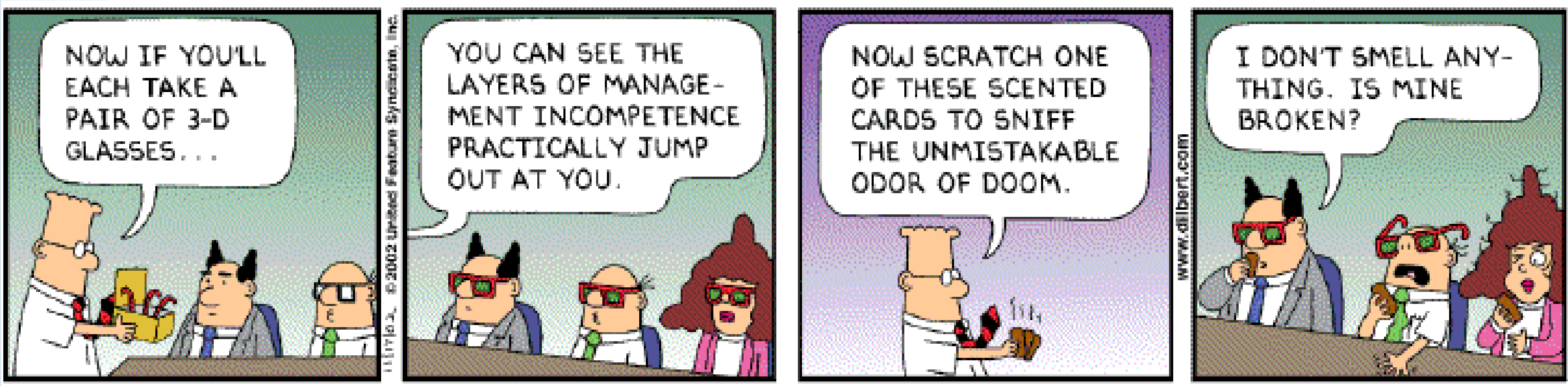
• Vision	~ 70%
• Hearing	~ 20%
• Smelling	~ 5%
• Tasting	~ 4%
• Touch/haptic perception	~ 1%

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

Hannes
Kaufmann

Display Hardware

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



Hannes
Kaufmann

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

Hannes
Kaufmann

Visual Displays

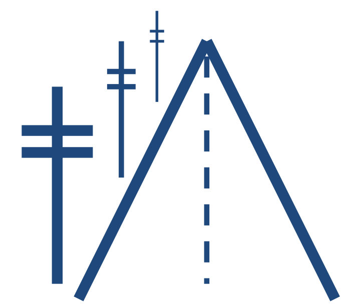
Hannes
Kaufmann

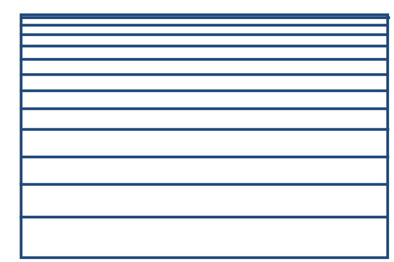
Visual Display Characteristics

- Field of View (FOV), Field of Regard
  - Human FOV ~200°
- 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

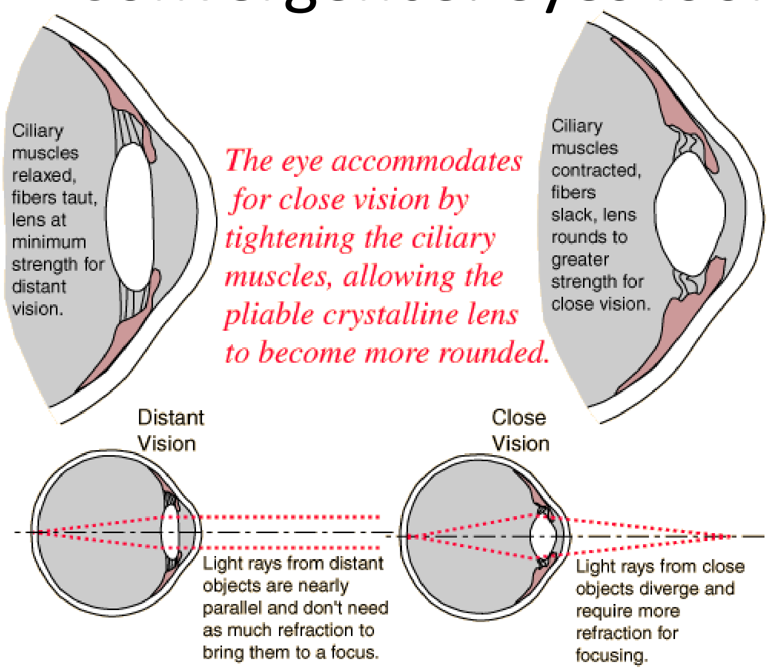


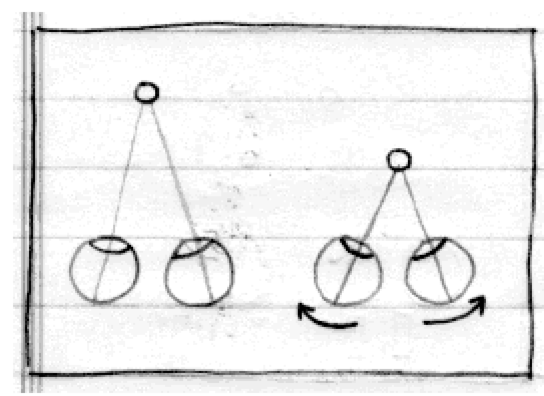


Hannes
Kaufmann

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

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

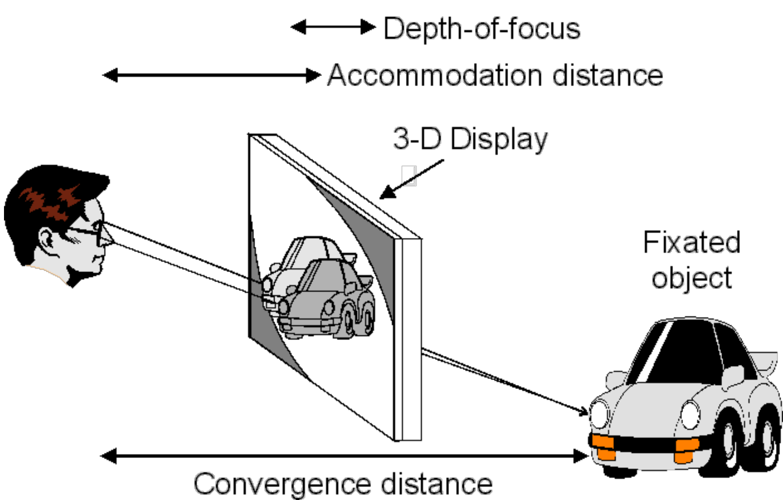




Hannes
Kaufmann

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

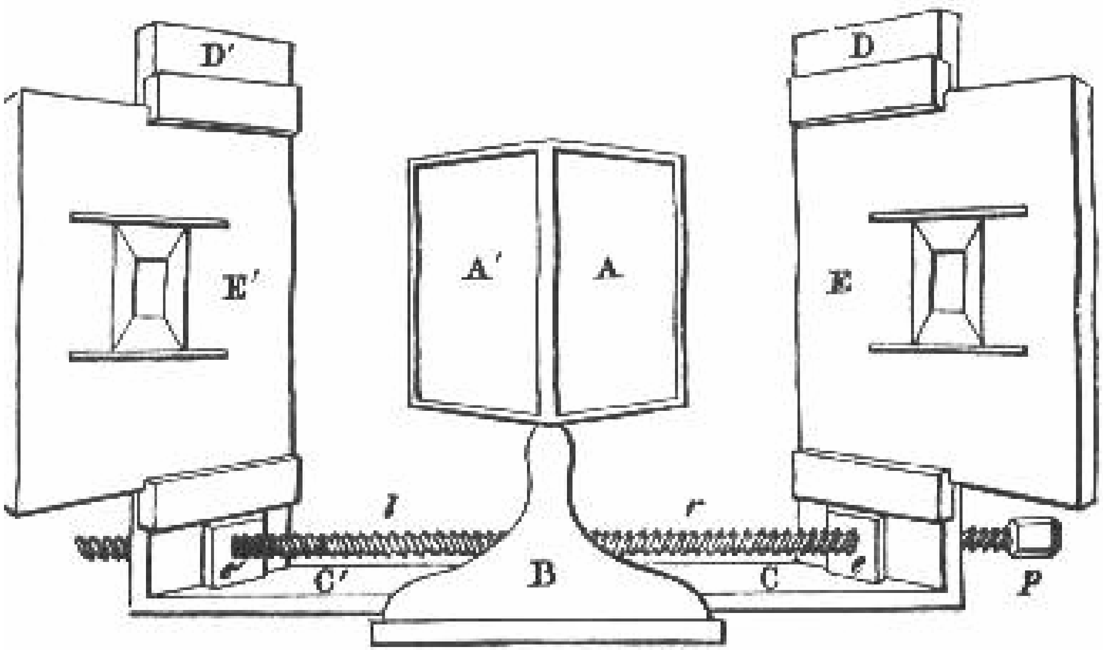
- Motion parallax
  - Closer objects move faster
  - Very strong cue (esp. for far objects)
- Binocular Disparity/Parallax
  - “shift” in left/right images
- Problem with stereo displays: Cue mismatch



Hannes
Kaufmann

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.

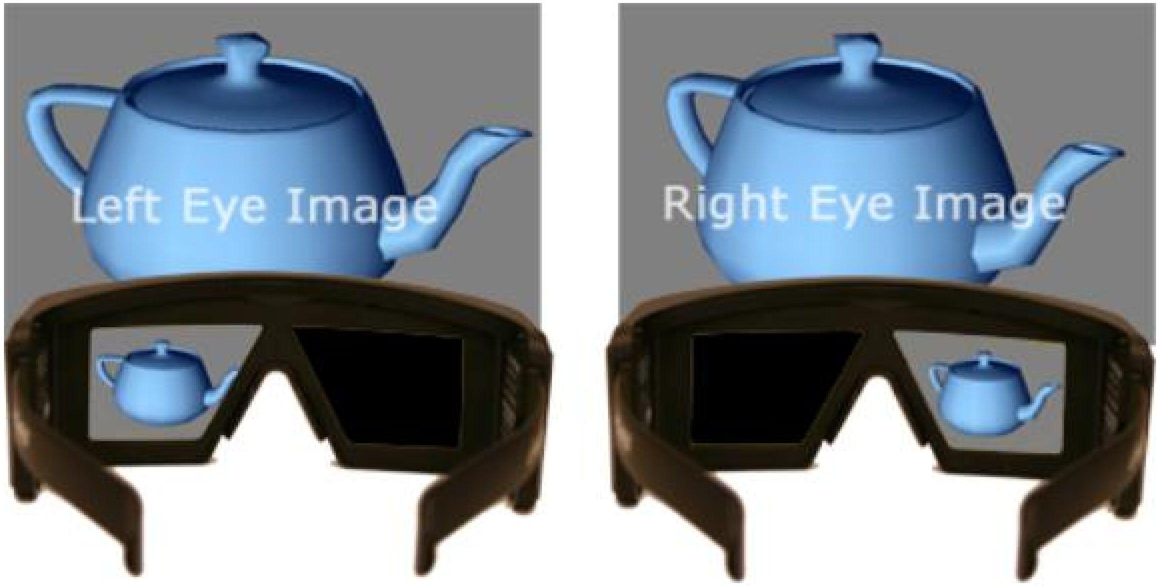
Stereo Principles: Active vs. Passive Stereo

- Active stereo:
  active switching
  e.g. shutter glasses

- Passive stereo:
  e.g. anaglyph stereo (red/blue), polarized filters, infinitec

Active Stereo: Shuttering

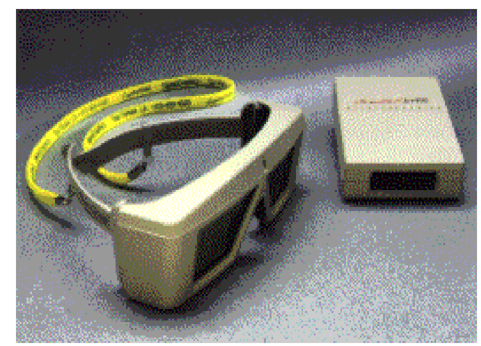
Shutter Glasses



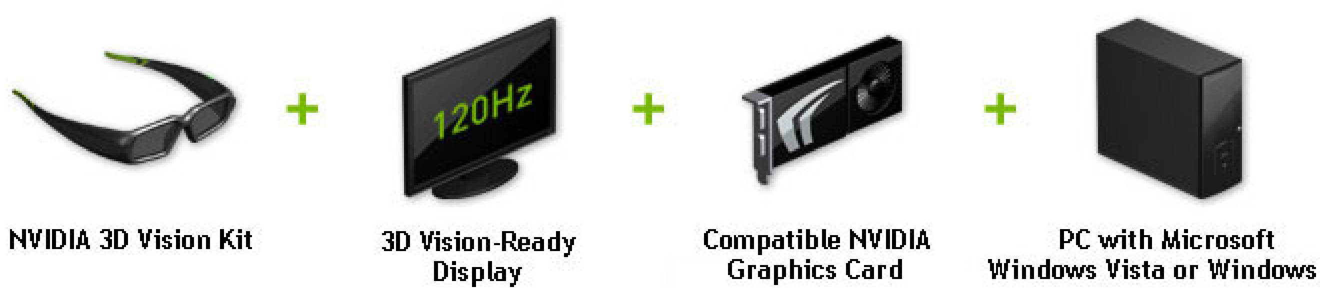
Hannes
Kaufmann

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



Hannes
Kaufmann

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

Hannes
Kaufmann

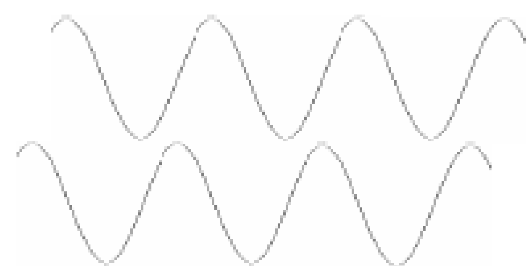
Stereo Monitor - Disadvantages

- 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

amplitude, wave-length, phase

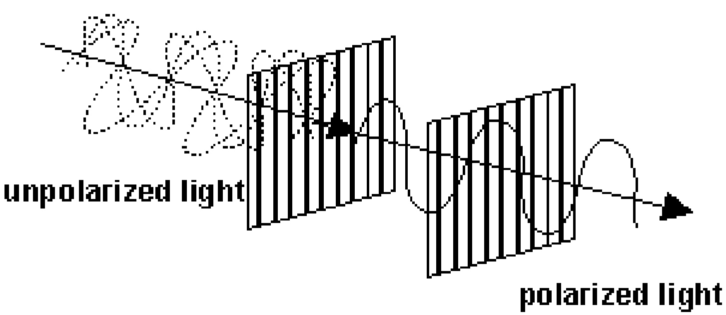


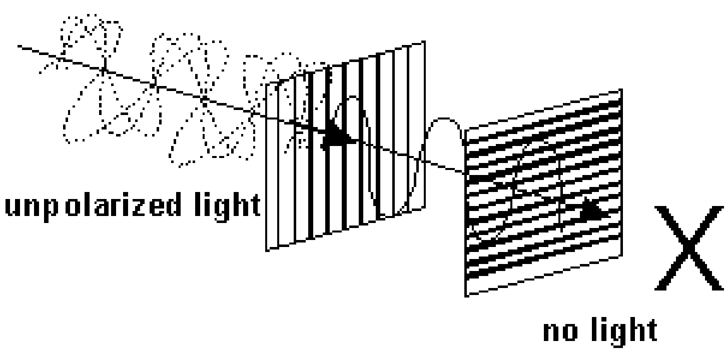
phase shift: δ

Hannes
Kaufmann

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





Hannes
Kaufmann

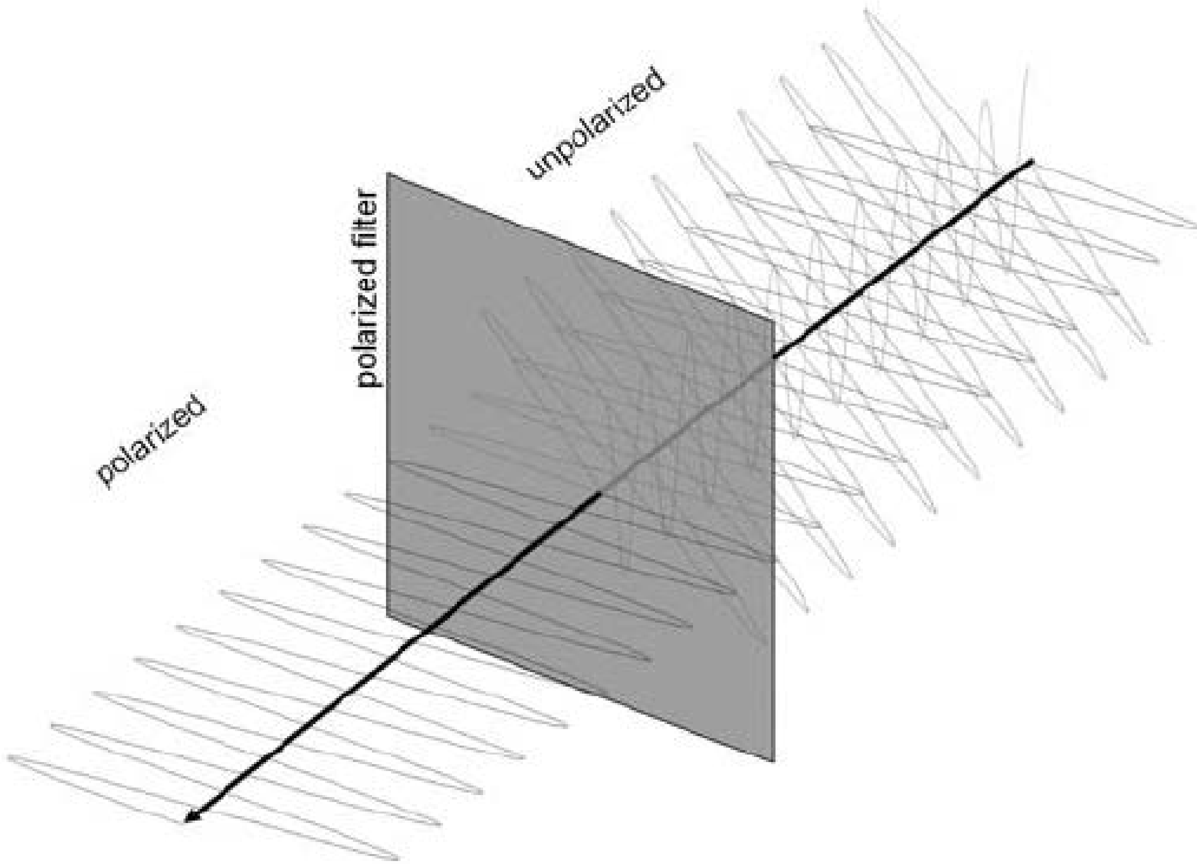
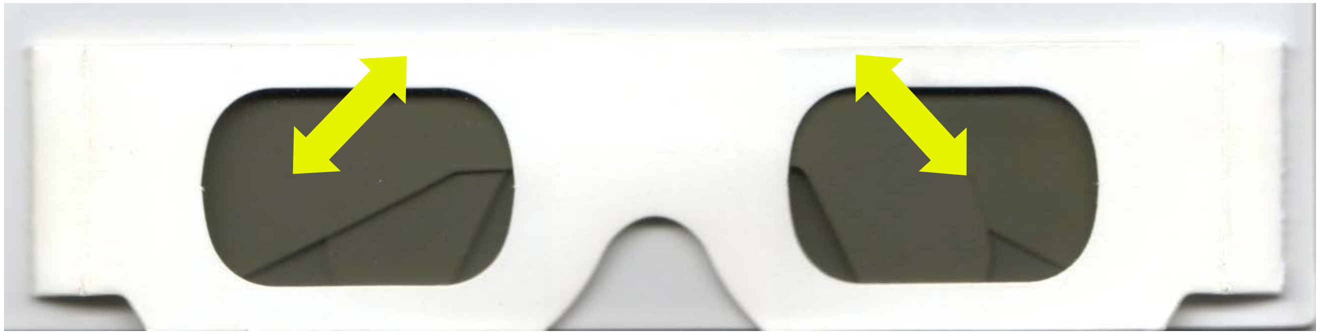


Figure 2.4. Polarization of light: only light waves with a specific orientation pass through the filter.

Hannes Kaufmann

Polarization glasses

- Very cheap, paper + plastic foil
- Trick: use +/-45° -> no wrong side wearing

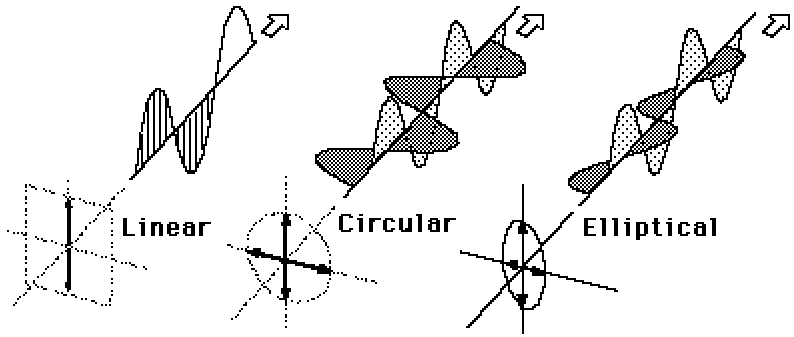


Polarization plane +/-45°

Hannes
Kaufmann

Polarization

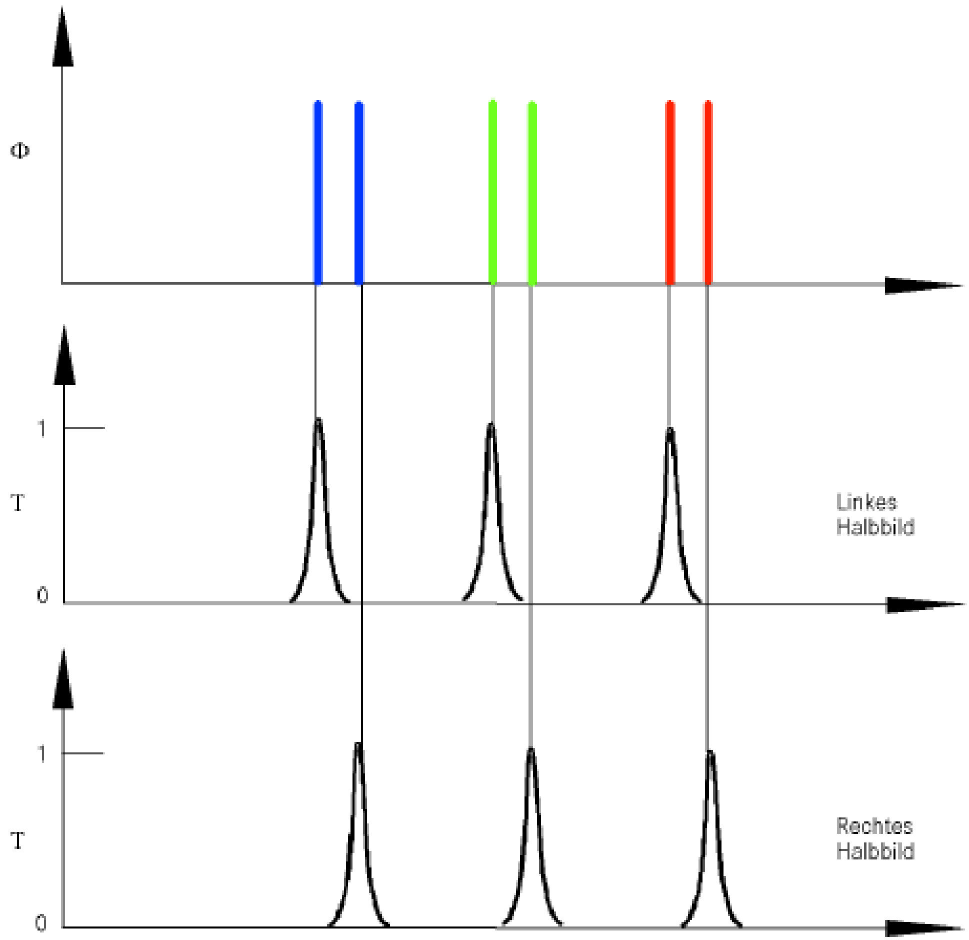
- Linear polarization
  - Can’t tilt head
  - Little ghosting



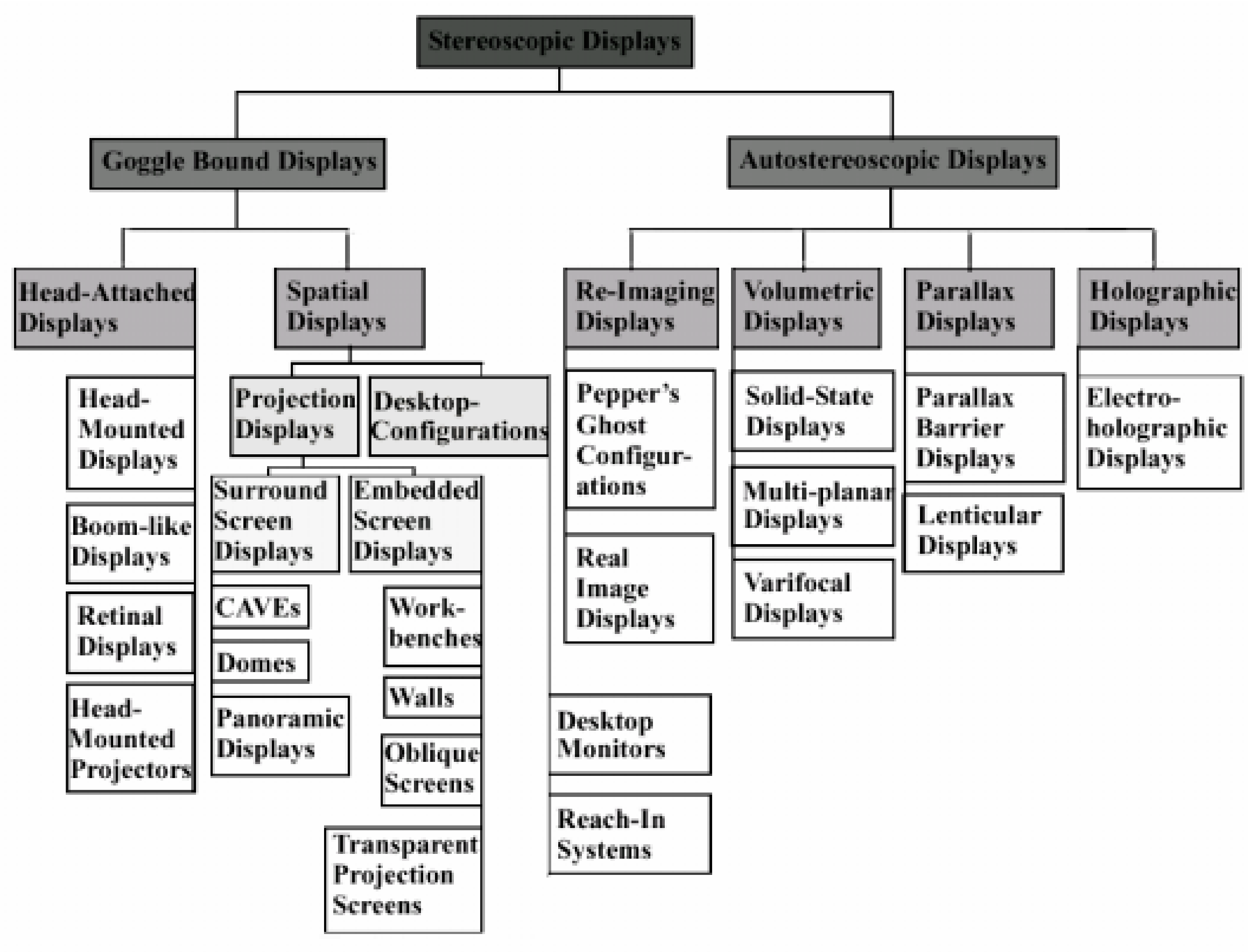
- Circular polarization
  - More involved physics
  - Principle: counter clockwise / clockwise
  - Allows arbitrary head orientations
  - In general more ghosting than linear polarization

Wellenlängenmultiplex Visualisierungssysteme

- Interferenzfiltertechnik (Infitec)

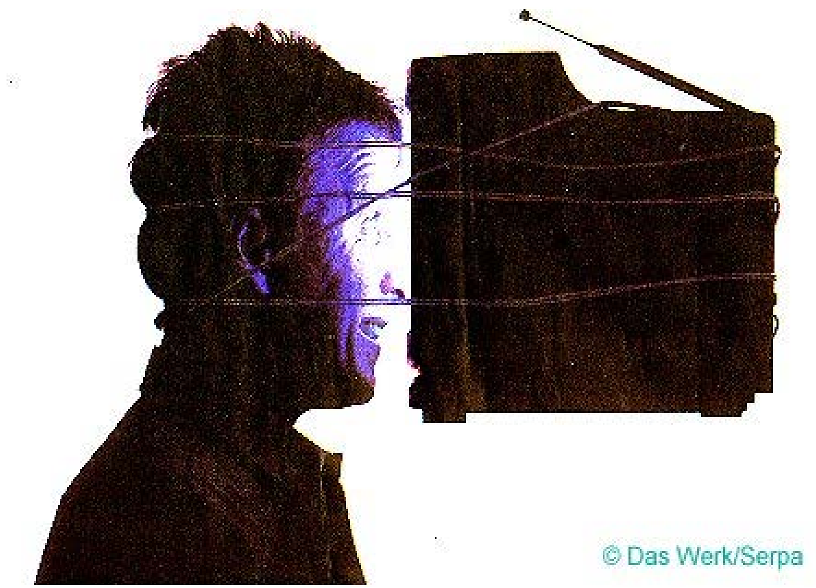


Stereoscopic Displays Today - Overview



Hannes
Kaufmann

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

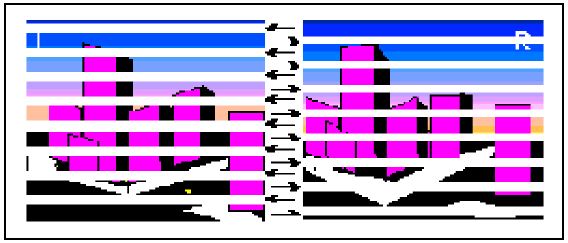
Sony Glasstron (1997-2002): LCD display,
Resolution: SVGA
(832×624 pixels)
FOV: 30 × 22 degrees
Weight: 120 grams

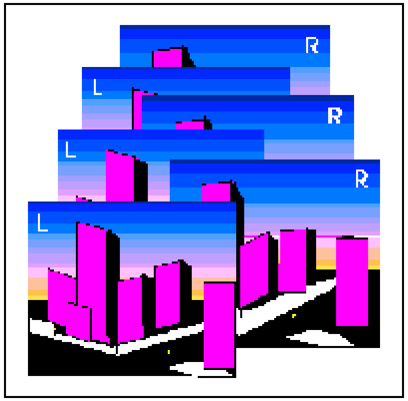
HMD - Stereo Transmission Principle: 3 Types

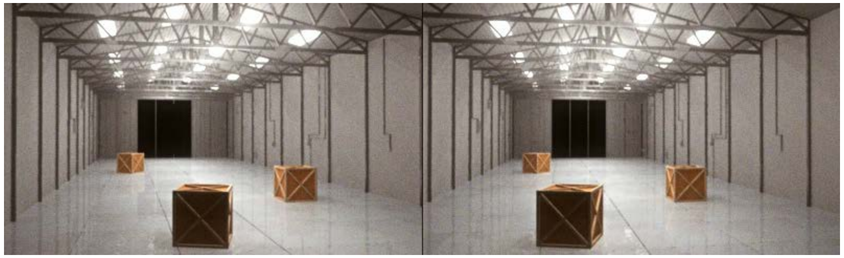
Line Interleaved Stereo

Field Sequential

Side-by-Side Stereo

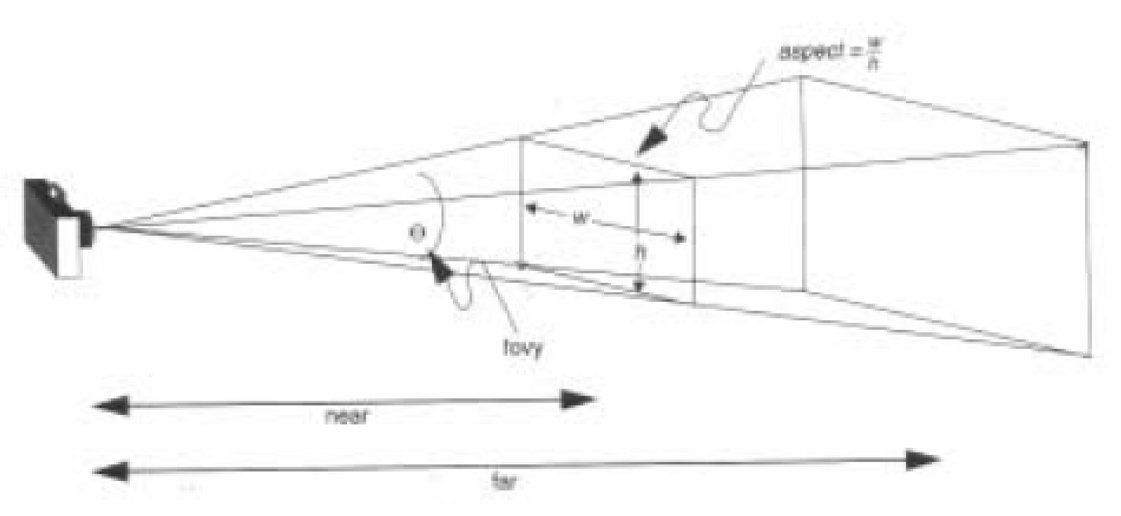






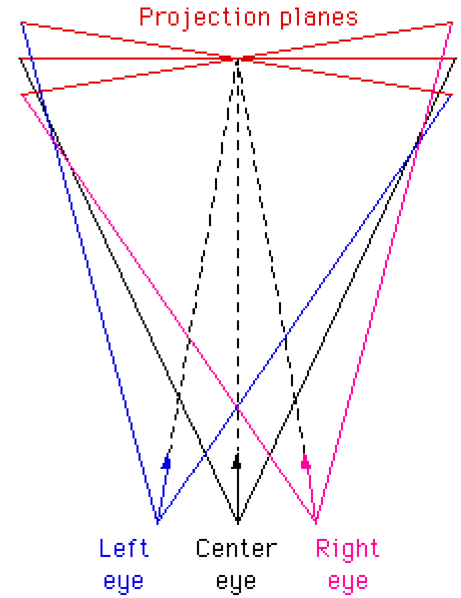
Sometimes: Top/Bottom

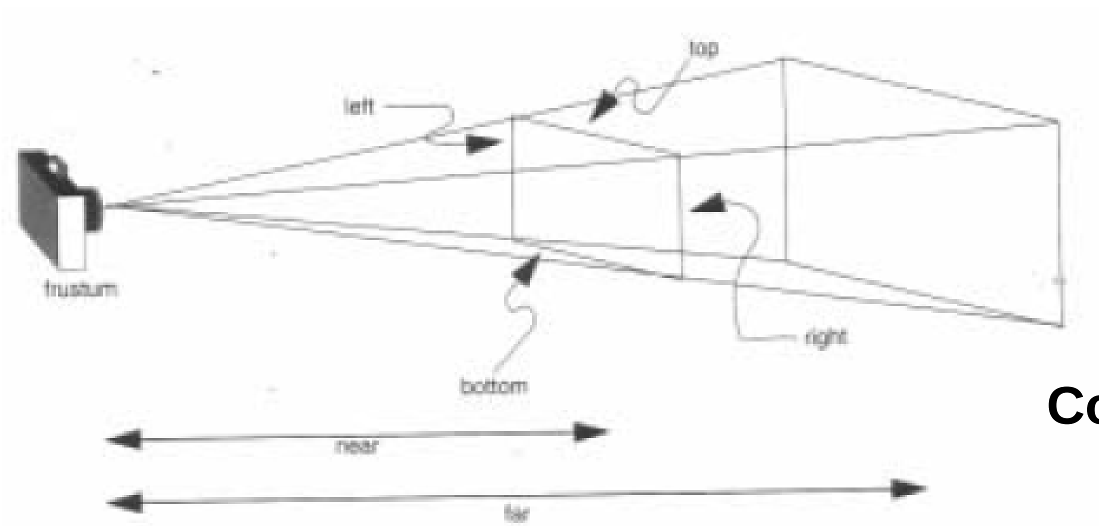
On/Off-Axis Projection



glPerspective → **On-Axis**

Toe-in projection (Top view)

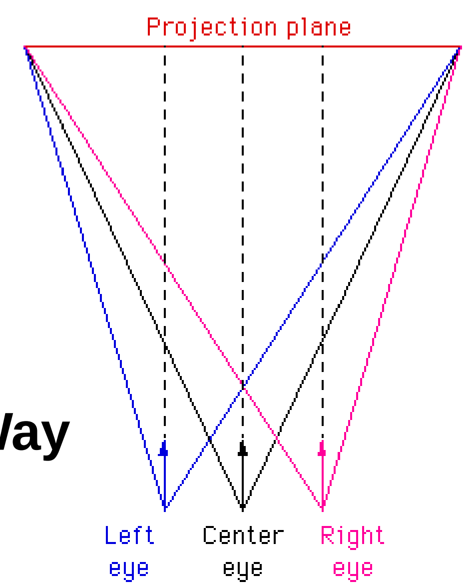




glFrustum → **Off-Axis**

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

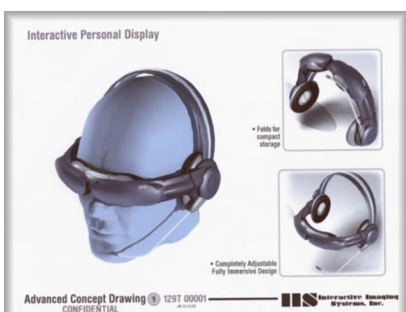
$10,000

$2,900

(Trivisio)

?

$500-2,000



$600

Hannes
Kaufmann

Head Mounted Displays (2006-)

eMAGIN, Inc.

$1500 w/3DOF Tracking

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

Hannes
Kaufmann

Organic Light-Emitting Diodes (OLEDs)

- No backlight necessary -> very thin
- Very high contrast
- Low power consumption
- Many improvements: AMOLED…

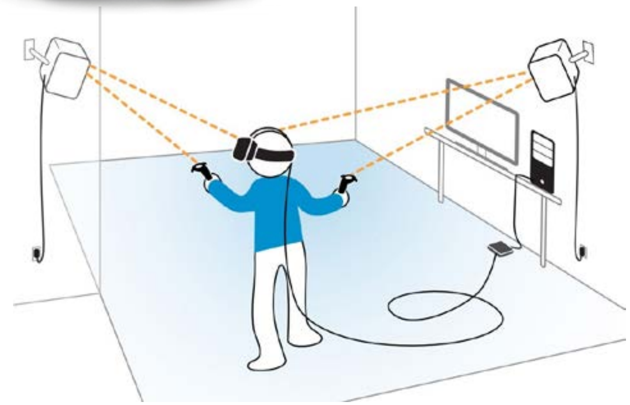
Hannes Kaufmann

Oculus Rift

- Stereoscopic
- FOV: 100° diagonal
- Weight: 470 grams
- Resolution: 2 AMOLED 1080x1200 per eye @ 90 Hz
- Price ~550 EUR
- Inertial Tracker built in
- Precise IR optical tracking
- Low-persistence display (2ms)
- Adjustable lens spacing from 58 to 72 millimeters

Hannes
Kaufmann

HTC Vive Pro



- FOV: ~110° diagonal
- Weight: 555 grams
- Price ~1400 EUR (€880 HMD)
- 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 7x7 meters
  - large scale tracking up to 16 base stations
- Adjustable IPD; Lens distance adjustment
- Microphones & headphones integrated

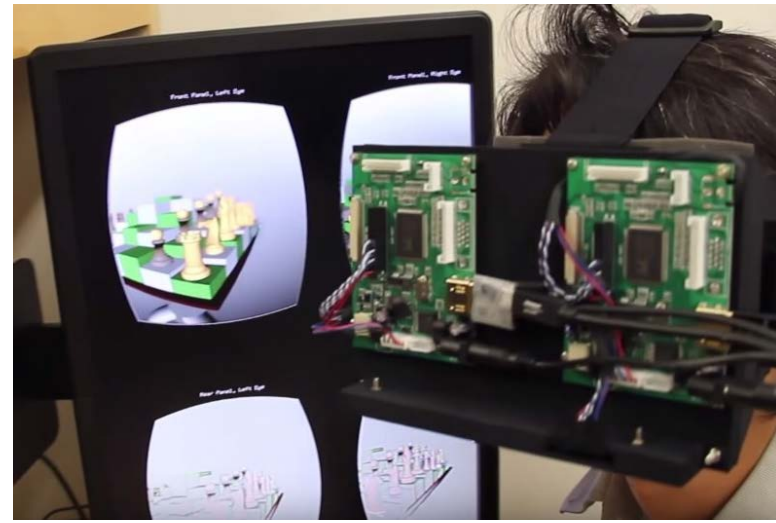
Hannes
Kaufmann

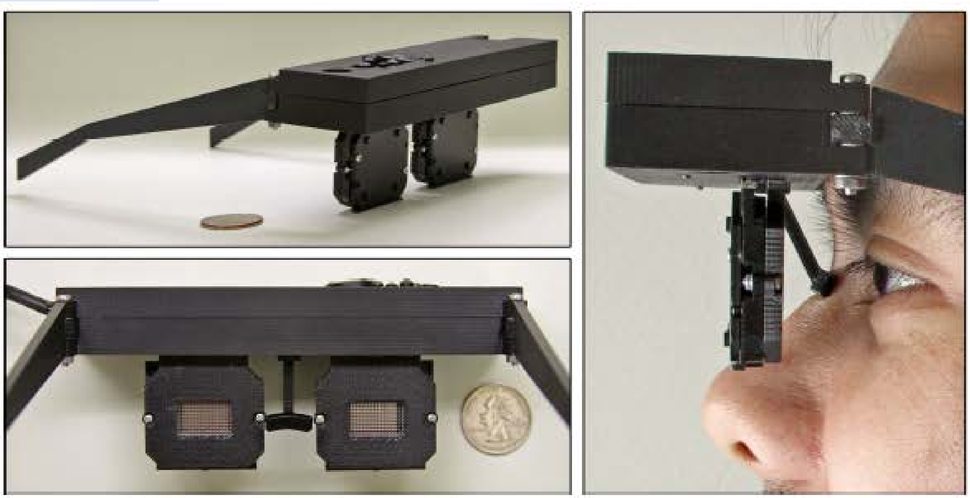
FOVE HMD

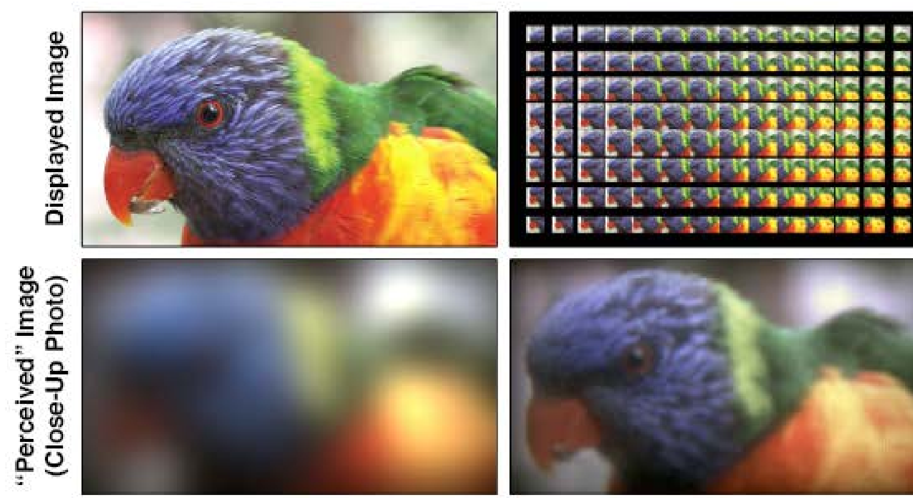
- 2560 x 1440 resolution (1280x1440 per eye)
- 70fps, 100° FOV
- 520g
- Integrated Eye Tracking, 120 Hz
- Access to eye cameras
- Unity, Unreal integration

Research: Near-Eye Light-Field Display

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

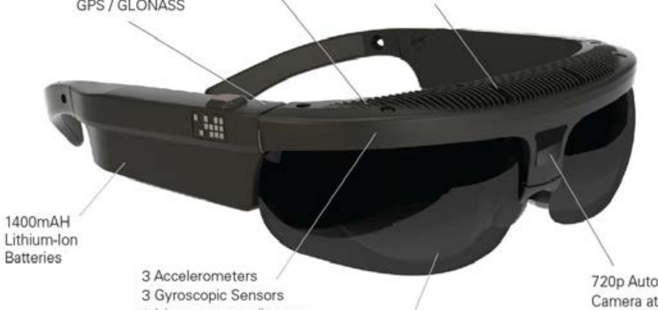




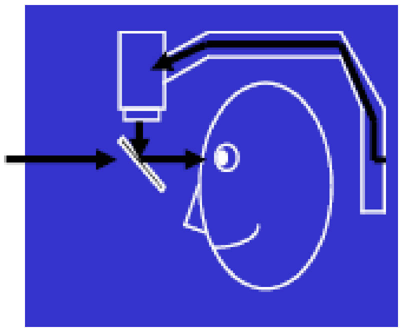


Hannes
Kaufmann

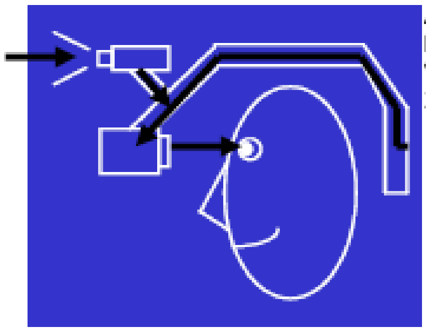
See-through HMDs



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



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 Reality Applications

Video See-Through: VRVANA Totem (Cancelled)

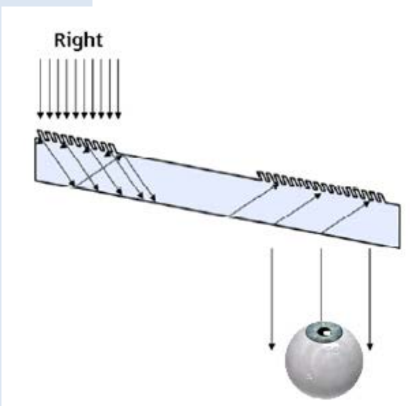
- 2560x1440 resolution
- 120° FOV
- 6MP 60Hz RGB camera per eye
- Inertial sensors
- Marker Tracking
- Inside-Out natural feature tracking

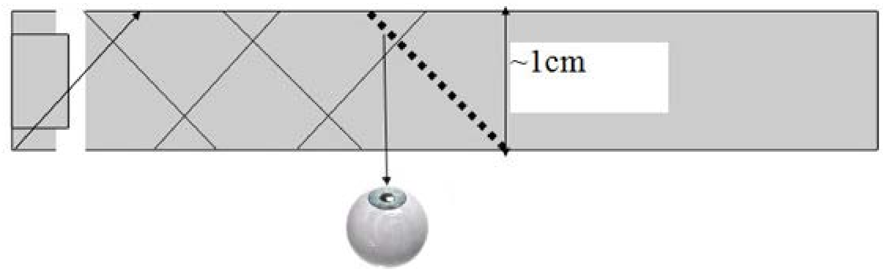
Hannes
Kaufmann

AR See-Through Wearable Displays

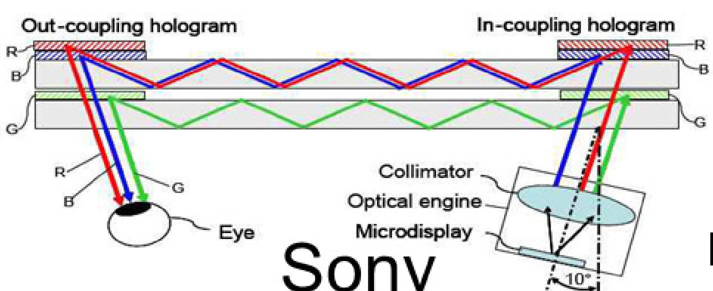
- Reflection on Curved Mirrors
- Waveguide-based

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

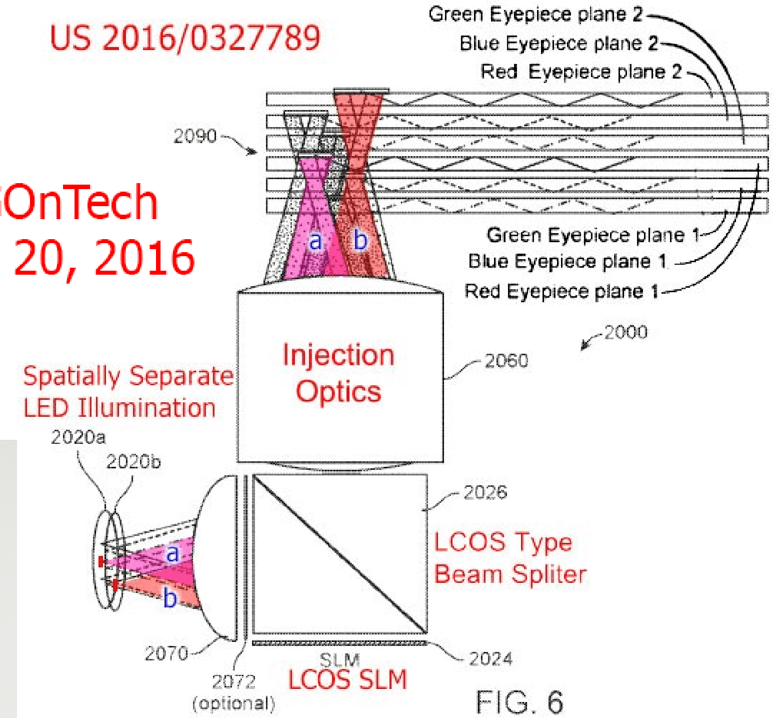
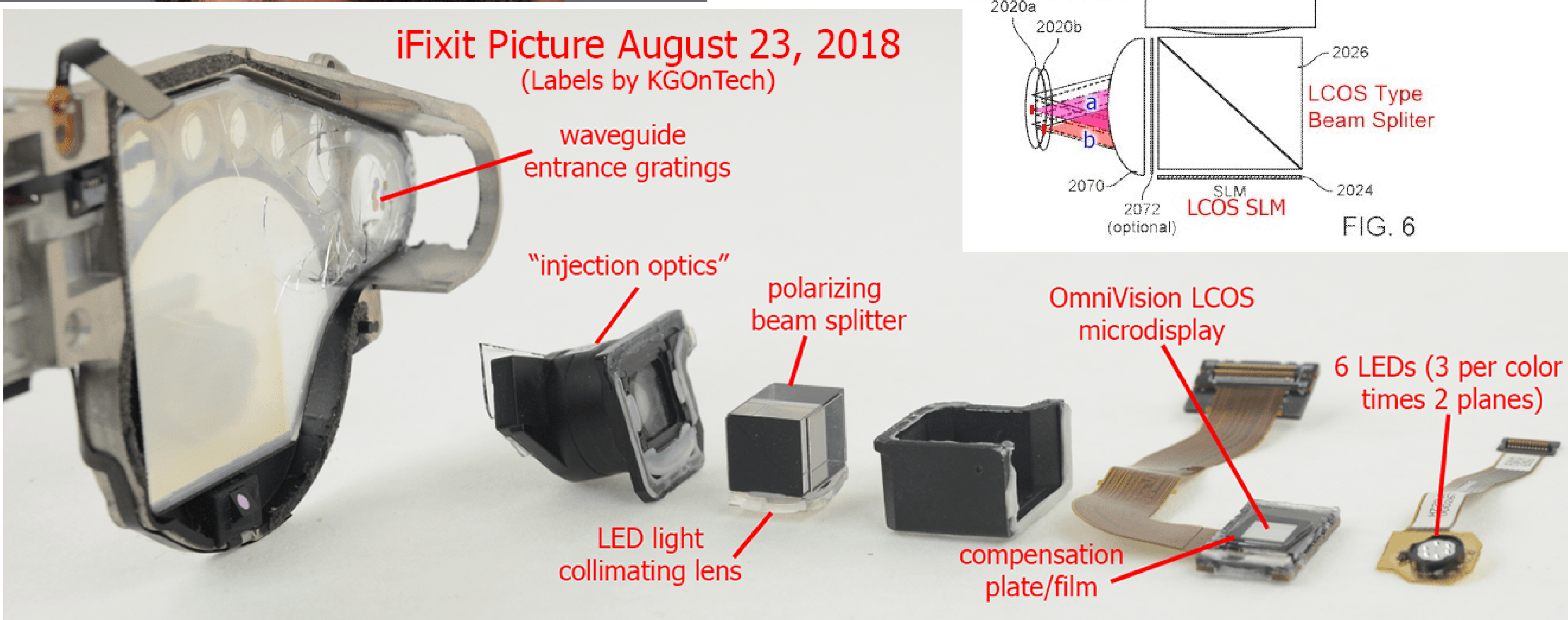


FIG. 6



Hannes Kaufmann

Microsoft Hololens

- Small screen, 34° FOV
- Resolution: ~1280x720 per eye
- ~550 grams (heavy on forehead)
- Excellent SLAM tracking using 4 cameras
- Depth camera, IMU, HD video cam, 4 mics
- Stand alone unit, 2GB RAM
- Windows 10
- Voice support

https://developer.microsoft.com/en-us/windows/holographic/hardware_details

DAQRI Helmet & Smart Glasses

- Intel Core m7
- Inside-Out Tracking
- Intel Realsense depth camera integrated
- Thermal camera (helmet)
- Inertial Sensors
- ~ 40° FOV

Meta 2

- 2560 x 1440 see through display,
  90° Field of View, via HDMI
- 720p RGB camera via USB
- “Sensor Array for hand interactions and positional tracking”
- SLAM tracking
- IMU, 4 near-ear speakers
- PC required
- ~950 USD

Hannes
Kaufmann

Virtual Retinal Displays (VRD)

- Laser diode projects images directly onto the retina
- Invented in 1986 at the HIT Lab, Seattle, in 1991
- Prototype by Microvision, Inc. (Video)
- Similar principle proposed by MagicLeap!

AiRScouter


VRDs – Advantages & Disadvantages

Advantages:

- Works under all lightning conditions (outdoors)
- Ability for high resolution and FOV

Disadvantages:

- Currently has low resolution and FOV is small
- Experimental
- Probably not easily accepted by end users

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, ...)

Hannes Kaufmann

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
- Can achieve good stereo quality

Hannes
Kaufmann

HMDs - Disadvantages

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

Projection Displays

Hannes
Kaufmann

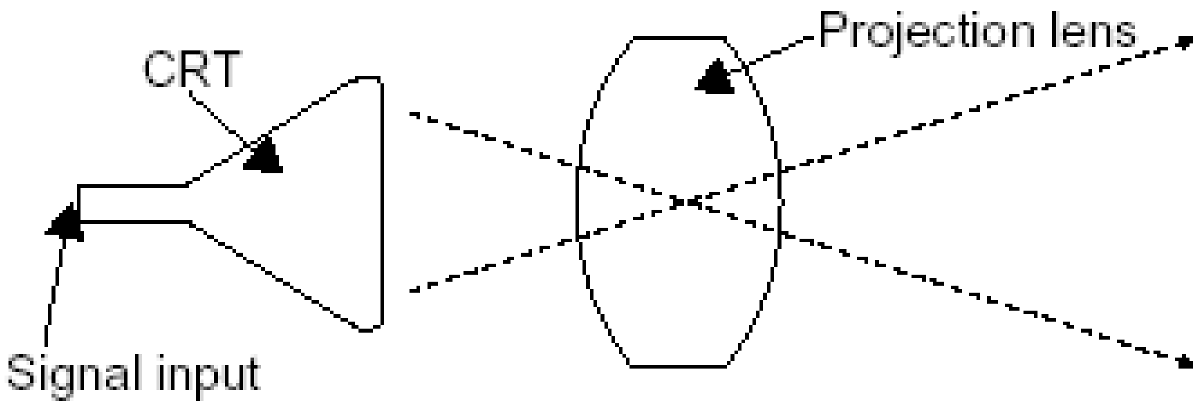
Basic Display & Projection Technologies

- 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/

Hannes
Kaufmann

Projection Technologies: CRT

- CRT (Cathode Ray Tube) Projectors

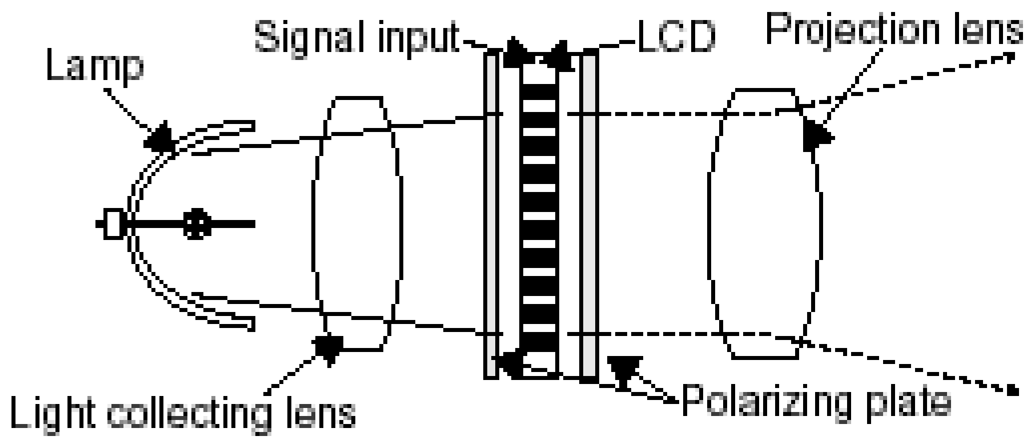


+ High refresh rates (>100Hz) – stereo capable
+ Relatively low cost
– Large and heavy devices, can implode
– Consume a lot of energy

Hannes
Kaufmann

Projection Technologies : LCD

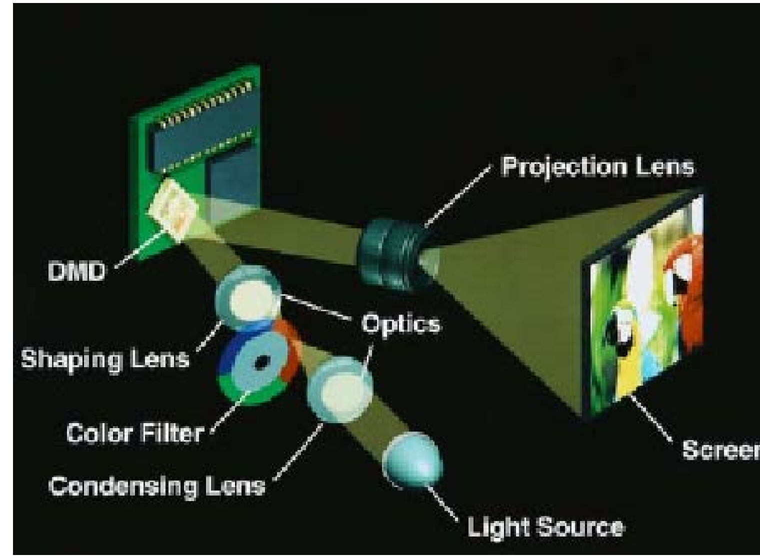
- Liquid Crystal Display (LCD) Projectors

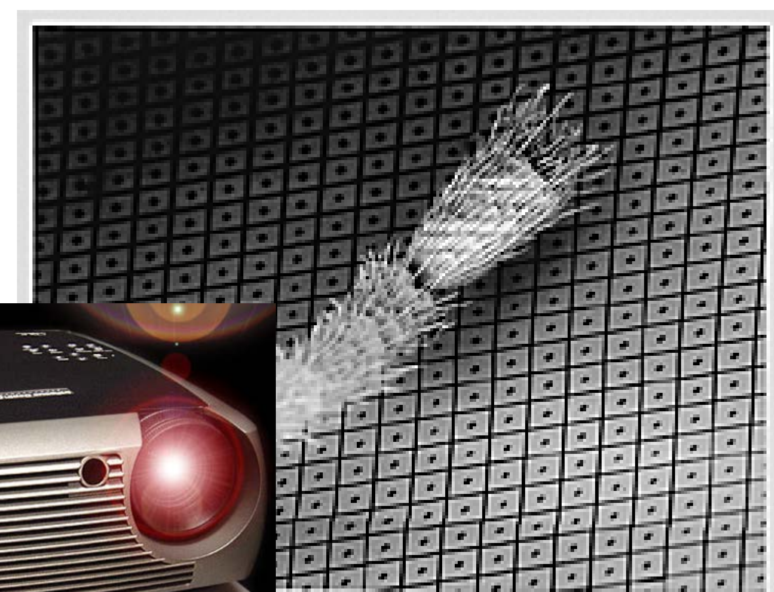


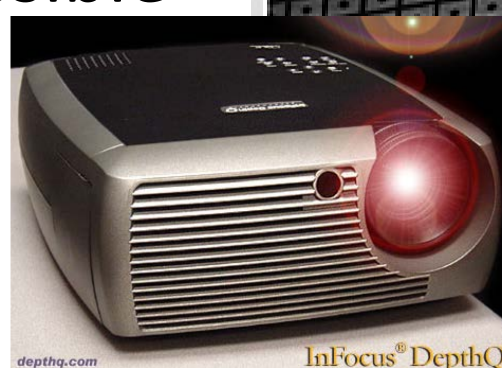
  - Individual grayscale LCD for each color
  - Pixel dimensions <50µm
  - \+ Low cost
  - Poor contrast and black level

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



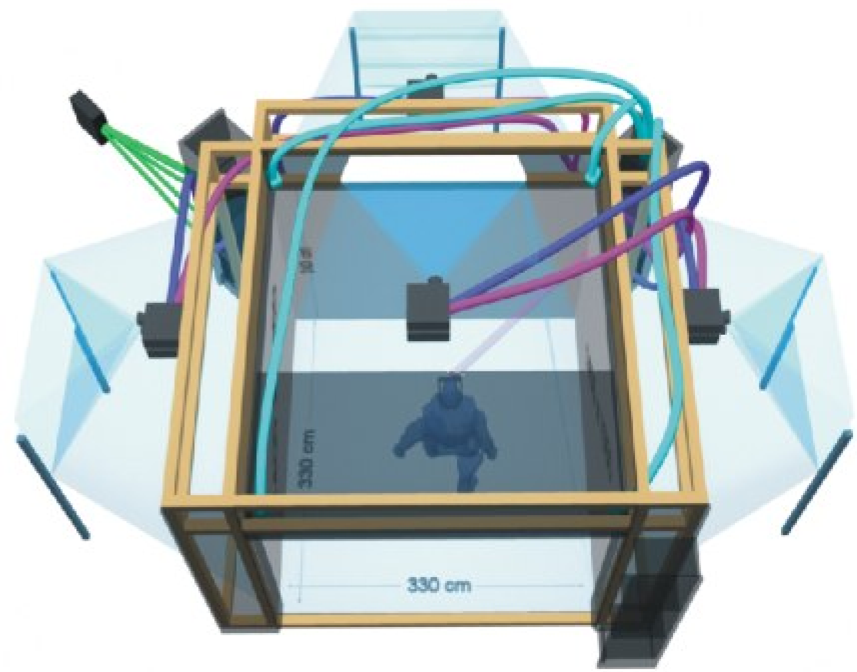




CAVE (1)

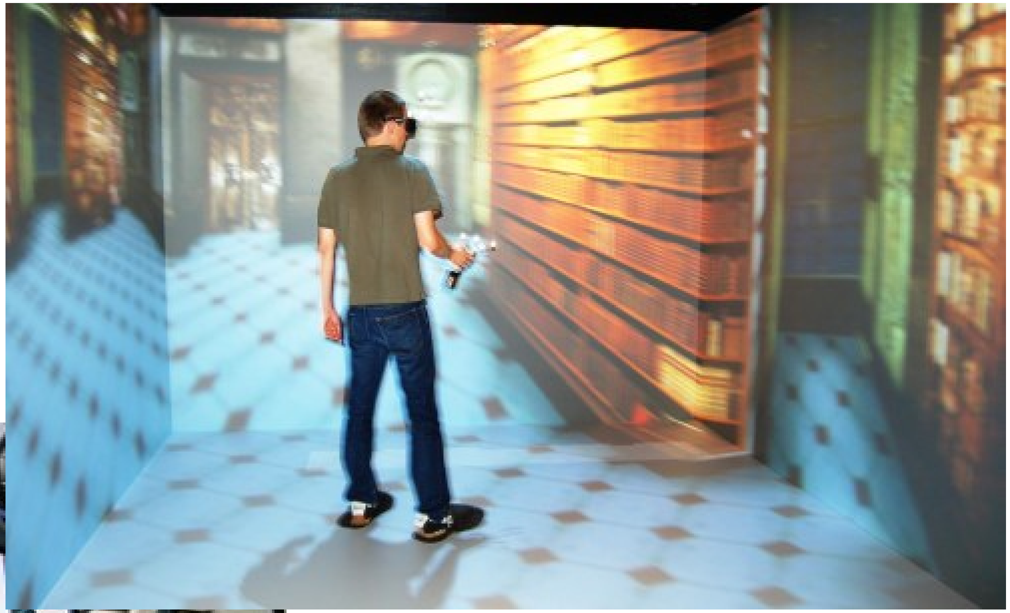
“Computer Assisted Virtual Environment” ™

- 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

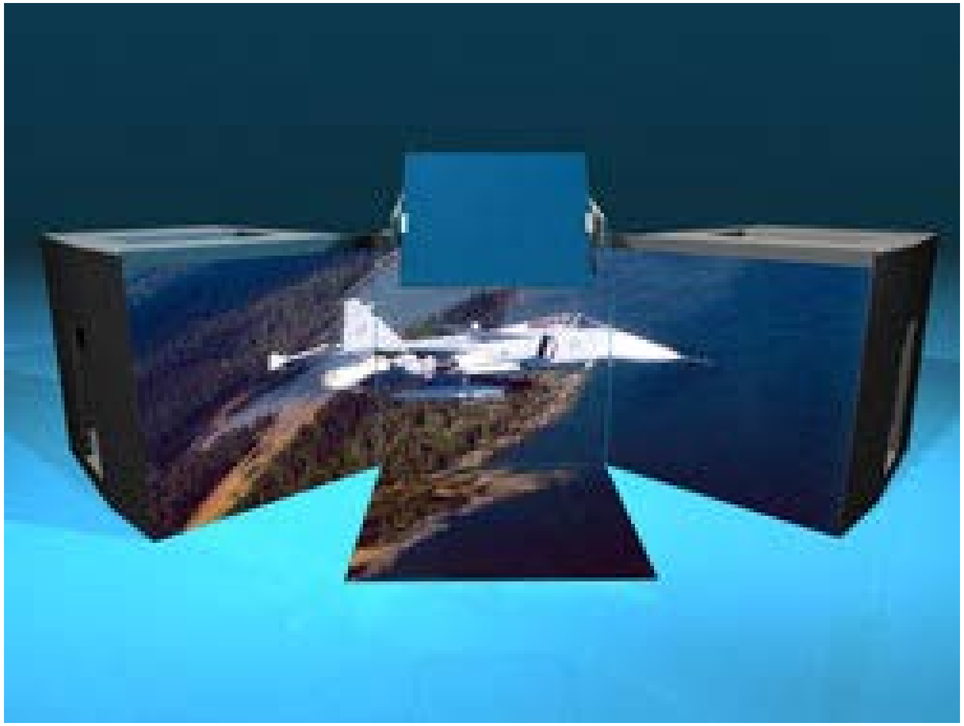


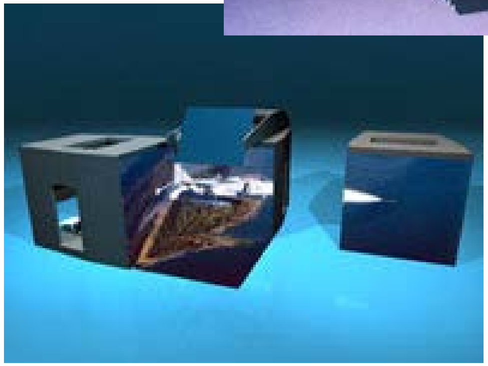
Hannes
Kaufmann

CAVE (2)



RAVE





"Reconfigurable Automatic Virtual Environment"

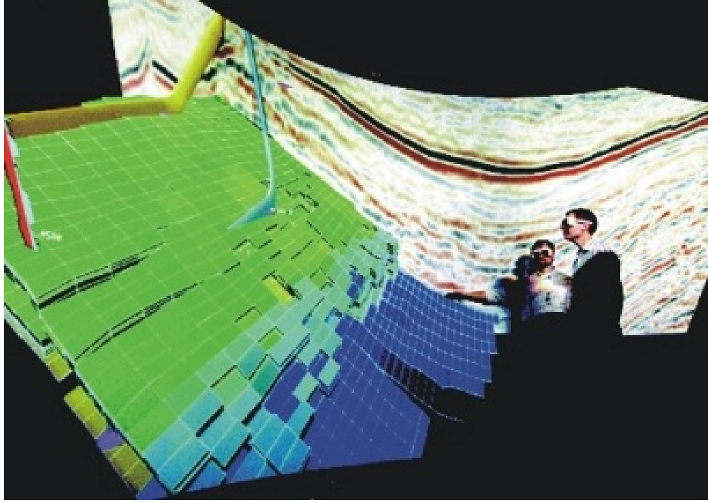
CAVE - Advantages

- 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)

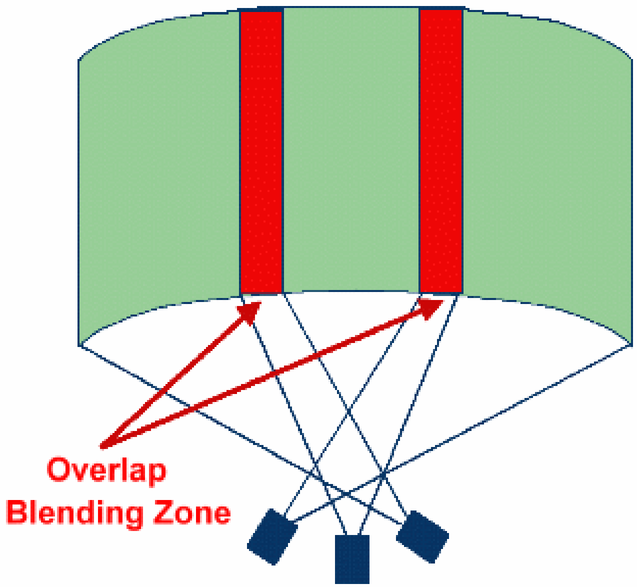
CAVE - Disadvantages

- 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

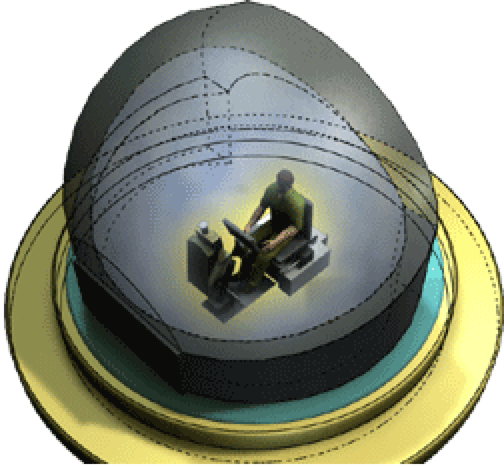


- Cylindrical or hemipherical screen
- Requires distortion correction
- Common in industry

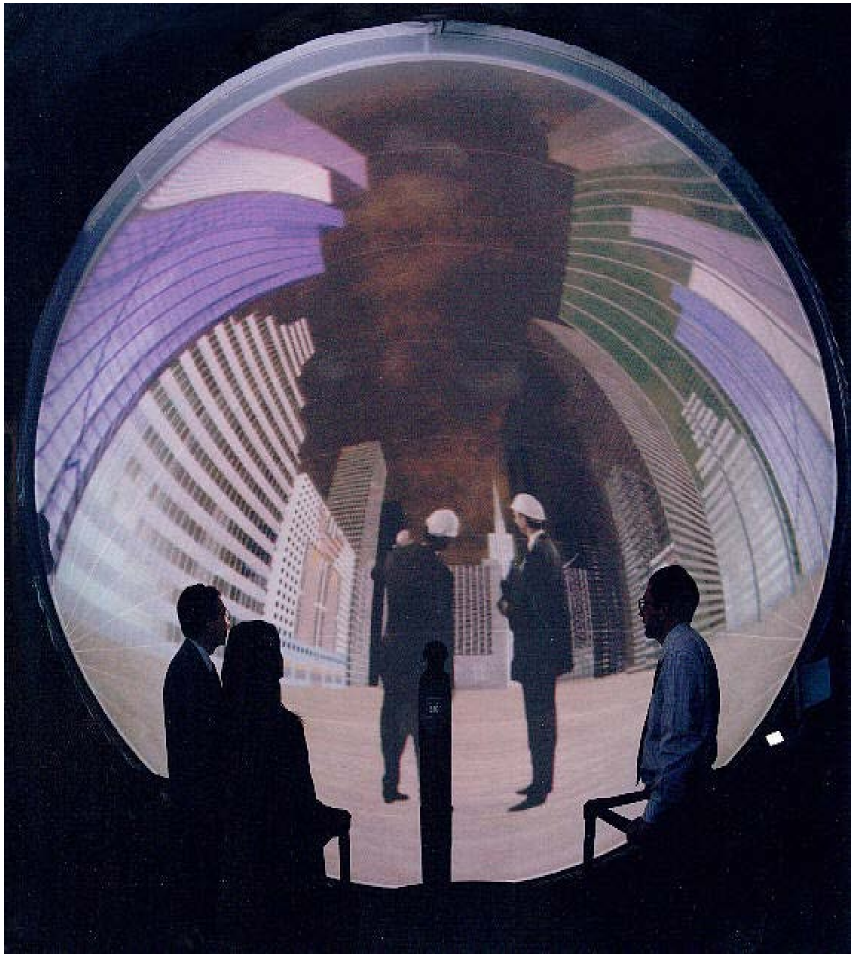


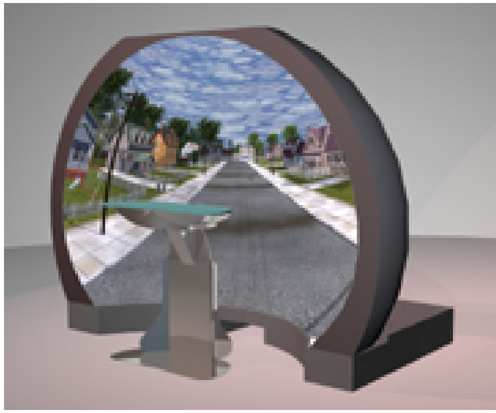
Hannes
Kaufmann

Vision Dome



Spherical
Display

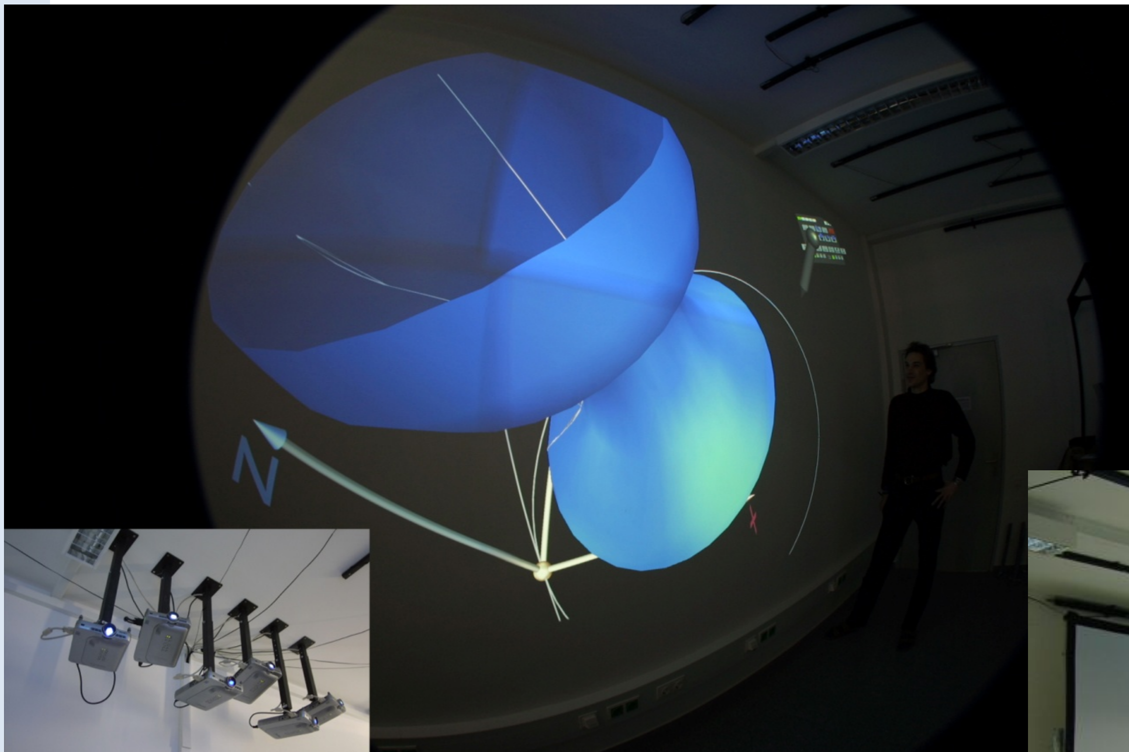




VisionStation

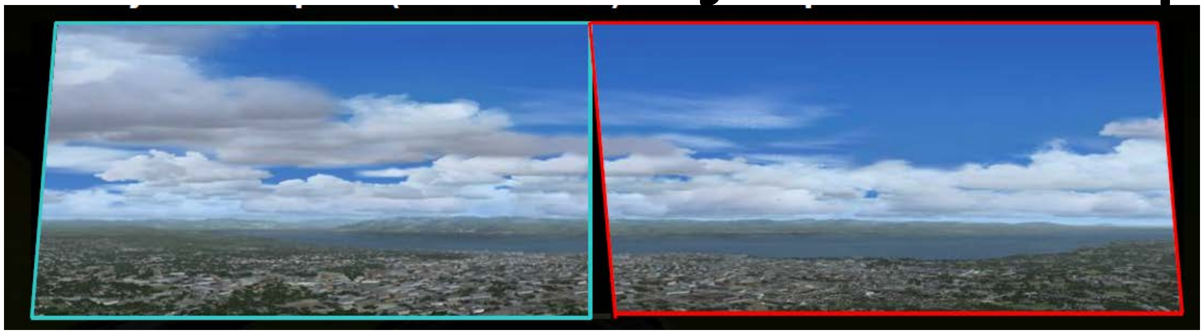
Hannes
Kaufmann

Tiled Projector Display

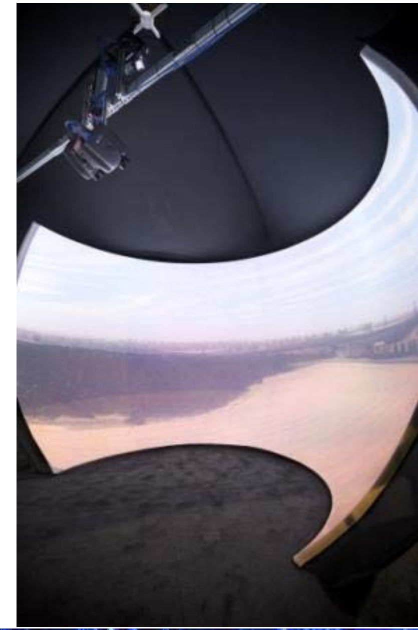


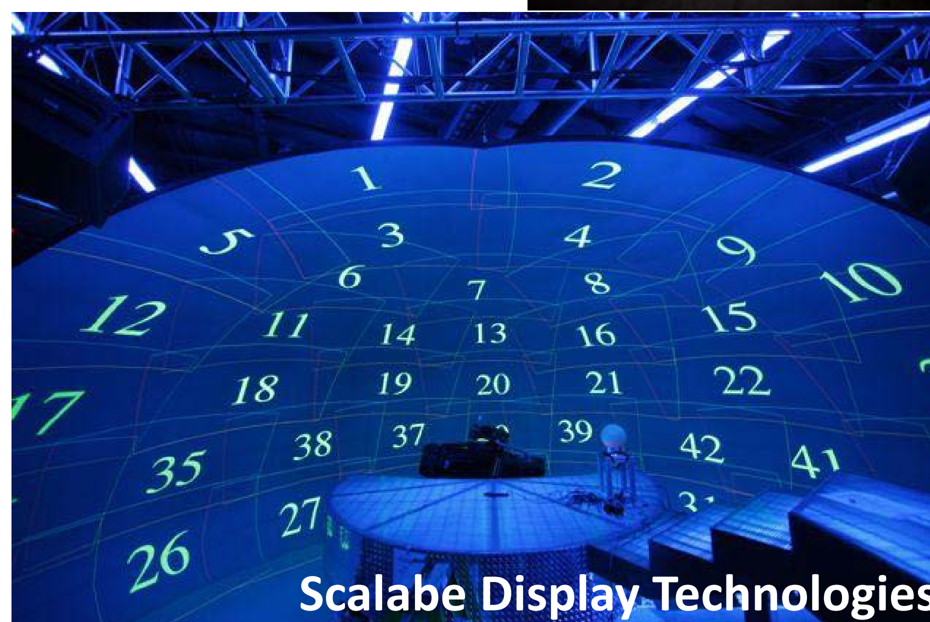
StubeRena
Gottfried Eibner, 2003

Multi-Projector Display



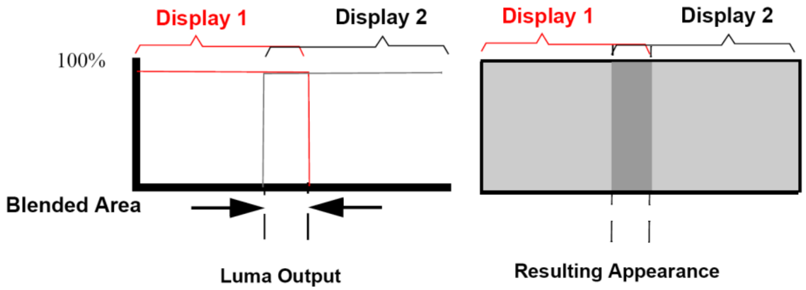
- Warp & Blend
  - Warp = Geometry Corrections
  - Blend = Intensity Adjustments

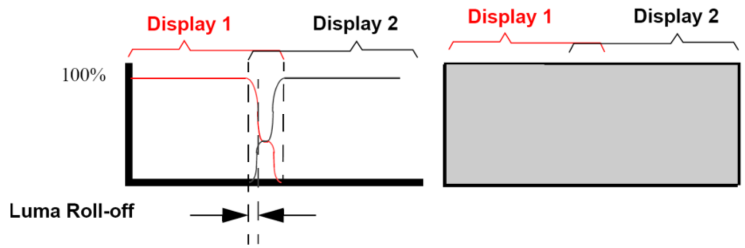




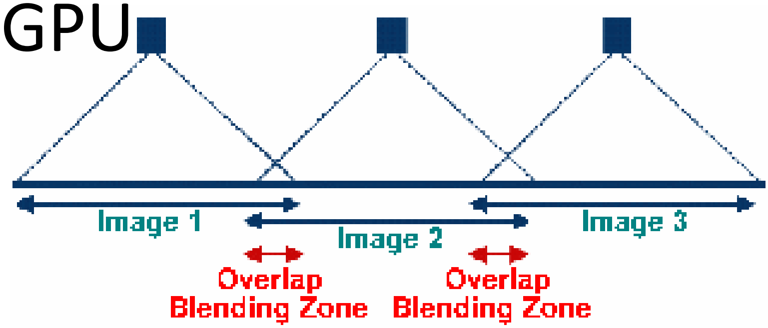
Multi-Projector Walls

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

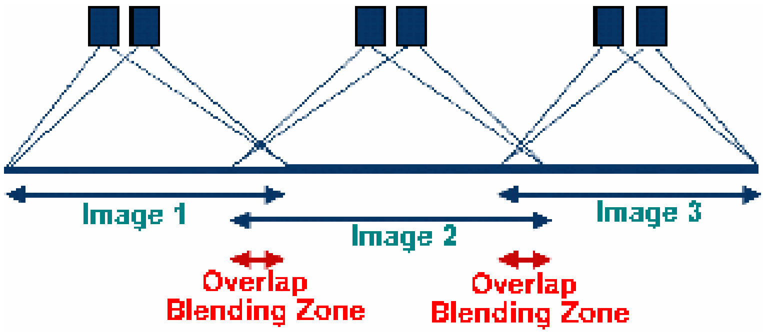




active



passive



Hannes
Kaufmann

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:

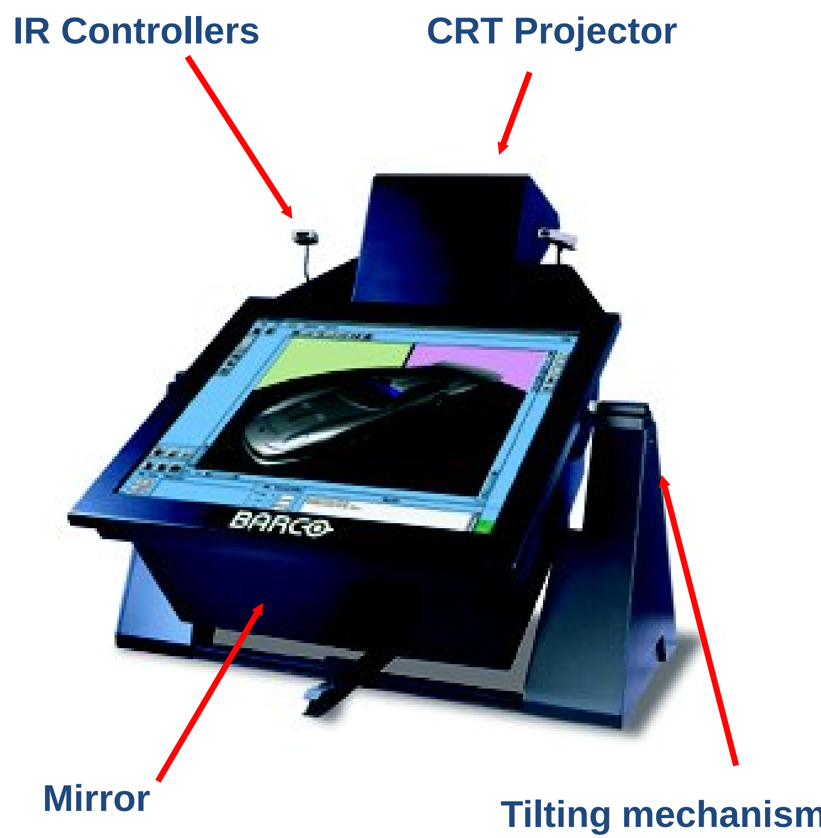
Synchronizing frame buffer swap

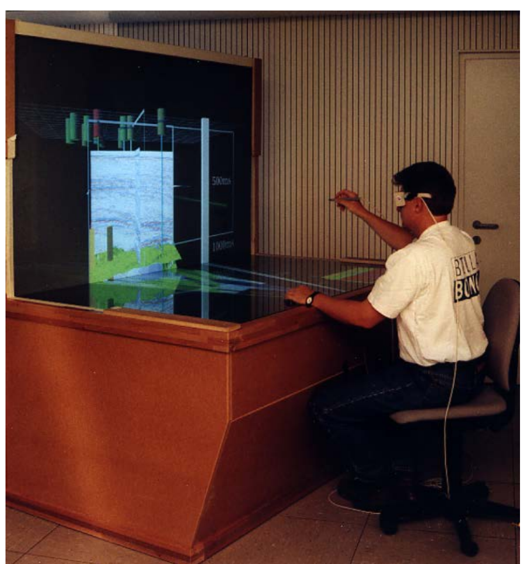
- Begins redrawing at the same time

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





Hannes
Kaufmann

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

Hannes
Kaufmann

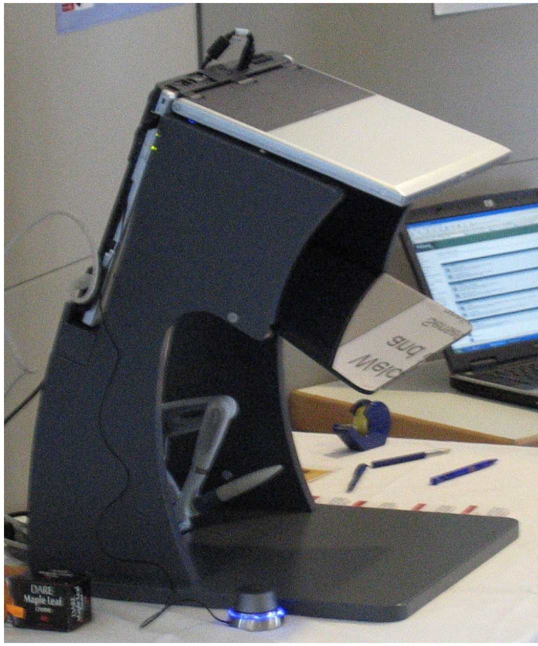
Two User Workbench

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

Hannes
Kaufmann

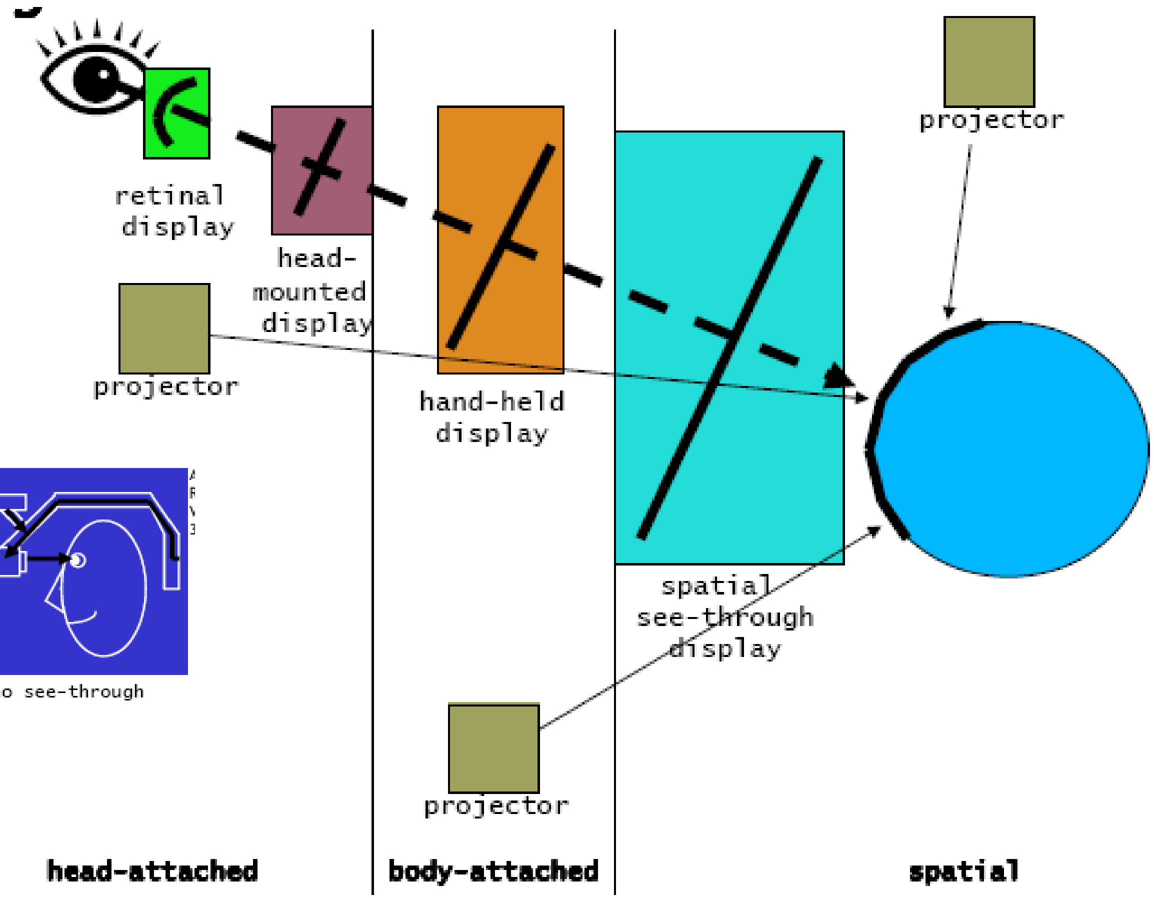
Multi-user Approaches

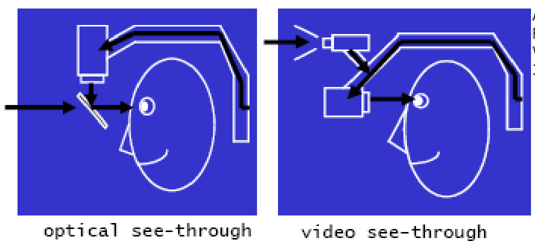
- Private screens
  - Individual screen(s) / frame-buffer(s) per user / HMD for each

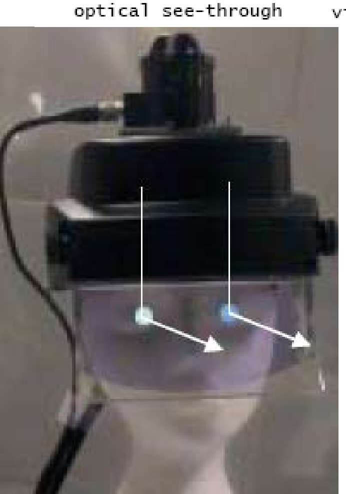


- Frame interleaving
  - Users share the same screen(s). Images rendered into individual frame-buffers displayed time-sequential. Special glasses seperate images.
- Screen partitioning
  - Images are separated by additional optics.

Current Augmented Reality Displays







Pico Projectors

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

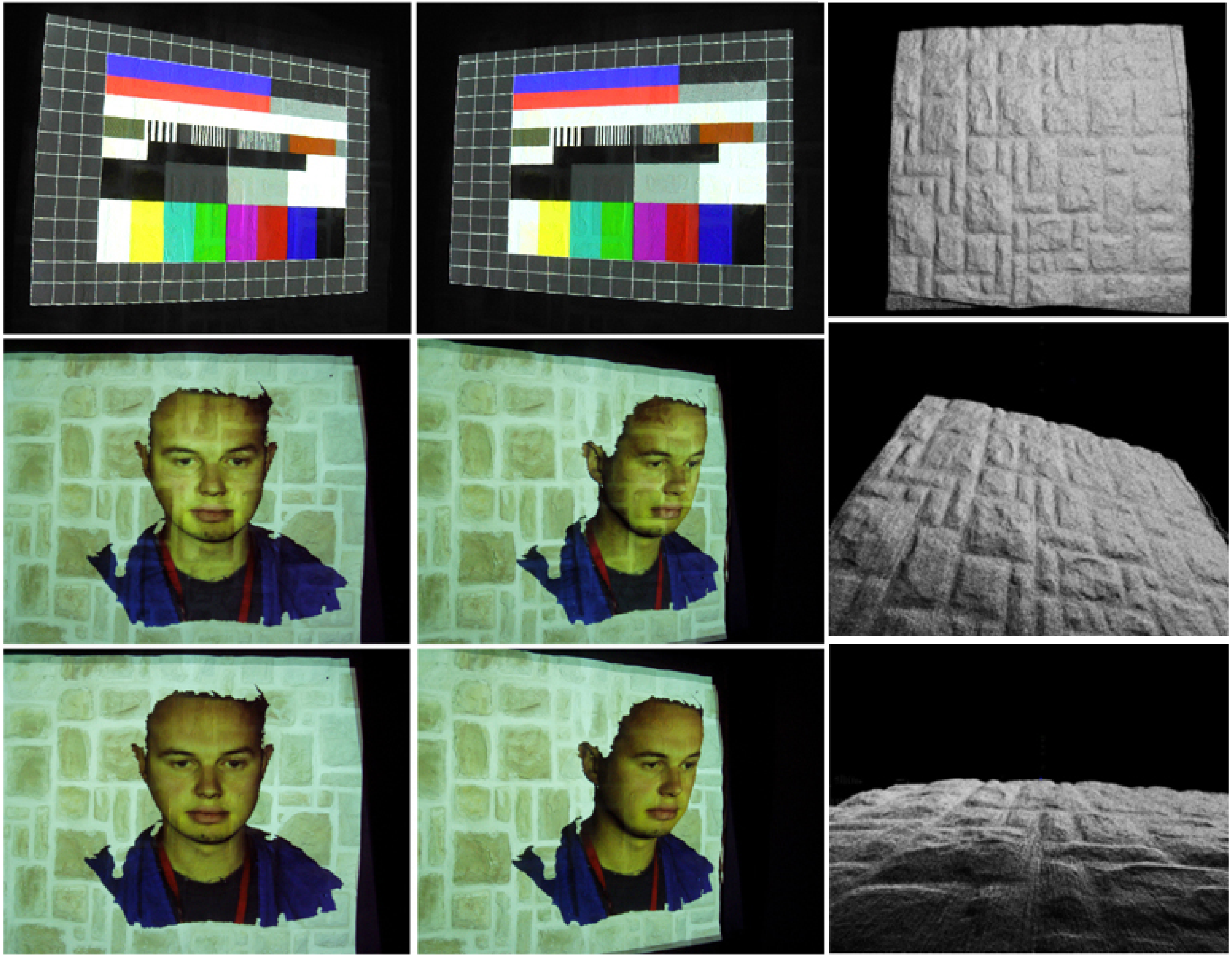
Laser Projectors

  – E.g. Extend3D Werklicht

Hannes
Kaufmann

Projected Environments

Oliver Bimber, 2005



Hannes
Kaufmann

Projected Environments

Bacardi Party Projection

Adidas 3D Mapping

Mobile Devices

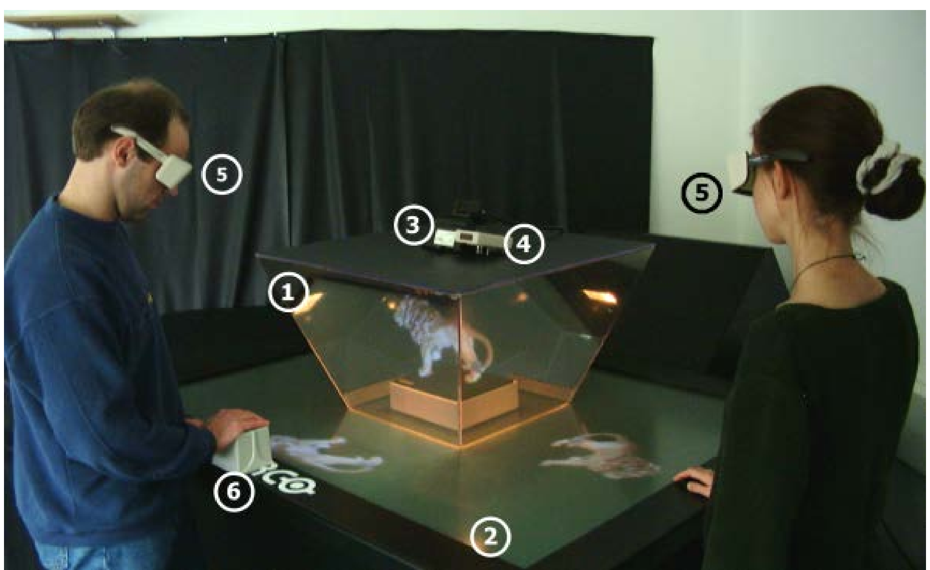
- Smartphones & Tablets
- Input device = Output device
- Output
  - Augmented Video Frames
    - Overlay real & virtual content
  - 2D (sometimes 3D)
- Input data
  - Video Frame (extract structures & information)
  - Touch & Device Orientation
  - Gyroscope, Accelerometer, GPS …

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

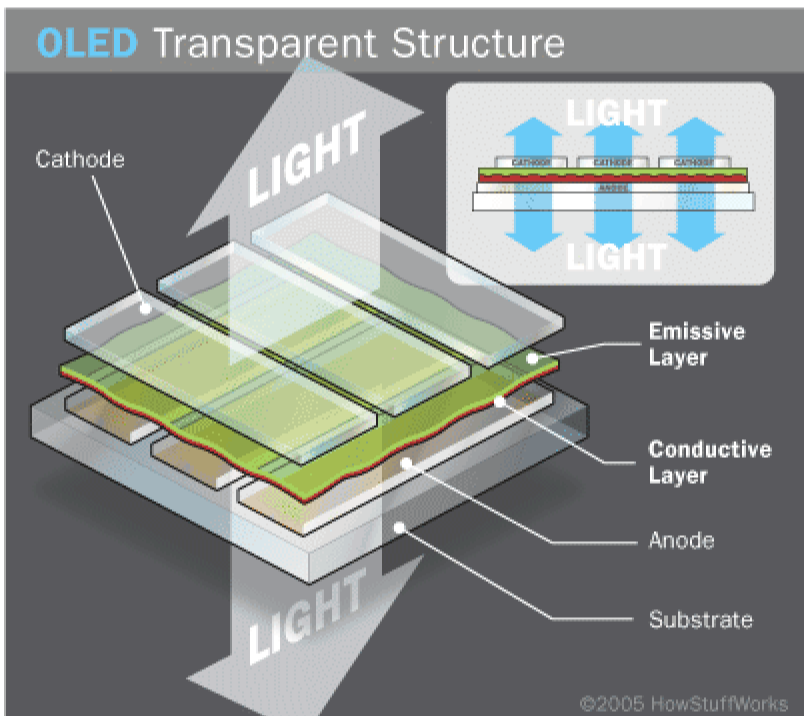
- Projection-based AR
- Special purpose display for museums
- Real and virtual images or objects are merged
- Max. 3 users



Hannes
Kaufmann

Transparent Displays

- Various Vendors
- Useful for AR applications



Hannes
Kaufmann

Auto-stereoscopic Display Technologies

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

Rotating volumetric display

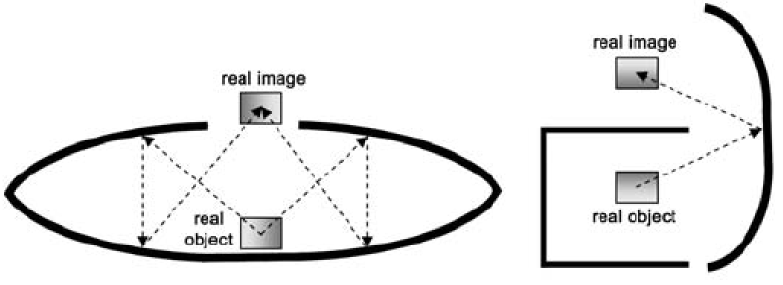


Figure 2.17. Examples of common real-image display configurations using one or two concave mirrors.

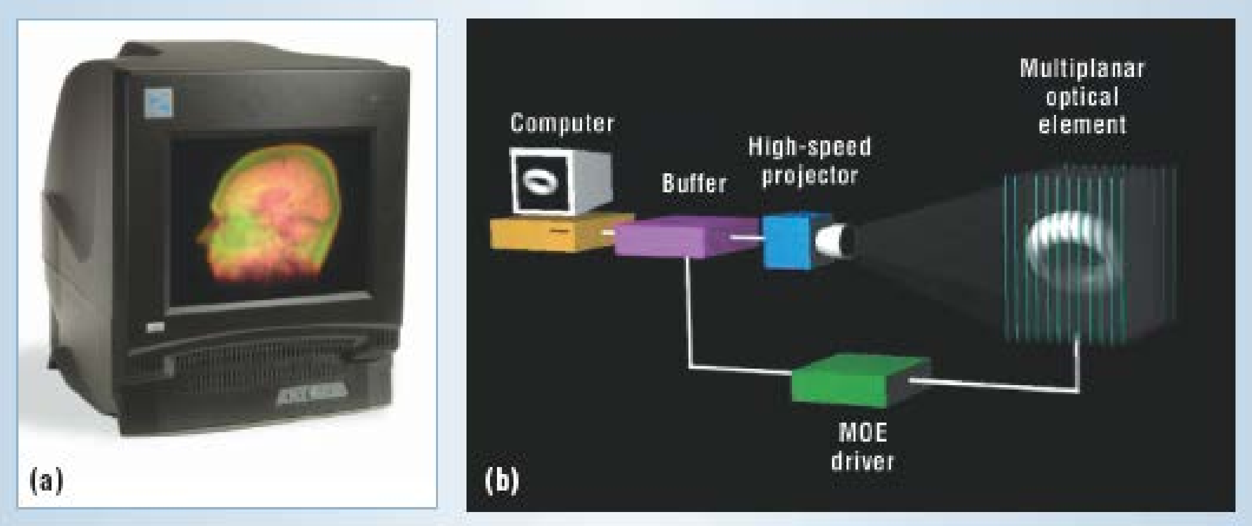
Lenticular 3D Displays

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

Hannes
Kaufmann

Volumetric Displays

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

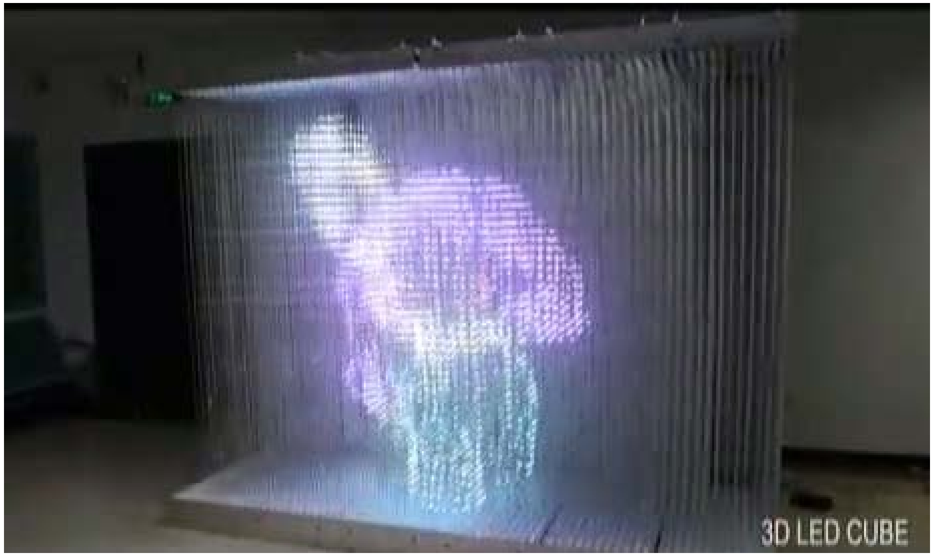


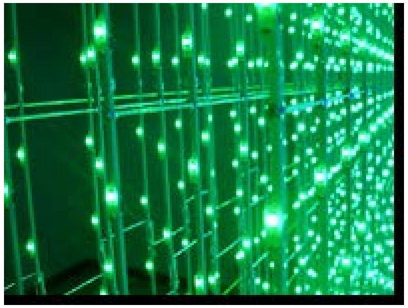
Hannes
Kaufmann

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

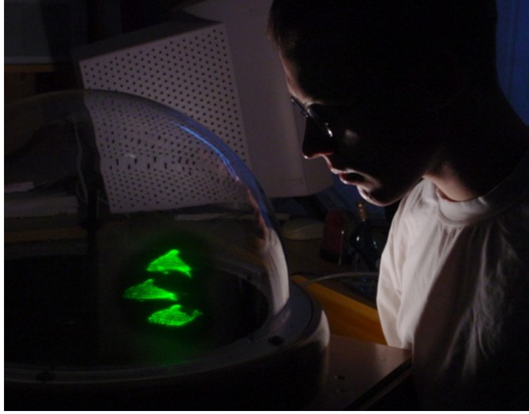


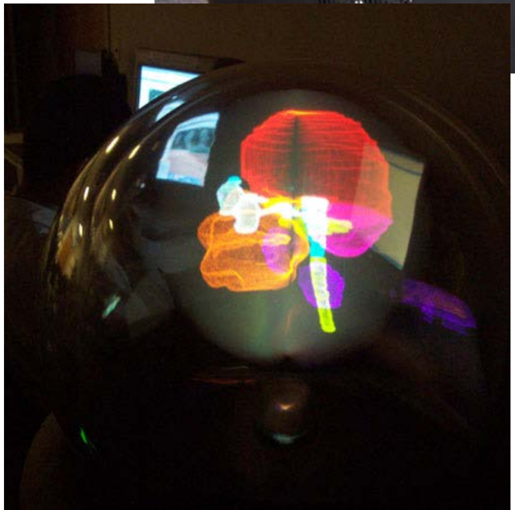


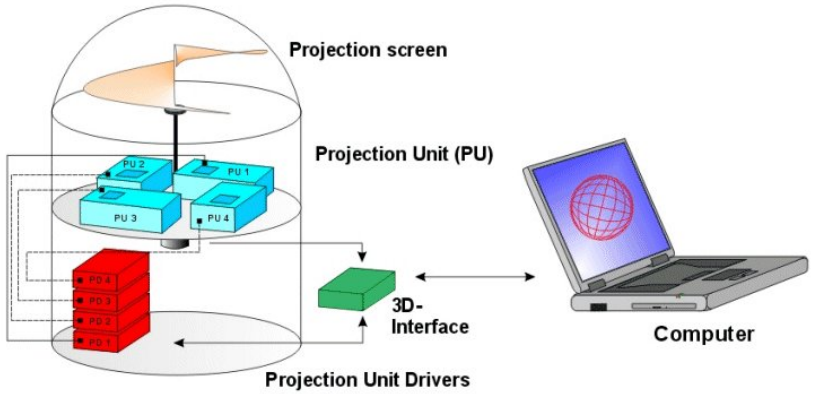
Hannes Kaufmann

Volumetric Displays

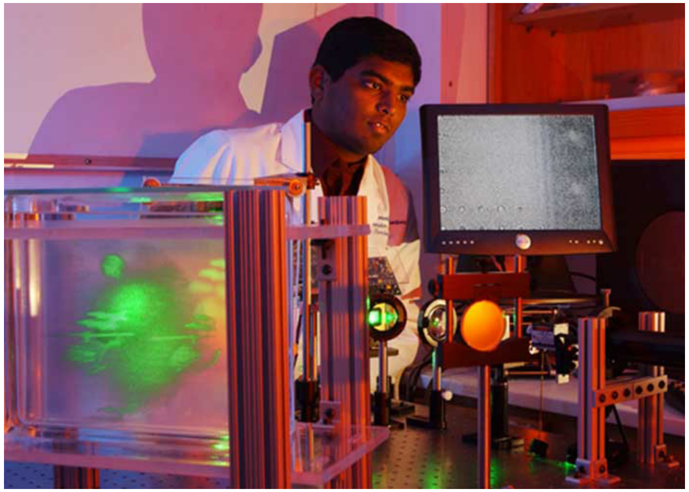
- Perspecta3D
  - 1024x768x3 digital projector, 198 images/slices, 900rpm
- Felix3D

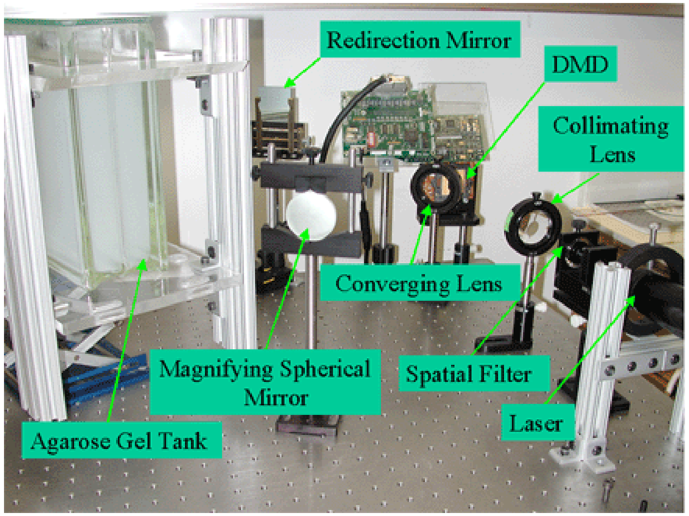




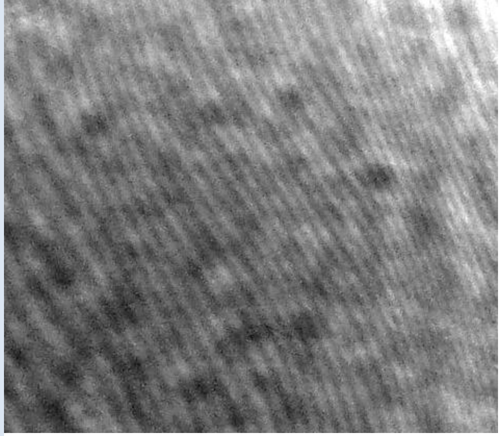


Holographic Displays





- 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://www.holografika.com/



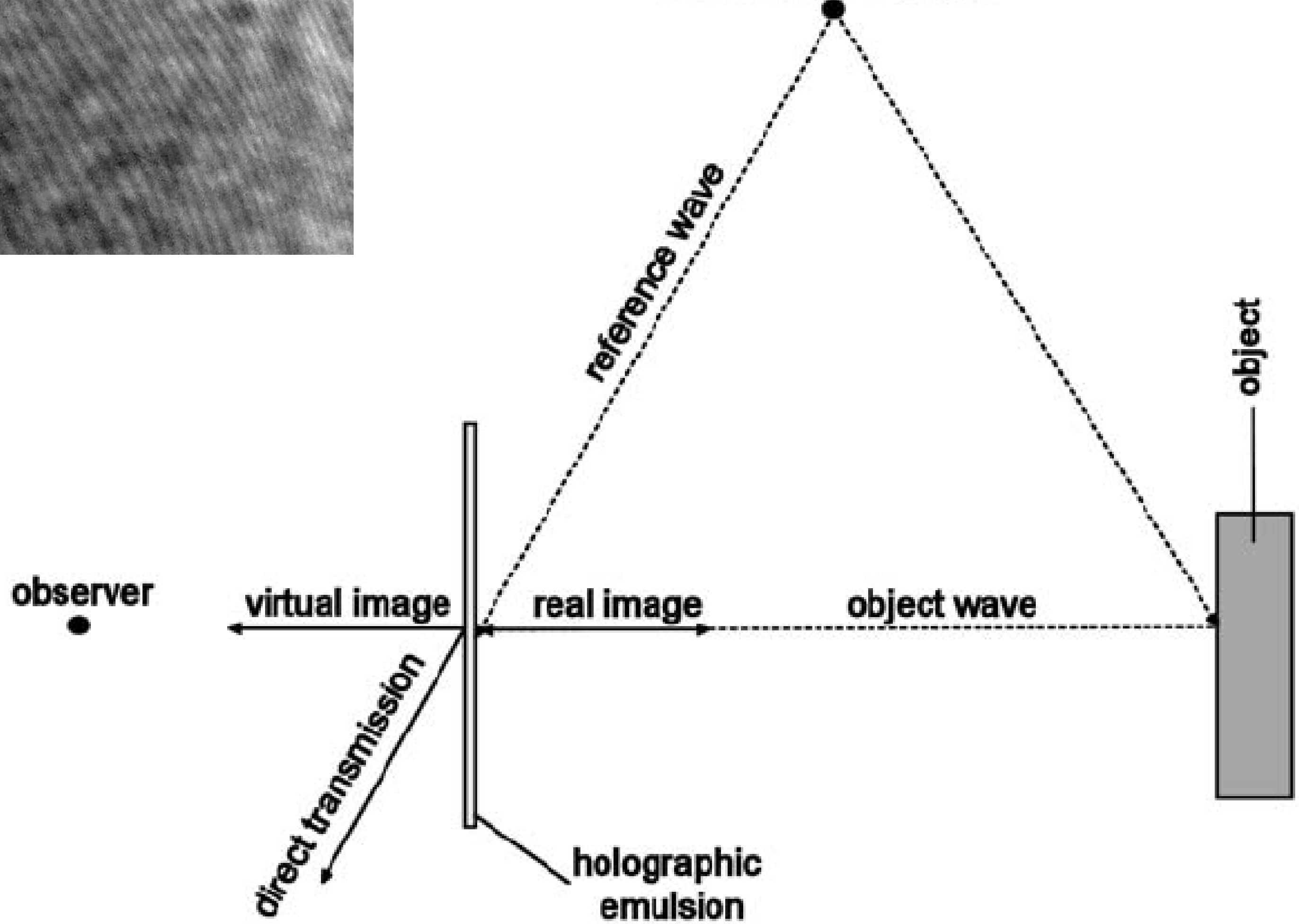


Figure 2.19. Optical holographic recording and reconstruction (example of a transmission hologram). (*Image reprinted from [18] © IEEE.*)

Hannes
Kaufmann

Holographic Displays

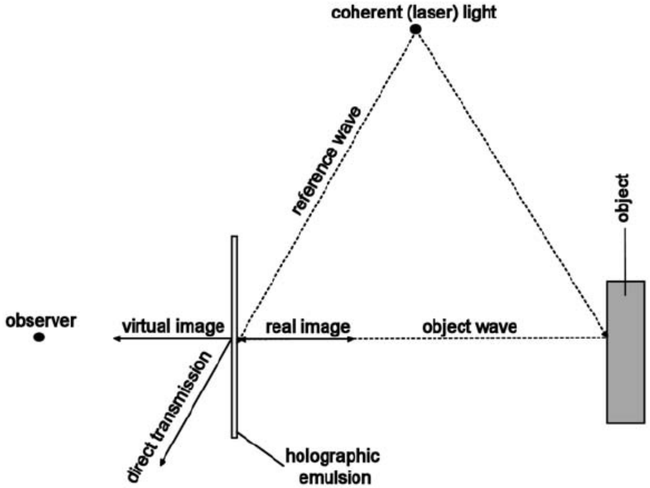


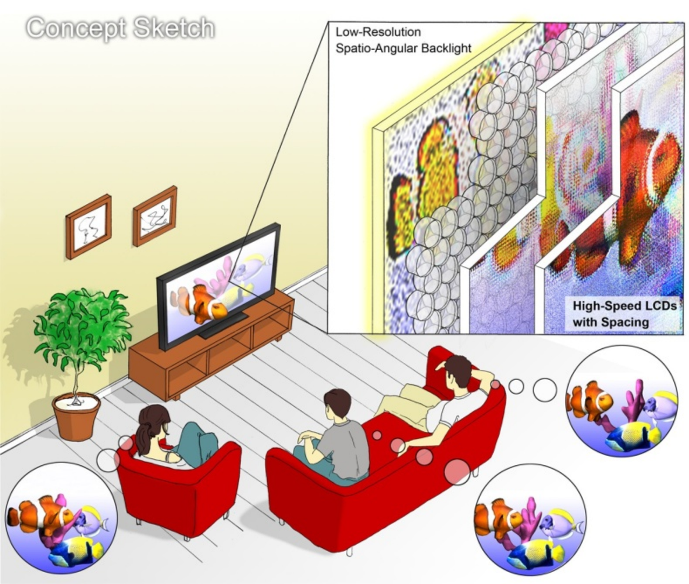
Figure 2.19. Optical holographic recording and reconstruction (example of a transmission hologram). (*Image reprinted from [18] © IEEE.*)

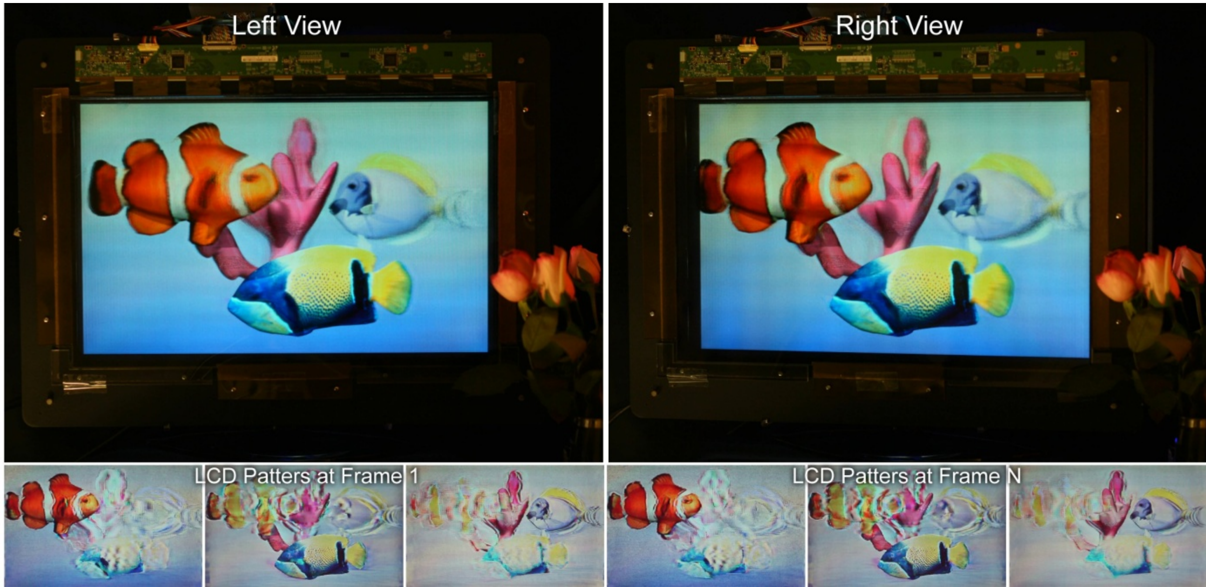
Hannes
Kaufmann

Tensor Displays

Compressive Light Field Synthesis using

- Multilayer Displays with
- Directional Backlighting



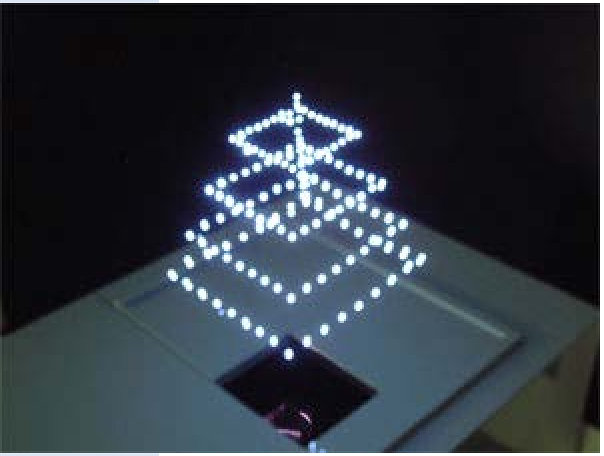


Hannes Kaufmann

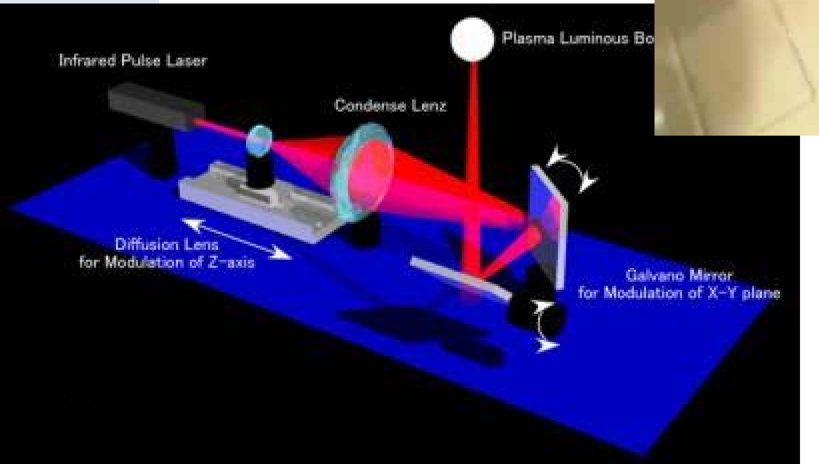
The Future… ?

SolidFelix

Laser Plasma



Transparent Display



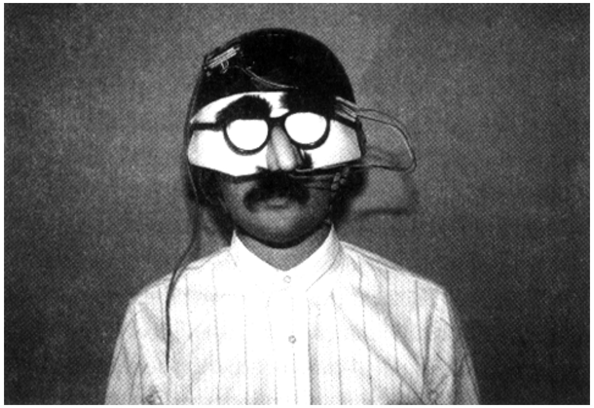
Foldable Displays

Auditory Output

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

Hannes
Kaufmann

Olfactory Displays – Scent



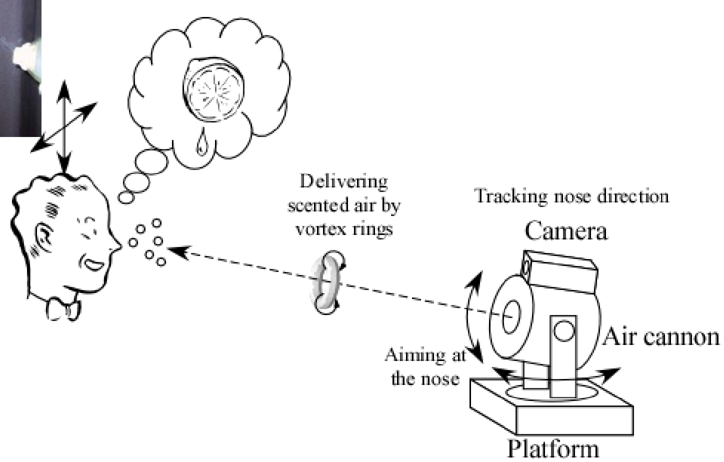
- Sense of smell (or olfaction) is a primal chemical sense for humans. Impact on the central nervous system and hormone balance.
- Smell can influence mood, memory, emotions, social behavior, mate choice.
- Scents can e.g., reduce stress, enhance concentration or act as stimulants.
- Smell is more closely 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

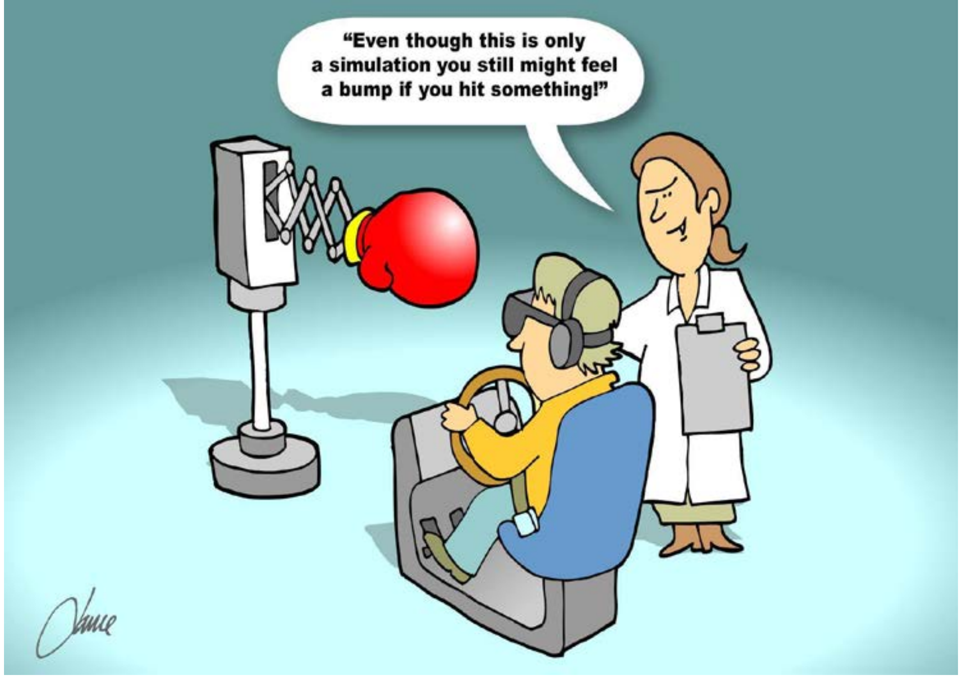
Hiroo Iwata, University of Tsukuba, Japan
Hiroaki Yano, Takahiro Uemura, Tetsuro Moriya
http://www.siggraph.org/s2003/conference/etech/food.htm

Hannes Kaufmann

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

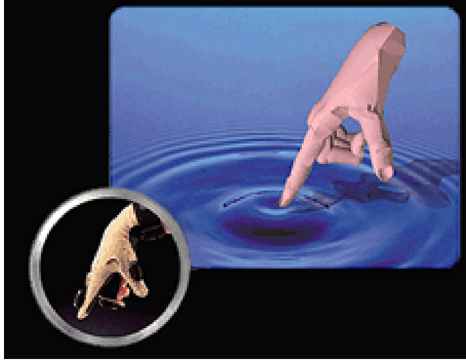
Haptics



- 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

Hannes Kaufmann

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

Hannes
Kaufmann

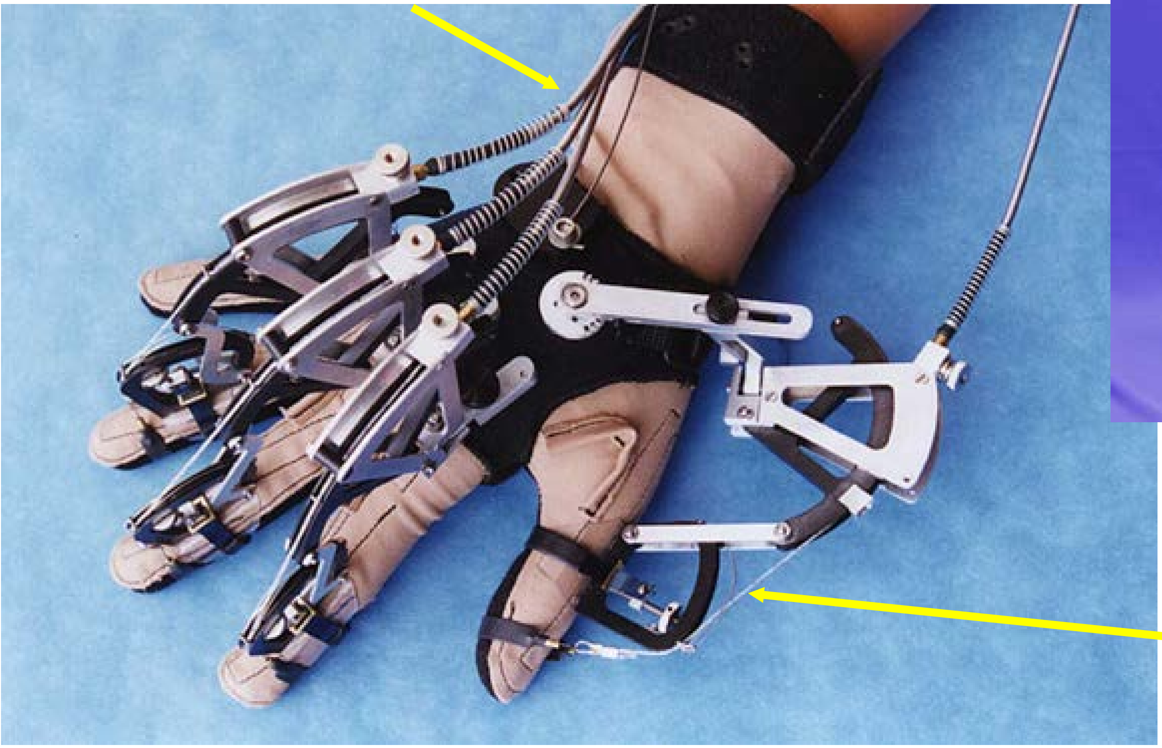
CyberTouch Glove

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.

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
30mm MSI	13,320 rounds (111 students x 120 rounds each)	$78 (£50)	$1.03 million (£666,000)
20mm GAM BO	26,160 rounds (218 students x 120 rounds each)	$50 (£32)	$1.3 million (£837,120)
Falcon 20 Aircraft	384 hours	$7666 (£4936)	$2.95 million (£1.9 million)
			$5.3 million (£3.4 million)

Hannes
Kaufmann

The Interface Challenge

Hannes
Kaufmann

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?

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

Hannes

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

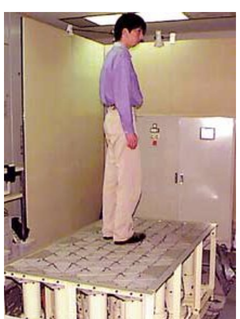
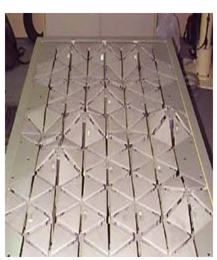
- Navigation
  - Travel – motor component
  - Wayfinding – cognitive component
- Selection
- Manipulation
- System control

The Interface Challenge

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



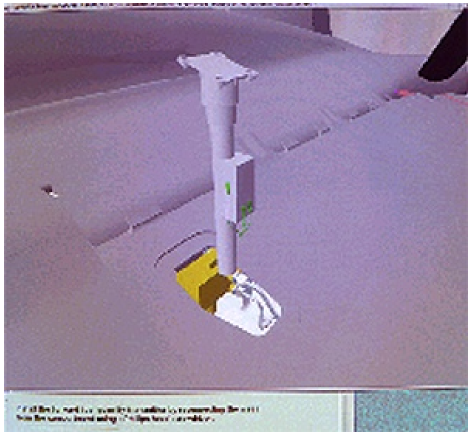


The Interface Challenge

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

Hannes
Kaufmann

The Interface Challenge

Cost vs. Precision?

vs.

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

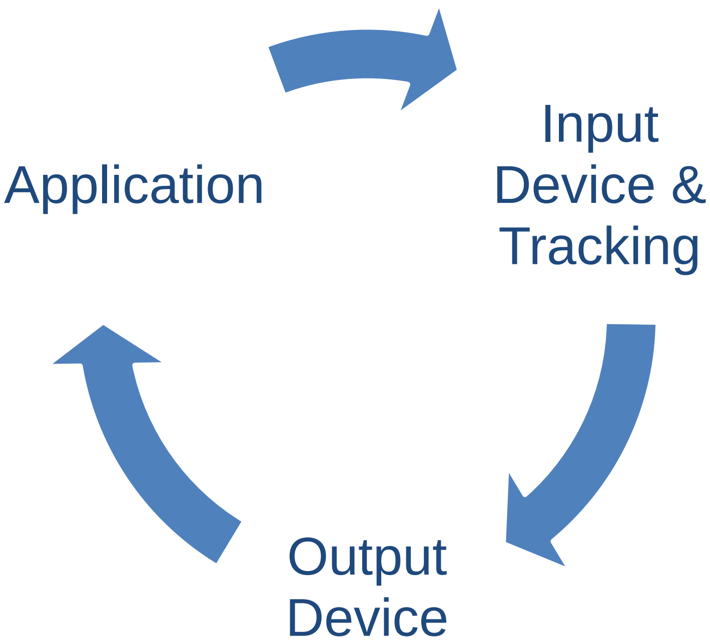
Hannes Kaufmann

Consider Human Factors!

Most people are not exited 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!

Hannes
Kaufmann

When is a VE effective?

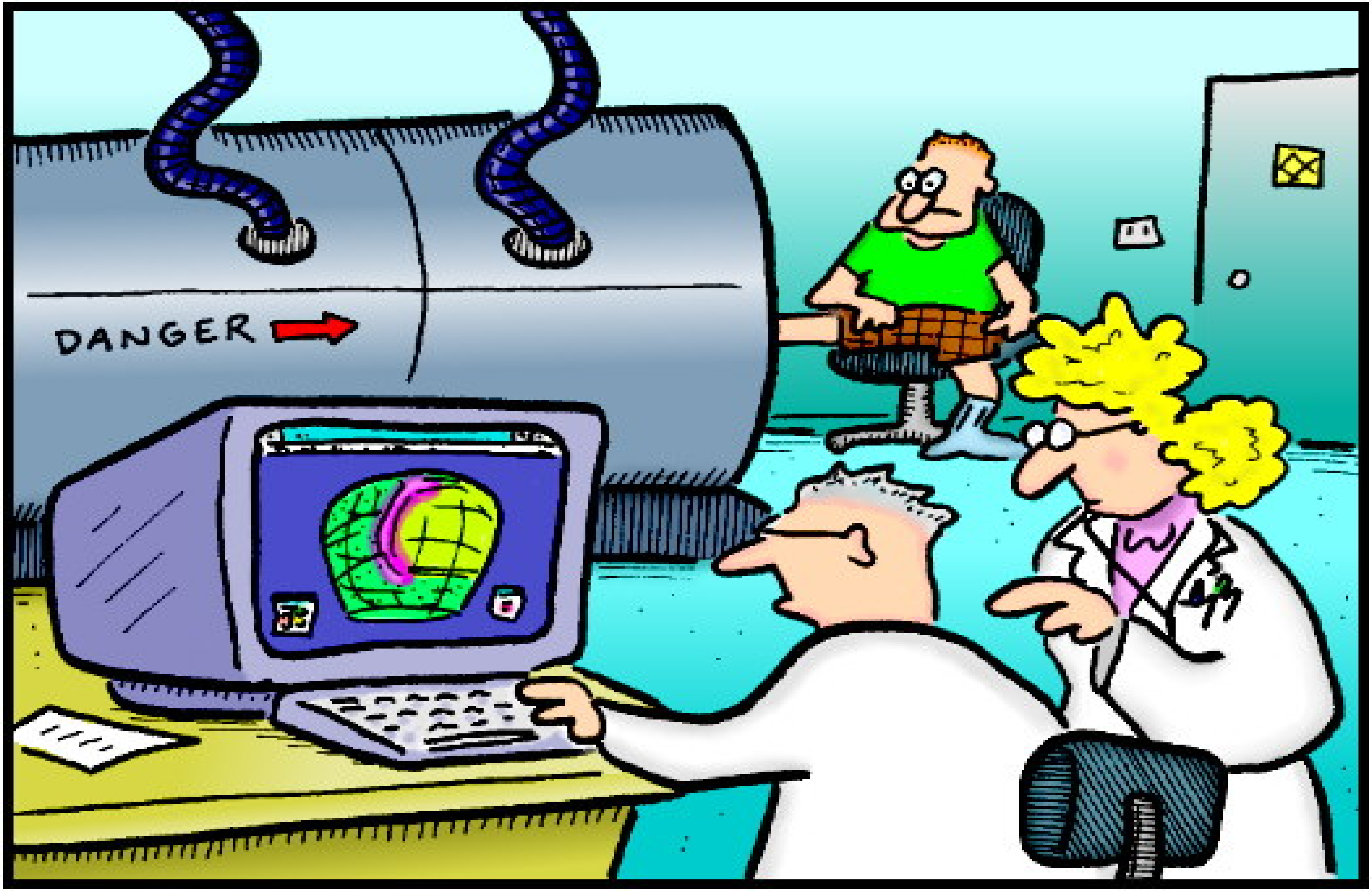
- Users' goals are realized
- User tasks done better, easier, or faster
- Users are not frustrated
- Users are not uncomfortable
- And there is some measurable gain in targeted real world performance

Hannes
Kaufmann

Literature

- 3D User Interfaces – Theory and Practice Doug Bowman, Ernst Kruijff, J. LaViola, Ivan Poupyrev; Addison Wesley, 2005.
- 3D Depth cues:
  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.