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Texture Mapping

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Materials i Textures

- Introduction and basic concepts
- Mapping functions
- Bump mapping
- Environment maps
- Illumination maps
- Textures en WebGL

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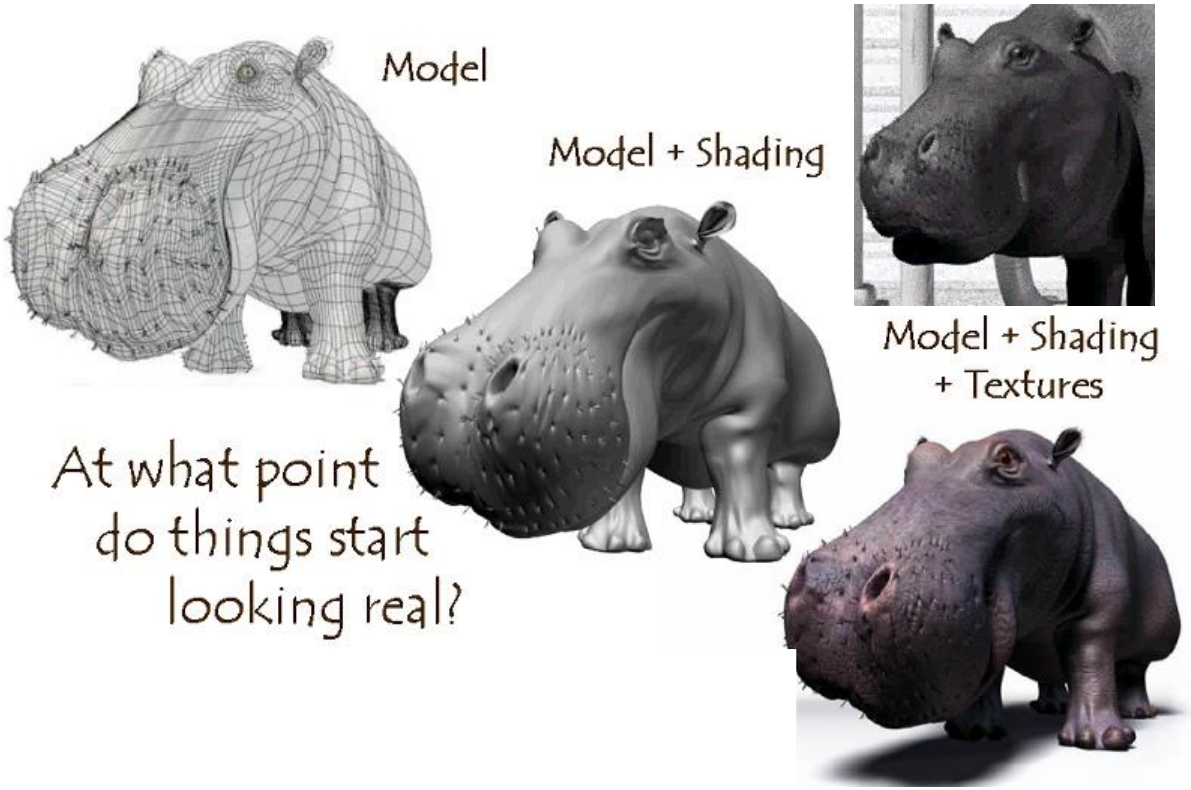
Introduction



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Hierarchical Scale (Westin et al 92)

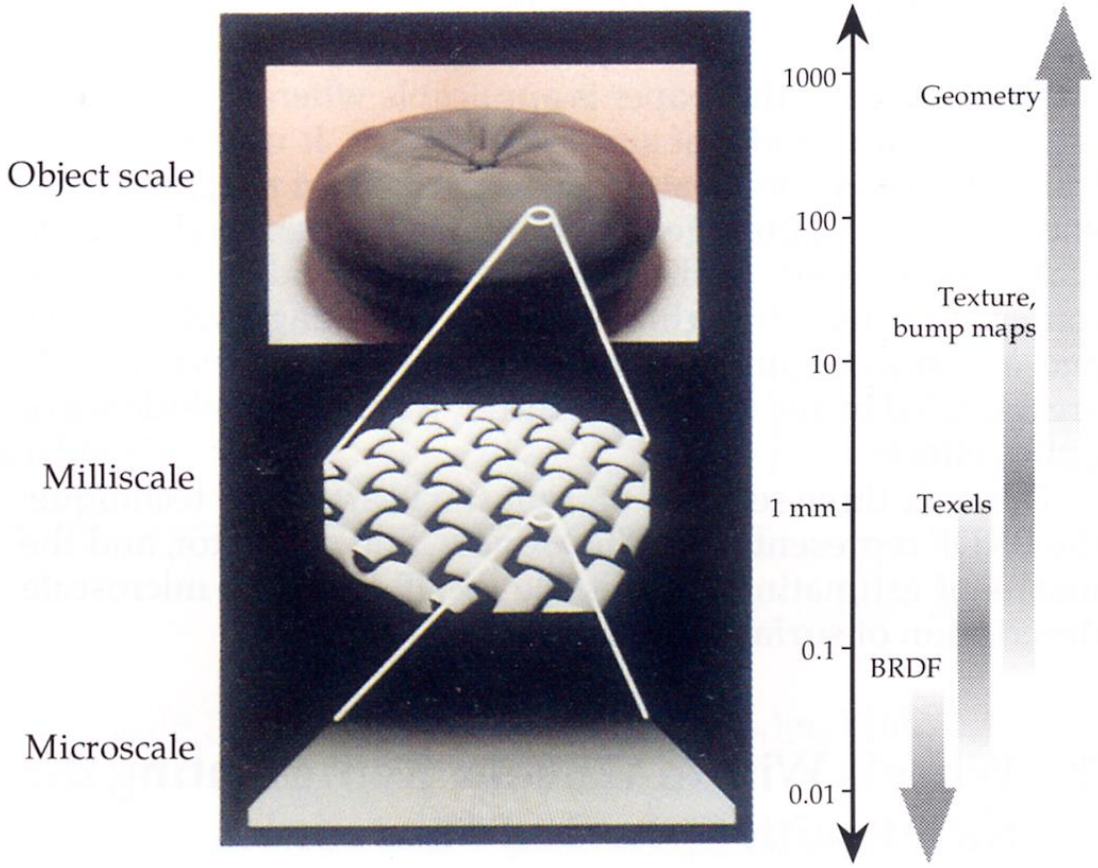

Figure 1: Applicability of Techniques

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Hierarchical Scale

Physics

Geometrical optics

Macro-structures

Transport

Micro-structures

Microfacets

Physical optics

Quantum optics

Computer Graphics

Geometry

Displacement (P) maps

Bump (N) maps

Reflection

Texture

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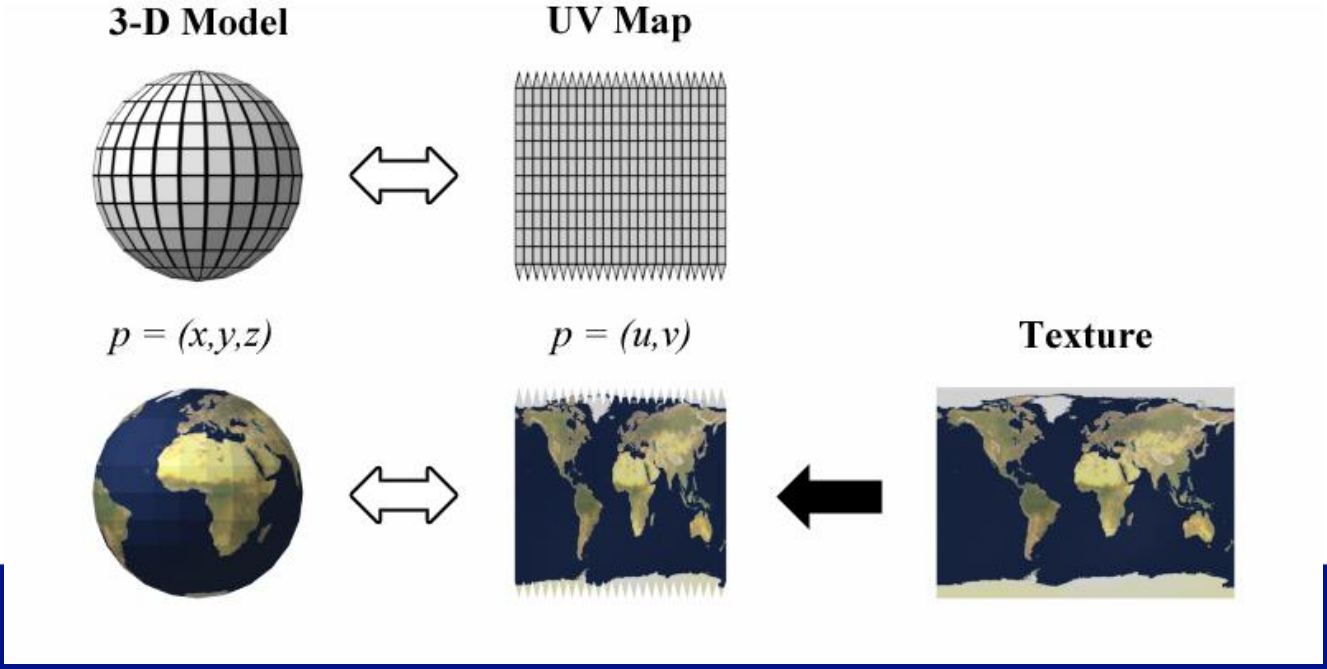
Texture Maps

- Com es pot mapejar una textura a una superfície?
  - Dimensió: 1D, 2D, 3D
  - Coordenades de Texture (s,t)
    - Paràmetres de superfície (u,v)
    - Direcció de vectors: reflexió R, normal N, halfway H
    - Projecció: cilindro, esfera, cub



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Texture Maps

- What can be controlled ?
  - Color and opacity of surfaces
  - Illumination function: environment maps, shadow maps
  - Reflection function: reflectance maps
  - Geometry: bump maps and displacement maps

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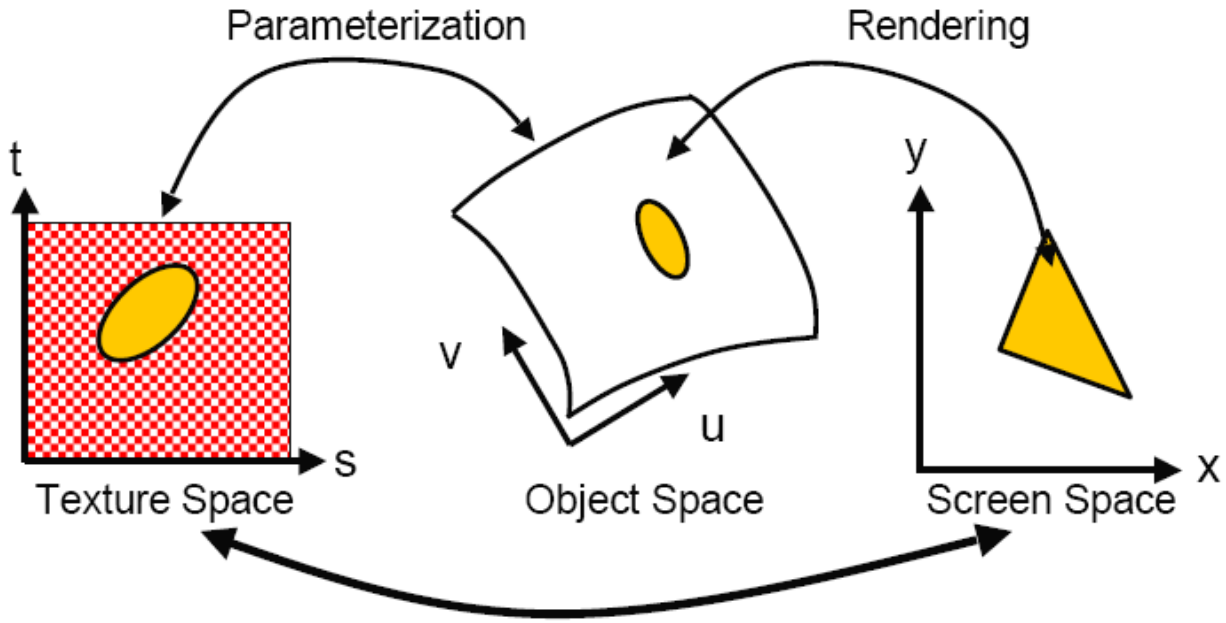
Texture mapping Spaces



Projection composition

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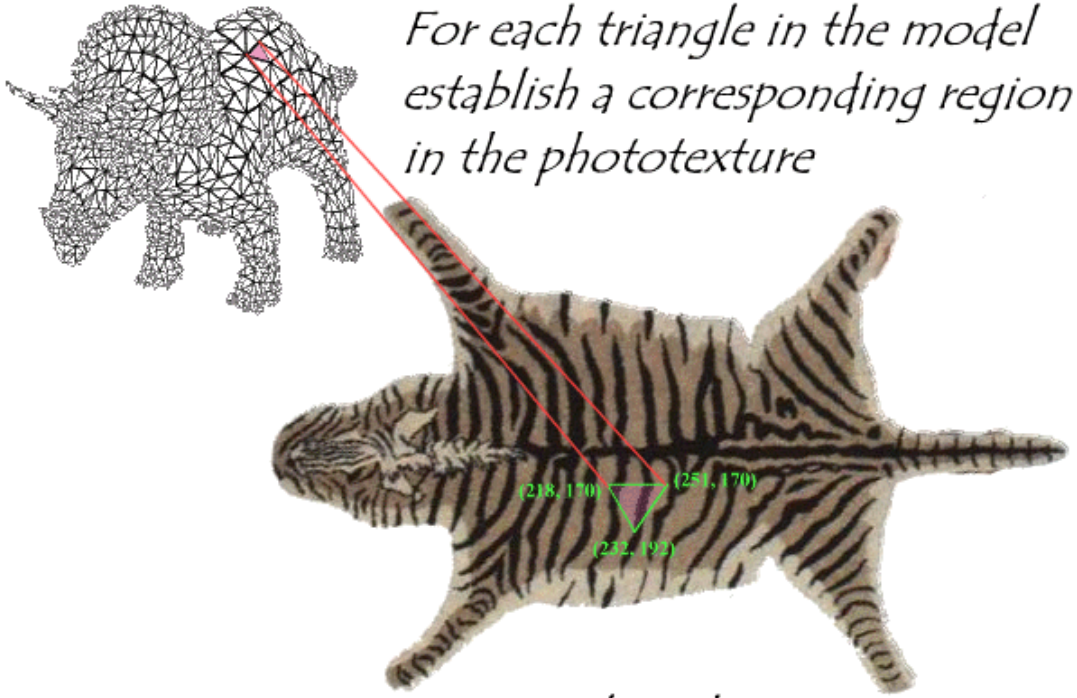
Imatge Textures



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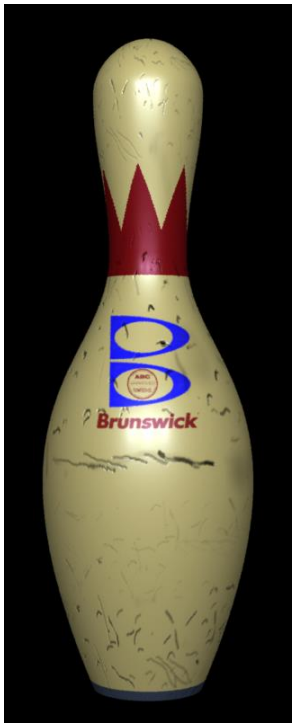
Material color and layers

Tom Porter's Bowling Pin



RenderMan Companion, Pls. 12 & 13

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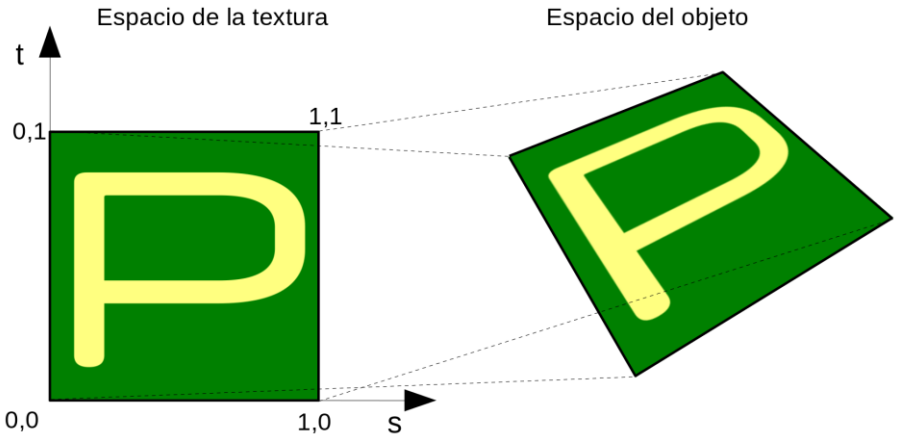
Texture mapping

- How to map an images ?

- Assign texture coordinates
  - –Attributes for each vertex
  - –Texture space range [0..1]
  - –Coordinate are provide by:
    - The geometric model
    - The program



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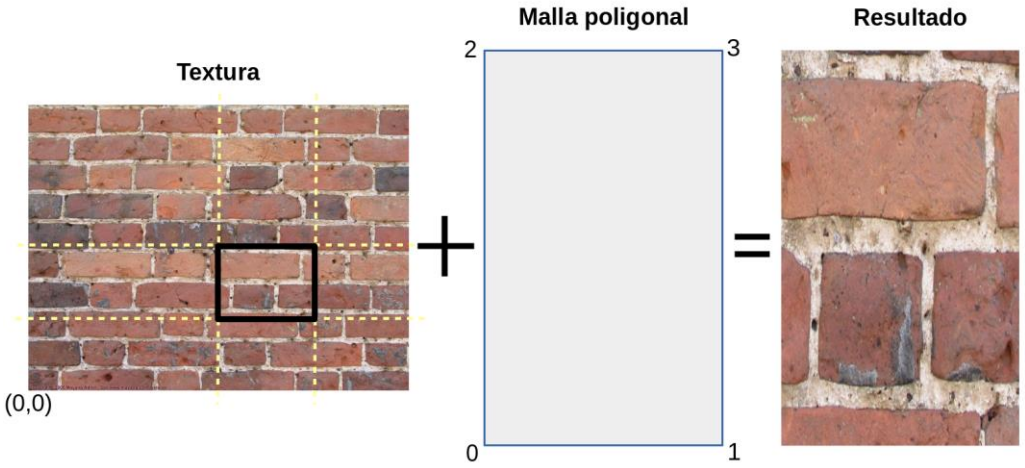
Example

- If the size of the texture portion is ¼ of the height and weight size,
- Which are the texture coordinates for the polygon ?



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Example

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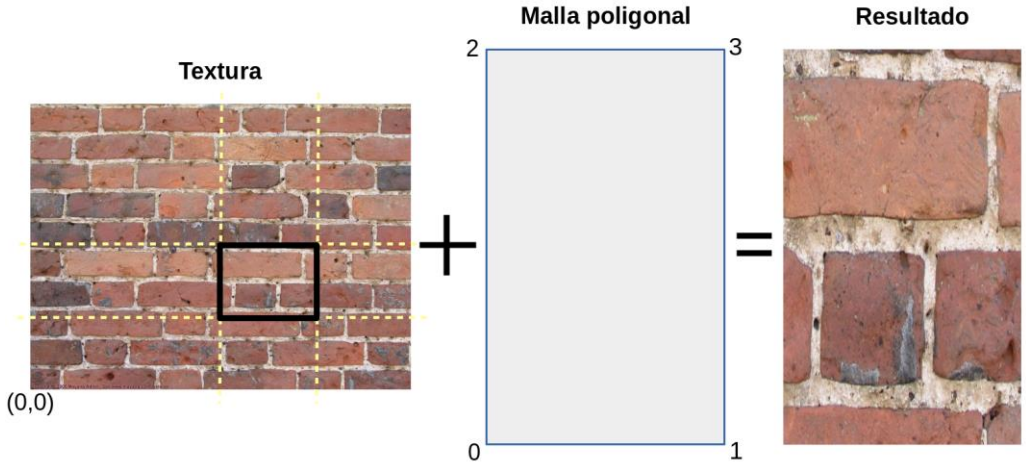

Solution:
0 -> 0.5, 0.25
1-> 0.75, 0.25
2-> 0.5, 0.5
3-> 0.75. 0.5

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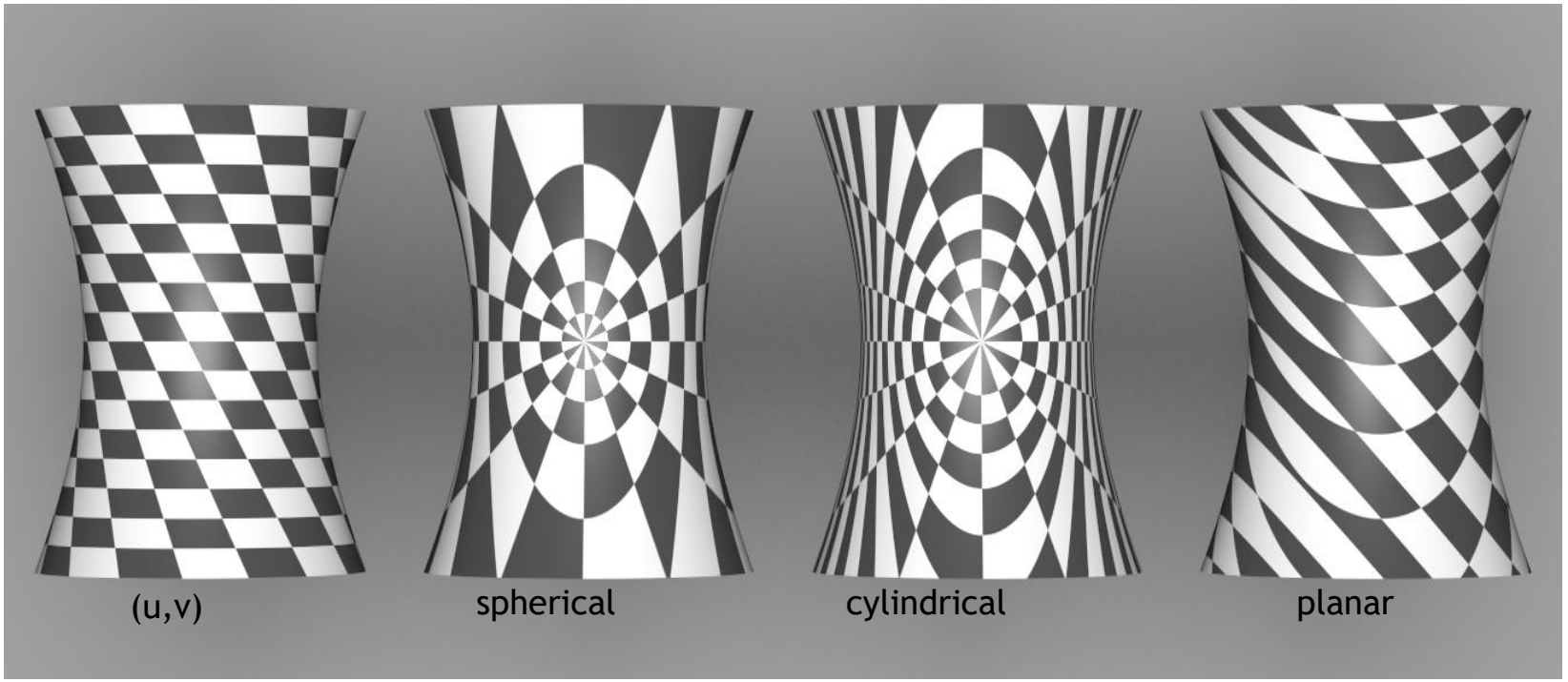
Texture Coordinate generation

Basic Projections



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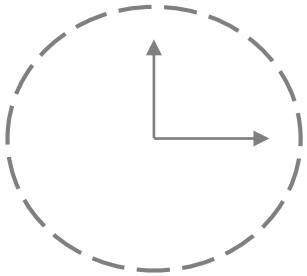
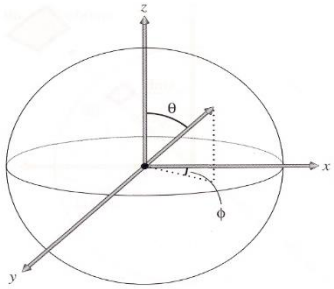
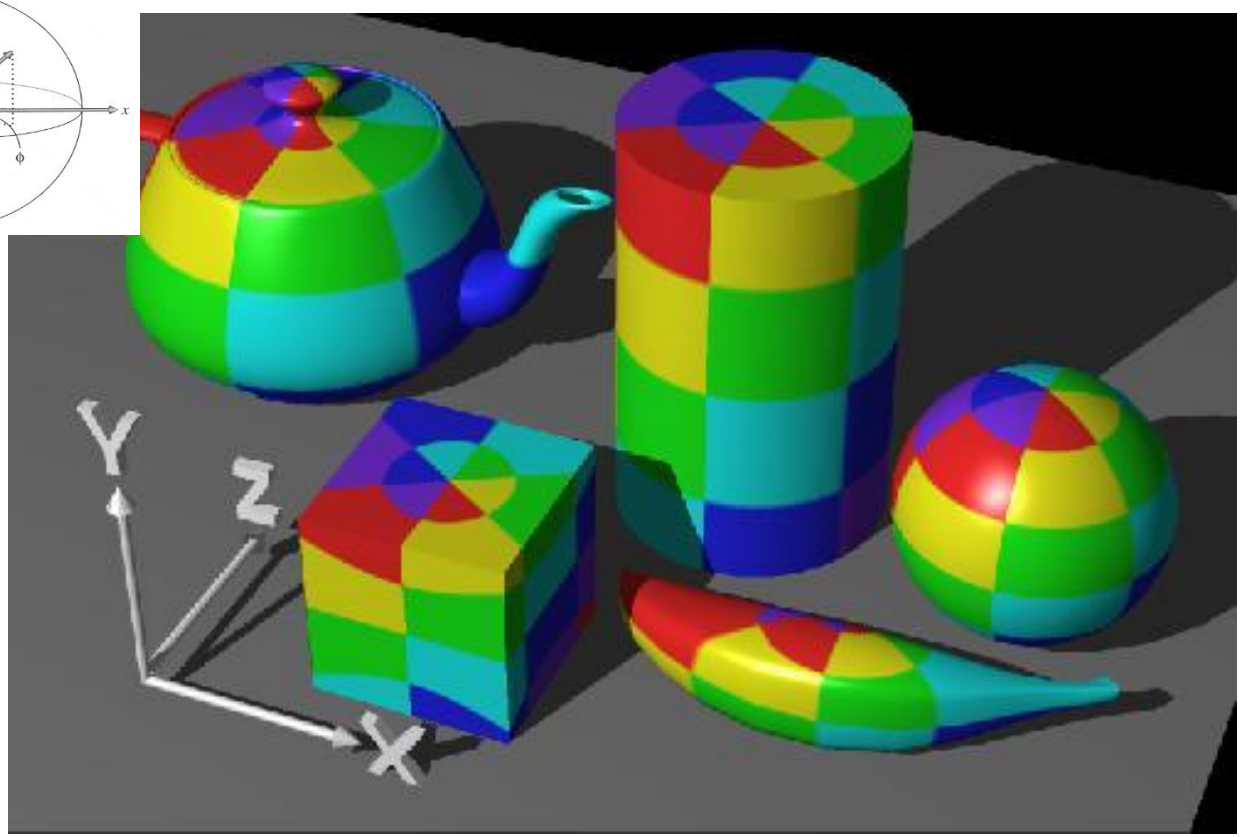
Spherical mapping







$x = r \cos 2\pi u$

$y = r \sin 2\pi u \cos 2\pi v$

$z = r \sin 2\pi u \sin 2\pi v$

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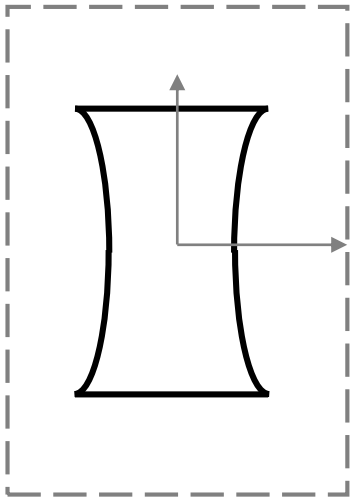
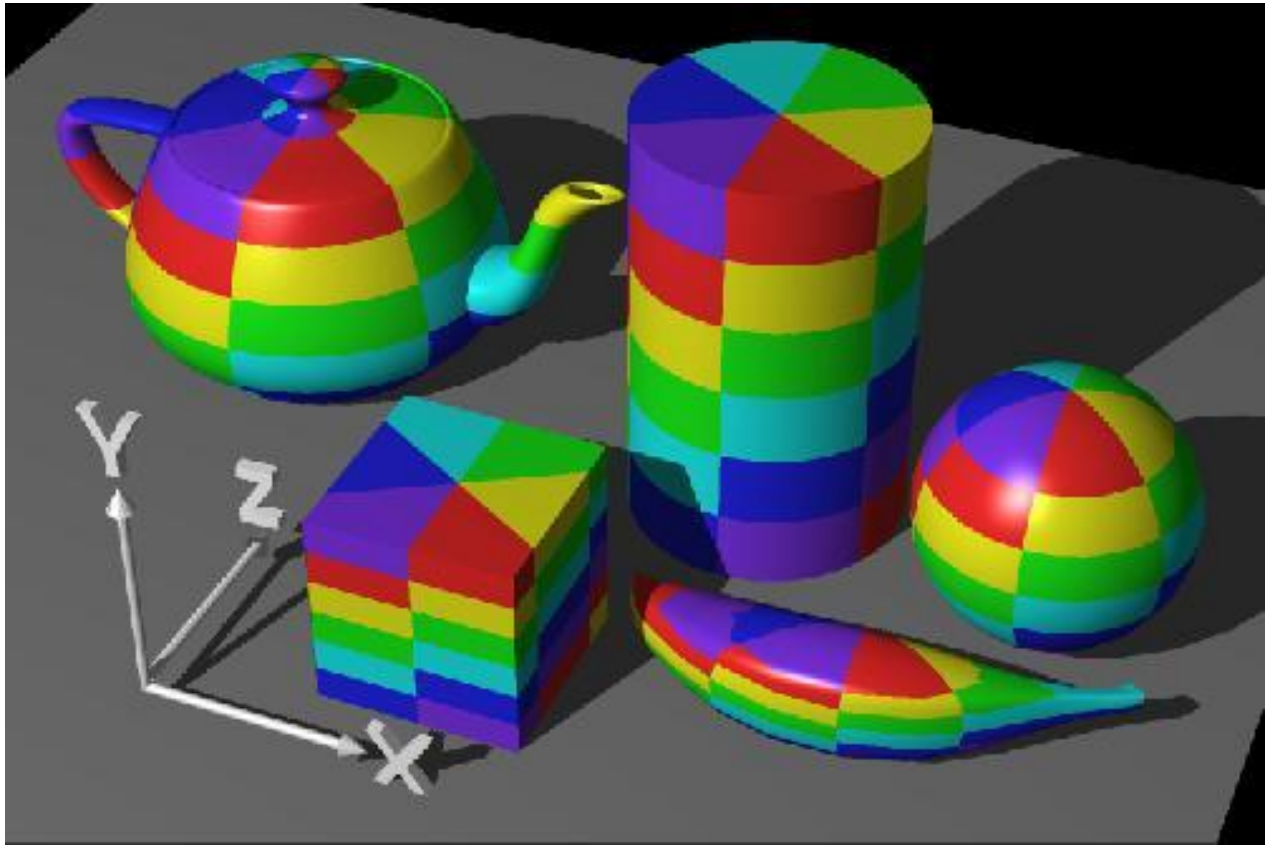
Cylindrical mapping



$x = r \cos 2\pi u$
$y = r \sin 2\pi u$
$z = v/h$



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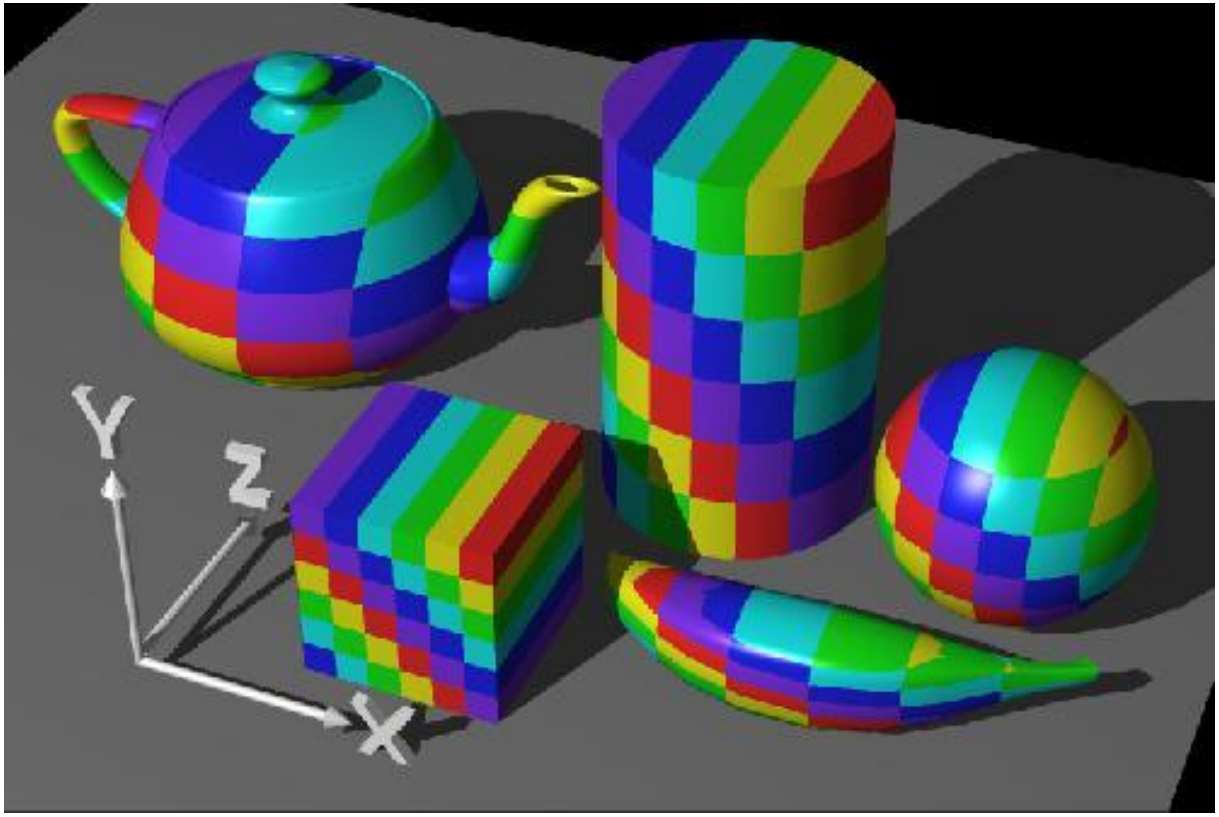
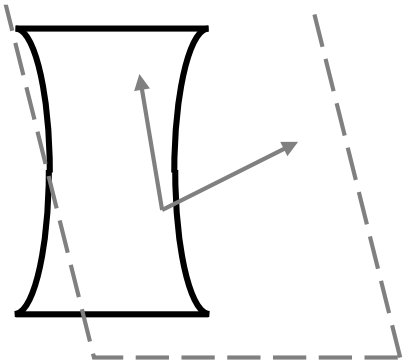
Planar mapping





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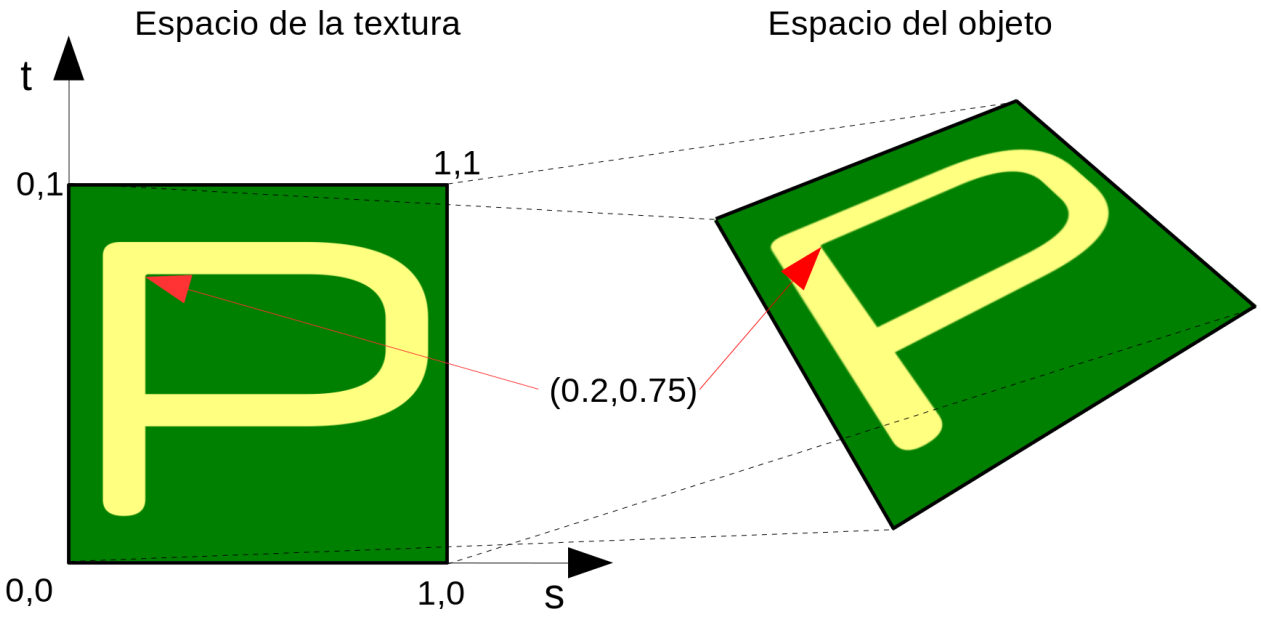
Coordinates at interior points

- Coordinates are interpolated for each fragment



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Basic Shaders for Texture 2D

- Send texture coordinates to fragment shader for interpolation (out)
- Use `sampler2D` type

```
// Vertex shader
...
in  vec2 VertexTexcoords;  // nuevo atributo
out vec2 texCoords;

void main()  {
   ...
   // se asignan las coordenades de textura del vertice a la variable texCoords
   texCoords   = VertexTexcoords;
}

// Fragment shader
...
uniform sampler2D myTexture;     // la textura
in vec2 texCoords;               // coordenadas de textura interpoladas

void main()
{
   ...
   // acceso a la textura para obtener un valor de color RGBA
   fragmentColor = texture(myTexture, texCoords);
}
```

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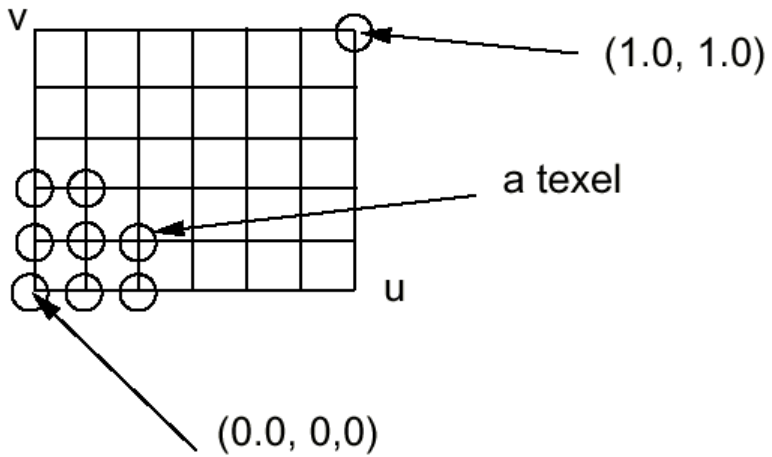
Texture and Texel

- Each pixel in a texture map is called a Texel (TEXture-ELement)
- Each Texel is associated with a (u,v) 2D texture coordinate
- The range of u, v is [0.0,1.0] due to normalization



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How do we get **F**(u,v) from F[i,j]?

- We are given a discrete set of values:
  - **F**[i,j] for i=0,…,N, j=0,…,M
- Nearest neighbor:
  - **F**(u,v) = **F**[round(N*u), round(M*v)]
- Linear Interpolation:
  - i = floor(N*u), j = floor(M*v)
  - interpolate from **F**[i,j], **F**[i+1,j], **F**[i,j+1], **F**[i+1,j]
- This is a filtering problem !

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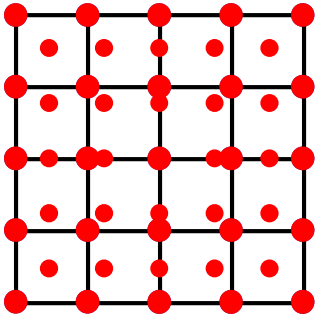
Interpolation



Nearest neighbor

Linear Interpolation

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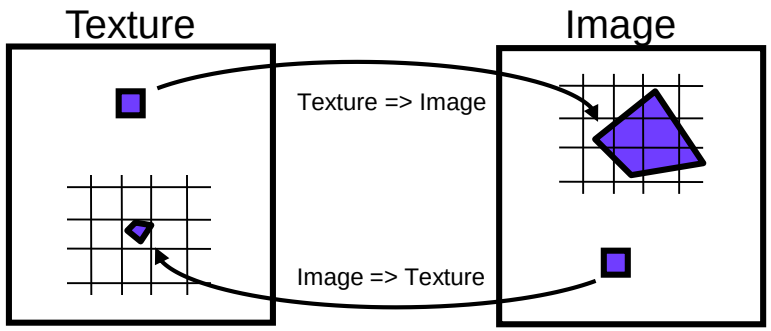
Filtering Textures



Footprint changes from pixel to pixel: no single filter

Resampling theory:

- Magnification: Interpolation
  - One texel correspond to many pixels
- Mignification: Averaging
  - One pixel correspond to many texels

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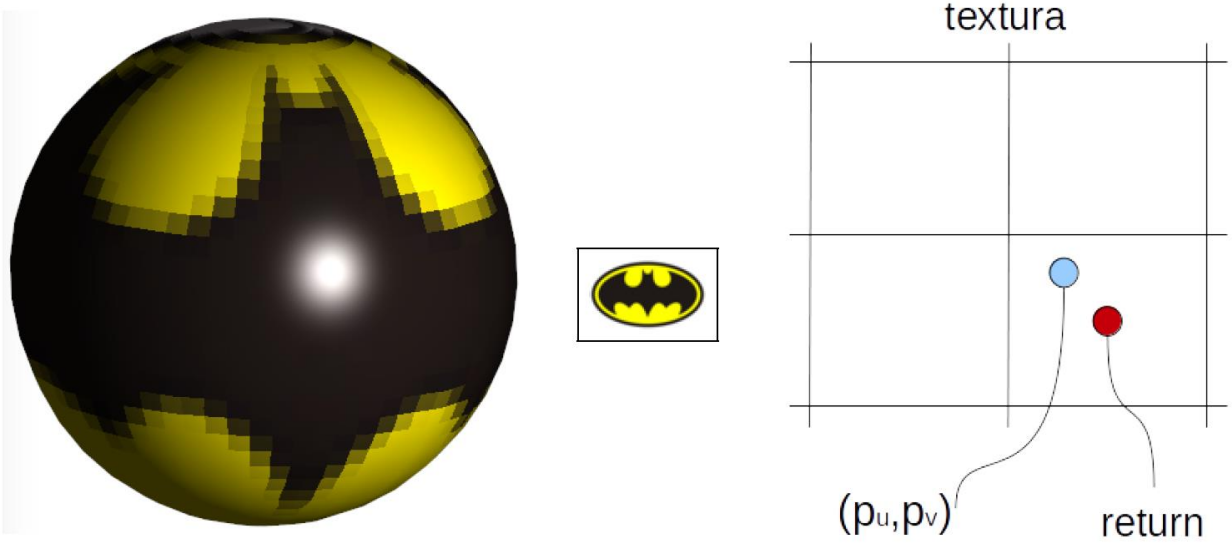
Magnification

- Box Filter
  - –Use closest texel
  - –Effect: “pixelated”



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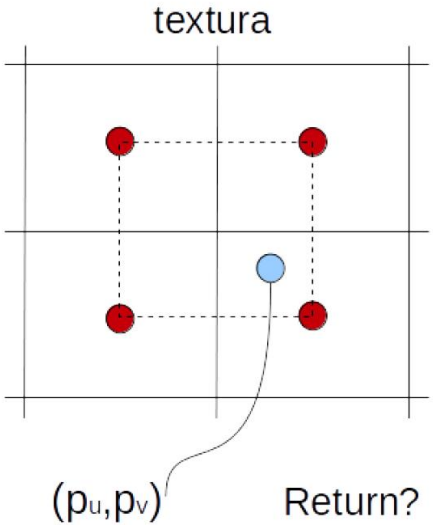
Magnification

- Bi-linear interpolation
  - –Interpolate linearly through 4 values
  - –Effect: “Blurring”



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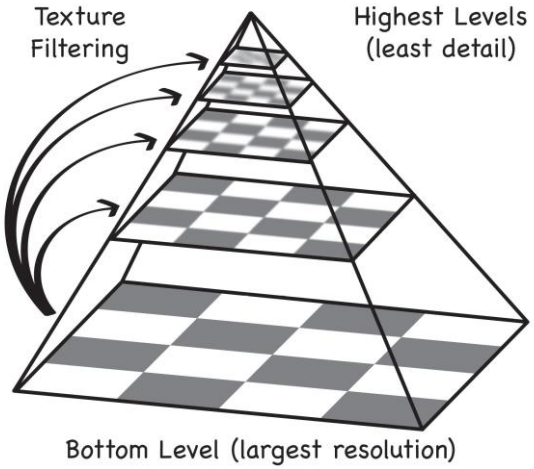
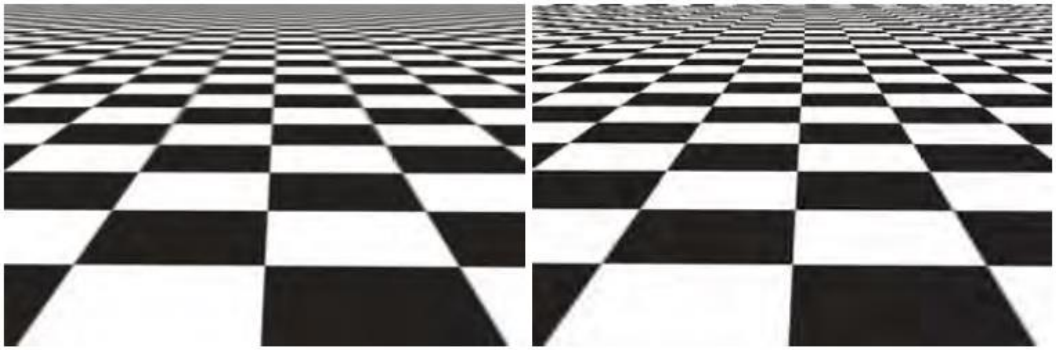
Minification



- Same filters as Magnification
- Mipmaping
  - –Use a set of textures at different resolutions
  - –Select which texture use at run time



Mipmapping

Bilinear

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Create texture from algorithms: “on the fly”

Do not use fixed images

PROCEDURAL TEXTURE

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Procedural Textures

- Advantages
  - –Extremely compact in size
  - –No fixed resolution (no matter how close you look at it)
  - –Can cover arbitrarily large areas (without repetition patterns)
  - –Can be parametric, generate classes of texture
- Disadvantages
  - –Difficult to build and debug
  - –Could be unpredictable
  - –Can be slow to compute
  - –Can produce aliasing

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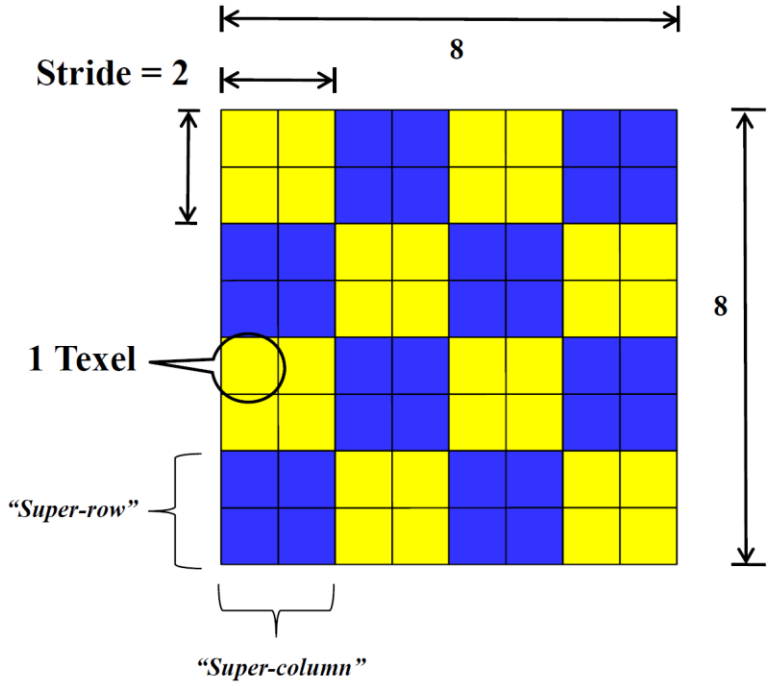
Checkerboard Texture



Observations:

```
if (superCol==superRow)
    color = yellow;

if (even(superCol) && even(superRow))
    color = yellow;

if (odd(superCol) && odd(superRow))
    color = blue;

if (even(superCol+superRow))
    color = yellow ;
else color = blue ;
```

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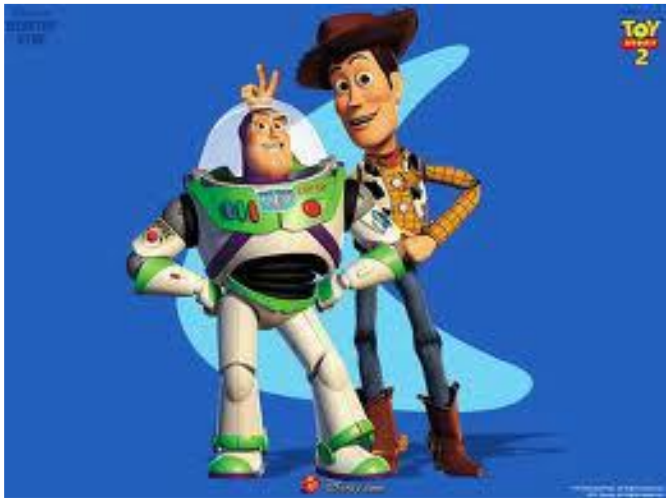
Toy Ball Shader

- Pixar classic Toy Ball



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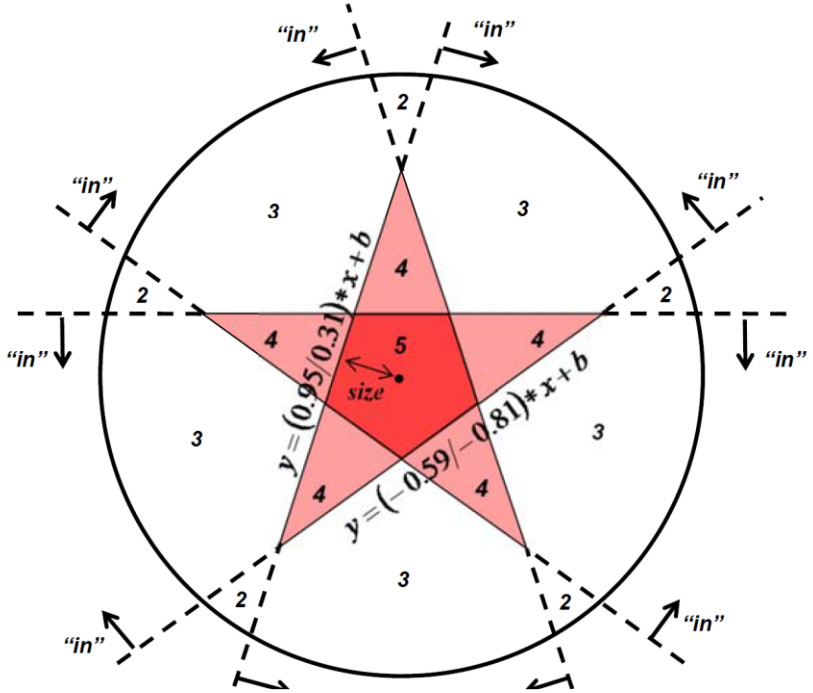
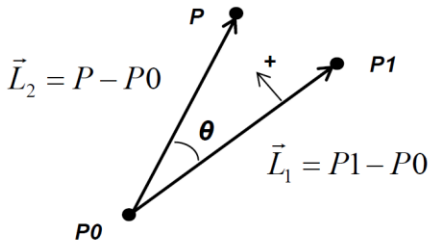
Toy Ball Shader

- Finding points inside the Star



A point is in the star if and only if it lies on the "in" side of at least 4 "half-space" lines.

A point P lies on the positive side of a line P0-P1 if and only if $L_1 \bullet L_2$ is positive:



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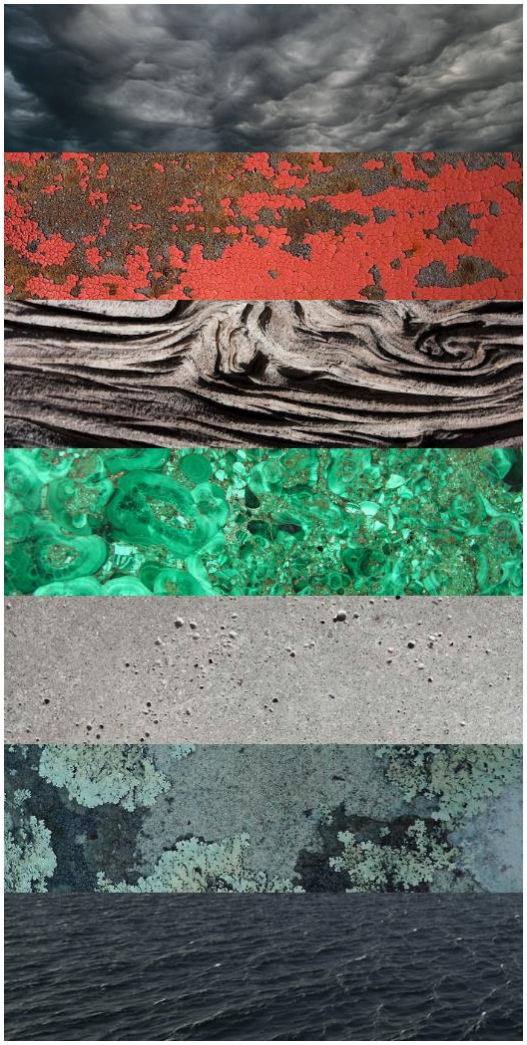
Noise

- Problem
  - How to build noise functions to simulate natural processes
- Ken Perlin
  - *"An Image Synthesizer"* SIGGRAPH 1985
  - He was trying to make realistic effects for the movie *"TRON"*
  - Later he won an Oscar (1997)!



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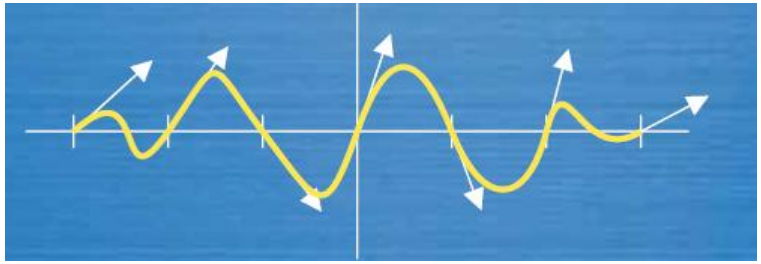
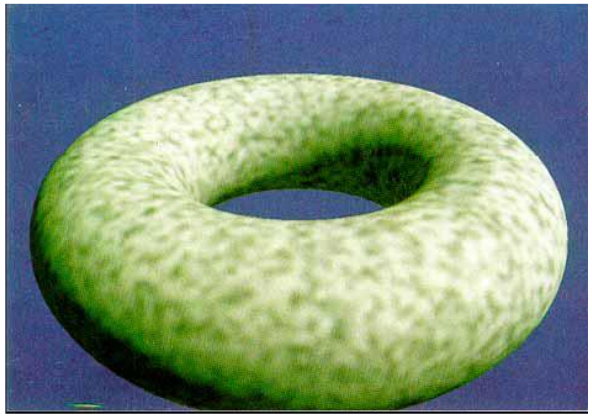
Making Noise

- Use random number to generate a stochastic process
- When x,y,z integer = integer lattice
- On lattice
  - Noise=0
  - Random gradient
    - Hash(x,y,z)
- Off-lattice
  - Smooth interpolation
  - Cubic interpolation





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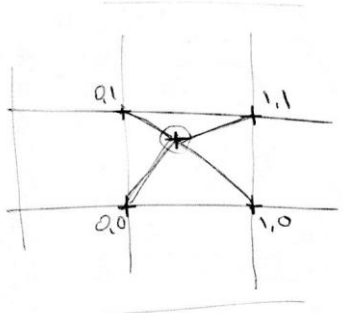
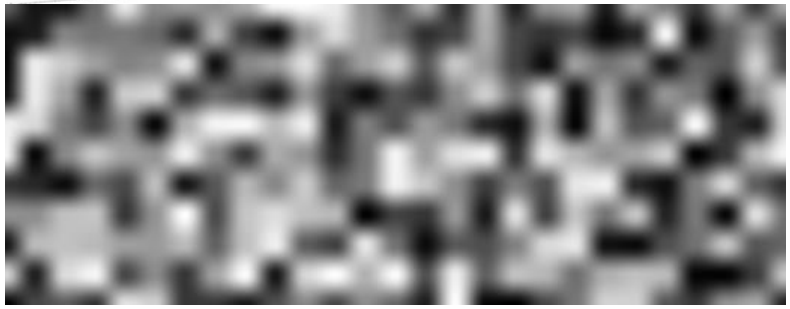
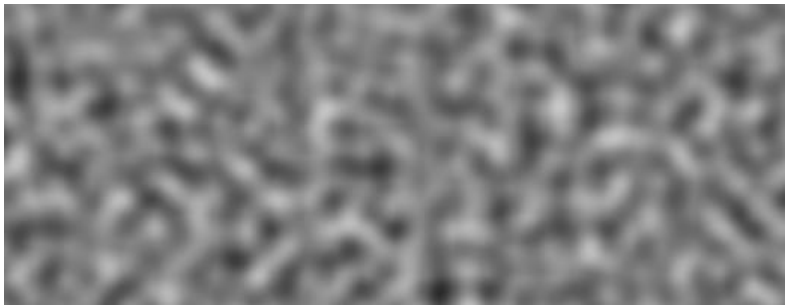
Making Noise



- Value Noise
  - Cubic interpolation for value
  - 2D Noise
    - 4 points
  - 3D Noise
    - 8 points
- Gradient Noise
  - Interpolate directions





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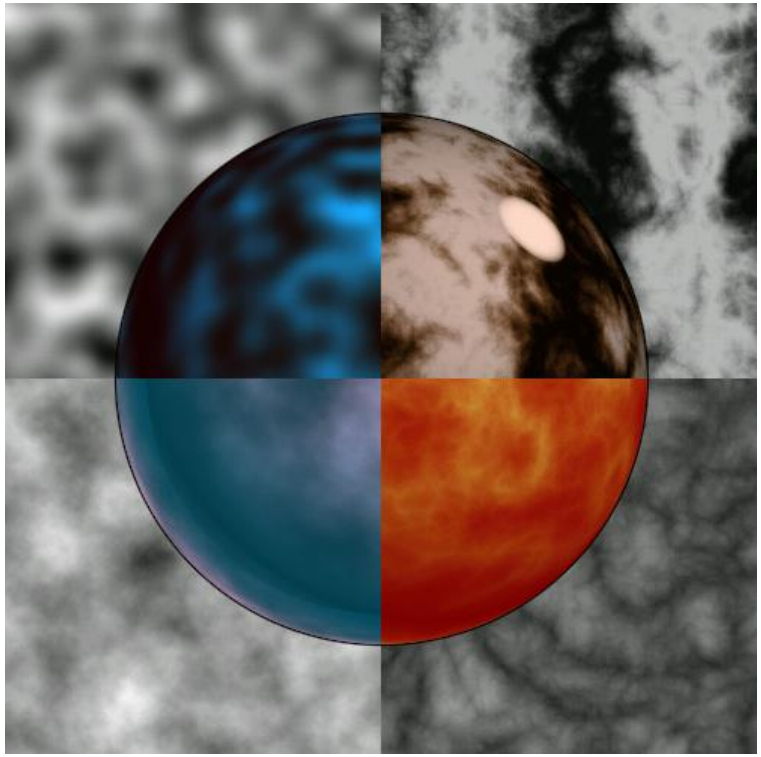
Weighted Sums: Different effects

noise:
-Worn metal
-Water wave (gradient)



Sin(x + Sum[1/f *|noise|]):
-Turbulent flows
-Fire
-Marble

Sum[1/f * noise]:
-Rock
-Mountains
-Clouds

Sum[1/f * |noise|]:
-Turbulent flows
-Fire
-Marble
-Clouds

K. Perlin

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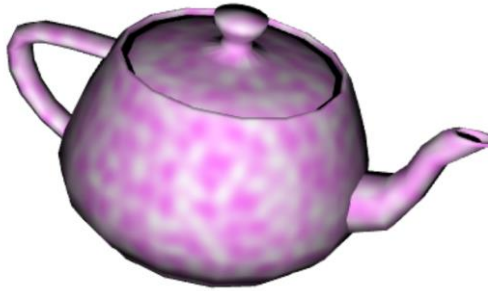
WebGL examples

- Implemented as Fragment Shaders
  - http://learnwebgl.brown37.net/10_surface_properties/texture_mapping_procedural.html
  - http://math.hws.edu/graphicsbook/demos/c7/procedural-textures.html

  - The Book of Shaders
  - https://thebookofshaders.com/11/



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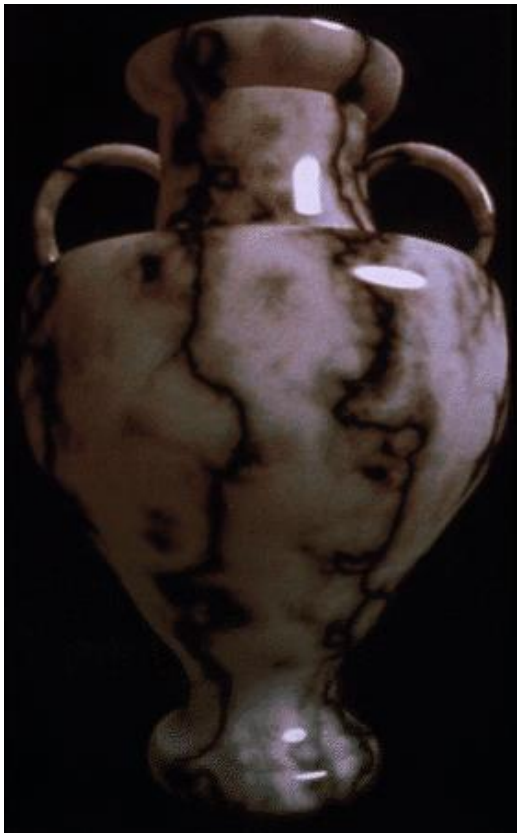
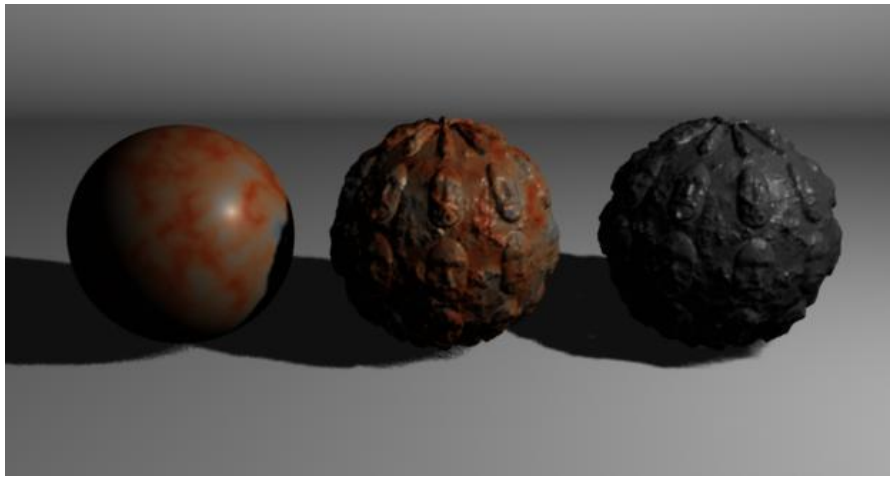
Solid Textures

- 3D maps: extend coordinate texture (s, t, r)
- En general procedurales: marmol, madera





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REFLECTIONS AND LIGHTING EFFECTS

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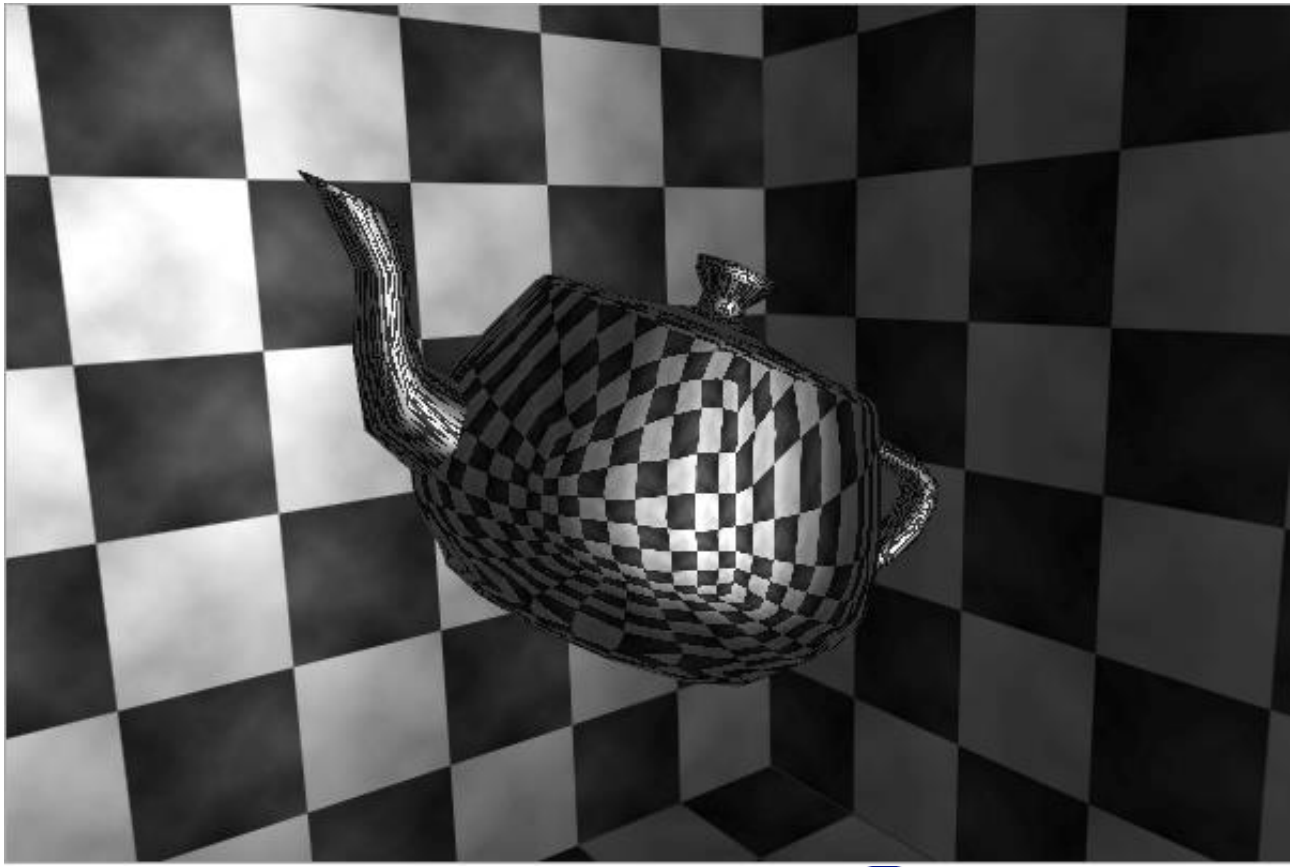
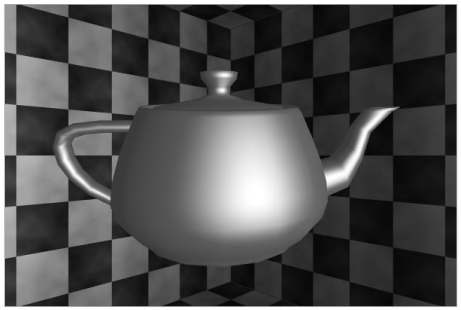
Reflections





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Reflection Maps

Blinn and Newell, 1976

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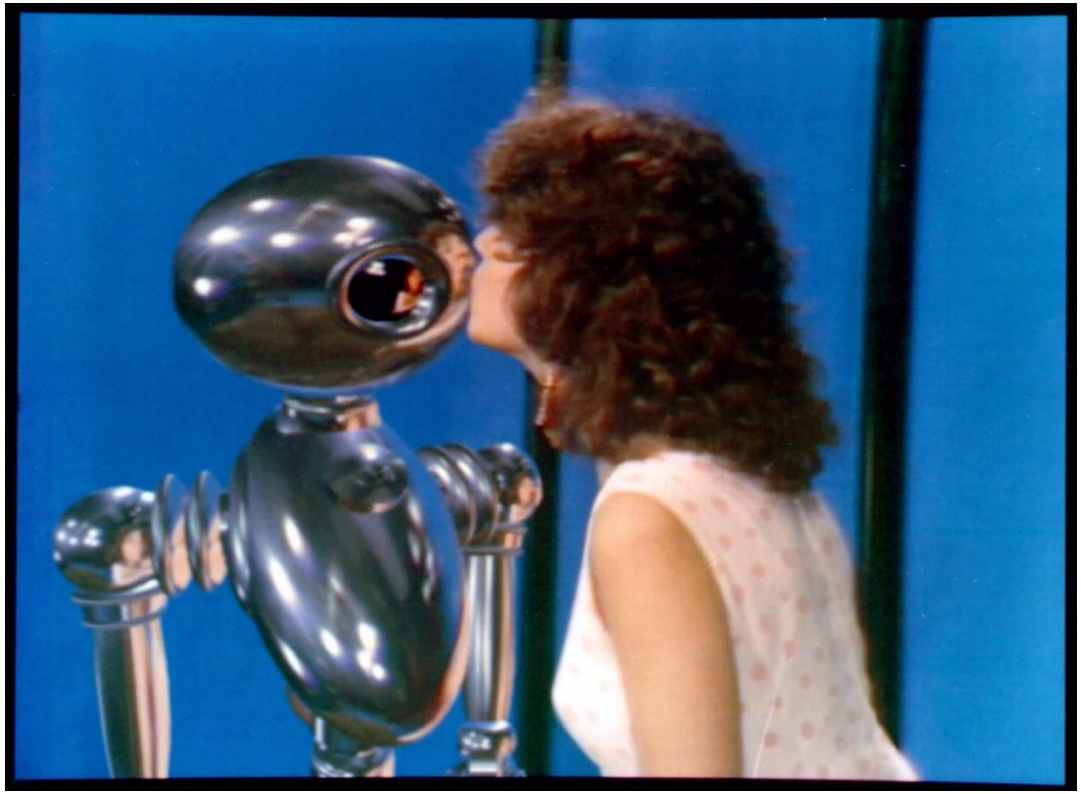
Environment Maps



***Interface*, Chou and Williams (ca. 1985)**

https://youtu.be/J7U_ZQop8b4

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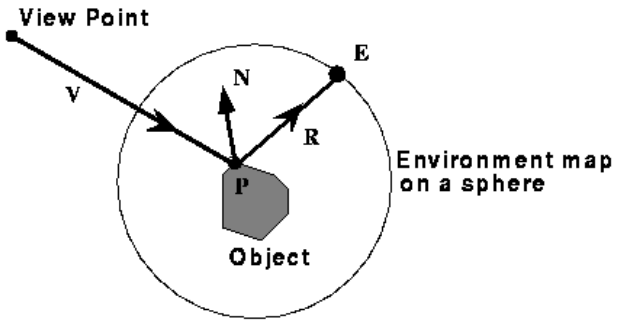
Environment Maps

- Consider illumination distant: light only depends on reflection
- Index to a texture map from reflection map
  - No texture coordinates !
- Maps could also be pre computed as irradiance



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Environment Maps

- Es una aproximació, problemes:
  - No considera interreflexions entre objectes de l'escena
  - No considera autoreflexions
  - Problemes amb objectes còncaves
- Funciona be per objectes corbats
- Cada objecte podria tenir el seu mapa
- Diferents formes de mapear el entorn
  - Cúbic
  - Esfèric
  - Paraboloide

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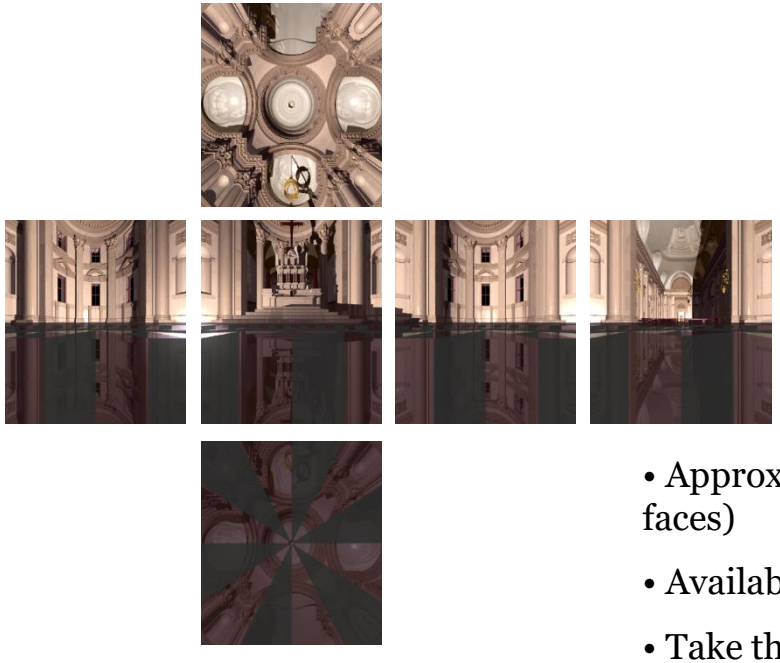
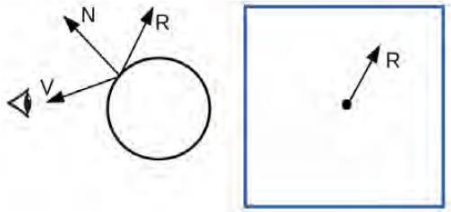
Environment Map Cubic



- Approximate environament with a cube (6 faces)
- Available in WebGL 2 (SamplerCube)
- Take the corresponding imatge from reflection direction



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Spherical Maps

- Es poden representar amb una foto d'una esfera que reflectí tot el entorn
- Paul DeBevec, www.debevec.org

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Environment Map Approximation

Ray tracing

Environment Map

Auto reflexions no es consideren en environment maps

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Reflections @ Grand Turismo 5

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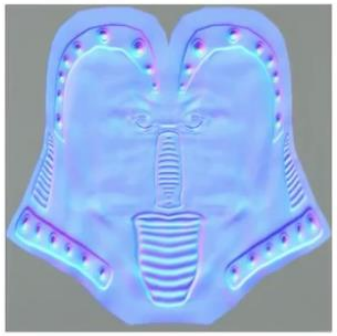
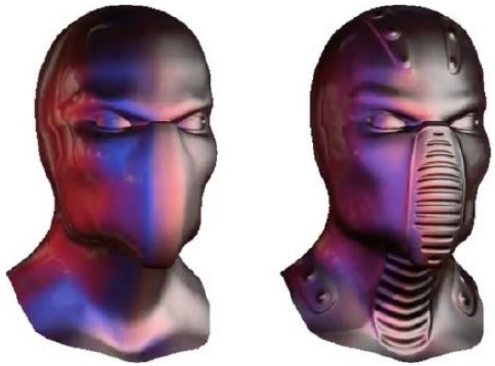
Bump Mapping (or Normal Mapping)

- Modify normal from a texture map
- Texture used as field of values
- Provides relief effects





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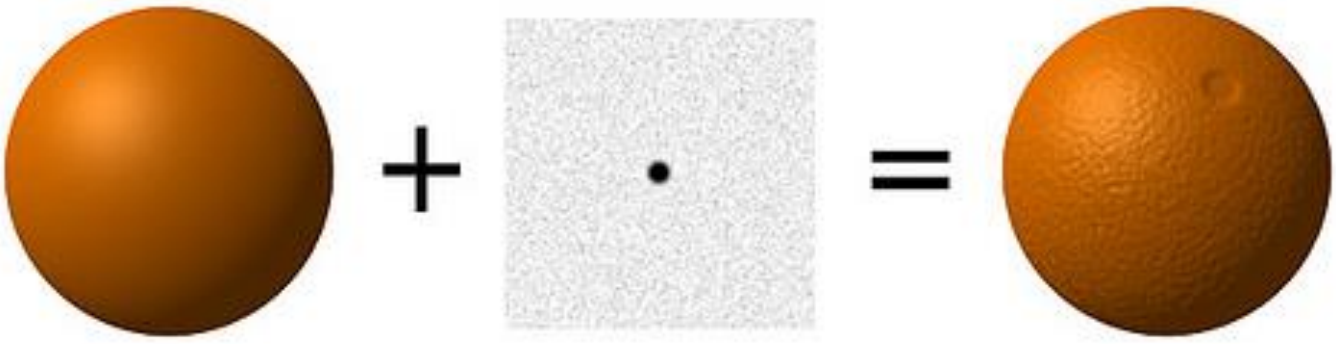
Bump Mapping

- Bump mapping is a technique used to add detail to a surface
  - Think roughness / texture



Does not change silhouette edges

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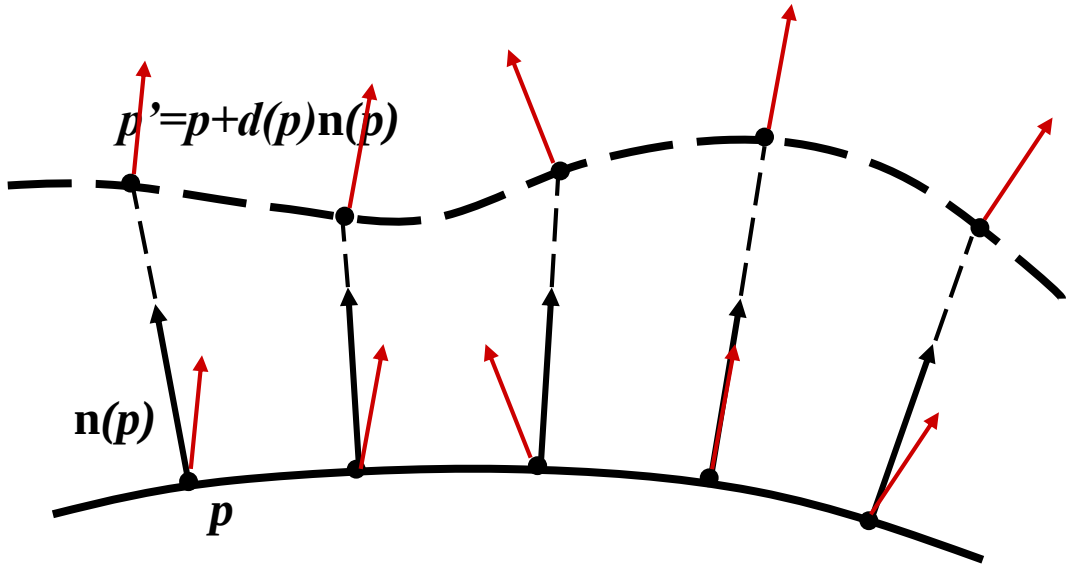
Bump mapping and Displacement mapping

- Displacement mapping adds geometrical details to surfaces



- Bump mapping: augments geometrical details to a surface without changing the surface itself
- It works well when the displacement is small

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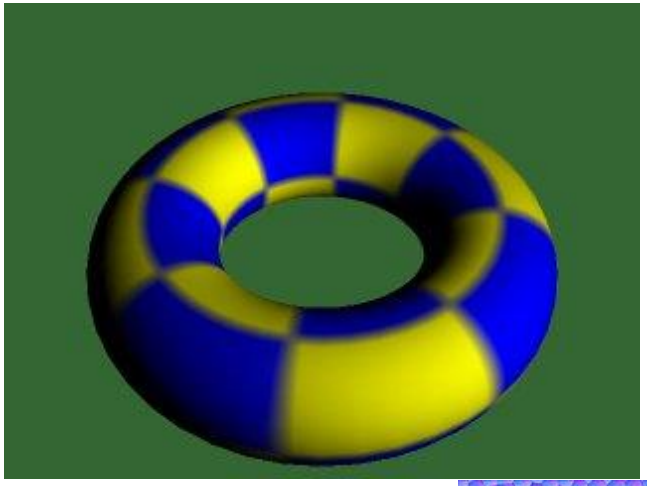
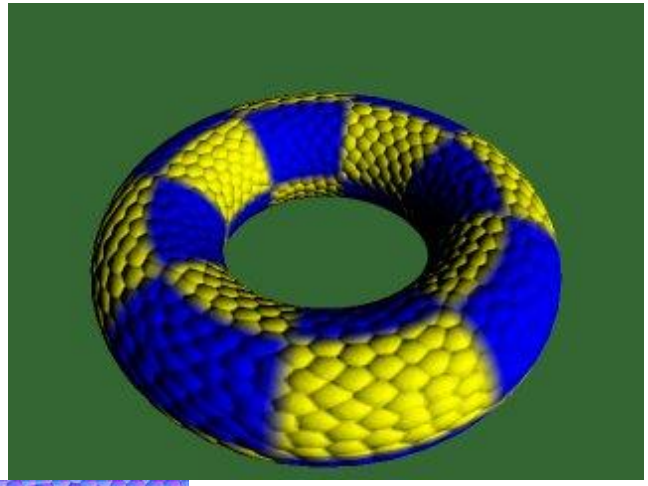
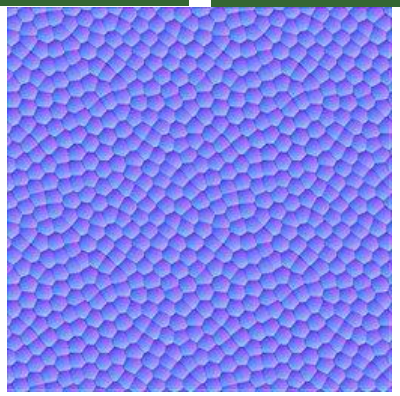
Example Bump Mapping







https://webglfundamentals.org/webgl/lessons/webgl-qna-apply-a-displacement-map-and-specular-map.html
Example

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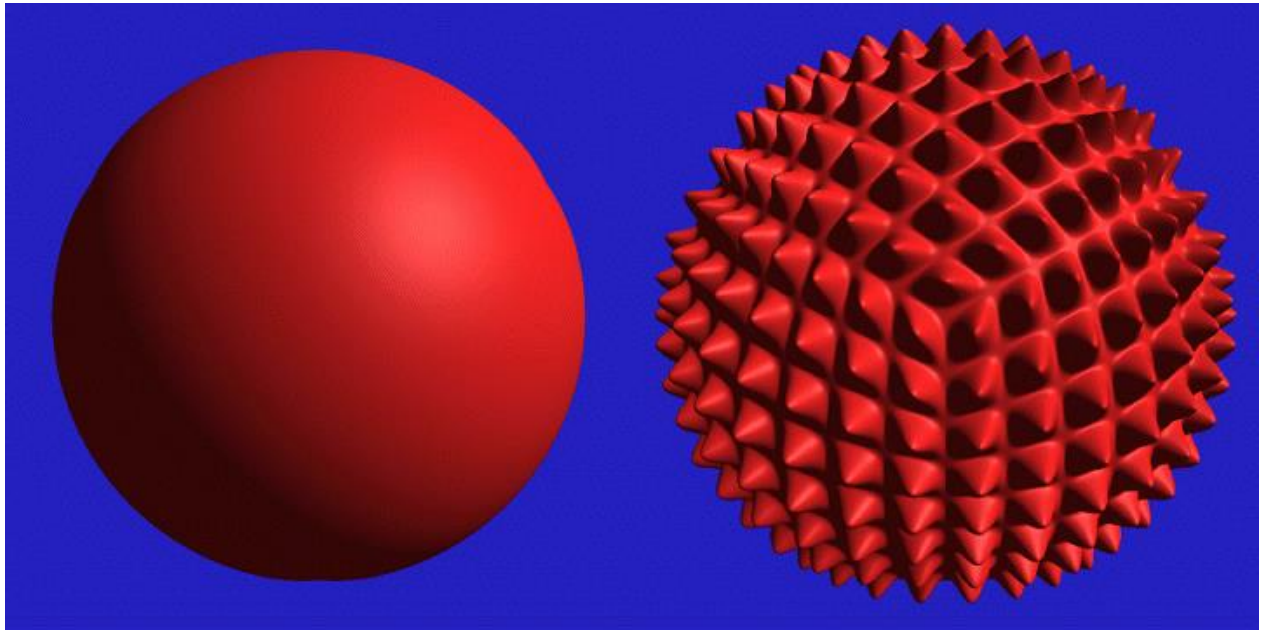
Examples Displacement Mapping

Modify geometry



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Displacement Mapping

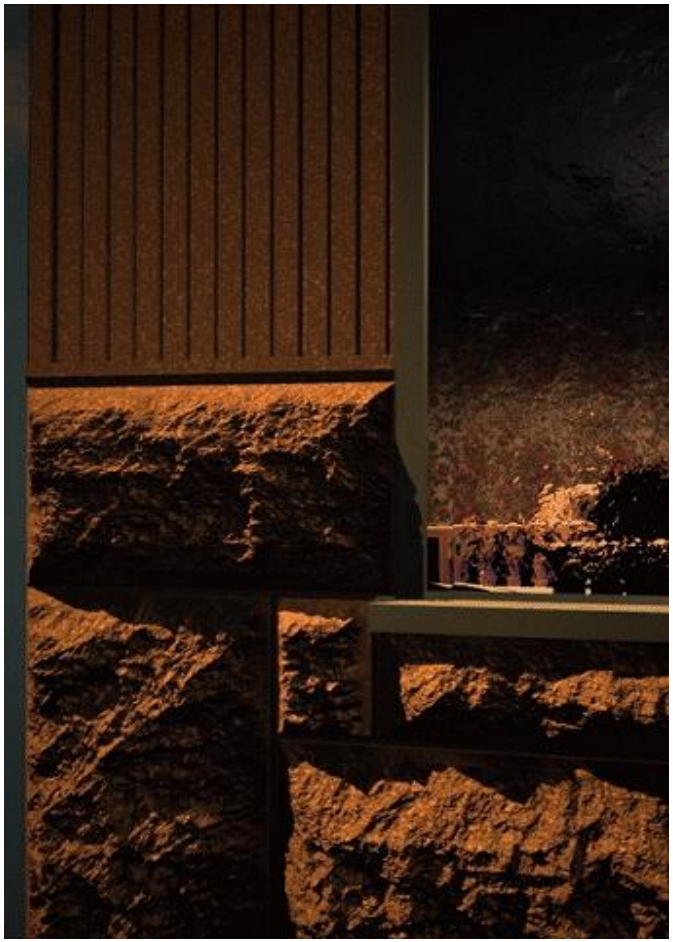

Image from

Geometry Caching for Ray-Tracing Displacement Maps

by Matt Pharr and Pat Hanrahan.

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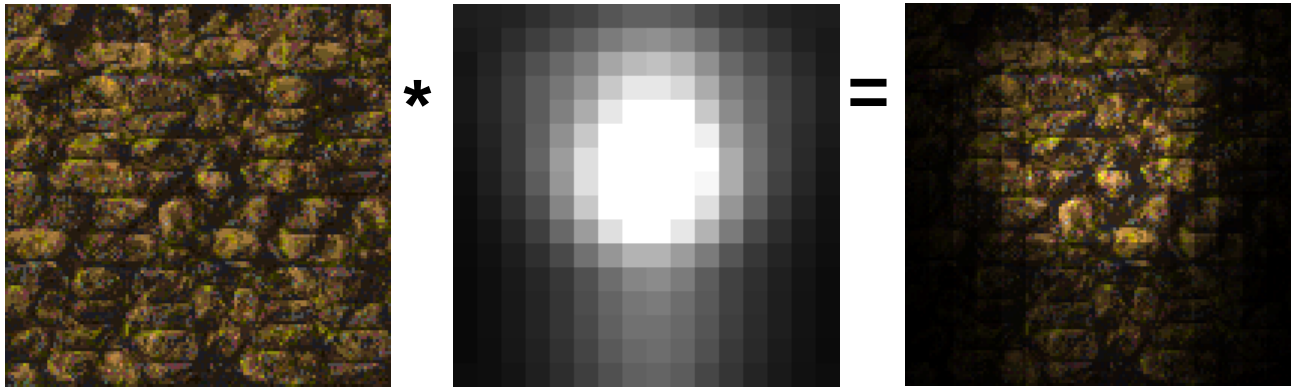
Illumination Maps

- Store illumination computed in texture maps
- Combines with texture



Reflectance **Irradiance** **Radiosity**

$$\rho(x) \qquad E(x) \qquad B(x)$$

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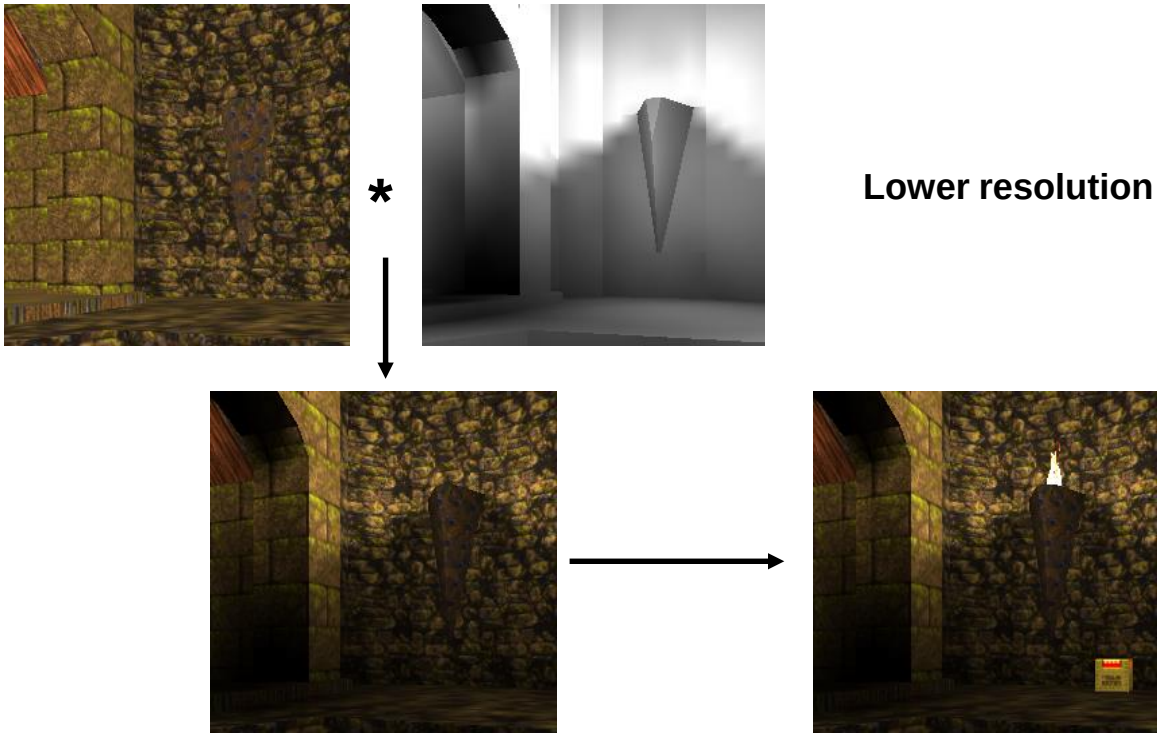
Quake Light Maps




without bump mapping
with bump mapping

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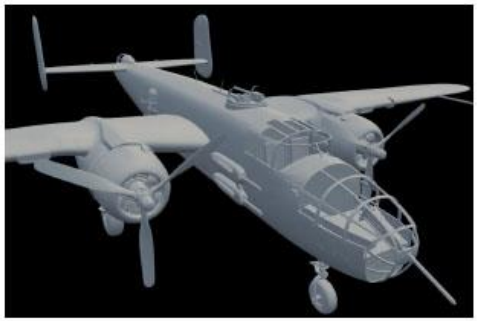
Ambient Occlusion Maps

- Efectes de il·luminació global amb mapes precalculats



From Production ready global illumination, Hayden Landis, ILM

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Final Remarks

- Texture mapping techniques
  - Material texture
  - Bump and displacement mapping
  - Environment mapping
  - Lighting maps
- All are crucial for realistic interactive techniques
- NEXT:
  - Shadow maps
  - Raytracing
  - Global Illumination

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TEXTURE IN WEBGL

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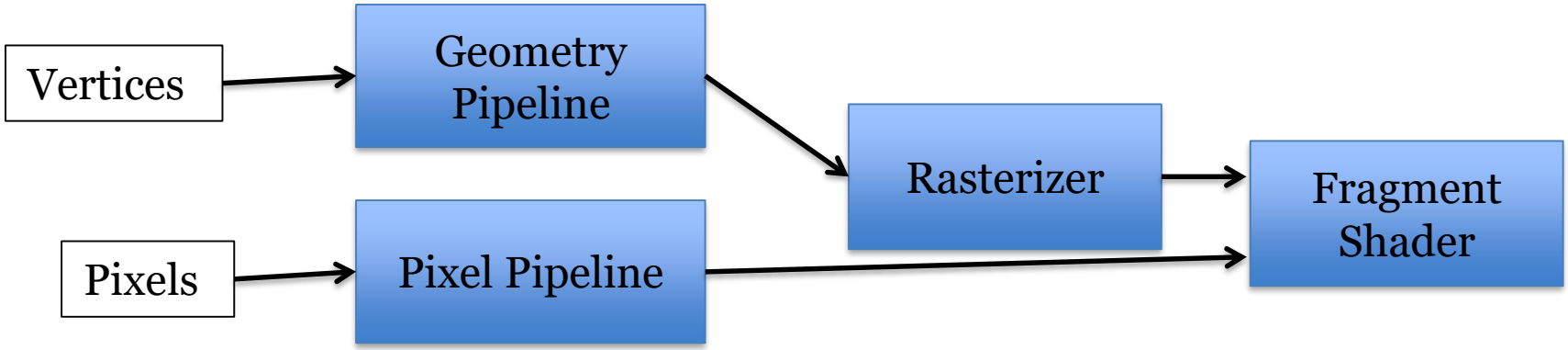
Texture Mapping and the OpenGL Pipeline

- Images and geometry flow through separate pipelines that join at the rasterizer
  - "complex" textures do not affect geometric complexity



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Applying Textures procedure

- Three basic steps for applying a texture
  1. specify the texture

»read (or generate) the image

»assign to texture

»enable texturing

  2. assign texture coordinates to vertices
  3. specify texture parameters

»wrapping, filtering

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Specifying a Texture Image

- Define a texture image from an array of *texels* (texture elements) in CPU memory
- Use an image in a standard format (such as JPEG)
  - Scanned image
  - Generate by application code
- WebGL 1.0 supports only 2 dimensional texture maps
  - no need to enable as in desktop OpenGL
- WebGL 2 supports 3 dimensional texture maps
- Desktop OpenGL supports 1-4 dimensional texture maps

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Define Image as a Texture

```
gl.texImage2D( target, level, components,
    w, h, border, format, type, texels );
```

`target:` type of texture, e.g. `gl.TEXTURE_2D`
`level:` used for mipmapping
`components:` elements per texel
`w, h:` width and height of `texels` in pixels
`border:` used for smoothing
`format and type:` describe texels
`texels:` pointer to texel array

Example:

```
gl.texImage2D(gl.TEXTURE_2D, 0, 3, 512, 512, 0, gl.RGB, gl.UNSIGNED_BYTE,
my_texels);
```

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Texture Objects

- Have WebGL store your images
  - one image per texture object
- Create an empty texture object

```
var texture = gl.createTexture();
```

- Bind textures before using

```
gl.bindTexture( gl.TEXTURE_2D, texture );
```

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Specifying a Texture Image

•Define a texture image from an array of *texels* in CPU memory

```
gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, texSize,
        texSize, 0,  gl.RGBA, gl.UNSIGNED_BYTE, image);
```

• Define a texture image from an image in a standard format memory specified

–For example, with the <image> tag in the HTML file

```
var image = document.getElementById("texImage");

gl.texImage2D( gl.TEXTURE_2D, 0, gl.RGB, gl.RGB, gl.UNSIGNED_BYTE, image );
```

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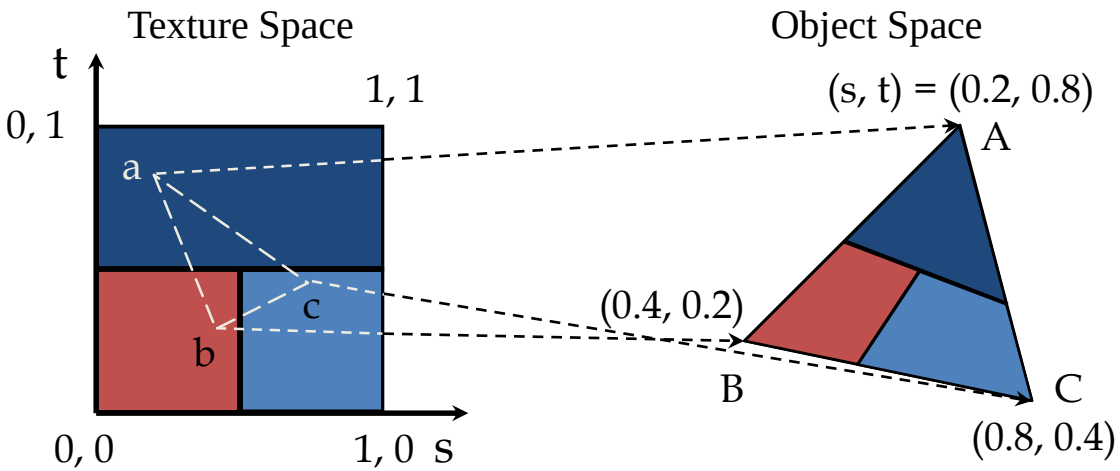
Mapping a Texture

- Based on parametric texture coordinates
- Specify as a 2D vertex attribute



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Cube Example

```
var exampleCube = {  // 24 vértices, 12 triángulos

  "vertices" : [-0.5, -0.5,  0.5,   0.0,  0.0,  1.0,   0.0, 0.0,
                 0.5, -0.5,  0.5,   0.0,  0.0,  1.0,   1.0, 0.0
                 0.5,  0.5,  0.5,   0.0,  0.0,  1.0,   1.0, 1.0,
                -0.5,  0.5,  0.5,   0.0,  0.0,  1.0,   0.0, 1.0
                 0.5, -0.5,  0.5,   1.0,  0.0,  0.0,   0.0, 0.0,
                 0.5, -0.5, -0.5,   1.0,  0.0,  0.0,   1.0, 0.0,
                 0.5,  0.5, -0.5,   1.0,  0.0,  0.0,   1.0, 1.0,
                 0.5,  0.5,  0.5,   1.0,  0.0,  0.0,   0.0, 1.0,
                 0.5, -0.5, -0.5,   0.0,  0.0, -1.0,   0.0, 0.0,
                -0.5, -0.5, -0.5,   0.0,  0.0, -1.0,   1.0, 0.0,
                -0.5,  0.5, -0.5,   0.0,  0.0, -1.0,   1.0, 1.0,
                 0.5,  0.5, -0.5,   0.0,  0.0, -1.0,   0.0, 1.0,
                -0.5, -0.5, -0.5,  -1.0,  0.0,  0.0,   0.0, 0.0,
                -0.5, -0.5,  0.5,  -1.0,  0.0,  0.0,   1.0, 0.0,
                -0.5,  0.5,  0.5,  -1.0,  0.0,  0.0,   1.0, 1.0
                -0.5,  0.5, -0.5,  -1.0,  0.0,  0.0,   0.0, 1.0,
                -0.5,  0.5,  0.5,   0.0,  1.0,  0.0,   0.0, 0.0,
                 0.5,  0.5,  0.5,   0.0,  1.0,  0.0,   1.0, 0.0,
                 0.5,  0.5, -0.5,   0.0,  1.0,  0.0,   1.0, 1.0,
                -0.5,  0.5, -0.5,   0.0,  1.0,  0.0,   0.0, 1.0,
                -0.5, -0.5, -0.5,   0.0, -1.0,  0.0,   0.0, 0.0,
                 0.5, -0.5, -0.5,   0.0, -1.0,  0.0,   1.0, 0.0,
                 0.5, -0.5,  0.5,   0.0, -1.0,  0.0,   1.0, 1.0
                -0.5, -0.5,  0.5,   0.0, -1.0,  0.0,   0.0, 1.0],

  "indices" :  [  0,  1,  2,  0,  2,  3,
                  4,  5,  6,  4,  6,  7,
                  8,  9, 10,  8, 10, 11,
                 12, 13, 14, 12, 14, 15,
                 16, 17, 18, 16, 18, 19,
                 20, 21, 22, 20, 22, 23]

};
```

Texture coordinates

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Basic Shaders for 2D Texture

```
// Vertex shader
...
in  vec2 VertexTexcoords;  // nuevo atributo
out vec2 texCoords;

void main()  {
   ...
   // se asignan las coordenades de textura del vertice a la variable texCoords
   texCoords    = VertexTexcoords;
}

// Fragment shader
...
uniform sampler2D myTexture;     // la textura
in vec2 texCoords;               // coordenadas de textura interpoladas

void main()
{
   ...
   // acceso a la textura para obtener un valor de color RGBA
   fragmentColor = texture(myTexture, texCoords);
}
```

type

GLSL function

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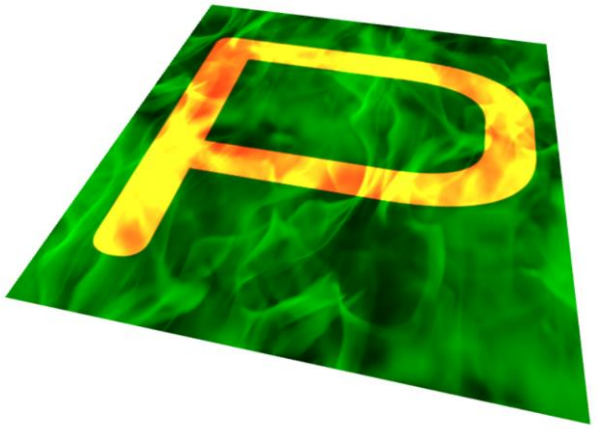
Multiple textures

```
// Fragment shader
...
uniform sampler2D myTexture1, myTexture2;     // las texturas
in vec2 texCoords;     // coordenadas de textura interpoladas

void main()
{
   ...
   // acceso a la textura para obtener un valor de color RGBA
   fragmentColor = texture(myTexture1, texCoords) * texture(myTexture2, texCoords);
}
```



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Texture Parameters

- WebGL has a variety of parameters that determine how texture is applied
  - Wrapping parameters determine what happens if s and t are outside the (0,1) range
  - Filter modes allow us to use area averaging instead of point samples
  - Mipmapping allows us to use textures at multiple resolutions
  - Environment parameters determine how texture mapping interacts with shading

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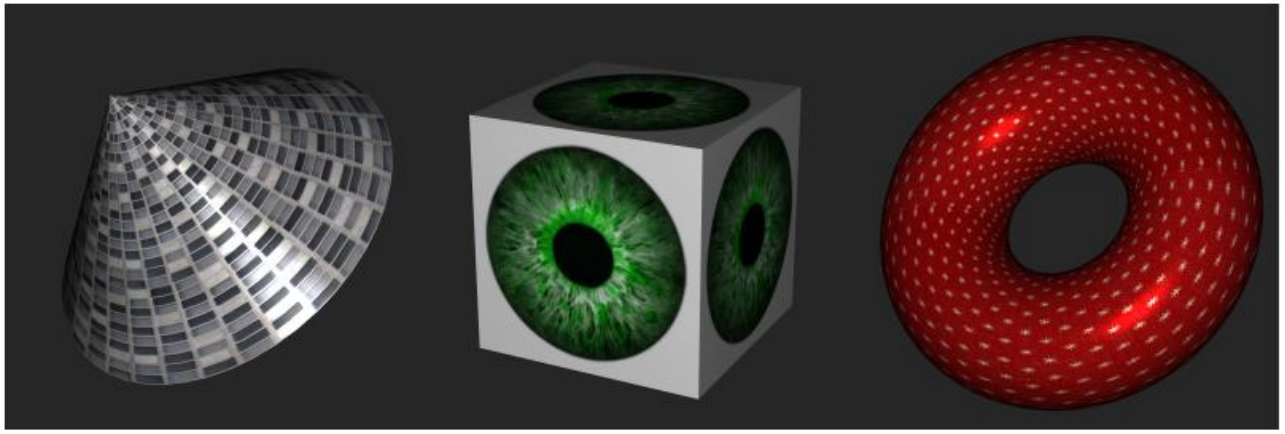
Class examples: Applying Textures

1. Create a texture object
2. Assign the unit texture
3. Specify vertex coordinate and texture coordinates



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Create texture

```
// Crea un objeto textura
texture = gl.createTexture();
gl.bindTexture(gl.TEXTURE_2D, texture);

// Especifica la textura RGB
gl.texImage2D (gl.TEXTURE_2D, 0, gl.RGB, image.ancho, image.alto, 0, gl.RGB, gl.UNSIGNED_BYTE,
      image);

// Repite la textura tanto en s como en t
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.REPEAT);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.REPEAT);

// Filtrado
gl.texParameteri (gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR_MIPMAP_LINEAR);
gl.texParameteri (gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR);
gl.generateMipmap(gl.TEXTURE_2D);
```

Assign texture: each object can have different textures

```
// Selecciona la unidad de textura 0
gl.activeTexture(gl.TEXTURE0);

// Asigna el objeto textura a la unidad de textura seleccionada
gl.bindTexture  (gl.TEXTURE_2D, texture);
```

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Link the shader variable with the texture unit

```
// Obtiene el indice de la variable del Shader de tipo sampler2D
program.textureIndex = gl.getUniformLocation(program, 'myTexture');

// Indica que myTexture del Shader use la unidad de textura 0
gl.uniform1i(program.textureIndex, 0);
```

Enable texture coordinate attribute

```
// se obtiene la referencia al atributo
program.vertexTexcoordsAttribute =
  gl.getAttribLocation ( program, "VertexTexcoords");

// se habilita el atributo
gl.enableVertexAttribArray(program.vertexTexcoordsAttribute);
```

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Procedural texture

- Examples
  - Damas
  - Enrejado
  - Rayado
  - Nubes