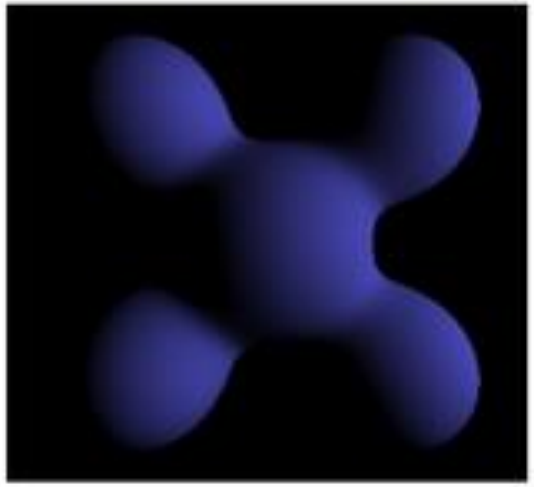
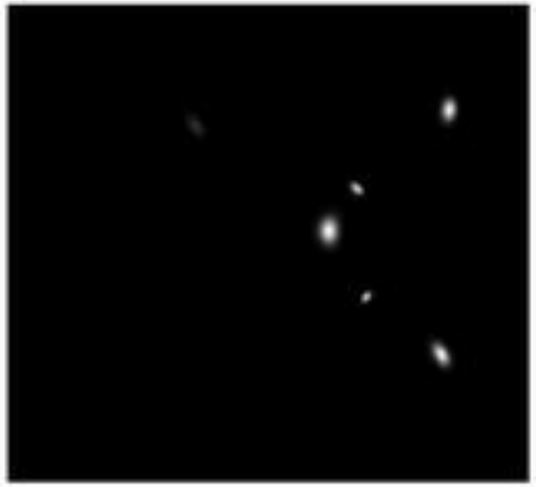
GRK 6

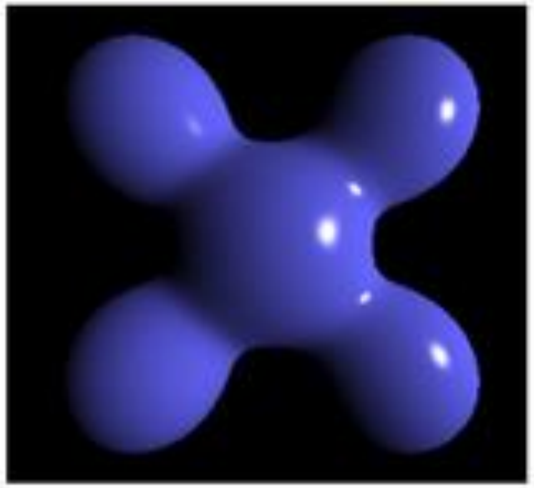
Dr Wojciech Palubicki

Phong Lighting Model


Ambient light


Diffuse light


Specular light

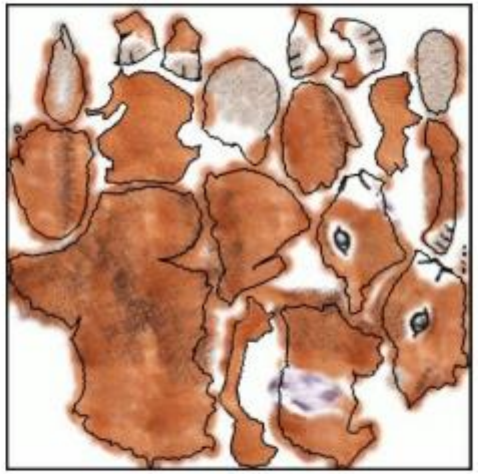

Phong lighting model

Color variation in space

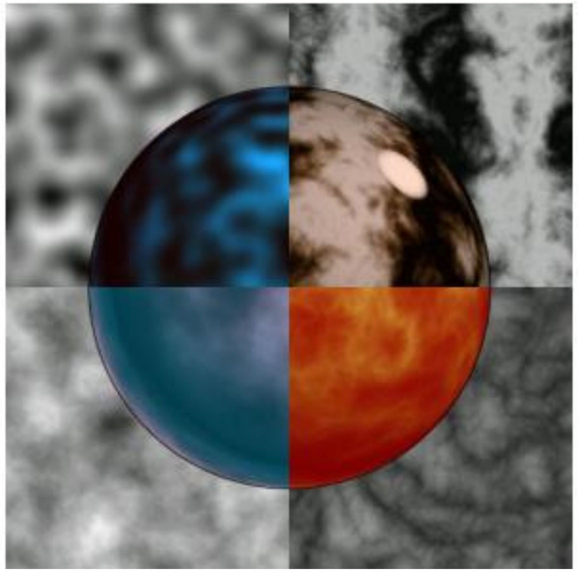
- Diffuse lighting color is the same for each pixel
- We can assume that the color k_d differs for pixels

Texturing

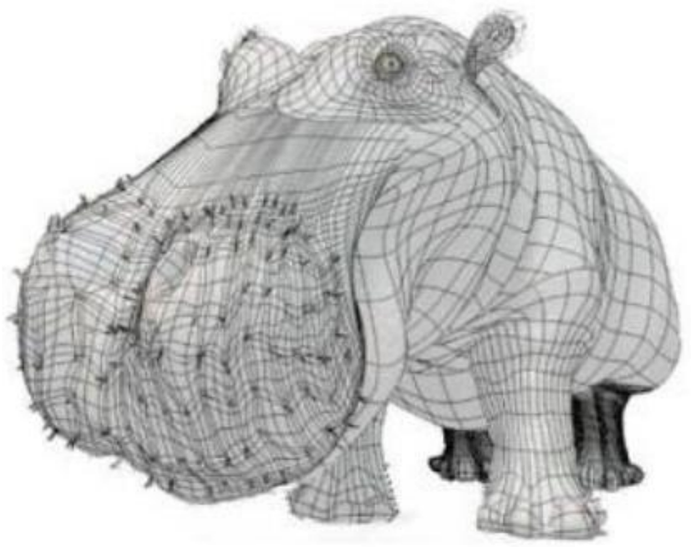
- From data:
  - Read information from 2D images



- Procedural:
  - Write a program that calculates color as a function of position

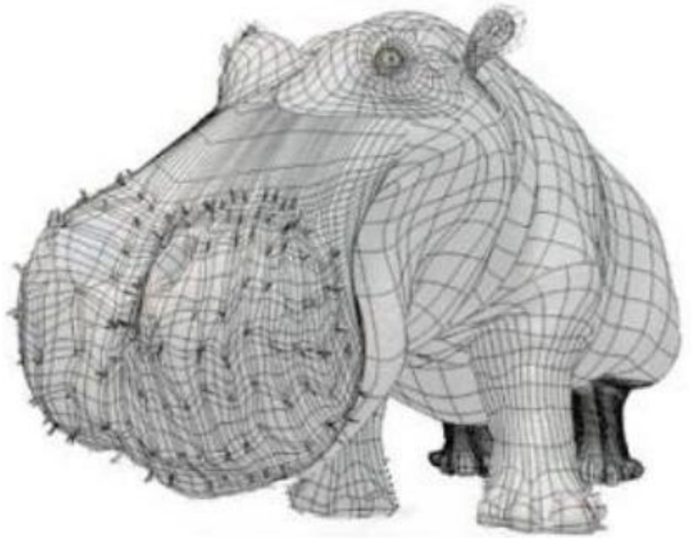


Texture effect



Model

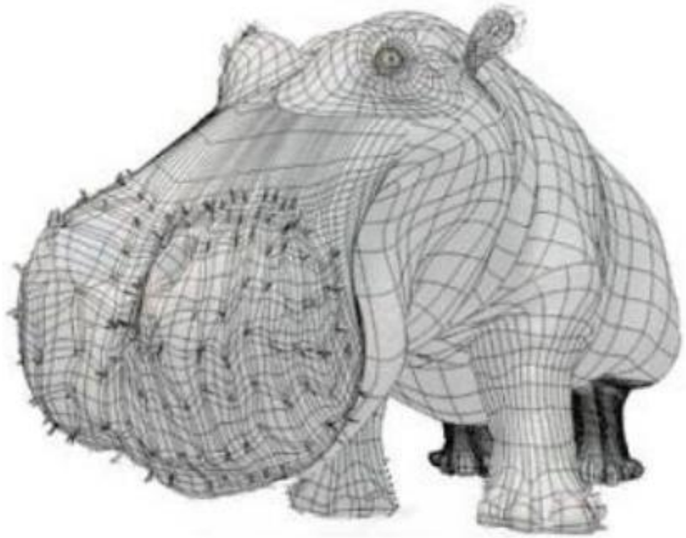
Texture effect



Model

Model + Shading

Texture effect

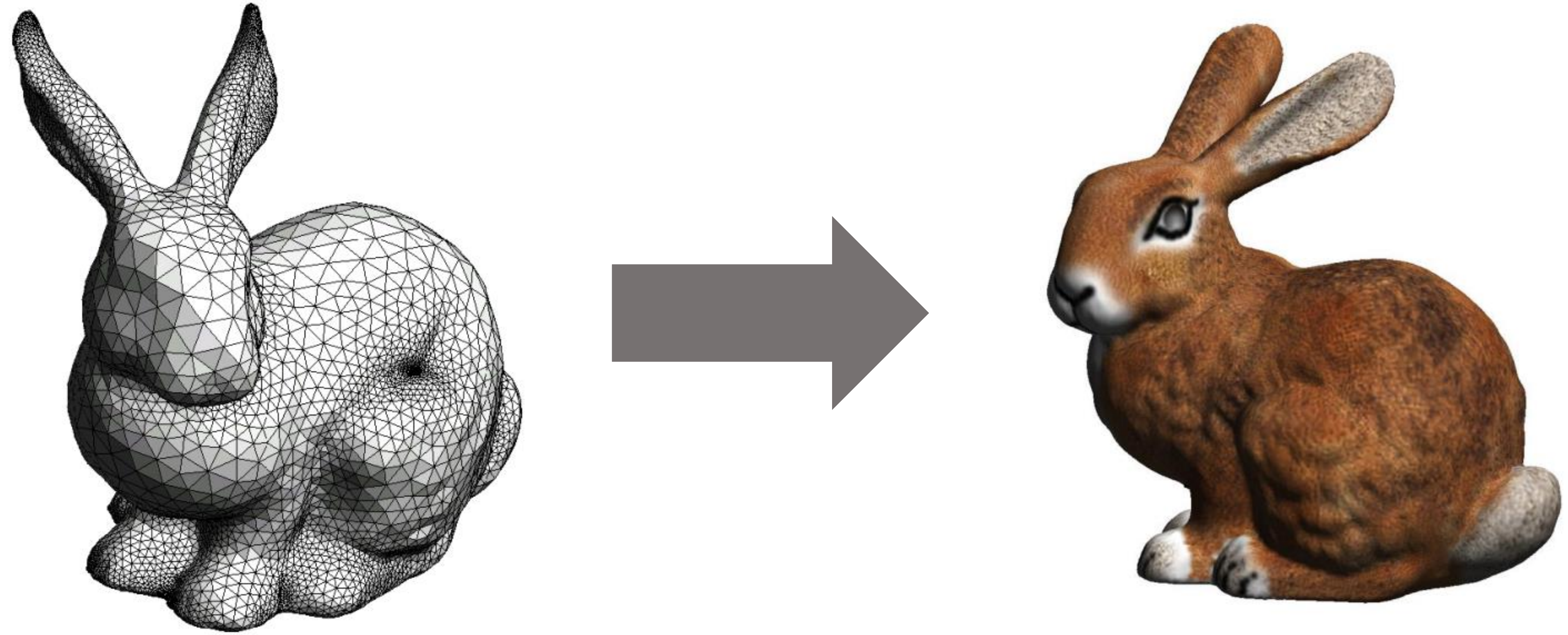


Model

Model + Shading

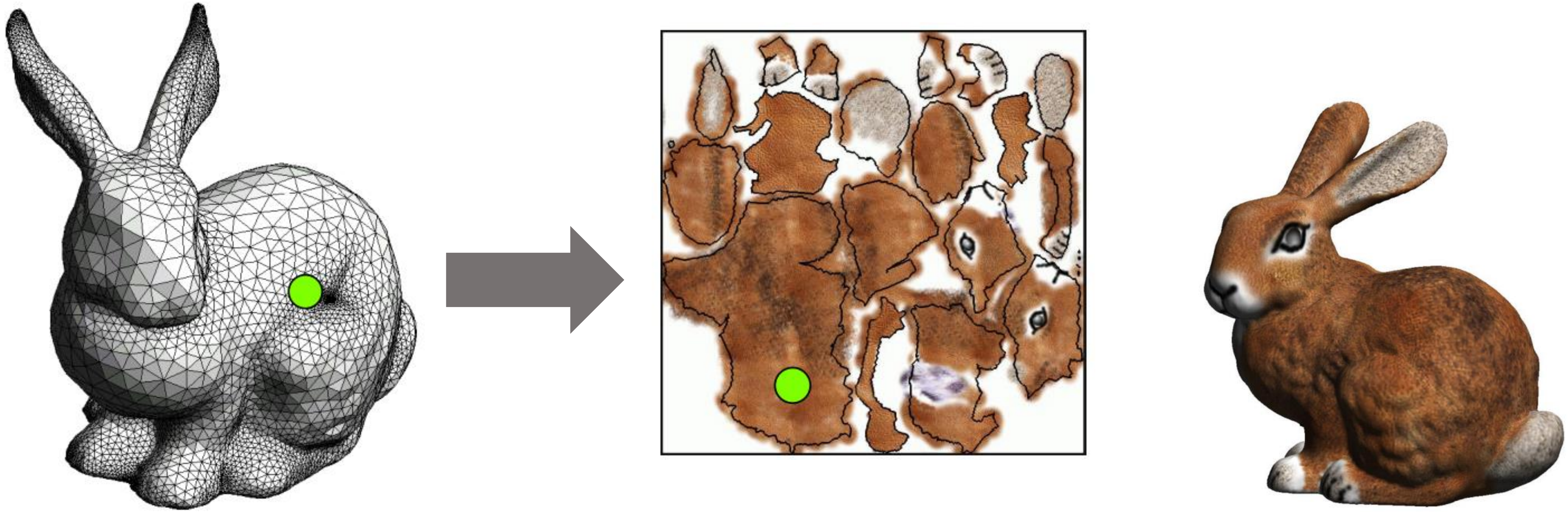
Model + Shading + Textures

Texturing



3D model

Textured model

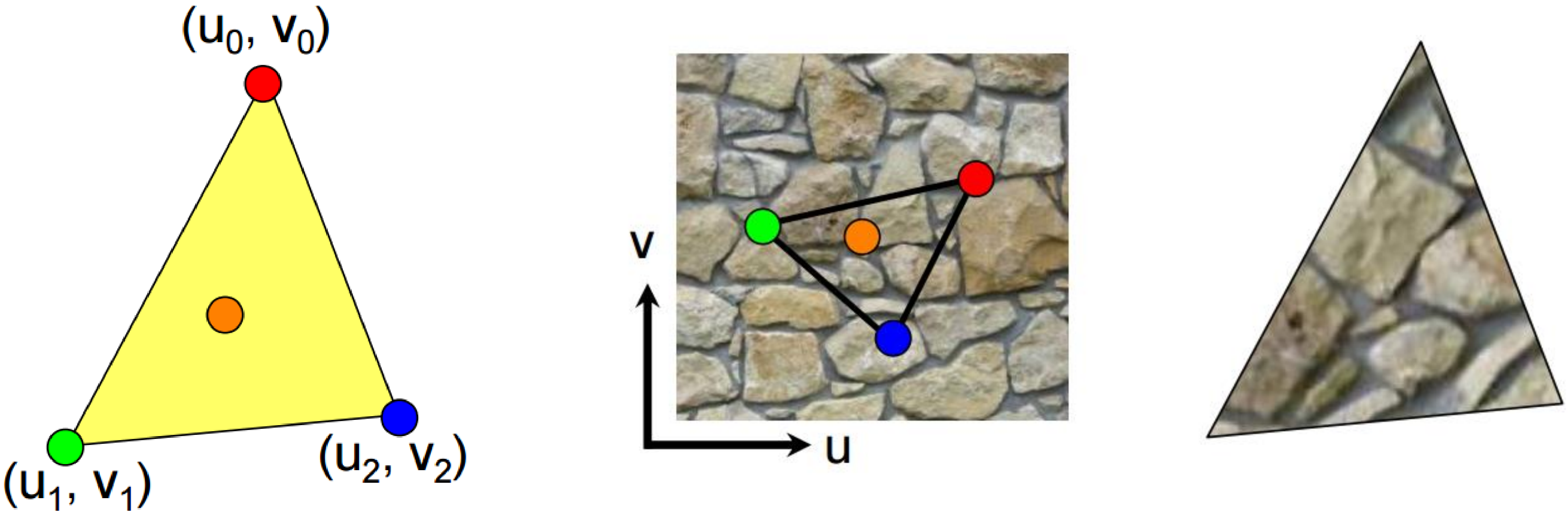


We need a function that associates every surface point of a model with a coordinate of a texture

For every point we are drawing we want to retrieve the color information stored in the texture

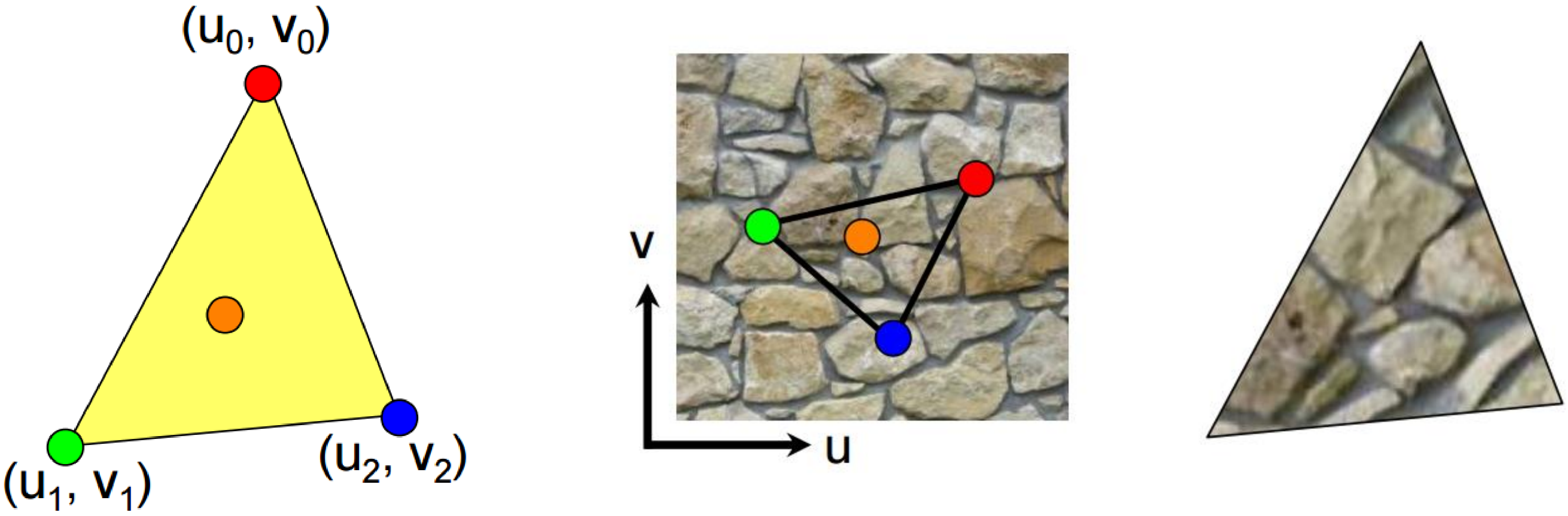
Coordinates u, v

- Every vertex stores 2D coordinates (u, v) in texture space
  - Coordinates u, v define positions in the texture for every vertex
- Color information between vertices is obtained via interpolation

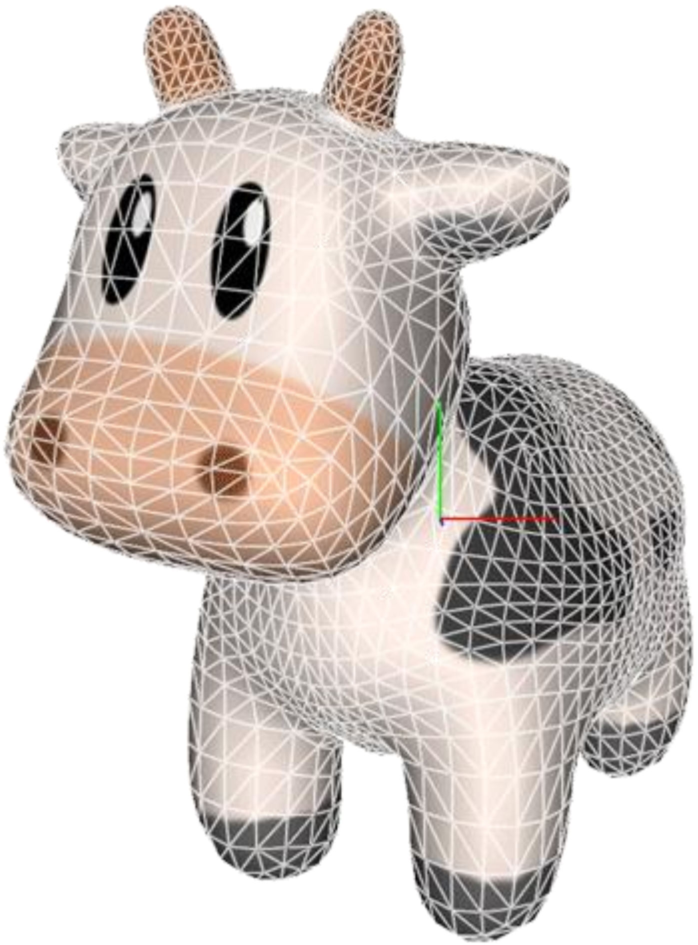


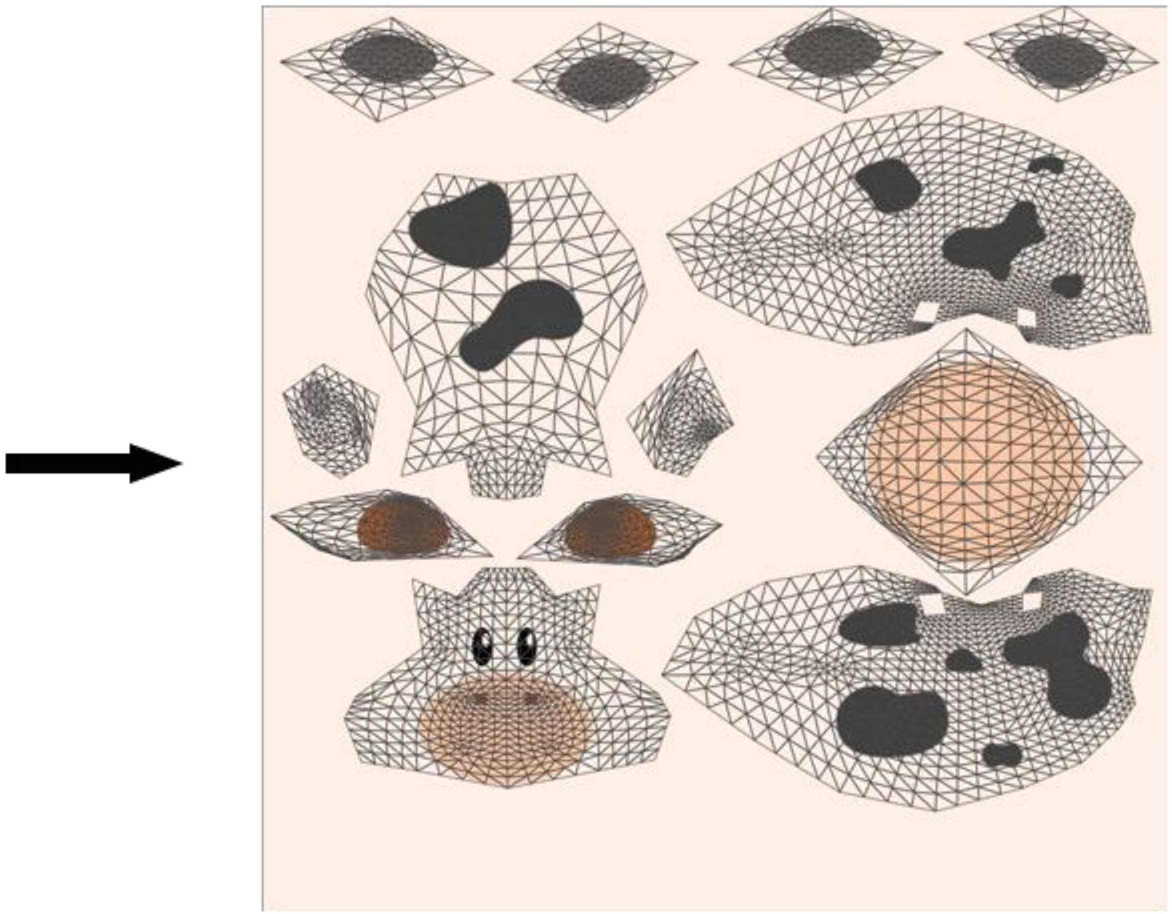
Coordinates u, v

- Texture coordinates u, v are specified:
  - Manually by the user
  - Automatically, using parametric optimization



Parametric optimization

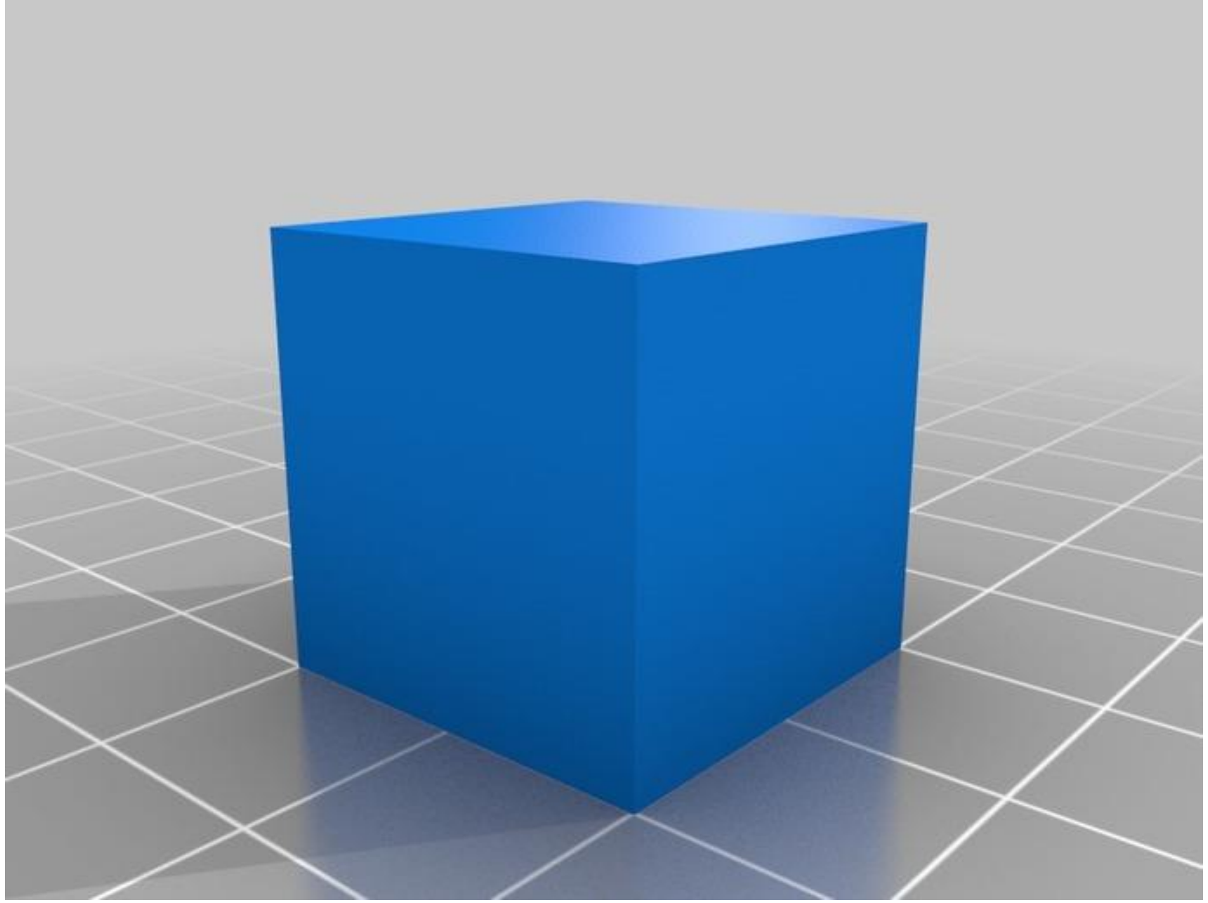




3D model

- Necessary information:
- For vertices:
  - Positions (4D/3D coordinates)
  - Normals (3D coordinates)
  - 2D u, v coordinates
- Other information:
  - Parameters and shading method
  - Images of our textures

Wavefront .OBJ file

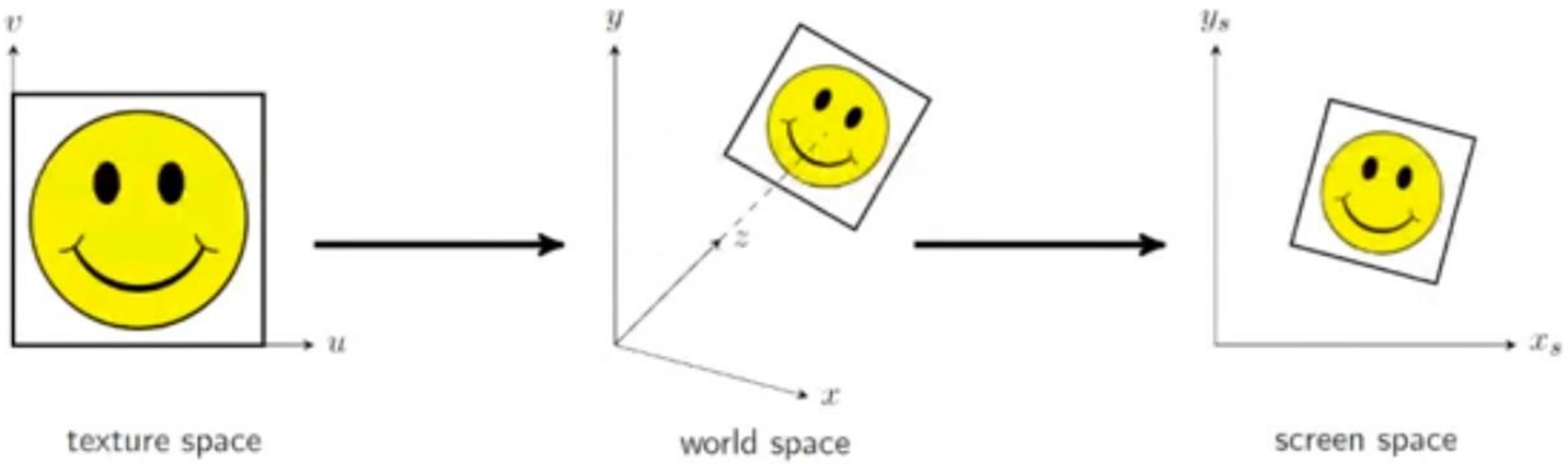


```
# Notes:
# v - vertices in x,y,z coordinates
# vt - texture in u,v coordinates
# vn - normals in nx,ny,nz coordinates
# f - faces: map vertices, UVs, normals

g cube

v 0.0 0.0 0.0
v 0.0 0.0 1.0
v 0.0 1.0 0.0
v 0.0 1.0 1.0
v 1.0 0.0 0.0
v 1.0 0.0 1.0
v 1.0 1.0 0.0
v 1.0 1.0 1.0

vt 0.0 0.0
vt 1.0 0.0
vt 1.0 1.0
vt 0.0 1.0

vn 0.0 0.0 1.0
vn 0.0 0.0 -1.0
vn 0.0 1.0 0.0
vn 0.0 -1.0 0.0
vn 1.0 0.0 0.0
vn -1.0 0.0 0.0

f 1/1/2 7/3/2 5/2/2
f 1/1/2 3/4/2 7/3/2
f 1/1/6 4/3/6 3/4/6
f 1/1/6 2/2/6 4/3/6
f 3/1/3 8/3/3 7/4/3
```

Texture mapping

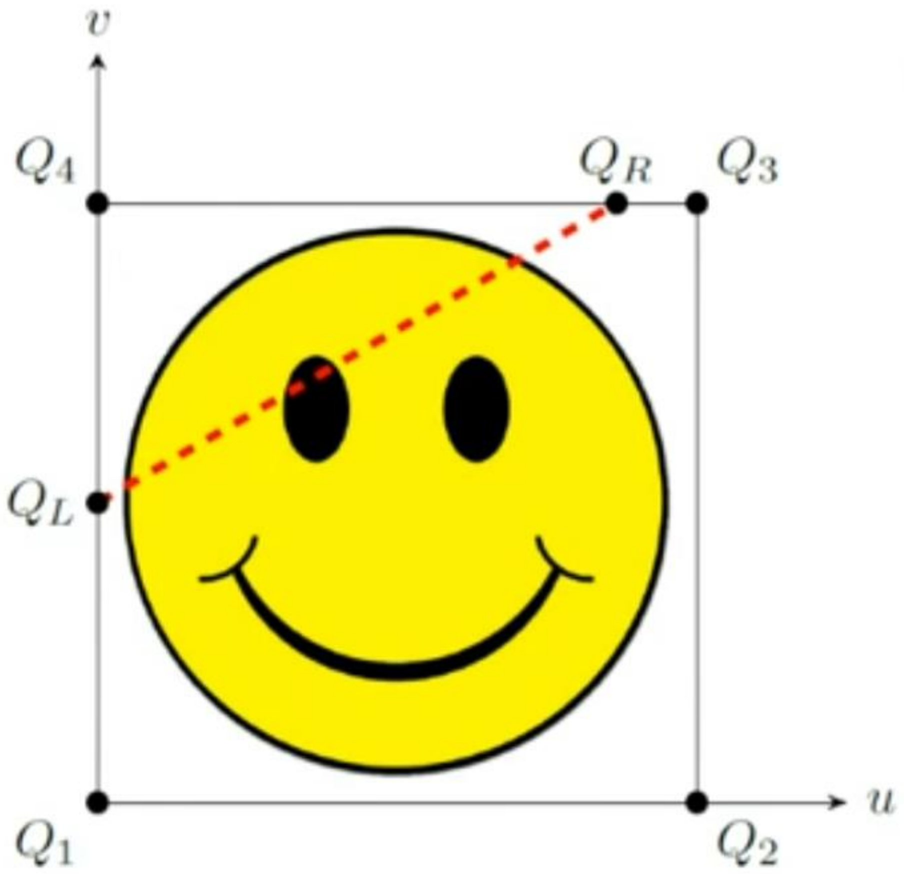
- **Texturing** is the mapping of **2D** images to **3D** polygons
- The image we are mapping we call **texture**
- A pixel in the texture we call **texel**
- Pixel colors are given by texels in the texture

Texturing

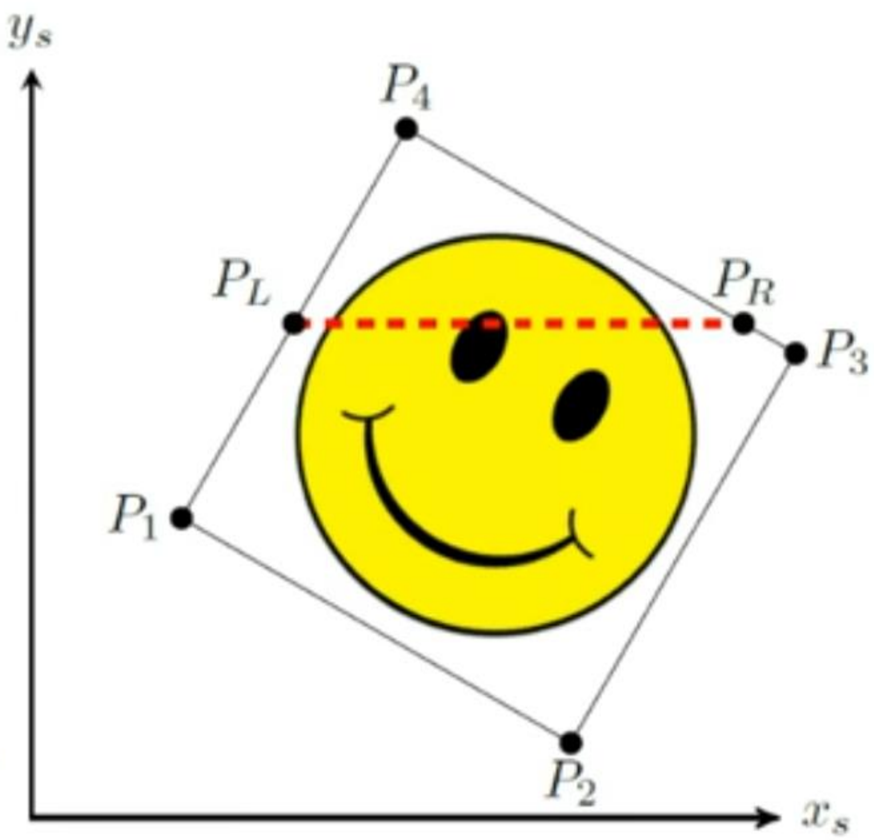


Texture space

- **Texture space** is the space in which the texture exists
- It is a 2D space where the horizontal and vertical axes are called u ∈ [0, 1] and v ∈ [0, 1]
- The texture completely fills the texture space, i.e. bottom left corner is in position (0,0) and top right corner at (1, 1)
- Texel coordinates (U, V) for a M_x x M_y texture are
  - $U = \lfloor M_x \cdot u + 1 \rfloor$
  - $V = \lfloor M_y \cdot v + 1 \rfloor$
  - If u = 0 then U = 0 and if u = 1 then $U = M_x + 1$, therefore we must test 0 < u, v < 1

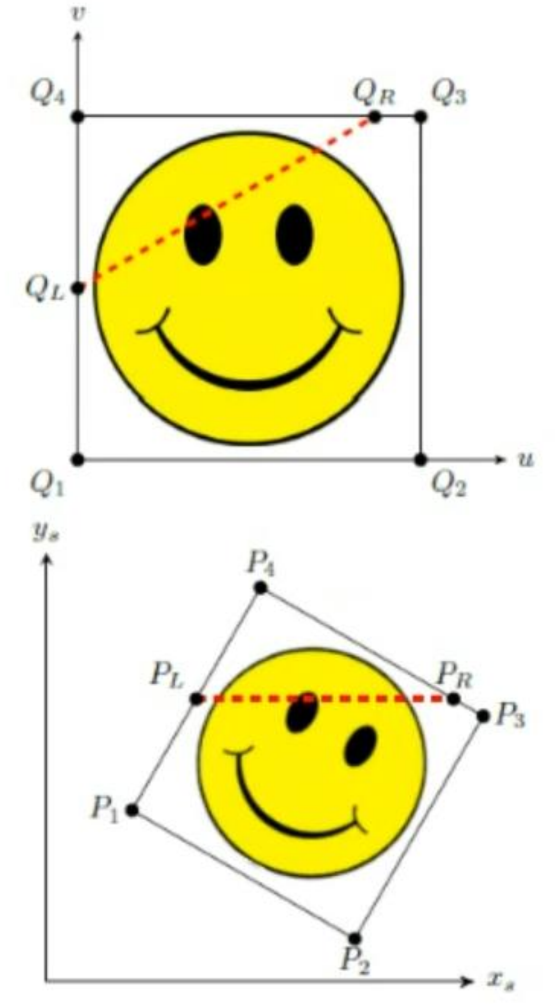


a texture space

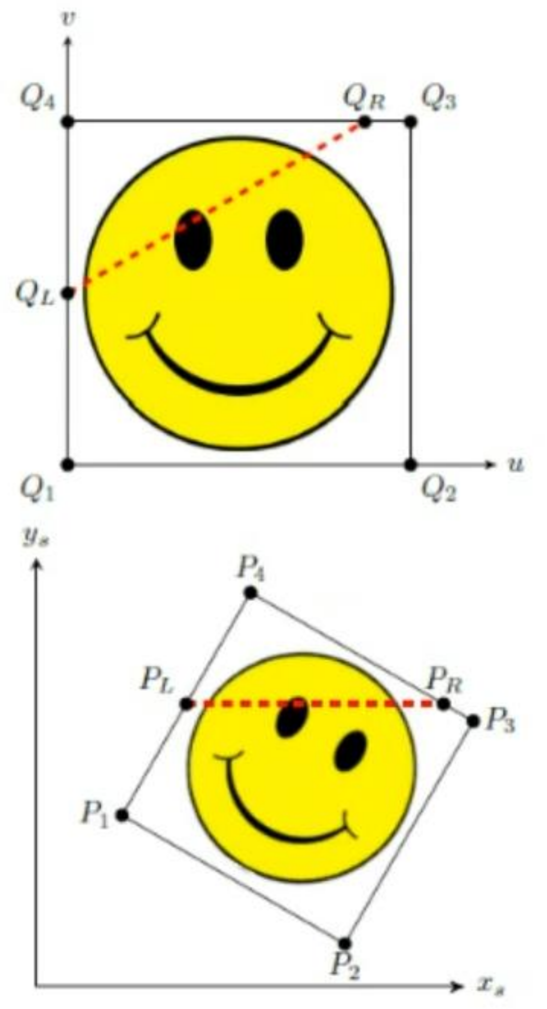


b screen space

- Vertices of polygon P, correspond to vertices Q in texture space
- Every transformation should be accounted for in texture space
- Using the scan-line method, maximum P_L is computed by interpolating between P_1 and P_4
- Similarly maximum P_R is computed by interpolating between P_4 and P_3



- Corresponding maxima in texture space Q_L and Q_R, are computed by interpolating the edges of the texture
- Pixels between P_L and P_R assume the same color as texels between Q_L and Q_R



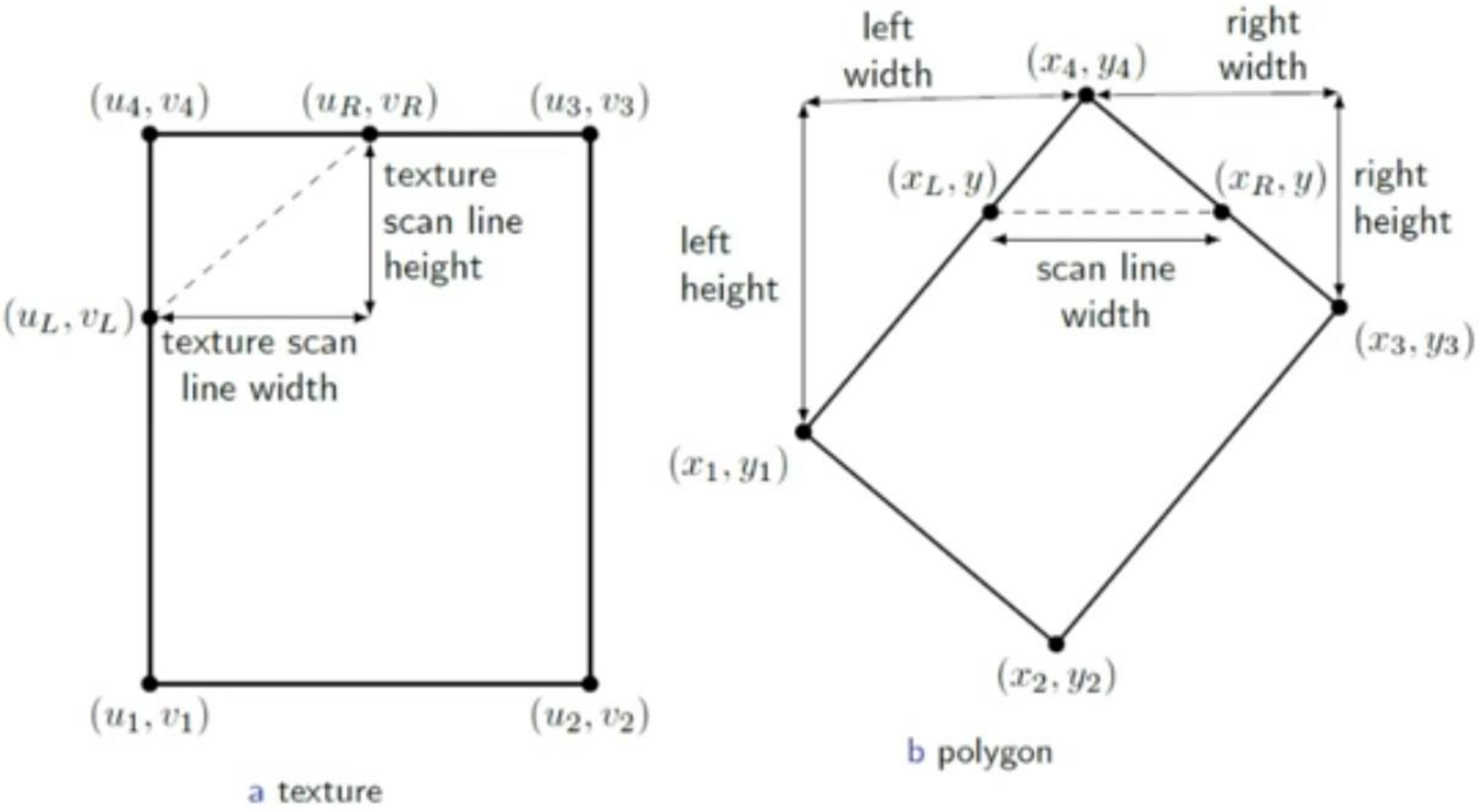
Computing the maxima

- Vertex coordinates are scaled to display size
- $x = max\left[1, (x_s + 1)\frac{N_x}{2}\right]$, $y = max\left[1, (y_s + 1)\frac{N_y}{2}\right]$
- Maxima P_L and P_R are initialized with value of the greatest coordinate y_s (i.e. P_4)
- Coordinate y of P_L and P_R is calculated by deducting 1 from the current coordinate
- x_L is calculated by interpolating between P_4 and P_1
- $x_L = x_4 - \frac{x_4 - x_1}{y_4 - y_1}$

Computing the maxima

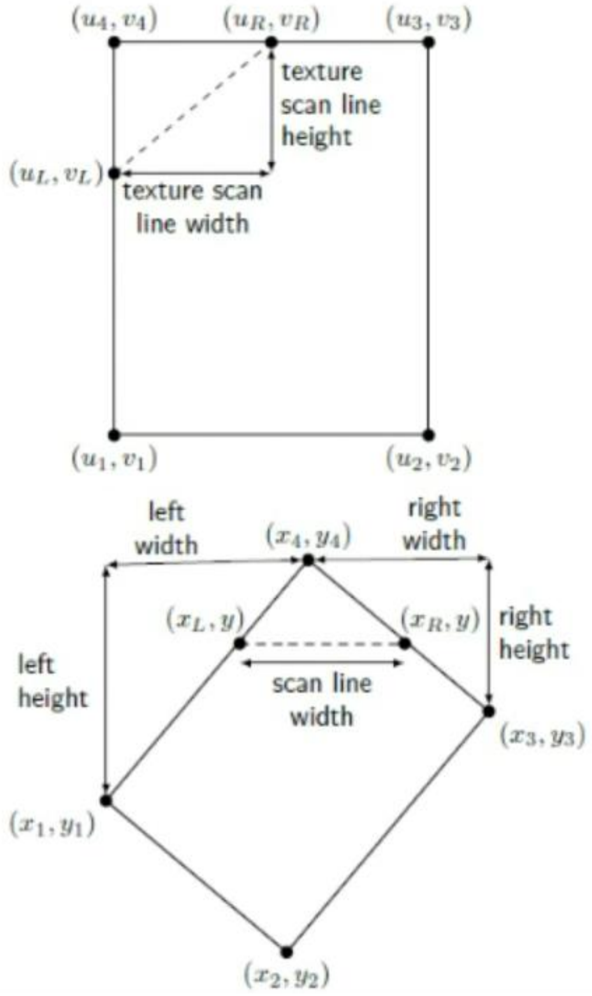
- $x_L = x_4 - \frac{x_4 - x_1}{y_4 - y_1}$
- Gradient is constant
- $x_L = x_L - \Delta x_L$
- $x_R = x_R - \Delta x_R$
- Where
- $\Delta x_L = \frac{left\ edge\ length}{left\ edge\ height} = \frac{x_4 - x_1}{y_4 - y_1}$
- $\Delta x_R = \frac{right\ edge\ length}{right\ edge\ height} = \frac{x_4 - x_3}{y_4 - y_3}$

Computing the maxima



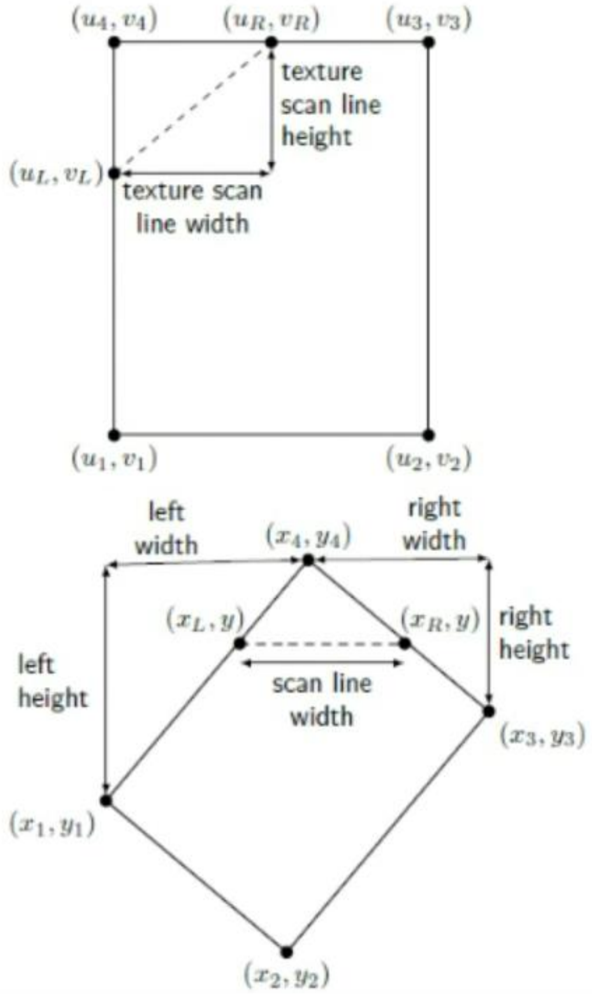
Computing the maxima in texture space

- v_L translates between v_4 and v_1 similarly as y between y_4 and y_1
- $\Delta u_L = \frac{u_4 - u_1}{y_4 - y_1}$
- $\Delta v_L = \frac{v_4 - v_1}{y_4 - y_1}$
- If P_L lowers to the next scan line:
- $u_L = u_L - \Delta u_L$
- $v_L = v_L - \Delta v_L$
- Similarly for u_R and v_R



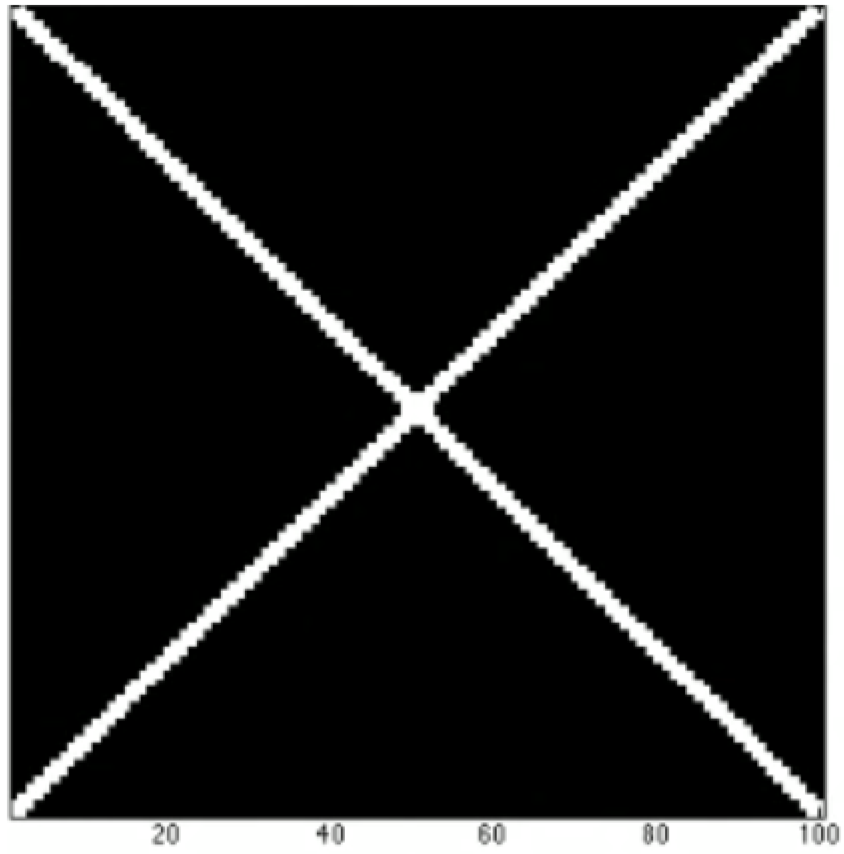
Interpolation of scan lines

- Starting with (x_L, x_R) we initialize u = $u_L$and v = v_L
- For each pixel we translate on the scan line and update the coordinates (u, v)
- $u = u + \Delta u$
- $v = v + \Delta v$
- We move from u_L to u_R in the same linear span as for x_L to x_R, therefore
- $\Delta u = \frac{u_R - u_L}{x_R - x_L}$
- $\Delta v = \frac{v_R - v_L}{x_R - x_L}$

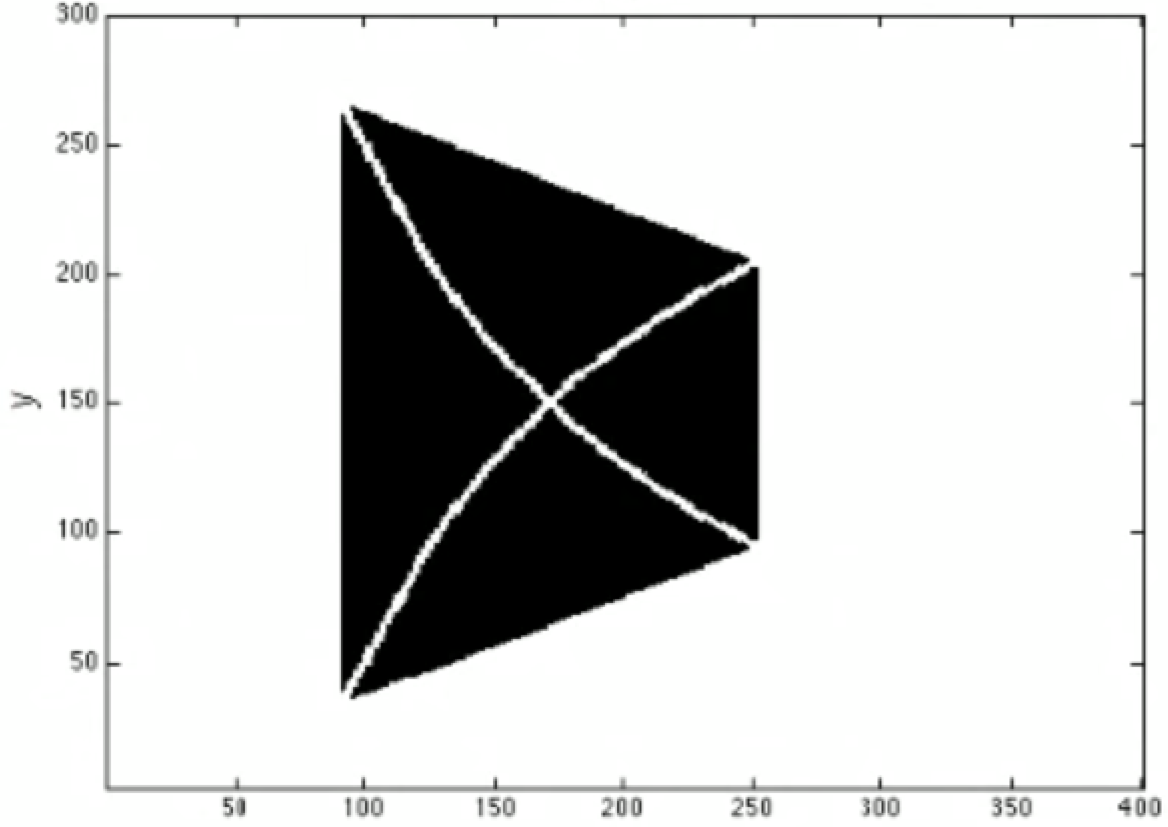


Texture space

Screen space



Texture space

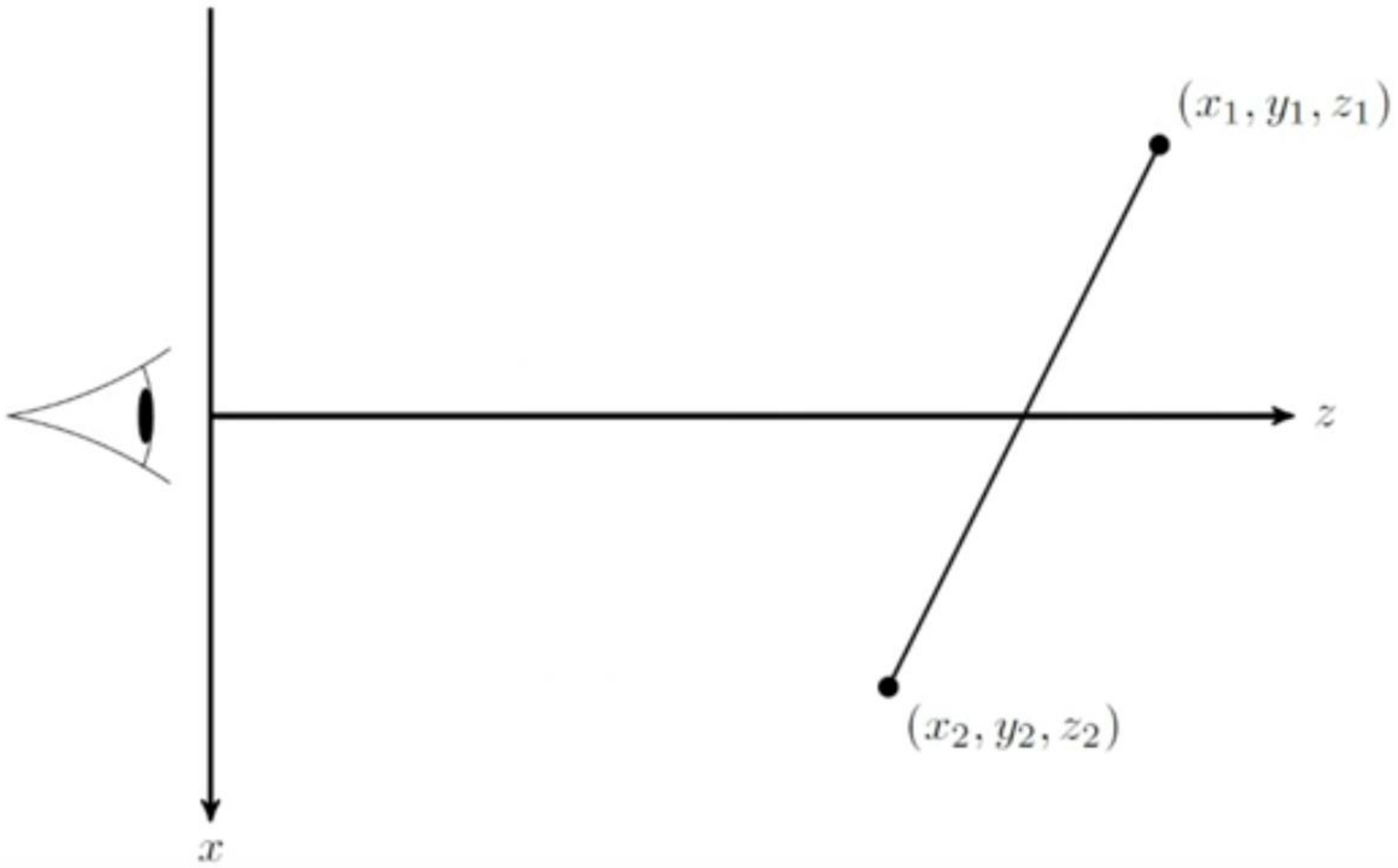


Screen space

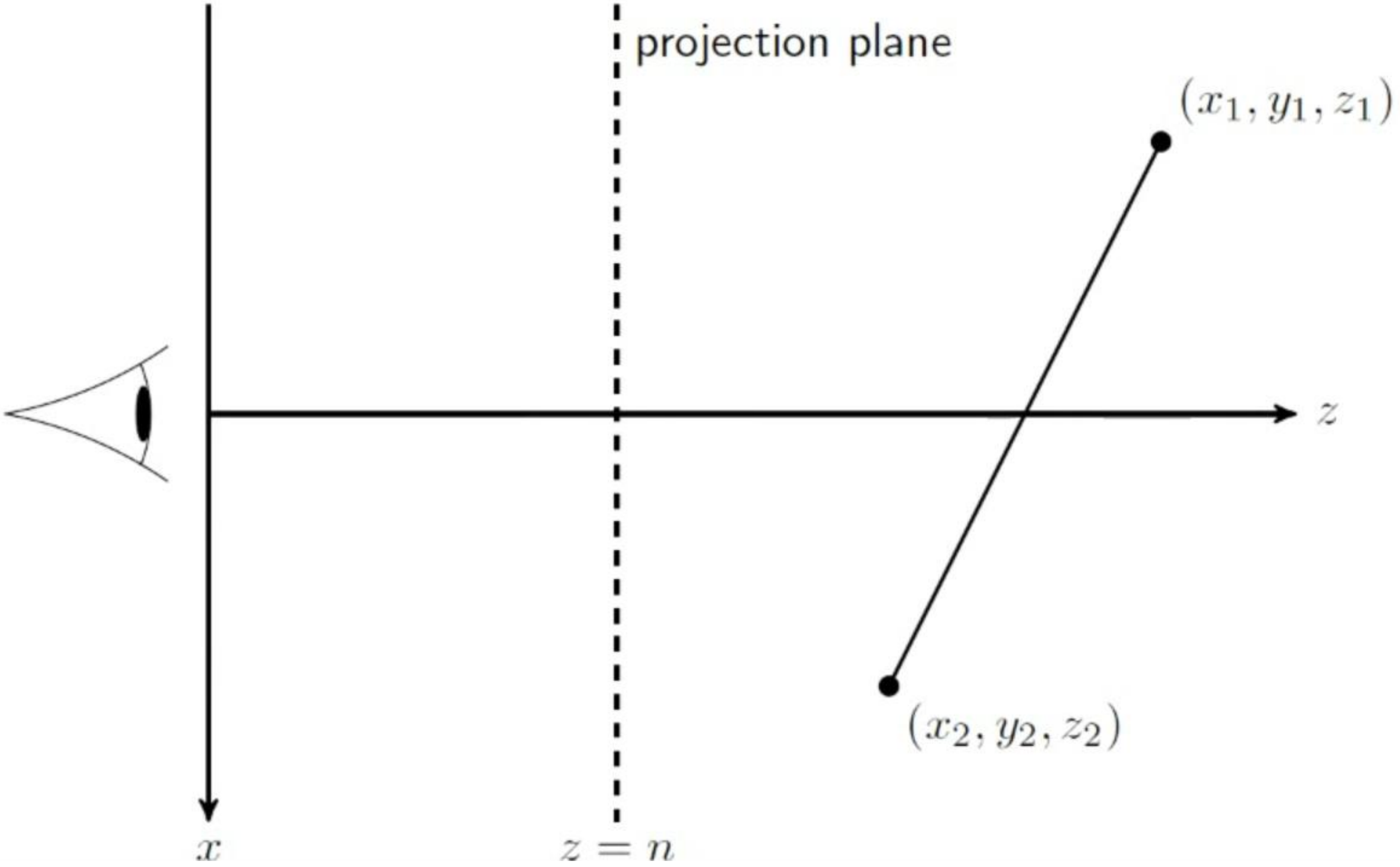
Why do we see artifacts?

- This texturing method relies on the assumption that mapping from 3D to 2D is a linear transformation
- Relations between x and x_s as well as y and y_s are linear, relations between z and z_s **are NOT linear**
- To remove the artifacts we have to take into account the distance of the observer

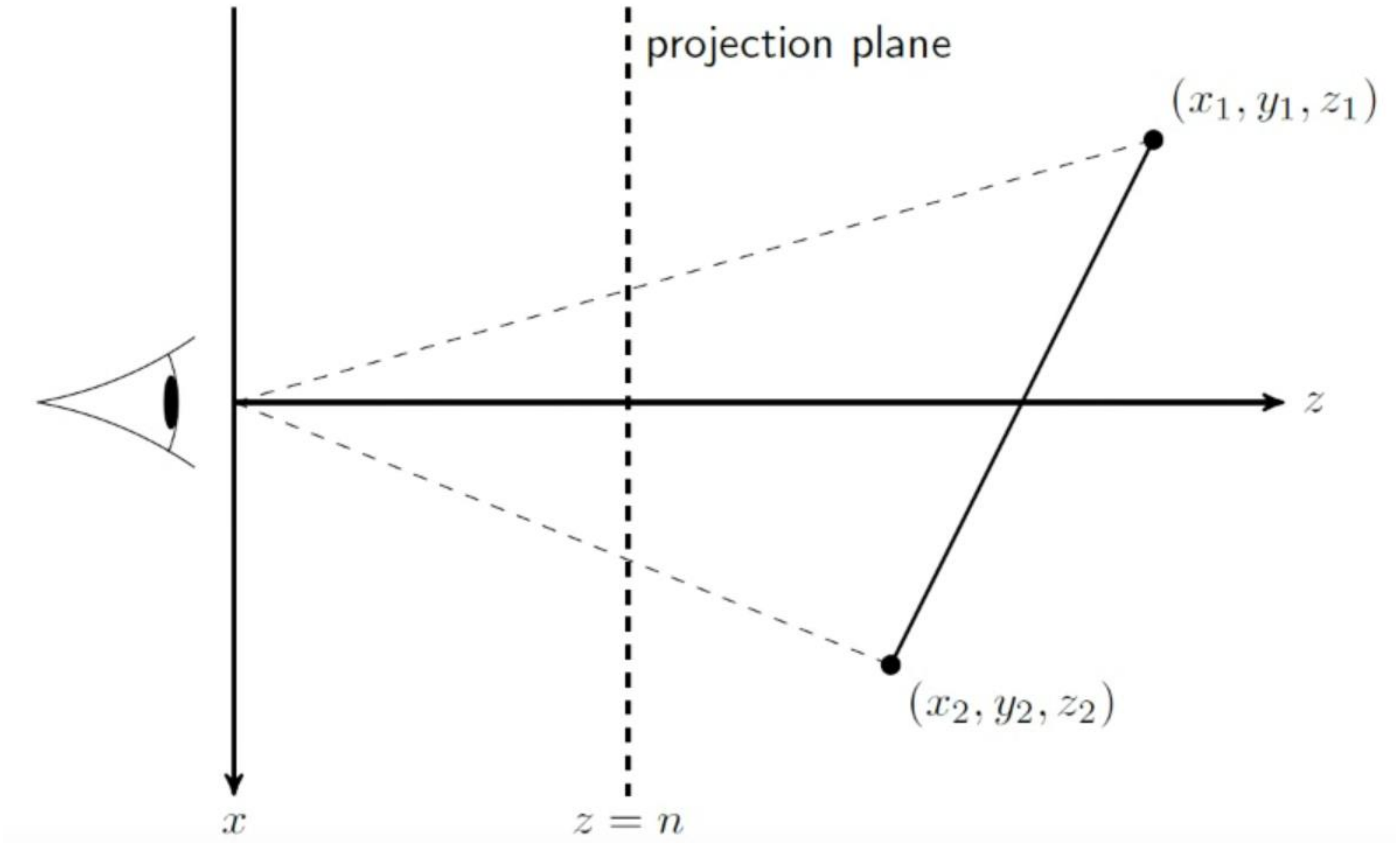
Perspective projection



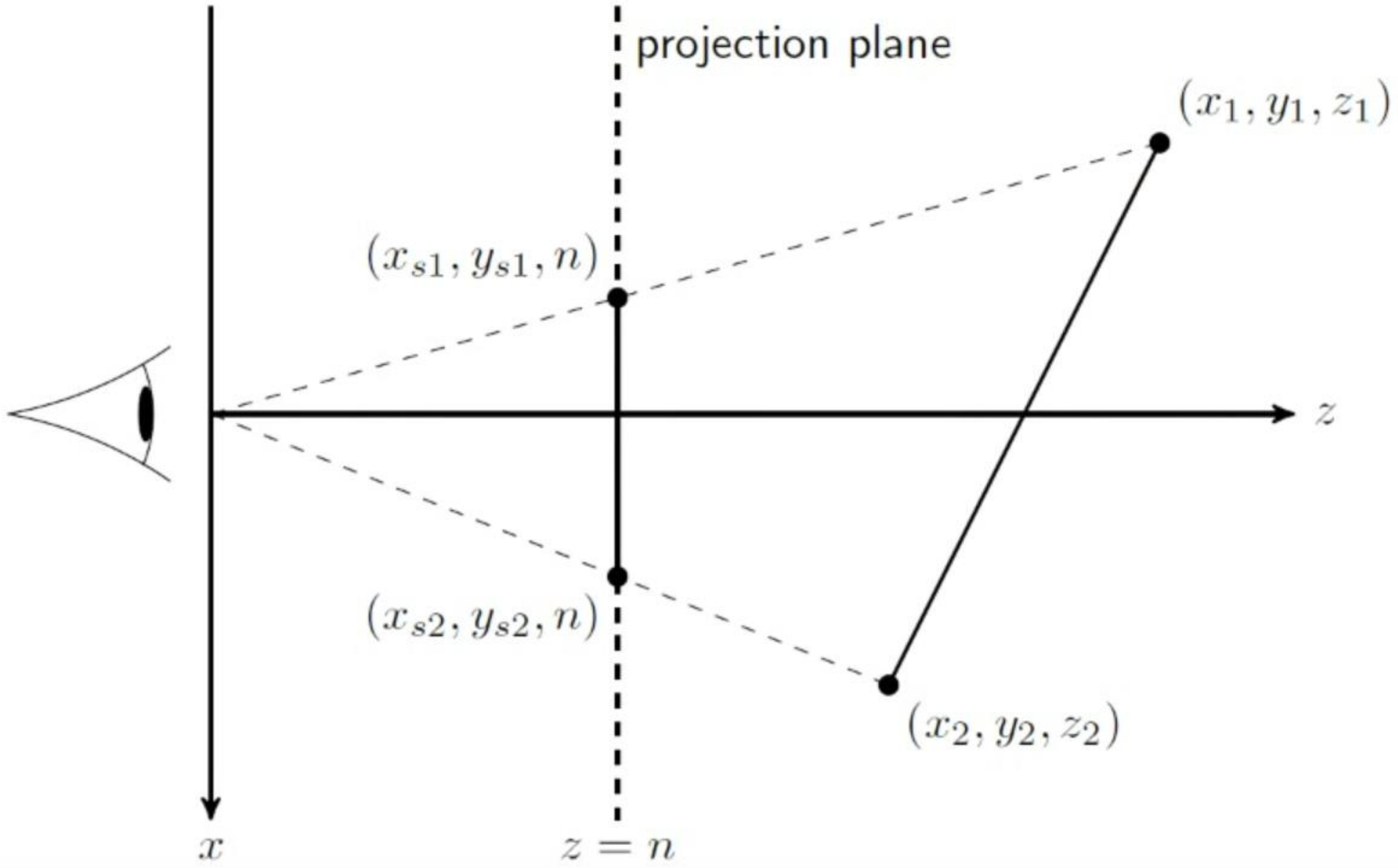
Perspective projection



Perspective projection

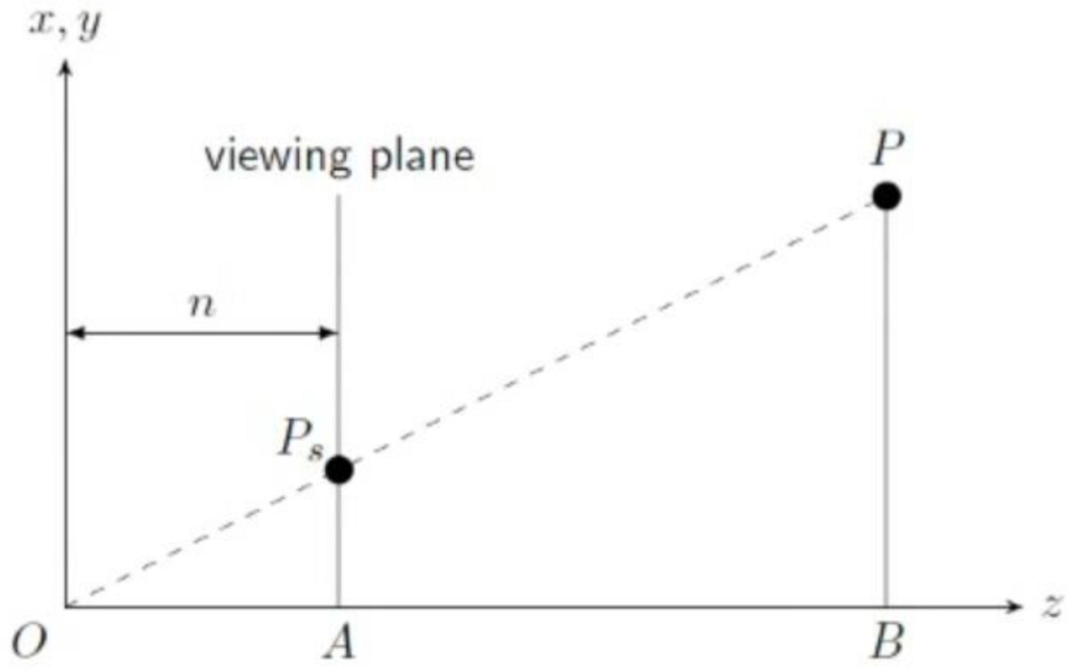


Perspective projection



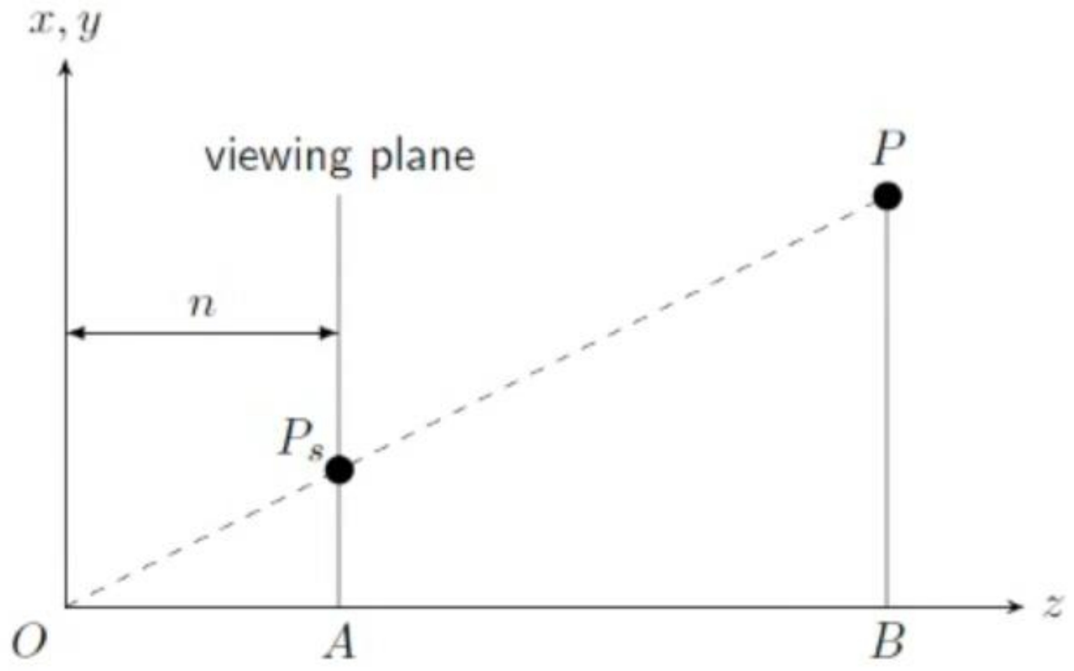
Perspective projection

- Point P in world space is projected onto screen space P_s
- Triangles OAP and OBP are similar:
- $\frac{x_s}{n} = \frac{x}{z} \quad \Rightarrow x_s = \frac{n}{z}x$
- $\frac{y_s}{n} = \frac{y}{z} \quad \Rightarrow y_s = \frac{n}{z}y$
- $z_s = n$



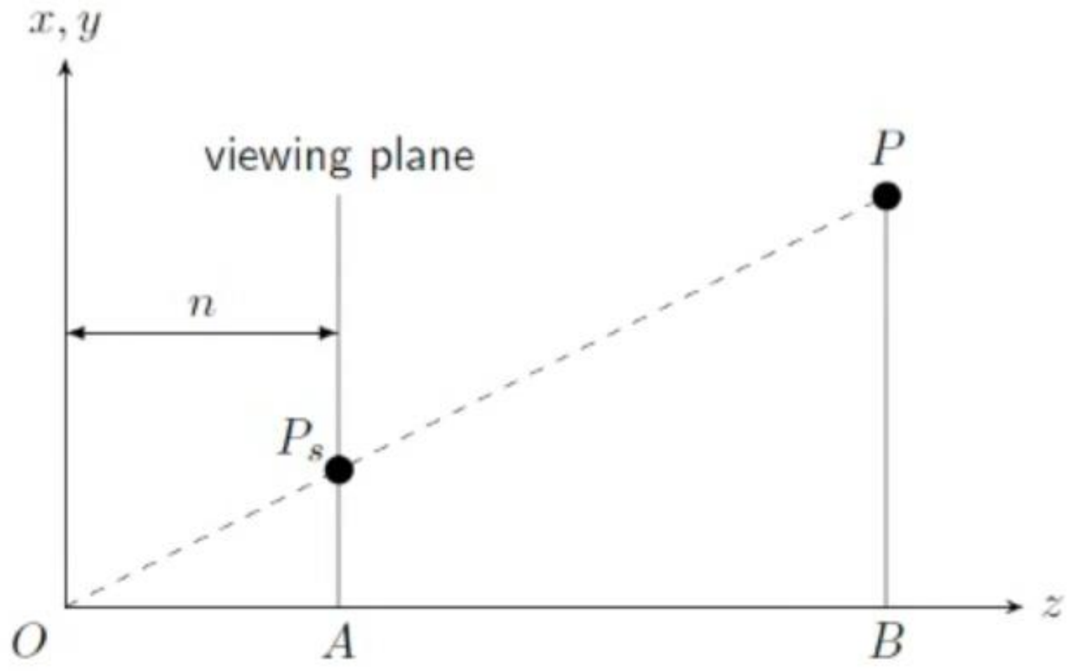
Perspective projection

- Line equation in world space is:
- $x = \alpha z + \beta$
- Reversing the perspective projection:
- $x = \frac{z}{n} x_s$



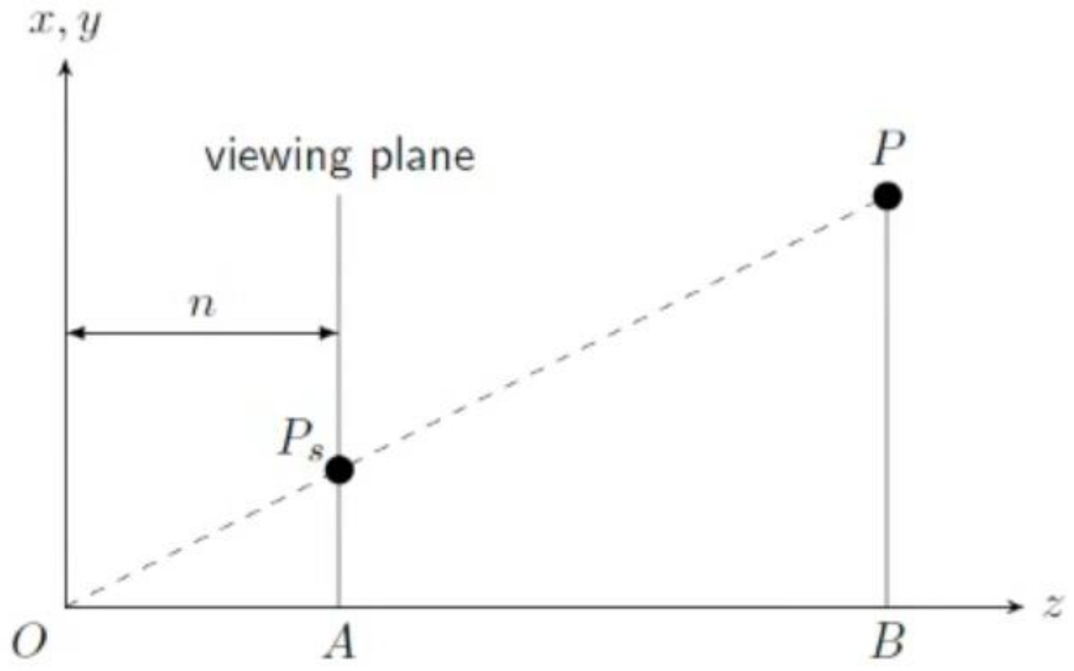
Perspective projection

- Line equation in world space is:
- $x = \alpha z + \beta$
- Reversing the perspective projection:
- $x = \frac{z}{n} x_s$
- Giving us $\frac{z}{n} x_s = \alpha z + \beta$

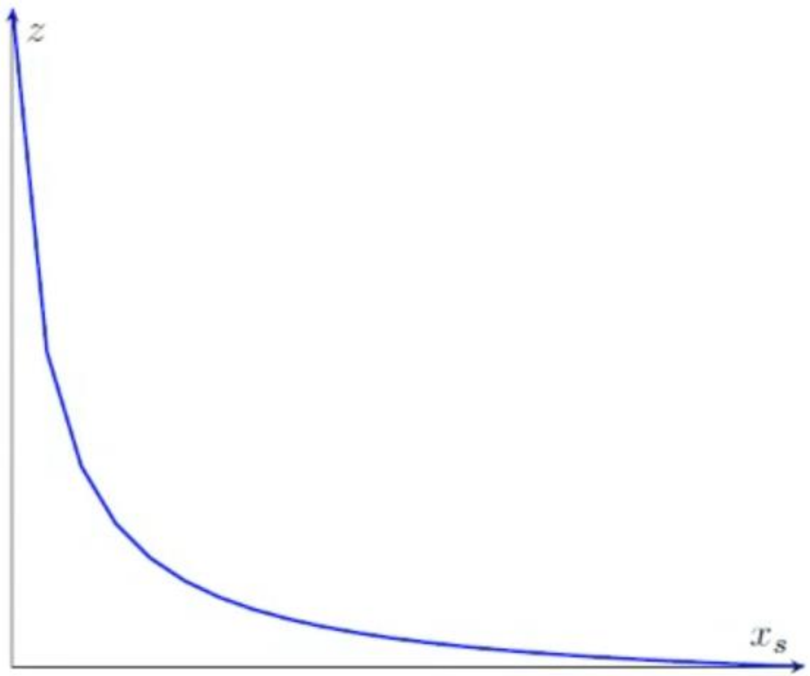


Perspective projection

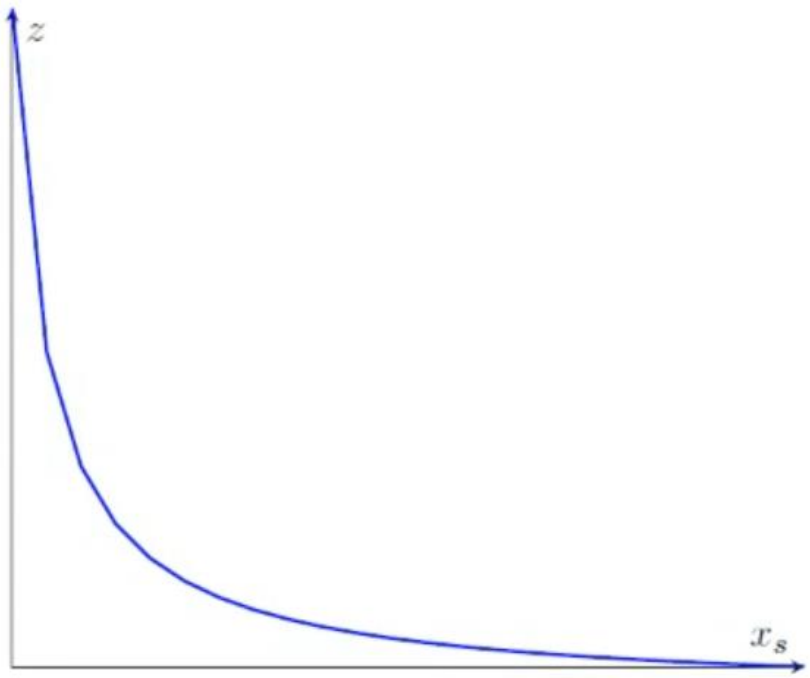
- Line equation in world space is:
- $x = \alpha z + \beta$
- Reversing the perspective projection:
- $x = \frac{z}{n} x_s$
- Giving us $\frac{z}{n} x_s = \alpha z + \beta$
- $z = \beta n \frac{1}{x_s} + \frac{\beta}{\alpha}$



- $z = \beta n \frac{1}{x_s} + \frac{\beta}{\alpha}$
- This is not a linear relation of z and x_s



- $z = \beta n \frac{1}{x_s} + \frac{\beta}{\alpha}$
- This is not a linear relation of z and x_s
- We can use the inverse relation
- $\frac{1}{z} = \frac{x_s}{\beta n} - \frac{\alpha}{\beta}$
- The relation between $\frac{1}{z}$ and x_s is linear

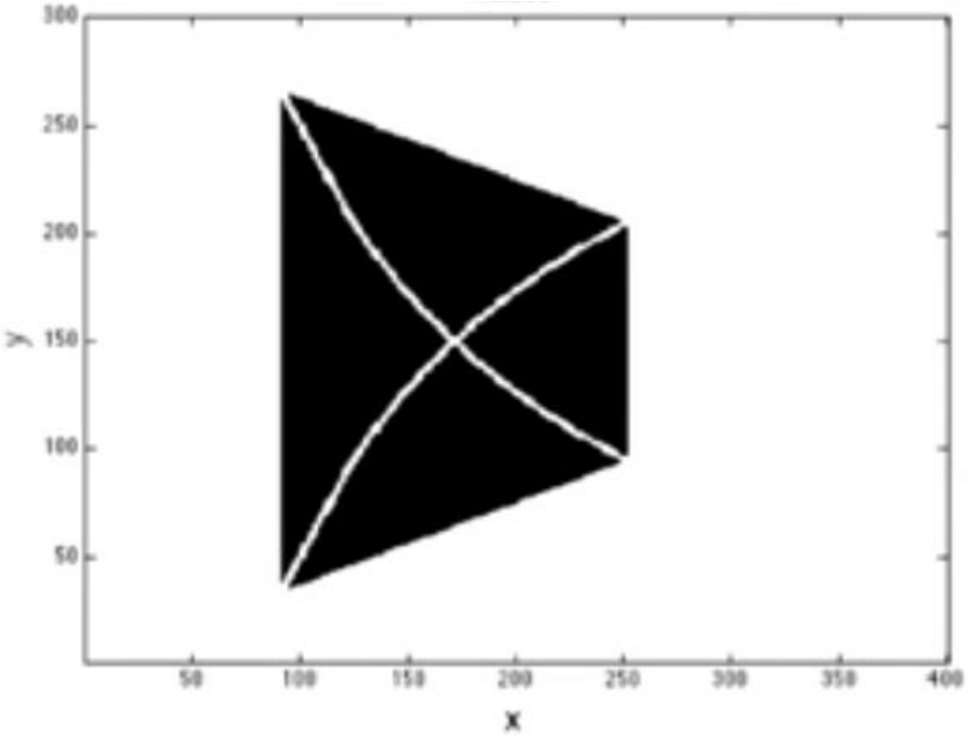


Perspective texturing

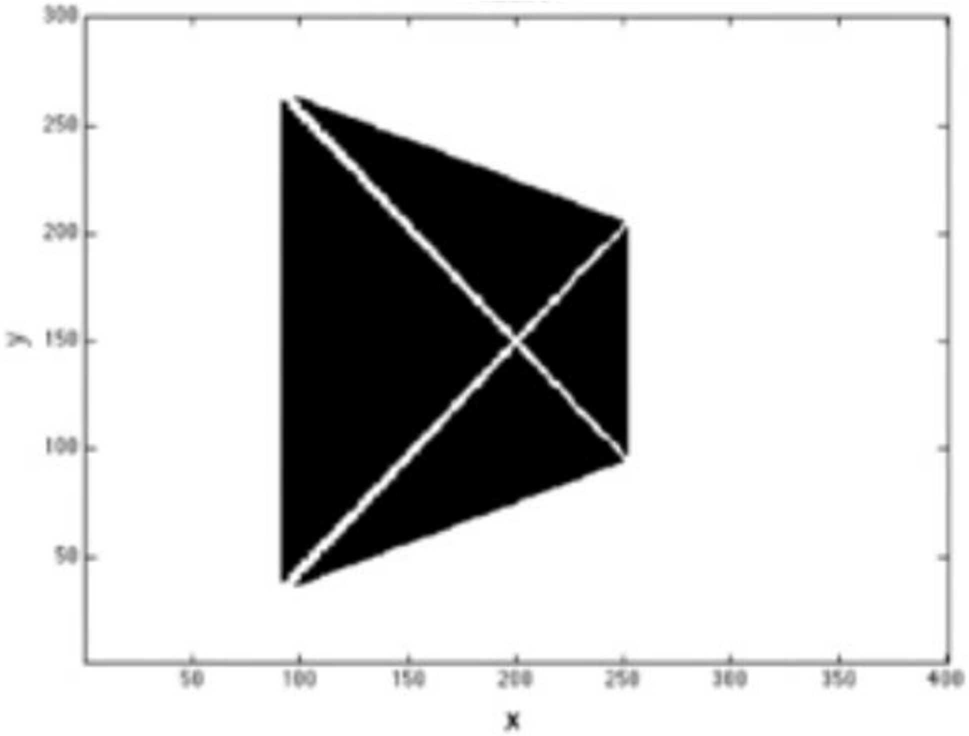
- To apply perspective projection but still use linear interpolation we have to compute the value $\frac{1}{z}$ for the maxima P_L and P_R

- The vertices in texture space are divided by z giving $\frac{u}{z}$ and $\frac{v}{z}$

- Linear interpolation is used as before but calculated for coordinates of texture space $(\frac{u}{z}, \frac{v}{z})$ which correspond to coordinates in screen space $(x_s, y_s, \frac{1}{z})$



Linear interpolation

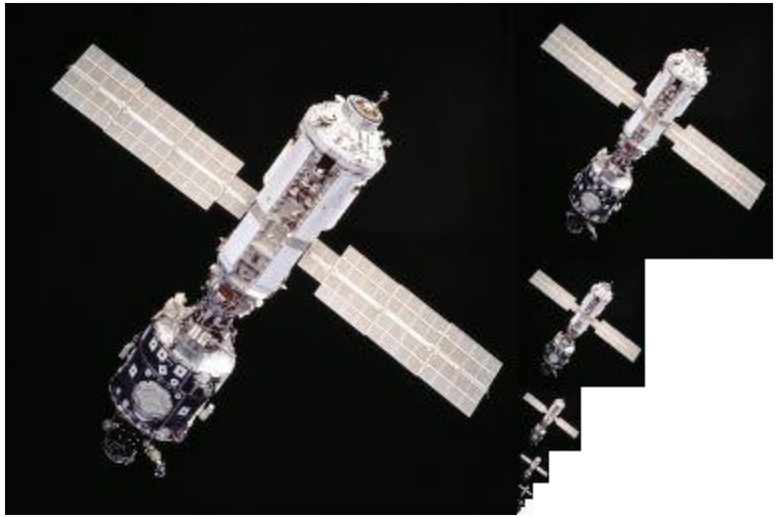


Perspective projection

Mipmapping

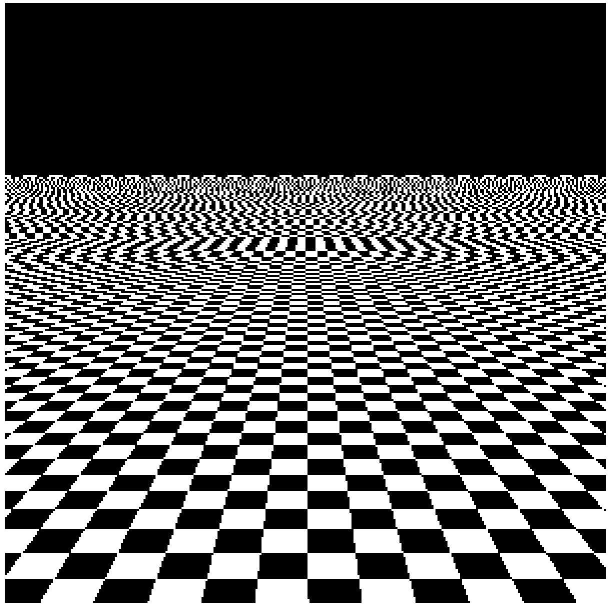
Mipmapping

- Faster texturing



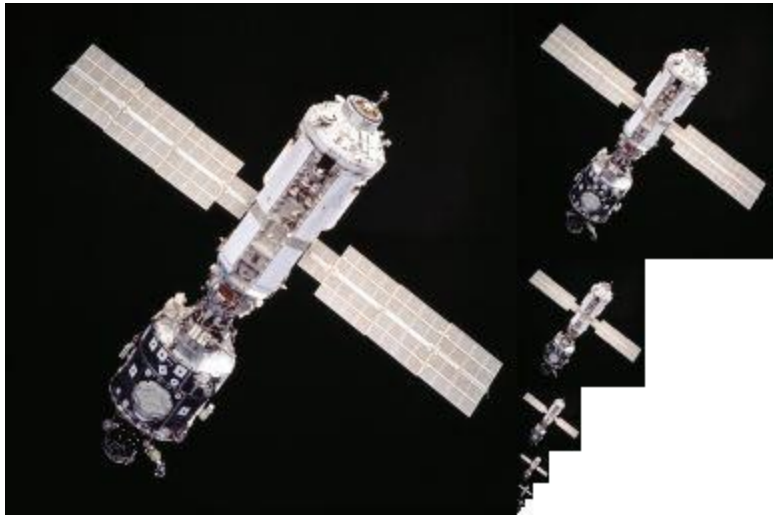
Mipmapping

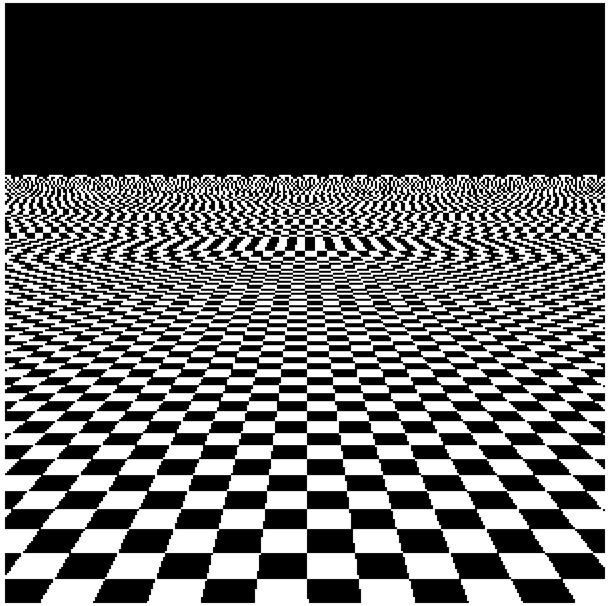
- Faster texturing



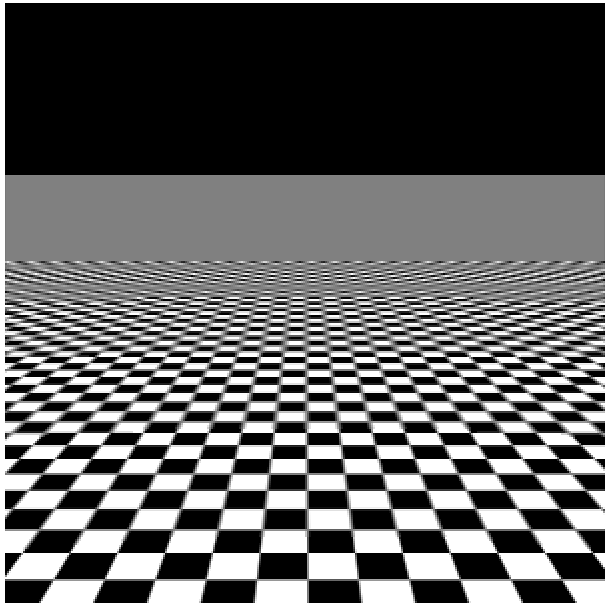
Mipmapping

- Faster texturing



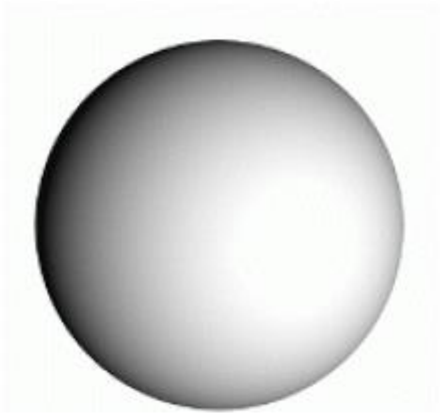


Without mipmapping

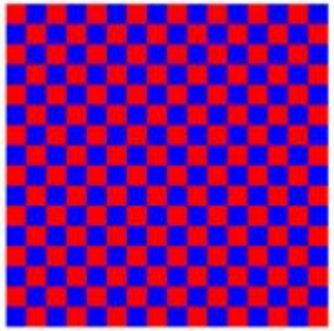


mipmapping

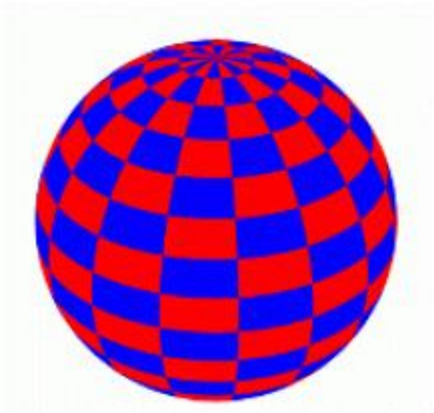
Texturing and lighting



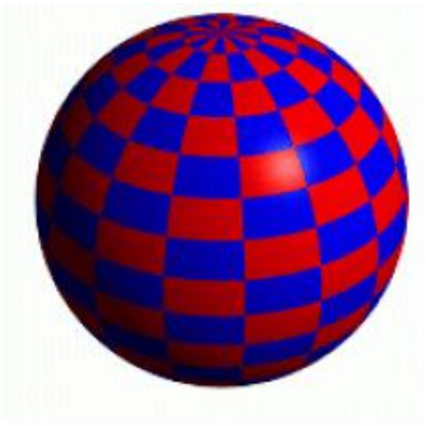
Shading



Texture



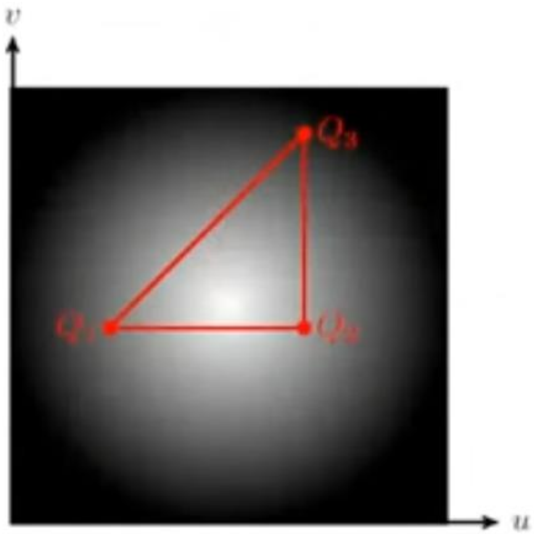
Applied texture



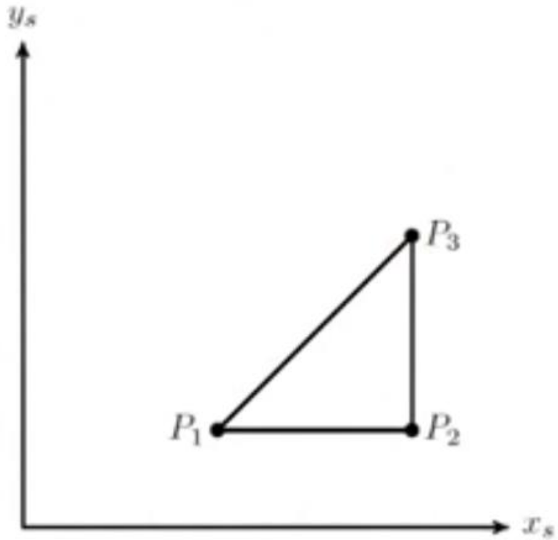
Lighting and texturing

Fast Phong shading

- Texturing can be used to speed up lighting



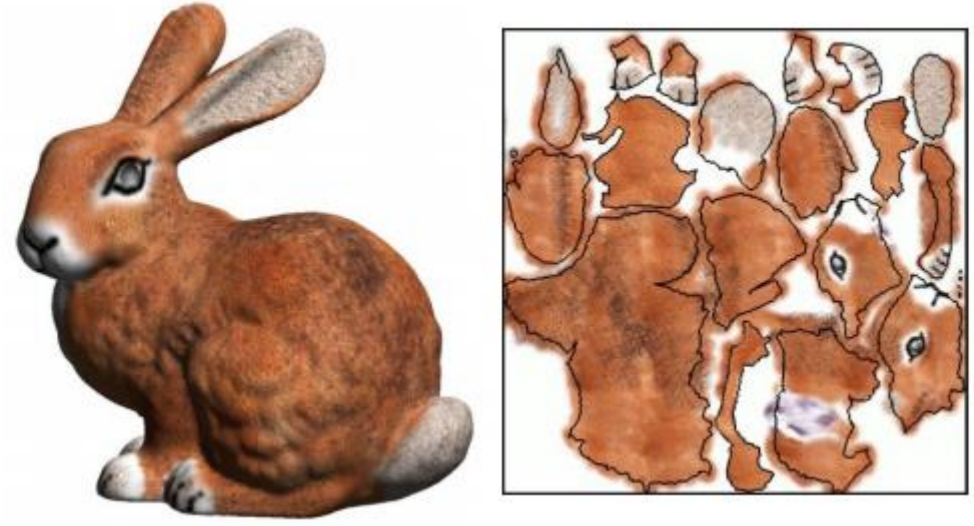
Phong map



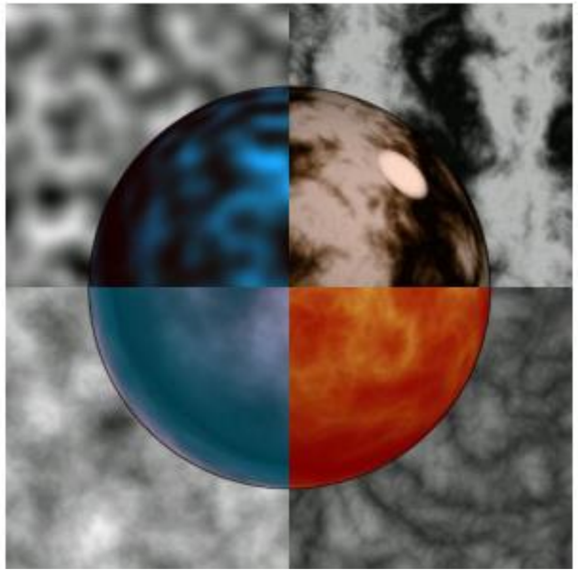
Screen space

Texturing

- From data:
  - Read information from 2D images



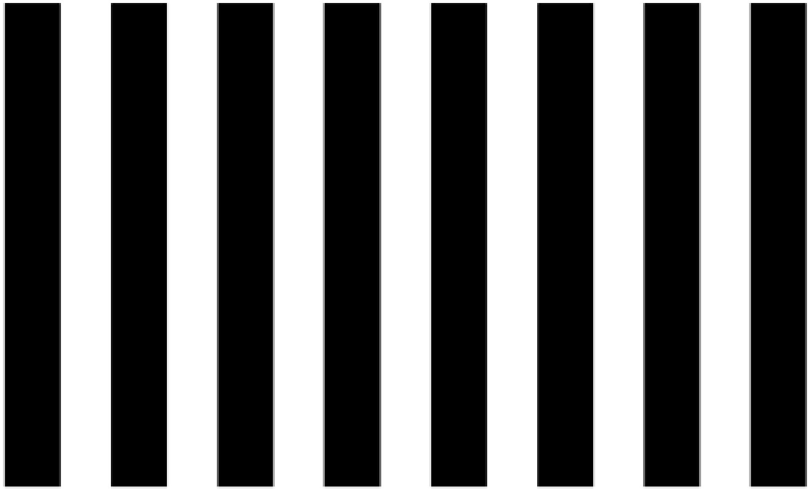
- Procedural:
  - Write a program that calculates color as a function of position



Procedural texturing

- Alternatively, to texture mapping we can write a program that calculates the pixel color as a function of position (x, y, z)

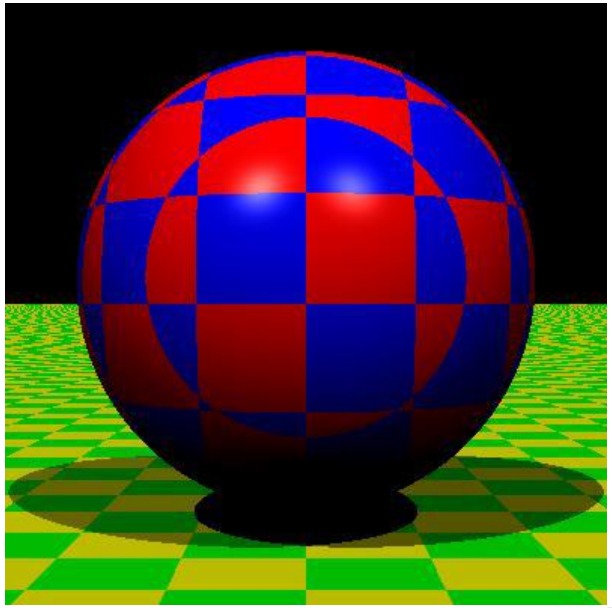
- $f(x, y, z) \rightarrow color$

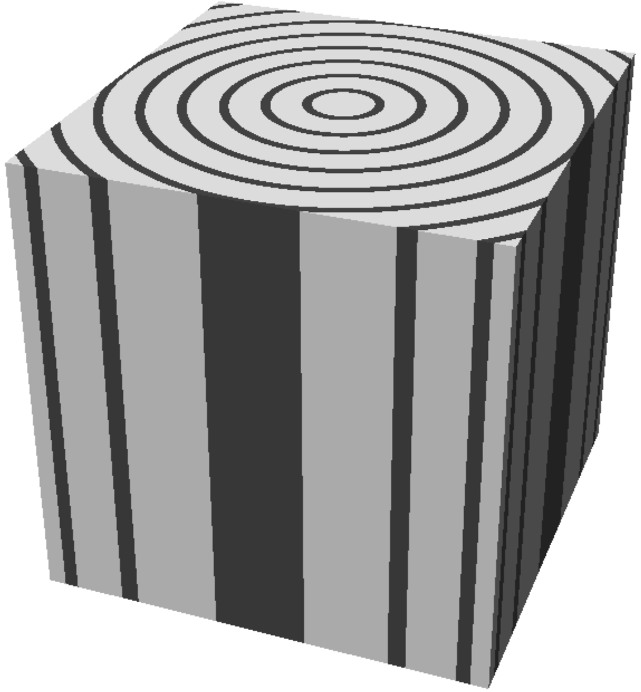


Procedural texturing

- Pros:
  - Uses up less memory
  - Infinite resolution

- Cons:
  - Less intuitive
  - Usually hard to find a function that simulates a given pattern

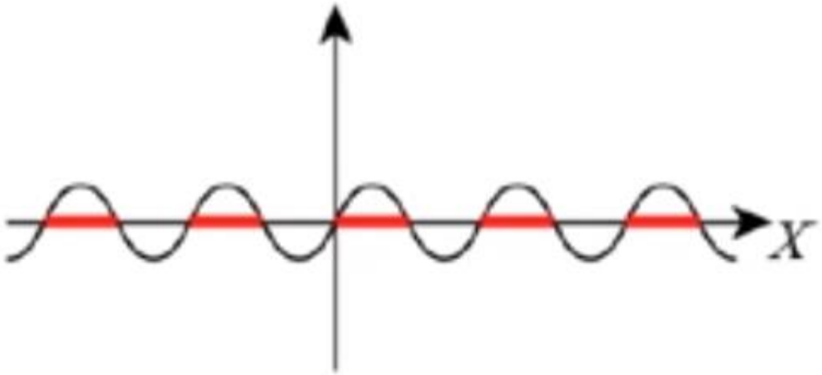




Example: 3D stripes

- Stripes along axis x:

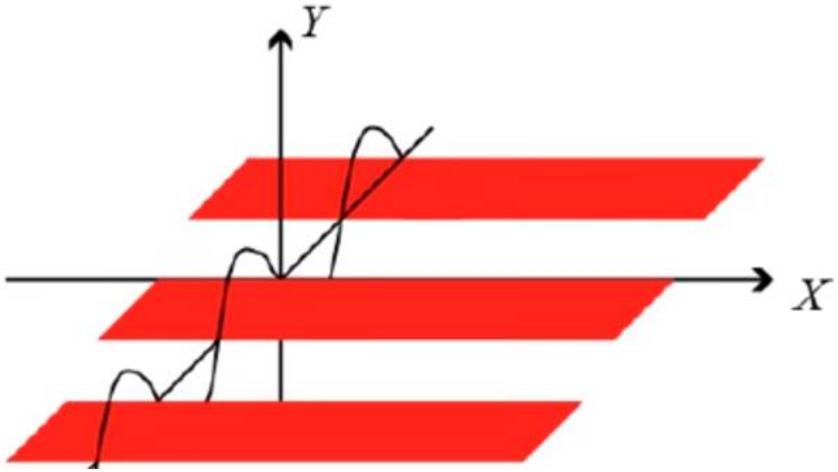
```
Stripes(x_s, y_s, z_s)
{
   If(sin x_s > 0) return color0
   Else return color1
}
```



Example: 3D stripes

- Stripes along axis z:

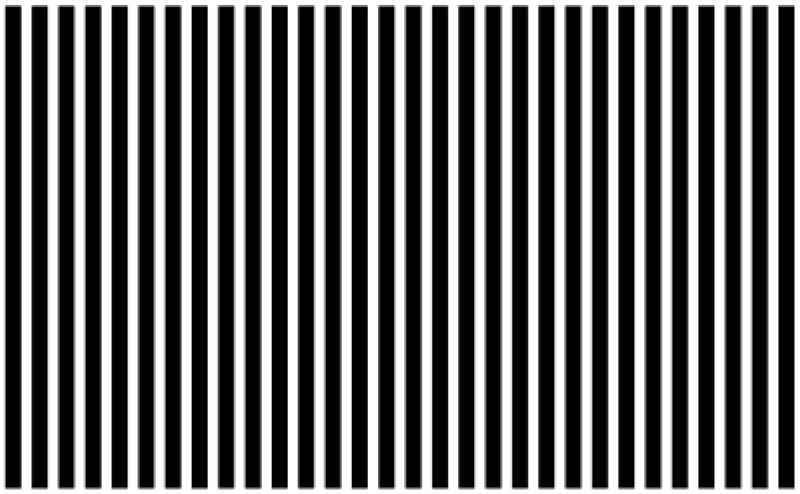

```
Stripes(xs, ys, zs)
{
   If(sin zs > 0) return color0
   Else return color1
}
```

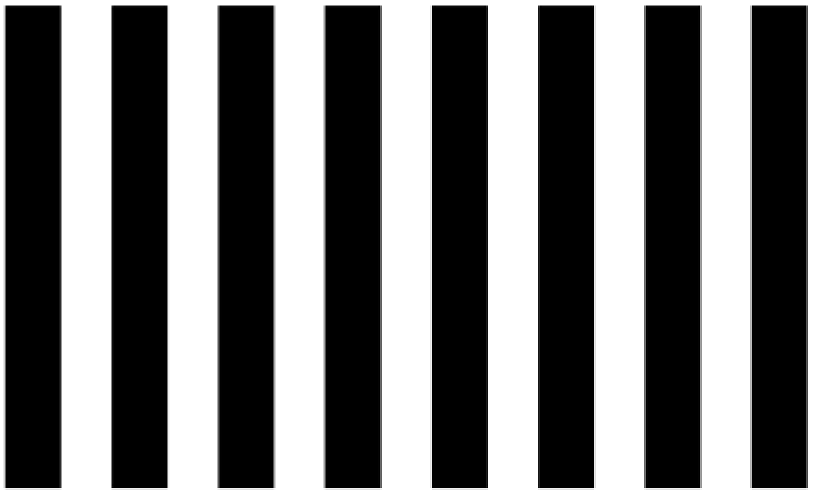


Example: 3D stripes

- Stripes with variable width

```
Stripes(x_s, y_s, z_s, width)
{
   If(sin (π * x_s / width) > 0)
      return color0
   Else return color1
}
```

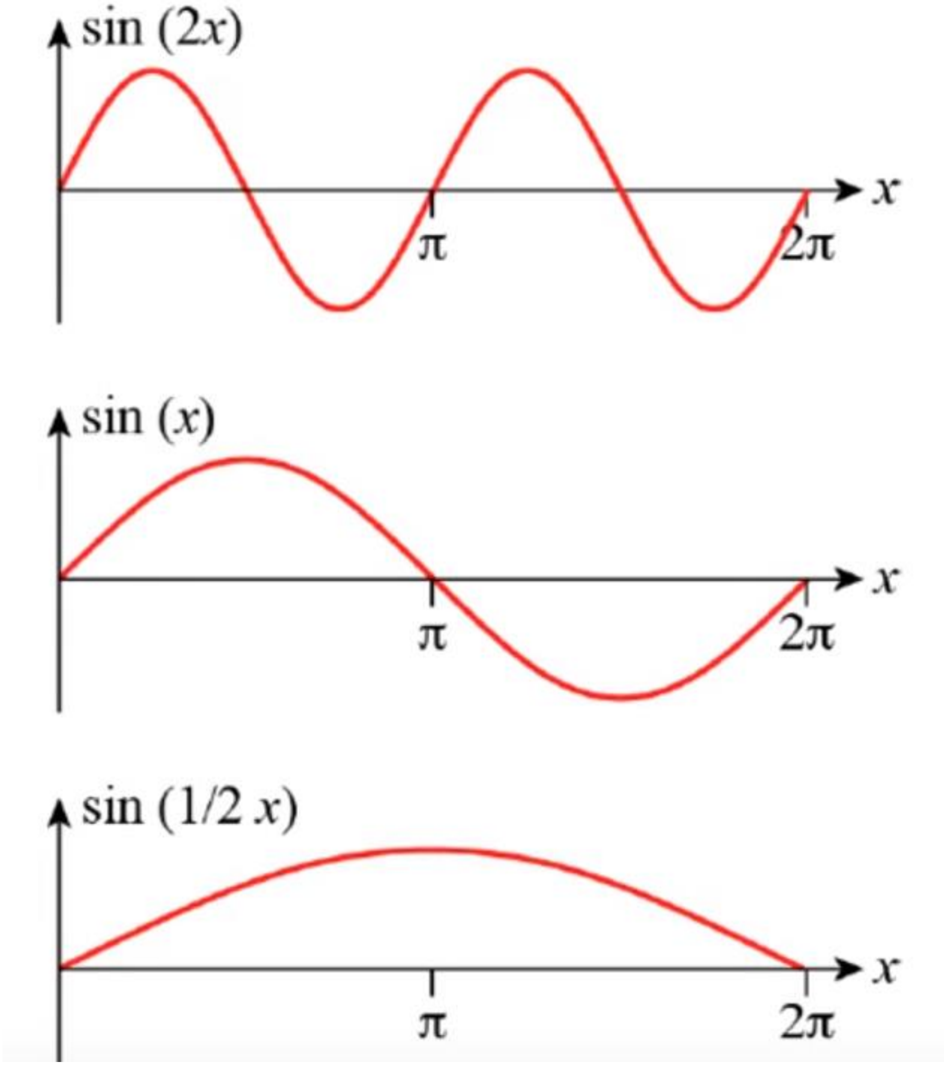




Example: 3D stripes

- Stripes with variable width

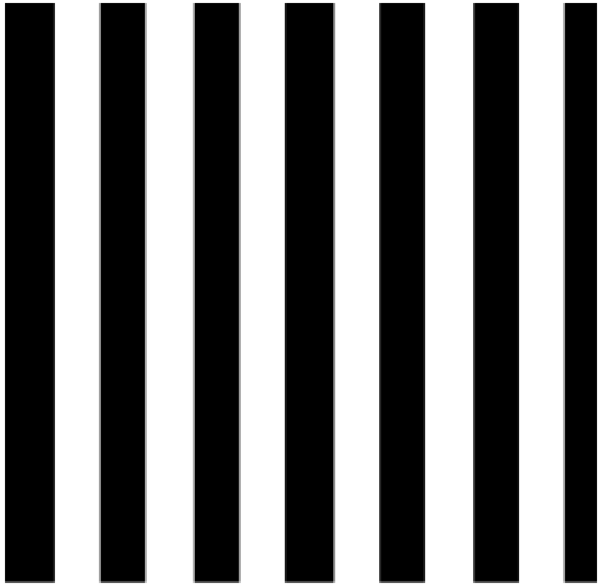
```
Stripes(xs, ys, zs, width)
{
   If(sin (π * xs / width) > 0)
      return color0
   Else return color1
}
```

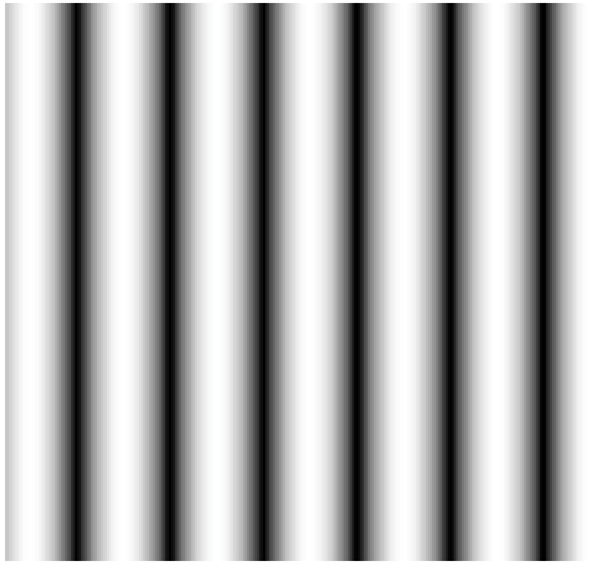


3D stripes

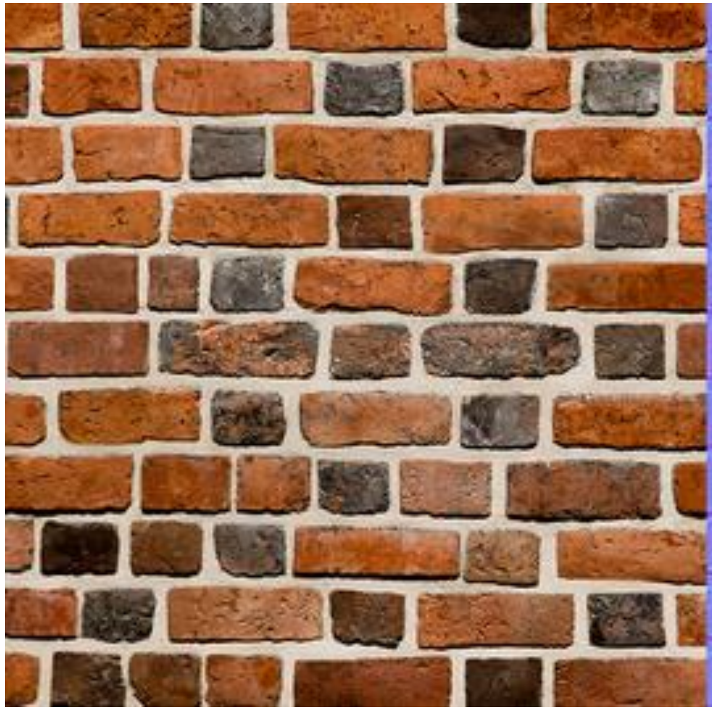
- Gradual variation of colors

```
Stripes(x_s, y_s, z_s, width)
{
   t = (1 + sin (π * x_s / width)) / 2
   Return (1 - t) color0 + t color1
}
```

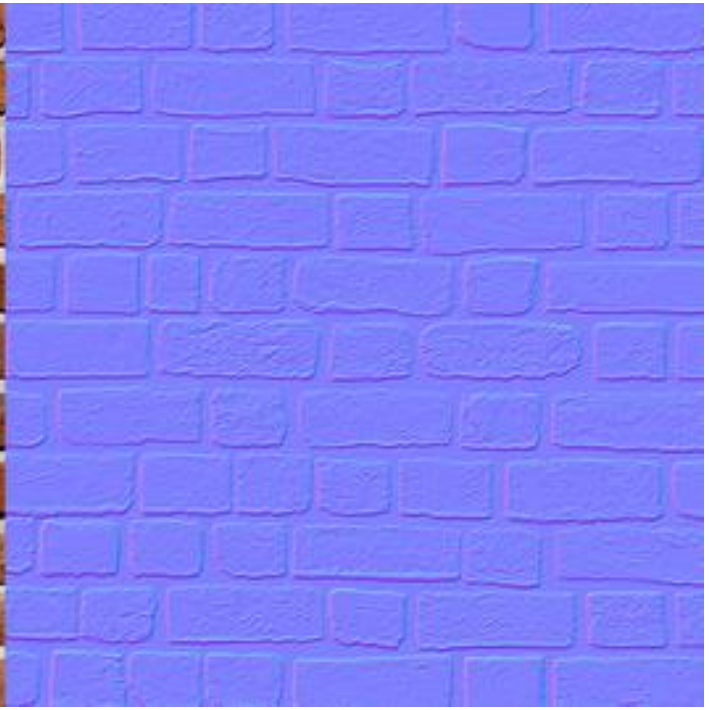




Normal mapping

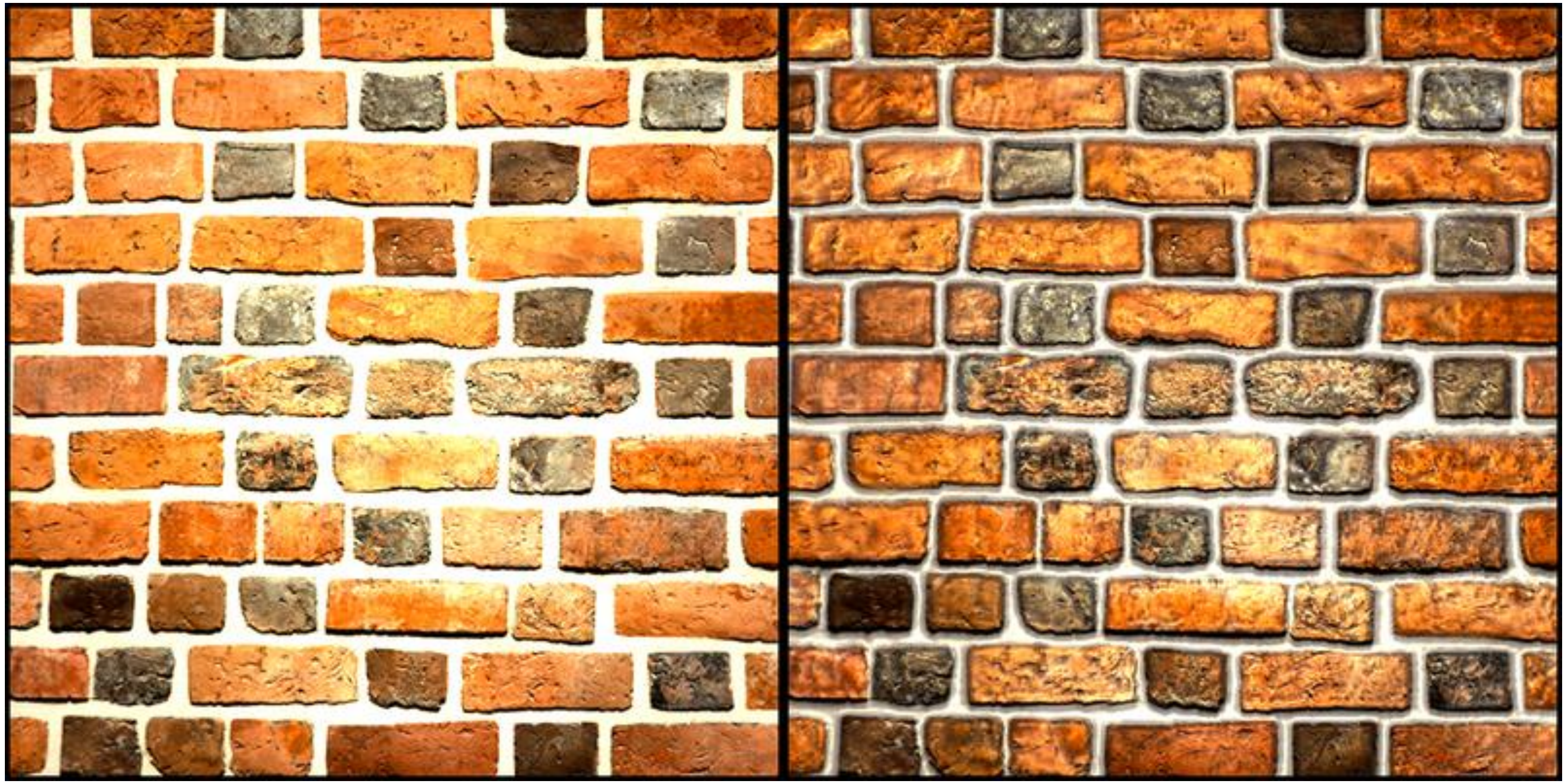


Texture



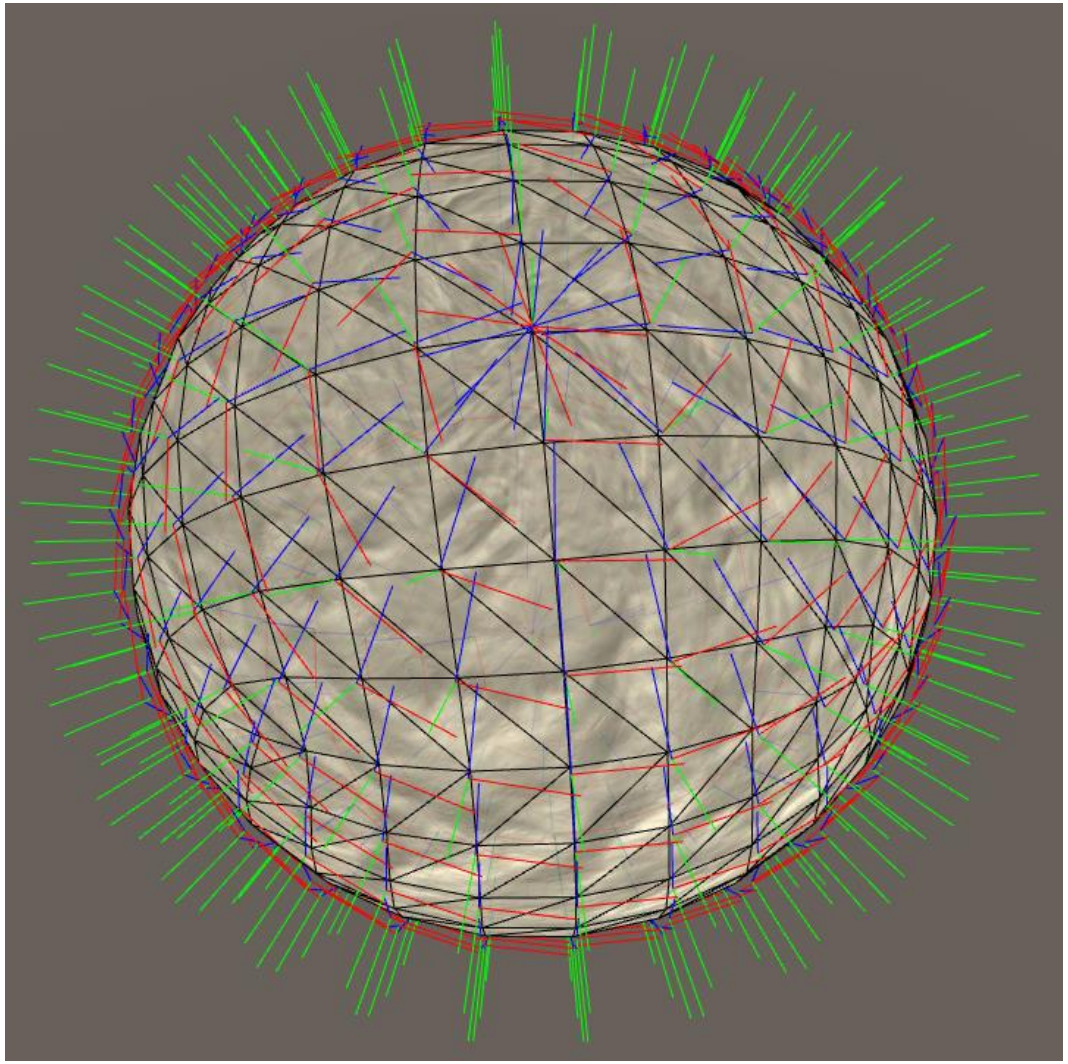
Normal map

Normal Mapping

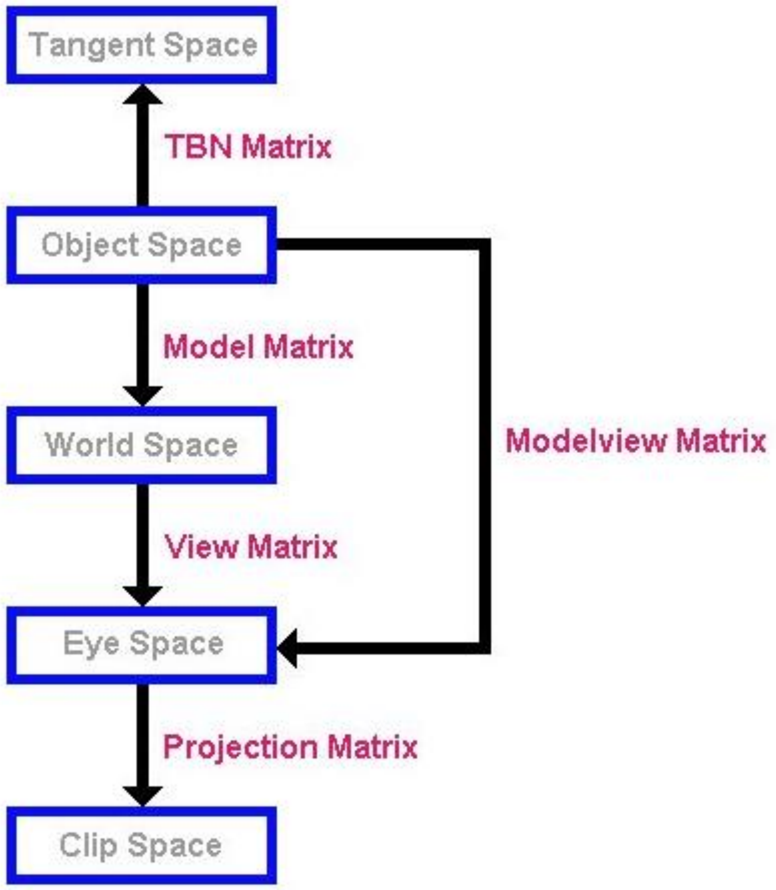


Without normal mapping   Normal mapping

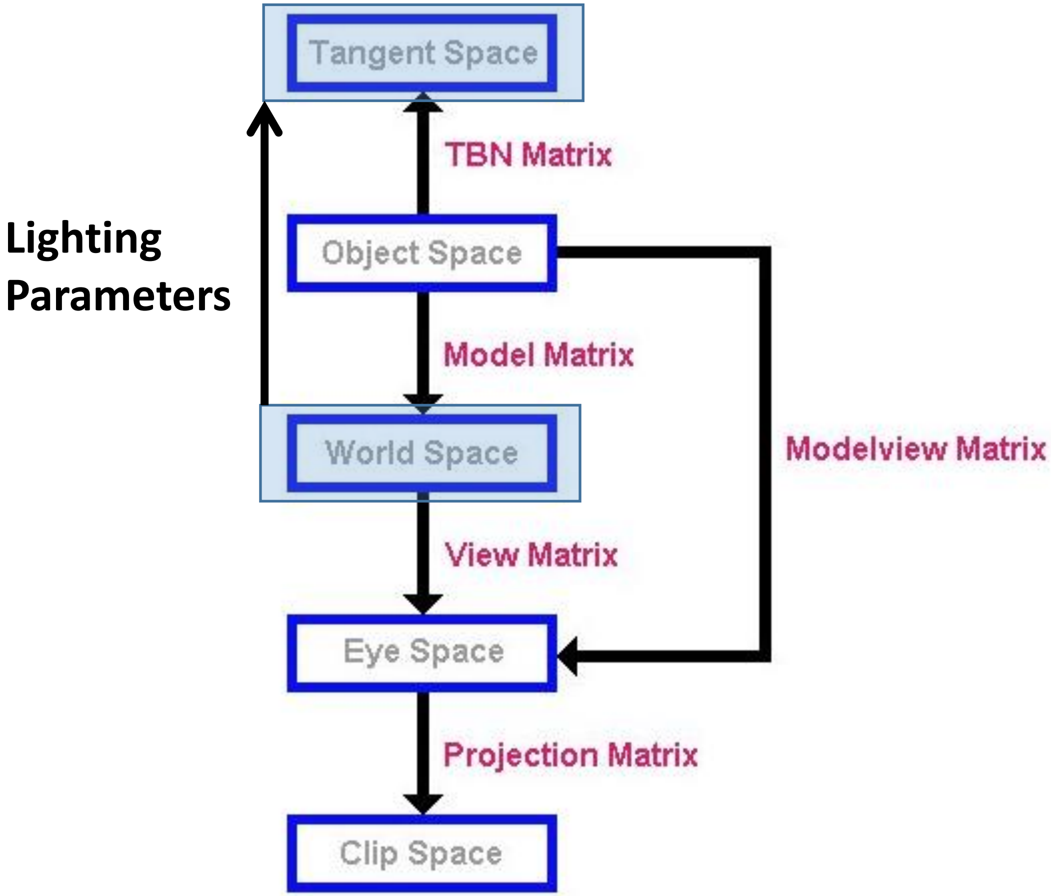
Tangent space



Where to calculate lighting?



Calculate lighting in tangent space



Vertex Shader

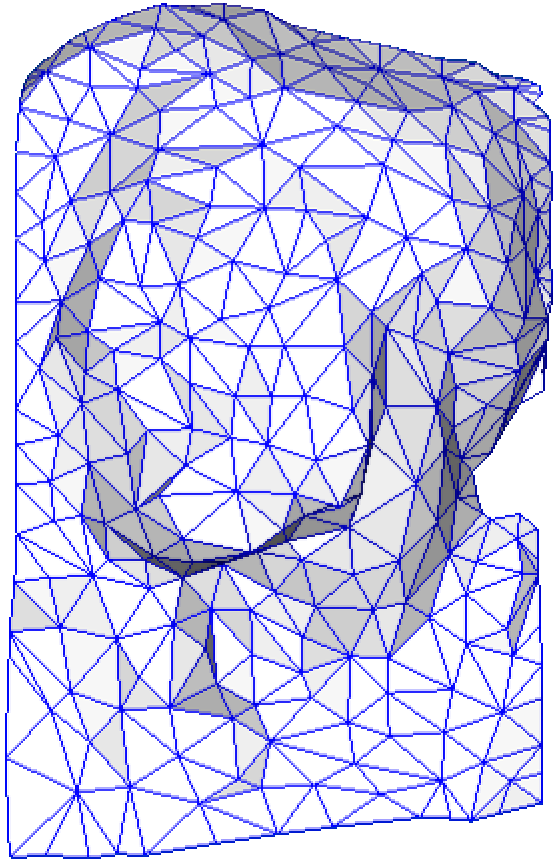
- Create a vertex shader with 4 attributes
  - layout(location = 0) in vec3 vertexPosition;
  - layout(location = 1) in vec2 vertexTexCoord;
  - layout(location = 2) in vec3 vertexNormal;
  - layout(location = 3) in vec3 vertexTangent;
- Calculate the normal, tangent and bitangent in world space (multiply modelMatrix with normal and tangent vectors – bitangent is the cross of transformed normal and tangent)
- Transform light, camera position and vertex position by tangent basis, e.g.
  - l.x = dot (lightDir, t);
  - l.y = dot (lightDir, b);
  - l.z = dot (lightDir, n);
- Pass the transformed vectors to fragment shader

Fragment Shader

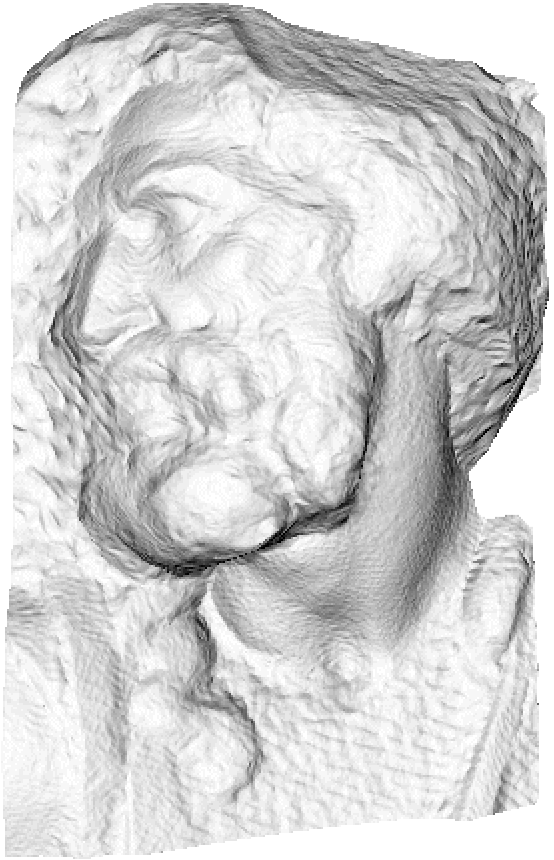
- Create 2 sampler2D variables for texture and normal map
- Instead of the interpolated normal use the normal stored in the normal map (you have to scale the normal $[0,1]^3 \rightarrow [-1,1]^3$)
- Calculate lighting model as before but use the transformed vectors

Normal mapping

original mesh
4M triangles



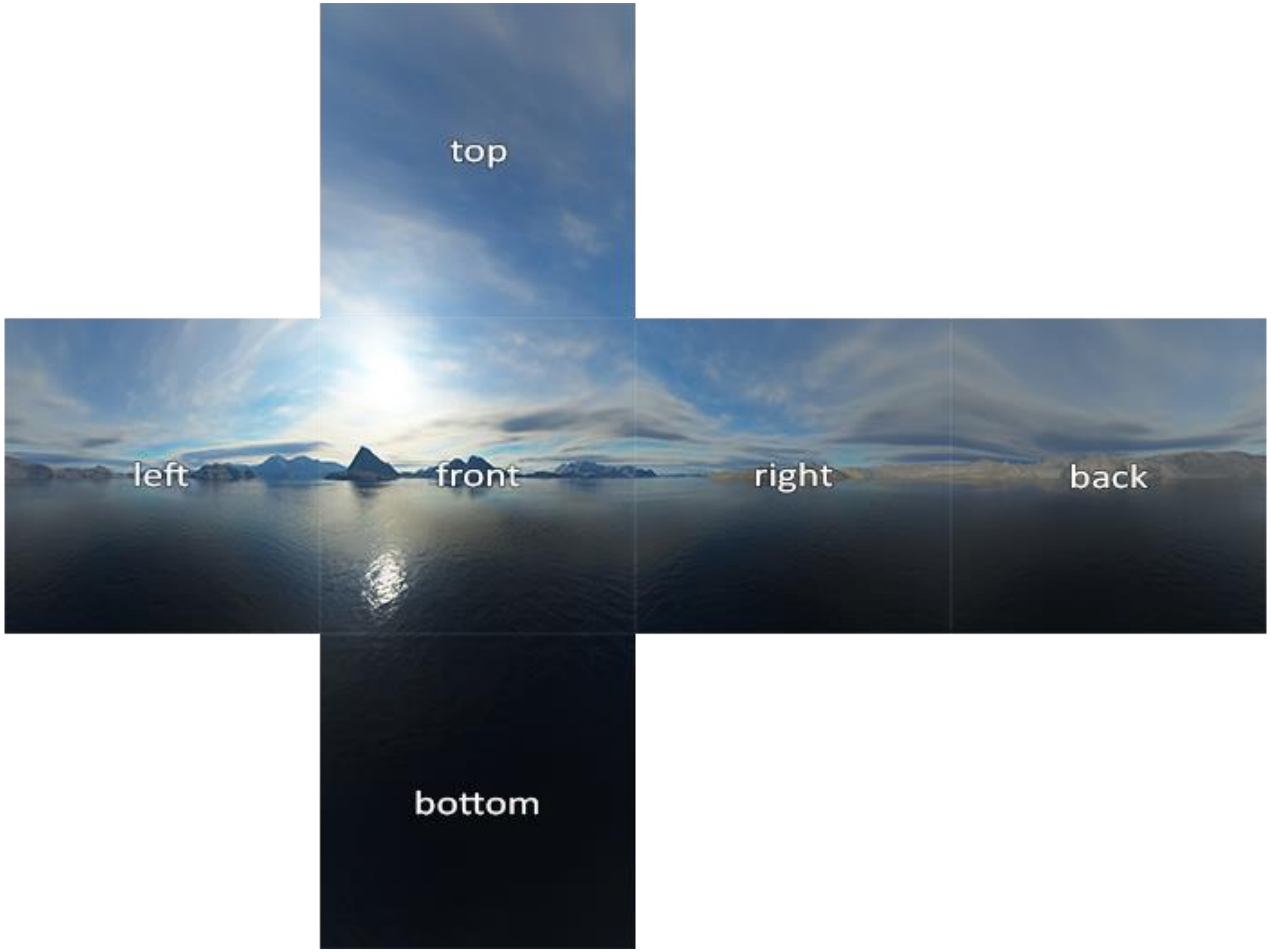
simplified mesh
500 triangles



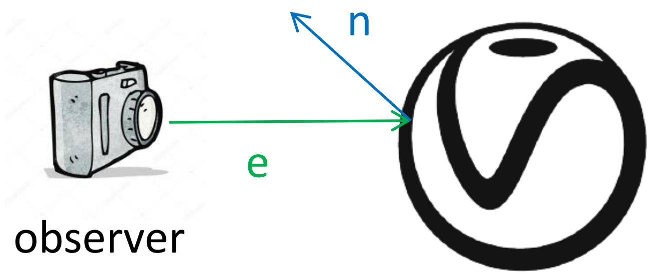
simplified mesh
and normal mapping
500 triangles

Environment mapping

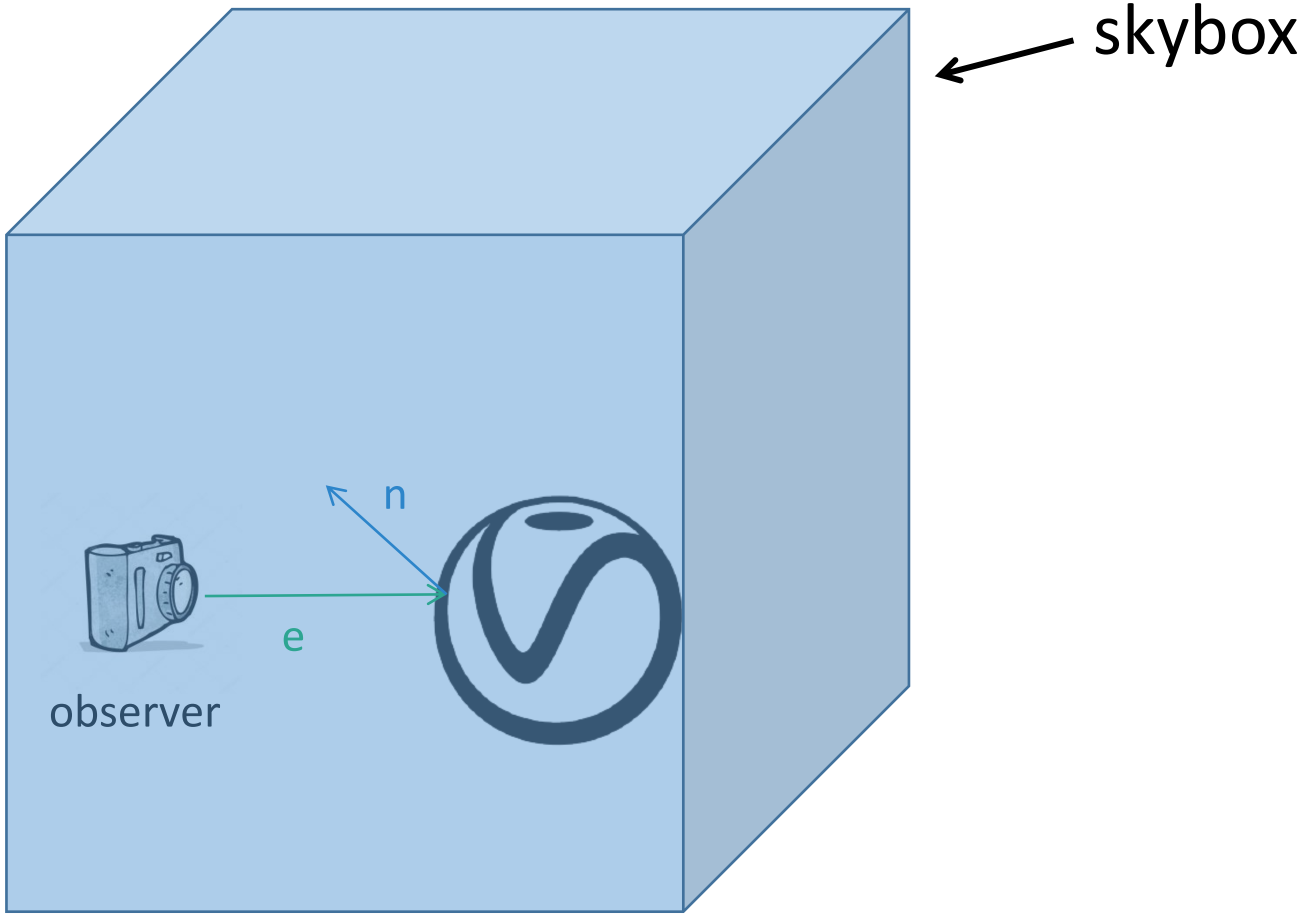
Skybox



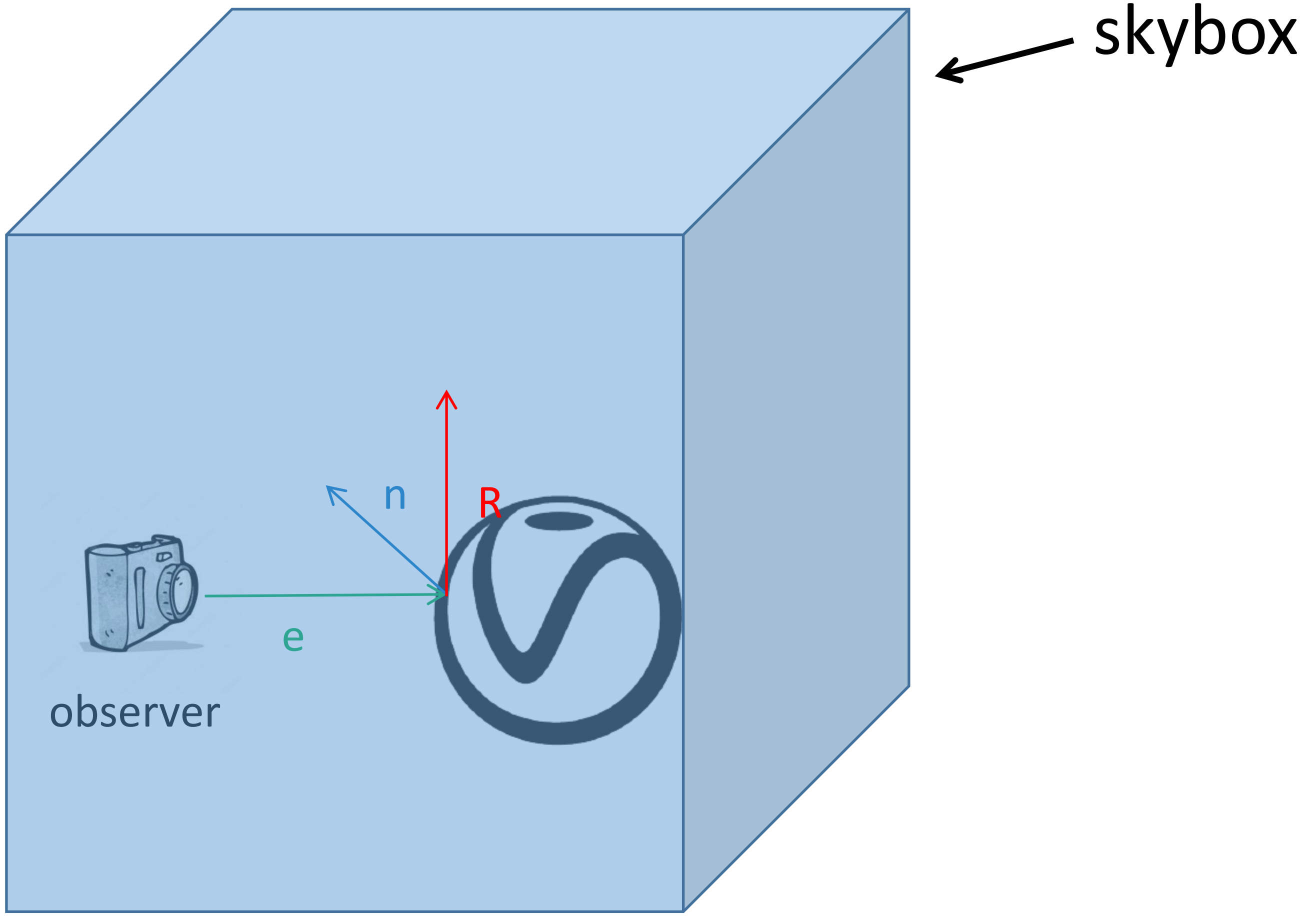
Idea: environment mapping



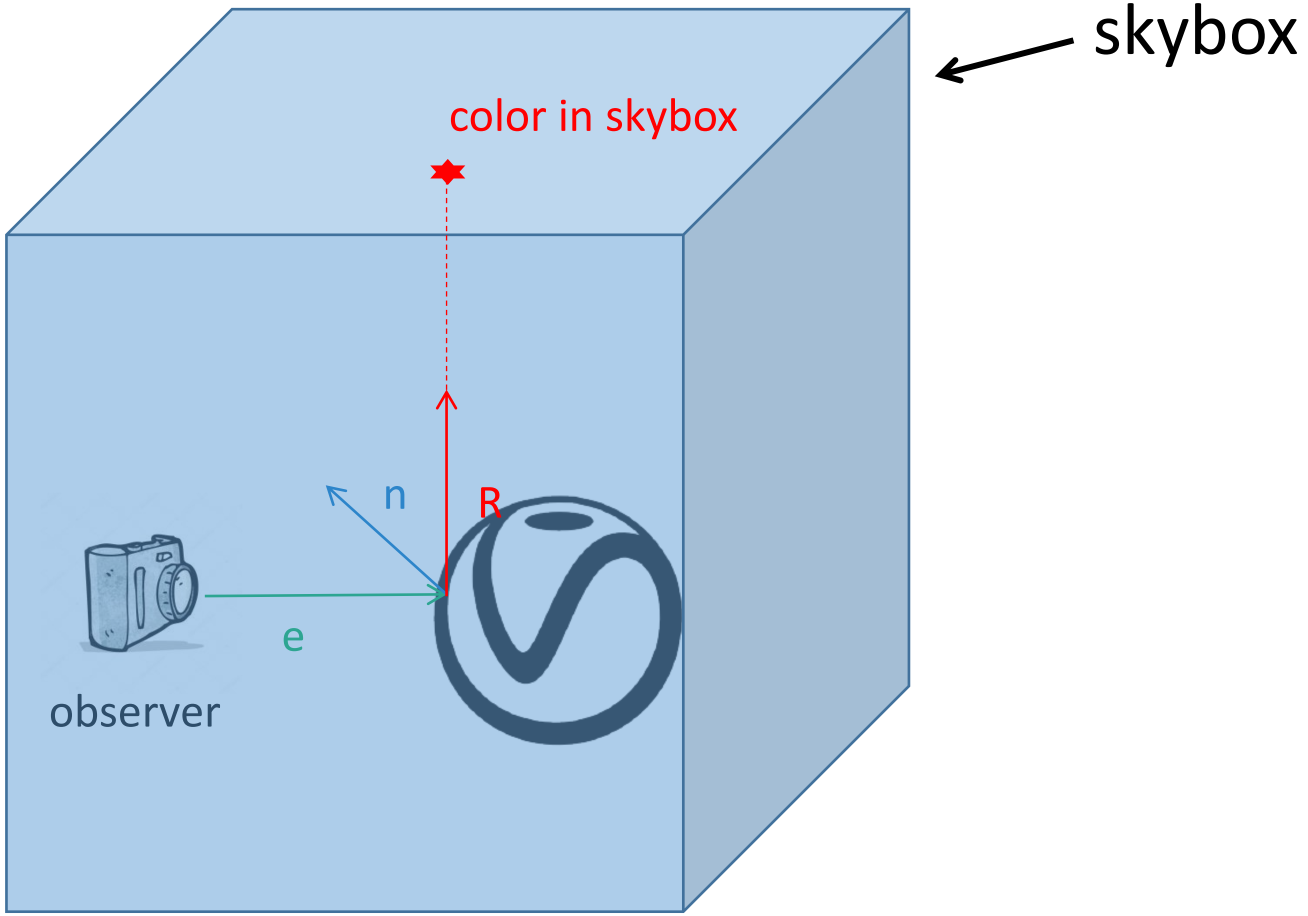
Idea: environment mapping



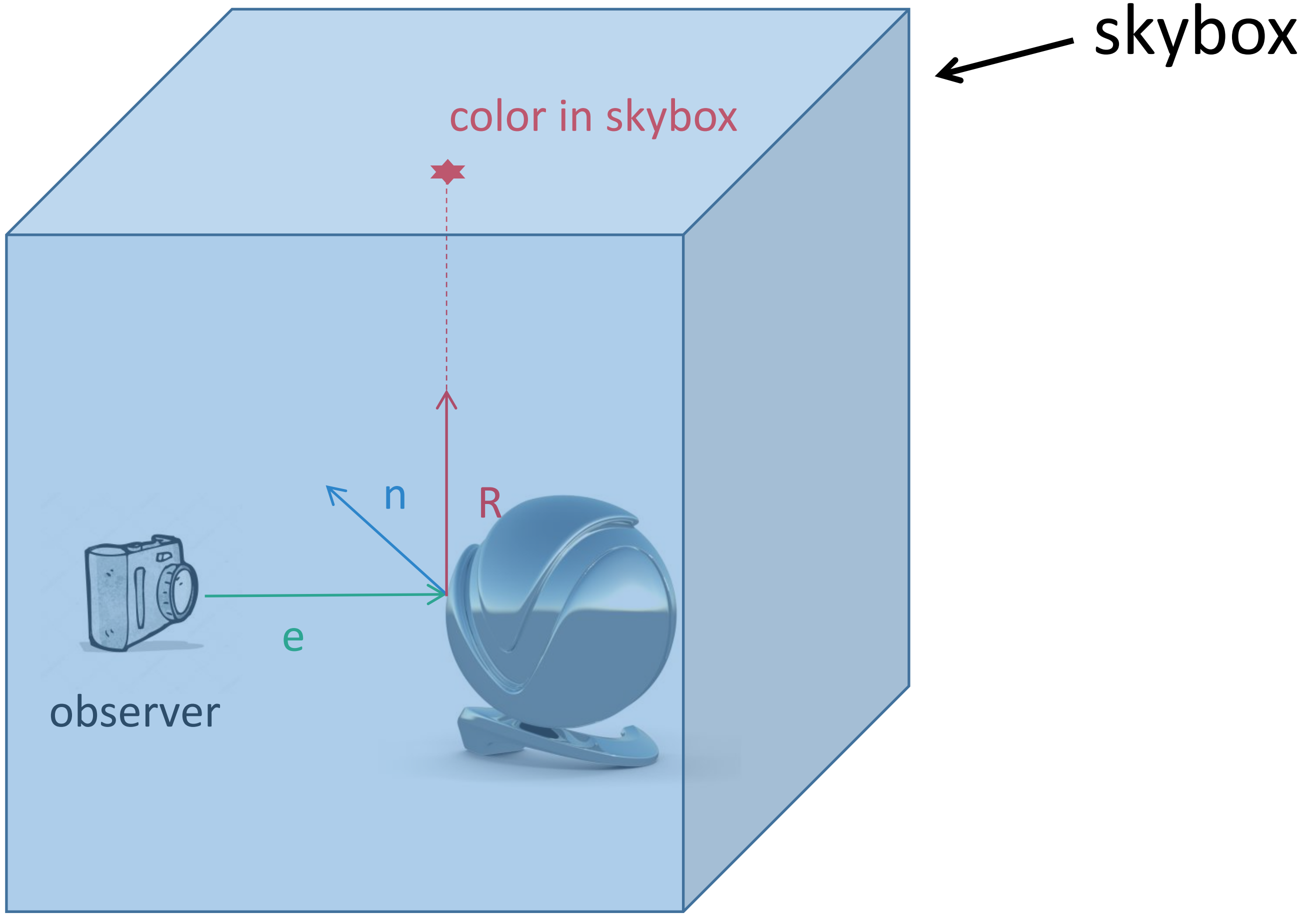
Idea: environment mapping



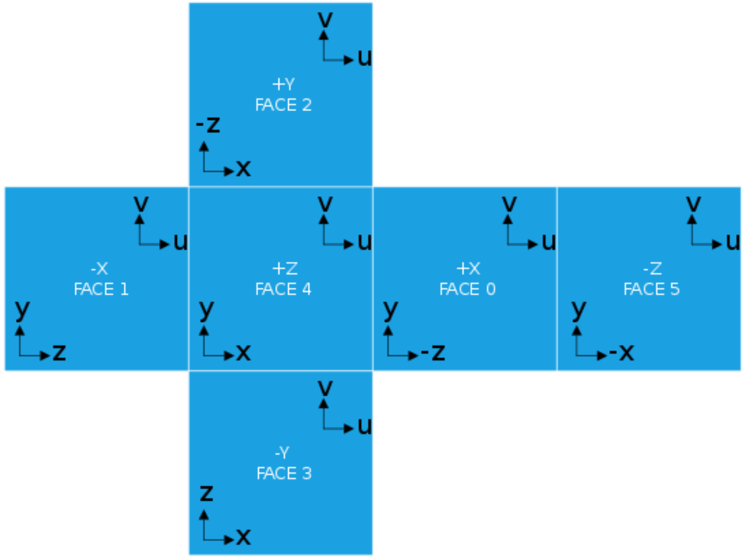
Idea: environment mapping



Idea: environment mapping



6 Textures define cube map



OpenGL:

glTexImage2D() // sends texture data to GPU

GL_TEXTURE_CUBE_MAP_POSITIVE_X, GL_TEXTURE_CUBE_MAP_NEGATIVE_X,
GL_TEXTURE_CUBE_MAP_POSITIVE_Y, GL_TEXTURE_CUBE_MAP_NEGATIVE_Y,
GL_TEXTURE_CUBE_MAP_POSITIVE_Z, GL_TEXTURE_CUBE_MAP_NEGATIVE_Z

Fragment shader:

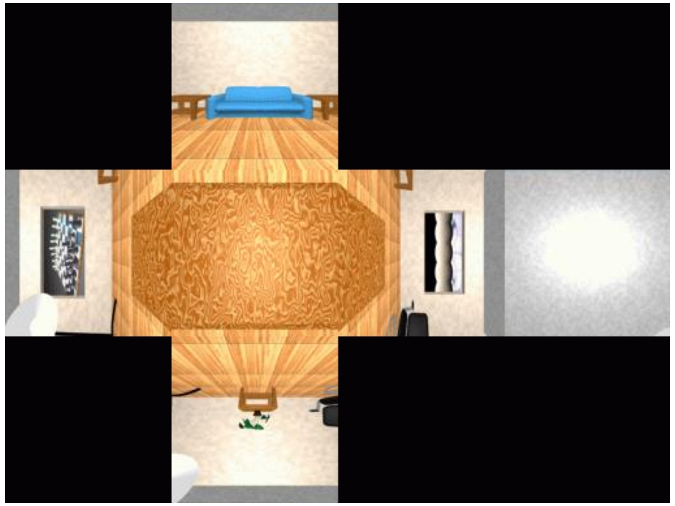
type samplerCube

compute texture coordinates in cube map using reflected vector

Sampling cubemap in GLSL

```
in vec3 texCoord;
out vec4 fragColor;
uniform samplerCube cubemap;

void main (void)
{
    fragColor = texture(cubemap, texCoord);
}
```

Environment mapping



Teapot environment

Final effect