Course on Virtual Reality

Vision

Vision, Audio & Haptics

	Vision	Audio	Haptics
Human Factors			
• *Anatomy*	• Human eye	• Human ear	Tactile / force receptors
• *Perception*	• 3D visual depth cues • Photometry	• 3D audio depth cues • Psychoacoustics	
Technology			
• *Compute HW*	• Graphical Processing Units	• Audio boards	

• *Displays*	• Head-mounted
	  • Helmets
	• Room-mounted
	  • CAVEs, PowerWalls
	    • Stereo techniques
	    • Projectors, Screens
		• Head-mounted
		  • Earphones
		• Room-mounted
		  • Loudspeakers
			• Body-mounted devices
			• Grounded devices

Algorithms			
• *Generation*	• Geometrical modeling	• Sound modeling	• Force modeling
• *Rendering*	• Rendering Pipeline • Stereoscopic projections • Viewer-centered projections	• Binaural synthesis • Cross-talk cancellation	• Virtual proxy rendering
• *Global effects*	• Ray Tracing, Radiosity	• Room Acoustics	• Multi-contact haptics

Aspects of Vision

- Human Factors
  - Anatomy of the Human Eye
  - Perception: Depth Cues in Vision, Photometry
- Technology
  - Graphics Hardware
  - Head-Mounted Displays
  - Room-Mounted Displays: Stereo Techniques, Projectors, Screens, Brightness, …
- Algorithms
  - Geometrical Modeling
  - Rendering
    - Rendering Pipeline
    - Stereo Projections
    - Viewer-Centered Projection
  - Global Illumination: Ray Tracing, Radiosity

Addressing
Physiological Depth Cues and Immersion:

Display Technology

Goal

Exact correspondence of visual perception in the real world and in the virtual world

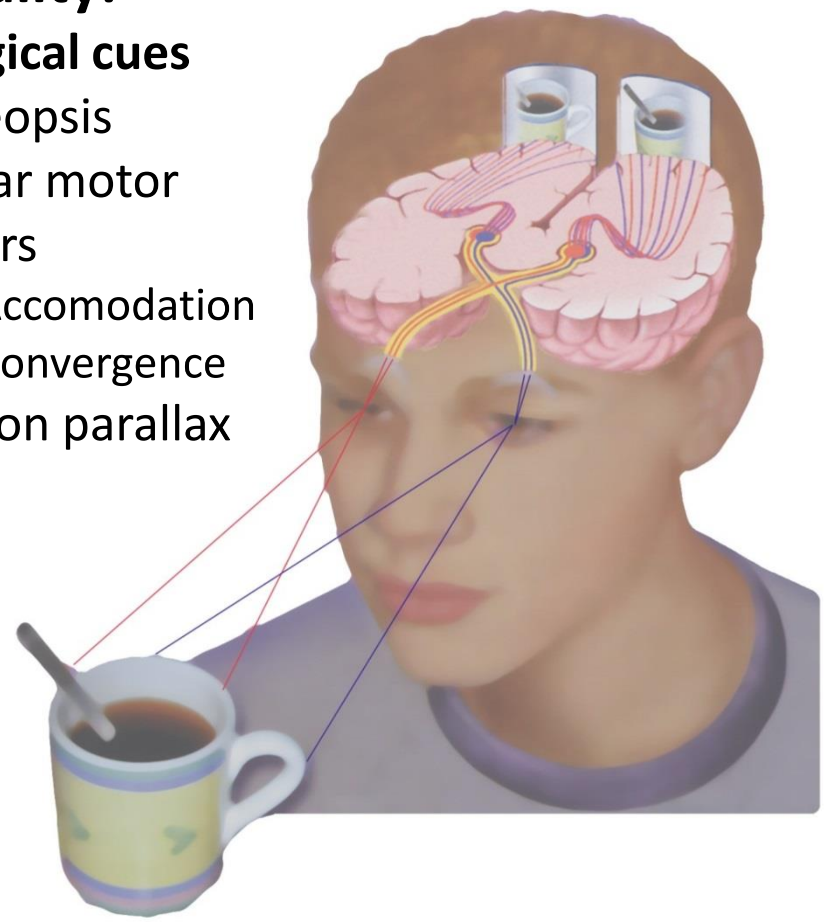
Physiological & Psychological Depth Cues

Traditional CG:

- **Psychological cues**
  - Perspective shortening
  - Occlusion of objects
  - Light and shadows
  - Texture gradients
  - Atmospheric perspective

Virtual Reality:

- **Physiological cues**
  - Stereopsis
  - Ocular motor factors
    - Accomodation
    - Convergence
  - Motion parallax



Head-Mounted Displays

HMDs: Critical Quality Criteria

- Resolution
- Field of View
- Lens Distortions
- Screen Door Effect
- Ergonomics
- Integrated Tracking System
  → see later in this course

Field of View

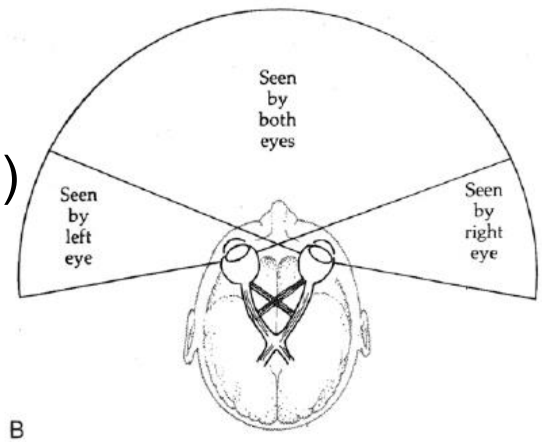
Riecke (2006)

- Oval shape
- At eye level:

  Horizontal: About 90° to both sides

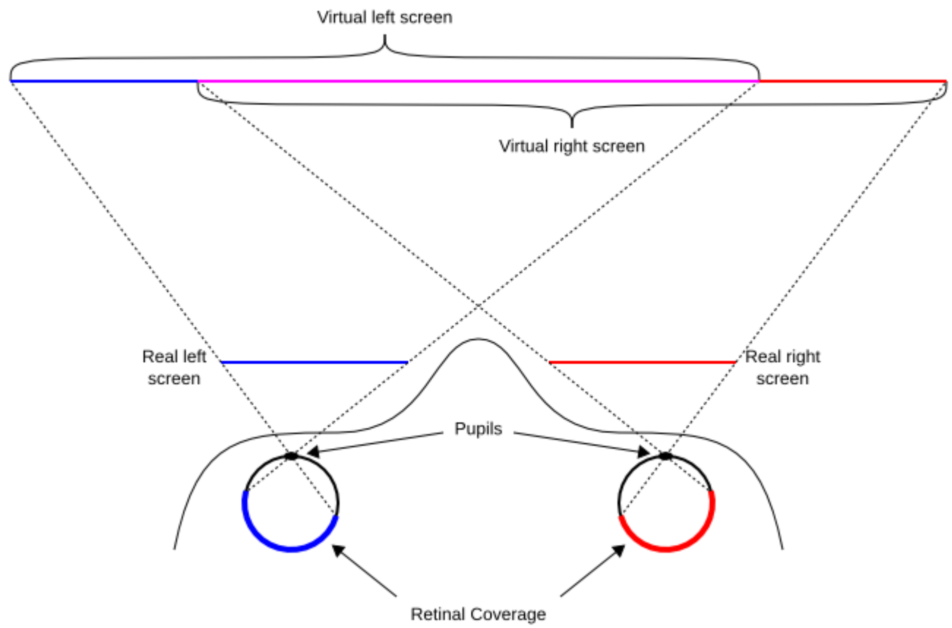
  Vertical: About 120° (↑ 50° and ↓70°)
- FOV center is being perceived by both eyes

  Stereoscopic (binocular) field: 100° - 120°



- **"Gesichtsfeld"** (Engl. Field of View):
  3D space that can be percieved at a particular time instant with head fixed and eyes looking straight ahead and not moving
- **"Blickfeld"** (Engl. Field of View):
  3D space where objects can be focused at (one after the other), eye movements allowed
- **"Sichtfeld"** (Engl. Field of View):
  3D space spanned by an optical instrument (e.g., camera)
- **"Blickfeld"** (Engl. Field of Regard):
  3D space that can be captured when eye and head movements are allowed

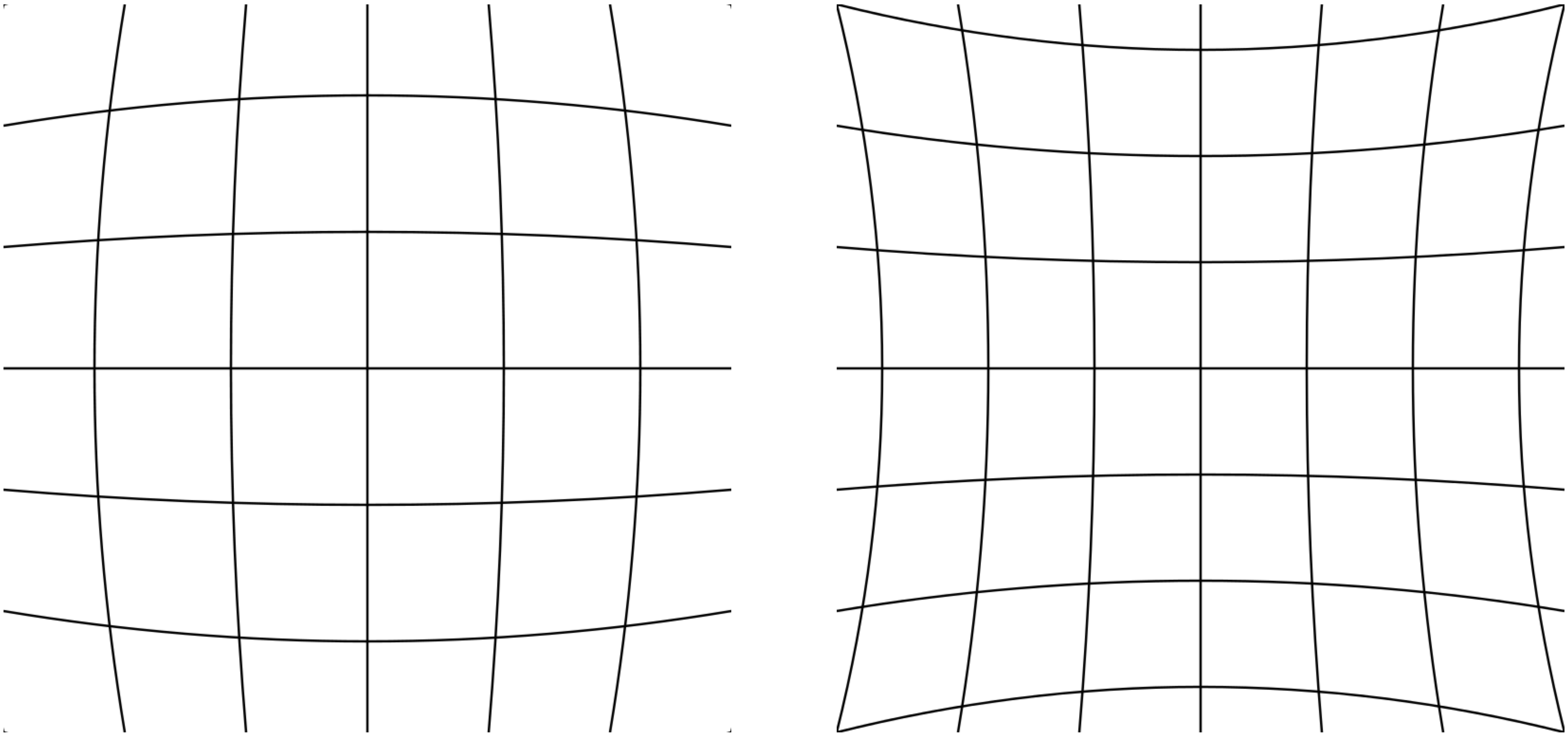
Stereo in Head-Mounted Displays



Oliver Kreylos, Doc-Ok.org

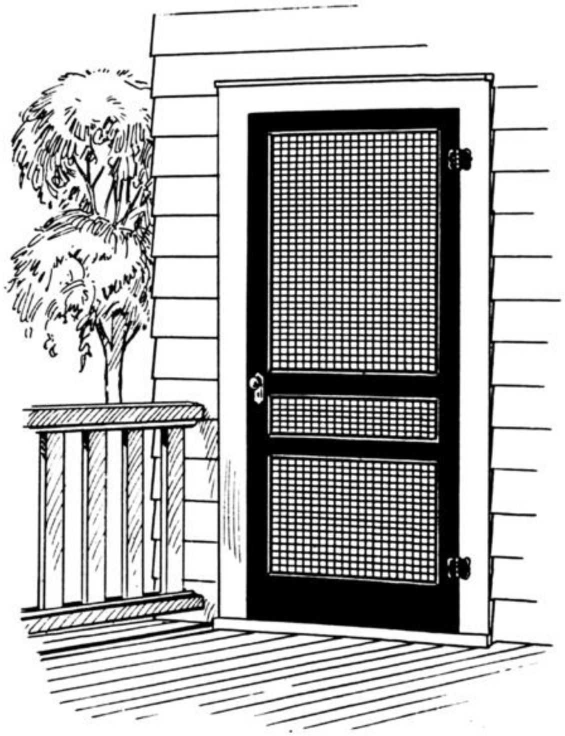
- Separate screens for left and right eye, screens move with user's head
- (Asymmetric) view volume does not change while user is moving
- Optics: Create larger virtual screens at a longer distance away to allow users to properly focus on those screens
- Proper calibration eyes/screens needed

Barrel and Pincushion Distortions

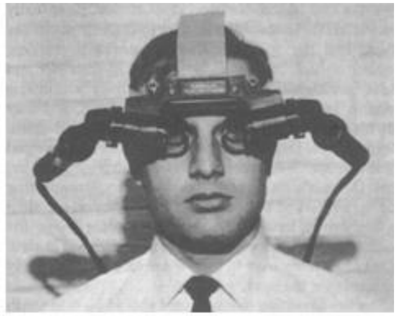


“Barrel & Pincushion distortion" by Wolf Wings - Own work. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Pincushion_distortion.svg#/media/File:Pincushion_distortion.svg

The „Screen Door Effect“ in HMDs



Head Mounted Display 1956 - 2010



I. Sutherland

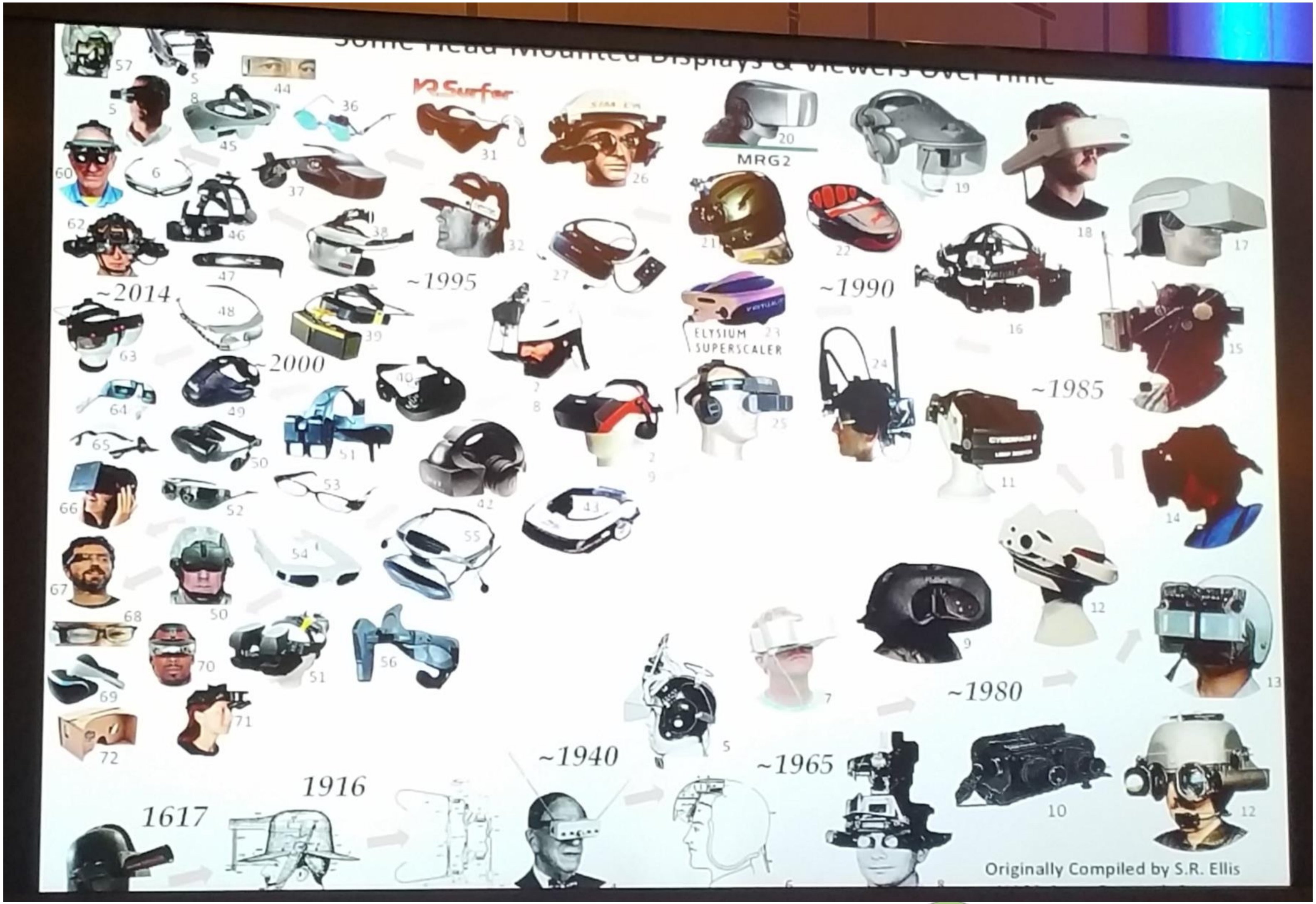
Sony

BOOM

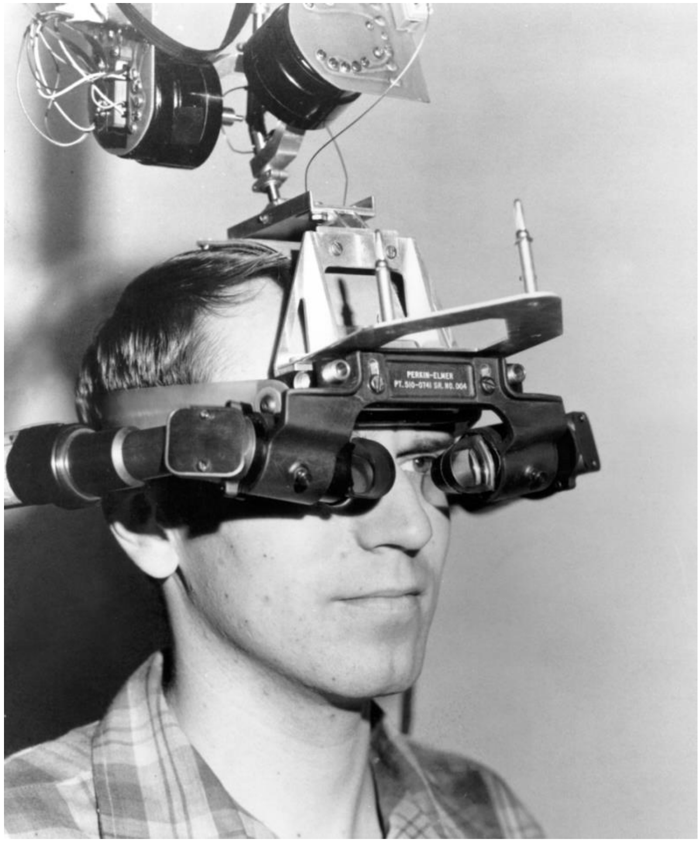
CAE

Retina Display,
Microvision

HMDs: More Models Than You Think!



1965: Ivan Sutherland

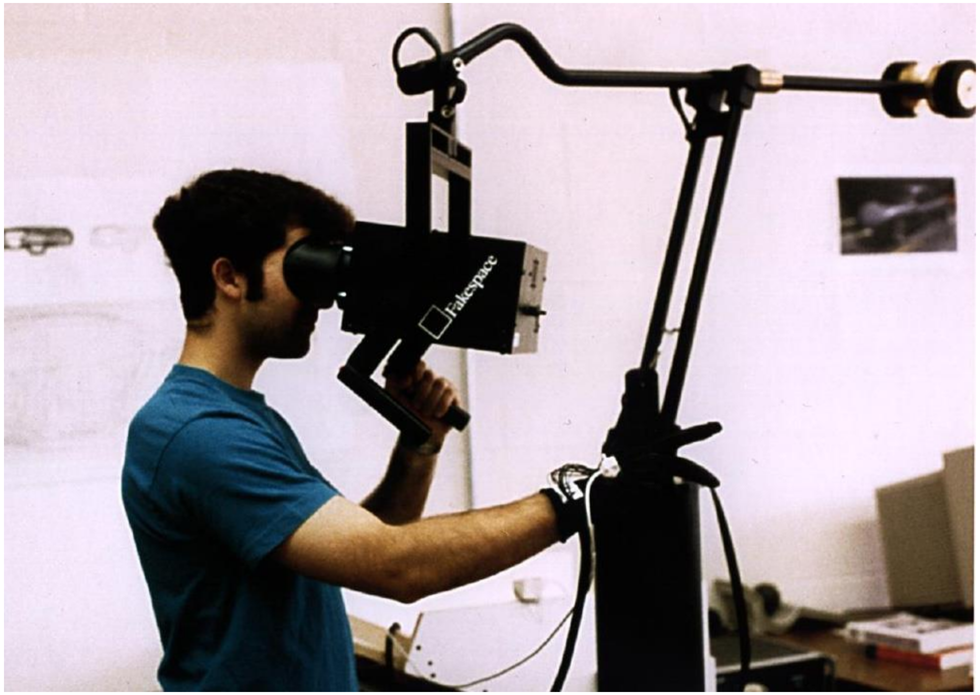


1989: The “EyePhone” from VPL Research

- Resolution: 442 x 238 Pixels
- 1st commercially available HMD

1993: BOOM – Binocular Omni-Orientation Monitor

- Head-coupled stereo display attached to counterbalanced multi-link arm
- U.S. patent held by Mark Bolas, manufactured by Fakespace Systems
- Driven by Silicon Graphics VGX380 workstation
  - 1280 x 1024 resolution, 800.000 shaded triangles/s



Devices in 2011

Sony HMZ-T1:
2 x 7 inches OLED screens
1280 x 768 pixels
~ 500 Euros

Hasbro my3D:
Add-on for Apple iPhone

2013: The Oculus Rift HMD

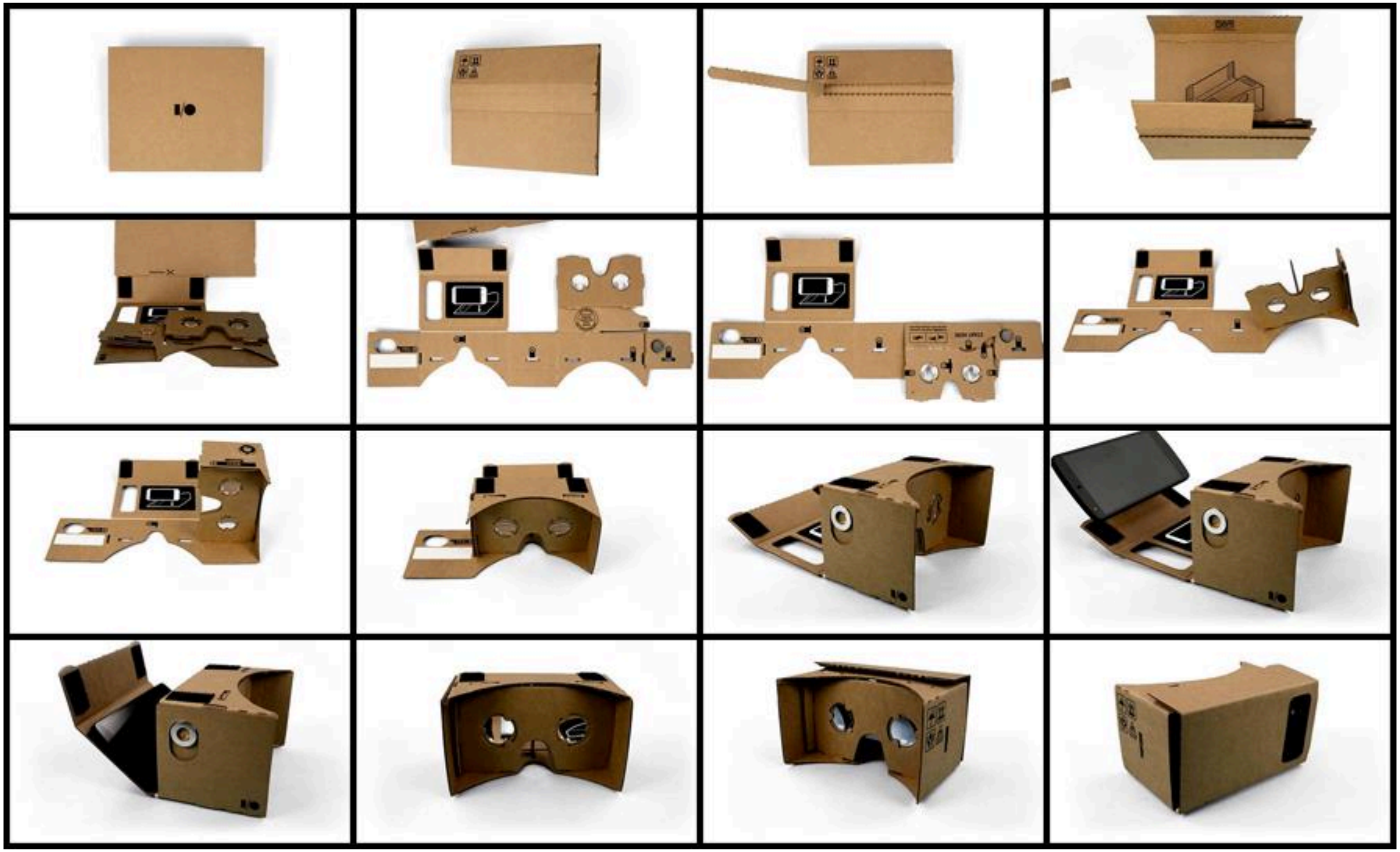
Oculus VR

- Resolution
  - In 2013: 640x800 pixels per eye
  - In 2016: 1080×1200 per eye @ 90 Hz refresh rate
- Field of view: 110° diagonal, 90° horizontal
- Tracking:
  - Rotation: combination of gyrometer, accelerometer, magnetometer
  - Translation: IR sensor (since 2015)

2015: Samsung Gear VR versus Oculus Rift HMD

Source: Spiegel Online, November 2015

2014: Google Cardboard Project



Source: www.miriamposner.com, November 2015

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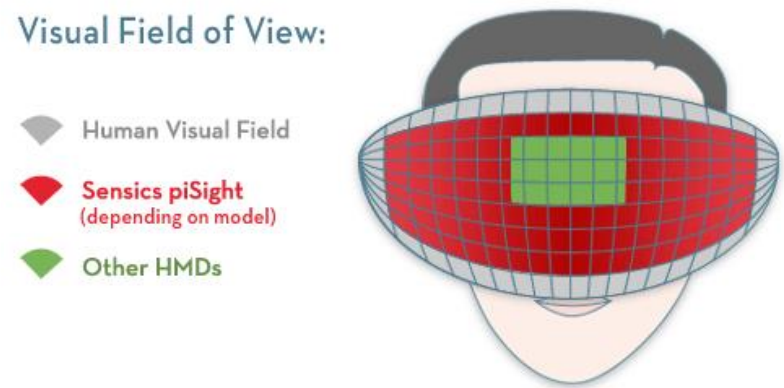
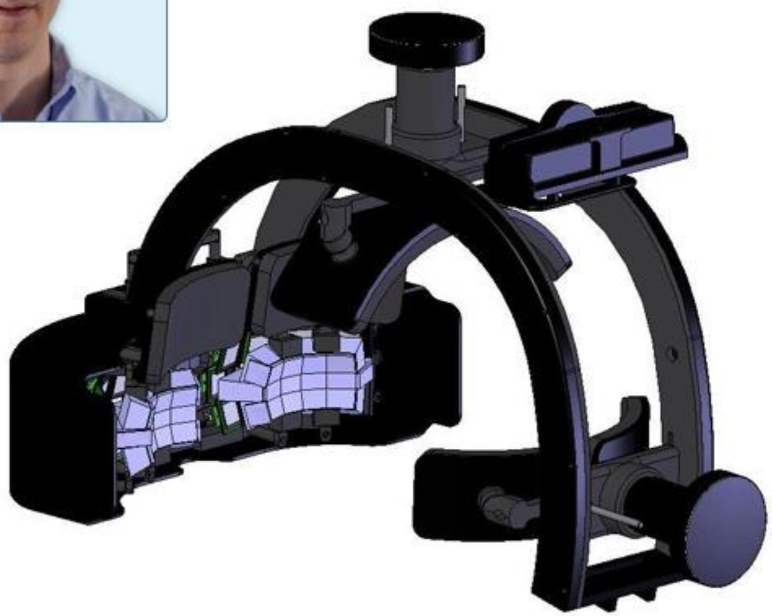
2011: The piSight HMD

Pictures: www.sensics.com and other Web Sites





Resolution up to 4200x2400 pixels per eye

2016: “StarVR” (Starbreeze & Acer)

- Resolution
  - Two 5.5 inch displays
  - 5120 x 1440 pixels in total
- Field of view: 210° horizontal, 130° vertical

HMDs: Critical Quality Criteria

- Resolution
- Field of View
- Lens Distortions
- Screen Door Effect
- Ergonomics
- Integrated Tracking System
  → see later in this course

What‘s Wrong with HMDs?

Room-Mounted Displays

Aspects of Vision

- Human Factors
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HMDs: Critical Quality Criteria

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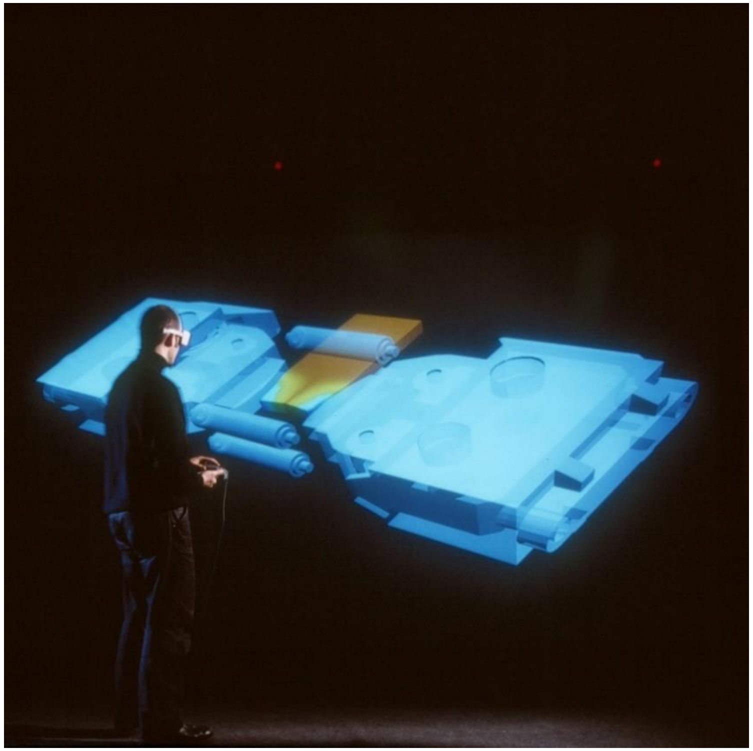
Room-Mounted Displays: Critical Quality Criteria

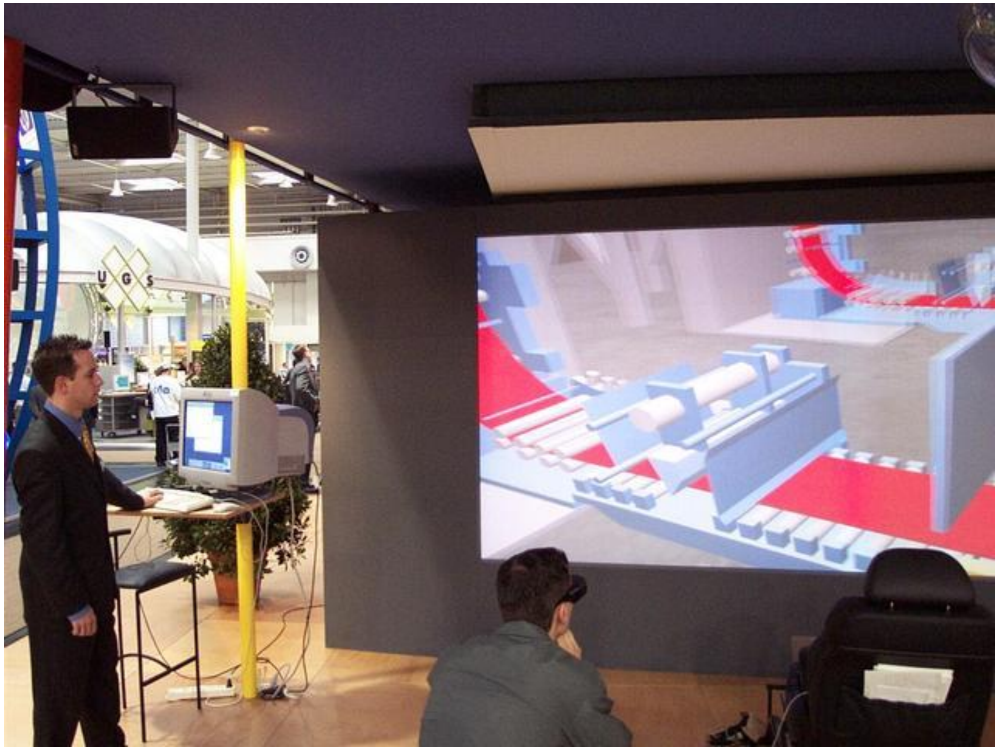
- Resolution
- Field of ~~View~~ Regard
- ~~Lens Distortions~~
- Screen Door Effect
- Ergonomics
- Tracking System
- Costs, Footprint, Maintenance

PowerWall

Optionally, place more projectors in row to enlarge screen size
Edge Blending



Analysis of forming processes on a PowerWall (IBF and VR Group, 2000)

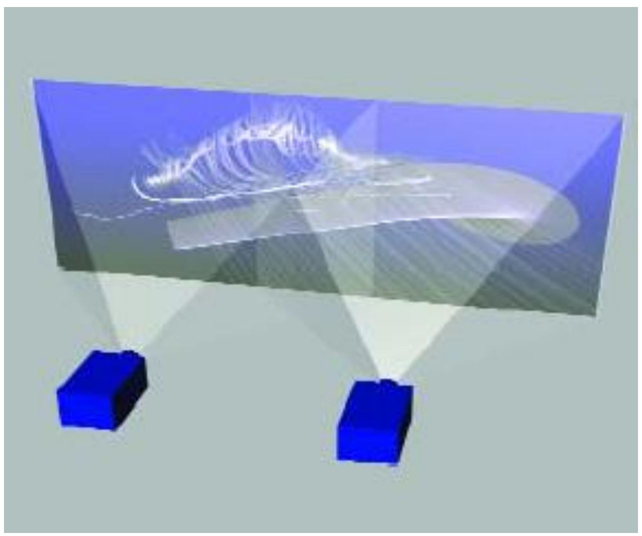


Virtual Rolling Mill on an INFITEC PowerWall (IBF, SMS Demag and VR Group, EUROMOLD Frankfurt2001)

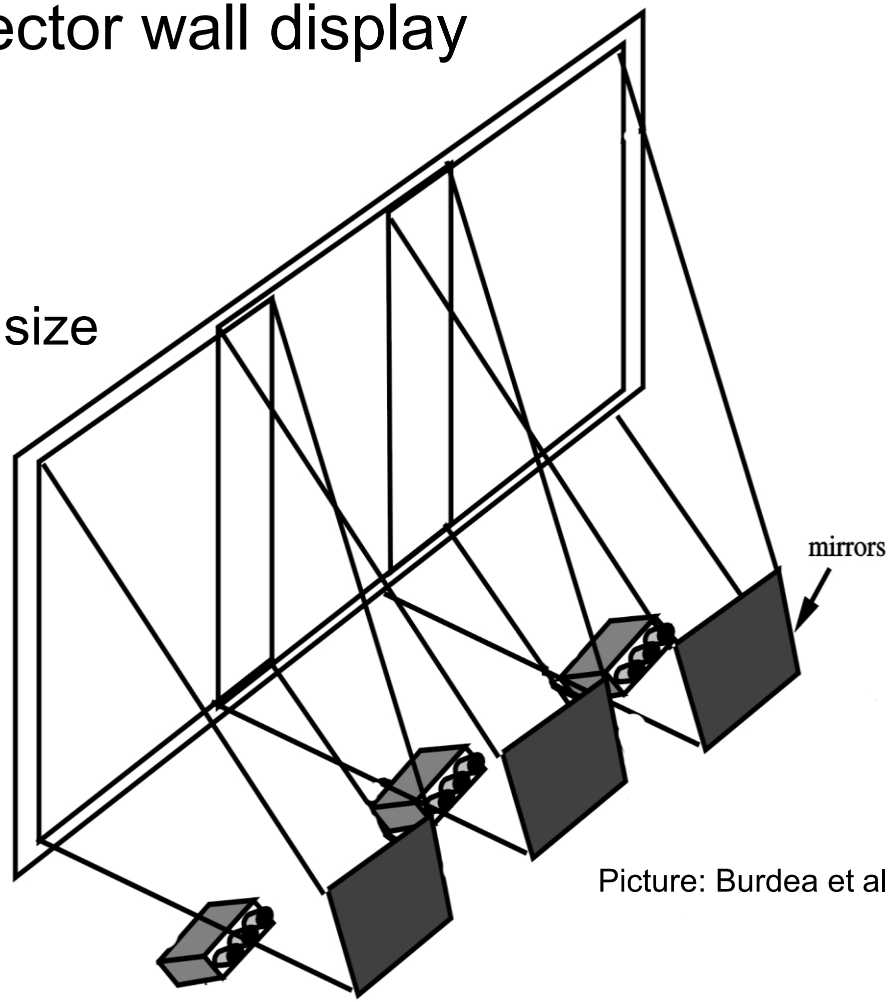
PowerWall

Rear-projected multiple-projector wall display

- Increase number of pixels
- Enlarge image
- Maintain or even decrease pixel size



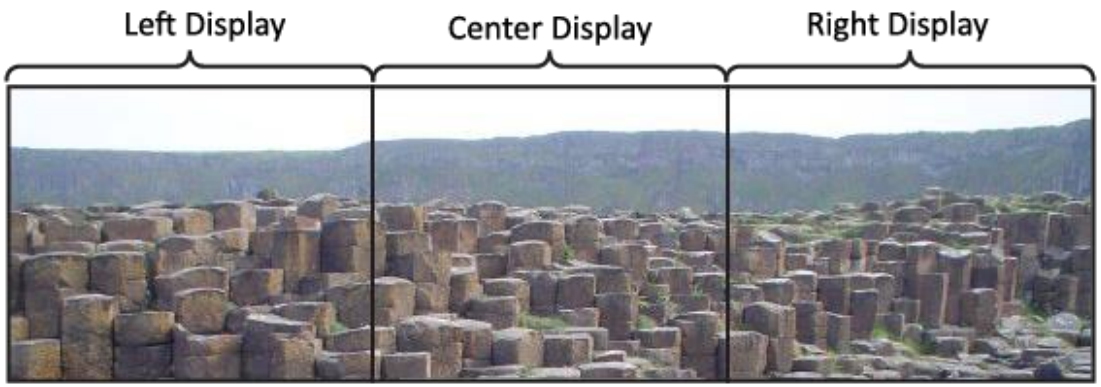
Picture: Panoram Technologies, Indeed Visual Concepts



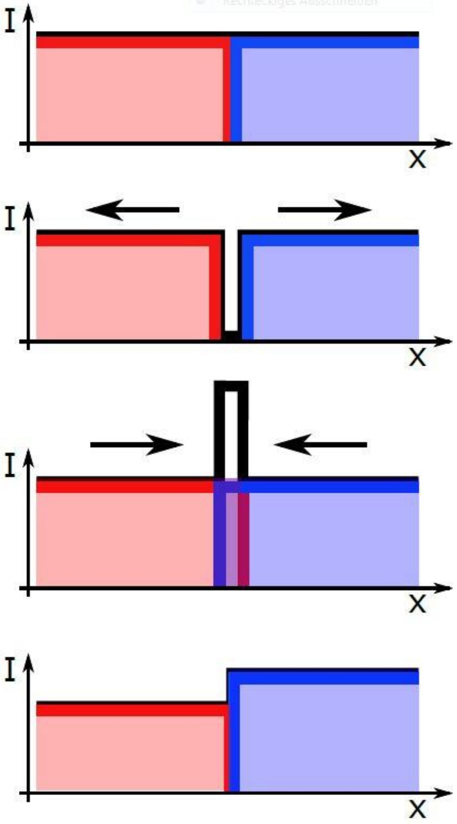
Picture: Burdea et al.

Hard Edge Blending

https://www.immersaview.com/resources/edge-blending/



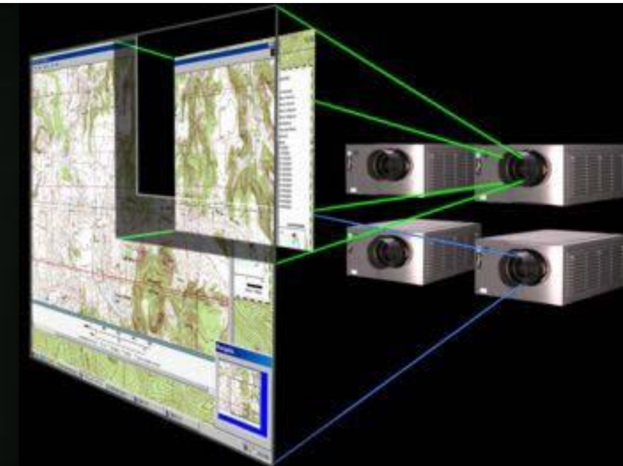
Picture: M. Lancelle



Seamless image needs „pixel-perfect“ alignment of projectors!

Discontinuities destroy illusion of presence

Tiled Displays

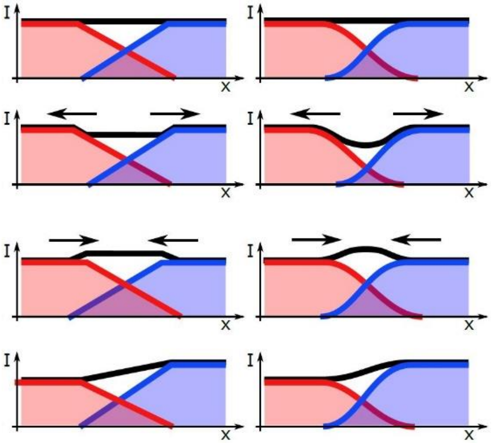


HEyeWall @ Fraunhofer IGD Darmstadt
(6x4 tiled display, 48 projectors at 1024x768 resolution, INFITEC, Hard edge blending, installed in 2004)

Soft Edge Blending

The same proportion of the image is projected from two adjacent projectors to provide a duplicate, overlapping image region

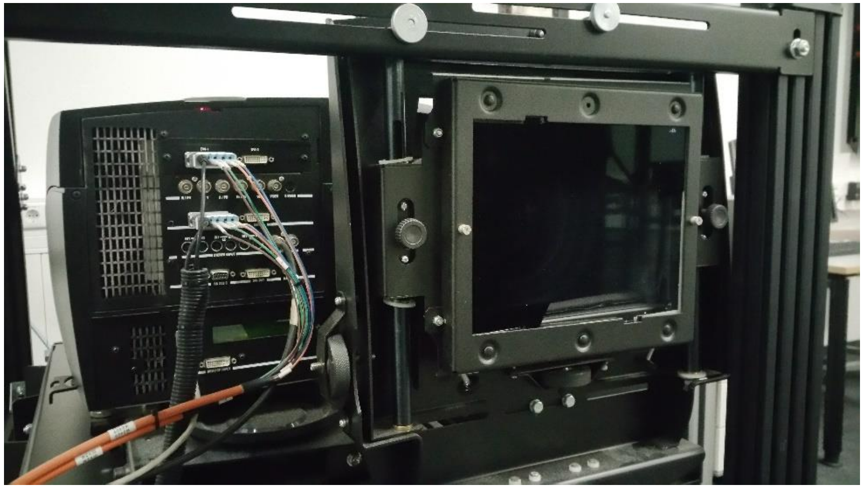
https://www.immersaview.com/resources/edge-blending/

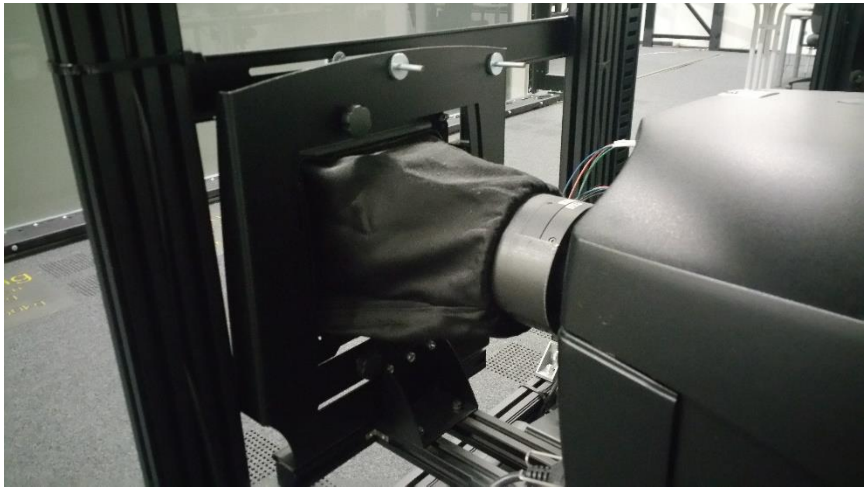


Picture: M. Lancelle

Visually combine the overlapping images by gradually decreasing luminance to make a single seamless image

Soft Edge Blending





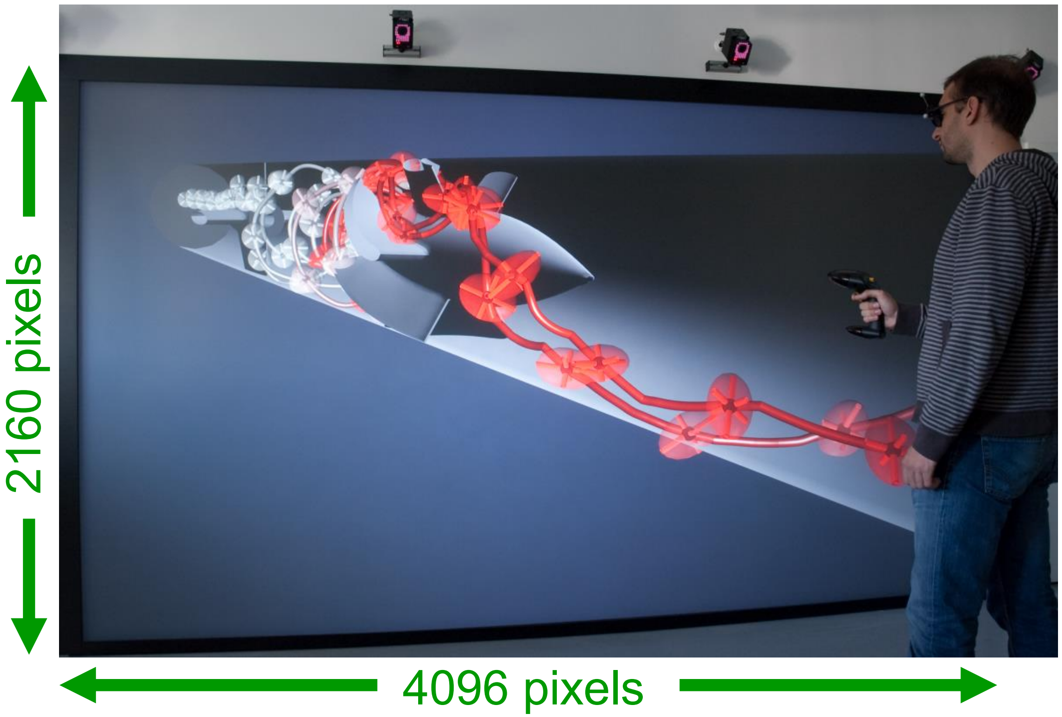
Two-Dimensional Soft-Edge Blending

Picture: Panoram Technologies, Indeed Visual Concepts

Ultra High Resolution Projectors

Sony 4K Projector
Resolution: 4xHDTV (4096x2160 Pixels)
4 DVI Graphics Inputs

High Resolution PowerWall @ AICES Graduate School



LCD-based Tiled Display @ EVL, Univ. Chicago

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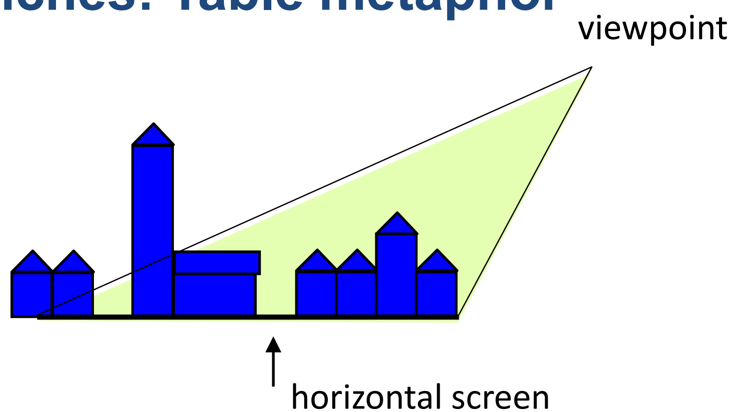
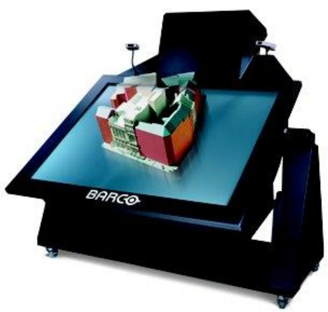
Table Rear Projection

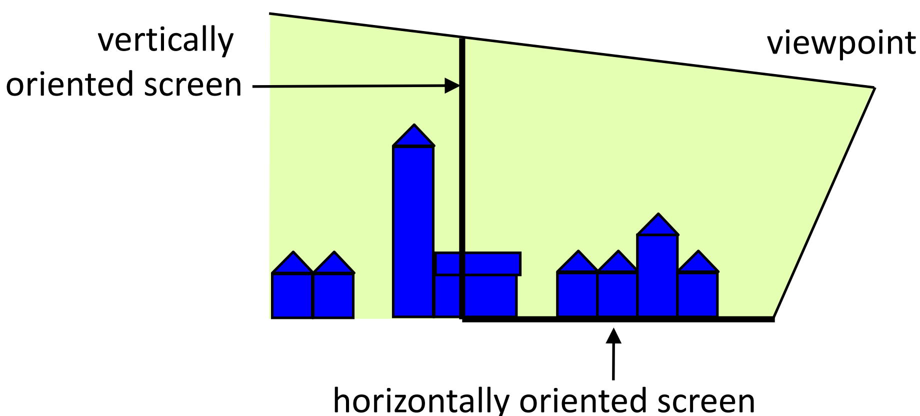
Benches: Table metaphor

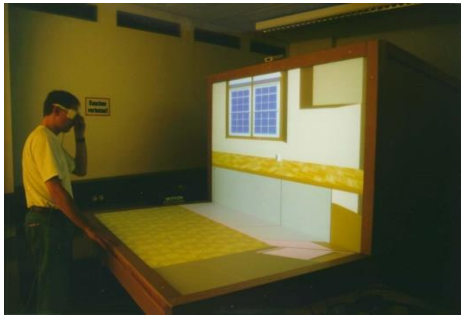




BARON (BARCO GmbH)

L-Bench: Enlarge view volume by adding a vertical screen

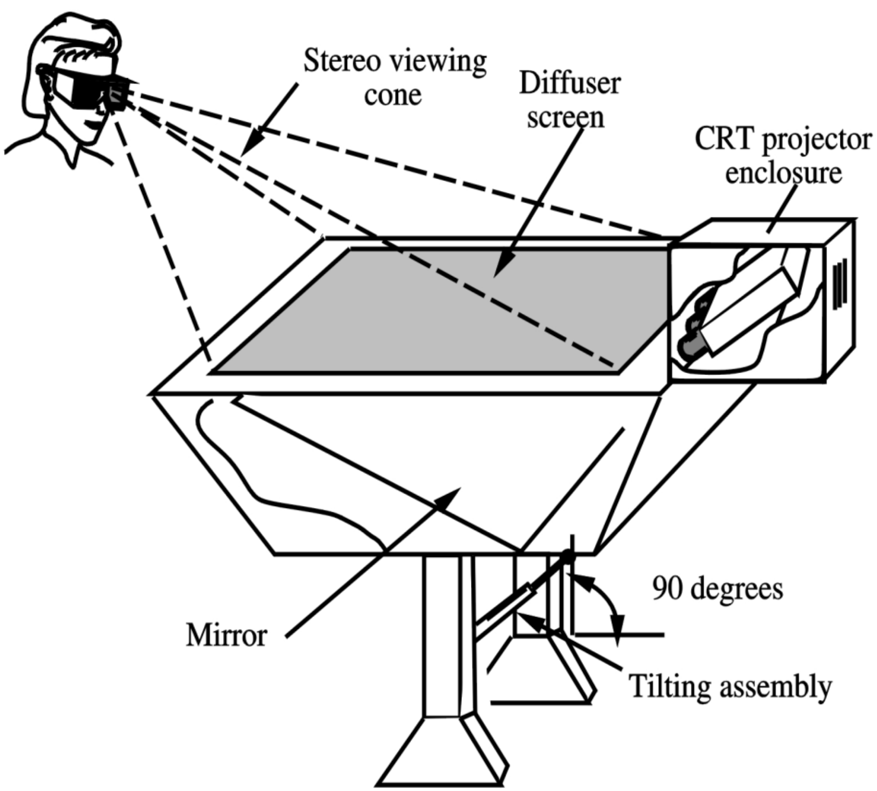


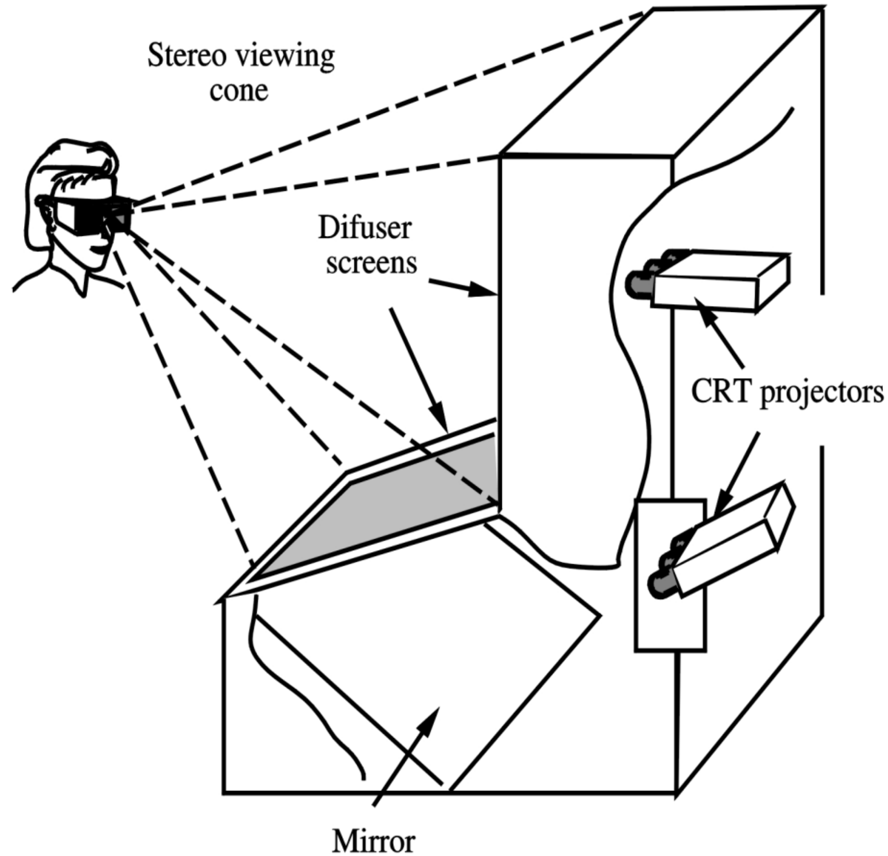


L-Bench @ IT Center in 1998 and in 2006

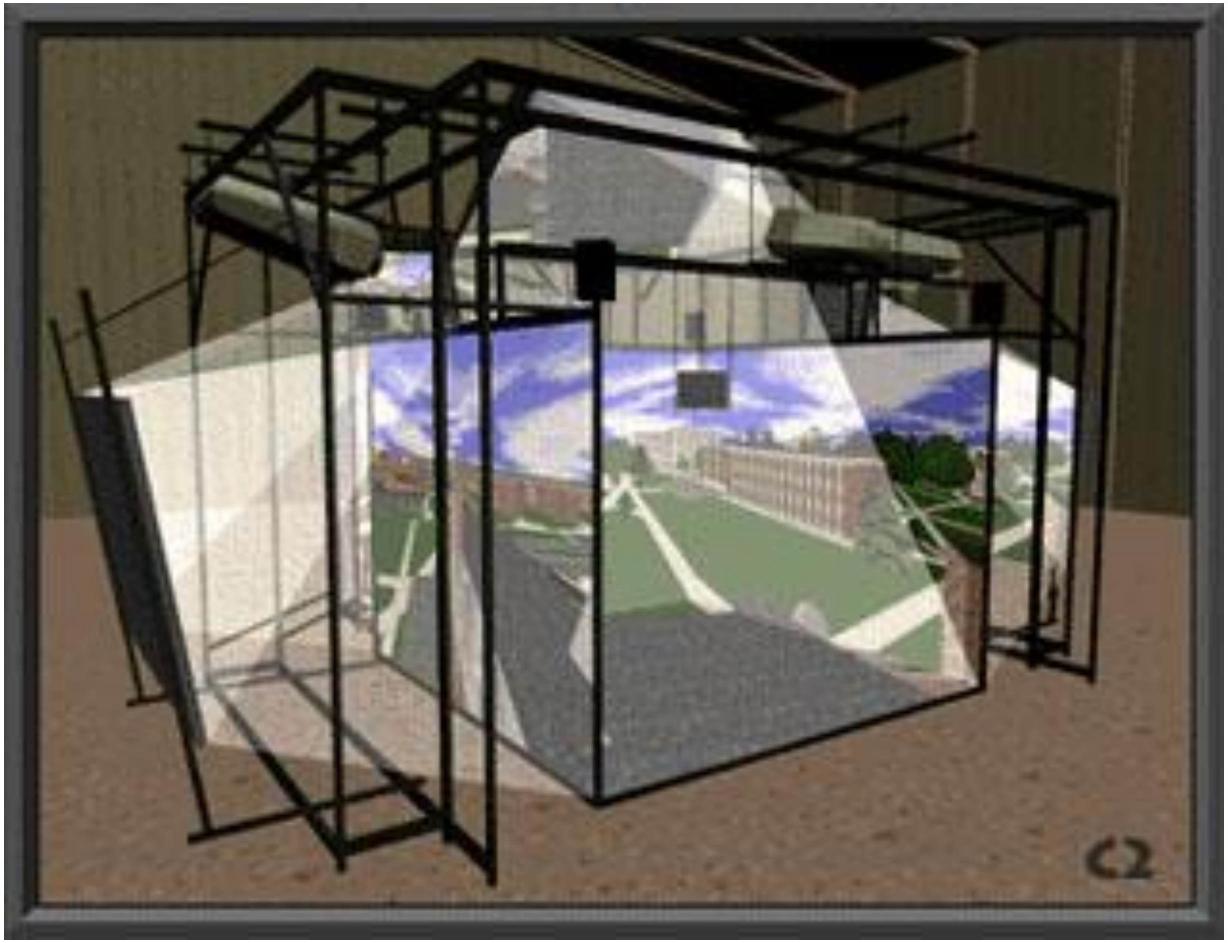
View Volumes of Bench and L-Bench

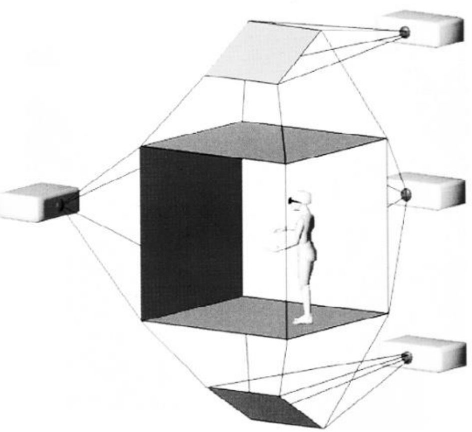
Pictures: Burdea et al.





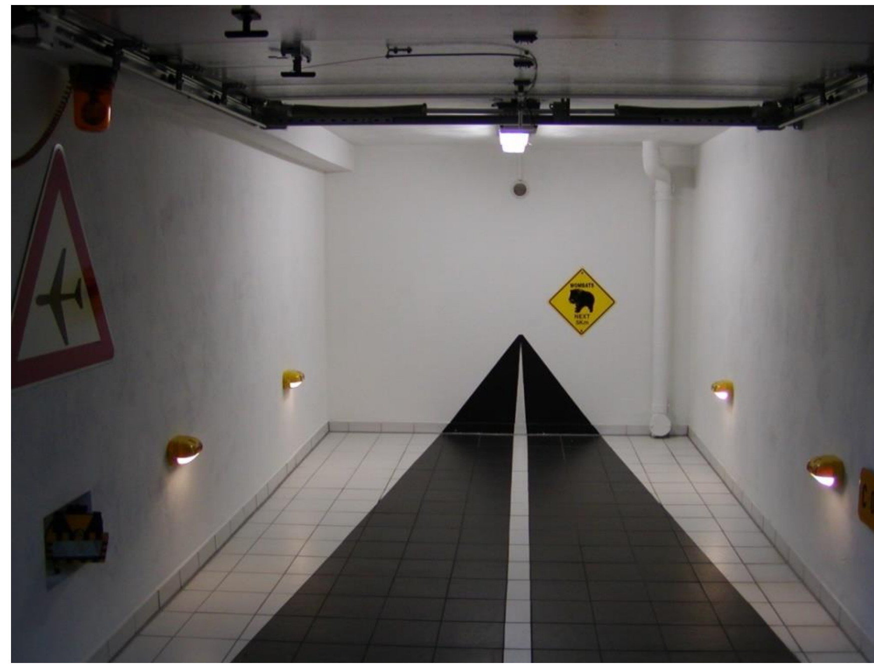
The CAVE



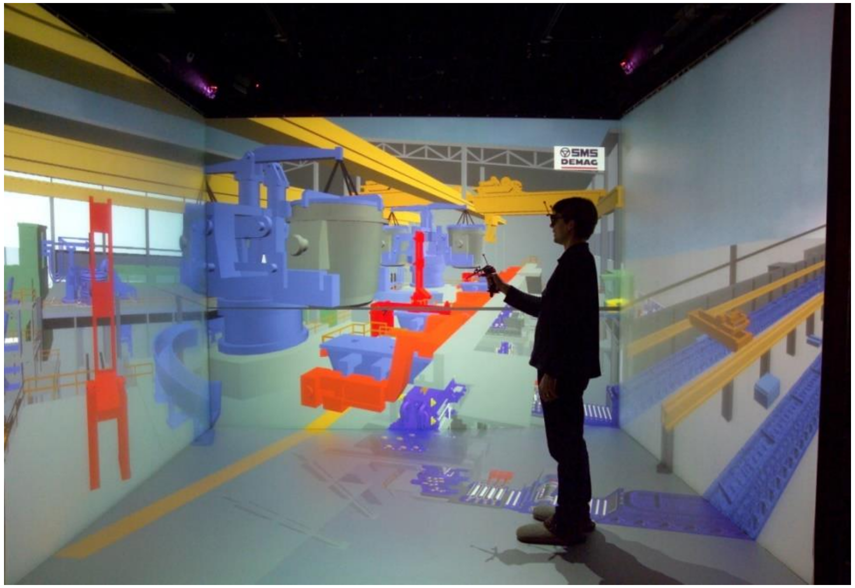


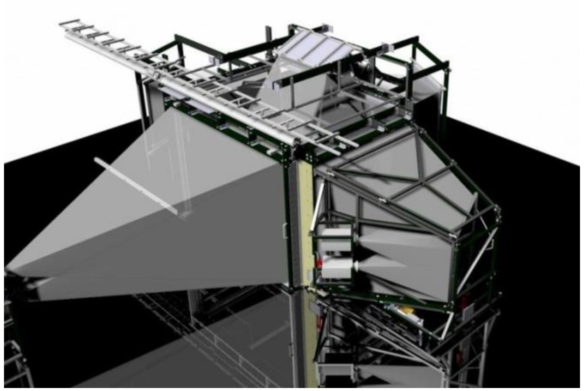
Carolina Cruz-Neira et al., 1993

The First CAVE in Aachen: In 1985 @ Professor's Home ;-)

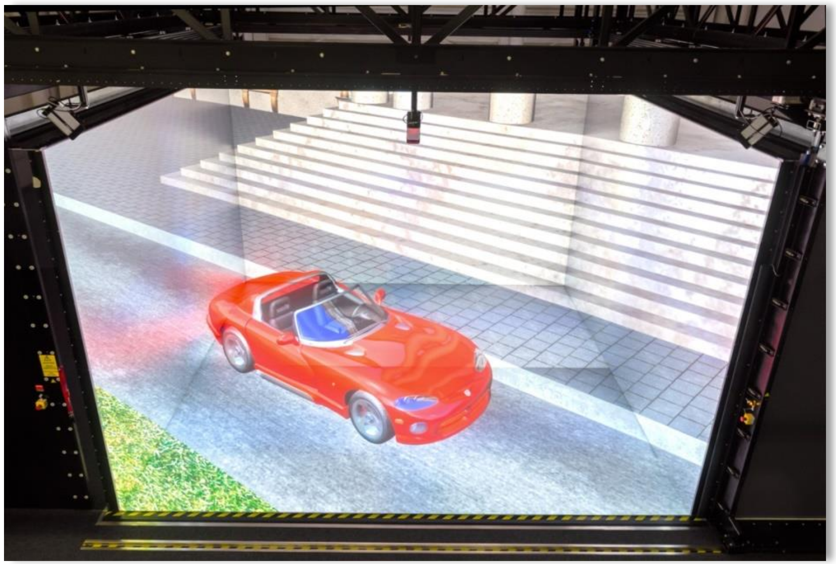


Reconfigurable CAVE@ RWTH (2004 – 2012)



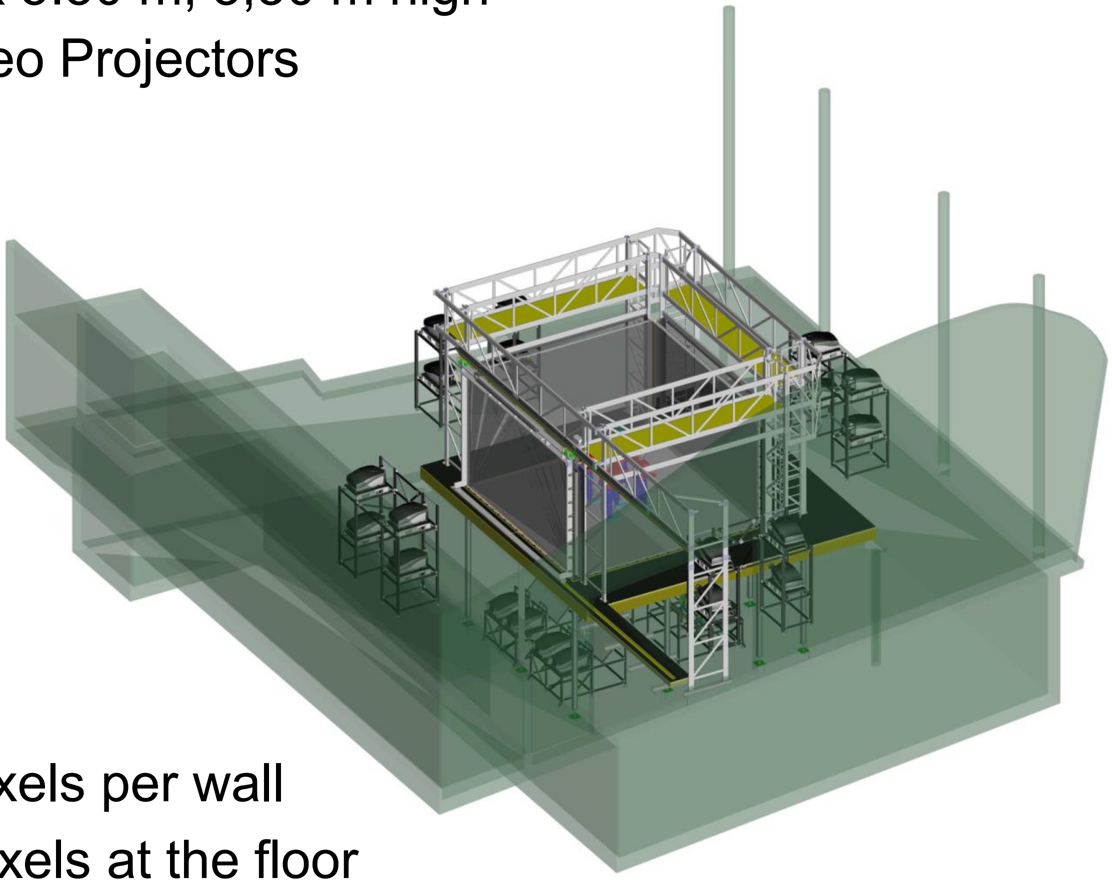


The aixCAVE @ RWTH (2013 -)



The aixCAVE Specs

- Footprint approx. 5.50 x 5.50 m, 3,30 m high
- 24 WUXGA Active Stereo Projectors

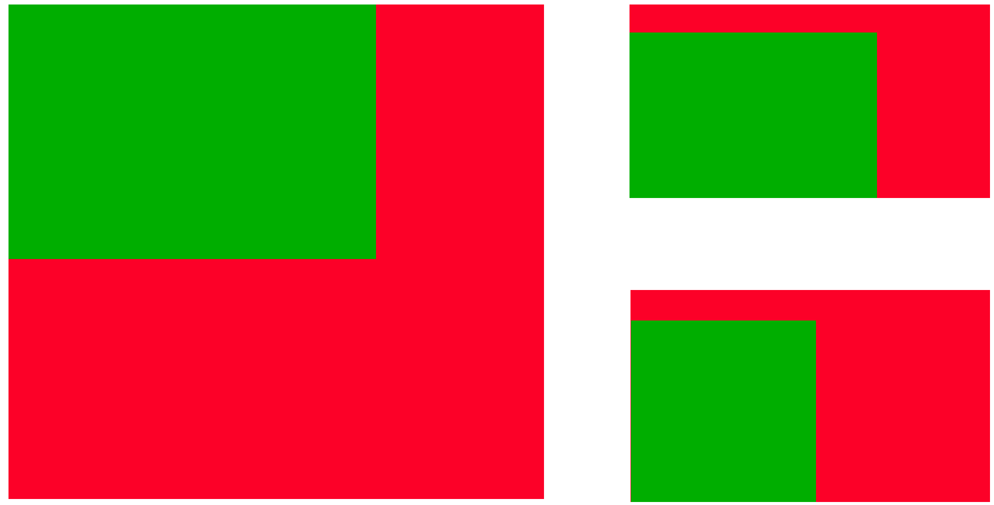


- Approx. 3200 x 2000 pixels per wall
- Approx. 3600 x 3600 Pixels at the floor
- Brightness: Nearly 300.000 ANSI Lumen

aixCAVE – Installation of Floor Glass Plate

aixCAVE versus CAVE…

Size: 5.25 x 5.25 x 3.30 m versus 3.30 x 2.70 x 2.70 m



Top View

Side View 1

Side View 2

Pixel size: 1.5 x 1.5 mm versus 2.3 x 2.3 mm

Number of pixels: 55 Mio (40 Mio with edge blending) versus 9 Mio

How to Get more and Smaller Pixels …

Better Projectors, …

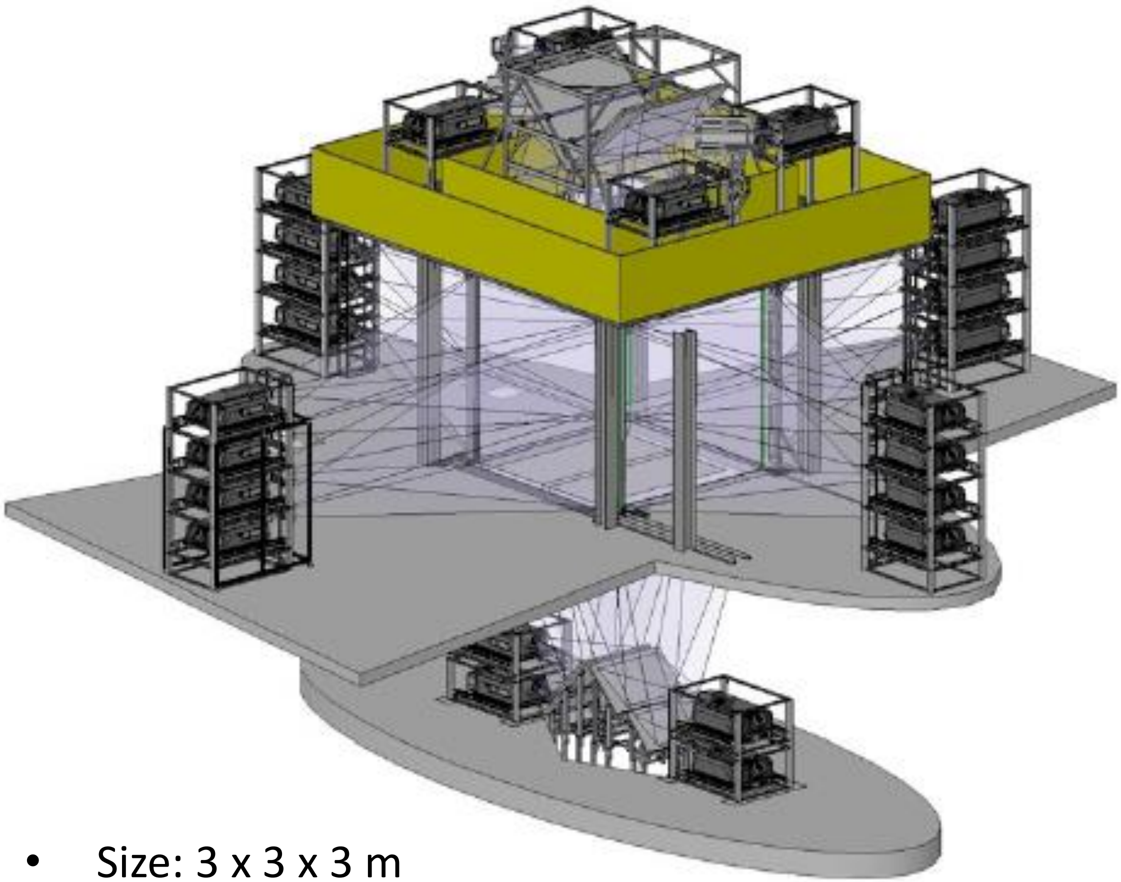
Barco Sim6
- 1600 x 1200 Pixel
- 3000 Ansi Lumen

Barco Galaxy
- 1920 x 1200 Pixel
- 12000 Ansi Lumen

… and more of them: 24 instead of 10

Active stereo shutter projection instead of polarization:
In a stronger sense, 24 instead of 5!

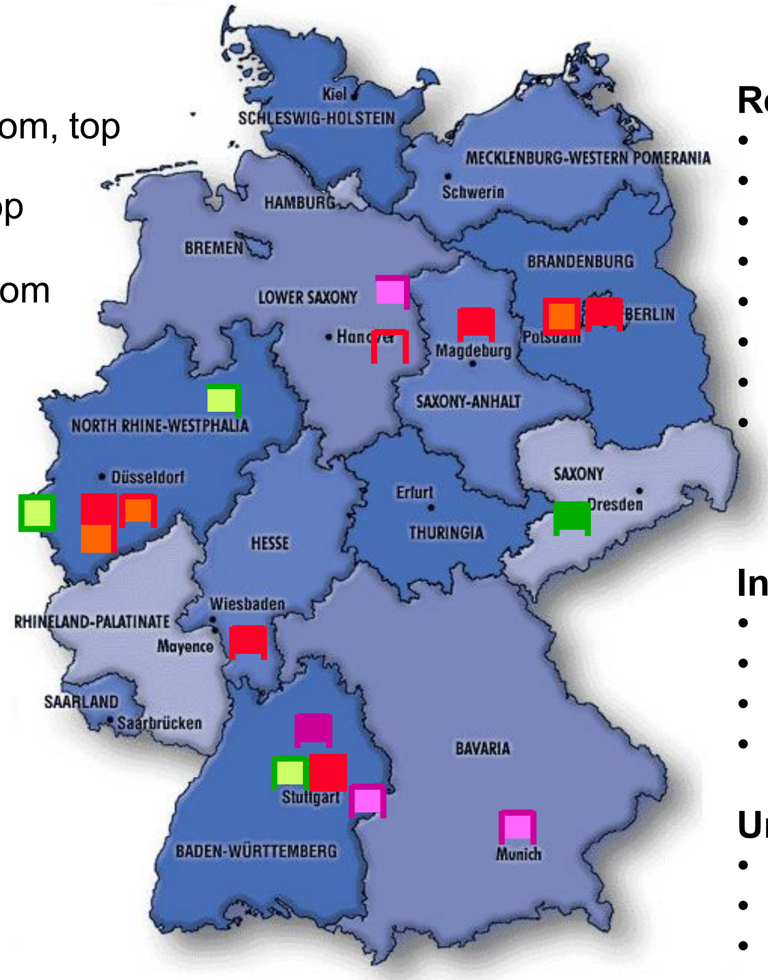
CAVE @ Iowa State University (identical installation @ KAUST)



- Size: 3 x 3 x 3 m
- 6-sided, non-rigid screens
- Resolution: 2 x 4 K resolution per wall, passive stereo

CAVE Installations in Germany in 2004

- Front, back, left, right, bottom, top
- Front, left, right, bottom, top
- Front, back, left, right, bottom
- Front, left, right, bottom
- Front, left, bottom
- Front, left, right

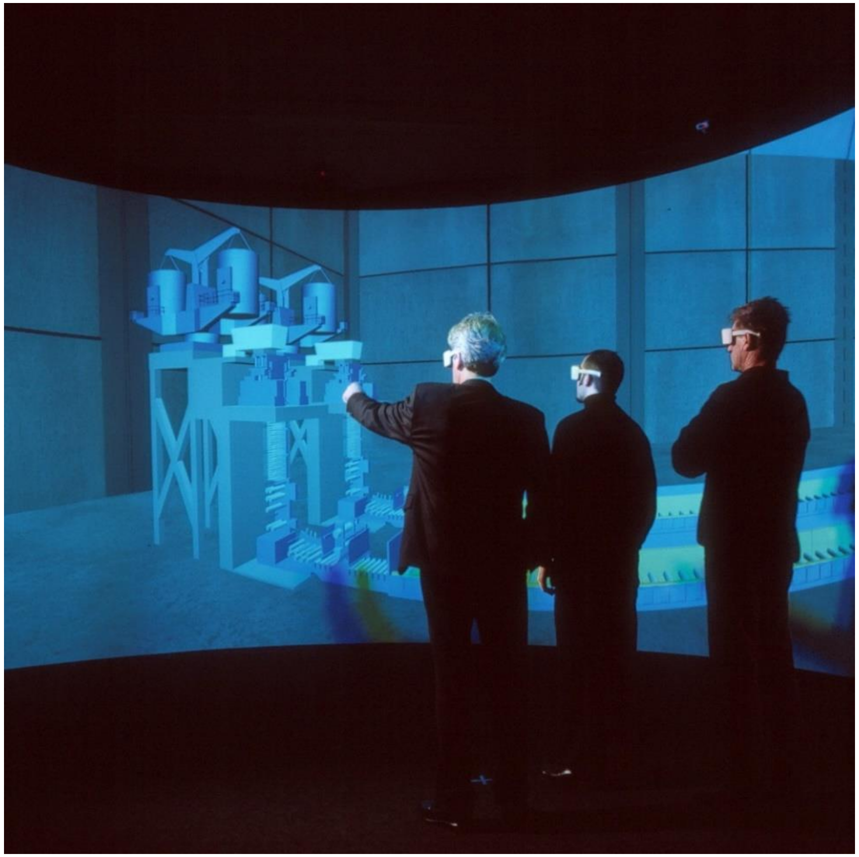


Research Institutes
- Stuttgart, Fraunhofer IAO/IPA (6)
- Bonn caesar (7)
- Darmstadt, Fraunhofer IGD (5)
- Magdeburg, Fraunhofer IFF (5)
- Berlin Fraunhofer IPK (5)
- Berlin Fraunhofer First (5)
- St. Augustin Fraunhofer IMK (4)
- Braunschweig DLR (3)

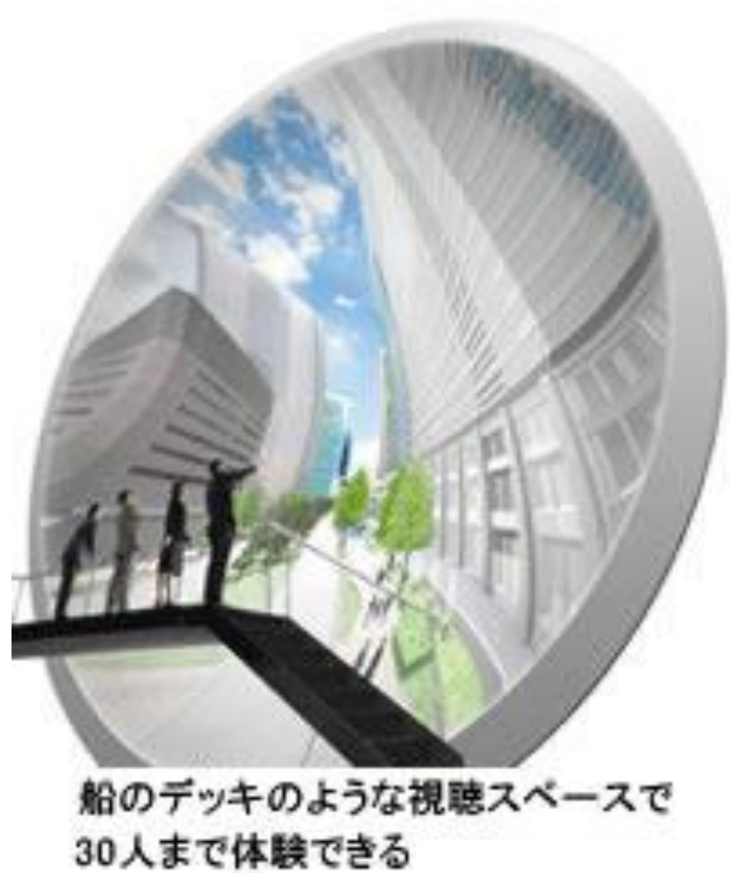
Industry
- München, BMW (4)
- Sindelfingen, DaimlerChrysler (5)
- Ulm, DaimlerChrysler (4)
- Wolfsburg, VW (3)

University
- Aachen RWTH, RZ (5)
- Bielefeld Univ. AG KI (3)
- Chemnitz, TU (5)
- Stuttgart Univ., HLRZ (4)

Curved Displays



Virtual Rolling Mill on a „TANORAMA“
(IBF, SMS Demag and RWTH IT Center, 1999)



Visual Dome (Matsushita Inc.)

Barco Dome Projection (2016)

Curved Displays

360 degrees immersive dome setup for flight training (Barco N.V.), 2013

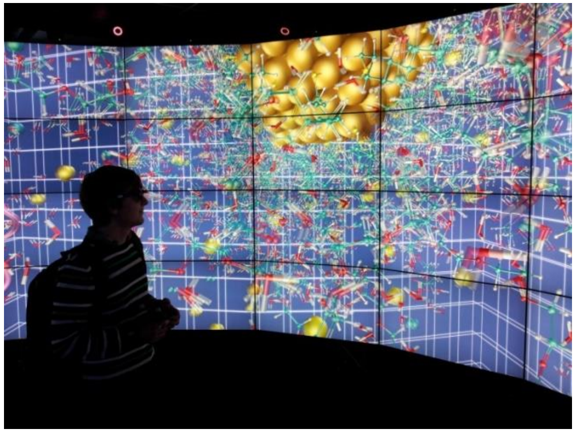
LCD-based Tiled Display @ EVL, Univ. Chicago

The Reality Deck @ Stony Brook University, 2013

- Mono Display (4 walls, no floor)
- 1 GPU renders 6 tiles

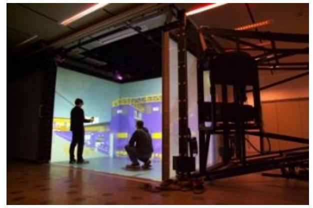
The CAVE2 @ UVL, University of Chicago, 2013

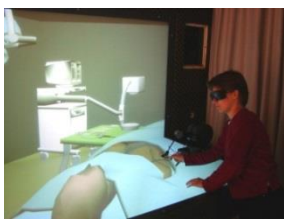


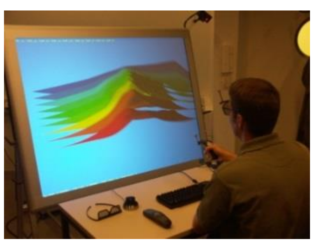


- Diameter: 24 feet
- Height: 8 feet
- Resolution: 72 LCD panels, 37 Megapixel
- Stereo technology: passive (polarization)

The Display Pyramid







CAVE

Wall

Bench

Office VR

Monitor

IT Center
JSC, FZ Jülich
MMI

IT Center
AICES
Informatik8

IT Center
WZL
AIA

IT Center
JSC, FZ Jülich
AICES
Informatik8
Geophysik
INM, FZ Jülich
IEM

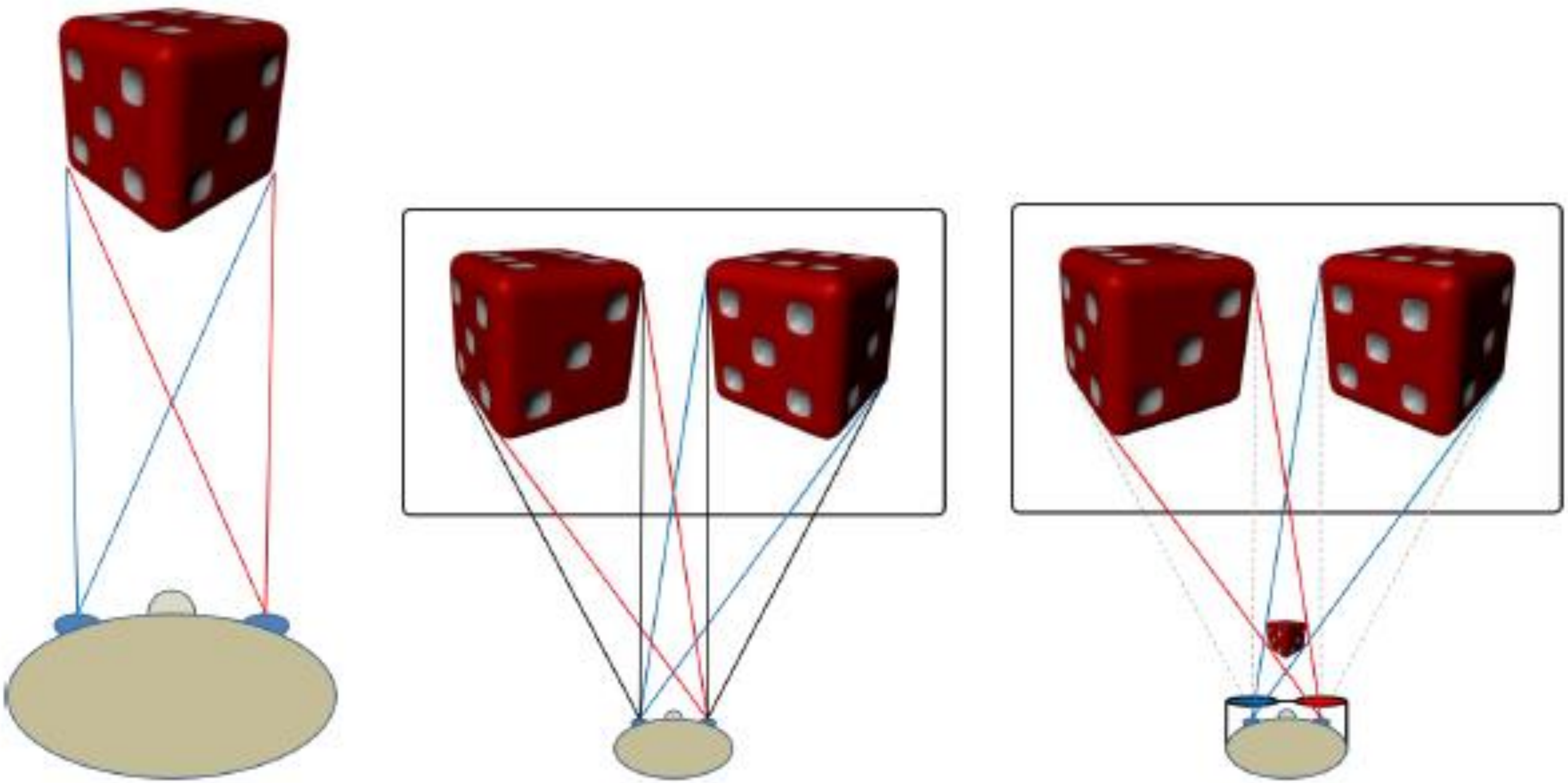
Aspects of Vision

- Human Factors
  - Anatomy of the Human Eye
  - Perception: Depth Cues in Vision, Photometry
- Technology
  - Graphics Hardware
  - Head-Mounted Displays
  - Room-Mounted Displays Stereo Techniques, Projectors, Screens, Brightness, …
- Algorithms
  - Geometrical Modeling
  - Rendering
    - Rendering Pipeline
    - Stereoscopic Projections
    - Viewer-Centered Projection
  - Global Illumination: Ray Tracing, Radiosity

Room-Mounted Displays

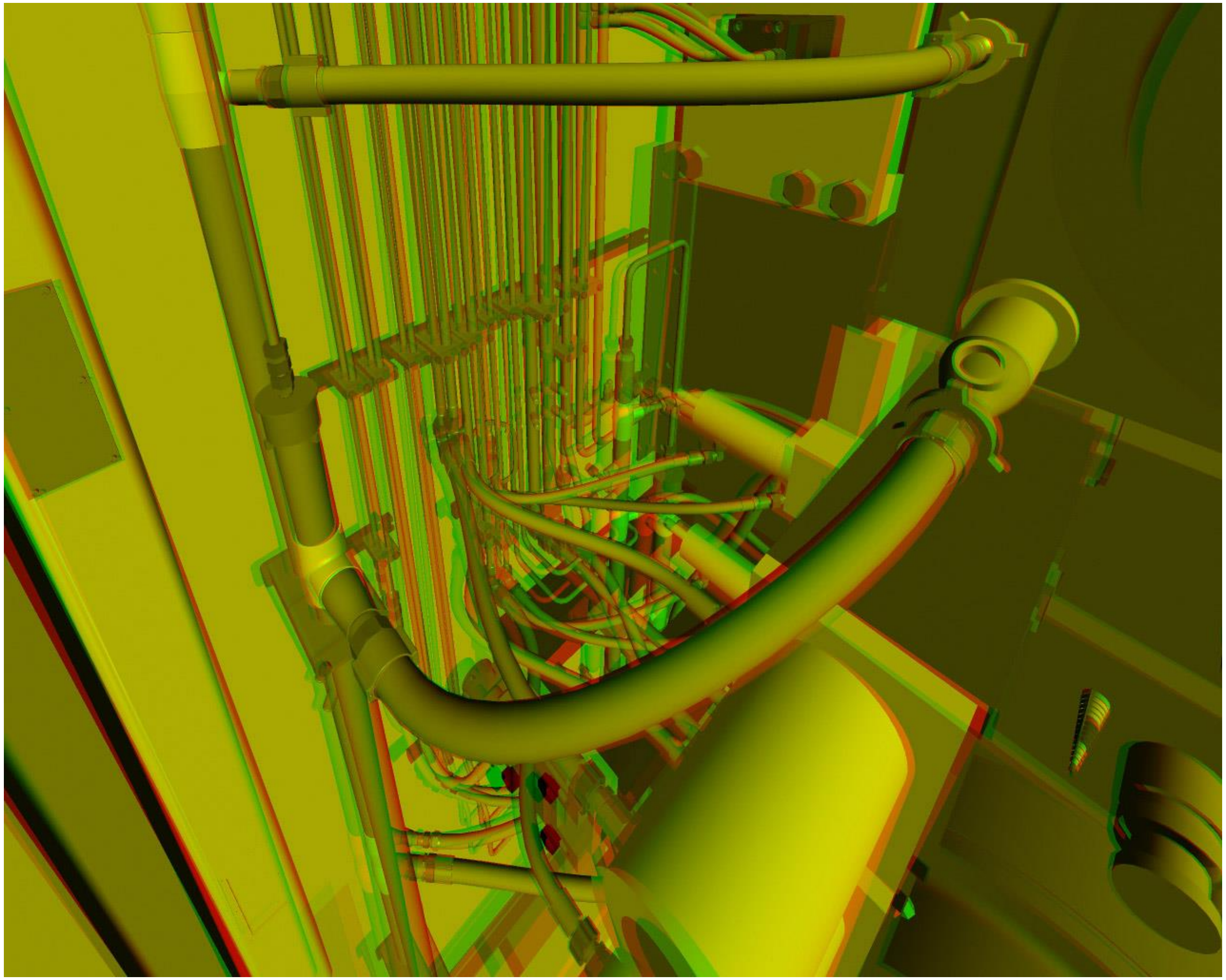
➢ **Stereo Techniques**

Stereo Parallax on Room-Mounted Displays



Tom Vaughan,
www.cyberlink.com

Stereo Glasses: Anaglyph Stereo

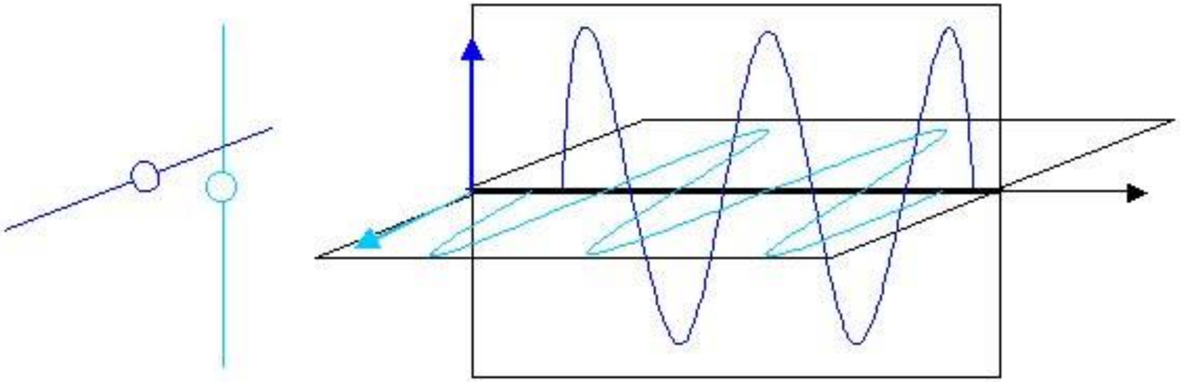


Stereo Projection – A New Technology!?

Movie theatre in Los Angeles, September 27, 1922

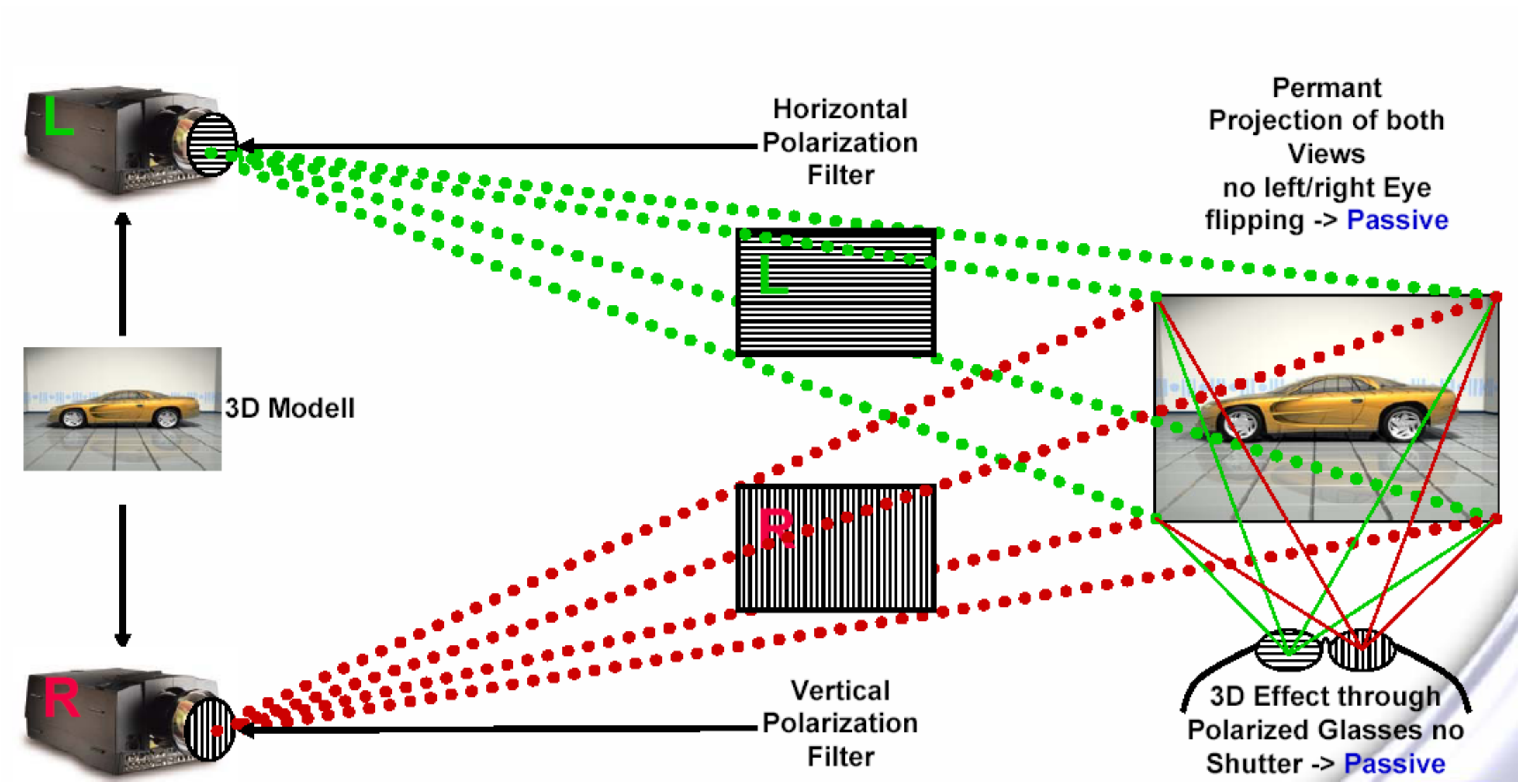
Stereo Glasses: Polarization ("Passive Stereo")

- Linear or circular polarization



Stereo Glasses: Polarization (cont.)

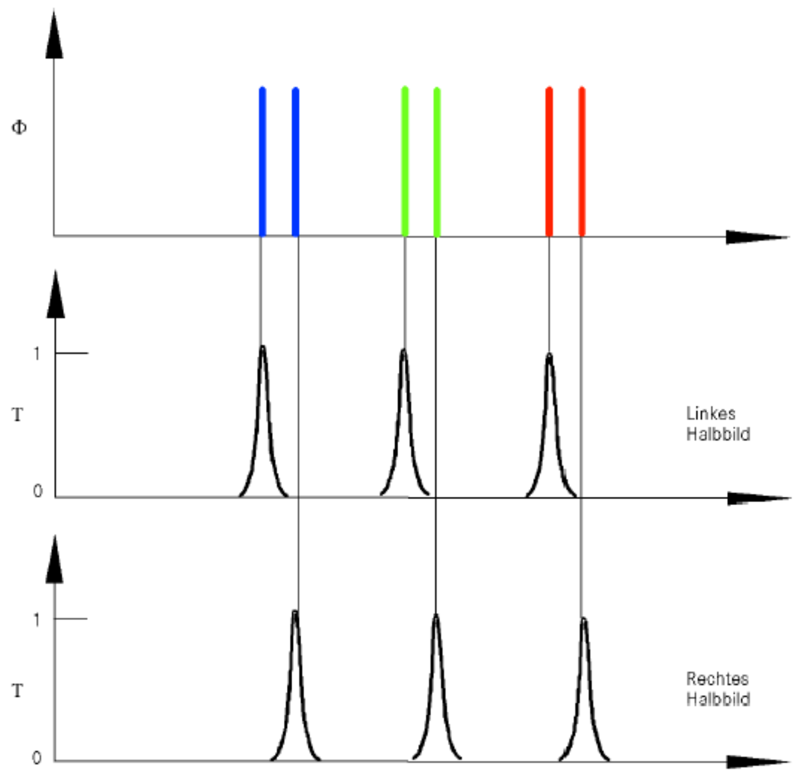
Picture: NVIDIA Corp.



Stereo Glasses: INFITEC

The INFITEC or Wavelength Multiplex Technology (WMT) is based on the fact that the visible light spectrum can be divided into different wavelength ranges using steep-edged optical filters. Some of these wavelength ranges are presented to the left eye, the others to the right eye. By an appropriate design of the transmission spectra of the filters it can be ensured that both eyes are reached by wavelengths in the red, green, and blue range of the visible light, so both eyes will see a fully colored image.[1] Such multi-bandpass optical filters can currently be made only as so called interference filters. The WMT requires filters for the glasses as well as for the projector

Developed by DaimlerChrysler



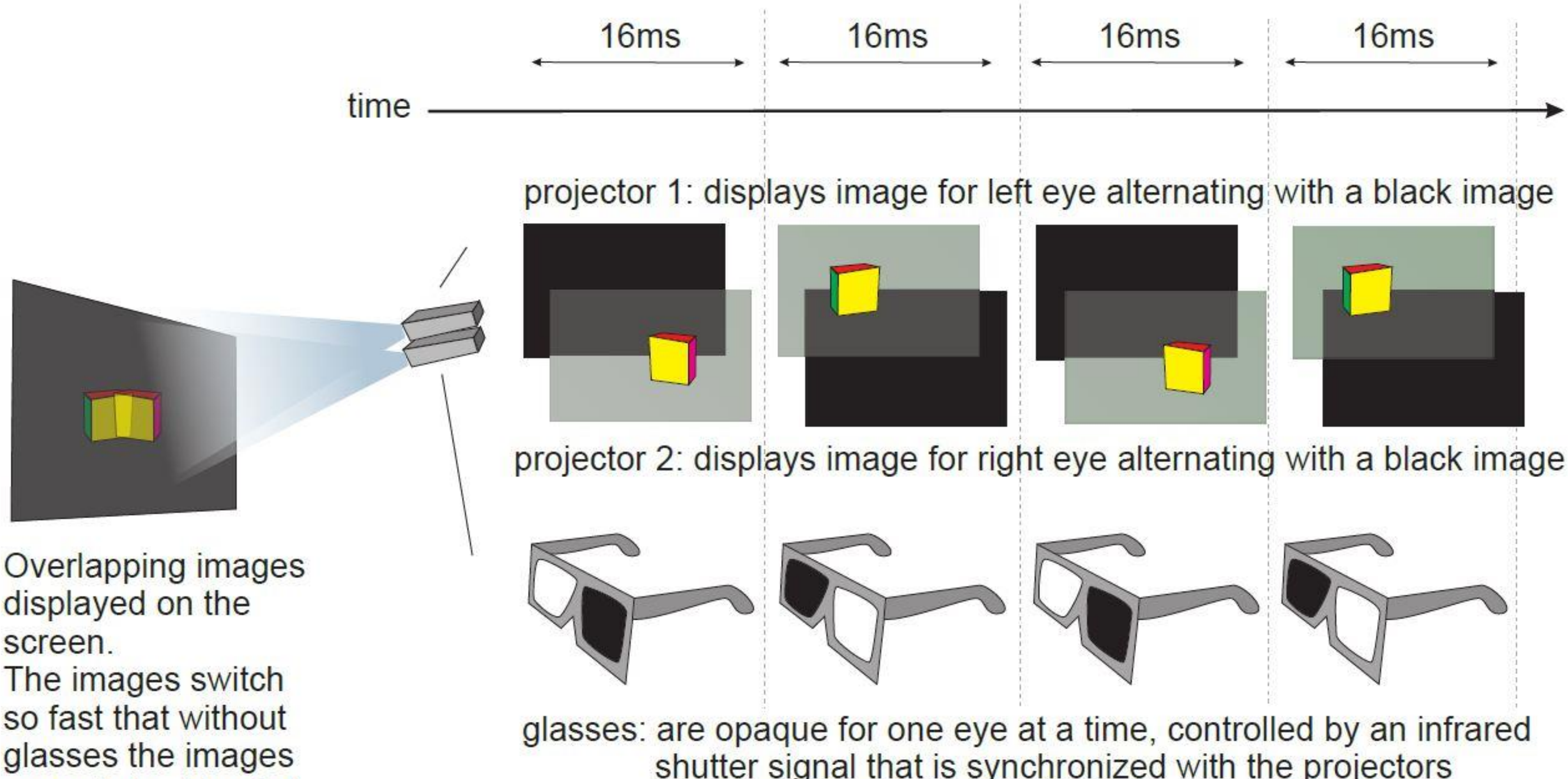
Stereo Glasses: Shutter ("Active Stereo")

- Time Multiplex

Infrared Stereo Emitter:
Synchronization of glasses and graphics hardware

Shutter Glasses with markers for opto-electronical tracking

Stereo Glasses: Shutter ("Active Stereo")



Overlapping images displayed on the screen.
The images switch so fast that without glasses the images seem to be blended.

VR Exercise – please discuss the pros and cons of stereo techniques

Shutter

Advantages:

- Protection - Interior shutters protect against sun and heat in summer and wind and cold in winter. Exterior shutters eliminate the need to install plywood over windows before a storm. They also protect windows from flying debris and high winds, especially in hurricane prone areas.
- Privacy - Shutters allow you to easily choose between privacy and visibility. When closed, you can still adjust the rod to allow light to enter.
- Easy customization - Ready-made shutters come in many sizes. Most of the time, finding the correct size for your windows isn't a problem. If it is, choose a pair slightly larger than your measurements and trim them with a table, miter, or radial arm saw for quick customization.

VR Exercise – please discuss the pros and cons of stereo techniques

- ~~Light control- Window shutters with louvers can be adjusted to allow varying amounts of sunlight to enter between the slats.~~ ✓
- ~~Security - Window shutters come with a latch or lock to keep them from flying open. This feature also provides additional security by adding a second “lock” to the windows.~~
- ~~Neat appearance - Wood shutters fold open neatly to expose the entire width of the window and close to display the details of the shutter.~~

~~Disadvantages:~~

- ~~Reduced visibility - Shutters must be wide open to enjoy the view. When closed, they can be adjusted to allow light to enter, but the slats will still be in the way.~~
- ~~Awkward - Interior shutters swing in, so furniture can get in the way when opening them.~~

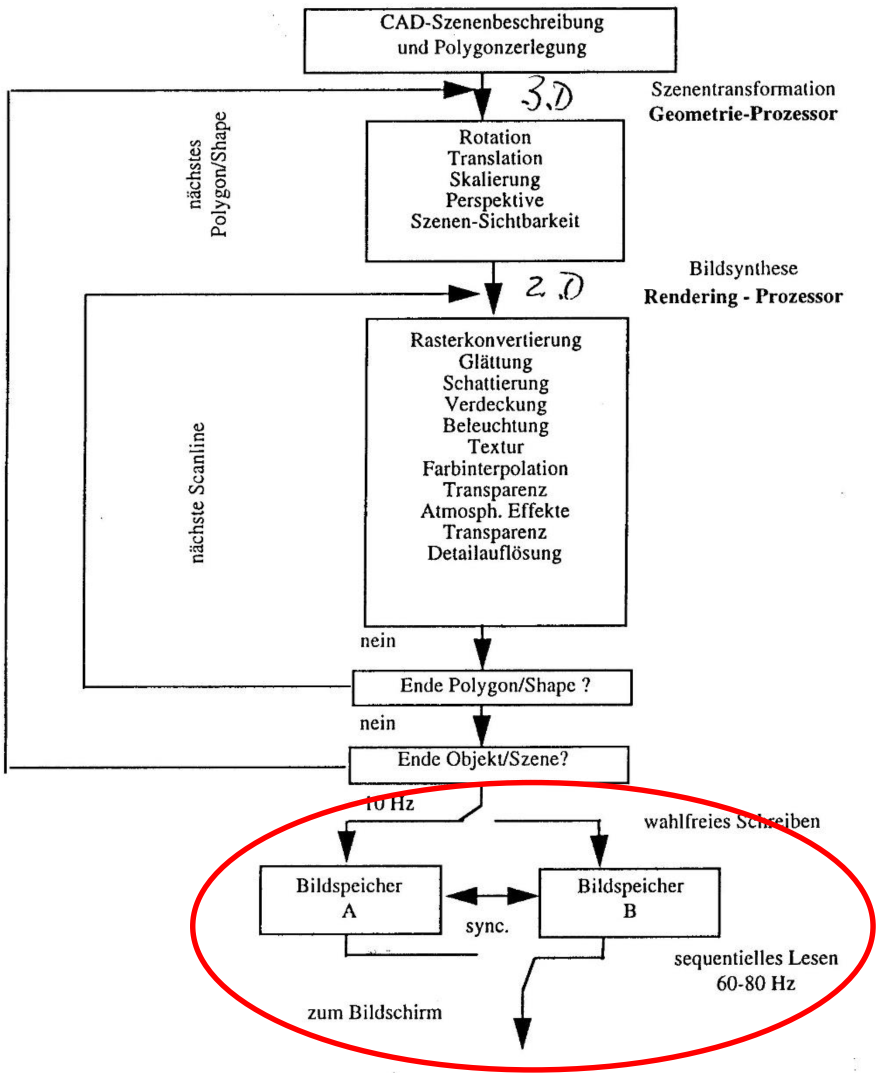
Aspects of Stereo Technologies

- Image quality
  - Color
  - Field of View
  - Ghosting
  - (Loss of) brightness
- Ergonomics
- Intrusiveness
- Costs
  - Glasses
  - Type & number of projectors
- Synchronization requirements
  - Between left & right eye
  - Across multiple screens / GPUs
- Need for batteries
- Screen Material
  - Brightness uniformity
  - Screen gain
    (see later in this chapter)

Passive Stereo versus Active Stereo

- **Passive stereo (polarization, INFITEC)**
  - 2 projectors for left and right eye, respectively
  - Swap buffer locking of multiple graphics hardware
  - Screen material may not destroy polarization →Brightness uniformity -
  - Color fidelity: polarization +, INFITEC –
  - Glasses +
- **Active stereo (shutter)**
  - 1 active stereo projector or 2 projectors with external shutters
  - Needs tight synchronization: Gen locking
  - Screen material may be diffuse → Brightness uniformity +
  - Color fidelity +
  - Glasses –
- **All technologies absorb light!**

Another Perspective of the Rendering Pipeline



Ghosting

- A (faded) version of the image for the left / right eye is perceived by the right / left eye
- By design, does not show up in HMDs (two separate screens)

- Polarization
  - with diffuse screens: -
  - With high screen gain: o
- Shutter: +
- INFITEC: ++

Passive Stereo versus Active Stereo

- **Passive stereo (polarization, INFITEC)**
  - 2 projectors for left and right eye, respectively
  - Swap (and Frame) locking of multiple graphics hardware
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- **Active stereo (shutter)**
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  - Color fidelity +
  - Glasses –
- **All technologies absorb light!**

Shutter Technology without Glasses

http://www.jonathanpost.com/3dNoGlasses

Shutter Technology without Glasses – Making Of

http://www.jonathanpost.com/3dNoGlasses

Course on Virtual Reality

Vision

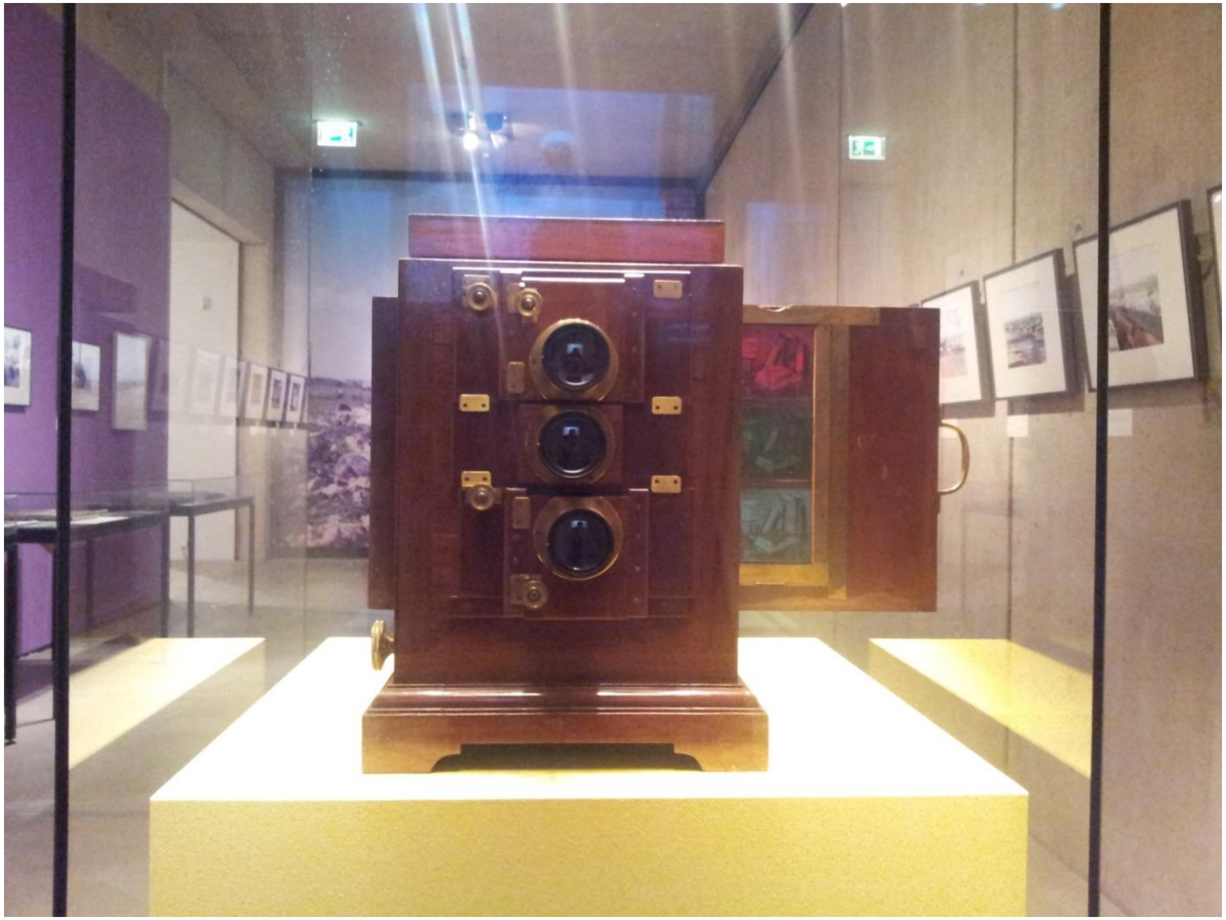
Aspects of Vision

- Human Factors
  - Anatomy of the Human Eye ✓
  - Perception: Depth Cues in Vision, ✓ Photometry
- Technology
  - Graphics Hardware
  - Head-Mounted Displays ✓
  - Room-Mounted Displays: Stereo Techniques ✓ Projectors, Screens, Brightness, …
- Algorithms
  - Geometrical Modeling
  - Rendering
    - Rendering Pipeline ✓
    - Stereo Projections ✓
    - Viewer-Centered Projection ✓
  - Global Illumination: Ray Tracing, Radiosity

Room-Mounted Displays

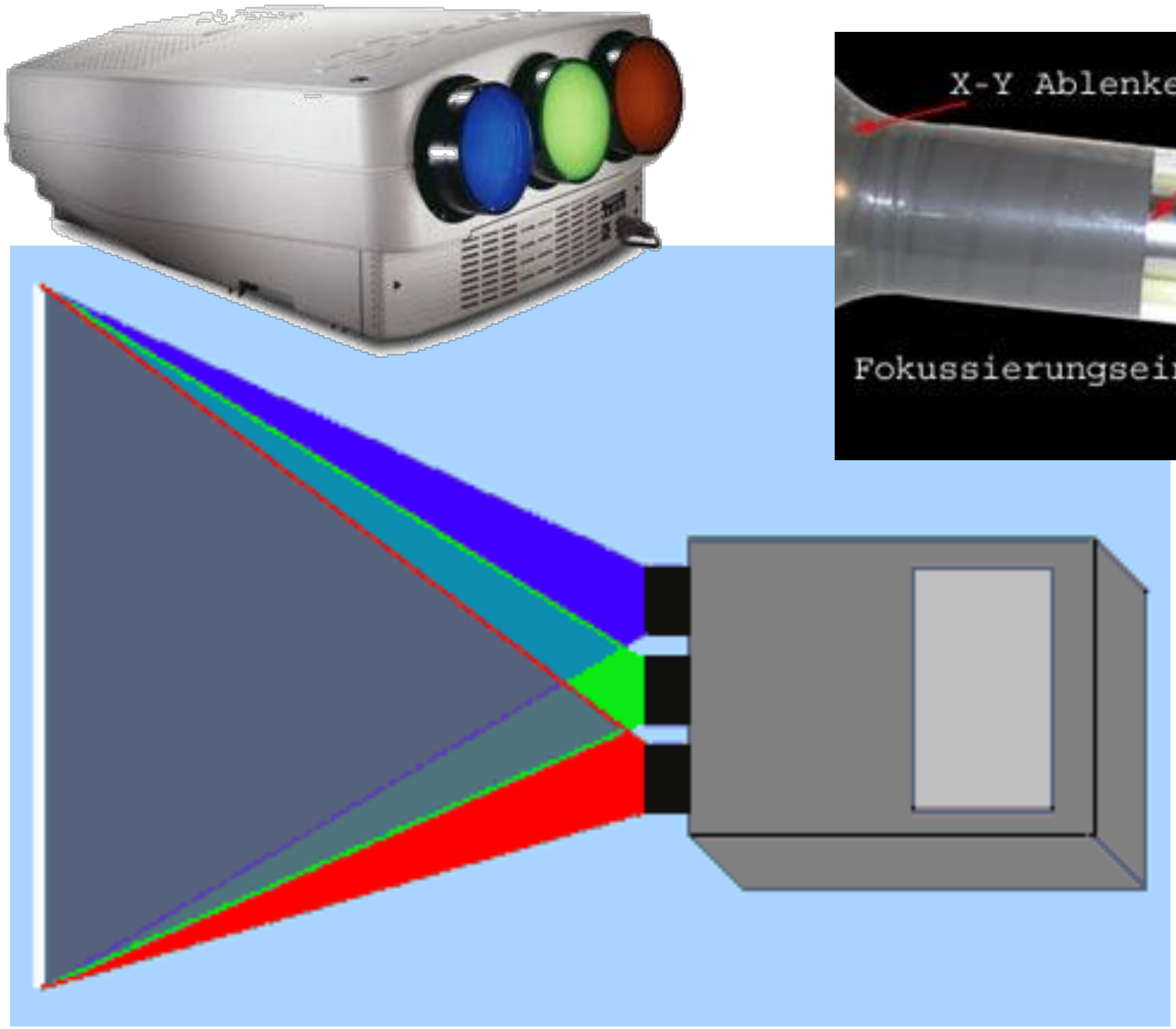
➢ **Projector Technology**

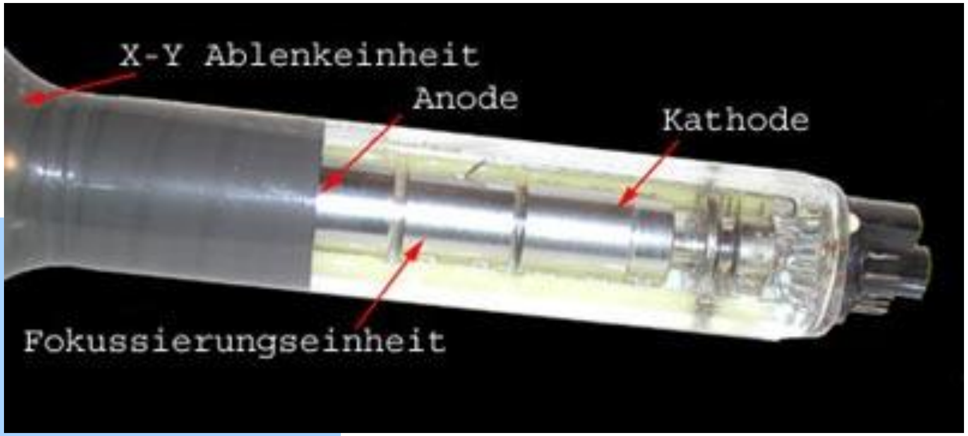
Portable 3-Colors Projector from Adolf Miethe, about 1900

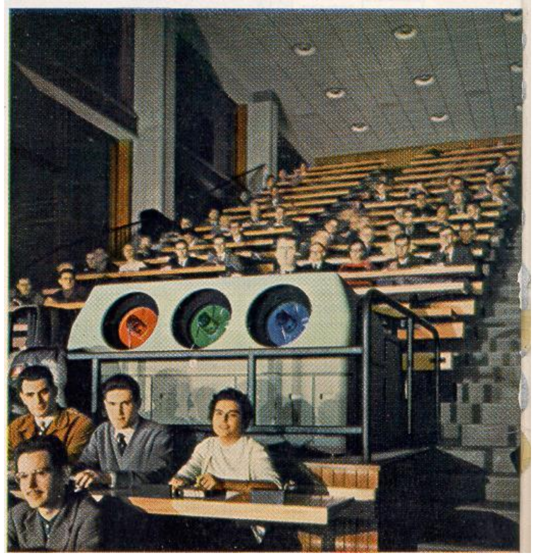


Deutsches Museum von Meisterwerken der Naturwissenschaft und Technik, München
Picture taken at LVR-LandesMuseum Bonn, 2013

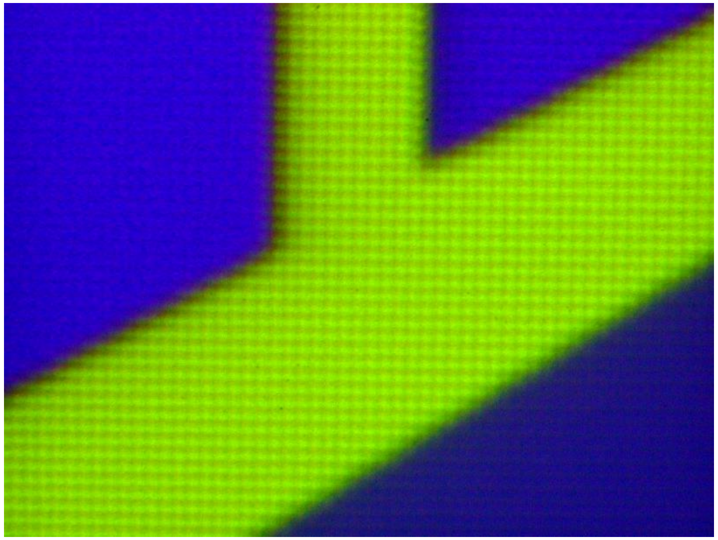
CRT Projectors



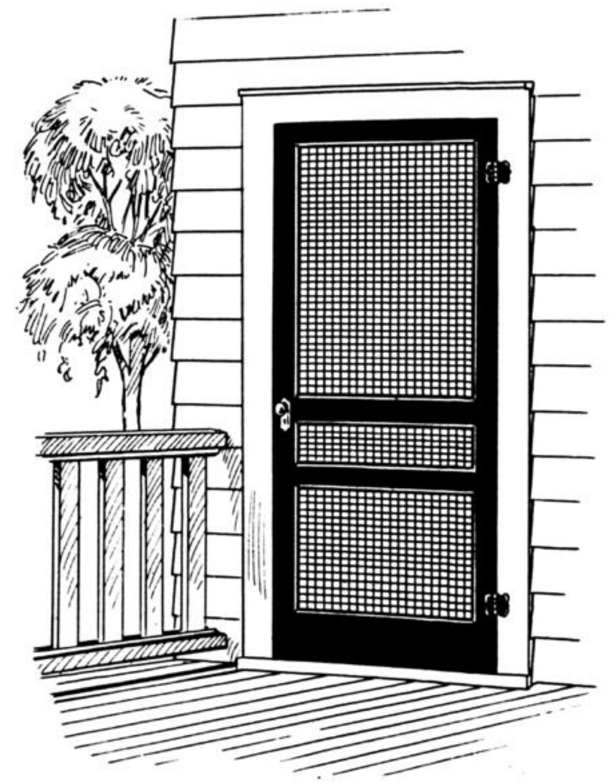




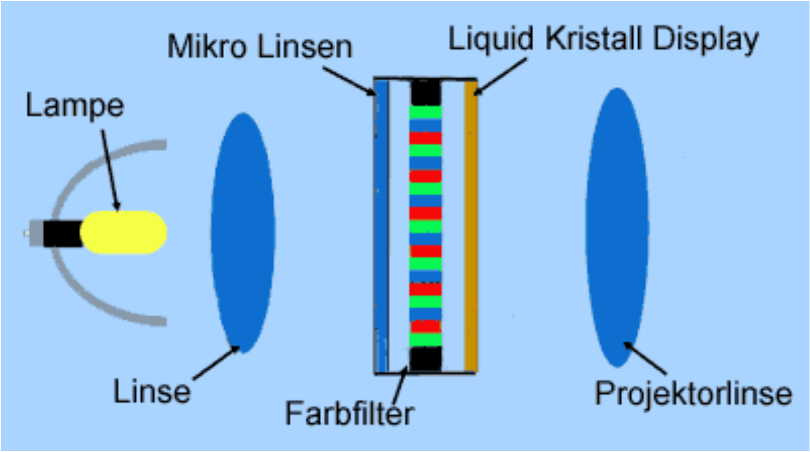
“Analog“ versus „Digital“ Projectors

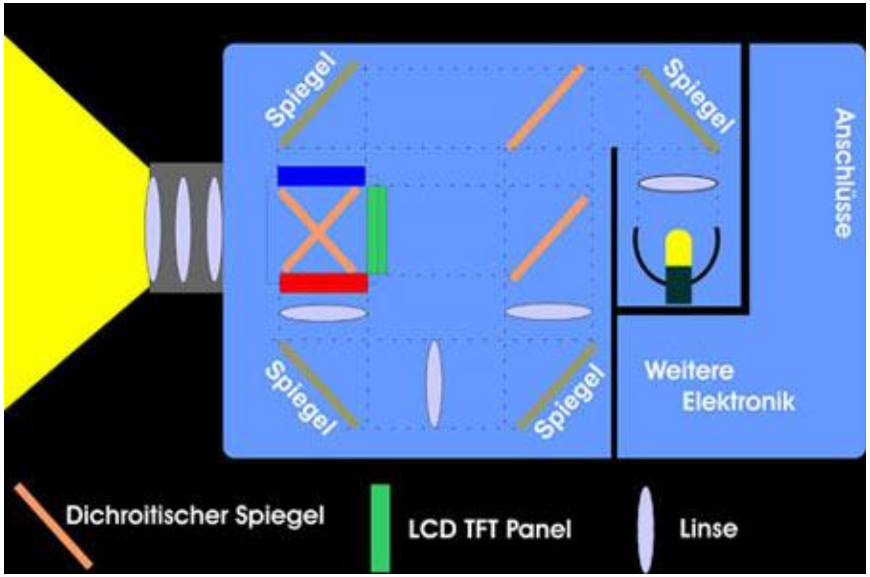
CRT		DLP/LCD
		
--	Brightness & Contrast	+
+	Adjustment	o
+	Image „naturalness“	-
-	Costs	+

The „Screen Door Effect“ in Digital Projectors

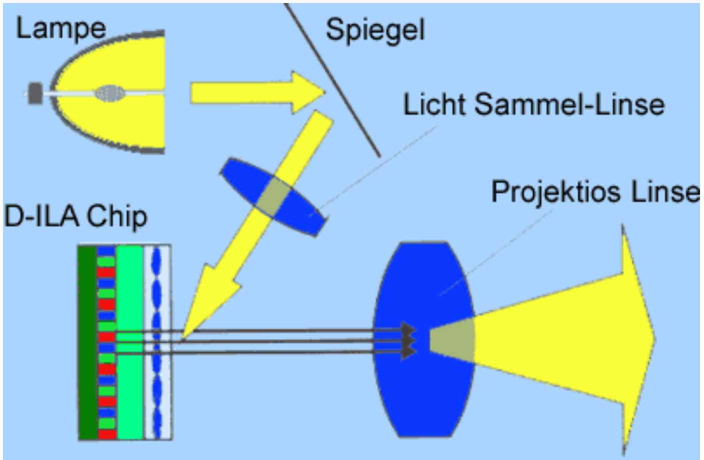


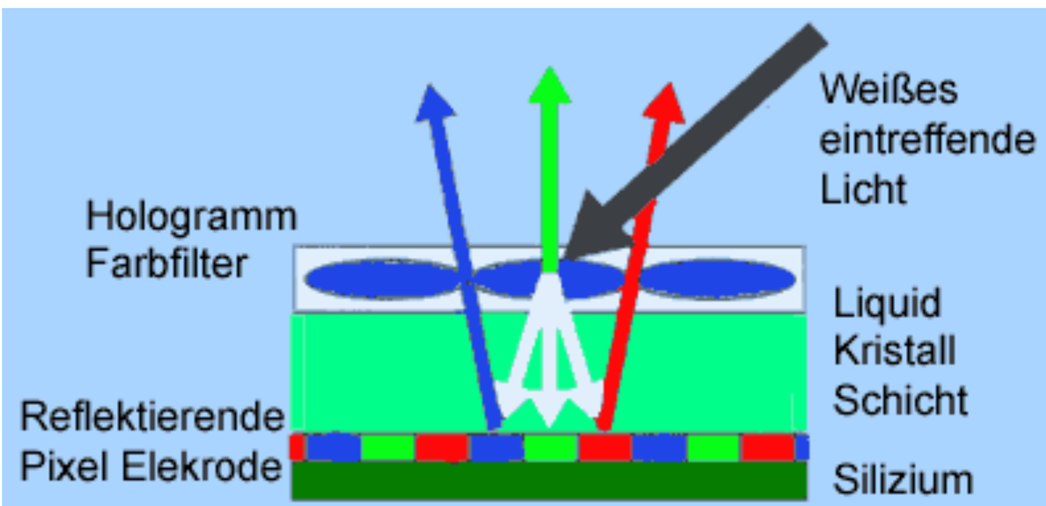
LCD (Liquid Crystal Display) Projectors

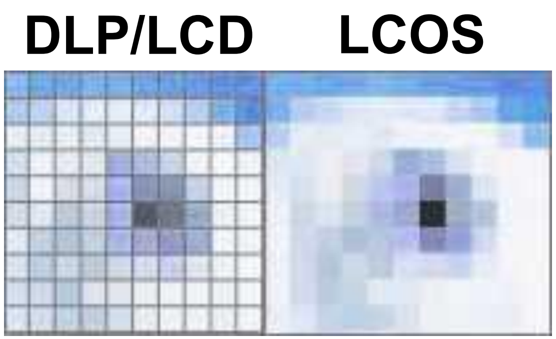




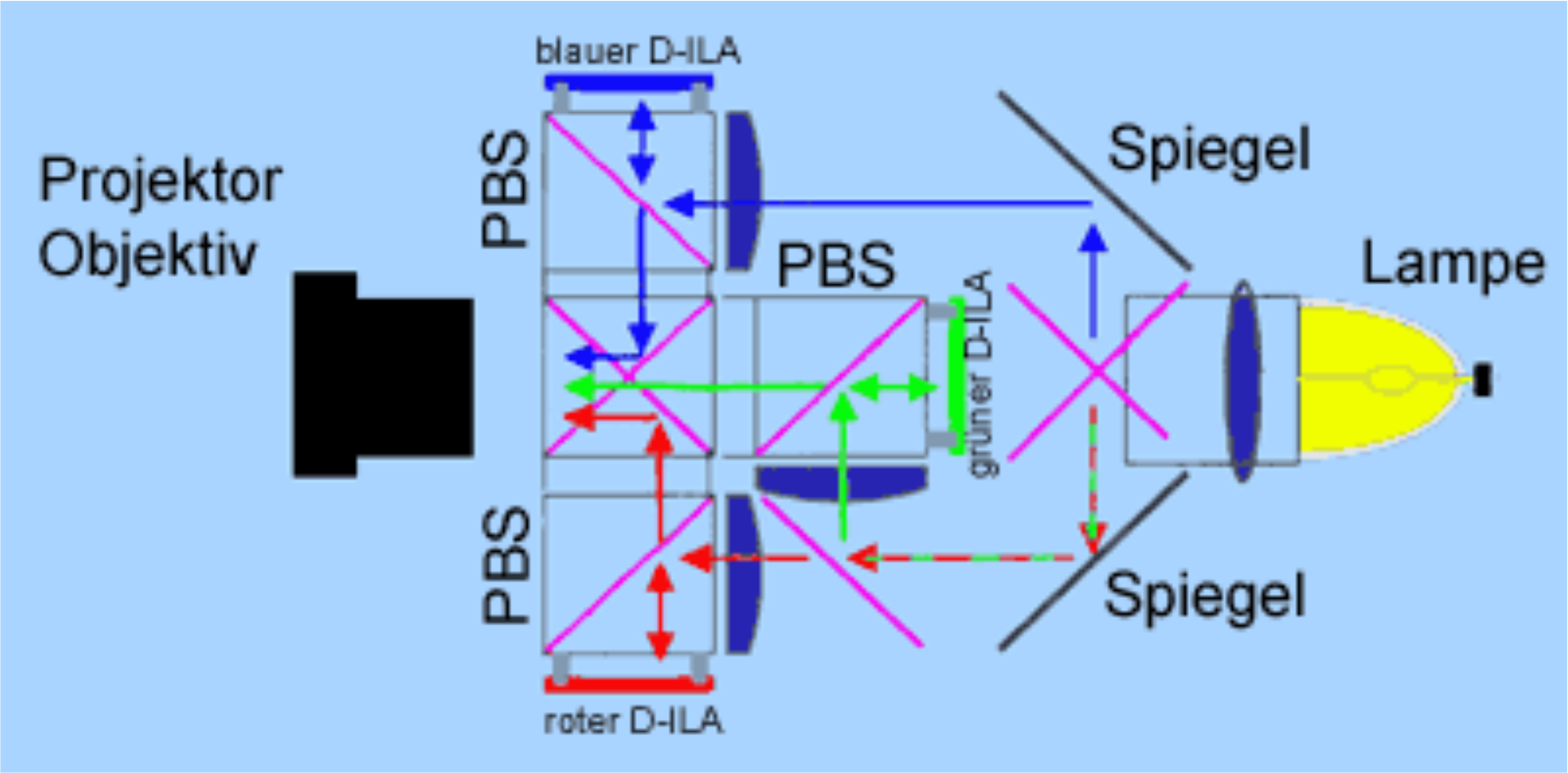
LCOS Projectors („Liquid Crystal on Silicon“)



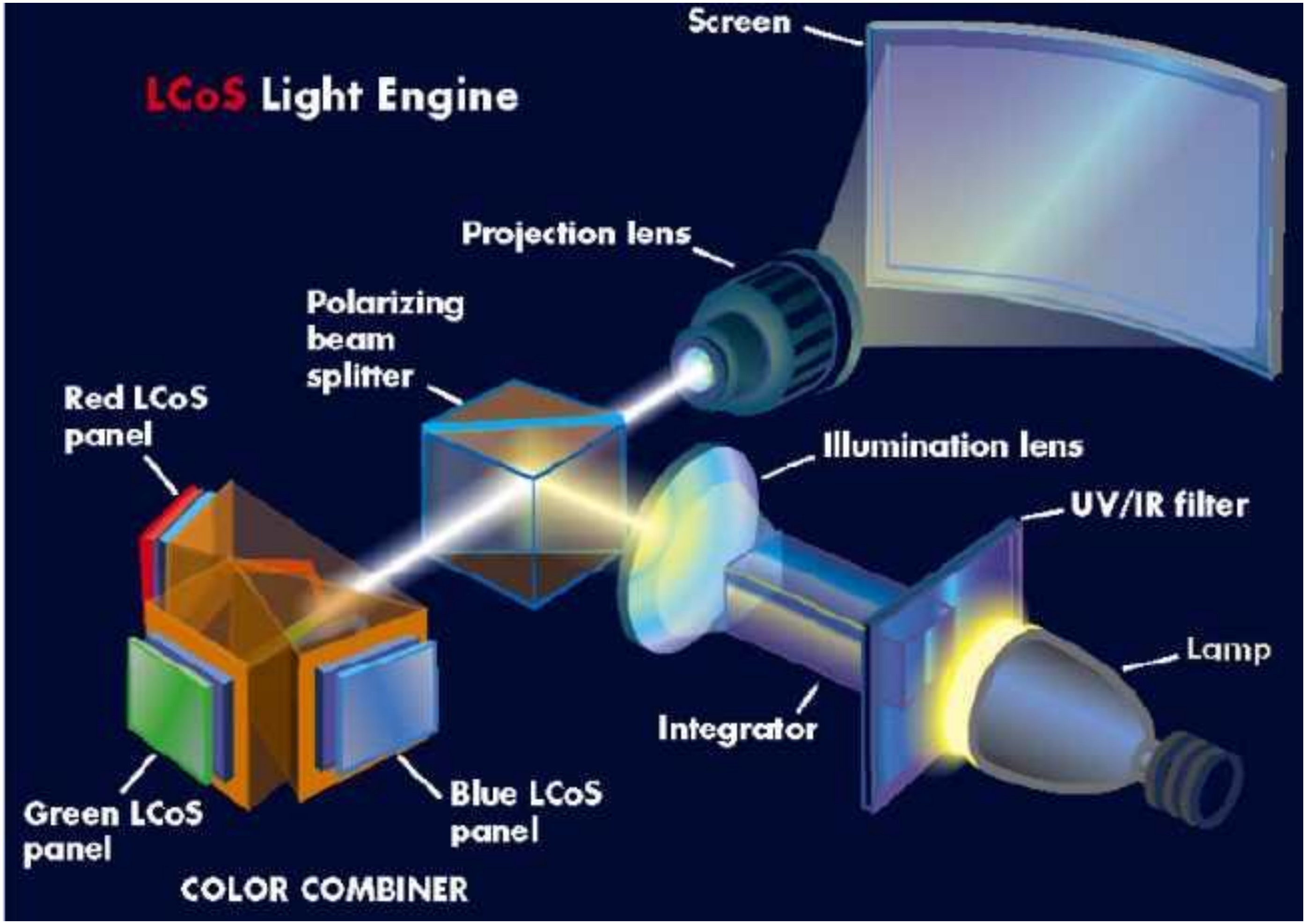




LCOS (cont.)

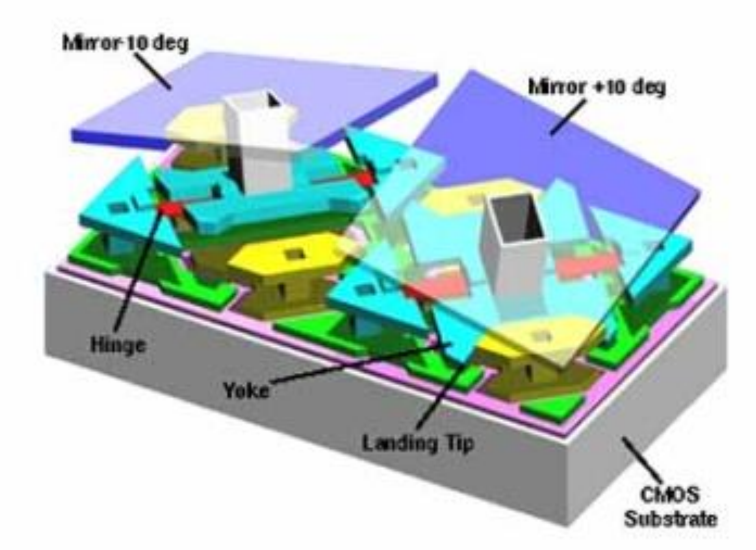

blauer D-ILA
Projektor
Objektiv
PBS
Spiegel
PBS
Lampe
grüner D-ILA
PBS
Spiegel
roter D-ILA

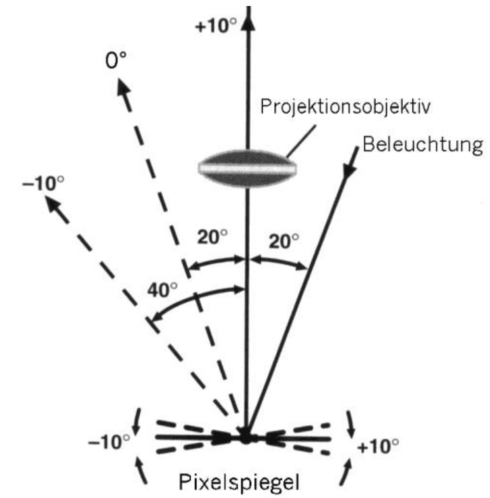
LCOS (cont.)

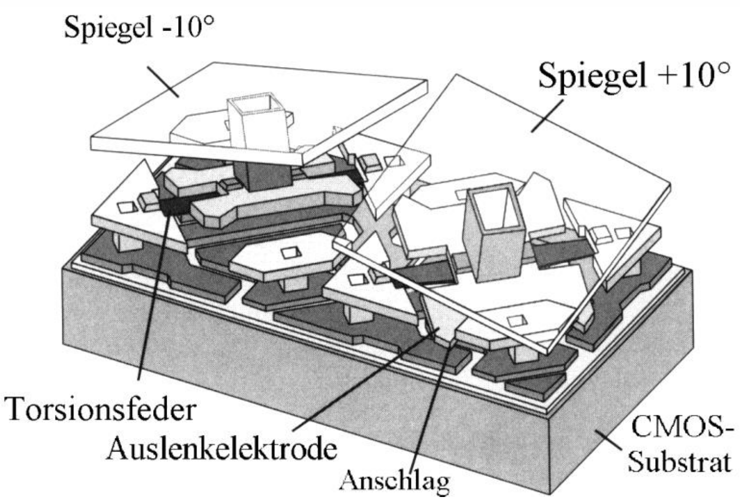


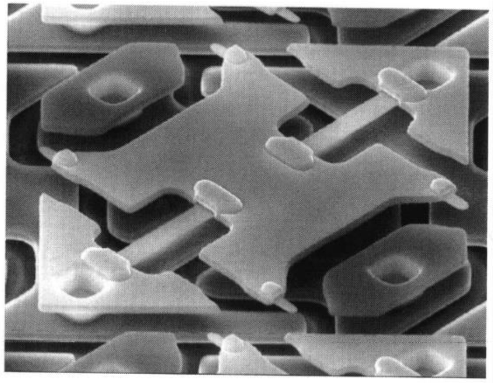
LCoS Light Engine
Screen
Projection lens
Polarizing
beam
splitter
Red LCoS
panel
Illumination lens
UV/IR filter
Lamp
Integrator
Blue LCoS
panel
Green LCoS
panel
COLOR COMBINER

DLP (Digital Light Processing) Projectors

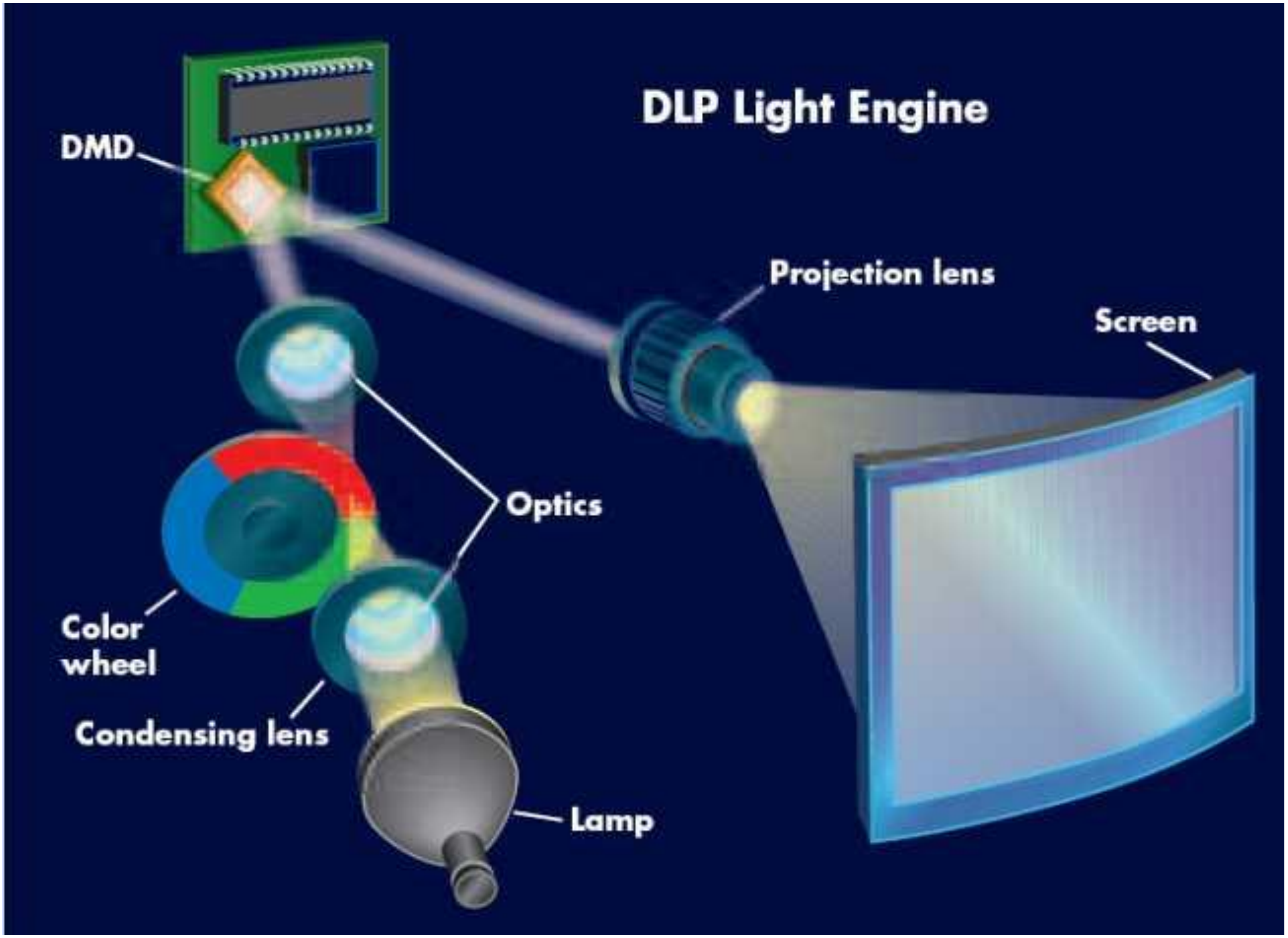




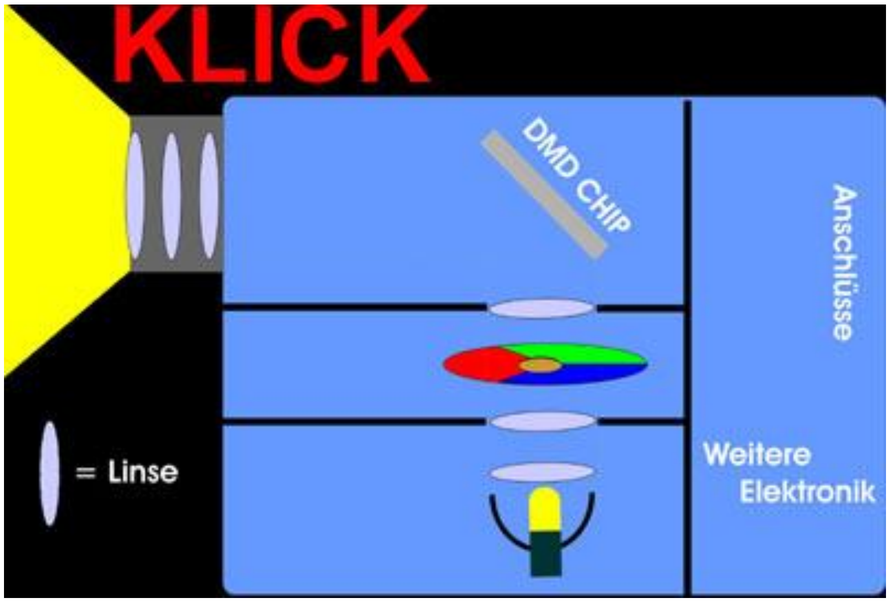


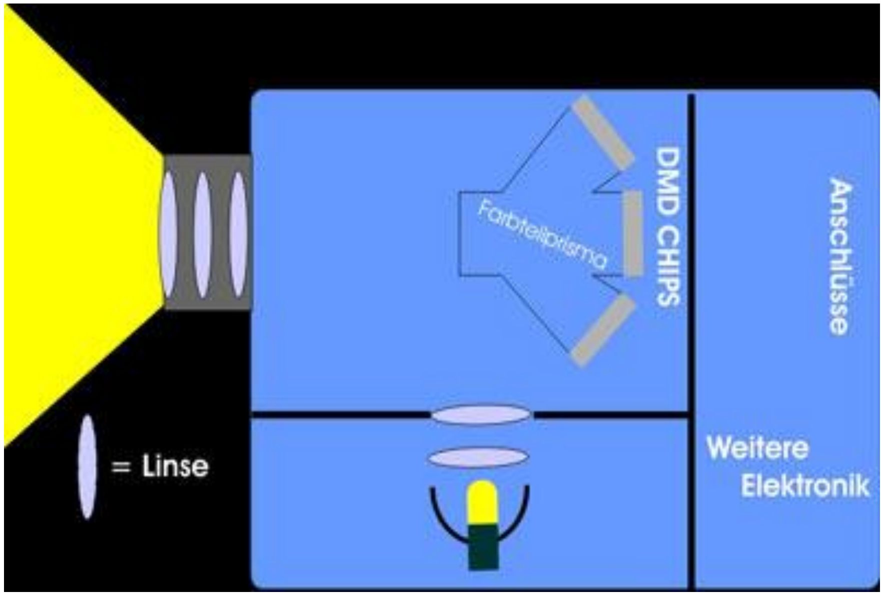


Single-Chip DLP Projectors



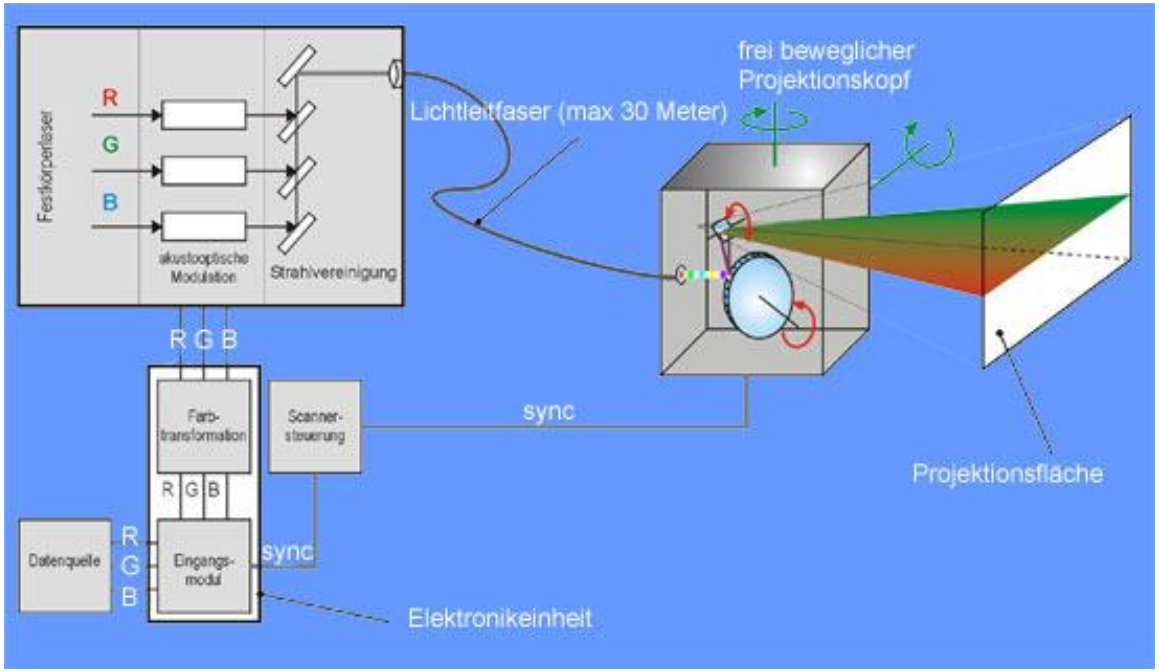
DLP Projectors (cont.)





Laser Projectors

- Much larger range of colors (richer color spectrum)
- Extremely high brightness
- Extremely high brightness uniformity
- Always in focus



The „Elbedom“ at Fraunhofer IFF Magdeburg, 2009

- Laser projectors: LDT Laser Display Technology GmbH
- Screen: Diameter 11 m, height 6 m
- Monoscopic projection

Barco 4K Laser Projector

- Launched in 2015
- 4K resolution, 60.000 ANSI Lumen
- Built-in stereo (similar to INFITEC)
- Designed for movie theatres in the first place
  → Laser PowerWalls installed in the automotive industry

Aspects of Vision

- Human Factors
  - Anatomy of the Human Eye ✓
  - Perception: Depth Cues in Vision, ✓ Photometry
- Technology
  - Graphics Hardware ✓
  - Head-Mounted Displays ✓
  - Room-Mounted Displays: Stereo Techniques, Projectors ✓ Screens, Brightness, …
- Algorithms
  - Geometrical Modeling
  - Rendering
    - Rendering Pipeline ✓
    - Stereo Projections ✓
    - Viewer-Centered Projection ✓
  - Global Illumination: Ray Tracing, Radiosity

Human factors: Photometry in a Nutshell

Photometry

Measuring light is somewhat complicated:

- Light propagates through 3-D space
  - Spreading out, reflection, concentration, …
- Different wavelengths
- Measured brightness versus perceived brightness
  - Different sensitivity of the human eye for different wavelengths

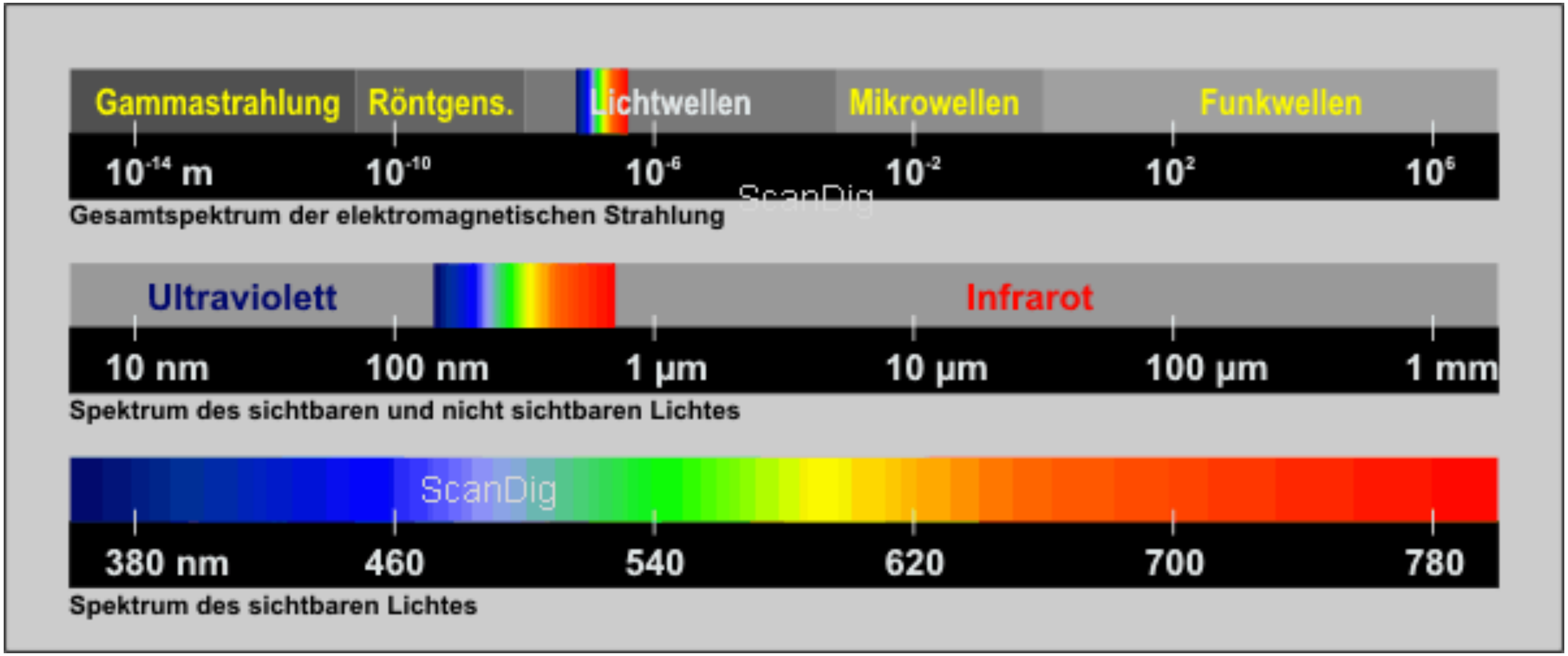
➢ Multiple methods for measuring light

➢ Multiple units (lumen, lux, candela …)

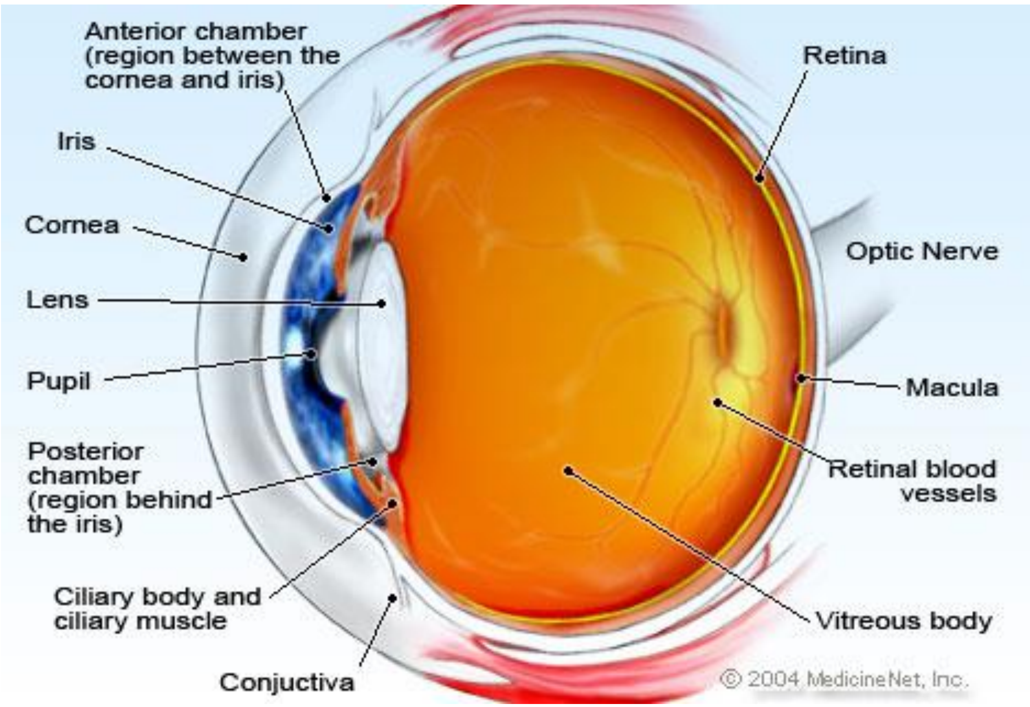
➢ Conversions exists but are somewhat dubious

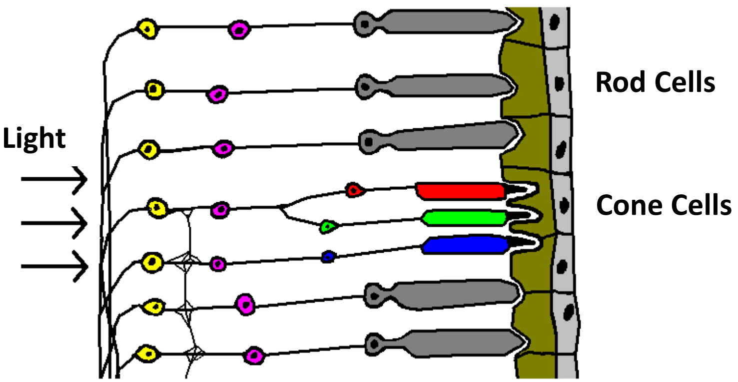
Photometry

Physics -> Optics -> Photometry: Science of measuring electromagnetic radiation in wavelengths between 380 nm and 780 nm („light”)



The Human Eye





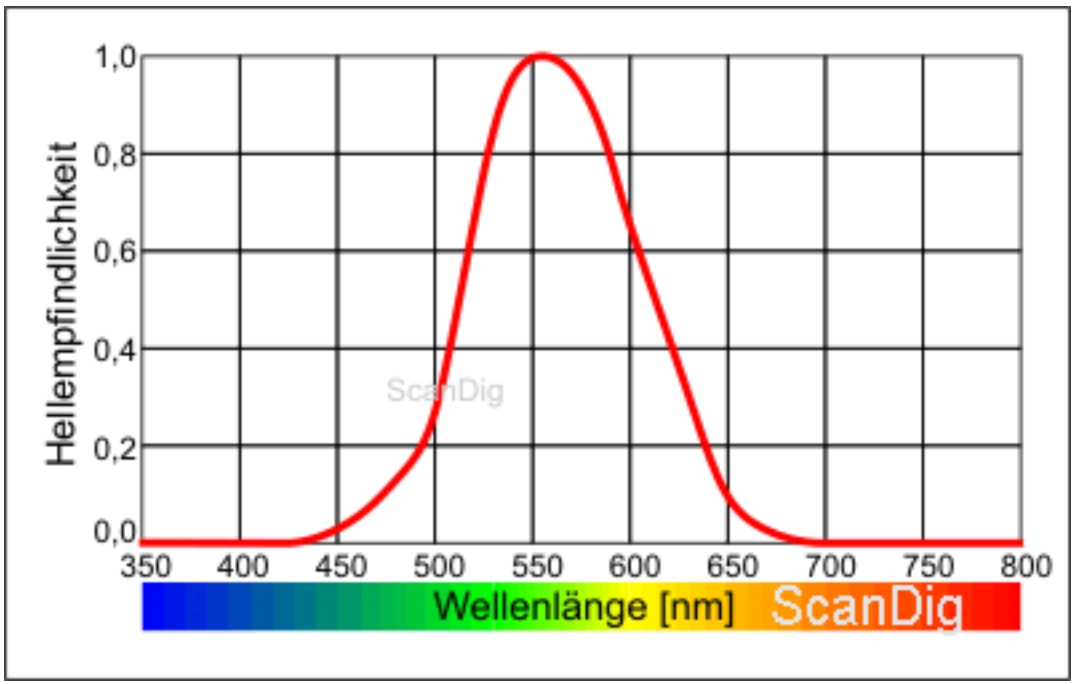
Source: WWW

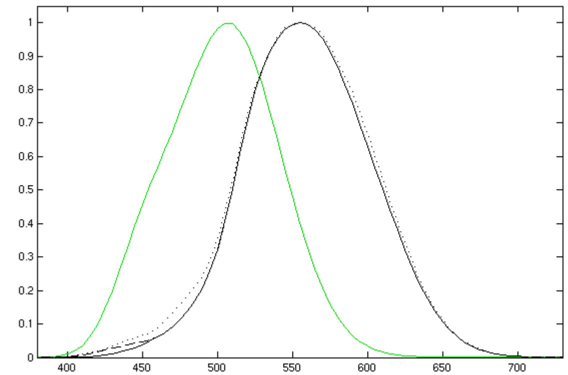
Radiometry versus Photometry

Photometric quantities are weighted with the luminosity function

Example:

Green LED and red LED have the same radiant flux (measured in Watts), but different luminous flux (measured in lumens) - 1/683 watt of 555 nanometer green light provides one lumen





Luminosity function is different for bright and dark conditions!

Patrick Wagner, www.filmscanner.info

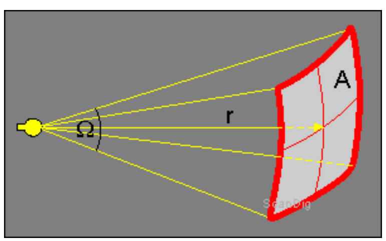
Luminosity Function: Brightness sensitivity of the human eye

Photometric Quantities and Units (cont.)

Luminous flux of a monochromatic light source: $\Phi_v = K_m \cdot \Phi_e \cdot V(\lambda)$
(K_m : max. light output, 683 lm/Watt)

Luminous flux of a polychromatic light source:

$$\Phi_v = K_m \cdot \int_{380\,nm}^{780\,nm} \Phi_{e,\lambda}(\lambda) \cdot V(\lambda) \cdot d\lambda$$

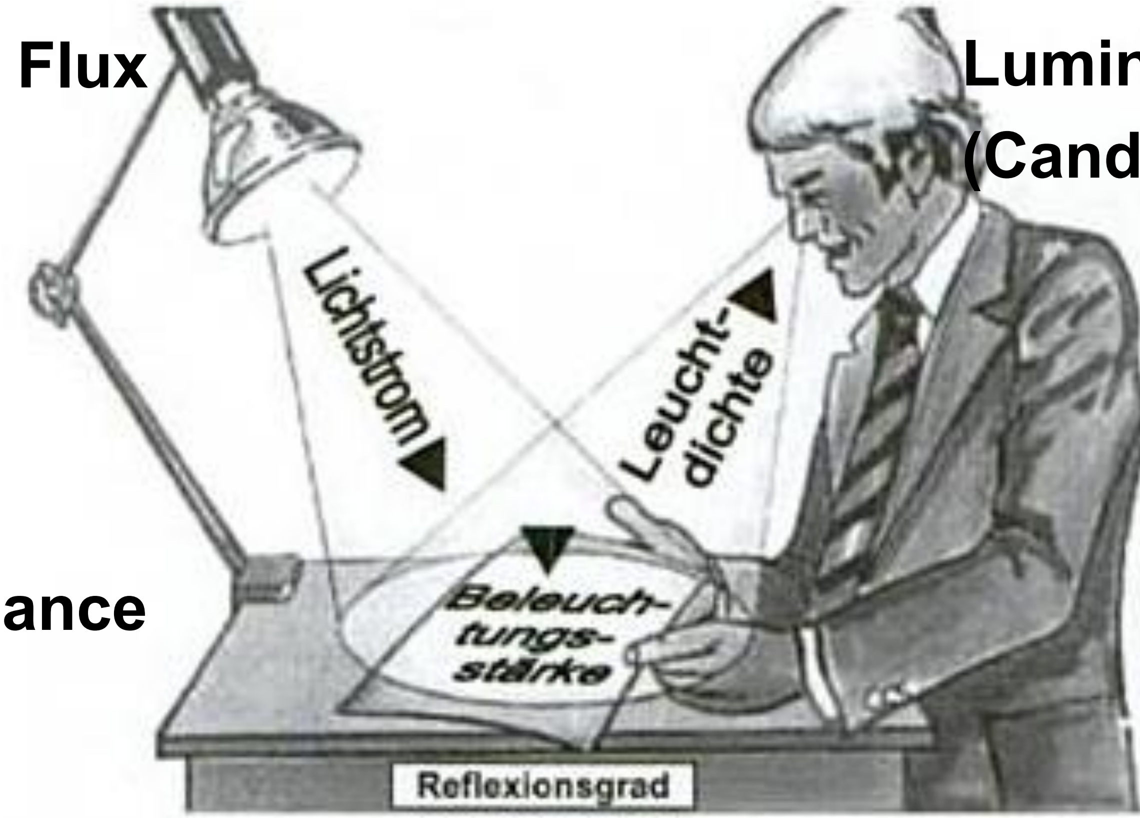


Solid angle (“Raumwinkel”) in sr (steradiant) $\Omega = \frac{A}{r^2}$

(Luminous Intensity of a candle is about 12 lm / 4 π sr = 1 cd)

Luminous Flux
(Lumen)

Luminance
(Candela/m²)



Illuminance
(Lux)

Martin Bantel: Messgeräte Praxis, Fachbuchverlag Leipzig

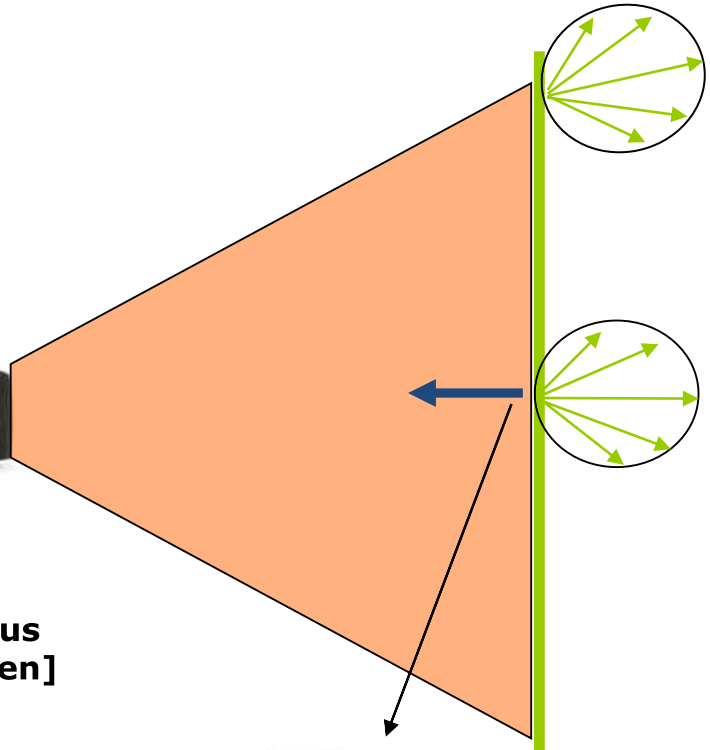
Photometric Quantities and Units

Quantity	(German)	Unit	Conv.	Notes
Luminous Energy	Lichtmenge		lm * s	
Luminous Flux	Lichtstrom („Lichtleistung“)	Lumen, lm		• Weighted with Luminosity Function
Luminous Intensity	Lichtstärke	Candela, cd	lm/sr	• Luminous flux per solid angle • Indicates the intensity of a light source into a specific direction • Independent from distance to light source
Illuminance	Beleuchtungsstärke („Helligkeit einer Oberfläche“)	Lux, lx	lm/m^2, $cd*sr/m^2$, $(cd*m^2)/(r^2*m^2)$	• Used for light incident on a surface • Decreases quadratically with distance to light source
Luminance	Leuchtdichte	„nits“	cd/m^2, $lm/(m^2\ sr)$	• Indicates the perceived brightness of a light source

Room-Mounted Displays

➢ **Screens**

Photometrical Quantities in VR Systems



Projector: luminous flux in [ANSI lumen]

Measured perception of brightness:

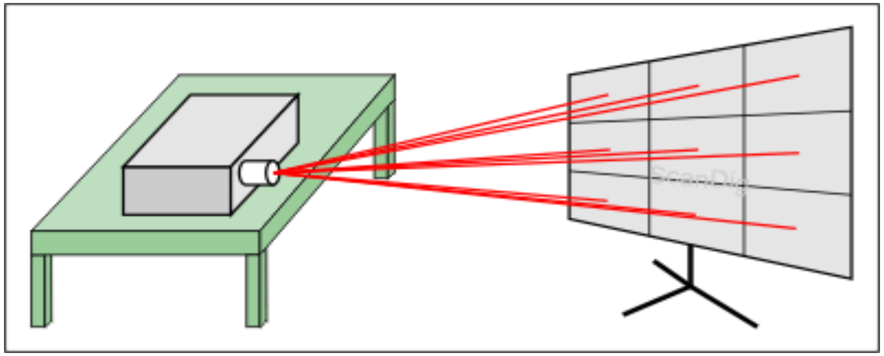
Luminance [nit or cd/m²]

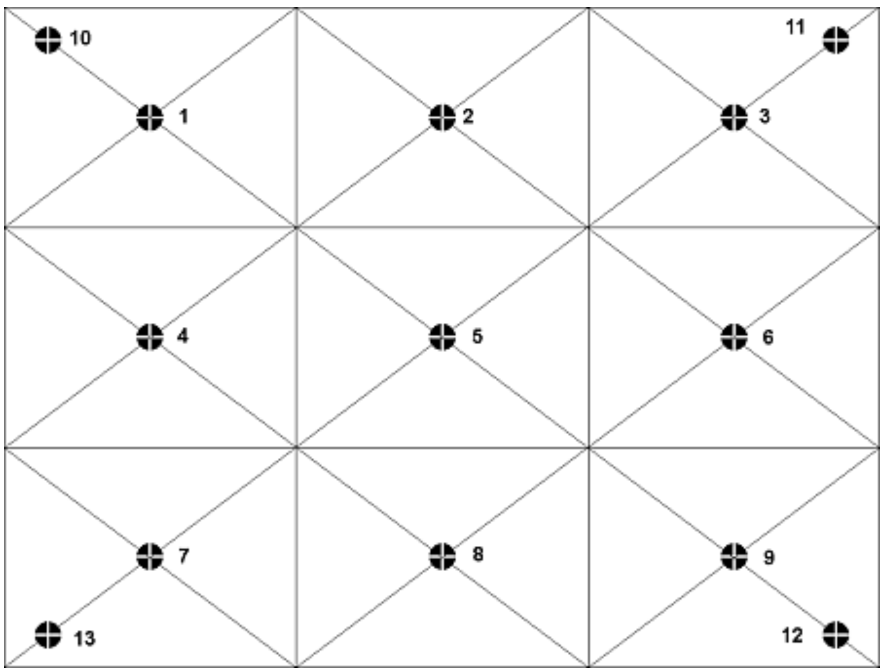
Illuminance [lux]

Incident light onto the screen

Lux= lumen/m²

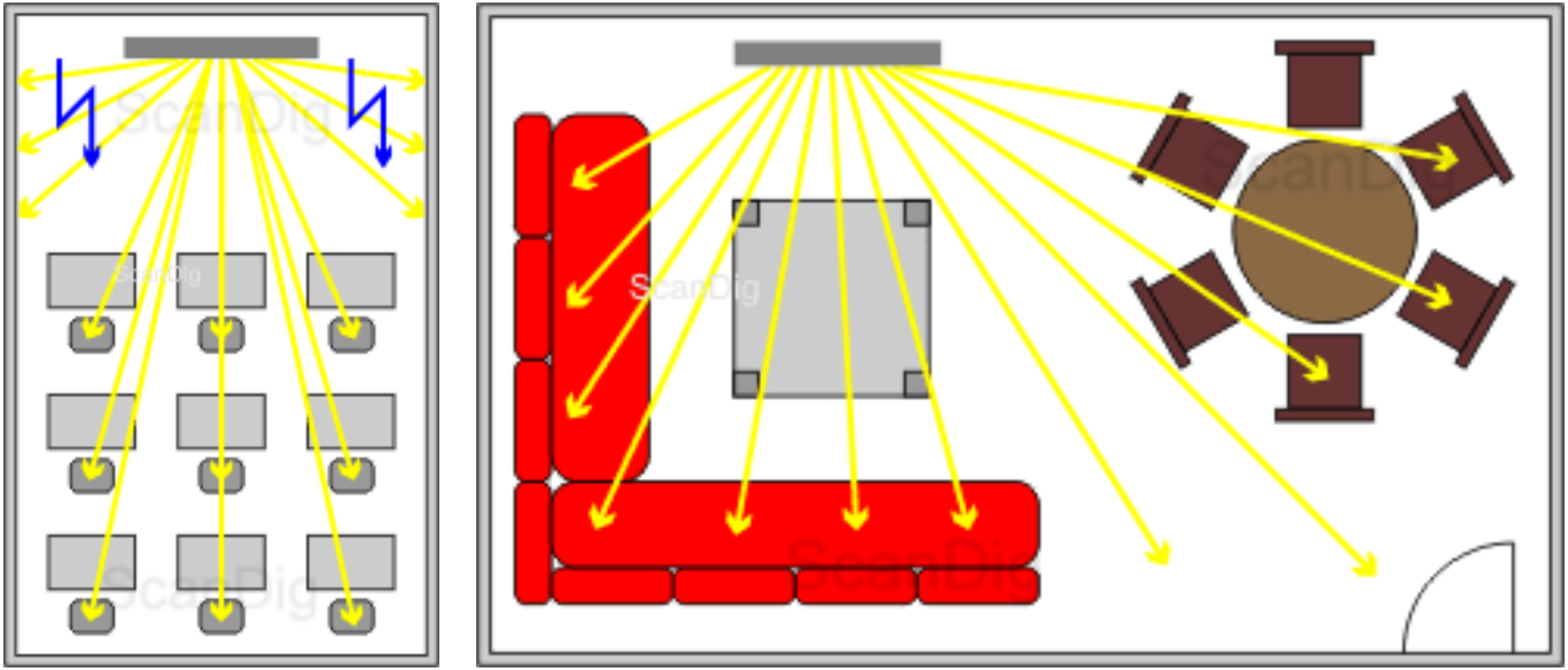
ANSI Lumen





13 ANSI points

Why Different Screen Materials?



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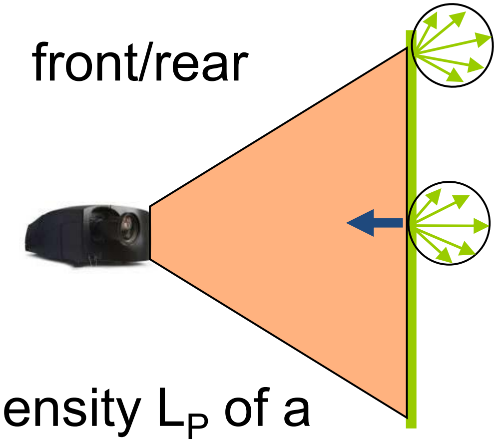
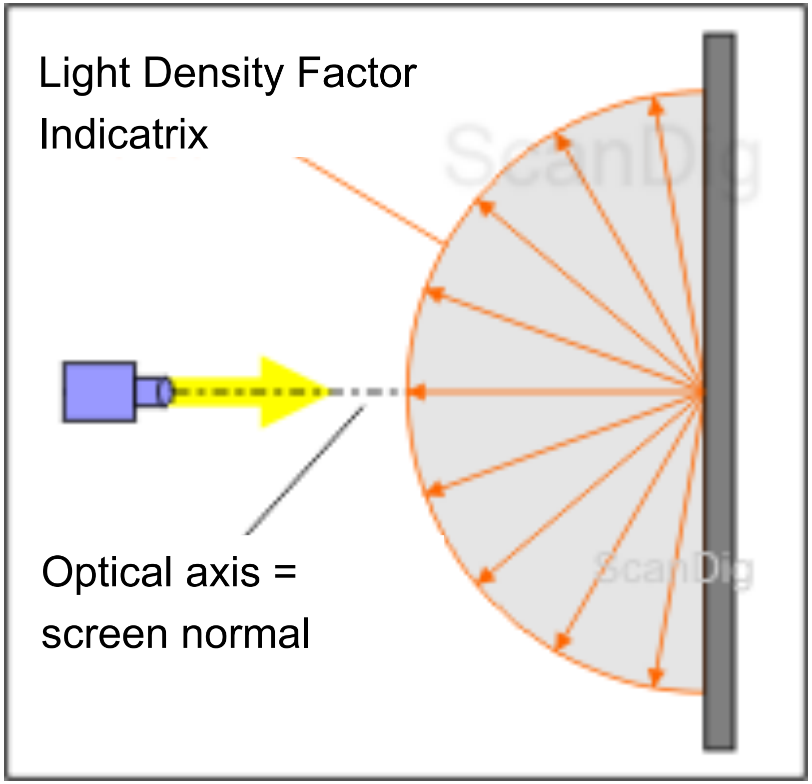
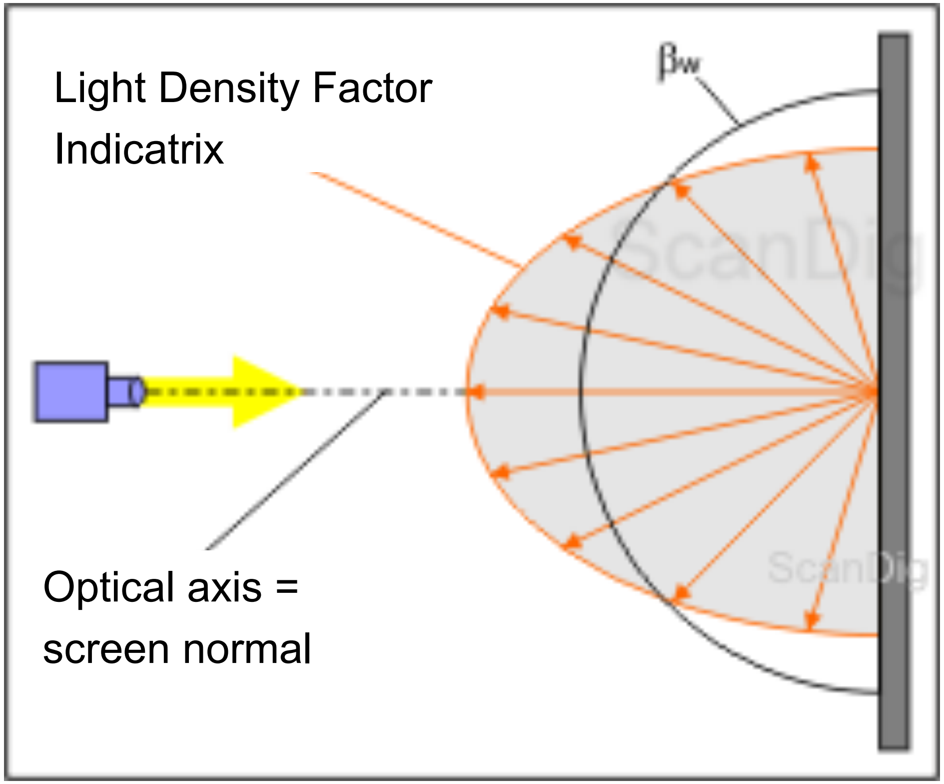
Screen Gain



- Describes reflection/transmission characteristics of a front/rear projection screen
- German: “Gain-Faktor”, “Leuchtdichtefaktor”
- Definition:
  The light density factor β_P is the relation of the light density L_P of a screen sample for a determined view direction to the light density L_W of a totally diffusing and reflecting surface (white standard) for a determined direction of radiation.
- Dimensionless
- Gain is not a single figure!
- Peak Gain: View direction perpendicular to screen
- Typically between 0.8 and 2.5

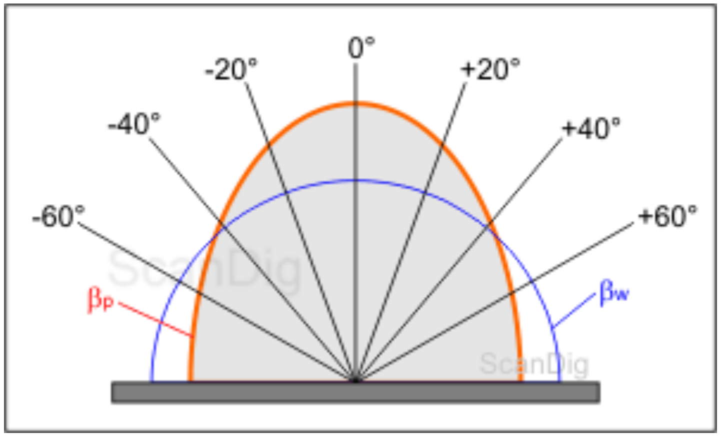
Gain Curves





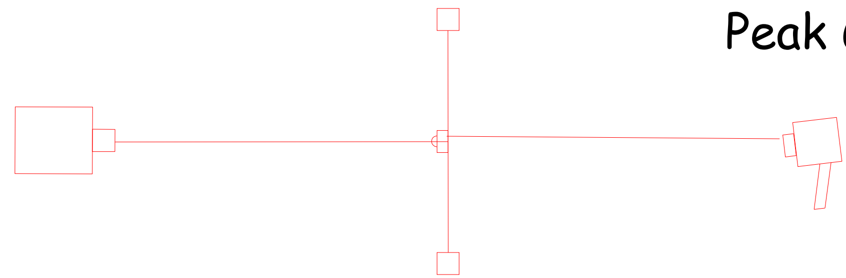
Patrick Wagner, wwww.filmscanner.info

Screen Gain: Not a Single Figure!

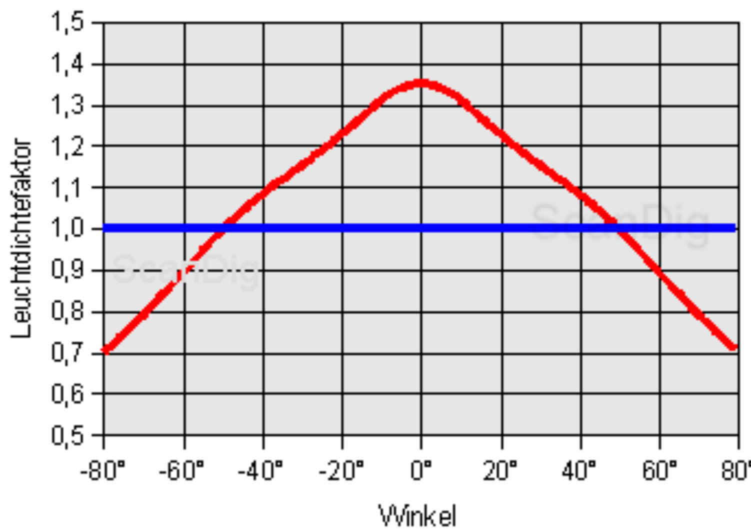


Polar coordinates

Peak Gain



Half Gain = angle at which gain is half peak gain



Cartesian coordinates

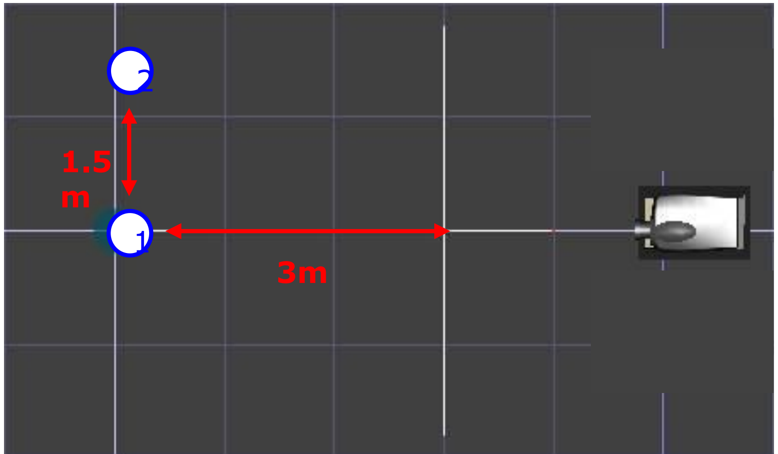
Peak Gain
2

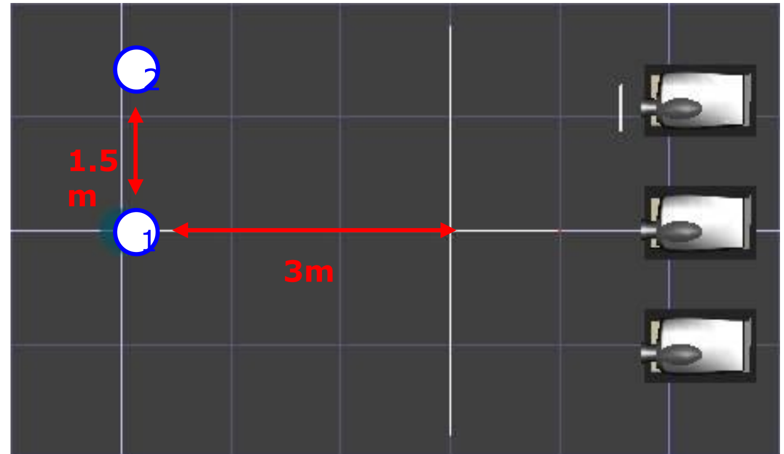
Patrick Wagner, wwww.filmscanner.info

Visual Computing Institute

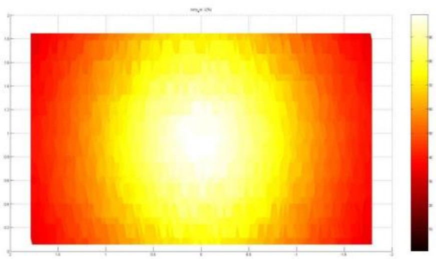
RWTH AACHEN UNIVERSITY

Single Projector versus Tiled Display (3x2) Setup

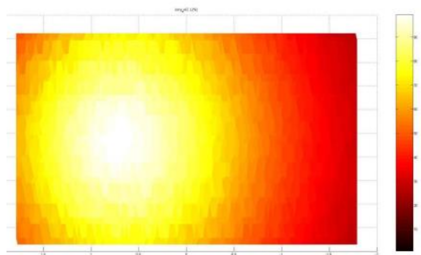




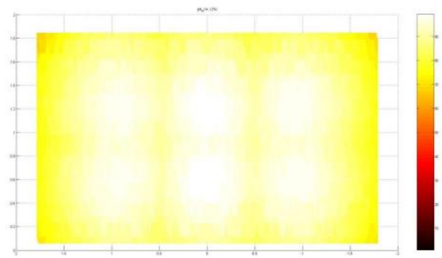
User Position 1



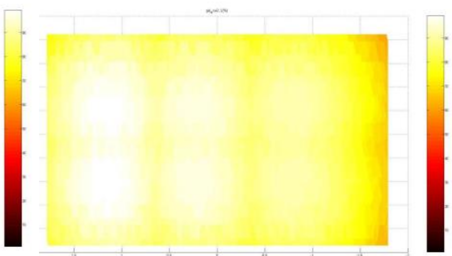
User Position 2



User Position 1



User Position 2



Passive Stereo versus Active Stereo

- **Passive stereo (polarization)**
  - 2 projectors for left and right eye, respectively
  - Swap (and Frame) locking of multiple graphics hardware
  - **Screen material may not destroy polarization →Brightness uniformity -**
  - Color fidelity: polarization +, INFITEC –
  - Glasses +
- **Active stereo (shutter)**
  - 1 active stereo projector or 2 projectors with external shutters
  - Needs tight synchronization: Gen locking
  - **Screen material may be diffuse → Brightness uniformity +**
  - Color fidelity +
  - Glasses –
- **All technologies absorb light!**

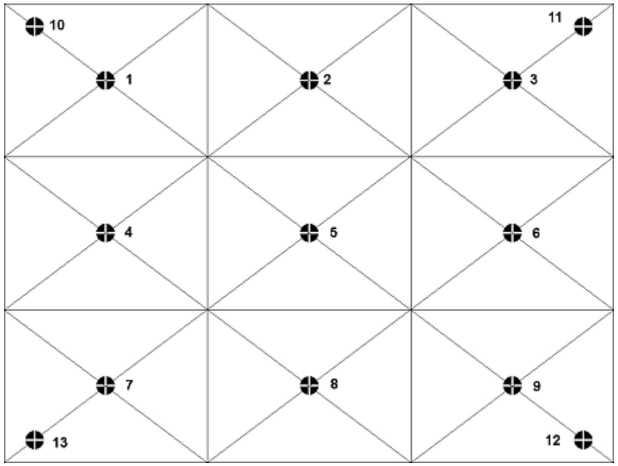
Ghosting

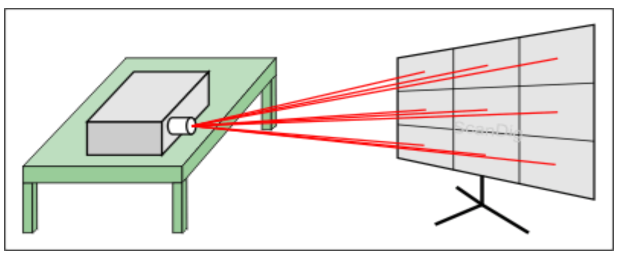
- A (faded) version of the image for the left / right eye is perceived by the right / left eye
- By design, does not show up in HMDs (two separate screens)

- **Polarization**
  - **with diffuse screens: -**
  - **With high screen gain: o**
- Shutter: +
- INFITEC: ++

Brightness in (old) RWTH CAVE

13 ANSI points





Luminance values for Right eye projector (no glasses) [cd/m²]
Luminance Uniformity

9,9%				13,6%
	12,8%	38,3%	18,1%	
	20,8%	100,0%	20,9%	
	13,0%	21,6%	12,4%	
10,3%				10,1%

- Extreme hot spot due to small half gain angle
  - Stereo technology: Circular polarization
    - ✓ Use UXGA LCD projectors (not capable of doing active stereo)
    - ✓ Use NVIDIA GeForce instead of expensive NVIDIA FX Quadro

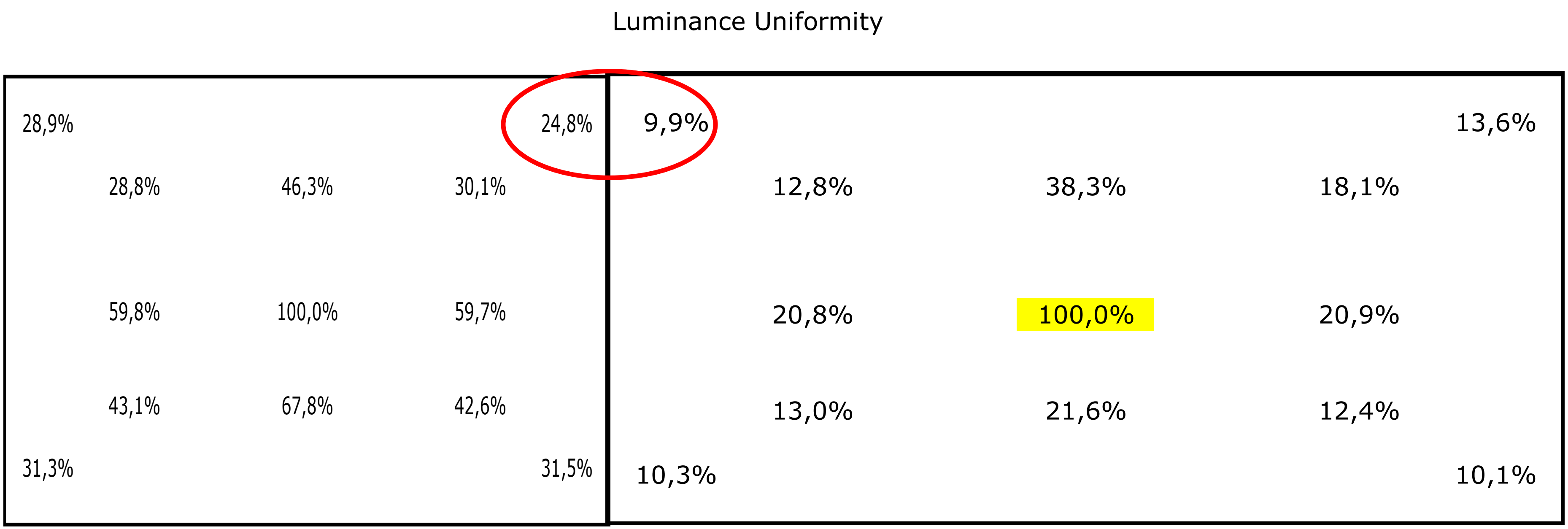
Visual Computing Institute

RWTH AACHEN UNIVERSITY

Brightness Uniformity in (old) RWTH CAVE

Different screen sizes for front and side walls (3.60 m wide versus 2.70 m wide):

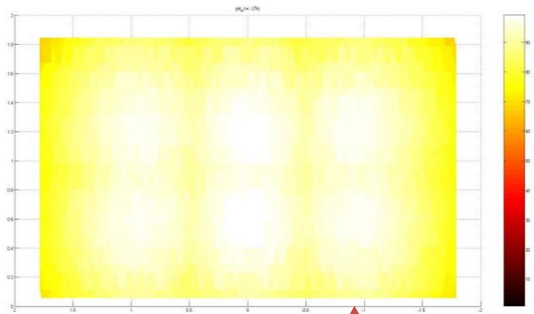
- Jump in brightness between screens



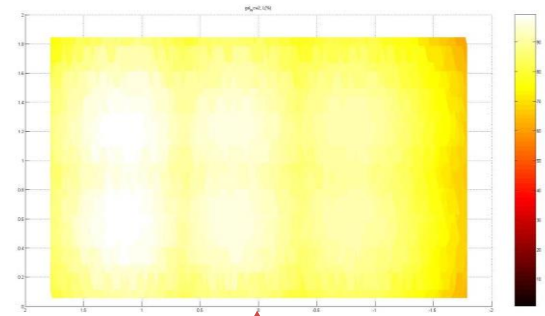
Brightness Simulations via Ray Tracing

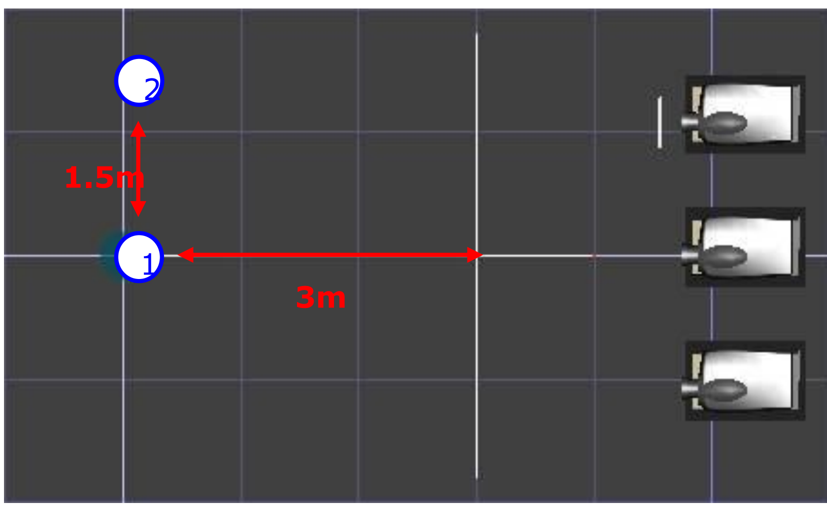
- Input Parameters:
  - Projector lumen
  - Lens
  - Screen
    - Gain curve
  - Position of the user

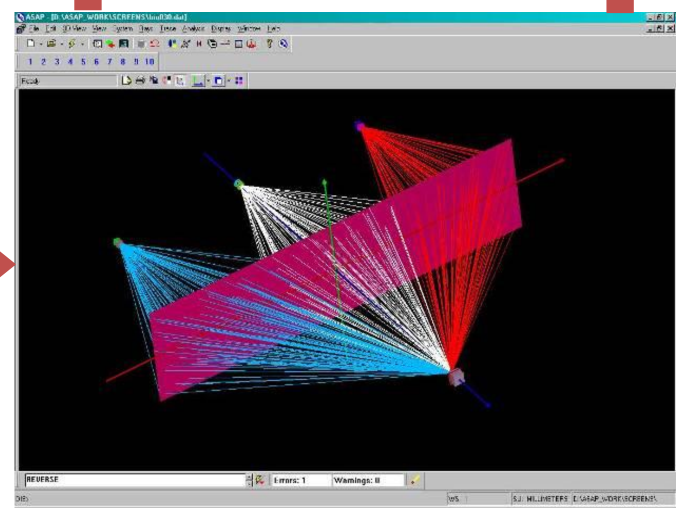
User Position 1



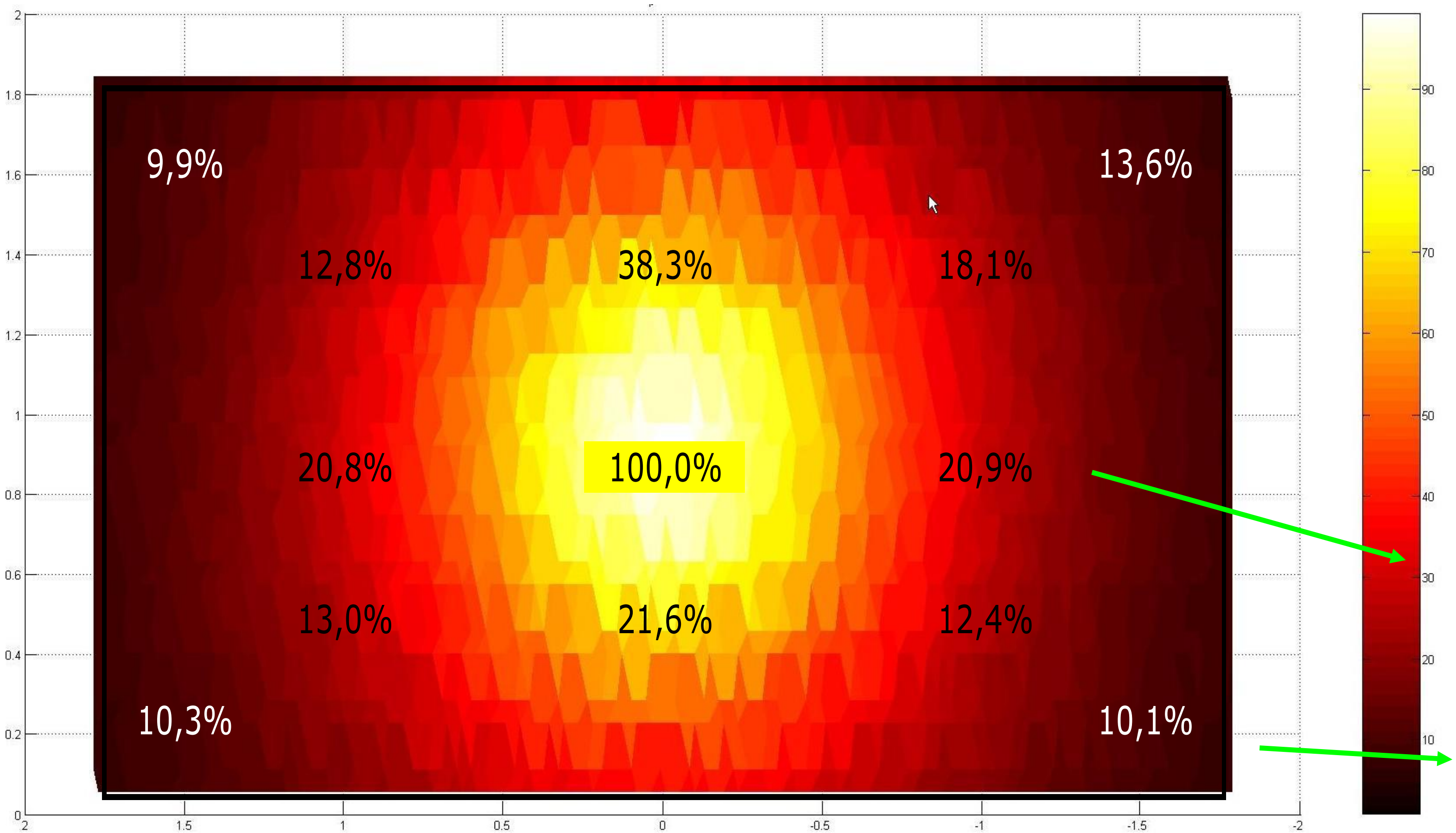
User Position 2







RWTH CAVE: Simulation versus Measurements



Different suppliers have different simulation tools!

(or none at all!)

Aspects of Vision

- Human Factors
  - Anatomy of the Human Eye ✓
  - Perception: Depth Cues in Vision, ✓ Photometry ✓
- Technology
  - Graphics Hardware ✓
  - Head-Mounted Displays ✓
  - Room-Mounted Displays: Stereo Techniques, Projectors, Screens, Brightness, … ✓
- Algorithms
  - Geometrical Modeling
  - Rendering
    - Rendering Pipeline ✓
    - Stereo Projections ✓
    - Viewer-Centered Projection ✓
  - Global Illumination: Ray Tracing, Radiosity

Head-Mounted or Room-Mounted!?

Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution

Field of View

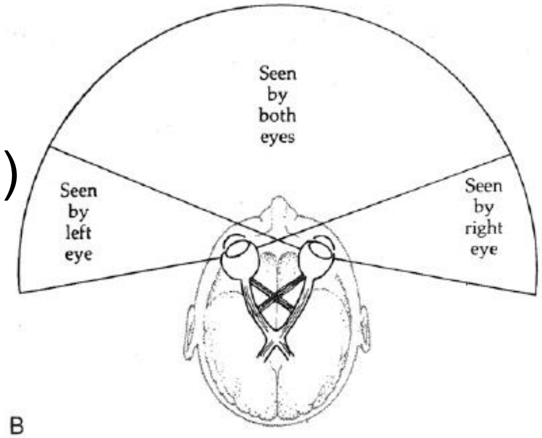
Riecke (2006)

- Oval shape
- At eye level:

  Horizontal: About 90° to both sides

  Vertical: About 120° (↑ 50° and ↓70°)
- FOV center is being perceived by both eyes

  Stereoscopic (binocular) field: 100° - 120°

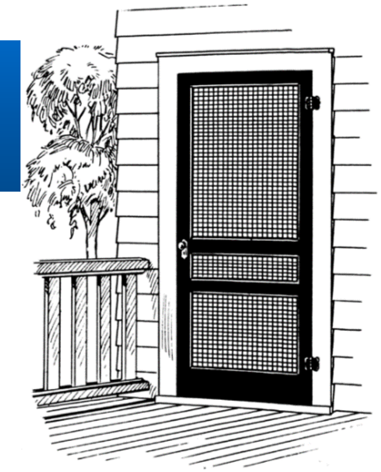


- **“Gesichtsfeld”** (Engl. Field of View):
  3D space that can be percieved at a particular time instant with head fixed and eyes looking straight ahead and not moving
- **“Blickfeld”** (Engl. Field of View):
  3D space where objects can be focused at (one after the other), eye movements allowed
- **“Sichtfeld”** (Engl. Field of View):
  3D space spanned by an optical instrument (e.g., camera)
- **“Blickfeld”** (Engl. Field of Regard):
  3D space that can be captured when eye and head movements are allowed

Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution
- Screen Door Effect

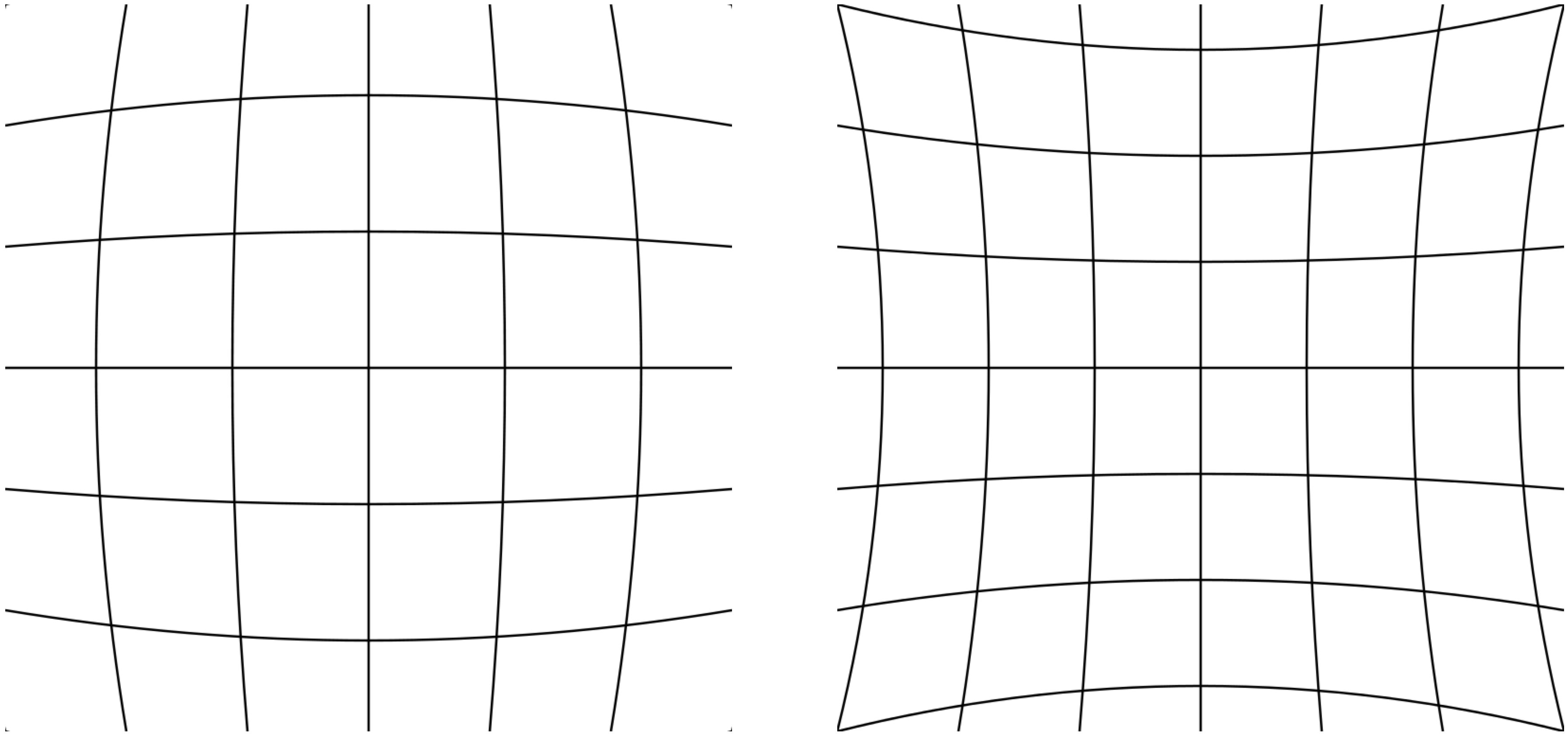
The „Screen Door Effect“ in HMDs and Projectors



Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution
- Screen Door Effect
- Image Distortions

Barrel and Pincushion Distortions



"Barrel & Pincushion distortion" by Wolf Wings - Own work. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Pincushion_distortion.svg#/media/File:Pincushion_distortion.svg

Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution
- Screen Door Effect
- Image Distortions

- Costs
- Real Estate Footprint

aixCAVE – Installation of Floor Glass Plate

Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution
- Screen Door Effect
- Image Distortions

- Costs
- Real Estate Footprint

- Ergonomics
- Cabling
- Intrusiveness
- Motion Sickness
- Self-Body Awareness

The Toshiba Bubble Helmet ;-)

Head-Mounted versus Room-Mounted Displays

- Field of View
- Field of Regard
- Resolution
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- Costs
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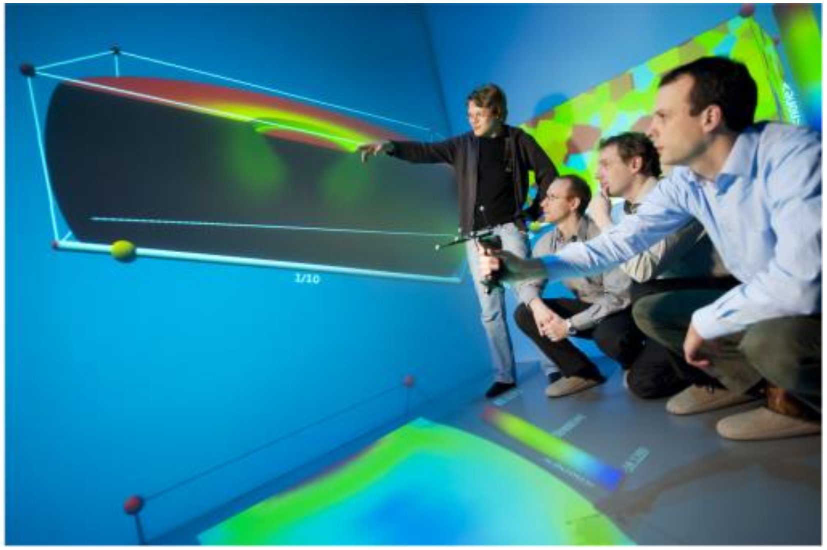
- Ergonomics
- Cabling
- Intrusiveness
- Motion Sickness
- Self-Body Awareness

- Interaction Techniques
- Navigation Techniques
- Navigation Volume
- Collaboration Capabilities

The CAVE – A Collaborative Environment?



- VCP as limiting factor
- Combination of different stereo technologies allows for multiple VCPs
  → See research at Bauhaus University Weimar, Prof. Bernd Fröhlich

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    - Rendering Pipeline
    - Stereo Projections
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  - Global Illumination: Ray Tracing, Radiosity

Addressing
Real-Time Capabilities:

Graphical Processing Units (GPU's)

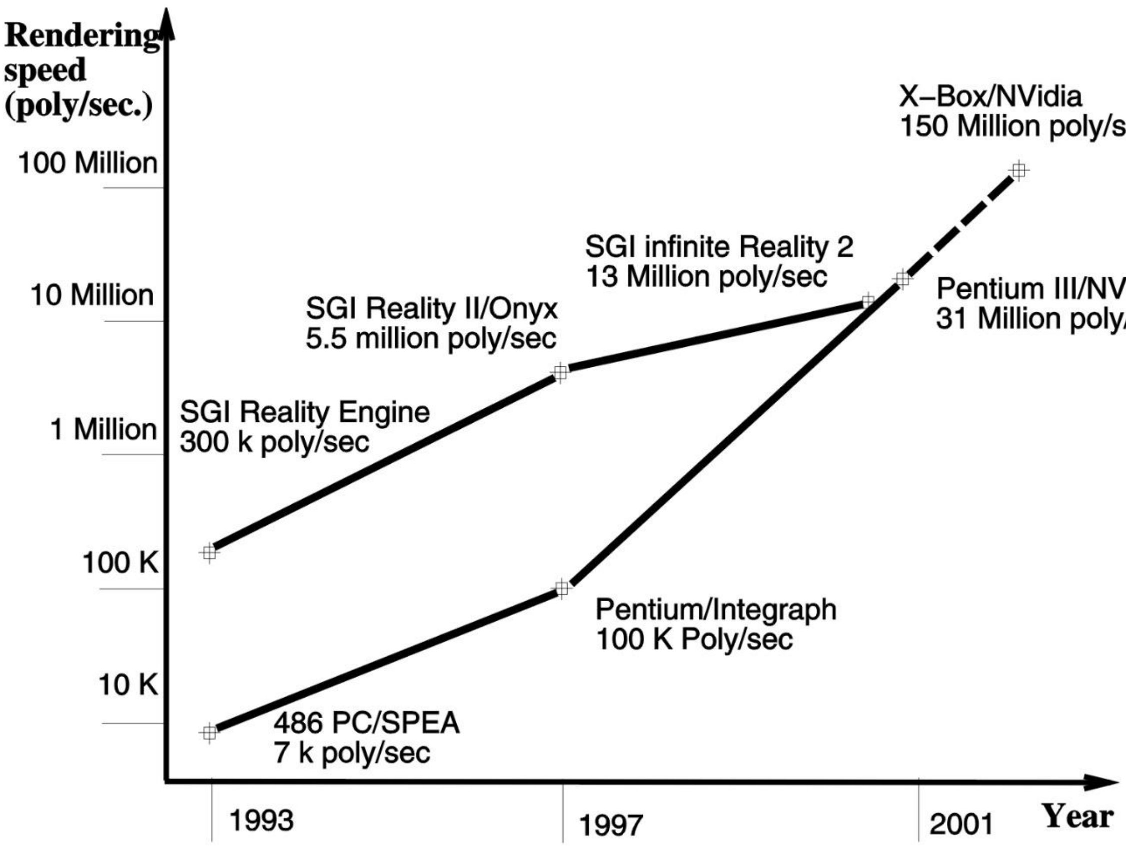
How to Measure Graphics Performance

- **Speed:**
  - Number of polygons per second (Attention: Size and shape of polygons, shading method, ...)
  - Fill Rate
  - Data transport: Graphics hardware – CPU – main memory
  - Benchmarks: ViewPerf, ... (see WWW)
- **Quality:**
  - Memory – Frame Buffer (size, color depth), Z-Buffer (depth), Texture Memory, ...
  - Texture Mapping Features
  - Hardware Anti-Aliasing
  - Special Features: Stereo, Vertex & Pixel Shaders, ...
- **Flexibility:**
  - Number of resolutions and screens supported, ...

History of Graphics Performance

Picture:Burdea et al

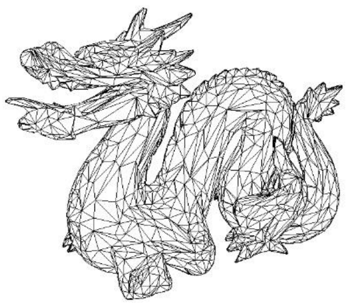
2014: 1.3 Billion poly/sec
(NVIDIA Quadro FX 6000)



How to make Graphics faster

- Chip development, processor clock speed
- Fast and larger busses (PC: AGP, PCI Express)
- Add more memory: Resolution, color depth, z-buffer depth, amount of textures, anti-aliasing
- **Pipelining**
  - **„macroscopical“ (Rendering Pipe)**
  - **onChip (float-multiplication)**
- **„Real“ parallel (SIMD,...)**
  - **„macroscopical“ (more Chips)**
  - **onChip (more ALUs, …)**

Rendering Pipeline Overview



→ Transformations: position and orientation of objects

→ Transformations:

- Local Coordinate Systems
- World Coordinate System
- View Coordinate System

↓ Culling

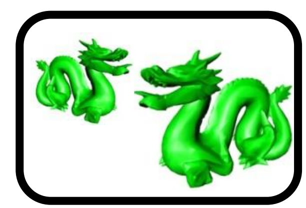
← **Projection**

← Clipping

↓ Shading

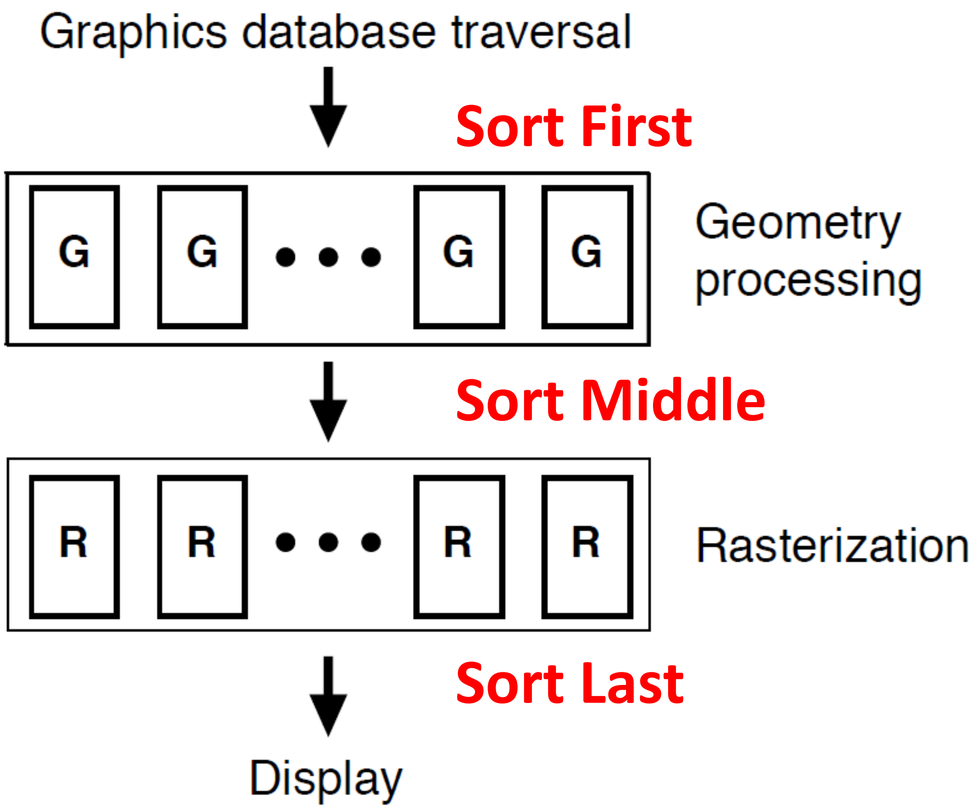
→ Hidden Surface Removal

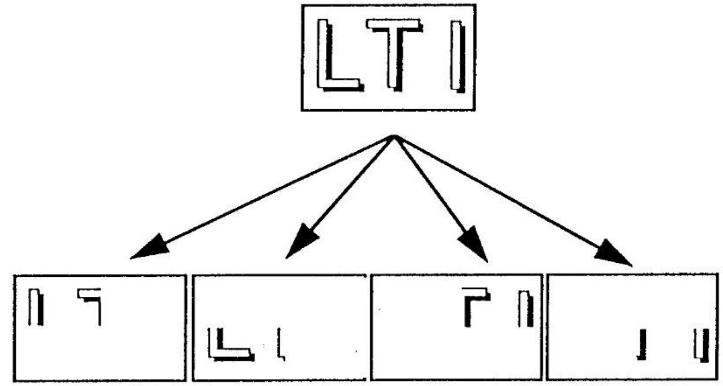
→ Scan Conversion

→ 

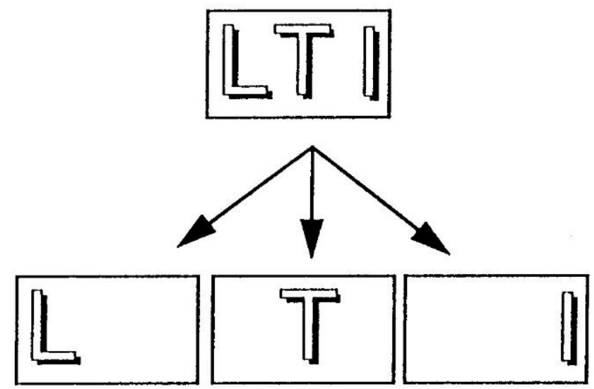
Parallel Rendering

[Steven Molnar, Michael Cox, David Ellsworth, Henry Fuchs]





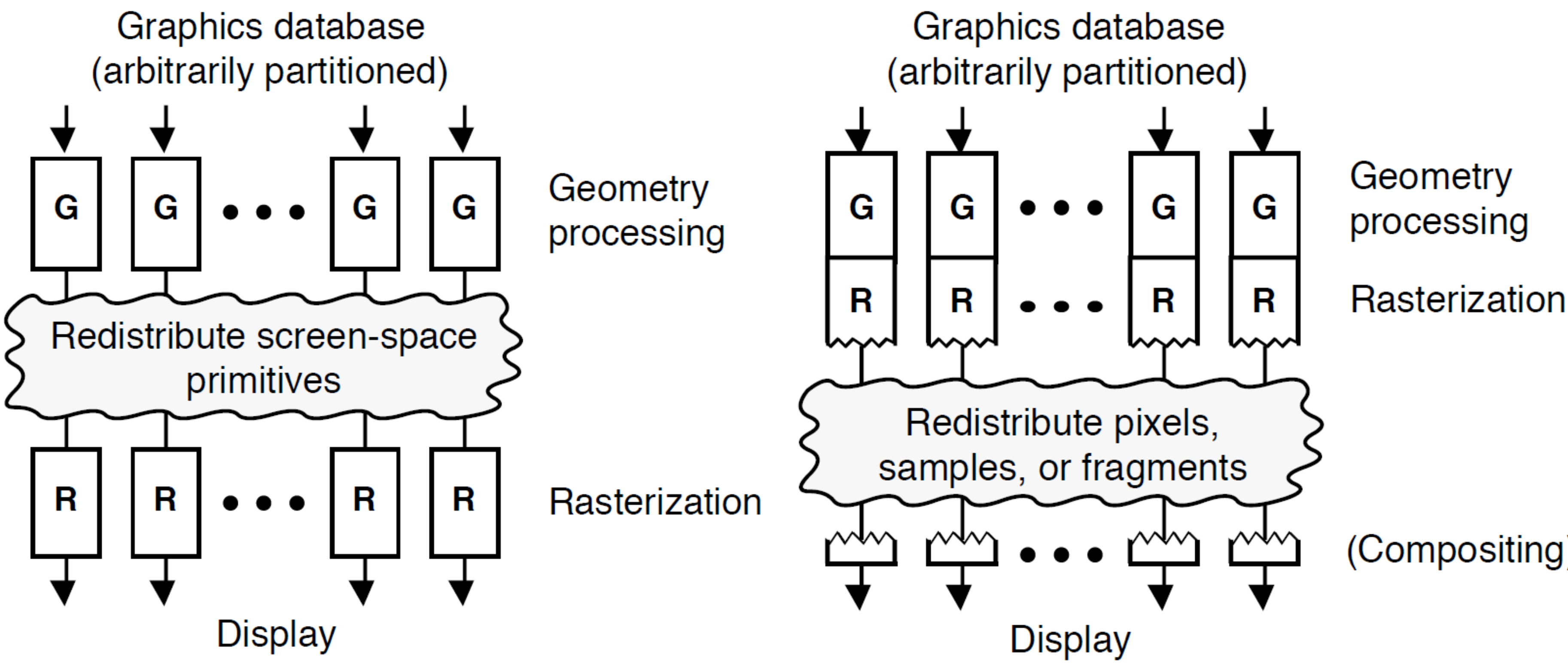
Sort First / Sort Middle: Partitioning



Sort Last: Compositing

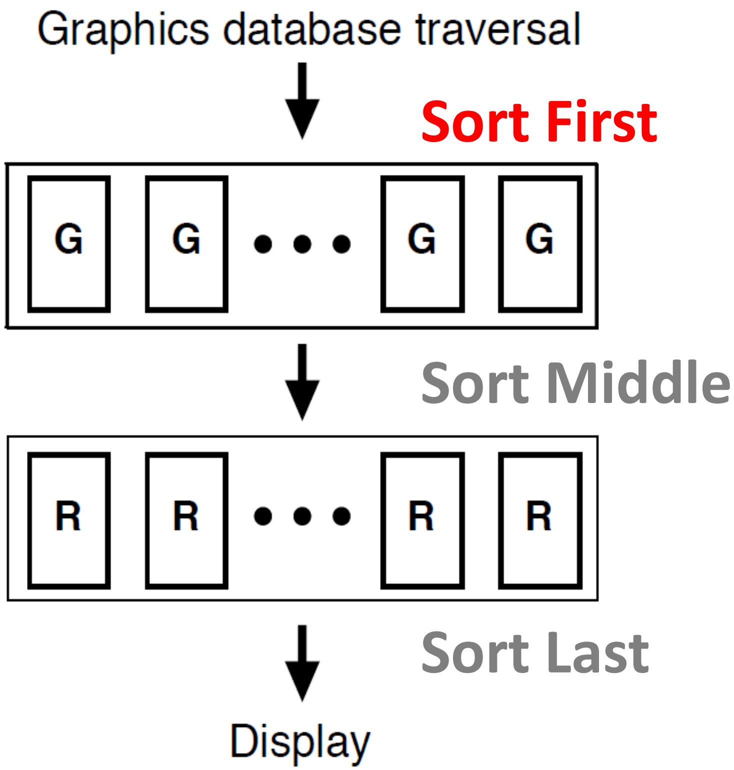
Parallel Rendering: Sort Middle versus Sort Last

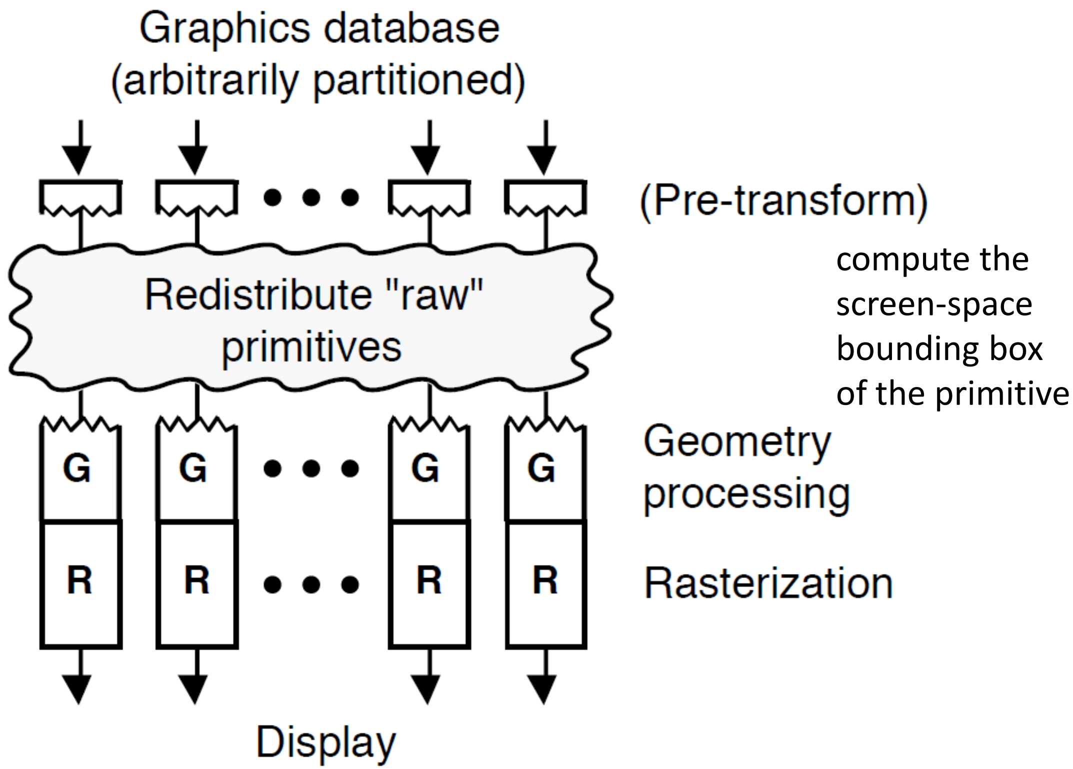
[Steven Molnar, Michael Cox, David Ellsworth, Henry Fuchs]



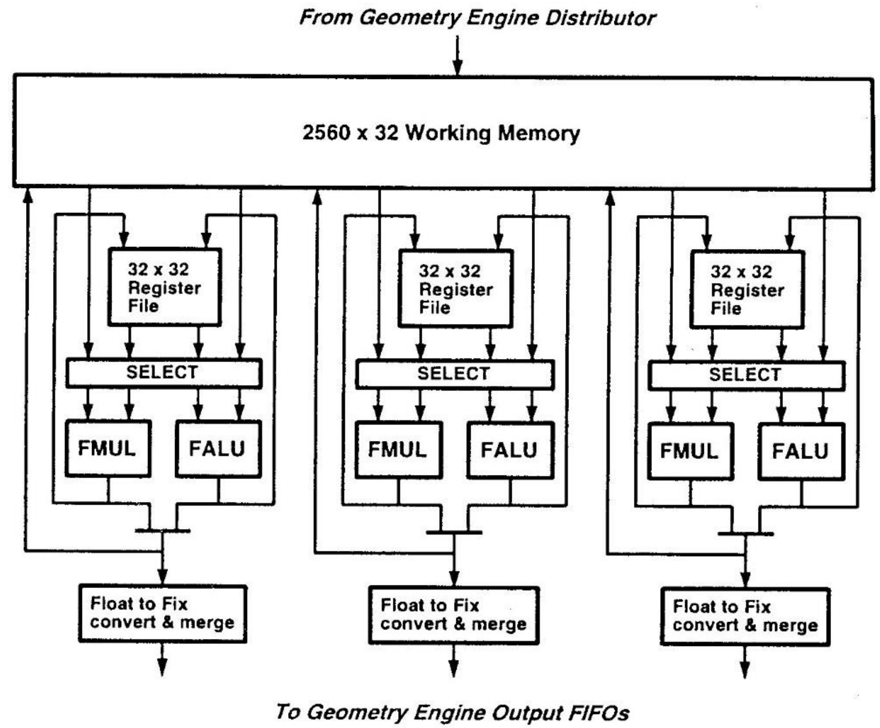
Parallel Rendering: Sort First

[Steven Molnar, Michael Cox, David Ellsworth, Henry Fuchs]





SGI Infinite Reality – Geometry Processing



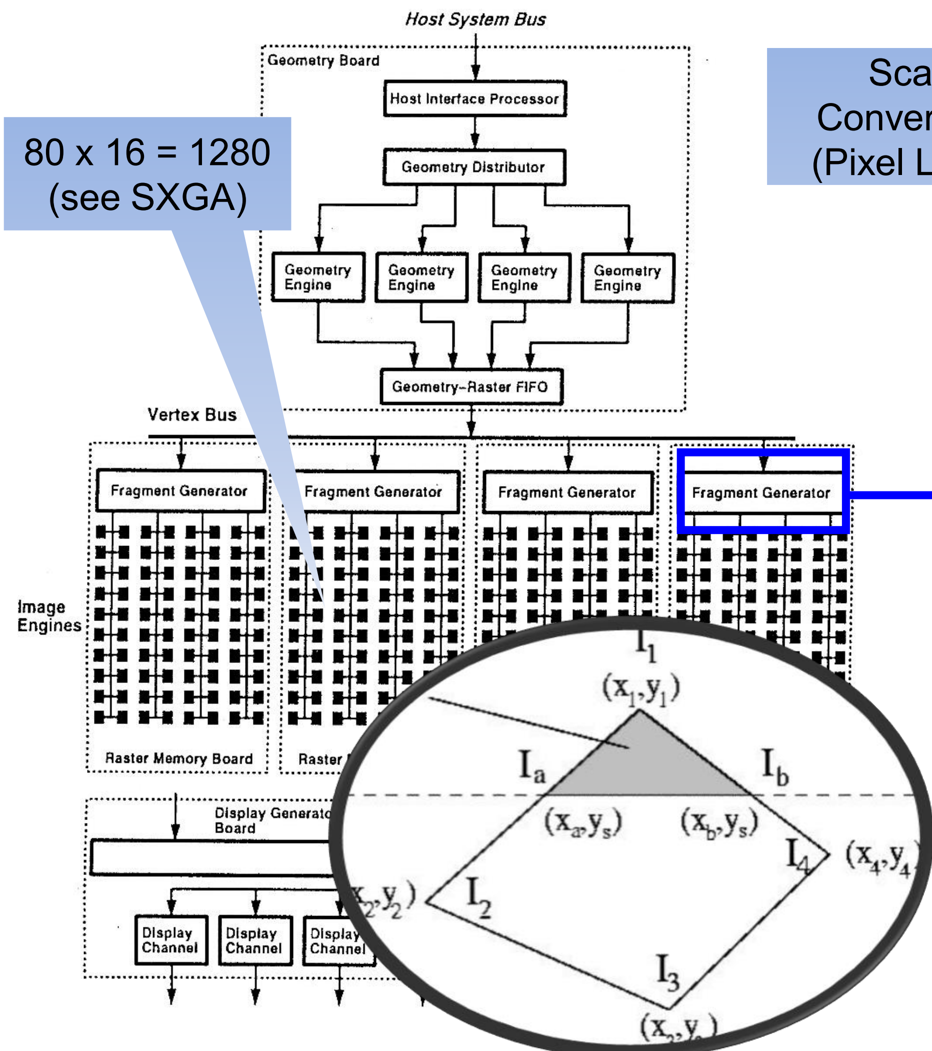
$$T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ T_x & T_y & T_z & 1 \end{pmatrix} \qquad R_y = \begin{pmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

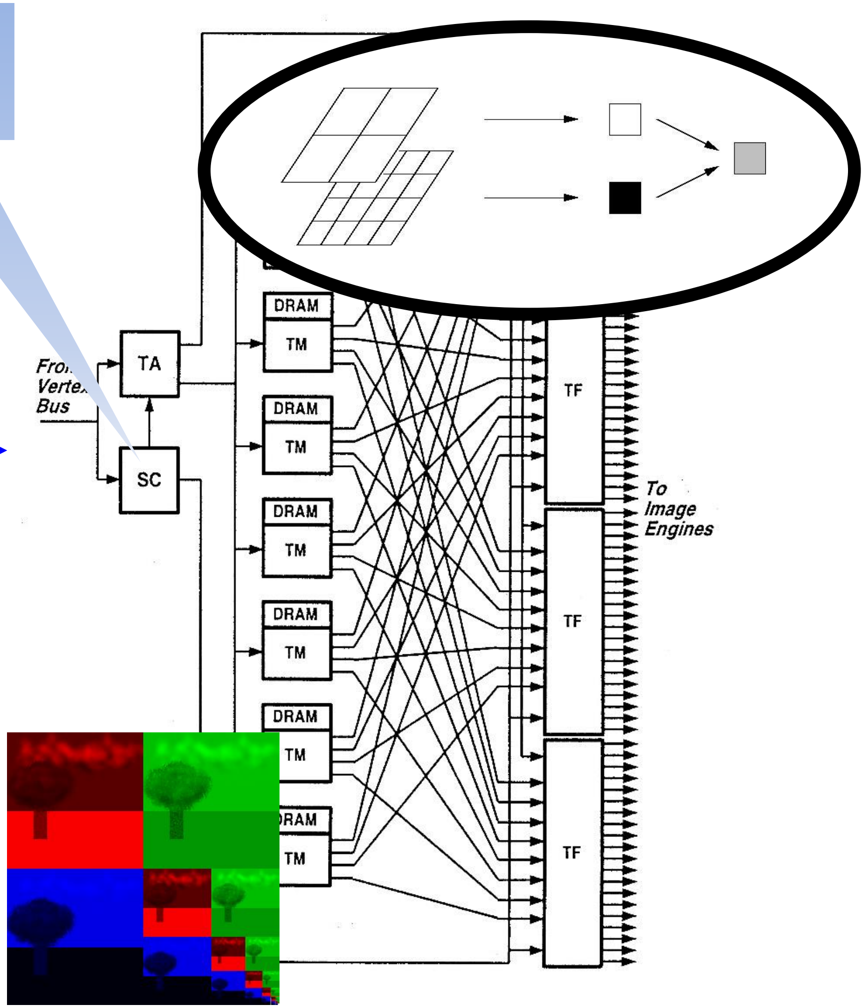
SGI Infinite Reality – Rasterization

Picture: Silicon Graphics Inc.

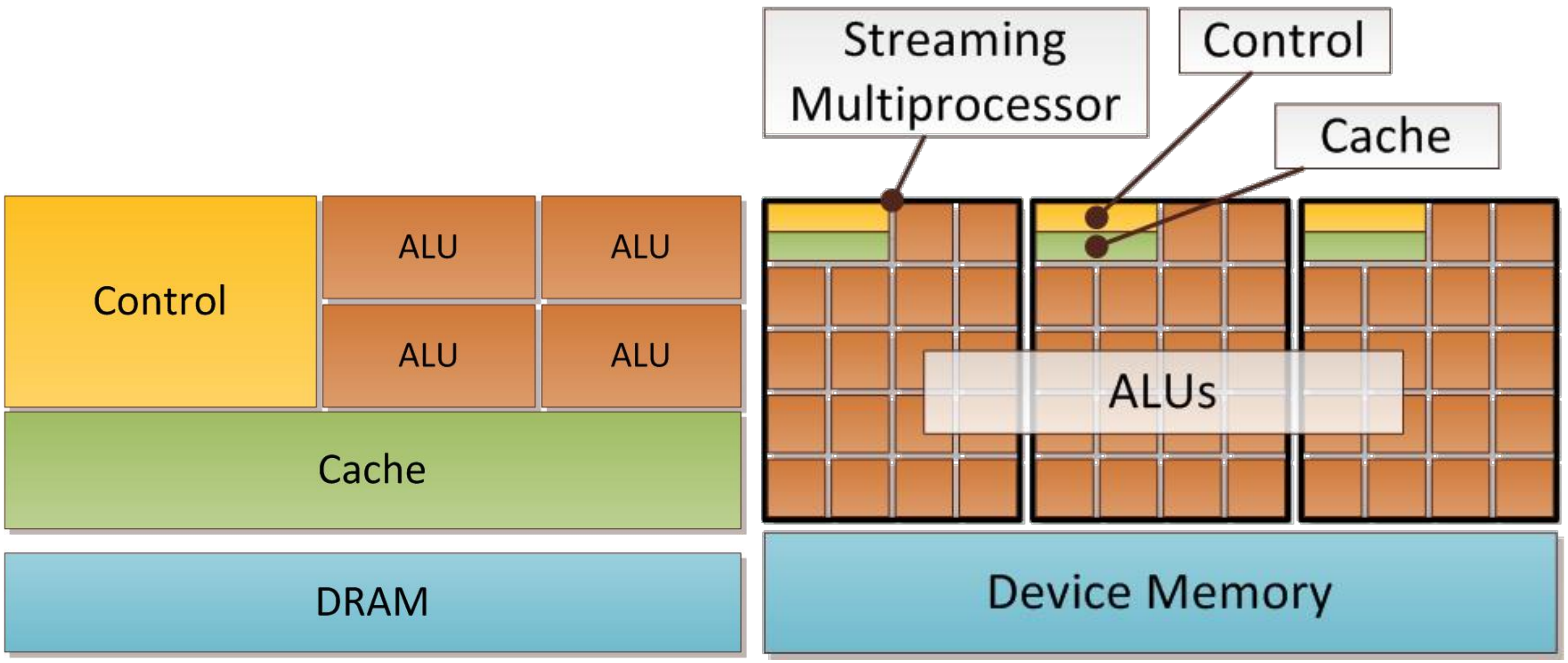
80 x 16 = 1280
(see SXGA)

Scan
Conversion
(Pixel Loop)





CPUs versus Modern GPUs

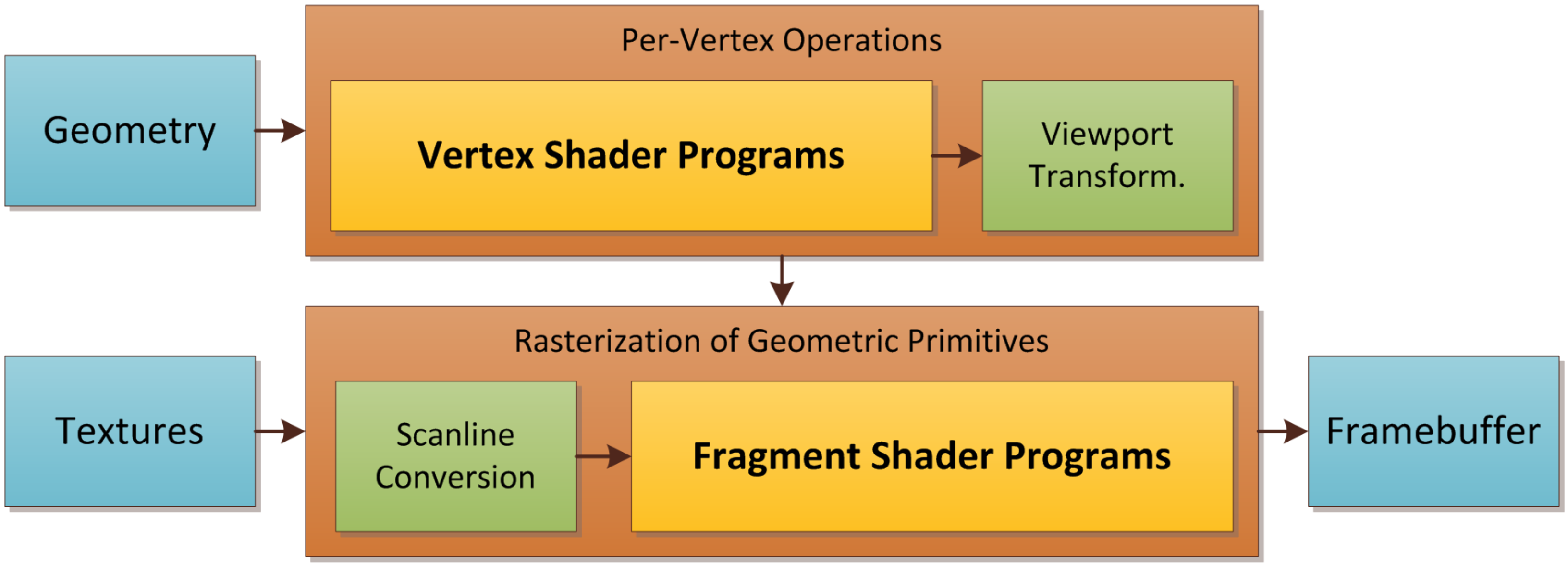


2011: About 100 GFLOPS

2011: About 1500 GFLOPS

Pictures: Tobias Rick

Modern GPU Architecture



Pictures: Tobias Rick

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