

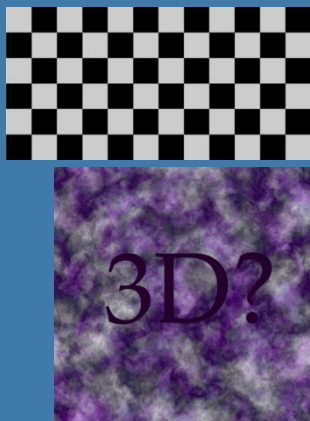
# Texturing

Slides done by Tomas Akenine-Möller  
and Ulf Assarsson

Department of Computer Engineering  
Chalmers University of Technology

# Texturing: Glue n-dimensional images onto geometrical objects

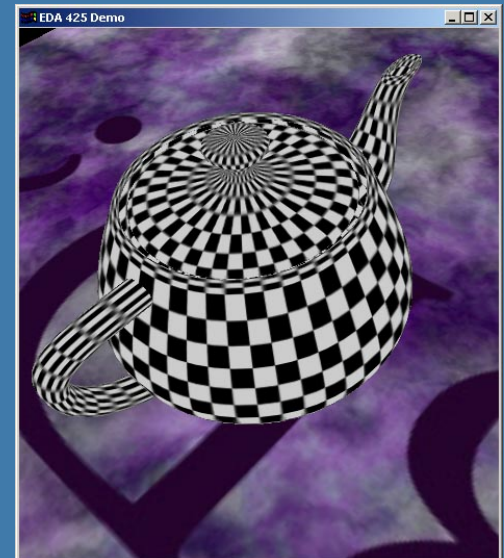
- Purpose: more realism, and this is a cheap way to do it
  - Bump mapping
  - Plus, we can do environment mapping
  - And other things



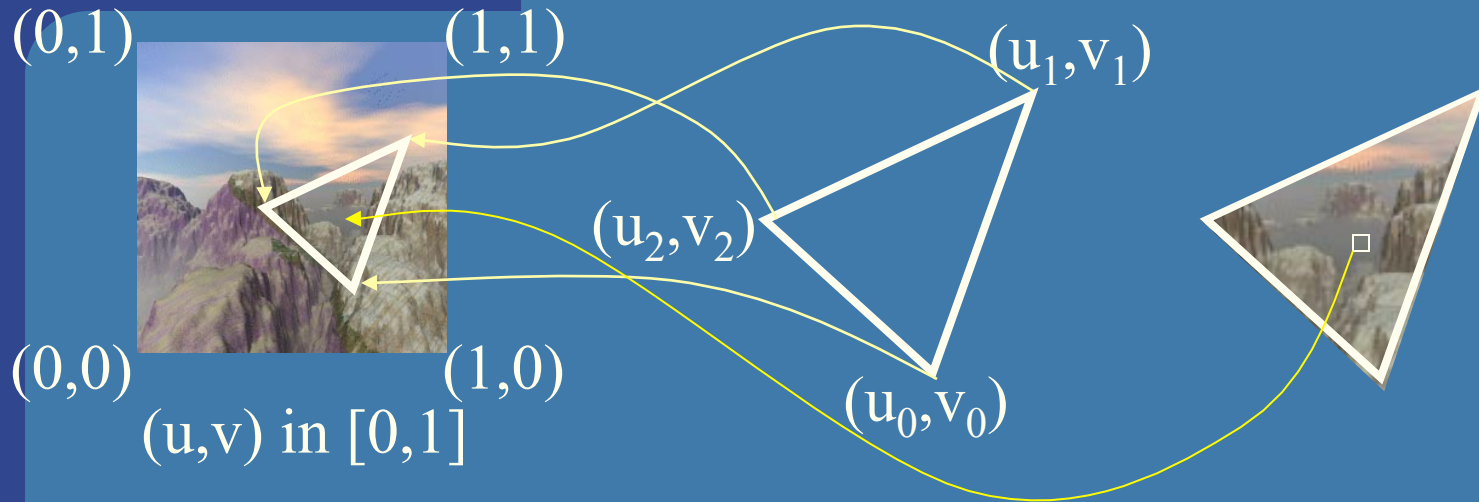
+



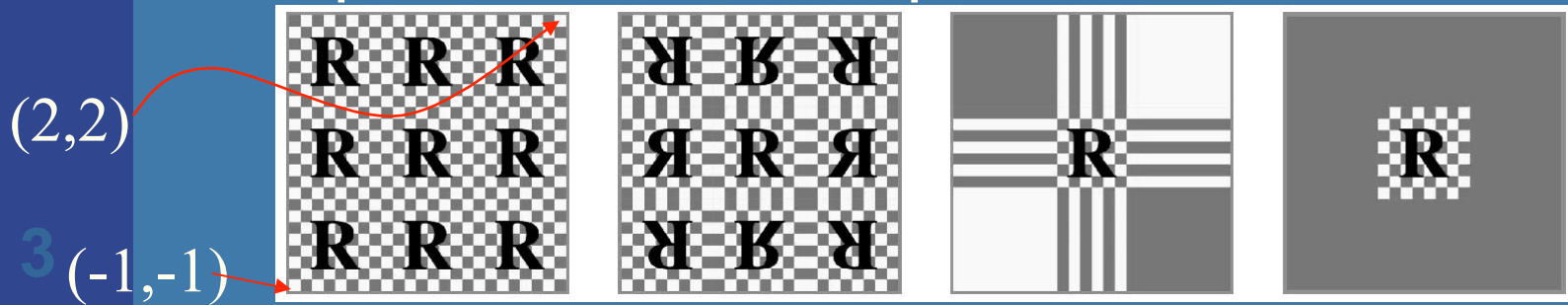
=



# Texture coordinates

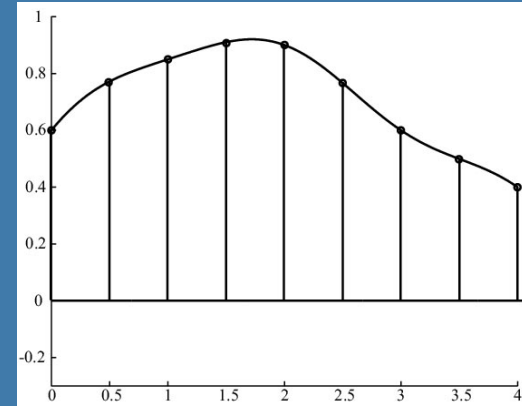
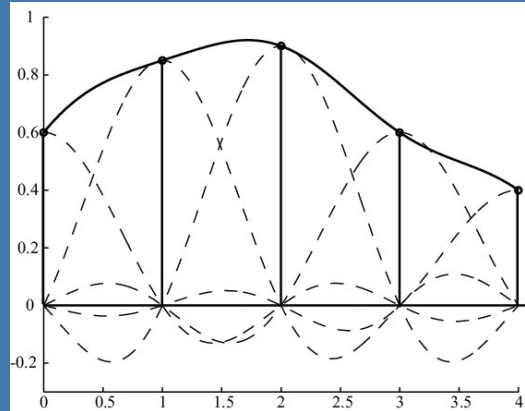


- What if  $(u,v) > 1.0$  or  $< 0.0$  ?
- To repeat textures, use just the fractional part
  - Example:  $5.3 \rightarrow 0.3$
- Repeat, mirror, clamp, border:

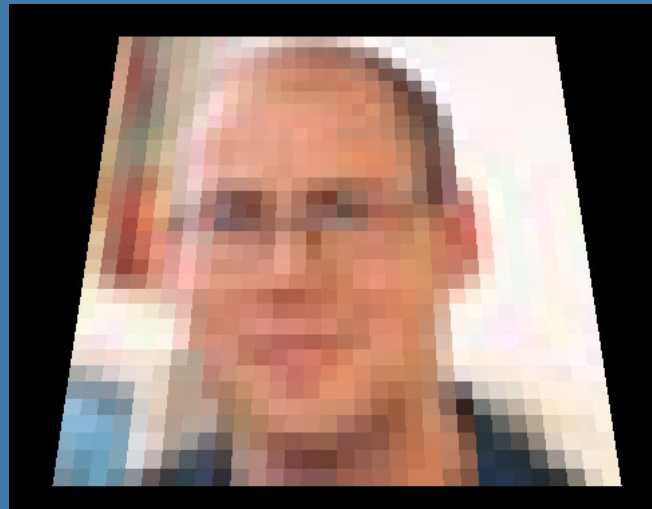


# Texture magnification

- What does the theory say...

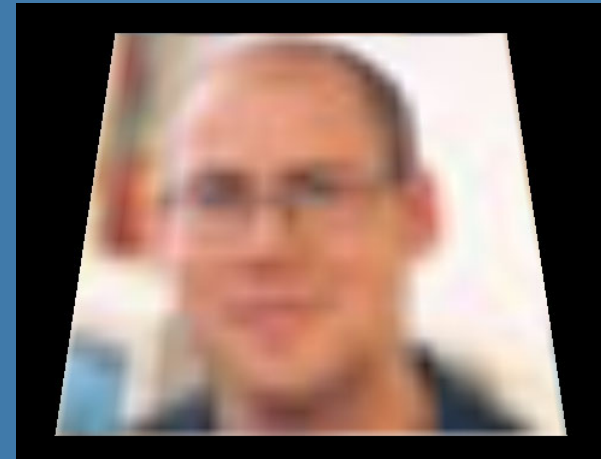
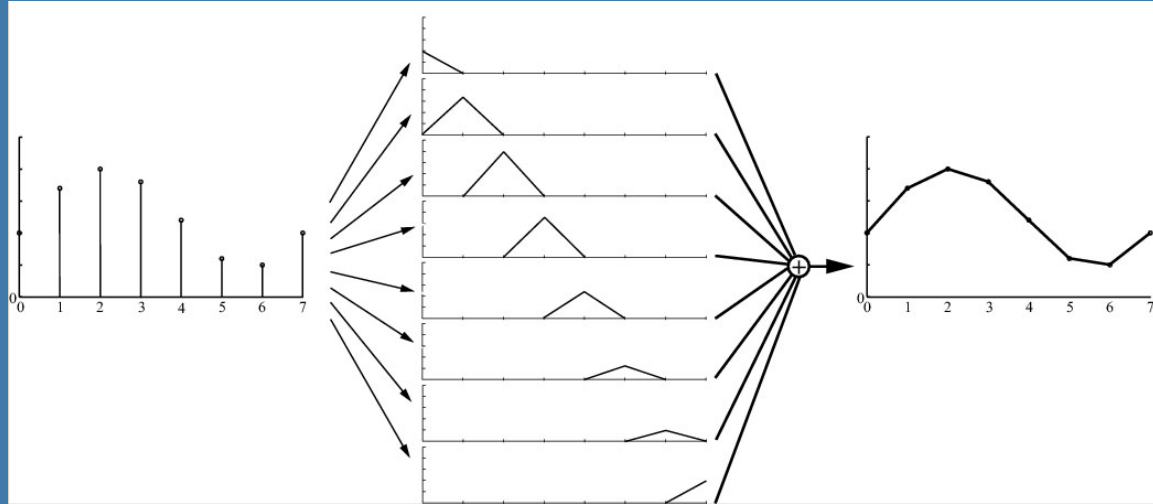


- $\text{sinc}(x)$  is not feasible in real time
- Box filter (nearest-neighbor) is
- Poor quality



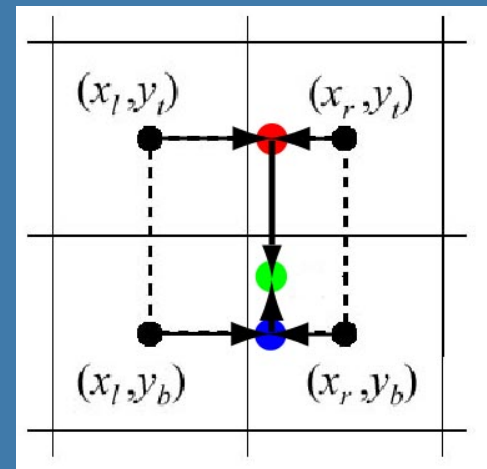
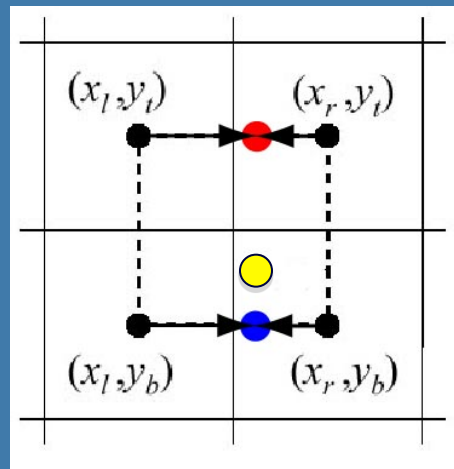
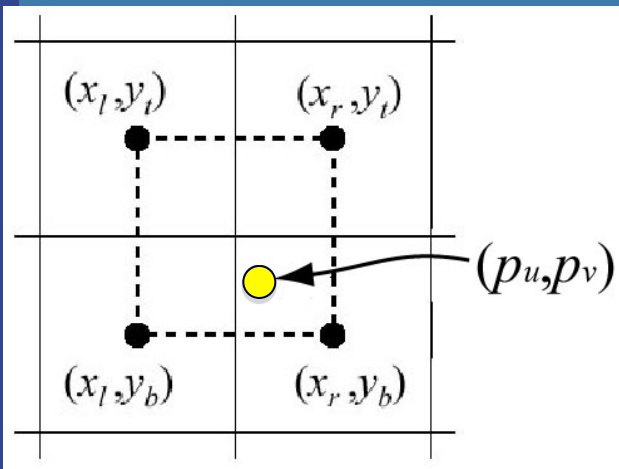
# Texture magnification

- Tent filter is feasible!
- Linear interpolation
- Looks better
- Simple in 1D:
  - $(1-t) \cdot \text{color}_0 + t \cdot \text{color}_1$
- How about 2D?



# Bilinear interpolation

- Texture coordinates  $(p_u, p_v)$  in  $[0,1]$
- Texture images size:  $n*m$  texels
- Nearest neighbor would access:  $(\text{floor}(n*u+0.5), \text{floor}(m*v+0.5))$
- Interpolate 1D in  $x$  &  $y$  respectively



# Bilinear interpolation

- Check out this formula at home
- $\mathbf{t}(u,v)$  accesses the texture map
- $\mathbf{b}(u,v)$  filtered texel

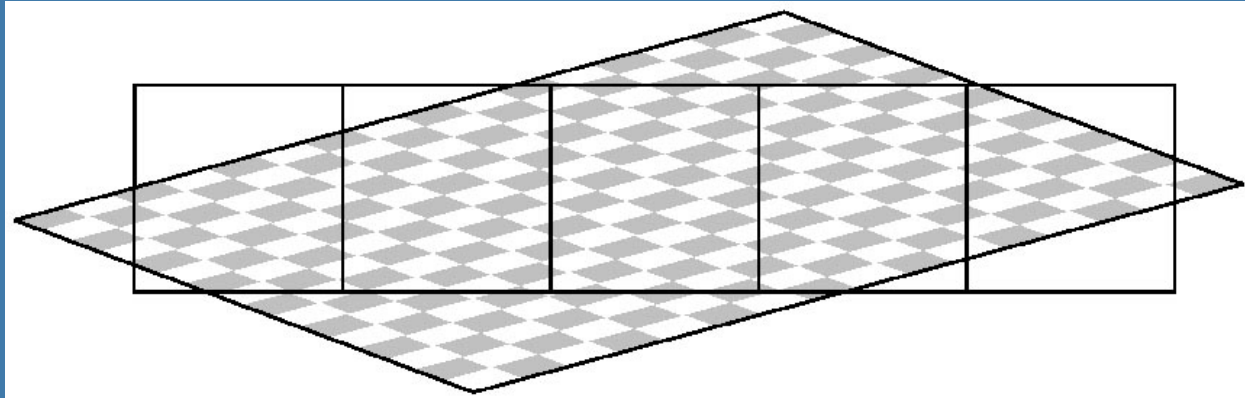
weights

$$(u', v') = (p_u - \lfloor p_u \rfloor, p_v - \lfloor p_v \rfloor).$$

$$\begin{aligned} \mathbf{b}(p_u, p_v) = & (1 - u')(1 - v')\mathbf{t}(x_l, y_b) + u'(1 - v')\mathbf{t}(x_r, y_b) \\ & + (1 - u')v'\mathbf{t}(x_l, y_t) + u'v'\mathbf{t}(x_r, y_t). \end{aligned}$$

# Texture minification

## What does a pixel "see"?

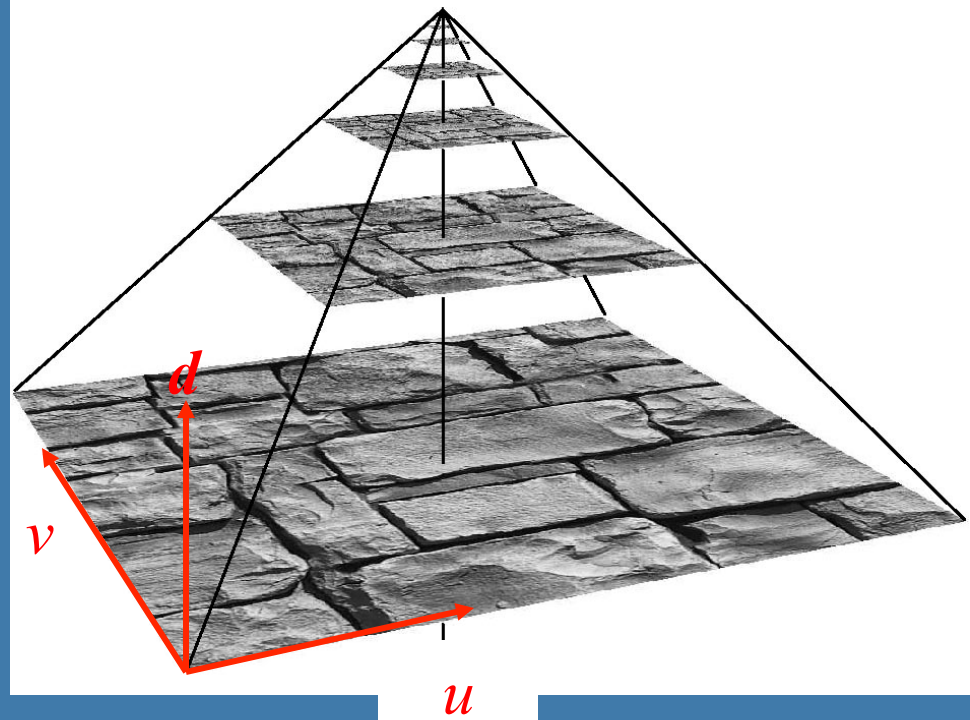


- Theory (sinc) is too expensive
- Cheaper: average of texel inside a pixel
- Still too expensive, actually
- Mipmaps – another level of approximation
  - Prefilter texture maps as shown on next slide



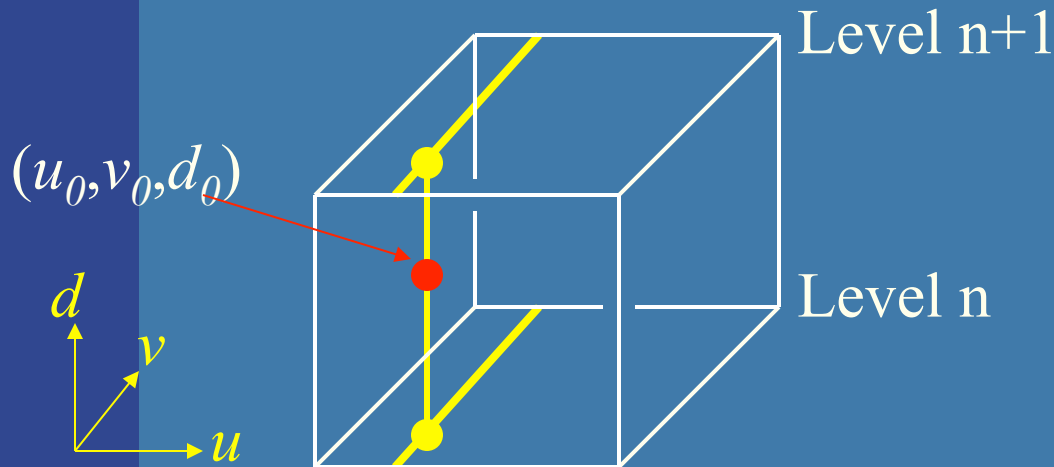
# Mipmapping

- Image pyramid
- Half width and height when going upwards
- Average over 4 "parent texels" to form "child texel"
- Depending on amount of minification, determine which image to fetch from
- Compute  $d$  first, gives two images
  - Bilinear interpolation in each



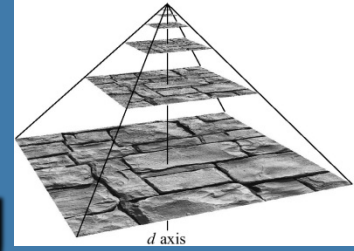
# Mipmapping

- Interpolate between those bilinear values
  - Gives trilinear interpolation

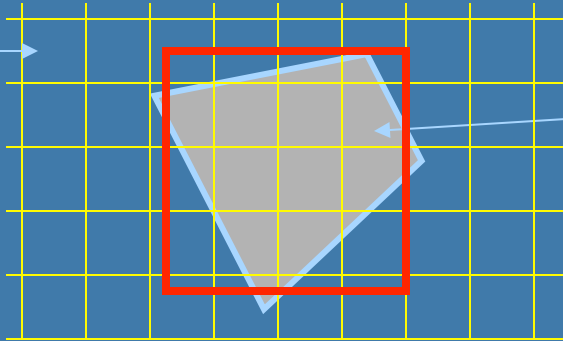


- Constant time filtering: 8 texel accesses
- How to compute  $d$ ?

# Computing $d$ for mipmapping



texel



pixel projected  
to texture space

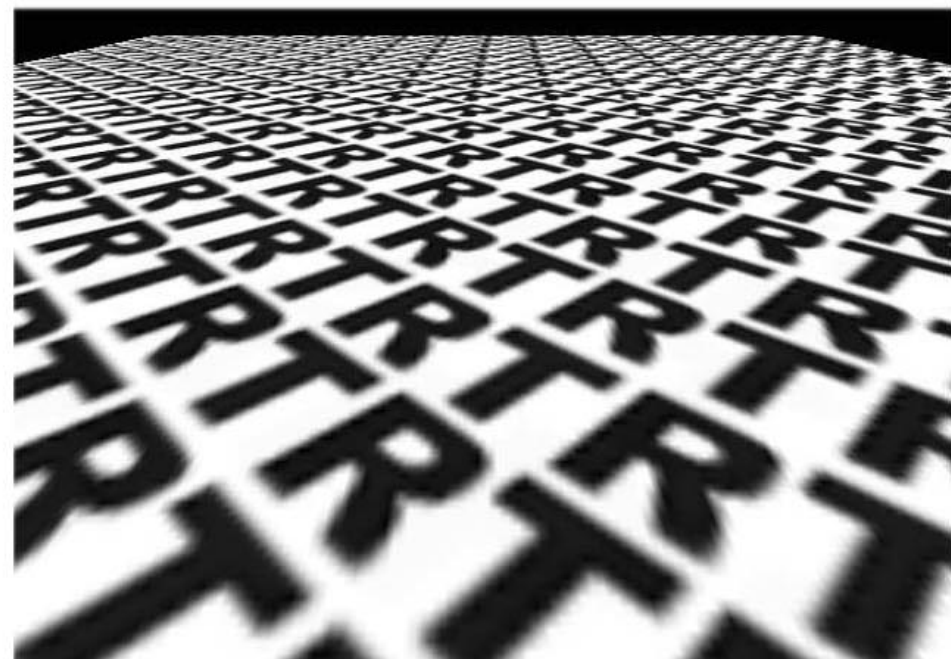
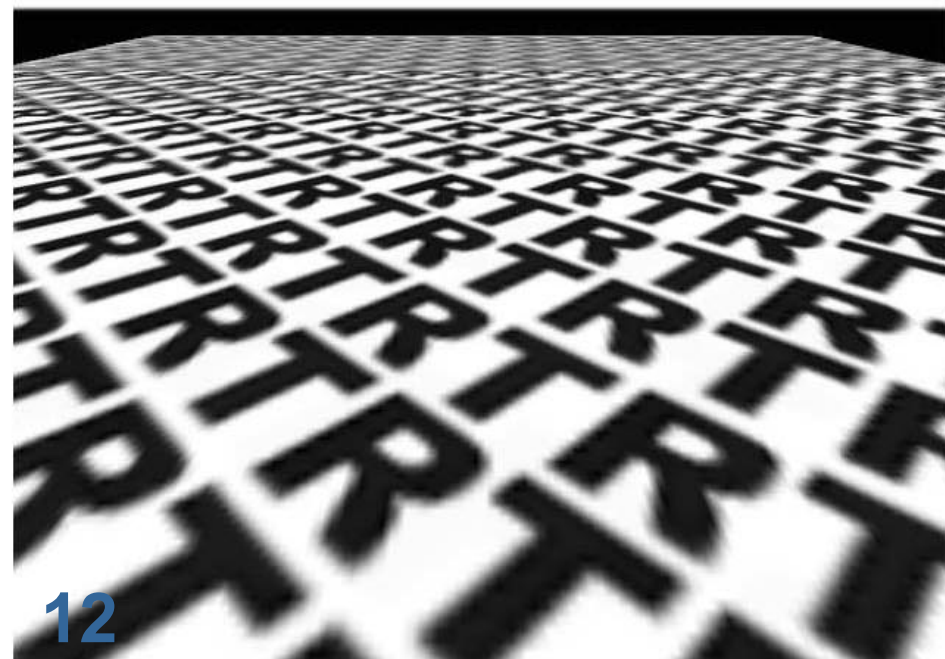
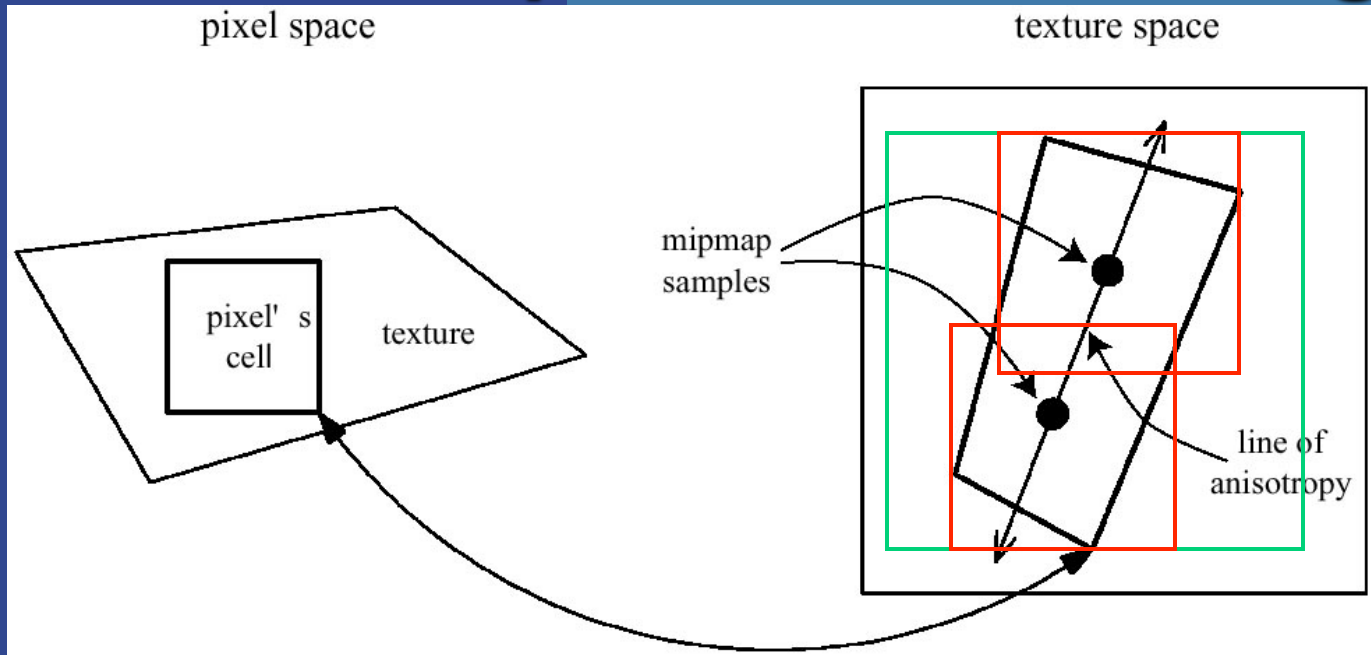
$A$  = approximative area of quadrilateral

$$b = \sqrt{A}$$

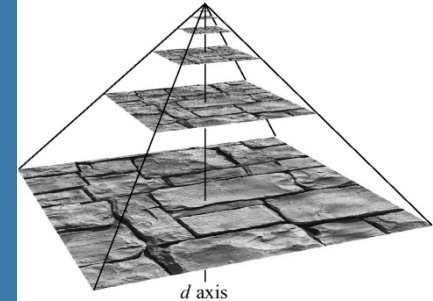
$$d = \log_2 b$$

- Approximate quad with square
- Gives overblur!
- Even better: anisotropic texture filtering
  - Approximate quad with several smaller mipmap samples

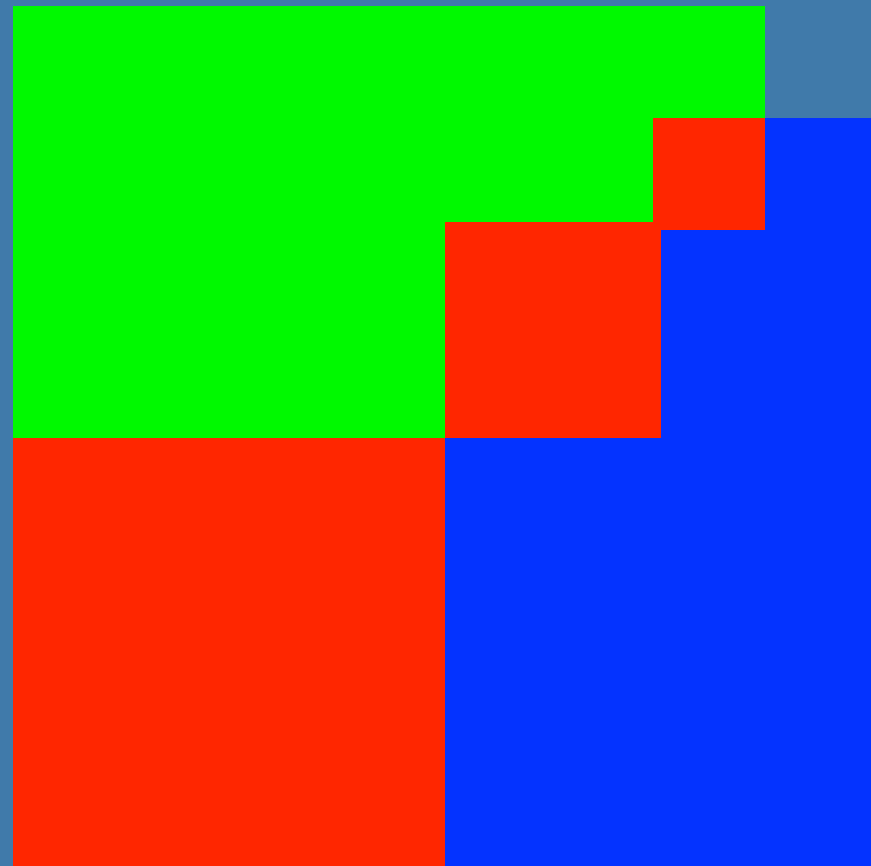
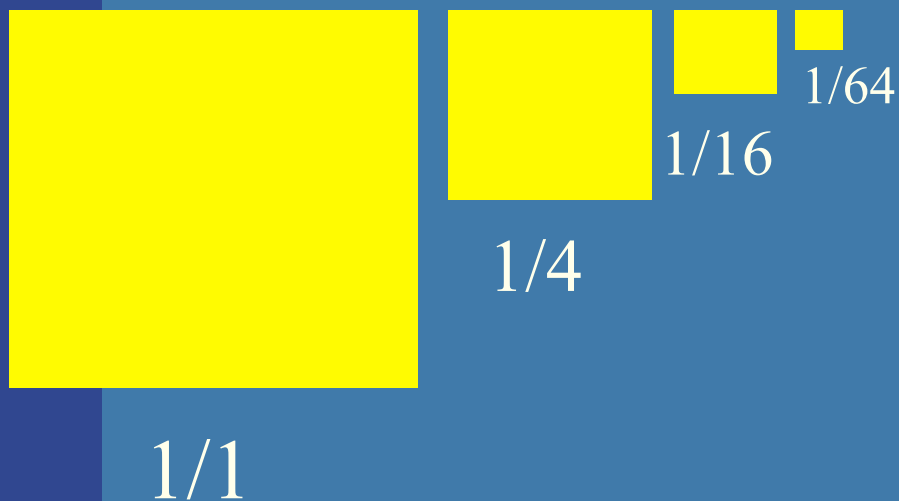
# Anisotropic texture filtering



# Mipmapping: Memory requirements



- Not twice the number of bytes...!



- Rather 33% more – not that much

Modified by Ulf Assarsson 2004

# Miscellaneous

- How to apply texturing:
  - Add, sub, etc as you like, using fragment shaders.

Common alternatives:

- Modulate (multiply texture with lighting)
- Replace (just use texture color)

# Modulate



# Using textures in OpenGL

Do once when loading texture:

```
texture = ilutGLLoadImage("flake.ppm");           // Here, we use DevIL
glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, texture);
glGenerateMipmap(GL_TEXTURE_2D);

glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MAX_ANISOTROPY_EXT, 16);

//Indicates that the active texture should be repeated over the surface
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
// Sets the type of mipmap interpolation to be used on magnifying and
// minifying the active texture. These are the nicest available options.
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER,
GL_LINEAR_MIPMAP_LINEAR);
```

Do every time you want to use this texture when drawing:

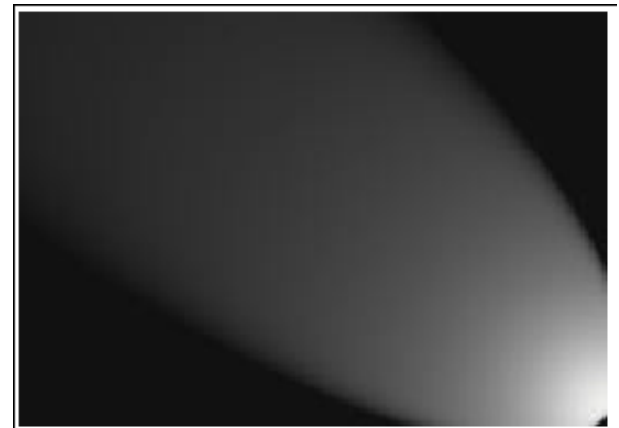
```
glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, texture);
// Now, draw your triangles with texture coordinates specified
```



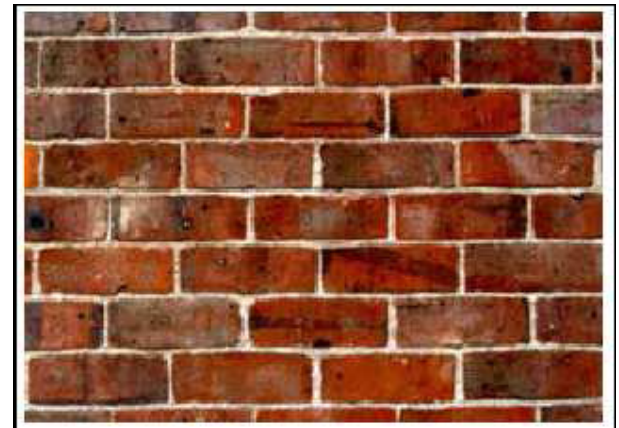
# Light Maps

- Often used in games
- Can use multitexturing, or
  - render wall using brick texture
  - render wall using light texture and blending to the frame buffer

Example



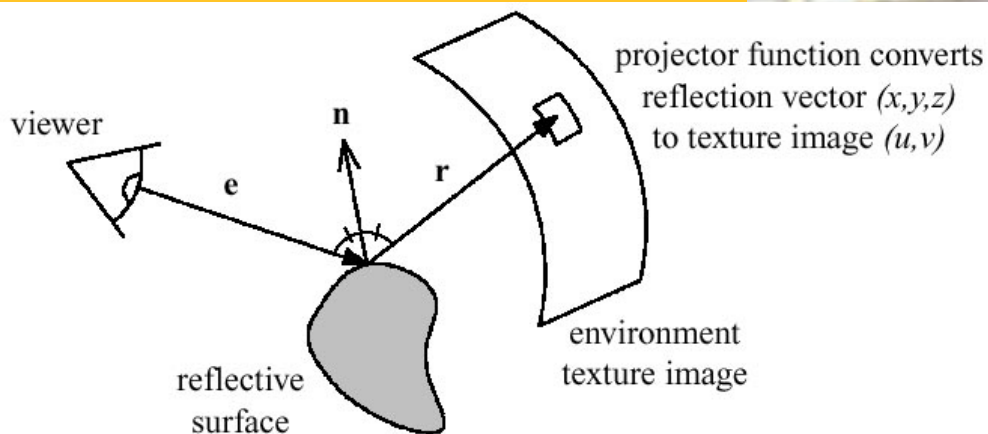
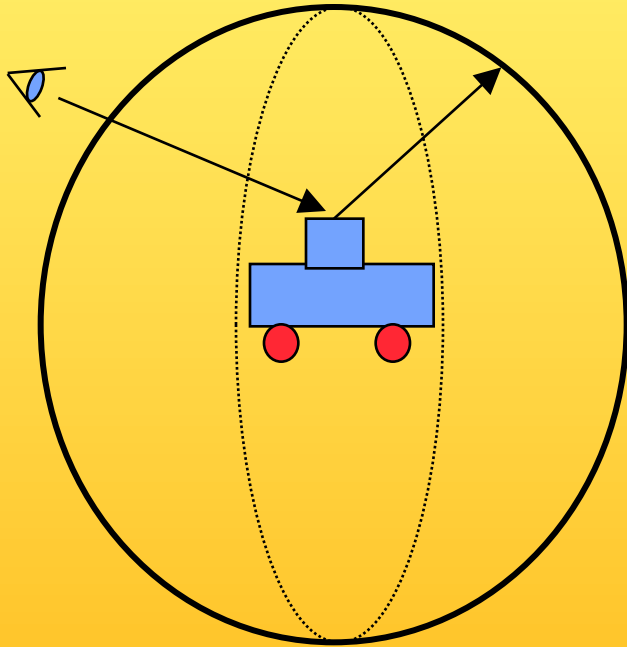
+



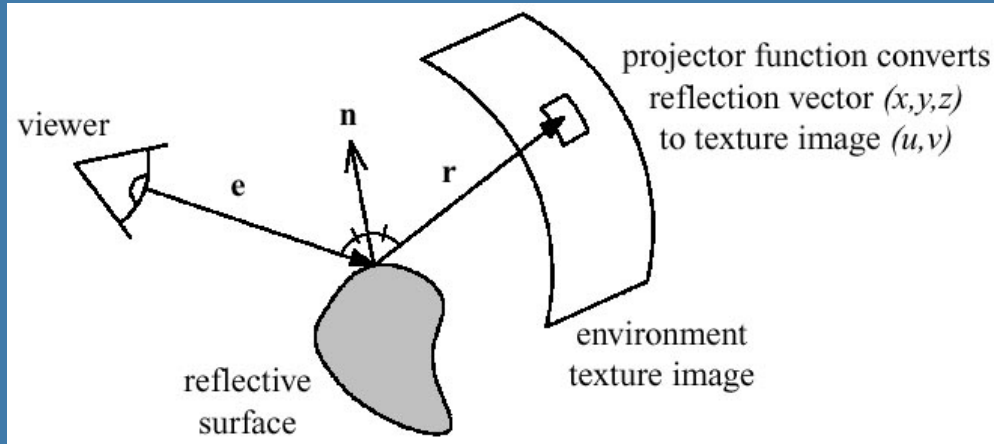
=



# Environment mapping



# Environment mapping



- Assumes the environment is infinitely far away
- Sphere mapping
  - For details, see OH 166-169
- Cube mapping is the norm nowadays
  - Advantages: no singularities as in sphere map
  - Much less distortion
  - Gives better result
  - Not dependent on a view position

# Sphere map

- example

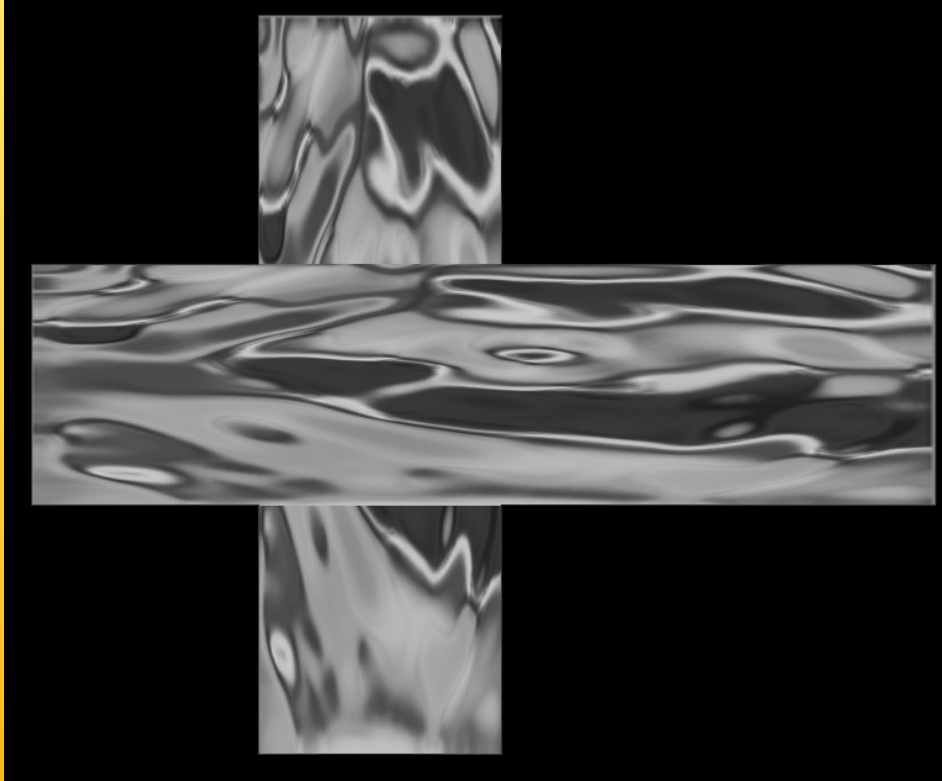


Sphere map  
(texture)



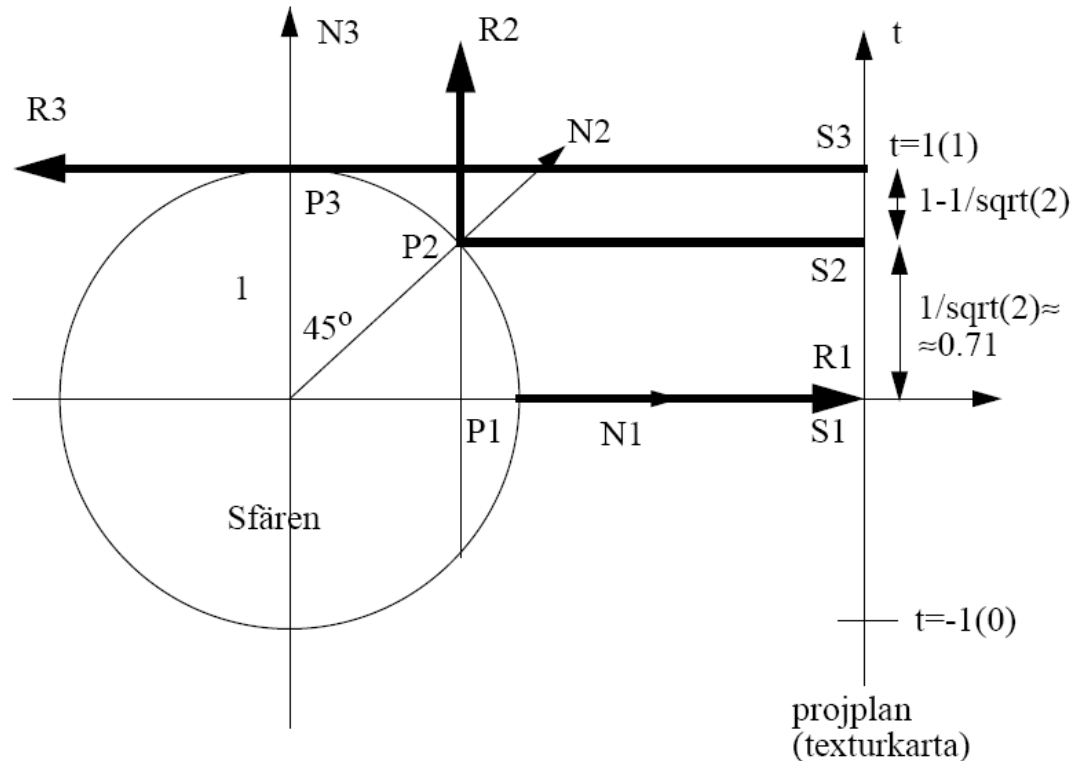
Sphere map  
applied on torus

# Example



# Sphere Map

- Infinitesimally small reflective sphere (infinitely far away)
  - i.e., orthographic view of a reflective unit sphere
- Create by:
  - Photographing metal sphere
  - Ray tracing
  - Transforming cube map to sphere map





# Sphere Map

- Assume surface normals are available
- Then OpenGL can compute reflection vector at each pixel
- The texture coordinates s,t are given by:
  - (see OH 169 for details)

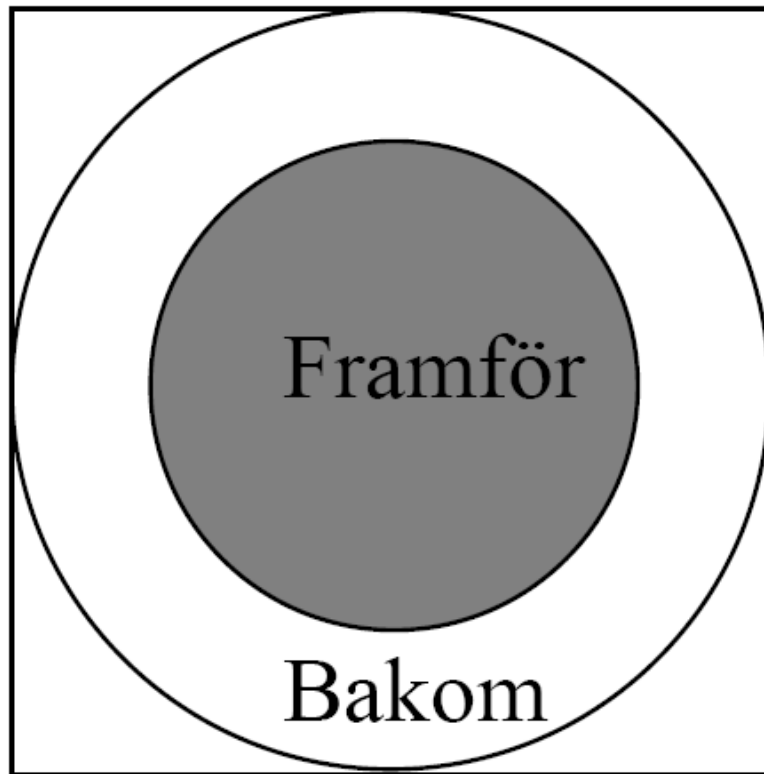
$$L = \sqrt{R_x^2 + R_y^2 + (R_z + 1)^2}$$

$$s = 0.5 \left( \frac{R_x}{L} + 1 \right)$$

$$t = 0.5 \left( \frac{R_y}{L} + 1 \right)$$

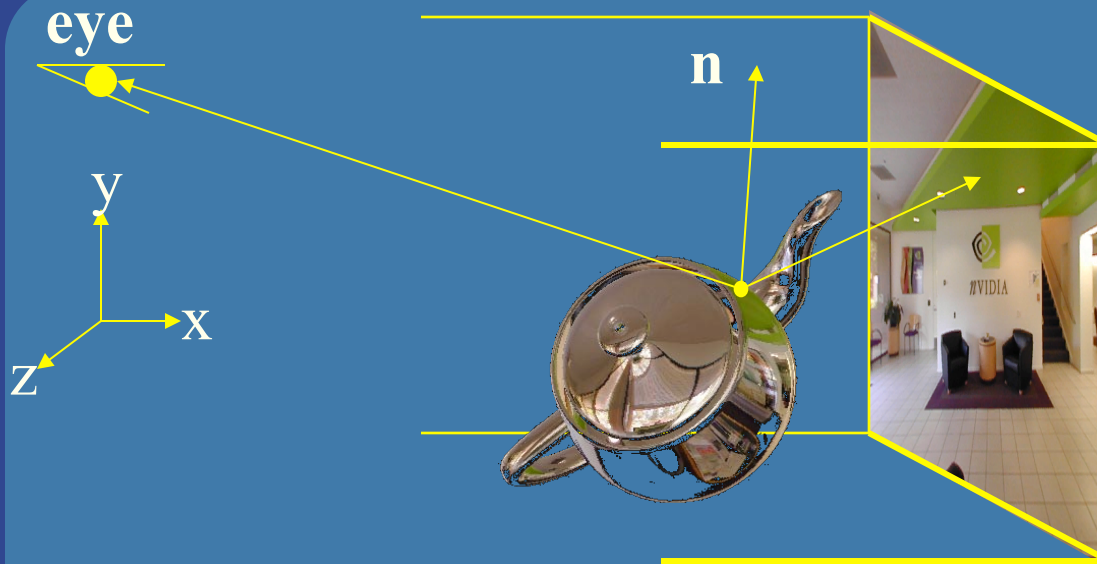


# Sphere Map





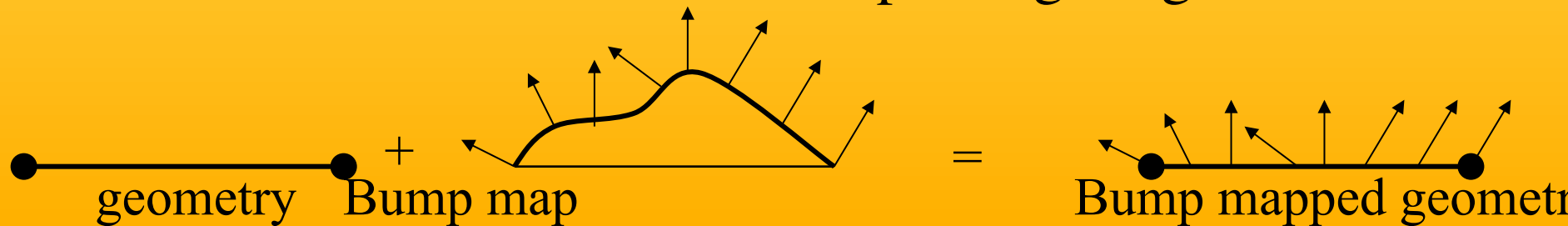
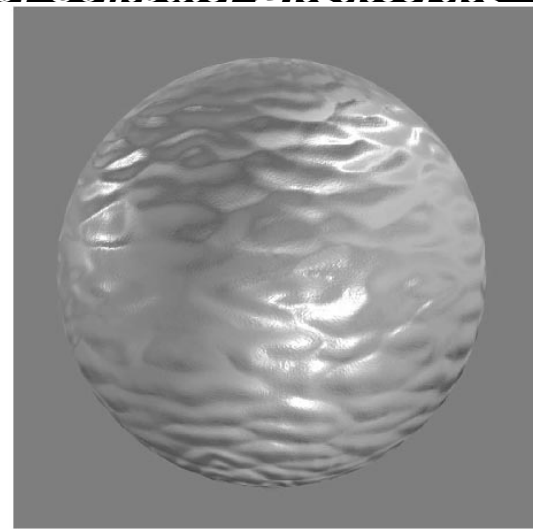
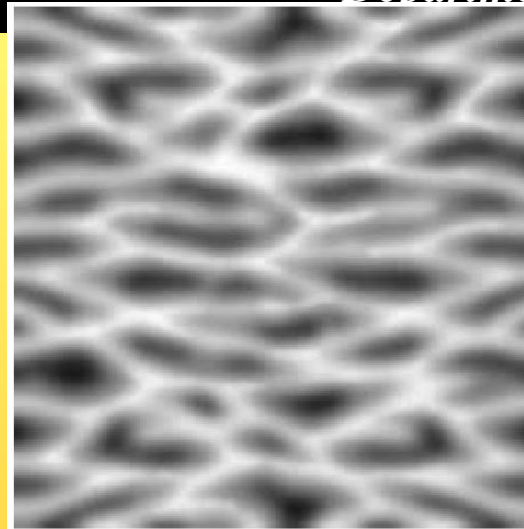
# Cube mapping



- Simple math: compute reflection vector,  $\mathbf{r}$
- Largest abs-value of component, determines which cube face.
  - Example:  $\mathbf{r}=(5,-1,2)$  gives POS\_X face
- Divide  $\mathbf{r}$  by  $\text{abs}(5)$  gives  $(u,v)=(-1/5,2/5)$
- Remap from  $[-1,1]$  to  $[0,1]$ , i.e.,  $((u,v)+(1,1))/2$
- Your hardware does all the work. You just have to compute the reflection vector. (See lab 4)

# Bump mapping

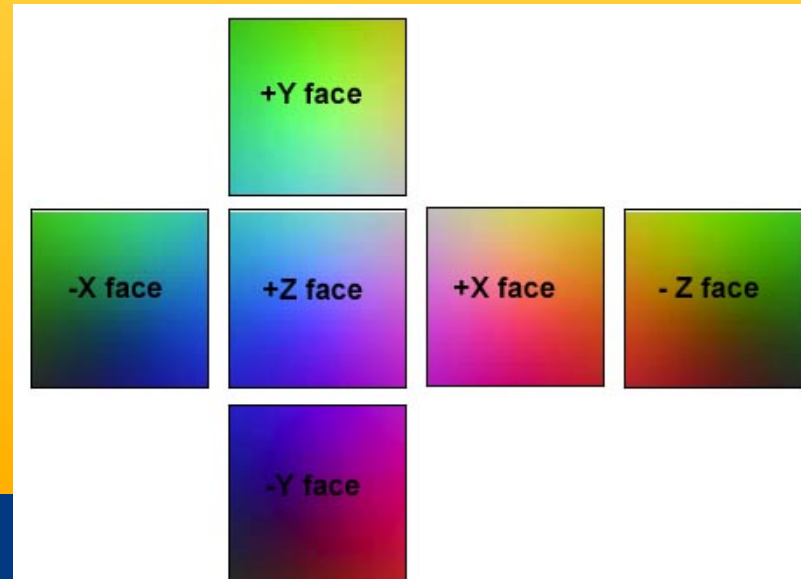
- by Blinn in 1978
- Inexpensive way of simulating wrinkles and bumps on geometry
  - Too expensive to model these geometrically
- Instead let a texture modify the normal at each pixel, and then use this normal to compute lighting



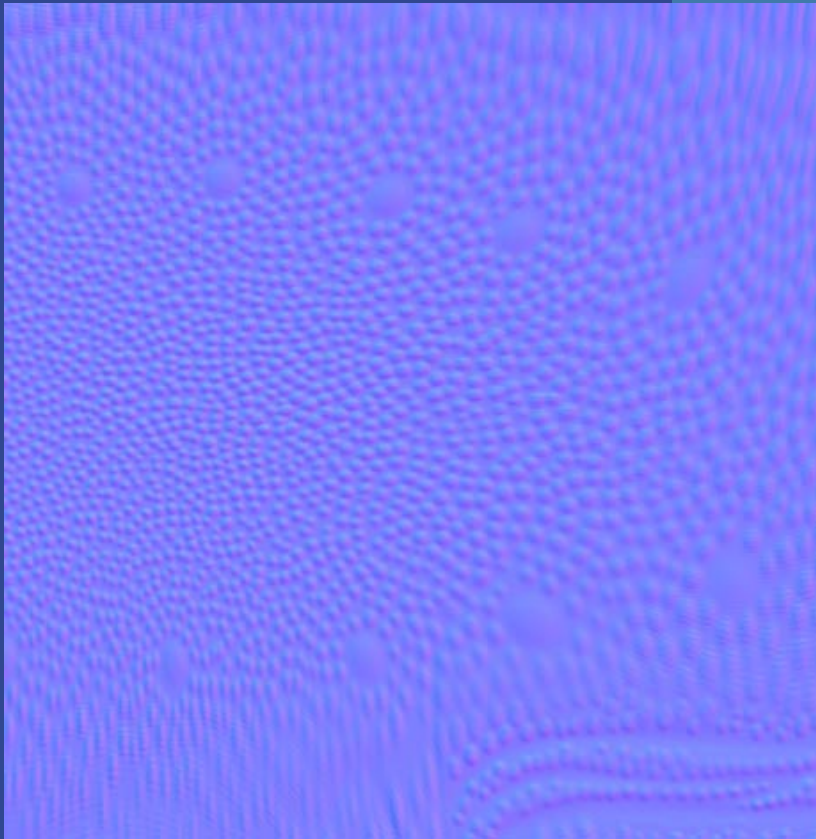
Stores heights: can derive normals

# Bump mapping lighting

- How store normals in texture (bump map)
- $\mathbf{n}=(n_x, n_y, n_z)$  are in  $[-1,1]$
- Add 1, mult 0.5: in  $[0,1]$
- Mult by 255 (8 bit per color component)
- Can be stored in texture:



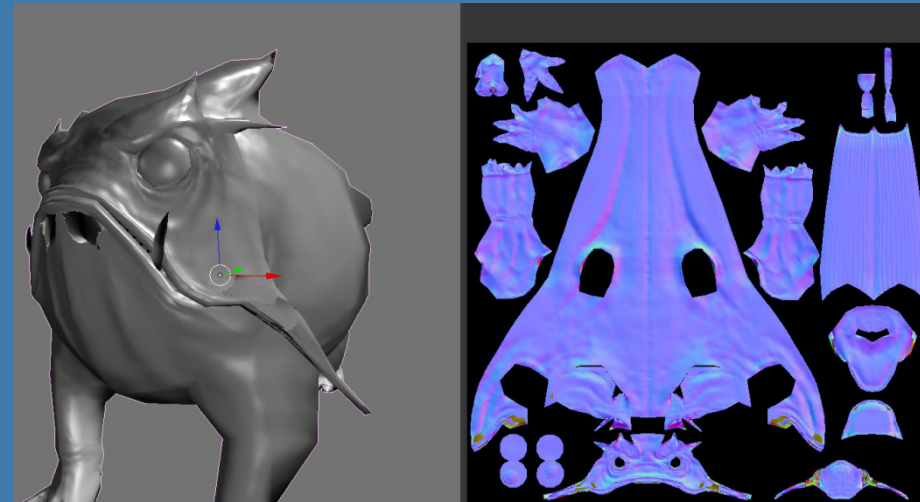
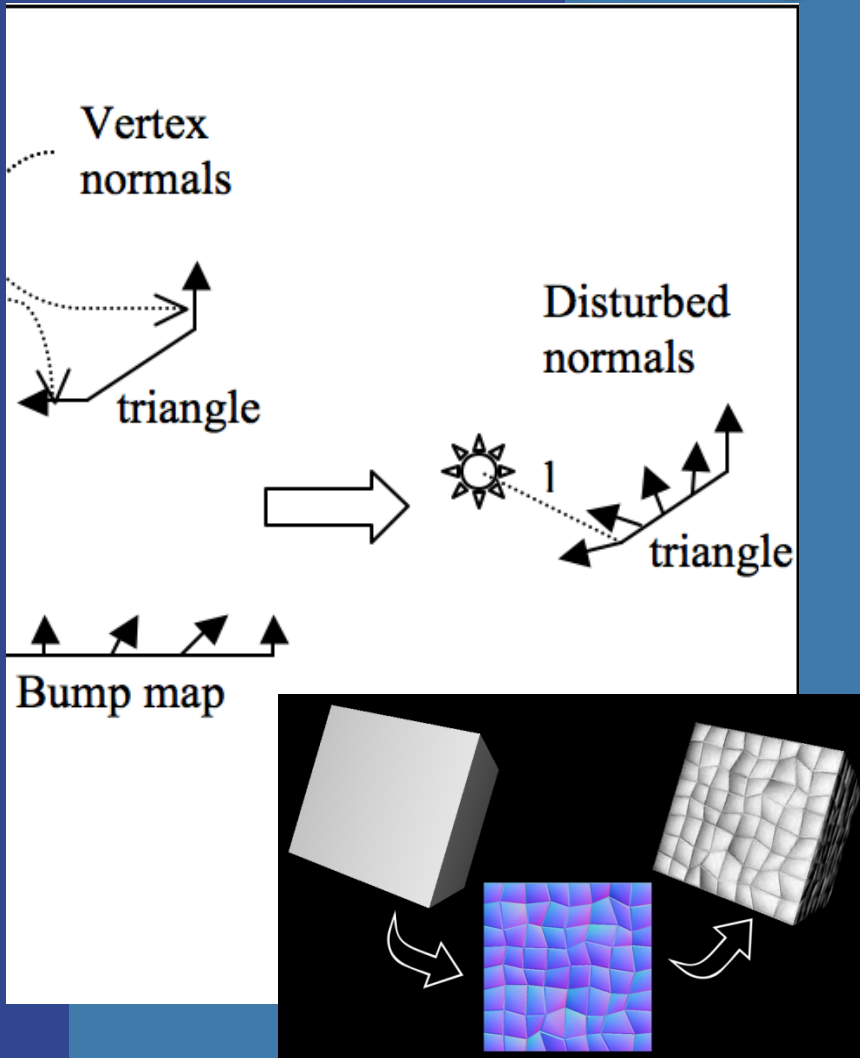
# Bump mapping: example



- Other ways to do bump mapping on
  - These are less expensive, and feasible on cheaper hardware



# Bump mapping vs normal mapping



## Normal mapping

(Normals are stored direction in model space. I.e., as including both face orientation plus distortion. )

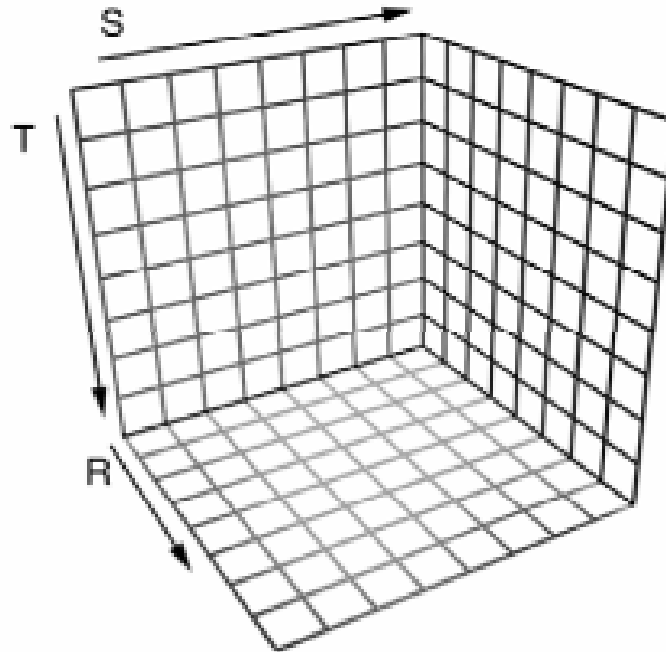
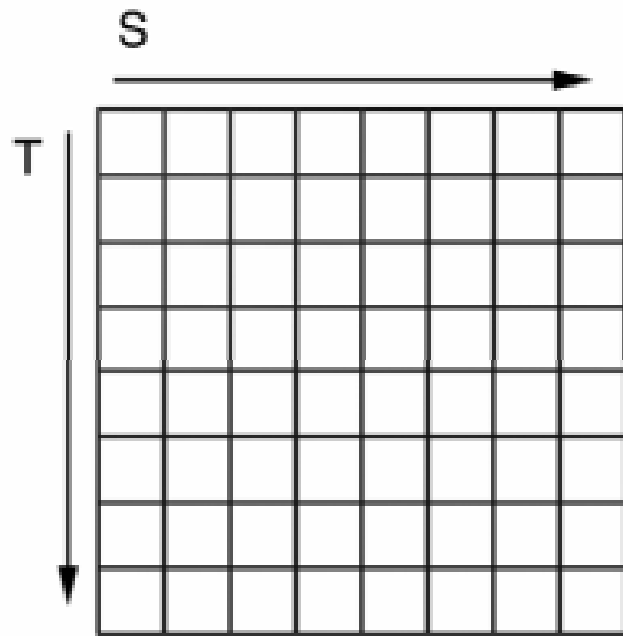
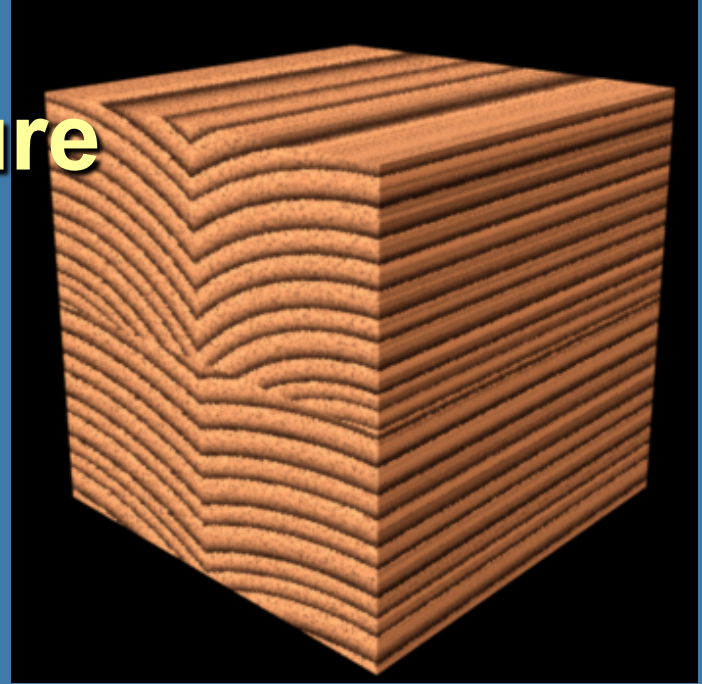
## Bump mapping

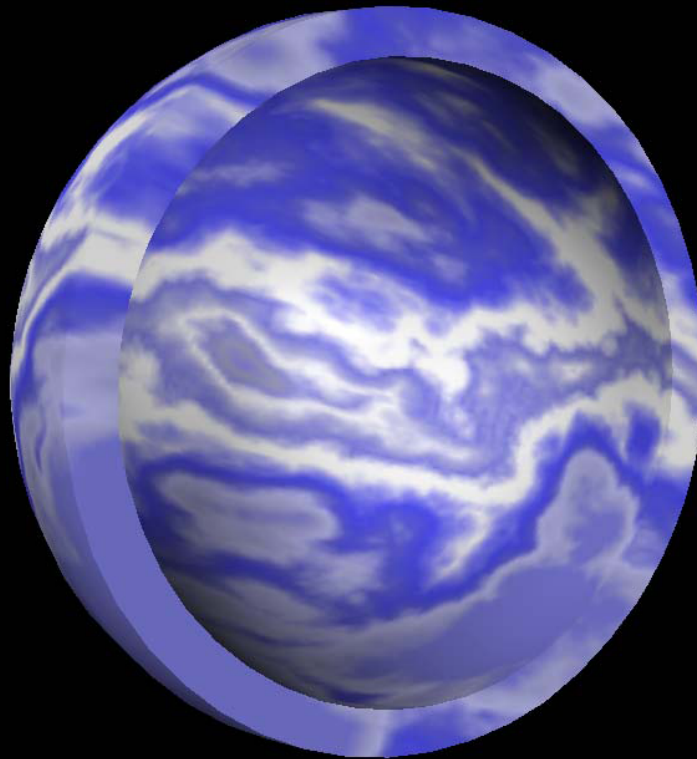
(Normals are stored as distortion of face orientation. The same bump map can be tiled/repeated and reused for many faces with different orientation)

# More...

- 3D textures:
  - Feasible on modern hardware as well
  - Texture filtering is no longer trilinear
  - Rather quadlinear (linear interpolation 4 times)
  - Enables new possibilities
    - Can store light in a room, for example
- Displacement Mapping
  - Offsets the position per pixel or per vertex
    - Offsetting per vertex is easy in vertex shader
    - Offsetting per pixel is architecturally hard
      - Cannot easily be done in fragment shader
      - Can be done using Geometry Shader (e.g. Direct3D 10) by ray casting in the displacement map

# 2D texture vs 3D texture





From [http://www.ati.com/developer/shaderx/ShaderX\\_3DTextures.pdf](http://www.ati.com/developer/shaderx/ShaderX_3DTextures.pdf)



# Precomputed Light fields

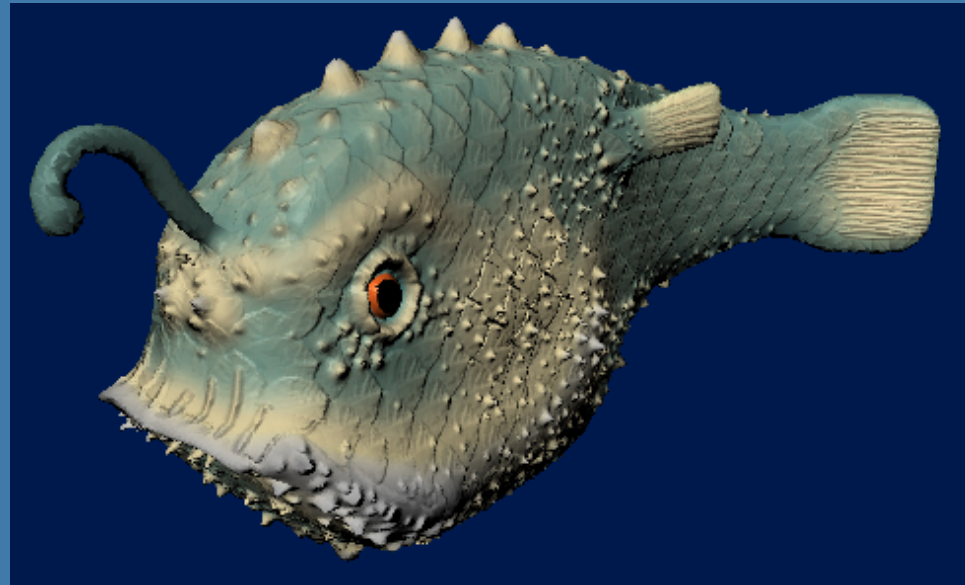
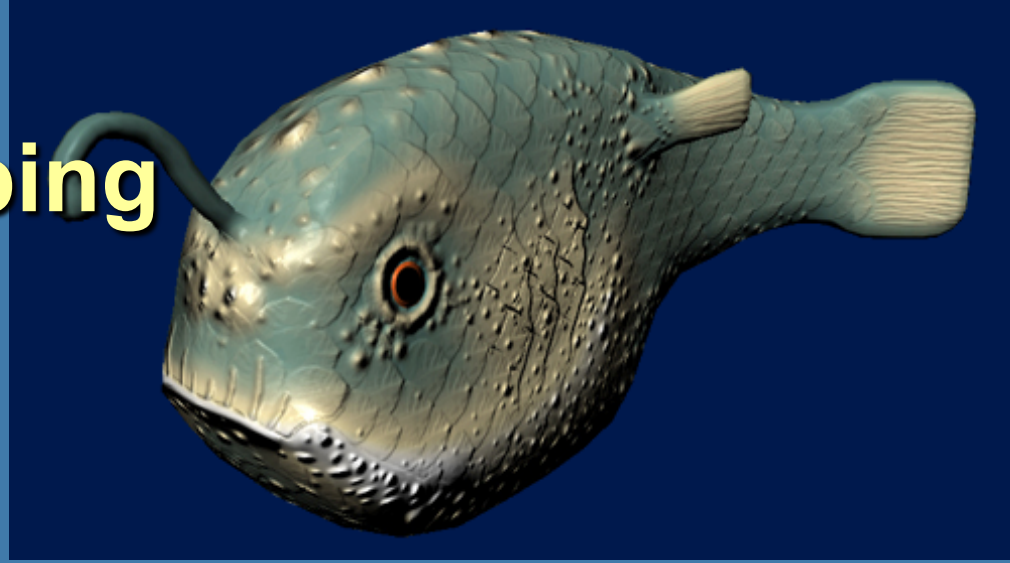


Max Payne 2 by Remedy Entertainment

Samuli Laine and Janne Kontkanen

# Displacement Mapping

- Uses a map to displace the surface at each position



# Rendering to Texture

(See also  
Lab 5)

```
//*****
// Create a Frame Buffer Object (FBO) that we first render to and then use as a texture
//*****

glGenFramebuffersEXT(1, &frameBuffer); // generate framebuffer id
glBindFramebufferEXT(GL_FRAMEBUFFER, frameBuffer); // following commands will affect "frameBuffer"

// Create a texture for the frame buffer, with specified filtering, rgba-format and size
glGenTextures( 1, &texFrameBuffer );
glBindTexture( GL_TEXTURE_2D, texFrameBuffer ); // following commands will affect "texFrameBuffer"
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR );
glTexImage2D( GL_TEXTURE_2D, 0, 4, 512, 512, 0, GL_RGBA, GL_UNSIGNED_BYTE, NULL );

// Create a depth buffer for our FBO
glGenRenderbuffers(1, &depthBuffer); // get the ID to a new Renderbuffer
glBindRenderbuffer(GL_RENDERBUFFER, depthBuffer);
glRenderbufferStorage(GL_RENDERBUFFER, GL_DEPTH_COMPONENT, 512, 512);

// Set rendering of the default color0-buffer to go into the texture
glFramebufferTexture2D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_2D,
                      texFrameBuffer, 0);
glFramebufferRenderbufferEXT(GL_FRAMEBUFFER, GL_DEPTH_ATTACHMENT, GL_RENDERBUFFER,
depthBuffer); // Associate our created depth buffer with the FBO
```

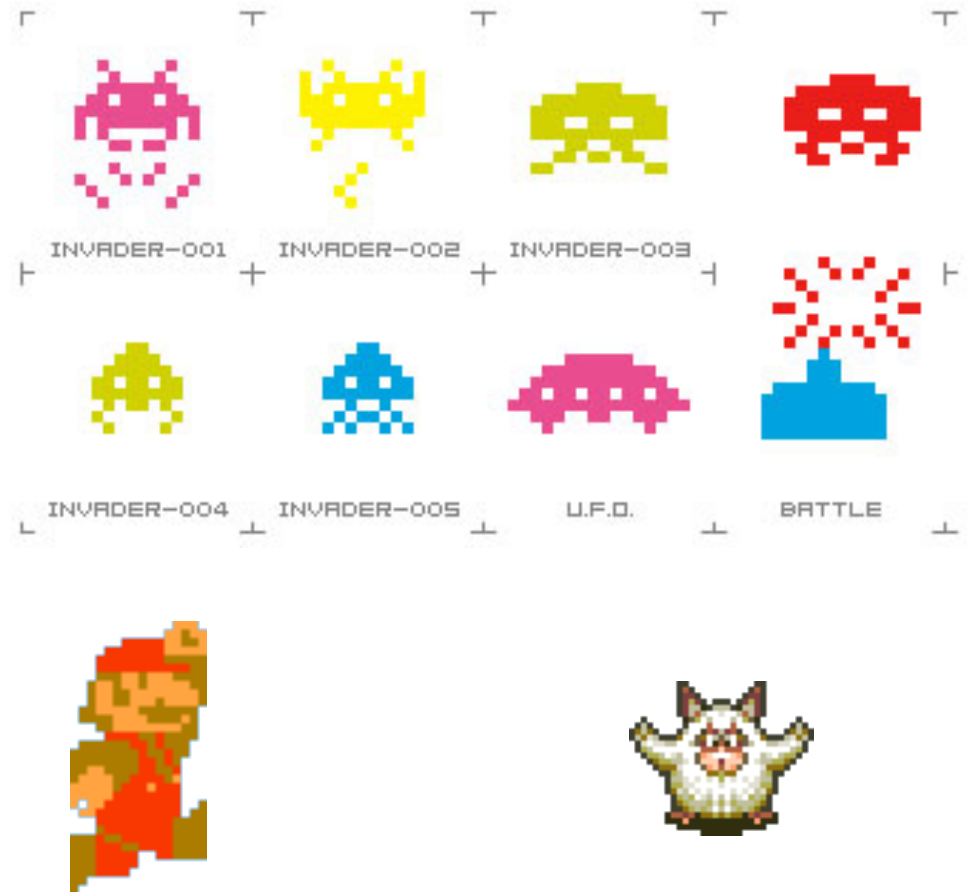
**Or simply use: glCopyTexSubImage**

# Sprites

```
GLbyte M[64]=
{ 127,0,0,127, 127,0,0,127,
  127,0,0,127, 127,0,0,127,
  0,127,0,0, 0,127,0,127,
  0,127,0,127, 0,127,0,0,
  0,0,127,0, 0,0,127,127,
  0,0,127,127, 0,0,127,0,
  127,127,0,0, 127,127,0,127,
  127,127,0,127, 127,127,0,0};

void display(void) {
    glClearColor(0.0,1.0,1.0,1.0);
    glClear(GL_COLOR_BUFFER_BIT);
    glEnable (GL_BLEND);
    glBlendFunc (GL_SRC_ALPHA,
                 GL_ONE_MINUS_SRC_ALPHA);
    glRasterPos2d(xpos1,ypos1);
    glPixelZoom(8.0,8.0);
    glDrawPixels(width,height,
                 GL_RGBA, GL_BYTE, M);

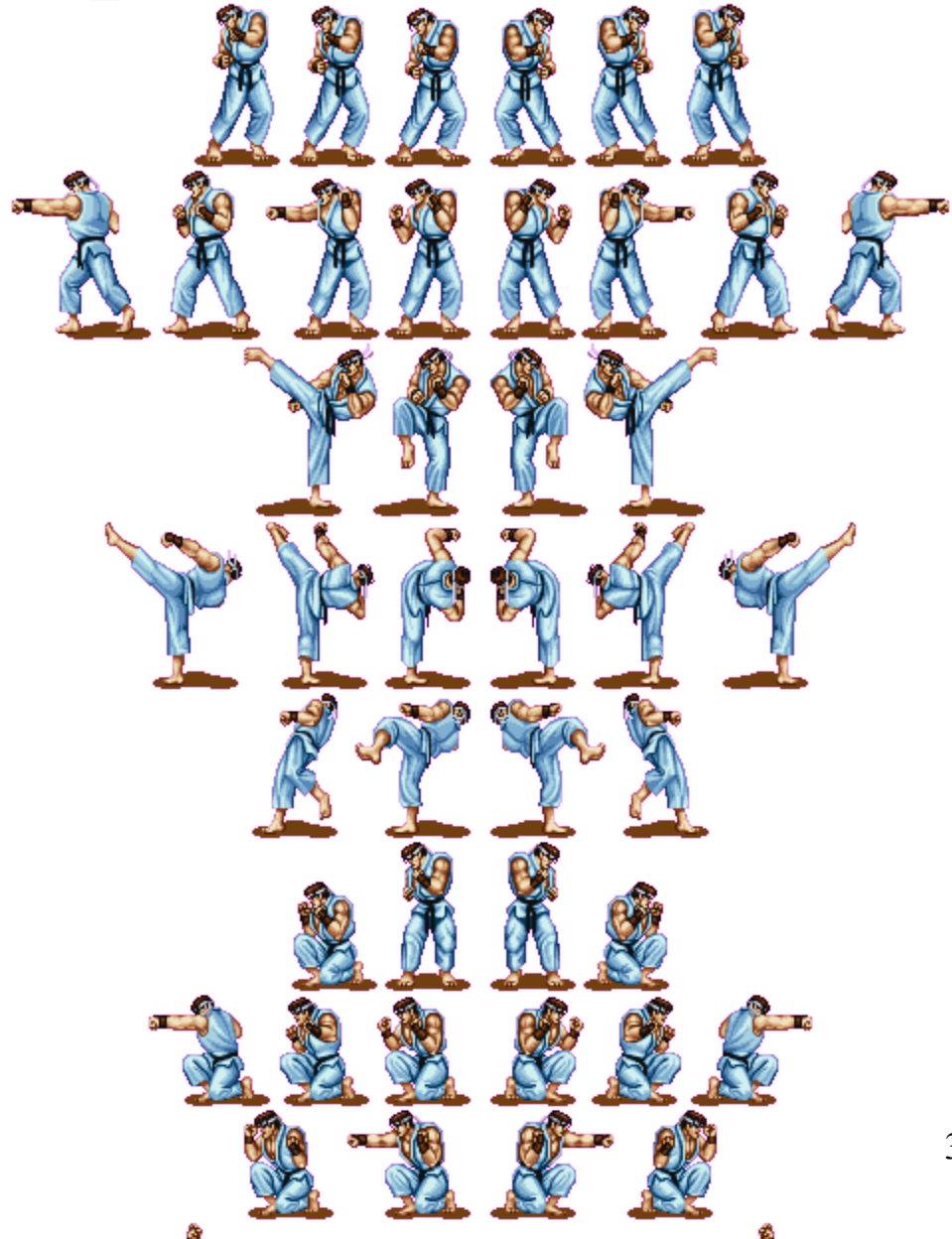
    glPixelZoom(1.0,1.0);
    glutSwapBuffers();
}
```



# Sprites

Animation Maps

The sprites for Ryu:





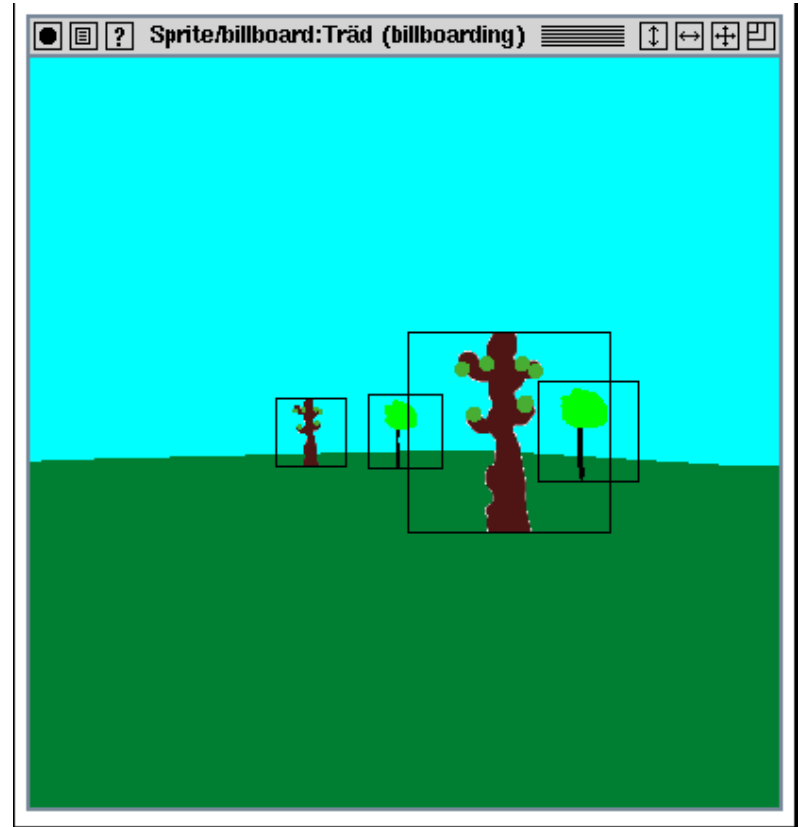
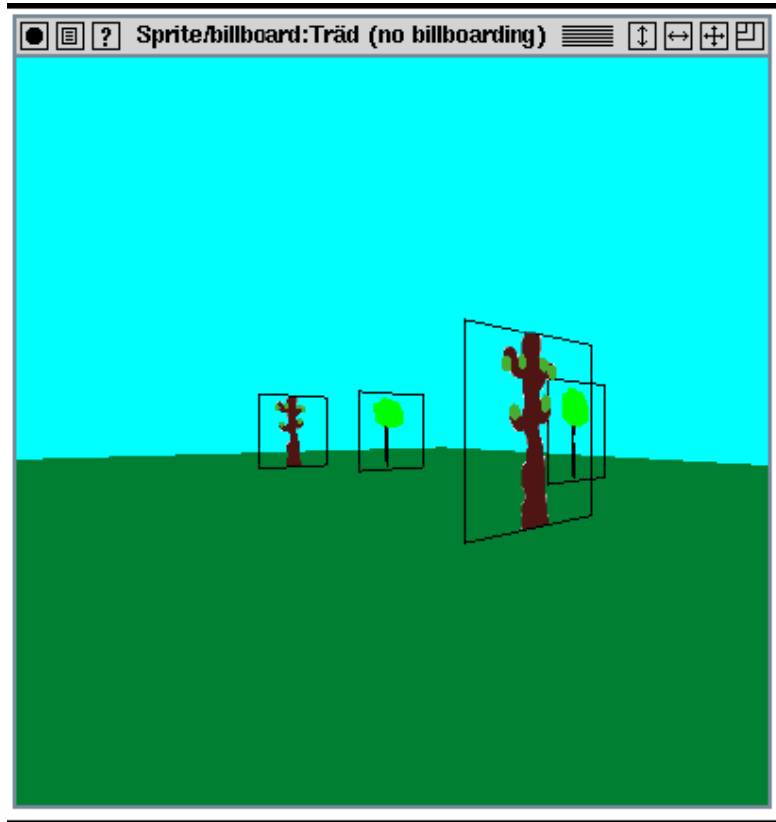
# Billboards

- 2D images used in 3D environments
  - Common for trees, explosions, clouds, lens-flares





# Billboards

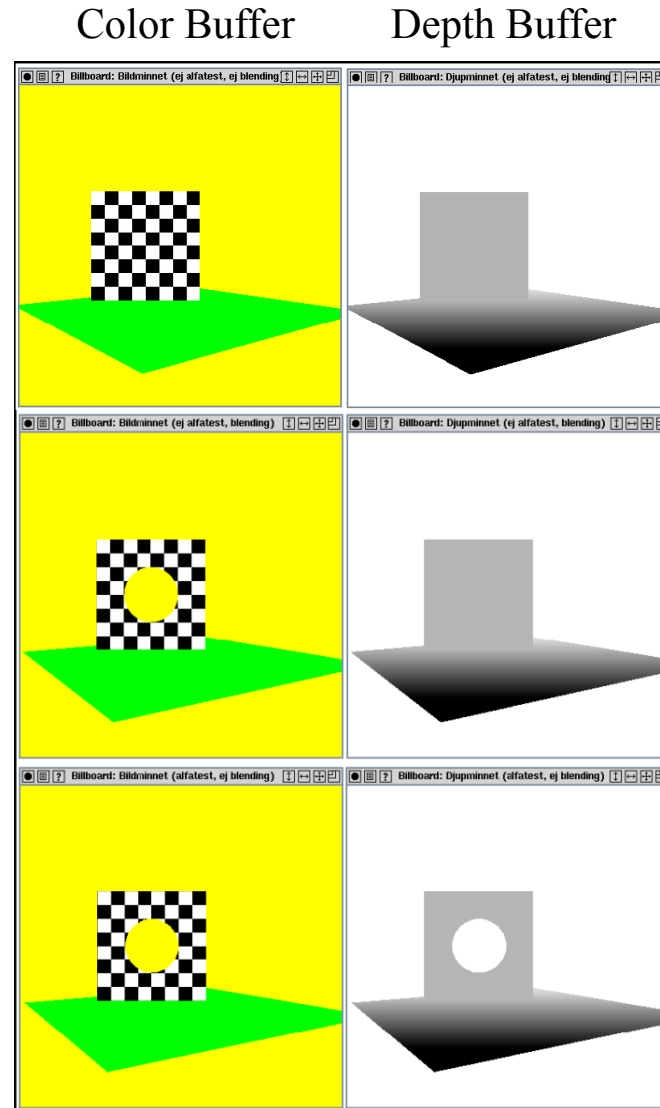


- Rotate them towards viewer
  - Either by rotation matrix (see OH 288), or
  - by orthographic projection



# Billboards

- Fix correct transparency by blending AND using alpha-test
  - In fragment shader:  
`if (color.a < 0.1) discard;`
- Or: sort back-to-front and blend
  - Depth writing can then preferably be disabled
    - `glDepthMask(0);`

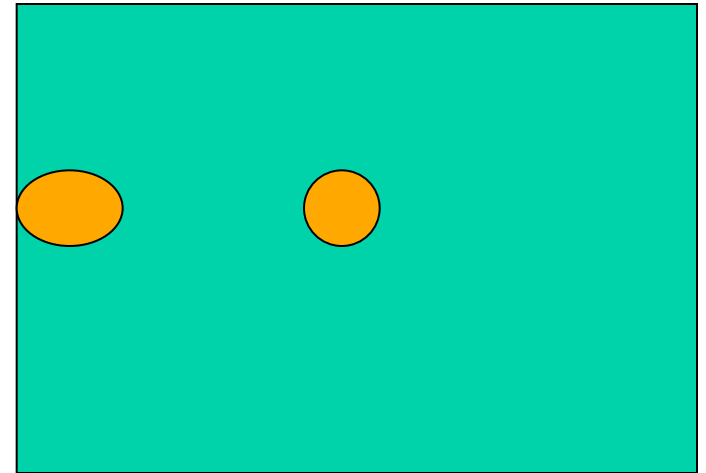
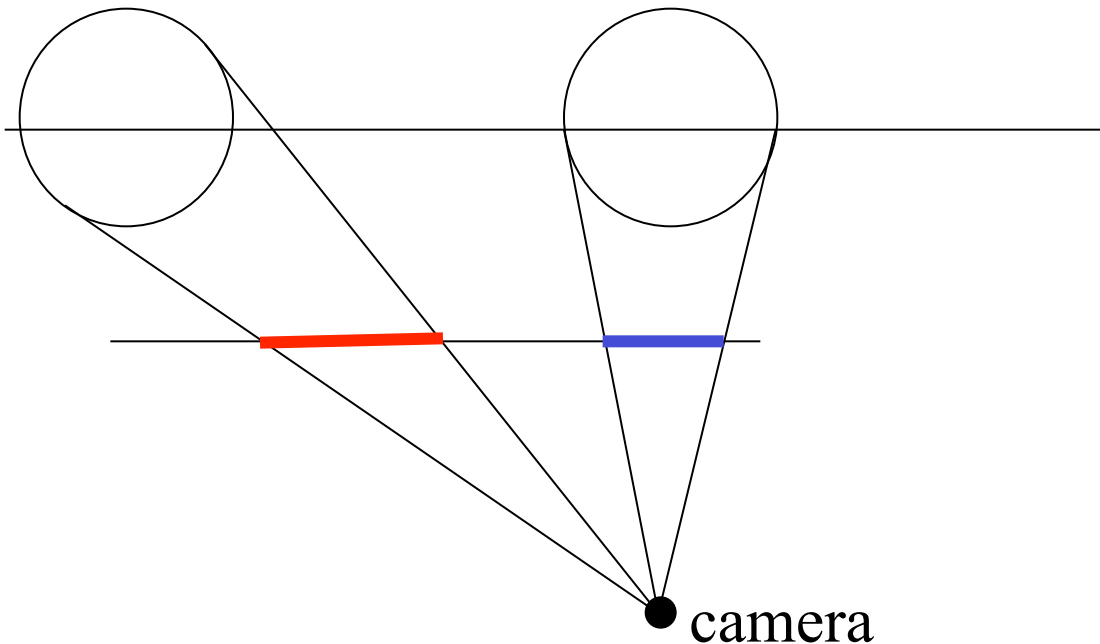


With  
blending

With  
alpha test

# Perspective distortion

- Spheres often appear as ellipsoids when located in the periphery. Why?



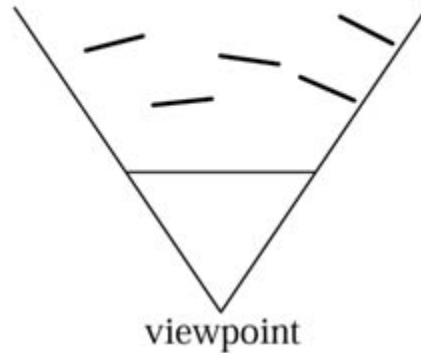
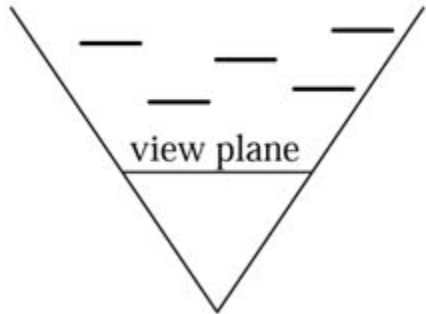
Exaggerated example

If our eye was placed at the camera position, we would not see the distortion. We are often positioned way behind the camera<sub>42</sub>

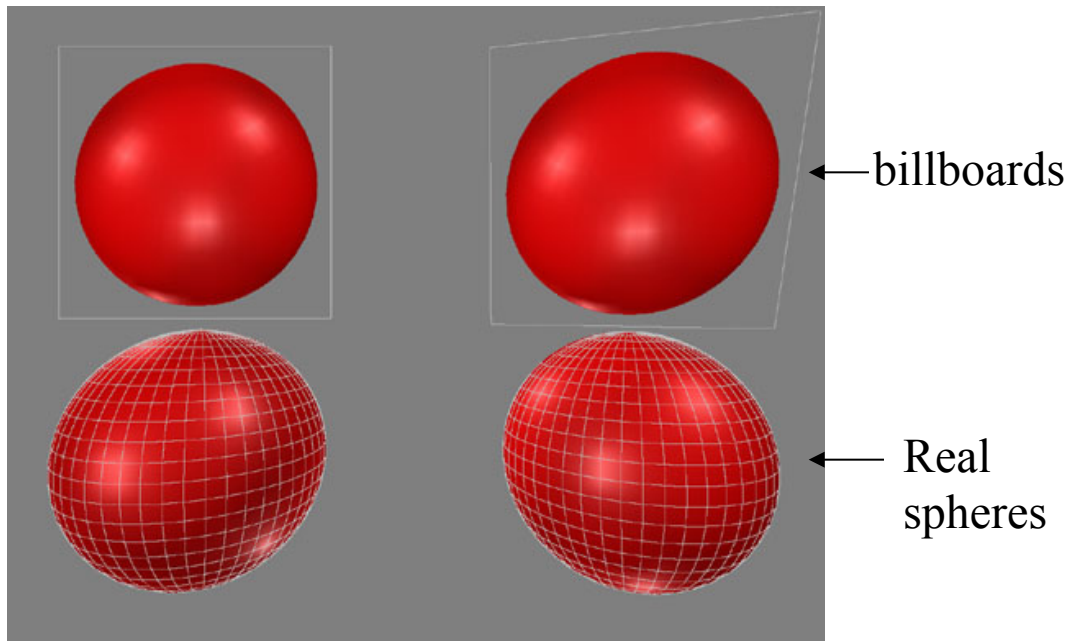
# Which is preferred?

view plane aligned

viewpoint oriented



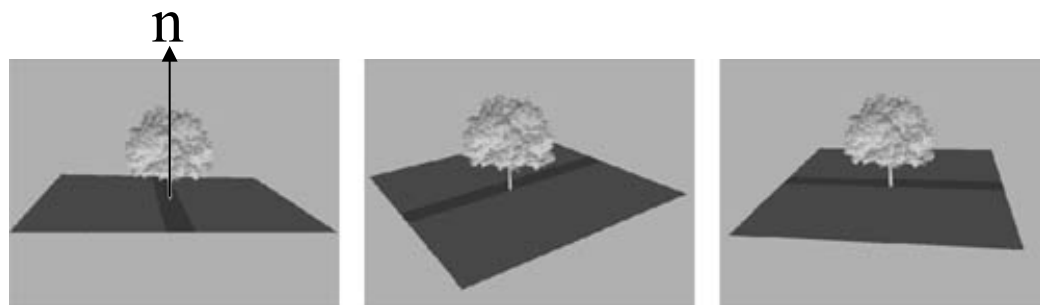
This is the result



Actually, viewpoint oriented is usually preferred since it most closely resembles the result using standard triangulated geometry



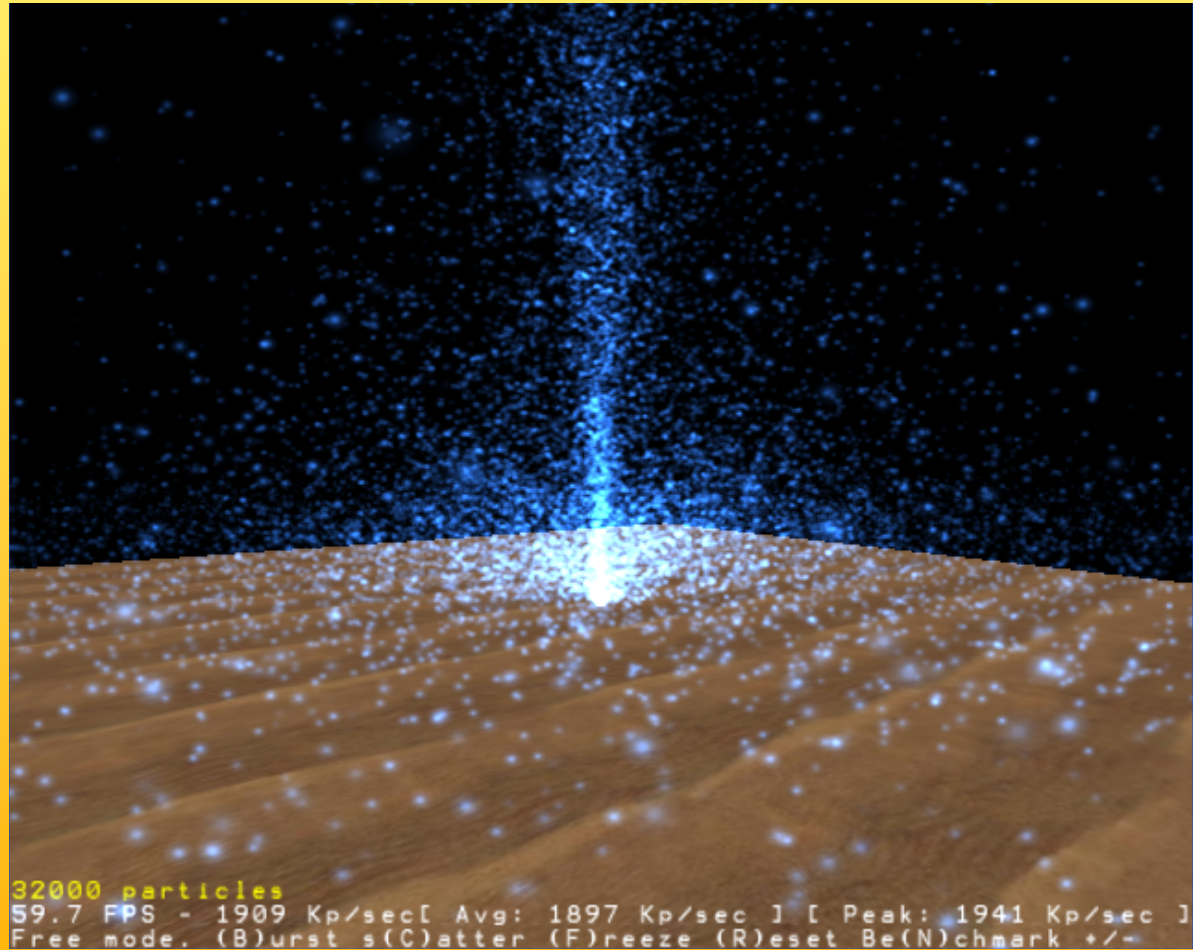
Also called *Impostors*



*axial billboarding*

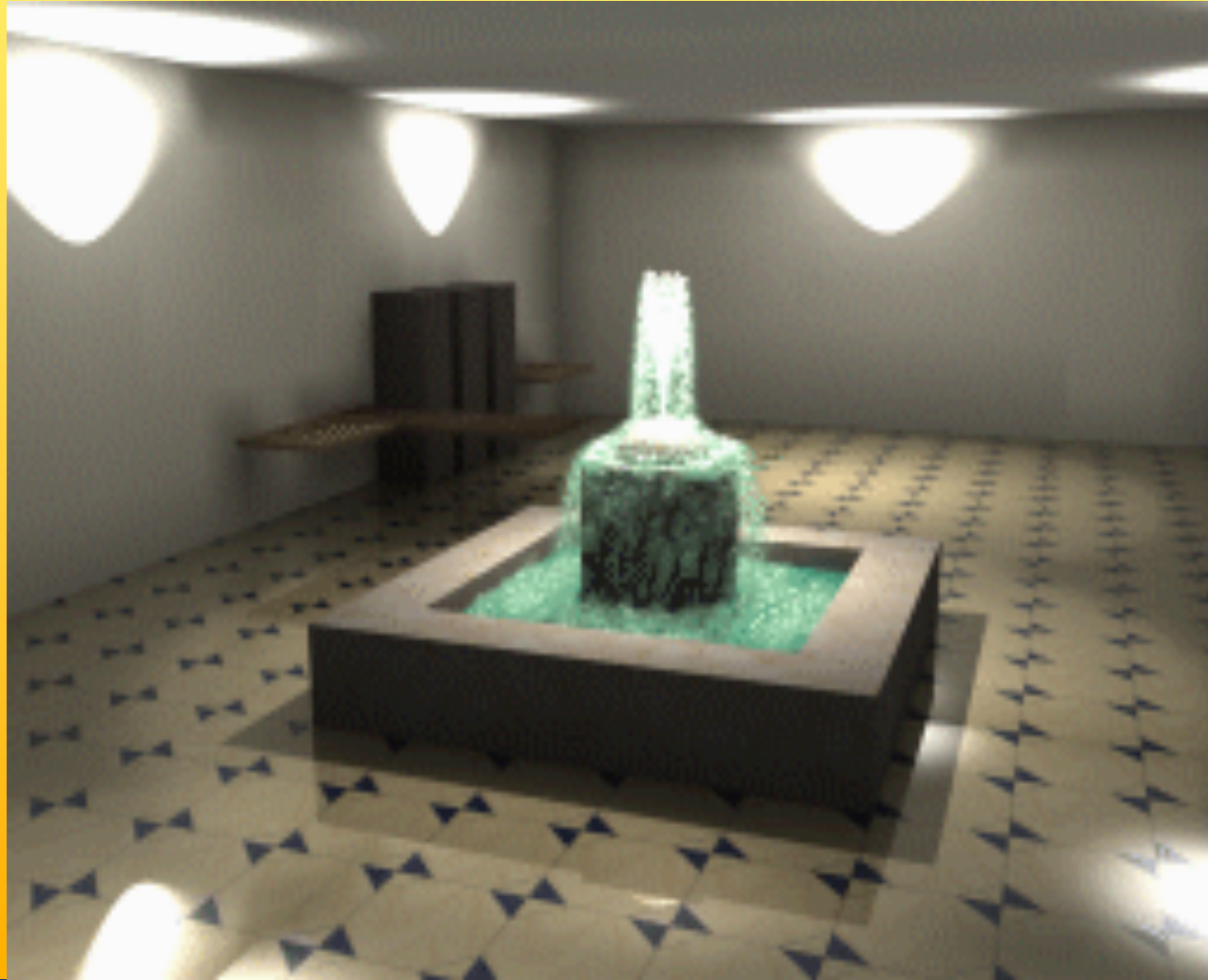
The rotation axis is fixed and  
disregarding the view position

# Partikelsystem



## Particles

# Partikelsystem





# Particle Systems

- Boids (flock of birds), see OH 230
  - 3 rules:
    1. Separation: Avoid obstacles and getting too close to each other
    2. Alignment (strive for same speed and direction as nearby boids)
    3. Cohesion: steer towards center of mass of nearby boids

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