Practical Data Visualization and Virtual Reality

Virtual Reality
VR Display Systems

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Synopsis

- Virtual Reality basics
- Common display systems
- Visual rendering
- Audio rendering
- Haptic rendering

- Next lecture: software systems

The Concepts of Virtual Reality

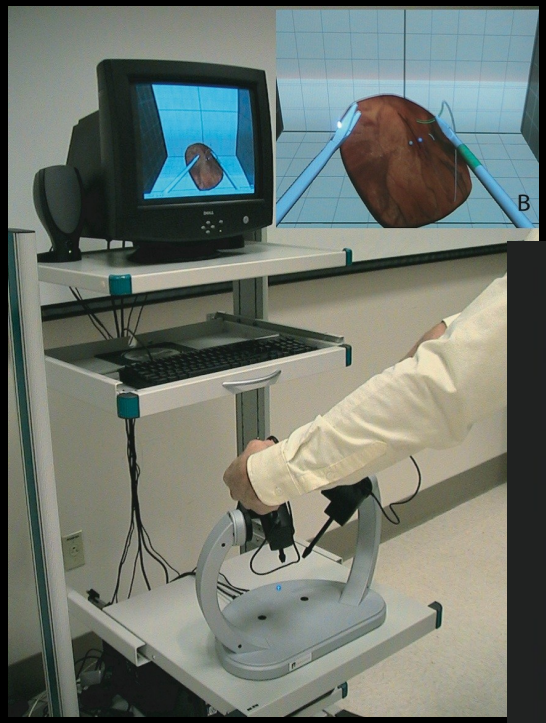
- Virtual Reality requires
  - Virtual Environment
    - 3D Computer Graphics
    - plausible appearance and behaviour
  - First person view
  - Real-time interaction
    - navigation
    - action and reaction

The Concepts of Virtual Reality

- Immersion
  - Physical immersion
    - multi-sensory stimuli (e.g. visual, auditory and haptic)
    - hiding the real world
  - Mental immersion
    - believable world
    - forget that it is virtual

Application Areas

- Entertainment, treatment and gaming
- CAD, information, control and planning
- Simulation and training



Multi-sensory Display

- VR (typically) address
  - Primarily: visual sense
  - Secondarily: auditory sense
  - Additionally: haptic senses

  ...by
  - Deploying advanced hardware (display systems)
  - Careful consideration of human perception

Visual Display Systems

- Presents 3D graphics to the user
- Adjusts the view for correct visual impression

- Examples
  - Head Mounted Display Systems (HMD)
  - VR Workbench
  - CAVE
  - Haptic Workstation
  - VR Theatre
  - Dome

Head Mounted Display System

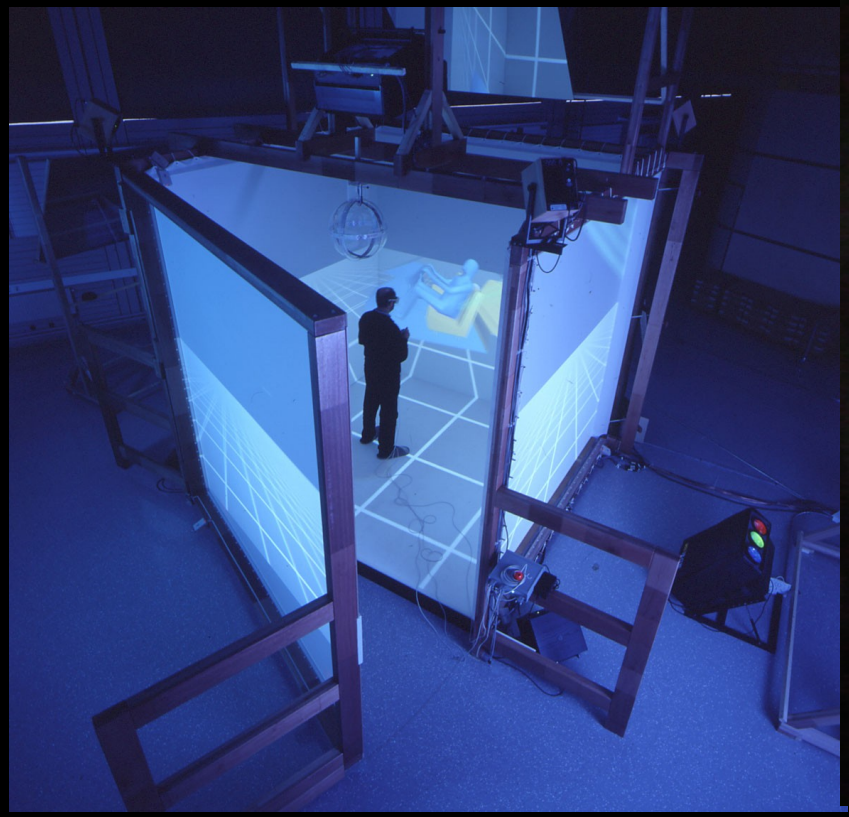
- One display per eye
- Advanced optics and tracking

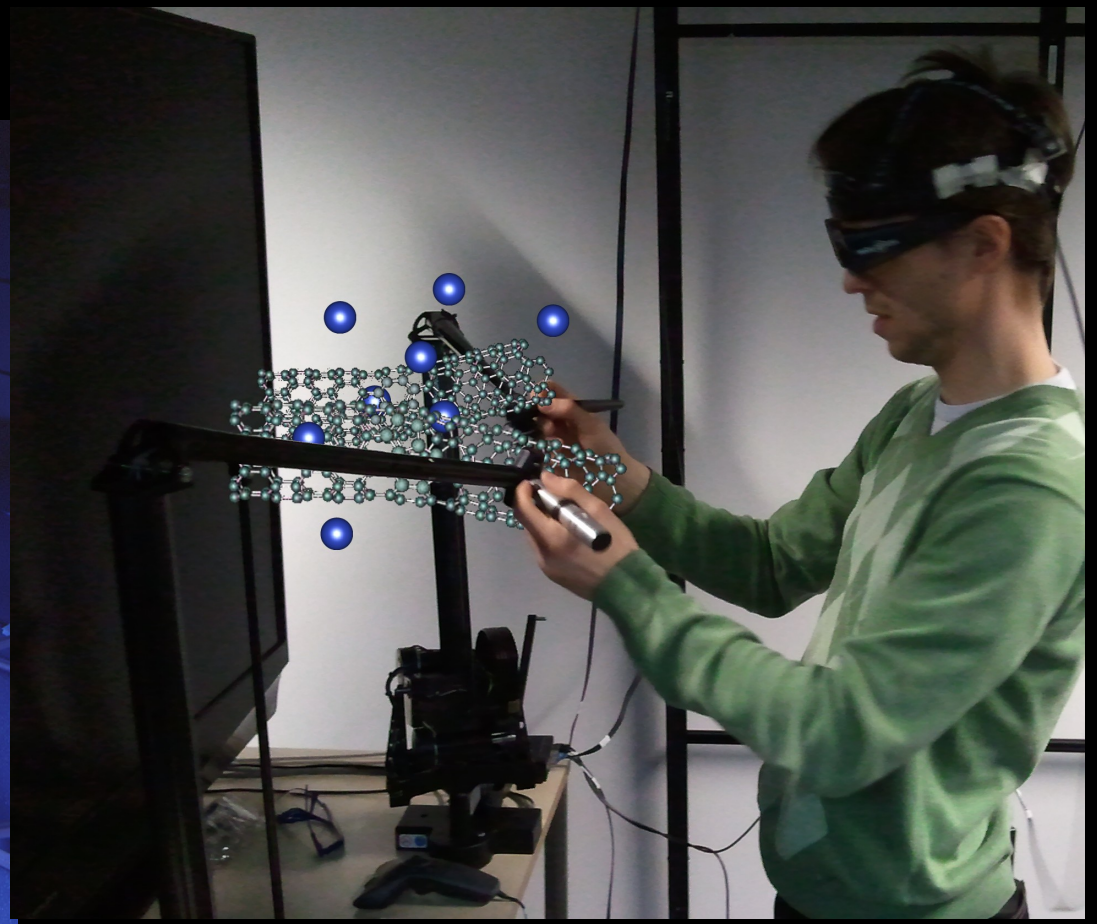
Head Mounted Display System

- Omni-directional – surrounded by the virtual world
- Covers vision – removes real world cues

VR Workbench / CAVE

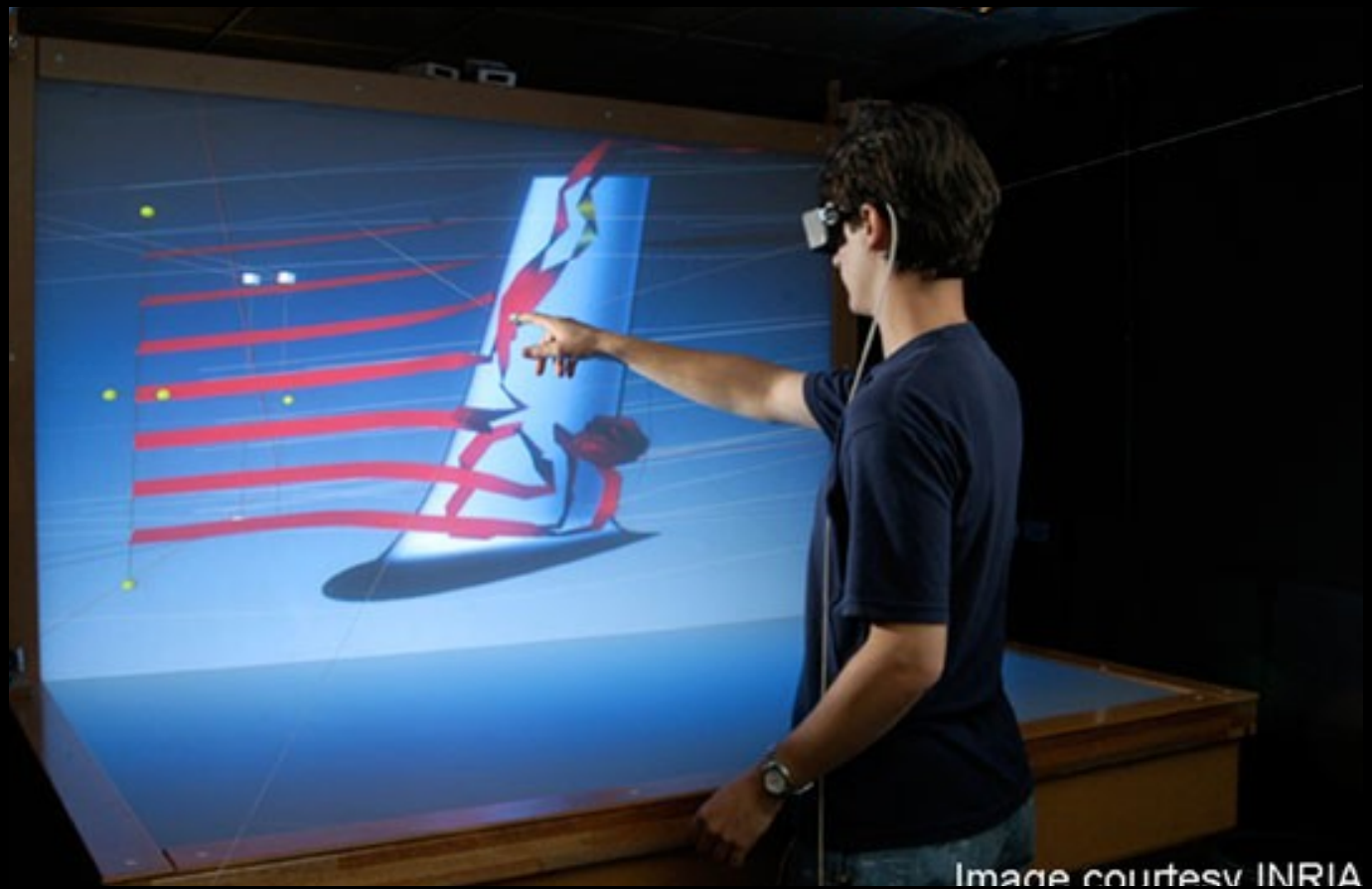
- Stereoscopic TV/projector
- Dynamic view by tracking





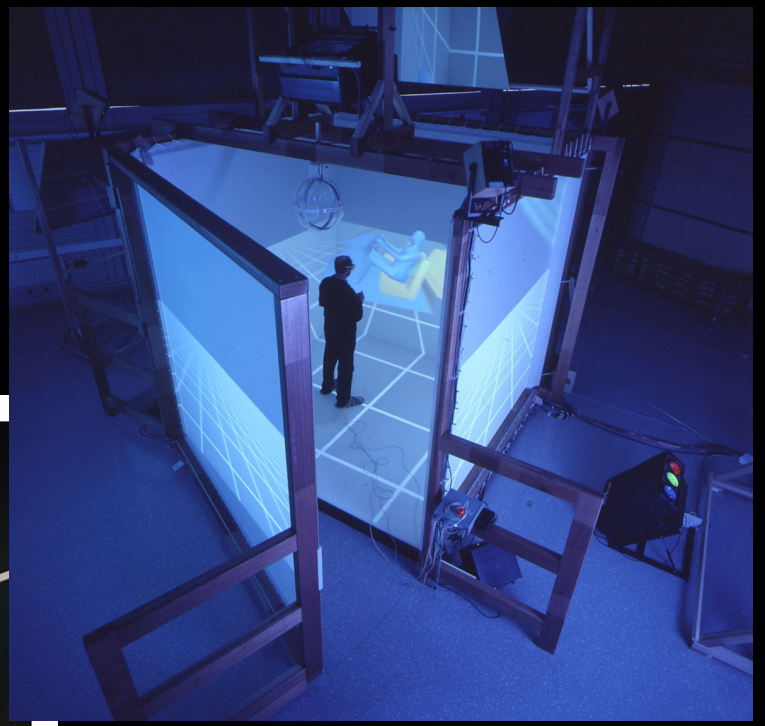
VR Workbench

- 3D immersive workbench
- Natural part of your workspace



CAVE

- Omni-directional
- Fully immersive



VR Theatre / Dome

- Multiple stereoscopic projectors
- Great for shared experience and presentations

Haptic Workstation

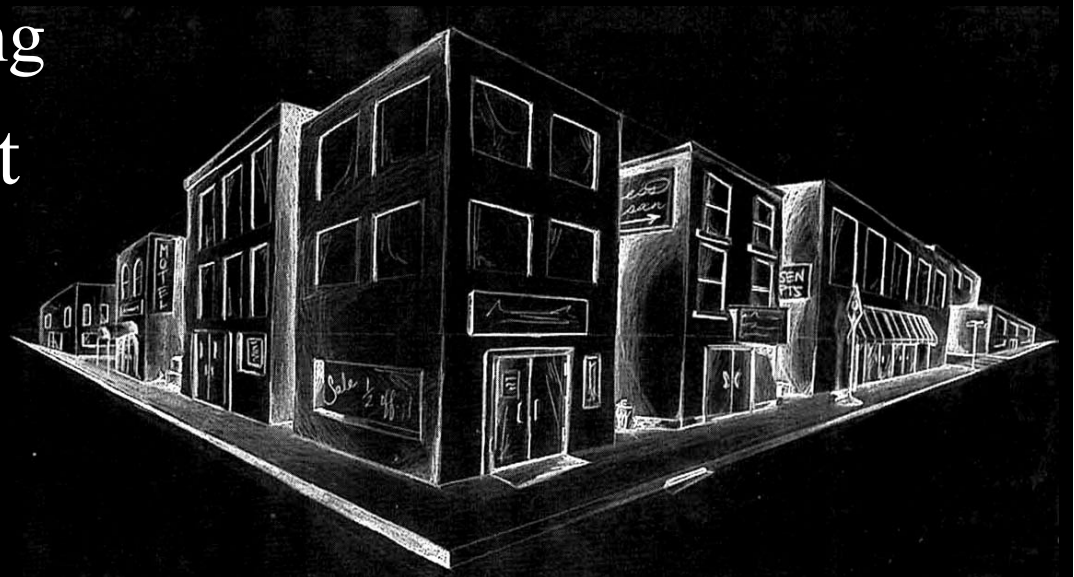
- Static stereoscopic view
- Haptic feedback (tri-modal display)

e.g. 2,5D = Image with Depth

- 3D world → 2,5D image
  - perspective effects
  - parallax effects
  - stereoscopic effects

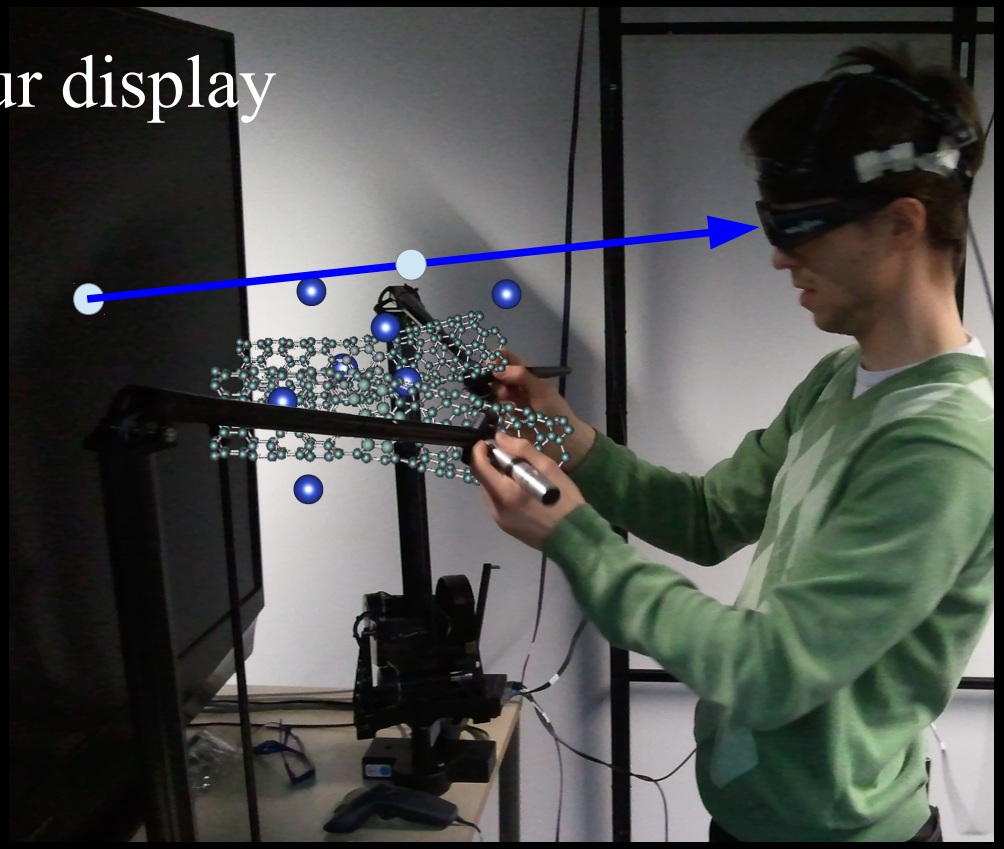
Rendering Perspective Effects

- Objects further away look smaller
  - ordinary OpenGL perspective projection
- Parallax effects
  - also a perspective effect
  - requires correct eye-based perspective projection
  - also requires head tracking
- Objects should look right
  - correct shape and size
  - correct position

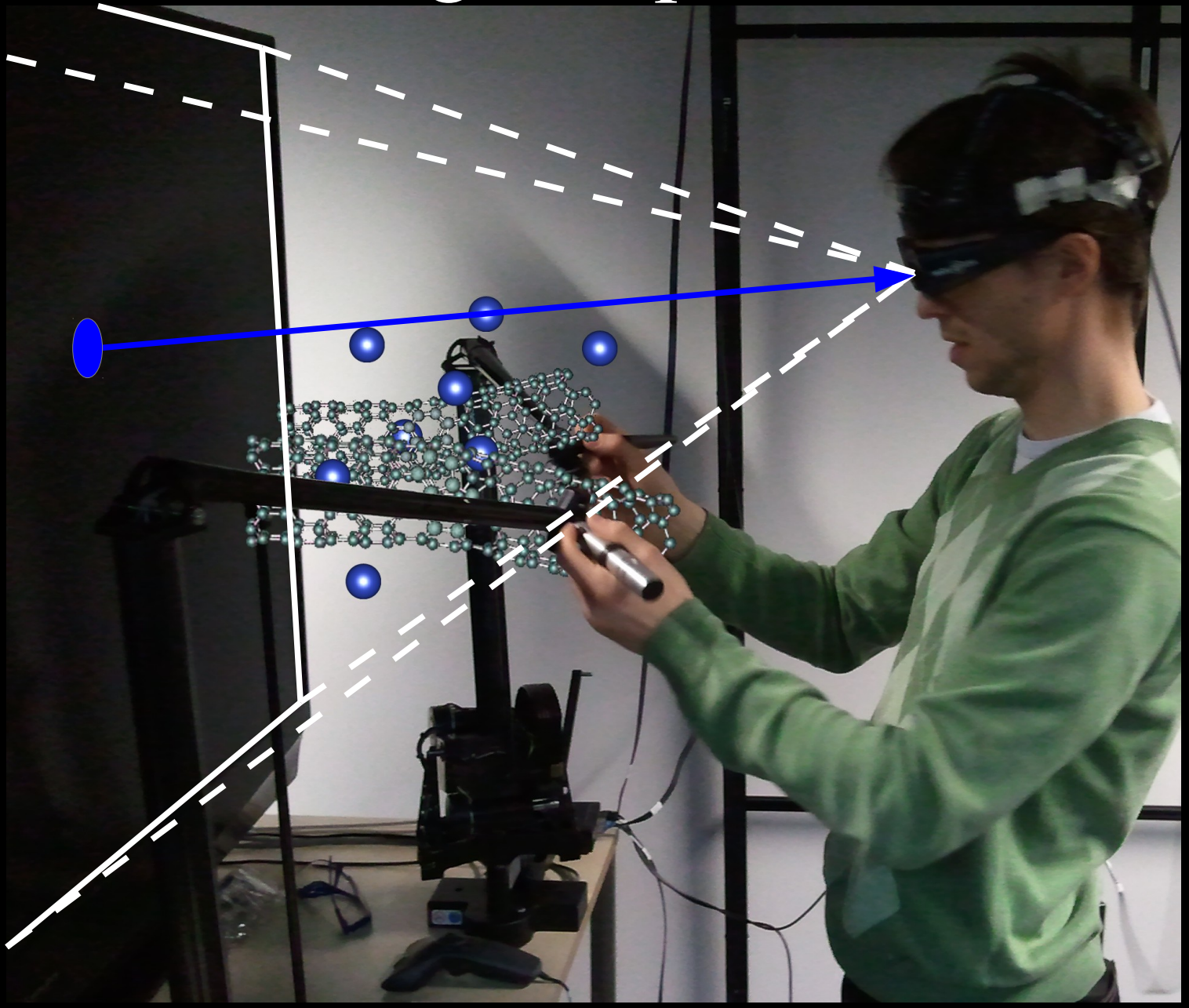


Rendering Perspective Effects

- Render objects at their “right” position
- Consider light transport
  - light does not know how far it's travelled
  - project 3D object onto your display



Rendering Perspective Effects



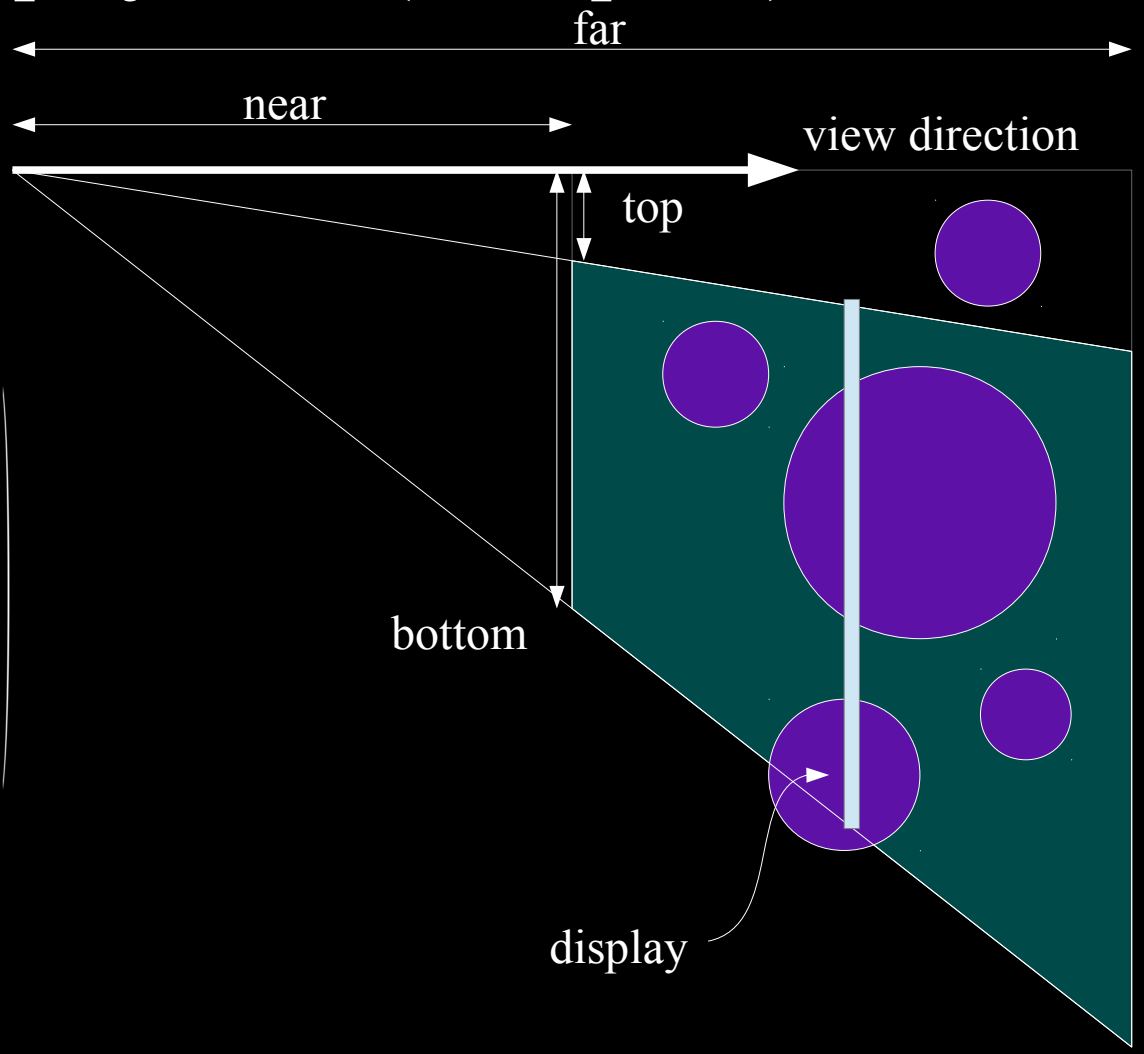
Camera Settings

- OpenGL perspective projection (Viewpoint)

glm::lookAt(...)

glm::frustum(...)

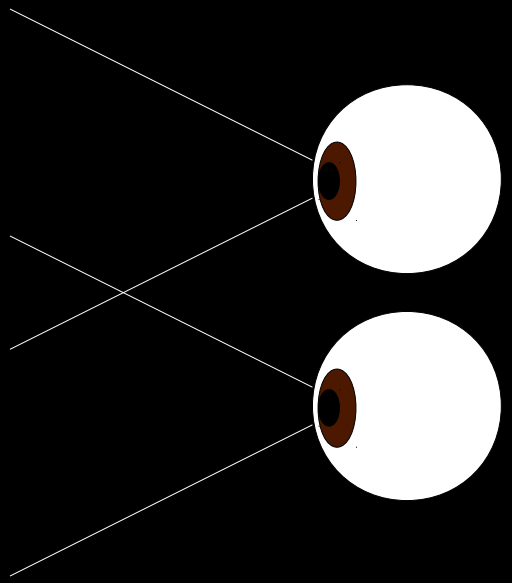
$$P = \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{pmatrix}$$



~~glm::perspective(...)~~

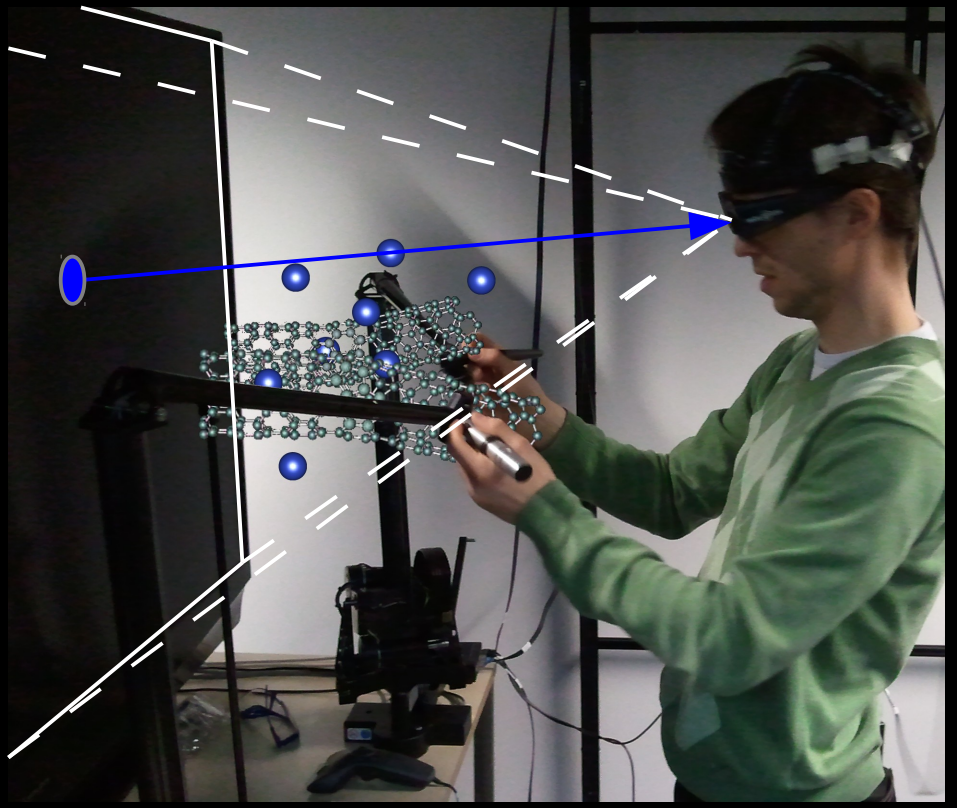
Stereo in Virtual Reality

- Correct perspective effect for *both* eyes
- Implications in VR
  - increased depth perception
    - However: stereo is *not* the only depth cue!
  - requires double the amount of images
    - Additional GPU demands
  - requires different images for the eyes
    - Special rendering
    - Specialized equipment



Stereo Calibration

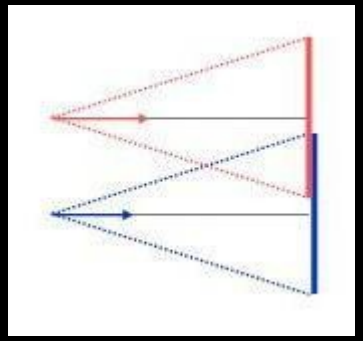
- Correct frustum
  - Screen size
  - Screen position
  - Eye position
    - head posture
    - eye separation

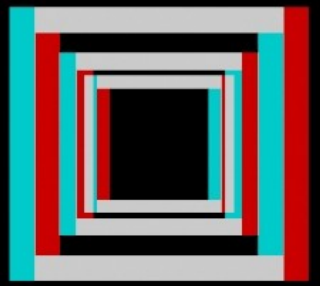


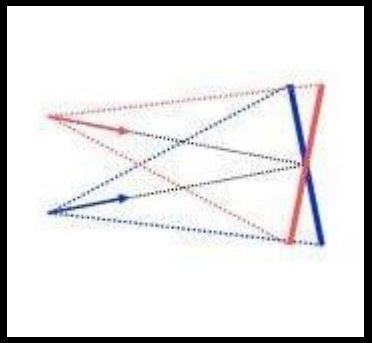
- Position dependent
  - Require tracking
    ...or assume fixed head position
  - Co-register real and virtual coordinates

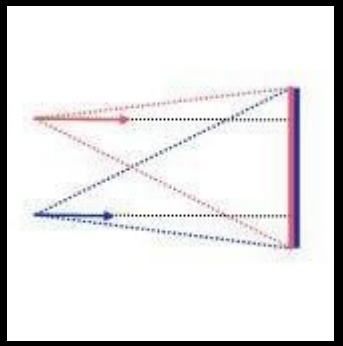
Camera Settings

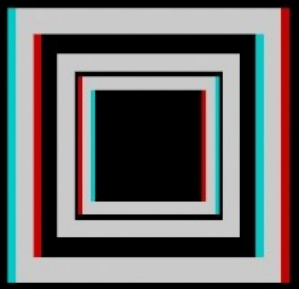
- Camera settings
  - Parallel (wrong)
  - Toe-in (wrong)
  - Off-axis (right)





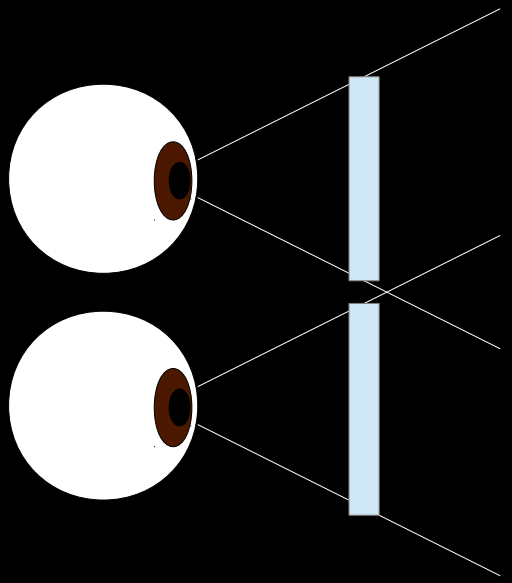






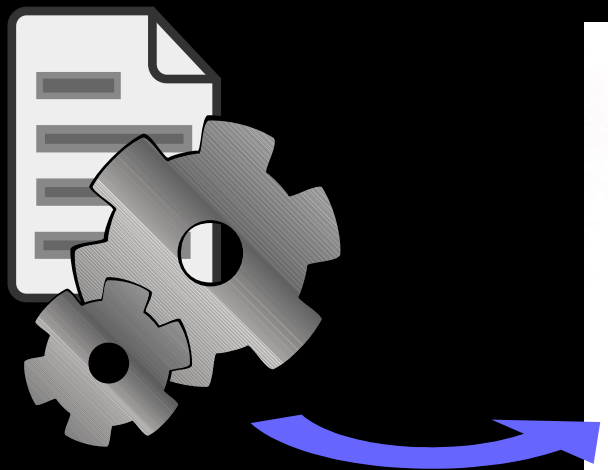
Stereo Calibration with Head Mounted Displays

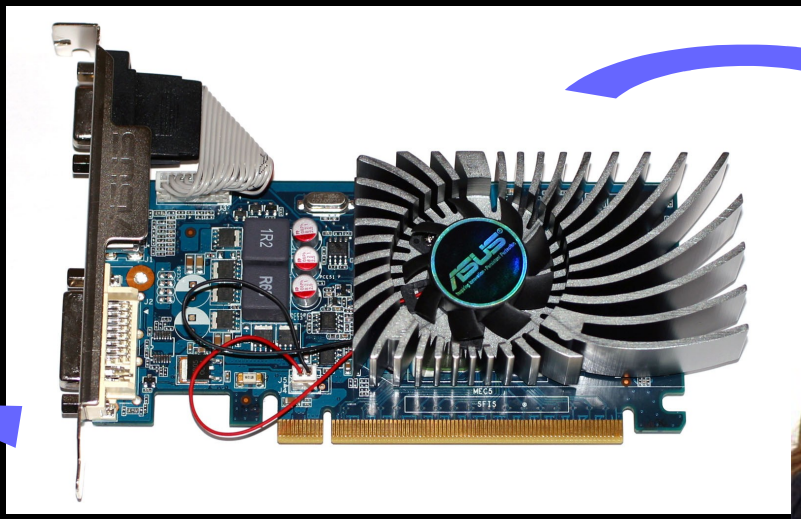
- Same thing but with the screen closer to the eye
- Correct perspective rendering
  - Calculated separately per eye
  - Based on fixed eye and monitor location
  - Needs to take optics into consideration

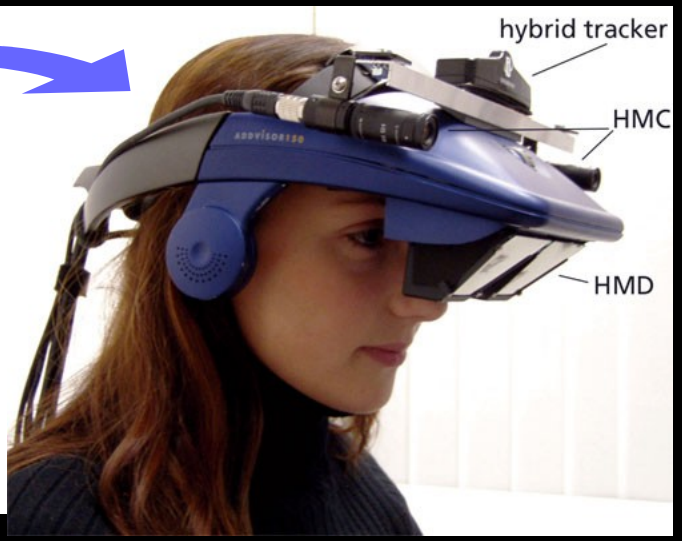


Stereo Rendering

- Separating the two eyes
  - Time multiplex – quad buffers
  - Interlaced – stencil mask
  - Split (e.g. side-by-side) – viewports



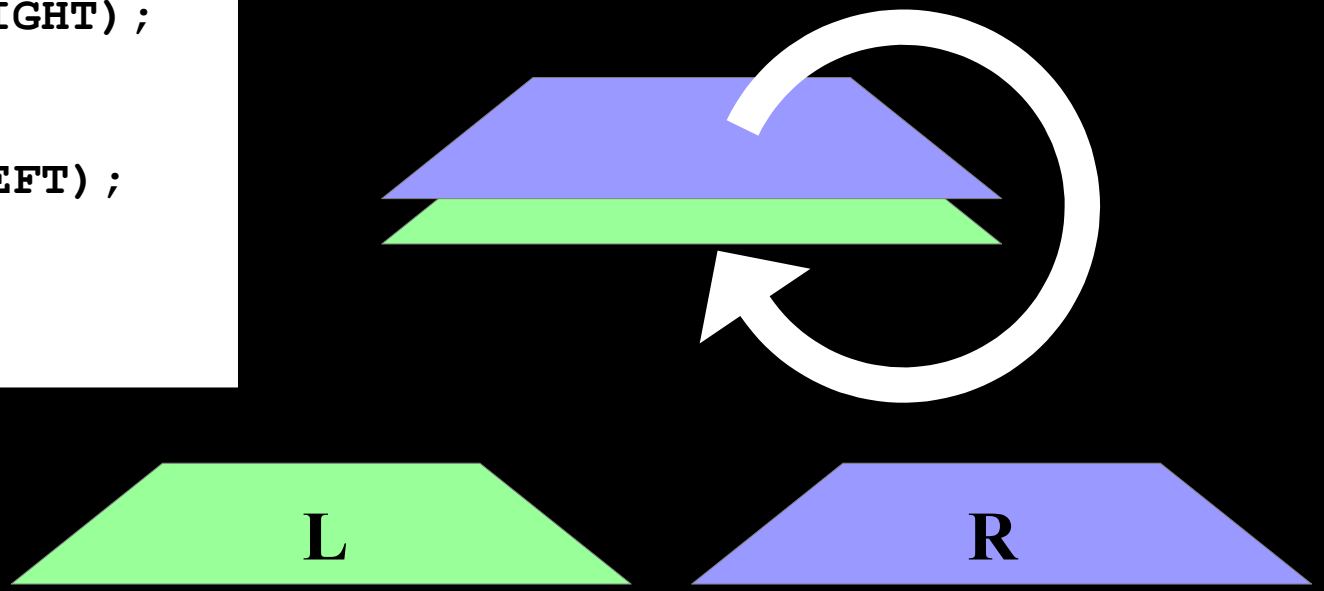




Stereo Rendering - Time Multiplex

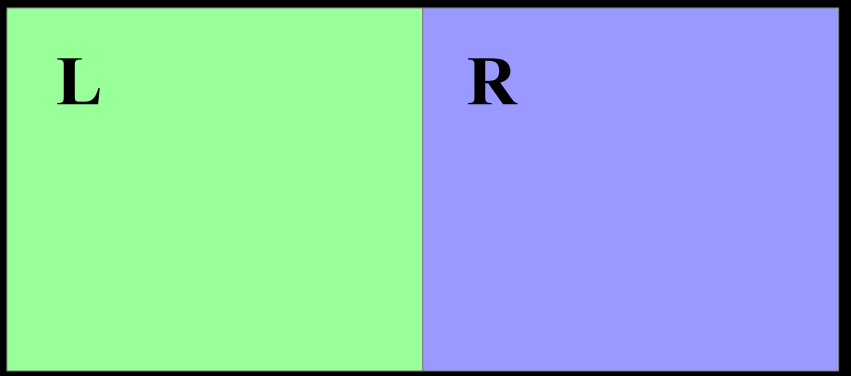
- Active stereo TV/monitor/projector
  - VR Theatre, Dome, CAVE, VR Workbench
- Quad Buffers
  - GL_BACK_LEFT, GL_BACK_RIGHT

```
glDrawBuffer(GL_BACK_RIGHT);
render(RIGHT_EYE);

glDrawBuffer(GL_BACK_LEFT);
render(LEFT_EYE);

glutSwapBuffers();
```



Stereo Rendering - Split

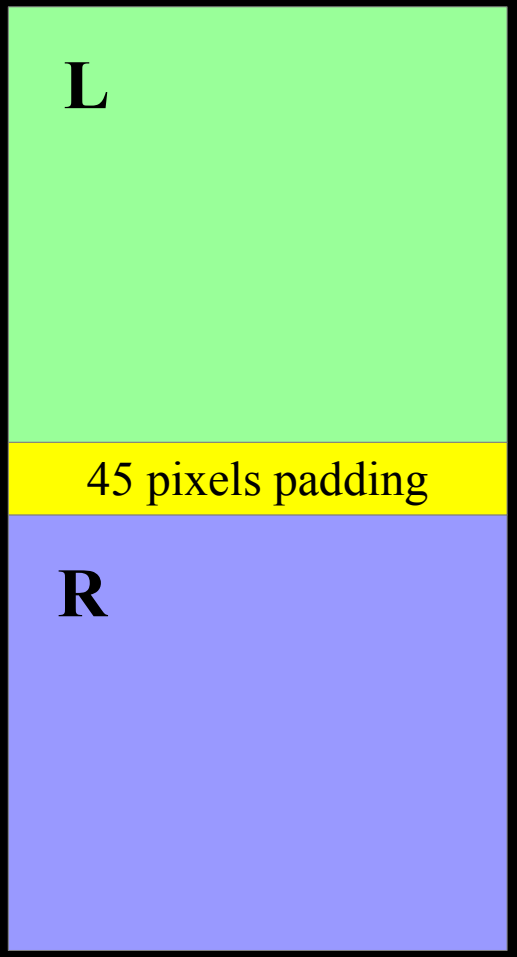
- Head Mounted Displays and 3DTV
- Viewports
  - Render one eye to each of two viewports
  - Side-by-side or above-below




```
glViewport(0,0,0.5*width,height);
render(RIGHT_EYE);

glViewport(0.5*width,0,0.5*width,height);
render(LEFT_EYE);

glutSwapBuffers();
```

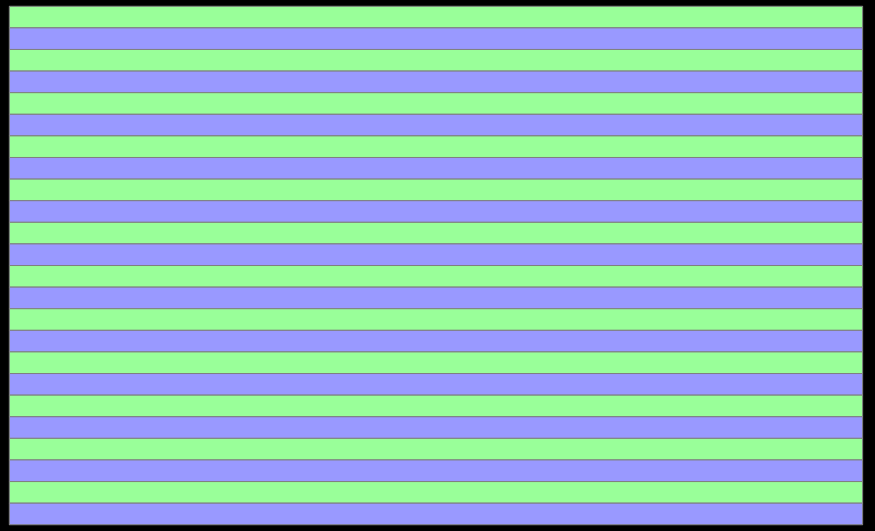
Stereo Rendering – Frame Packing 3D

- Frame Packing format
  - HDMI HD standard ≥1.4
  - Height: 2x 1080 + 45 = 2205 pixels
  - Width: 1920 pixels



Stereo Rendering - Interlaced

- Polarized TV/monitor
  - VR Workbench
- Stencil mask
  - Masking out the other eye



```
For i and j
  stencil_mask[i*w+j]=(i+1)%2;
glDrawPixels( stencil_width, stencil_height,
              GL_STENCIL_INDEX, GL_UNSIGNED_BYTE,
              stencil_mask );
```

```
glEnable(GL_STENCIL_TEST);
glStencilOp(GL_KEEP,GL_KEEP,GL_KEEP);
glStencilFunc(GL_EQUAL,1,1);
render(RIGHT_EYE);

glStencilFunc(GL_NOTEQUAL,1,1);
render(LEFT_EYE);
```

Sound Modality

Sound in Virtual Reality

- Environmental sound
  - ambient
  - atmosphere
- Direct sound
  - events and attention
  - speech, objects and actions

Environment Simulation

- Simplified model
- Reverberation – add echo
  - long delay for large rooms
  - short delay for small rooms
  - less reverberation for outdoor

Environment Simulation

- Filters – especially low pass
  - filters for occluded sound sources
  - filter to simulate phones, intercom, etc.
- Materials and geometries
  - hard surfaces reflect more
  - textiles and furniture removes reverberation
  - sound around corners, behind objects, etc

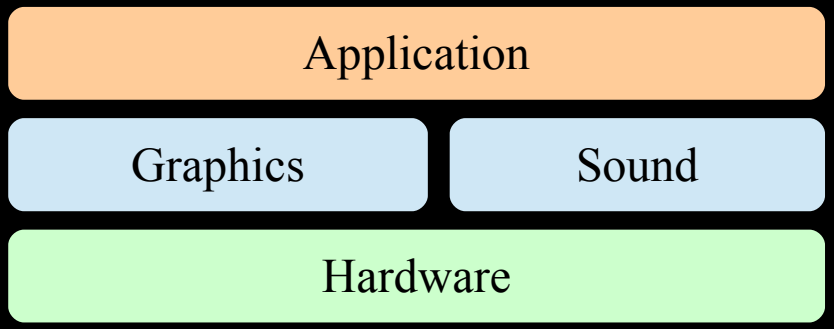
3D Sound

- Simple approach
  - inter-aural intensity difference
- Advanced CPU or Sound Card Processing
  - HRTF, spatialization, ambisonics
  - Advanced filtering
- Requires
  - Head tracking
  - Good audio system

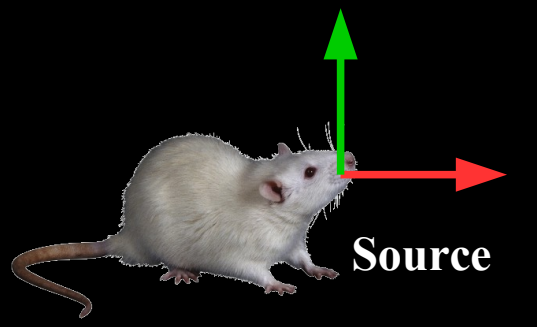
    (headphones)

Sound Rendering

- Sound card support
  - OpenAL (Creative AFX, EFX, etc)
  - DirectSound3D (DirectX submodule)
- Software rendering
  - ALSoft, Rapture3D, FMOD Ex, etc
  - Not any API!



Sound Rendering




```
Vec3 listener_pos = T_view * vp_pos;

alListener3f(AL_POSITION, listener_pos.x, listener_pos.y,
listener_pos.z);

Vec3 listener_up = R_view * vp_orn * Vec3f(0, 1, 0);
Vec3 listener_lookat  = R_view * vp_orn * Vec3f(0, 0, -1);
ALfloat listener_orn[] =
  { listener_lookat.x, listener_lookat.y, listener_lookat.z,
    listener_up.x, listener_up.y, listener_up.z };

alListenerfv(AL_ORIENTATION, listener_orn);

alSource3f(al_source, AL_POSITION,
           sound_pos.x, sound_pos.y, sound_pos.z);
```

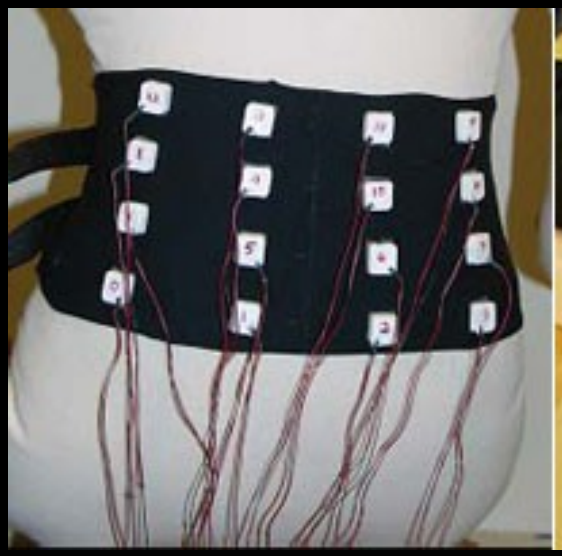
Haptic Modality

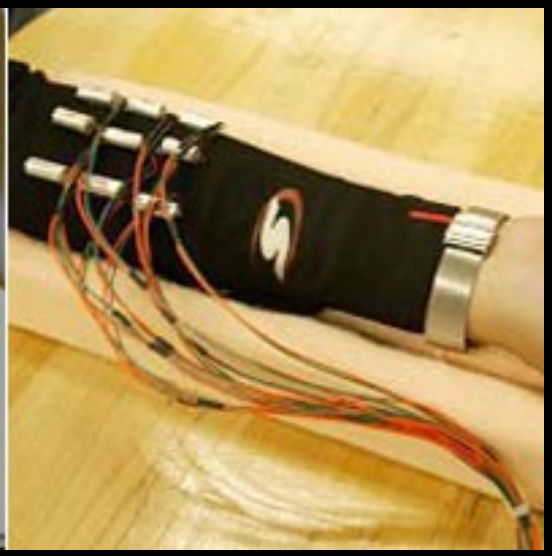
Haptic Perception

- Tactile senses (cutaneous)
  - Nerves under skin
  - Pressure, shear, slip
    - Micro shape, vibrations, etc
  - Temperature, pain
- Kinaethetic senses (proprioception)
  - Nerves in muscles and joints
  - Forward kinematics
  - Position, force, macro shapes, weight

Vibrotactile Devices

- Vibrating elements
  - Based on motor or speaker
  - Distributed over body
  - Put into objects, e g input devices



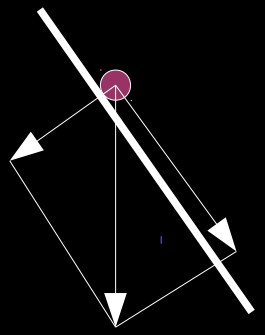


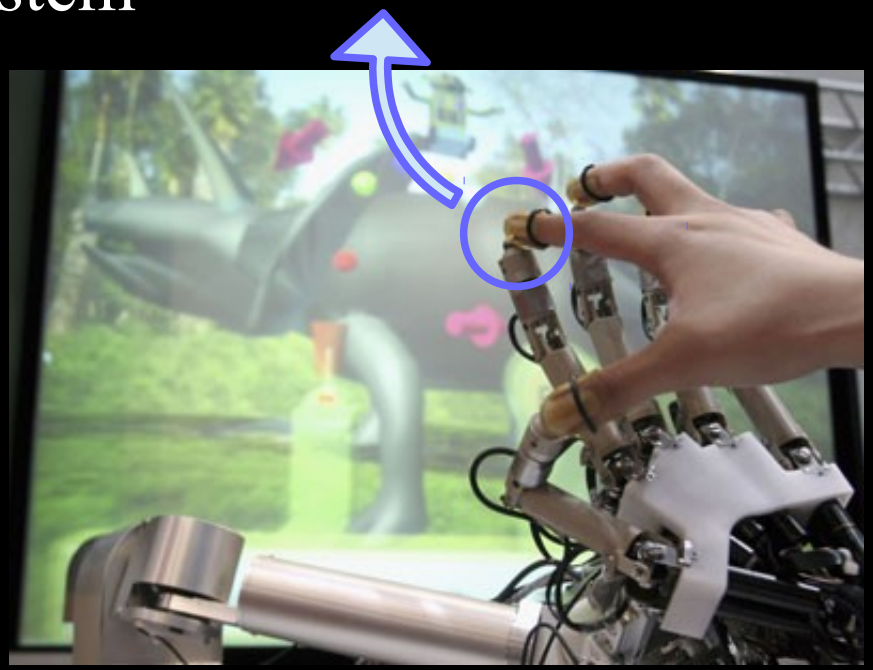
Force Feedback Wand/Stylus

- Single mechanical arm
  - Sensable
    - Desktop PHANToM
    - Premium PHANToM
    - PHANToM Omni
- Multiple mechanical arms
  - Force Dimensions
    - Delta, Omega
  - Novint
    - Falcon (Force Dimension)
  - Haption
    - Virtuose 6D

Haptic Rendering

- Low level programming
  - `EffectOutput calculateForces(const EffectInput &input );`
- Medium level programming
  - Define simple surface
  - The API handles the control system
- High level programming
  - Multi-modal scenegraph
  - Add material properties
  - For example H3D API





Haptics in Virtual Reality

Haptics in Scientific Visualization