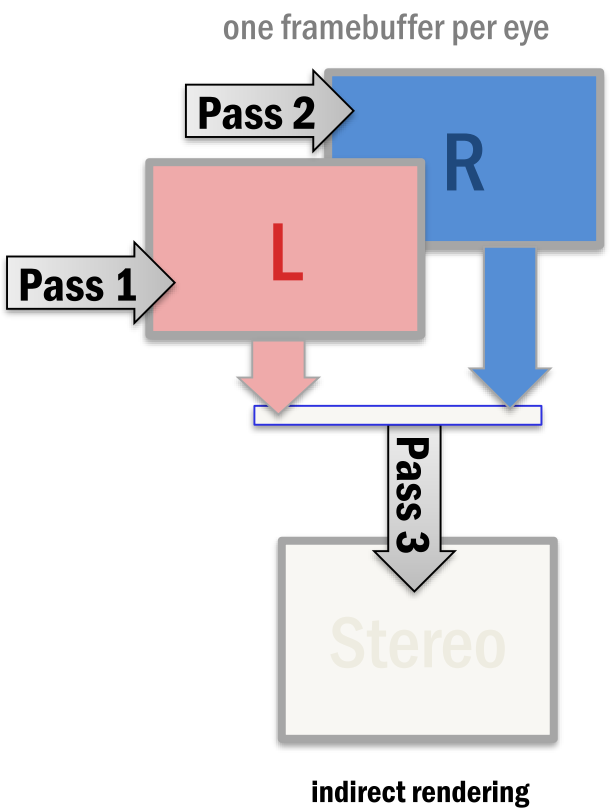
Exercise 1

Stereo

Multi Pass Rendering

- One framebuffer per eye - each with color and depth texture
- Corresponding Indices:
  - 0 .. Left
  - 1 .. Right
- Final shader program combining the two views



Stereo Rendering – Indirect Mode


```
protected:
    texture      col_texs[2], dep_texs[2], rnd_tex;
    frame_buffer fbos[2];
    shader_program finalize_prog;
public:
    stereo() : node("stereo"), col_texs{ "[R,G,B]", "[R,G,B]" },
               dep_texs{ "[D]", "[D]" }, rnd_tex("[R,G,B]")
    {
        for (int i = 0; i < 2; ++i) {
            col_texs[i].set_mag_filter(TF_NEAREST);
            col_texs[i].set_min_filter(TF_NEAREST);
            dep_texs[i].set_mag_filter(TF_NEAREST);
            dep_texs[i].set_min_filter(TF_NEAREST);
    }  }
    void init_frame(context& ctx)
    {
        unsigned w = ctx.get_width(), h = ctx.get_height();
        if (!fbos[0].is_created()) {
            for (int i = 0; i < 2; ++i) {
                col_texs[i].set_width(w); col_texs[i].set_height(h);
                col_texs[i].create(ctx);
                dep_texs[i].set_width(w); dep_texs[i].set_height(h);
                dep_texs[i].create(ctx);
                fbos[i].create(ctx, w, h);
                fbos[i].attach(ctx, dep_texs[i]);
                fbos[i].attach(ctx, col_texs[i]);
                if (!fbos[i].is_complete(ctx)) {
                    std::cerr << "ups should be complete!" << std::endl;
    :
```

declaration of color & depth textures, framebuffer object and shader program

Initialization of texture format and disabling of texture filtering

creation of textures and fbo as GPU objects based on render context ctx

textures are attached to fbo who is then checked for completeness

Stereo Rendering – Indirect Mode


```
void indirect_two_pass_stereo(context& ctx)
{
   mat4 MVP[2];
   // render once per eye
   for (int i = 0; i < 2; ++i) {
      // enable rendering to fbo of eye
      fbos[i].enable(ctx);
      // clear framebuffer and setup modelview projection of eye
      :
      // store per eye modelview projection matrix
      MVP[i] = ctx.get_projection_matrix()*ctx.get_modelview_matrix();
      // render scene
      render_scene(ctx);
      // recover previous state
      fbos[i].disable(ctx);
   }
   mat4 iMVP[2] = { inv(MVP[0]), inv(MVP[1]) };
   col_texs[0].enable(ctx, 0); finalize_prog.set_uniform(ctx, "col_tex_0", 0);
   dep_texs[0].enable(ctx, 2); finalize_prog.set_uniform(ctx, "dep_tex_0", 2);
   :
   finalize_prog.set_uniform(ctx, "MVP_l", MVP[0]);
   finalize_prog.set_uniform(ctx, "iMVP_l", iMVP[0]);
   :
   glDisable(GL_DEPTH_TEST);
   render_screen_filling_quad(ctx, finalize_prog);
   glEnable(GL_DEPTH_TEST);
   col_texs[0].disable(ctx);
   dep_texs[0].disable(ctx);
   :
```

One offline render pass per eye. Modelview projection matrices are memorized

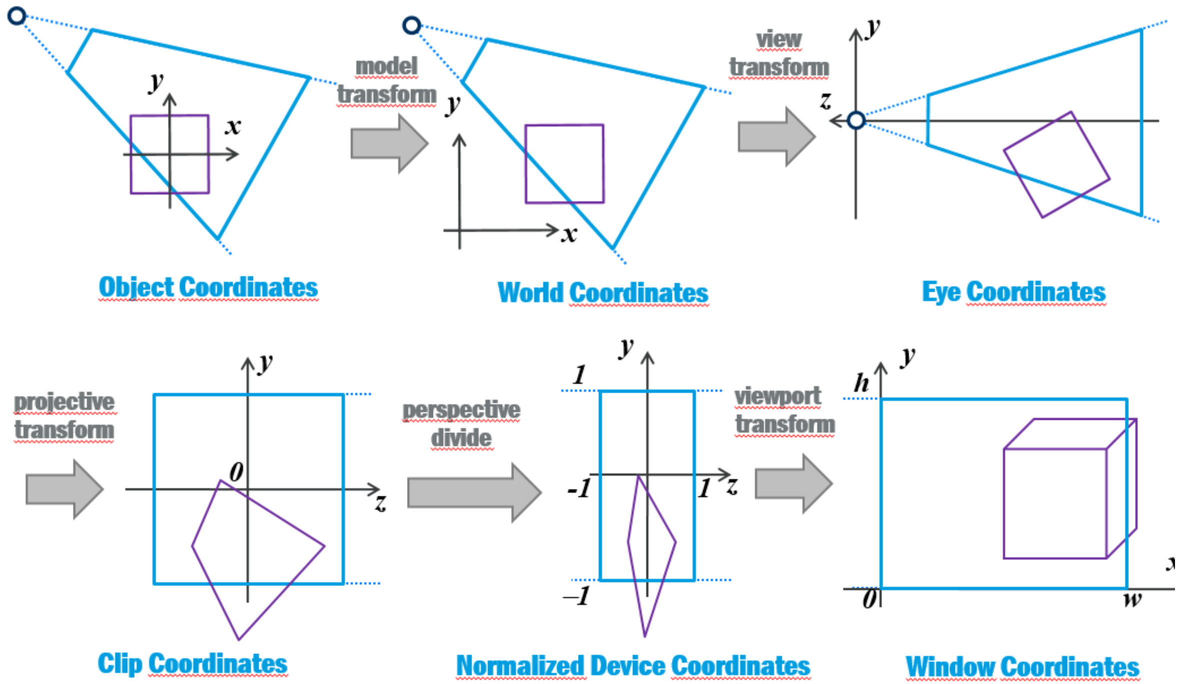
Invert matrices, enable textures and pass uniforms to program

Render screen filling quad ignoring depth test. Here the finalize_prog is used to combine the two images in a single stereo frame

Computergraphik und Visualisierung

Transformation Matrices

see data viz on rendering



Transformation Matrices

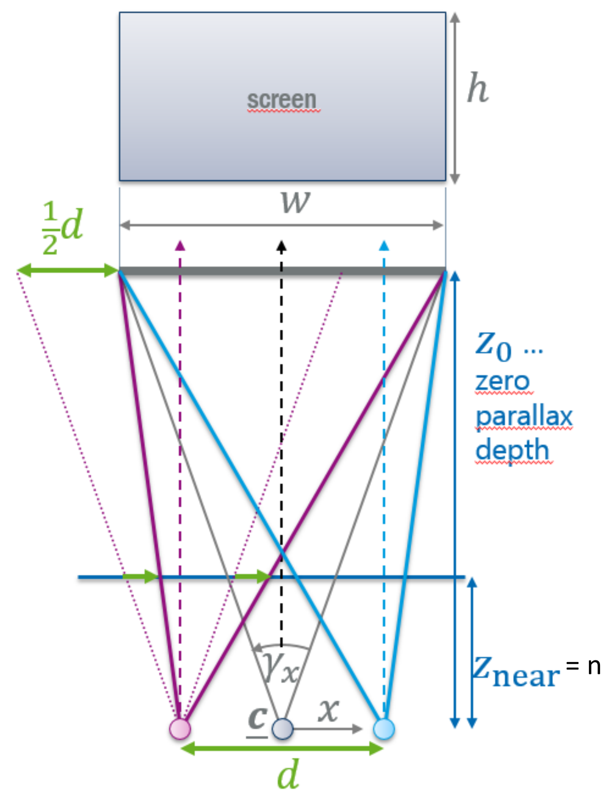
Projection Matrix Frustrum:

$$\boldsymbol{P}_{\text{frustum}}(l,r,b,t,n,f) = \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{n+f}{n-f} & \frac{2nf}{n-f} \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

- l, r … left and right on near clipping plane
- t, b … top and bottom on near clipping plane
- n, f … depth of near and far clipping planes

- view frusti for left / right eye are
  - translated by $\mp½d$ and
  - sheared by $\pm½d/z_0$

Now we have two view frustri:



Transformation Matrices

- **per eye**

$$\boldsymbol{MVP}_{\pm} = \boldsymbol{P}_{\text{frustum},\pm}(l,r,b,t,n,f) \cdot \boldsymbol{MV}_{\pm}$$

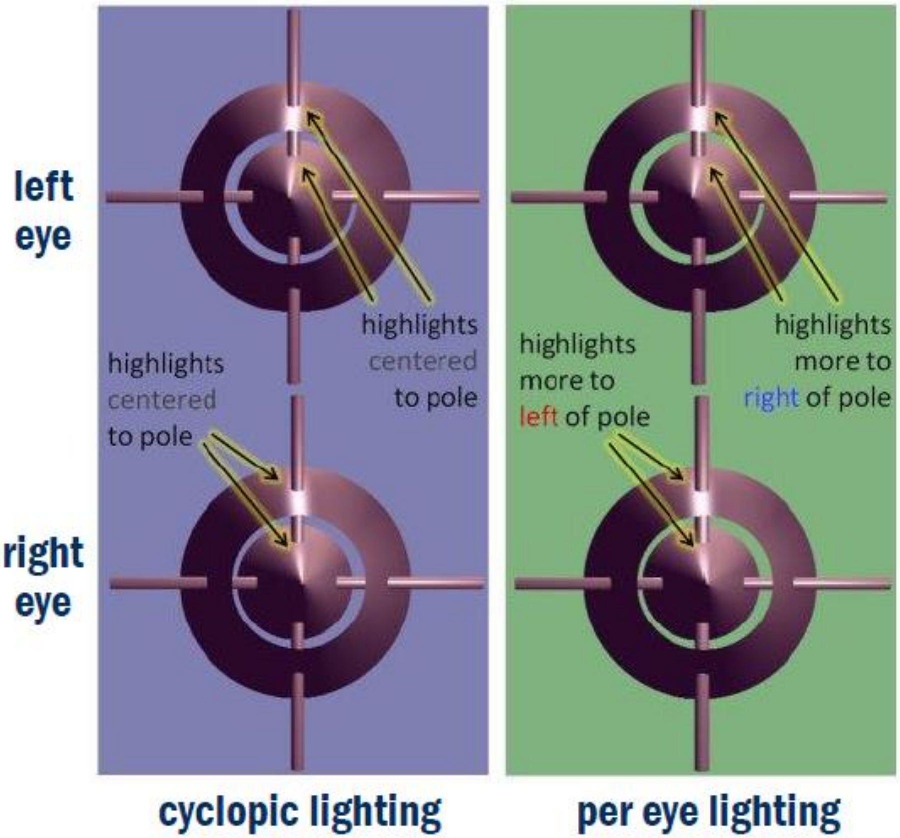
$$\boldsymbol{MV}_{\pm} = \boldsymbol{T}_{\pm} \cdot \boldsymbol{MV}$$

- **cyclopic**

$$\boldsymbol{P}_{\pm} = \boldsymbol{P}_{\text{frustum},\pm}(l,r,b,t,n,f) \cdot \boldsymbol{T}_{\pm}$$

$$\boldsymbol{MVP}_{\pm} = \boldsymbol{P}_{\pm} \cdot \boldsymbol{MV}$$

(subscript −/+ for left/right exe)

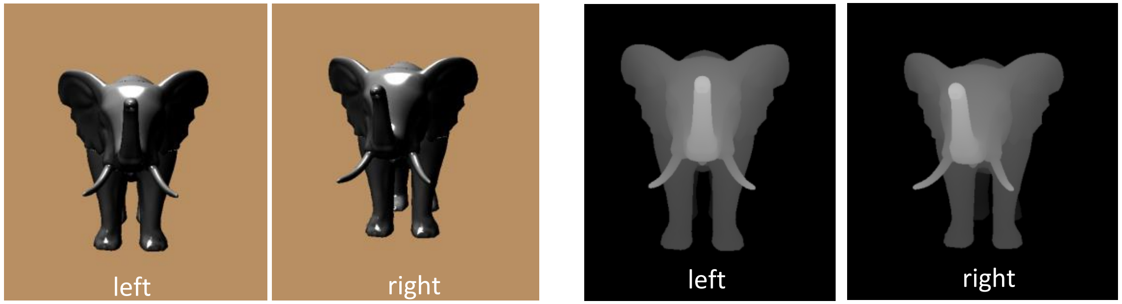


Exercise 1 – Stereo

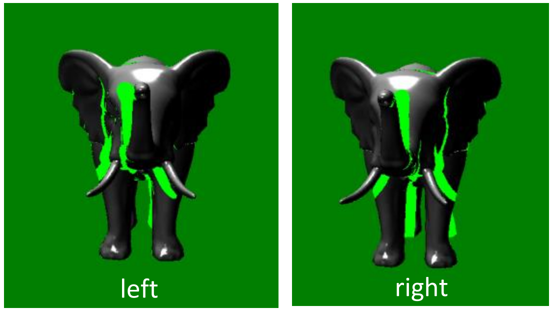
Computergraphik
und Visualisierung

Finalize fragment shader

- Input



- Remapped

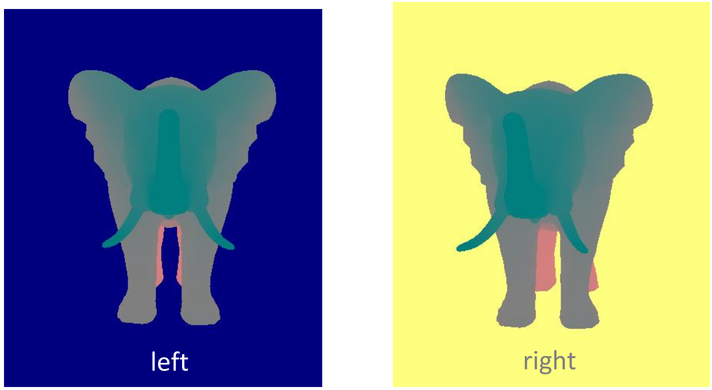


Exercise 1 – Stereo

Computergraphik
und Visualisierung

Finalize fragment shader

- Parallax



- Anaglyph

Exercise 1 – Stereo

Anaglyph

- True Anaglyph

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0{,}299 & 0{,}587 & 0{,}114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0{,}299 & 0{,}587 & 0{,}114 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

- Gray Anaglyph

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0{,}299 & 0{,}587 & 0{,}114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0{,}299 & 0{,}587 & 0{,}114 \\ 0{,}299 & 0{,}587 & 0{,}114 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

http://3dtv.at/Knowhow/AnaglyphComparison_en.aspx

Computergraphik und Visualisierung

Anaglyph

- Color Anaglyph

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

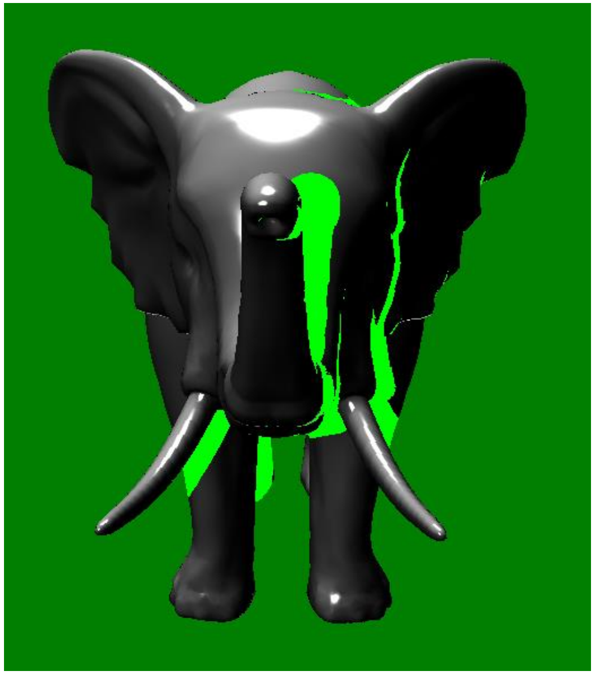
- Half Color Anaglyph

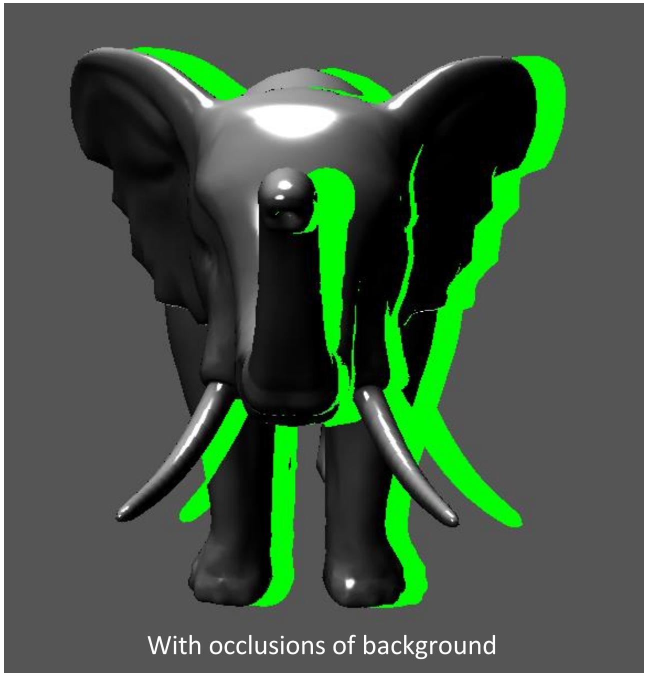
$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0{,}299 & 0{,}587 & 0{,}114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

http://3dtv.at/Knowhow/AnaglyphComparison_en.aspx

Remapping

- Making occlusions visible by using color that the other eye sees





Right view with color texture of left view showing that regions that cannot be seen by the left eye

Stereo Rendering – Remapping

pixel & tex coords

$\underline{x} = (x, y)$ $\underline{\tau} = (u, v)$

colors and depths at $\underline{x}$

$\dddot{c}_0, \dddot{c}_1,$
d_0, d_1

surface points seen at $\underline{x}$ in each image

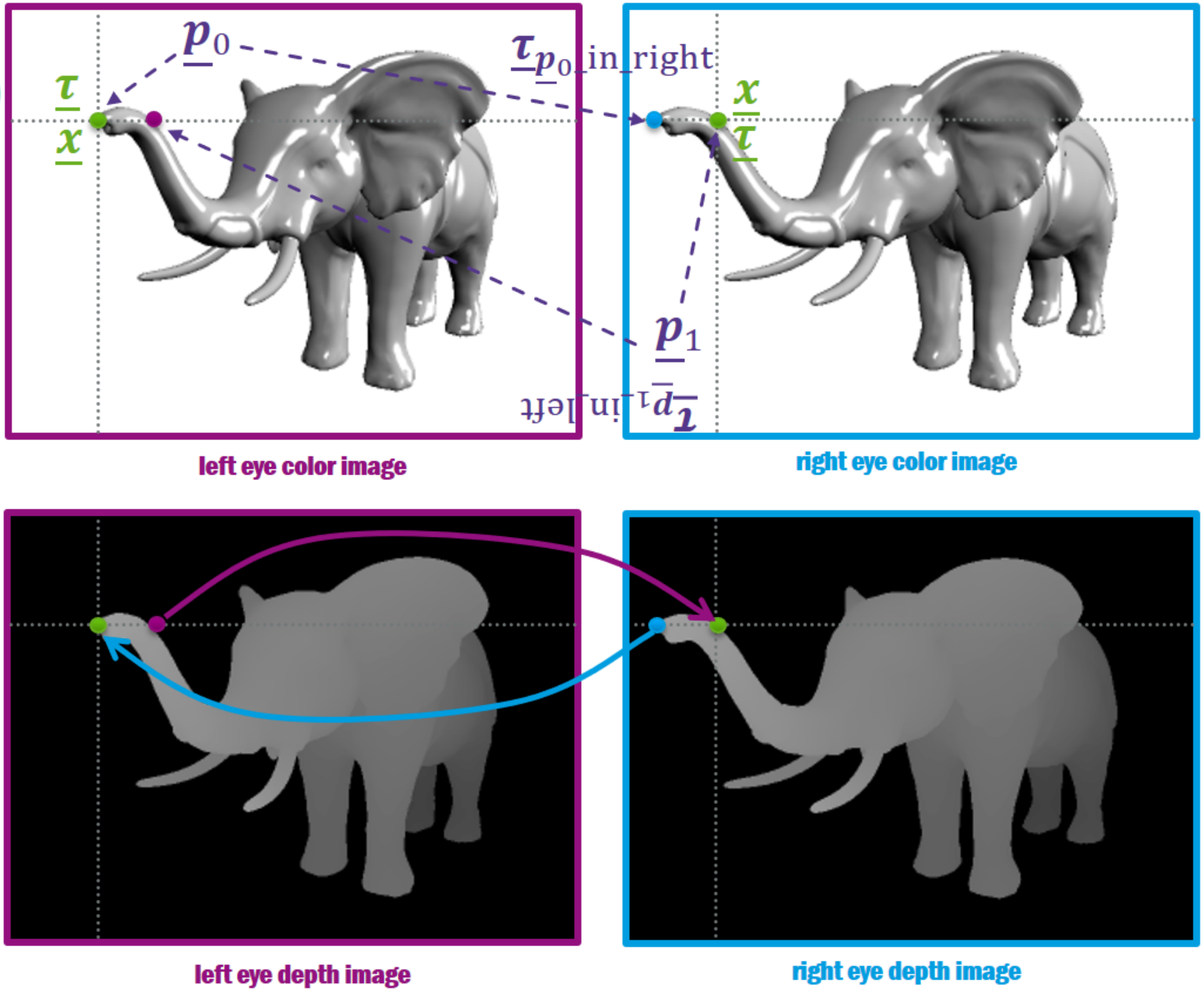
$\underline{p}_0, \underline{p}_1$

remapping surface points into other image by using texture coordinates

$\underline{\tau}_{\underline{p}_0}$_in_right
$\underline{\tau}_{\underline{p}_1}$_in_left

resulting in corresponding colors and depths from other image

$\dddot{c}_{1\_in\_left}, \dddot{c}_{0\_in\_right}$
$d_{1\_in\_left}, d_{0\_in\_right}$



Stereo Rendering – Remapping

$$\begin{pmatrix} x_{window} \\ y_{window} \\ z_{window} \end{pmatrix} = \begin{pmatrix} \frac{w}{2}(x_{NDC}+1)+x \\ \frac{h}{2}(y_{NDC}+1)+y \\ \frac{1}{2}(z_{NDC}+1) \end{pmatrix}$$

slide 72

- For remapping one needs to compute texture coordinates $\underline{\tau}_{\underline{p}_0\text{\_in\_right}}$, which is achieved as follows:
  - extract window coordinates of $\underline{p}_0$ from `gl_FragCoord.xy` and depth value from left eye depth image
  - Transport $\underline{p}_0$ back to world coordinates with inverse modelview projection matrix ($\boldsymbol{MVP}_l$) of left eye
  - Transform $\underline{p}_0$ to clip coordinates of right eye with $\boldsymbol{MVP}_r$
  - Perform w-clip and extract texture coordinates from normalized device coordinates
- Finally, use $\underline{\tau}_{\underline{p}_0\text{\_in\_right}}$ to lookup corresponding color / depth values in other textures

```
vec3(gl_FragCoord.xy,
     texture(depth_l,texcrd))
```

$$\begin{pmatrix} x_{window,l} \\ y_{window,l} \\ z_{window,l} \end{pmatrix}$$

$$\begin{pmatrix} x_{NDC,l} \\ y_{NDC,l} \\ z_{NDC,l} \end{pmatrix} = \begin{pmatrix} \frac{2}{w}(x_{window,l}-x)-1 \\ \frac{2}{h}(y_{window,l}-y)-1 \\ 2z_{window,l}-1 \end{pmatrix}$$

$$\begin{pmatrix} x_{clip,r} \\ y_{clip,r} \\ z_{clip,r} \\ w_{clip,r} \end{pmatrix} = \boldsymbol{MVP}_r \boldsymbol{MVP}_l^{-1} \begin{pmatrix} x_{NDC,l} \\ y_{NDC,l} \\ z_{NDC,l} \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} x_{NDC,r} \\ y_{NDC,r} \\ z_{NDC,r} \end{pmatrix} = \frac{1}{w_{clip,r}} \begin{pmatrix} x_{clip,r} \\ y_{clip,r} \\ z_{clip,r} \end{pmatrix}$$

$$\underline{\tau}_{\underline{p}_0\text{\_in\_right}} = \frac{1}{2} \begin{pmatrix} x_{NDC,r}+1 \\ y_{NDC,r}+1 \end{pmatrix}$$

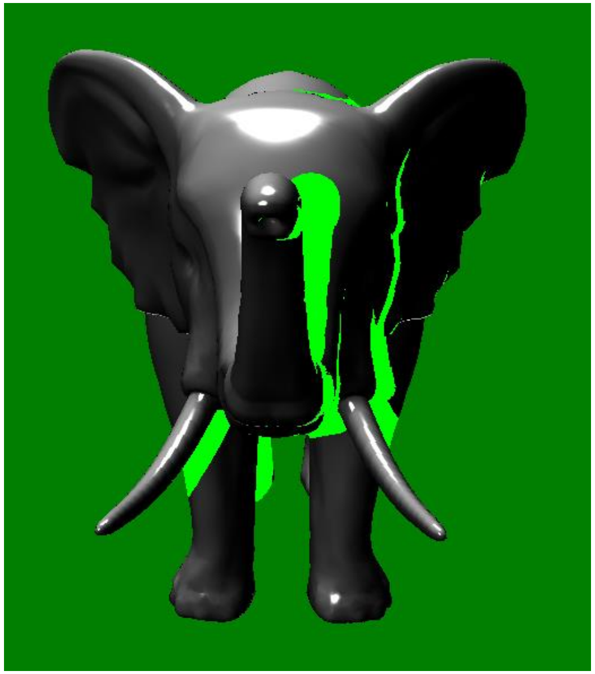
Exercise 1 – Stereo

Computergraphik und Visualisierung

Visibility Check

- Check if surface point $\underline{\boldsymbol{p}}_0$ seen in left image is visible in right image: $d_{1\_\mathrm{in\_left}} = depth_1(\underline{\boldsymbol{\tau}}_{\underline{\boldsymbol{p}}_0\_\mathrm{in\_right}}) \approx d_0$

  If violated, only $d_{1\_\mathrm{in\_left}} < d_0$ possible.

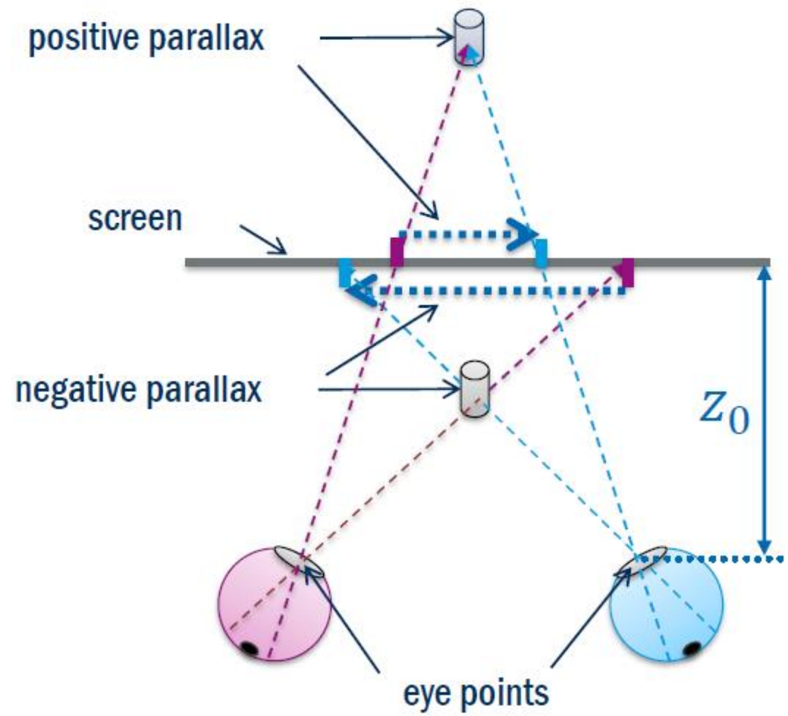


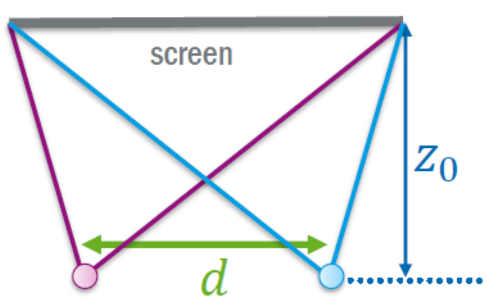
Exercise 1 – Stereo

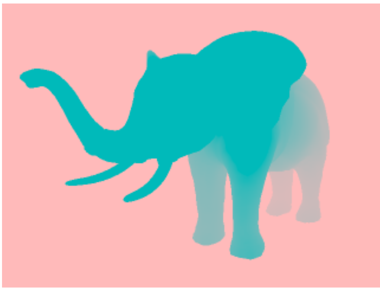
Parallax and Eye Seperation

- Distance between projection points is called parallax
- Parallax p depends on depth z of object, screen depth z_0 (distance of screen wrt eye points) and eye separation d:

$$p(z) = d \cdot (1 - z_0/z)$$







parallax mapped to color (blue negative, red positive)

→ You can use this parallax view if you implemented remapping