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COMPUTER-AIDED GEOMETRIC DESIGN AND COMPUTER GRAPHICS:

TEXTURE AND BUMP MAPPING

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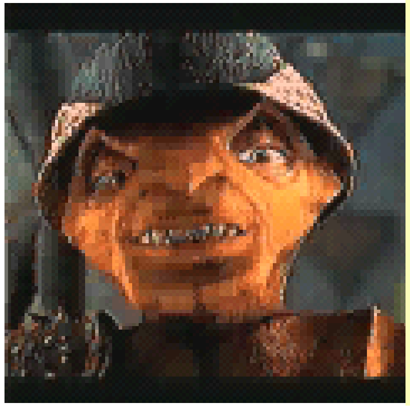
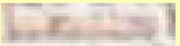
Texture

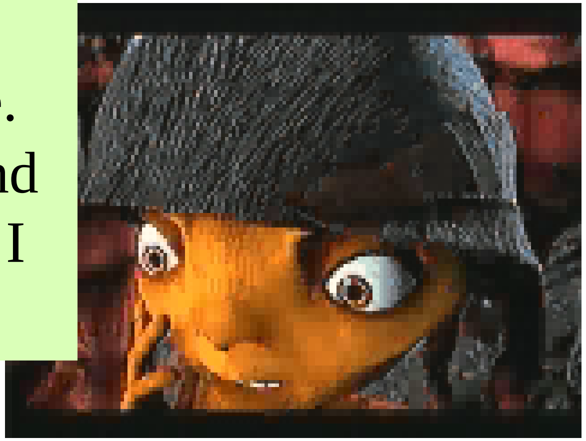
Motivation



Today, we're going to build a brick wall. It is easy! Each ant must take a brick like this  With some hundreds of ants we'll finish the wall before the battle. Come on!

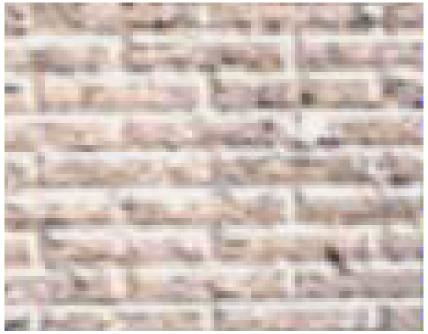
1 brick,
2 bricks,
3 bricks,
....

My God! We won't finish the wall in time. They arrive before, and we'll die!!! What can I do alone?



Don't worry! I'm so strong...

I have a trick!! We only need to apply a single textured polygon. Something like this:



ANTZ
E online.

Texture

In computer graphics, the fine surface detail on an object is generated using *textures*.

Three aspects of texture are generally considered:

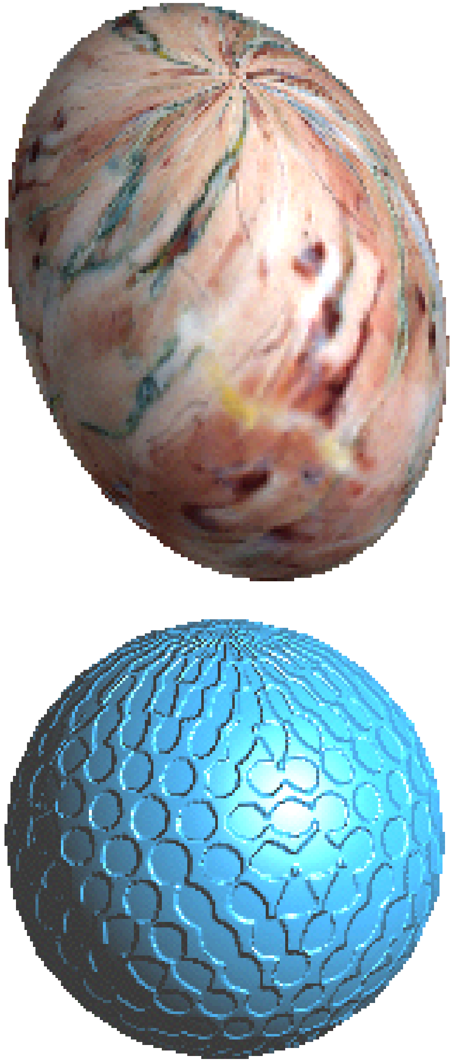
1. *Texture mapping:* the addition of a separately specified pattern to a smooth surface. After the pattern is added, the surface remains smooth.

Also known as *patterns* or *colour detail*

2. *Bump mapping:* the addition of roughness to the surface. This is obtained perturbation function that changes the geometry of the surface.

Also known as *roughness*

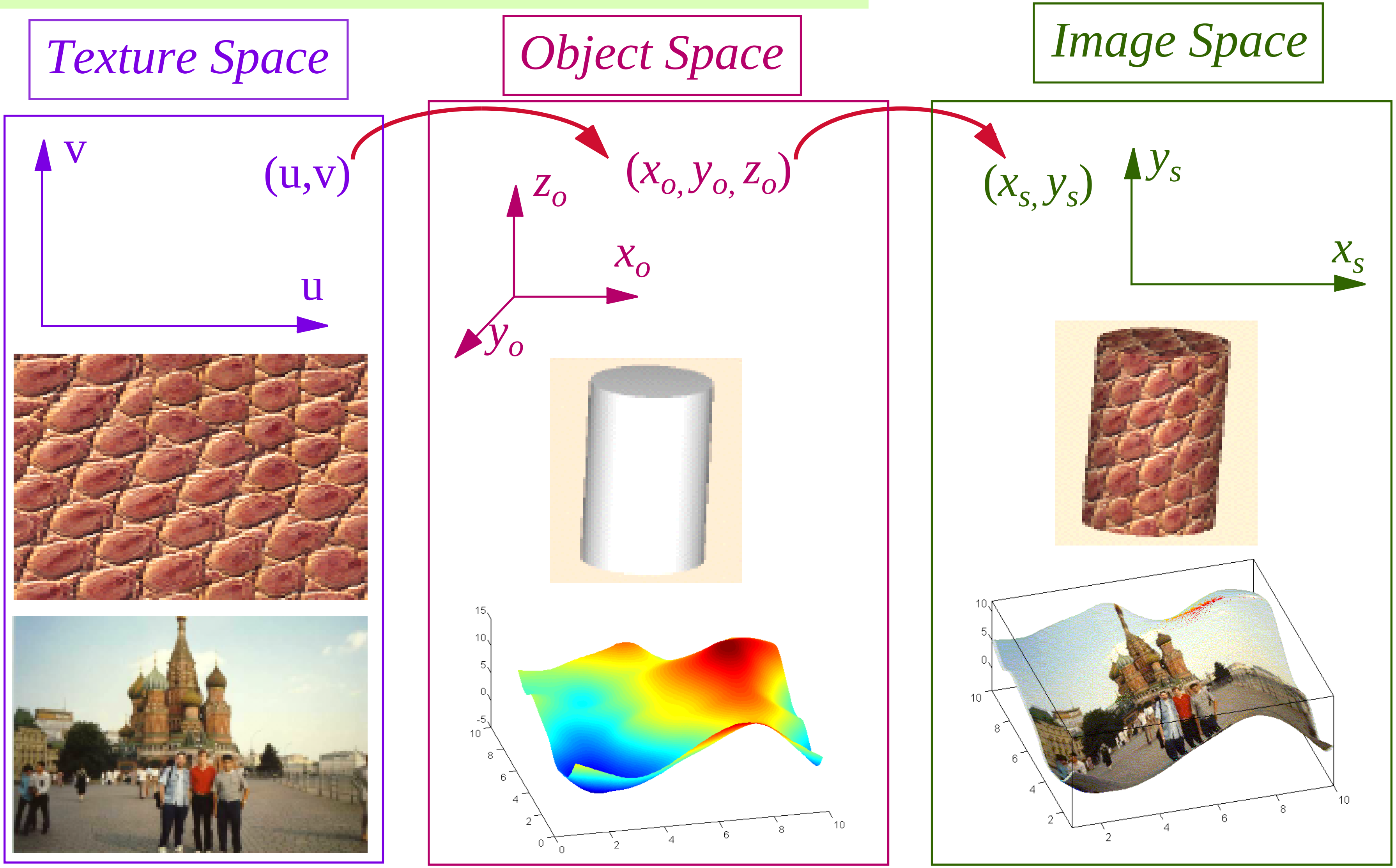
3. *Simulating environments:* for example, shadows and lighting using textures.



Texture

Texture mapping

The basis of adding texture patterns is mapping:



Texture Space

Object Space

Image Space

(u,v)

(x_o, y_o, z_o)

(x_s, y_s)

Texture

Texture mapping

Object space mapping: We map an image onto the surface of an object.

Texture pattern defined in an orthogonal coordinate system (u,v) in texture space

The surface is defined in a second orthogonal coordinate system (x,y,z) represented in a parametric space

The surface is represented in parametric space (s,t) as: $\boxed{x(s,t),\ y(s,t),\ z(s,t)}$

Therefore, we need to determine the mapping function between the texture space and the parametric space:

$$\boxed{s=f(u,v) \quad , \quad t=g(u,v)}$$

The inverse mapping from parametric space to texture space is:

$$\boxed{u=F(s,t) \quad , \quad v=G(s\ ,t)}$$

Texture

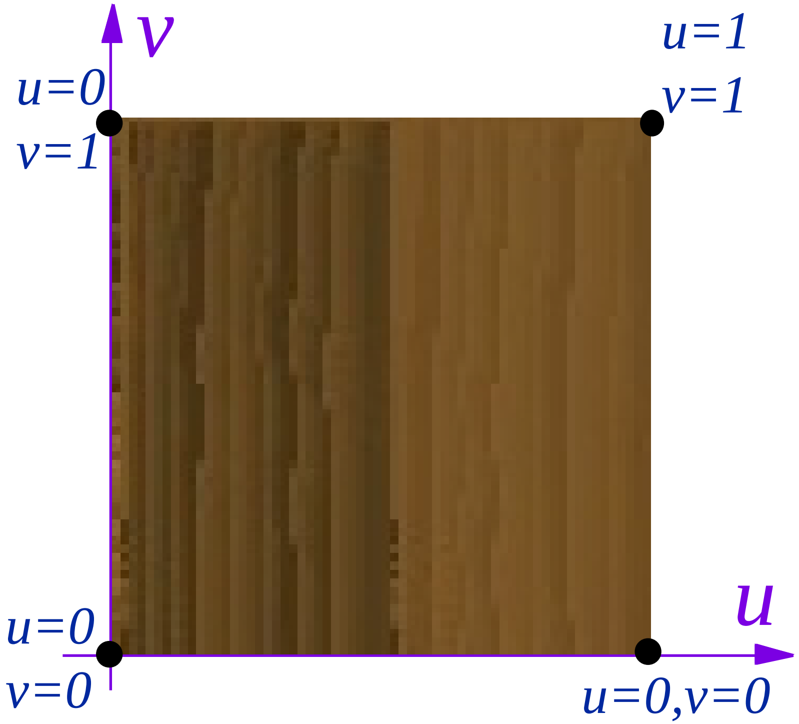
Texture mapping

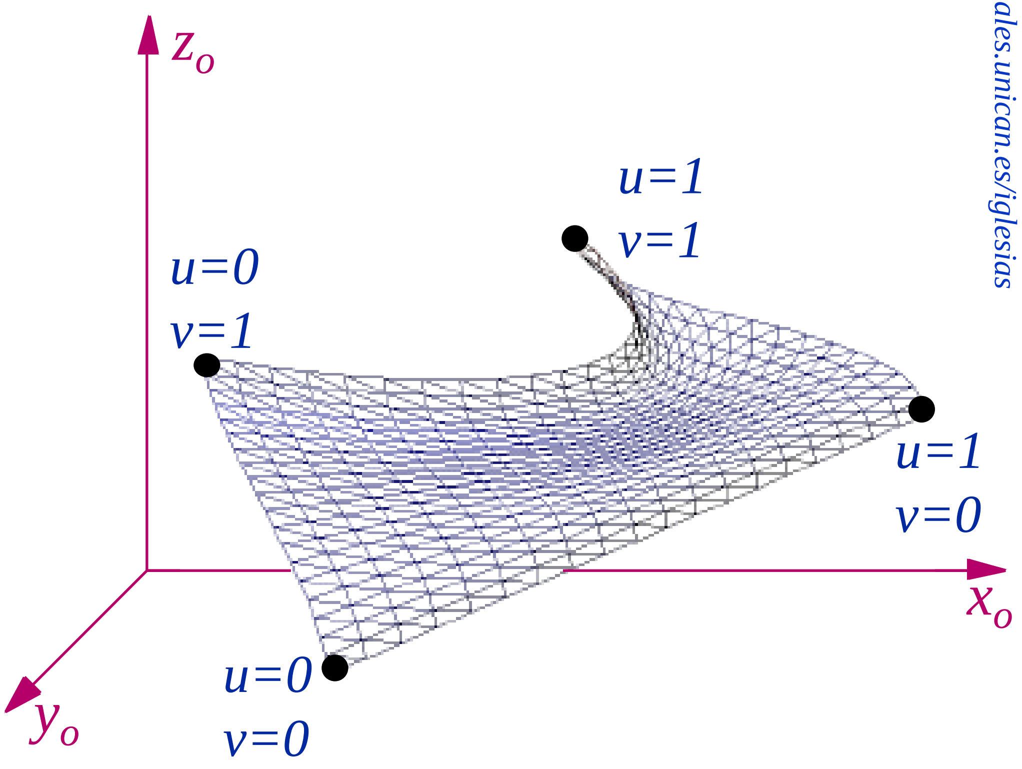
Texture Space

Object Space

Given a particular *(x,y,z)*:

- Compute the corresponding *(u,v)*
- shade the surface with the colour pointed to in the image by *(u,v)*





Texture

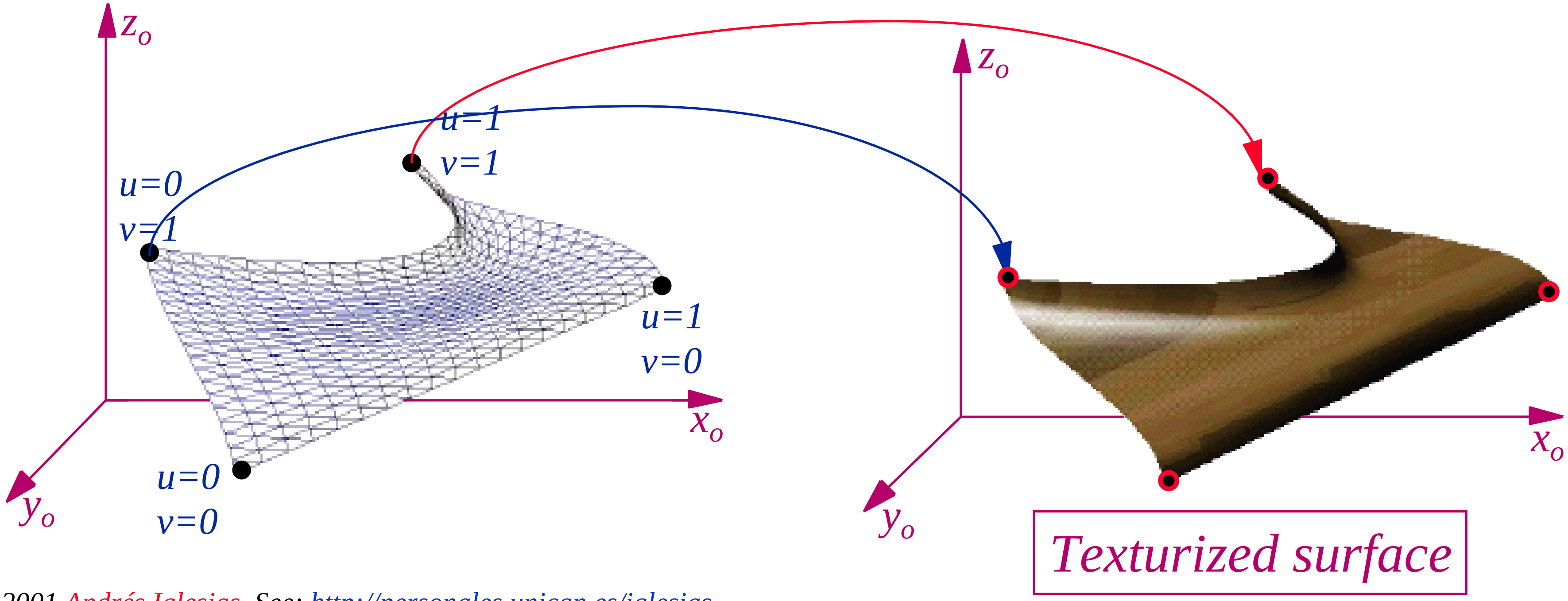
Texture mapping

Mapping functions: $s=f(u,v) \quad , \quad t=g(u,v)$

The mapping functions are frequently assumed to be linear:

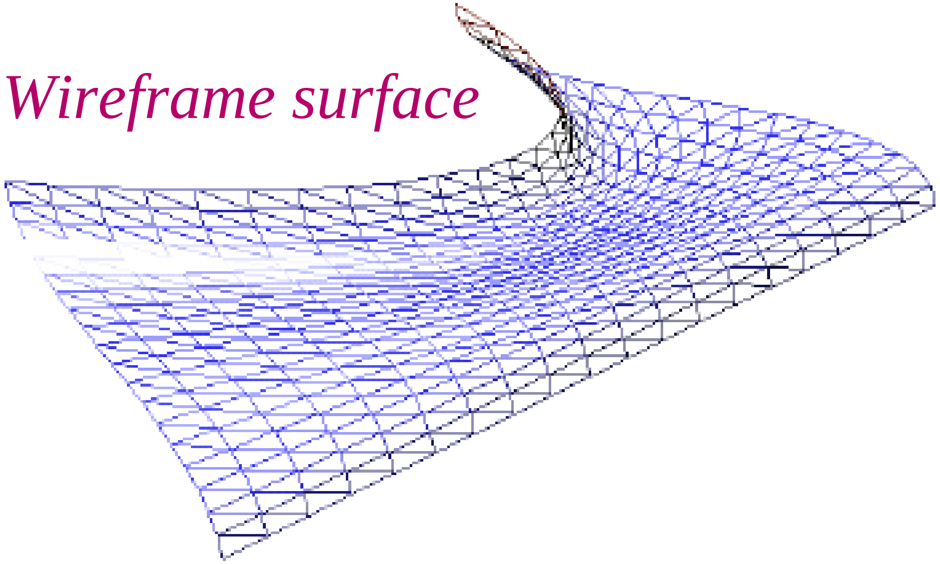
$$s=A\,u+B$$
$$t=C\,v+D$$

where the constants A, B, C and D are obtained from the relationship between known points in the two systems.

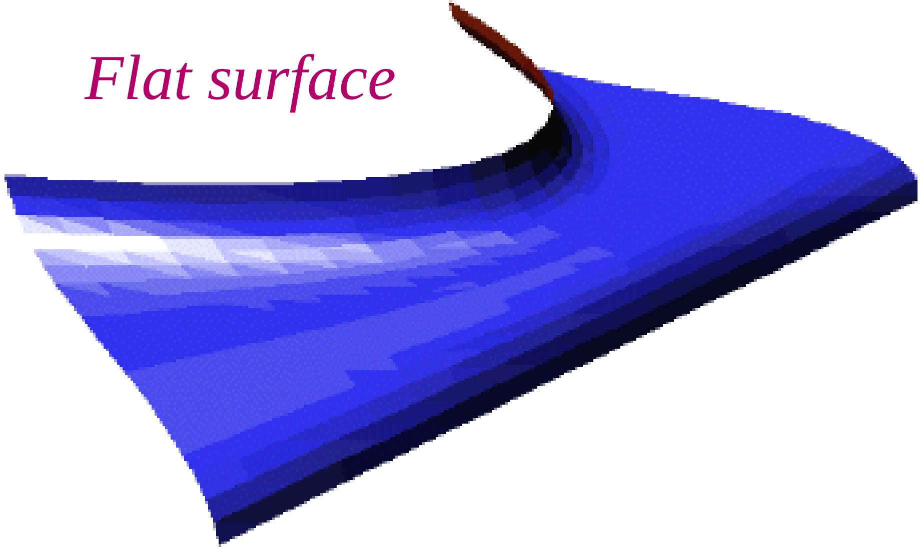


Texture

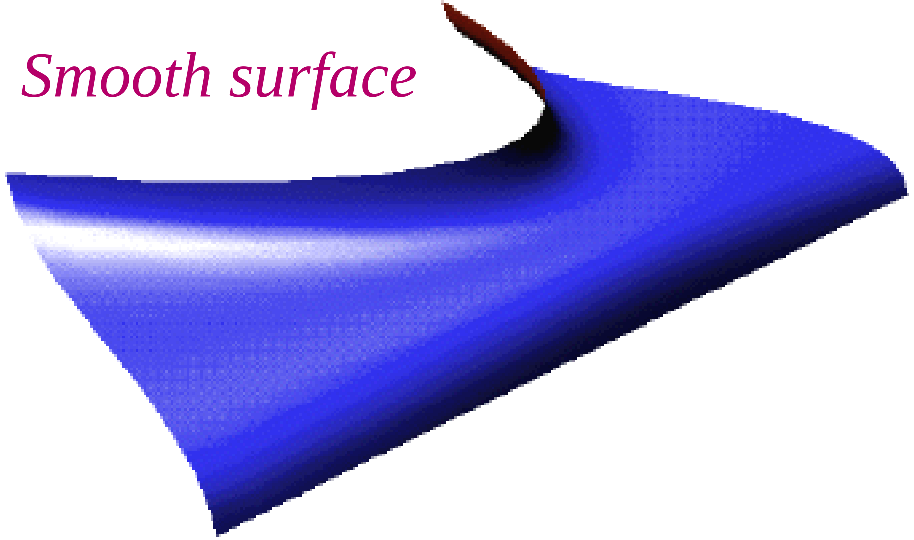
Comparing models



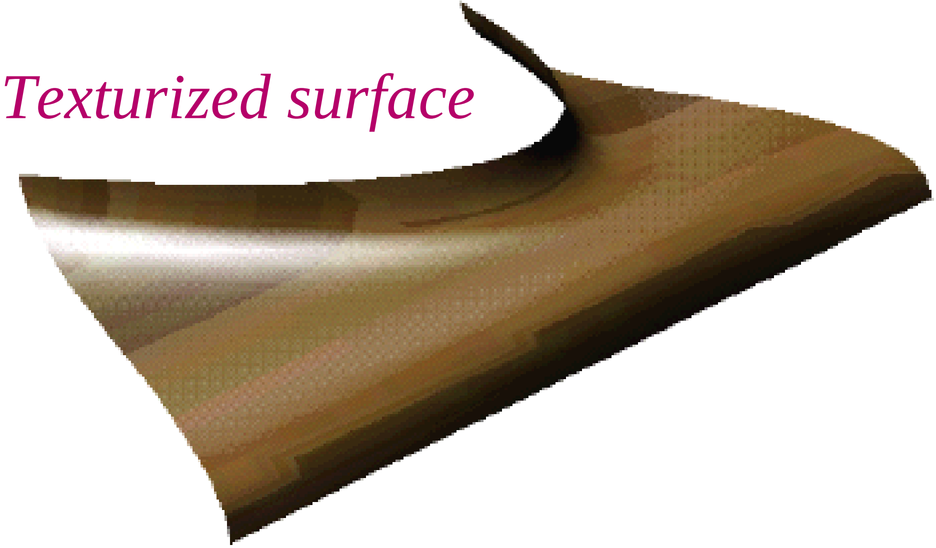
Wireframe surface



Flat surface



Smooth surface



Texturized surface

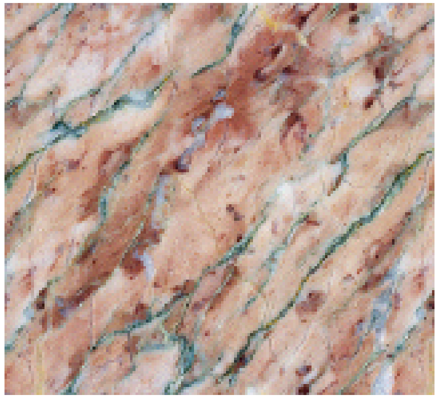
Texture

Texture mapping

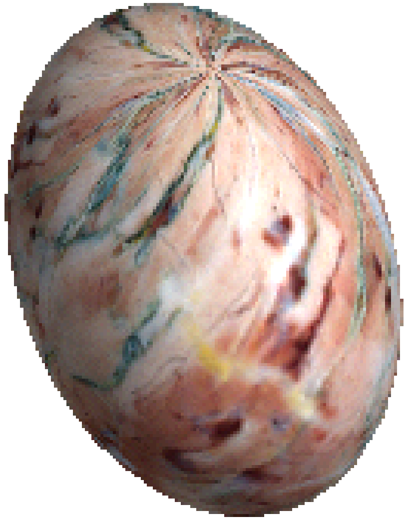
However, linear mapping functions may lead to *unsatisfactory results*.

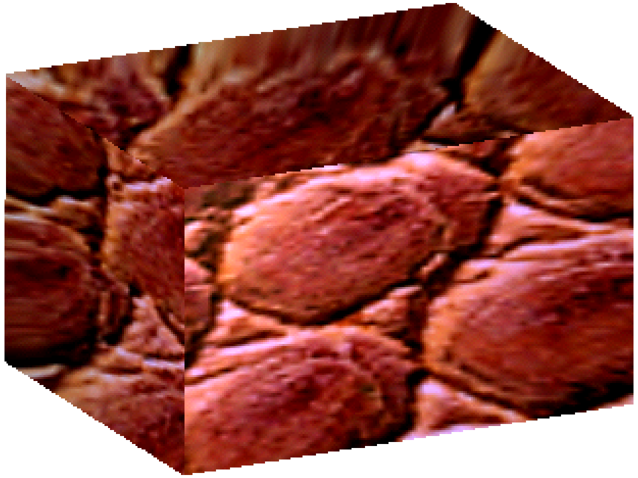
It’s better to use nonlinear functions (because the mapping between parametric space and object space is nonlinear).

Texture Space



Object Space





Texture

Texture mapping

Bier, E.A., Sloan, K.R. *Two-part Texture Mappings*, IEEE Comput. Graph. and Appl., Vol. 6, Nº 9, pp. 40-53, 1986.

Two-part mapping

Overcomes the mapping problems introducing an *“easy” intermediate surface*.

- First, mapping the texture image onto a simple three-dimensional surface (a plane, a cylinder, a sphere or a box). This is known as the *S mapping*.

- Then mapping the result onto the final three-dimensional surface. This is referred to as the *O mapping*.

$$\begin{tikzcd}
(u,v) \arrow[r, "S"] & T'(x_i, y_i) \arrow[r, "O"] & O(x_s, y_s, z_s) \\
\text{Texture Space} \arrow[r] & \text{Intermediate space} \arrow[r] & \text{Object space}
\end{tikzcd}$$

Texture

Texture mapping

Two-part mapping

For the *S mapping* the authors described four intermediate surfaces:

1.- A plane at any orientation

To align the texture with the plane require:

3 rotations + 3 translations

Then, the pattern must be scaled. Ignoring rotations and translations, the transformation is given by:

$$\boxed{(u,v) \longrightarrow (a\,x_i\,,d\,y_i)}$$

a, d - scaling factors

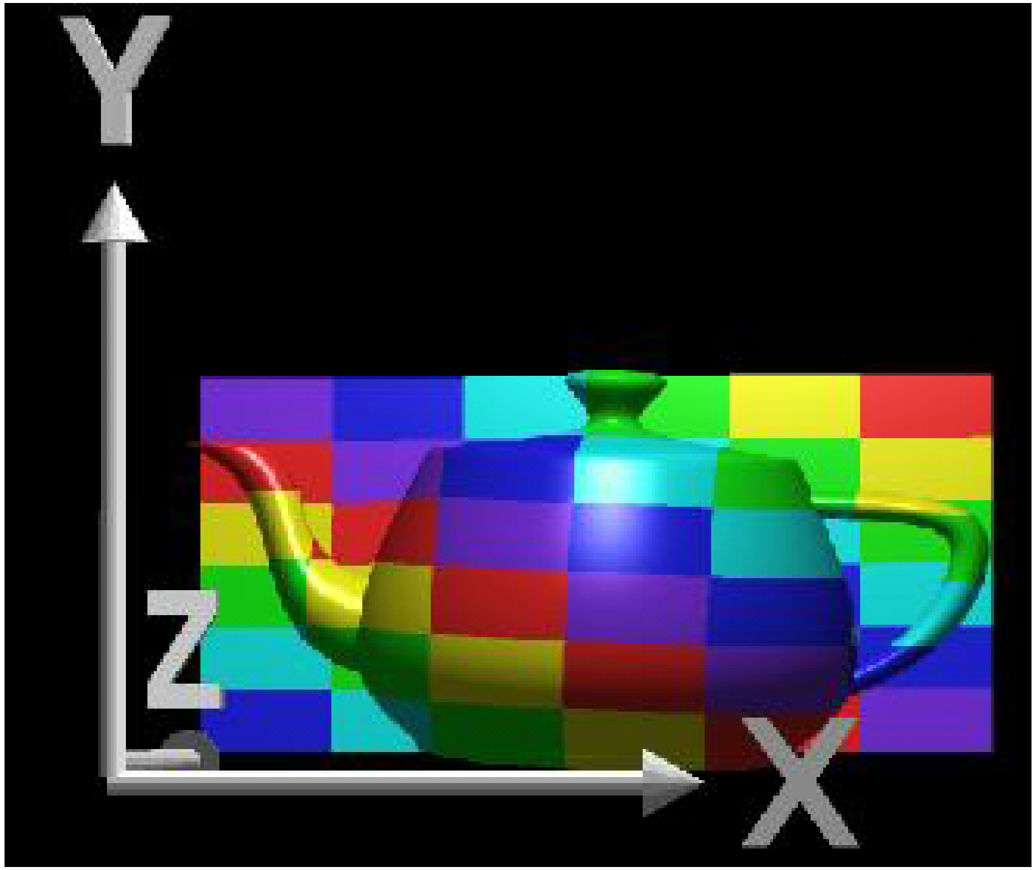


Image from: © SIGGRAPH'97 R. J. Wolfe (DePaul University)

Texture

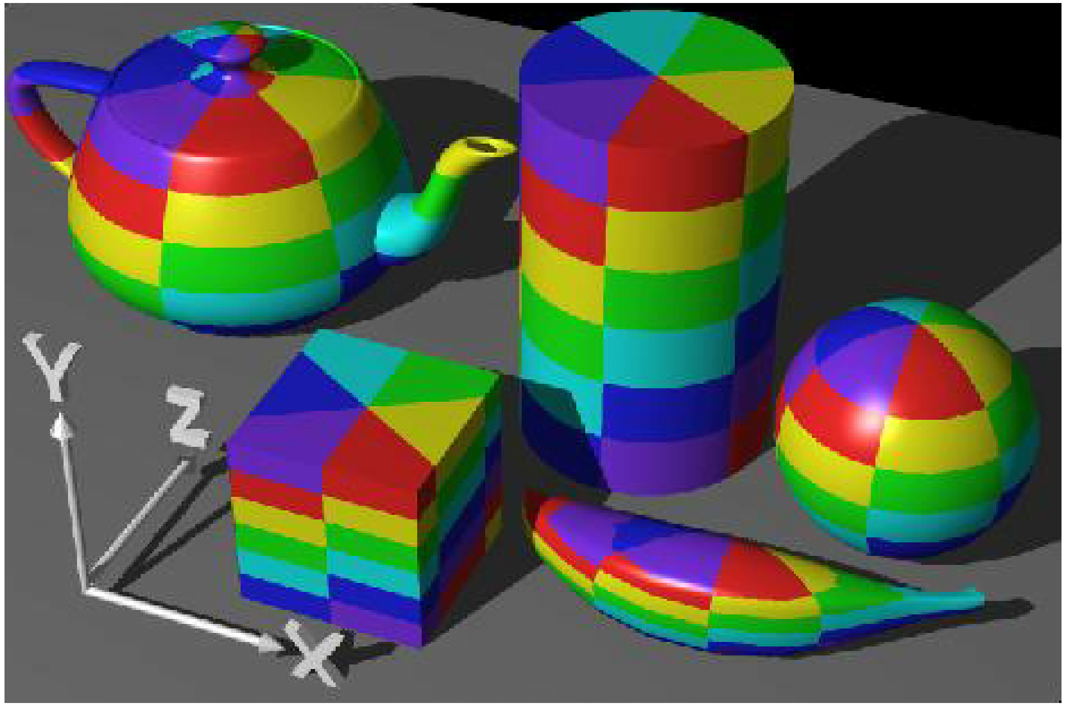
Texture mapping

Two-part mapping

2.- The curved surface of a cylinder (Useful for surfaces of revolution)

$$(u,v) \longrightarrow [a\, r\, (\theta-\theta_0)\, , d\, (h-h_0)]$$

where a, d are scaling factors, and θ_0 and h_0 position the texture on the surface of the cylinder of radius r.



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Texture

Texture mapping

Two-part mapping

3.- The surface of a sphere

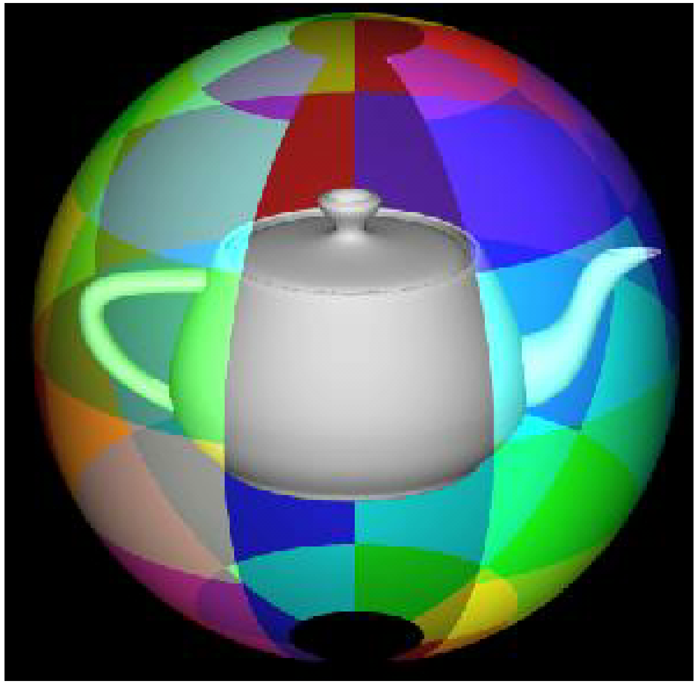
Using the stereographic projection:

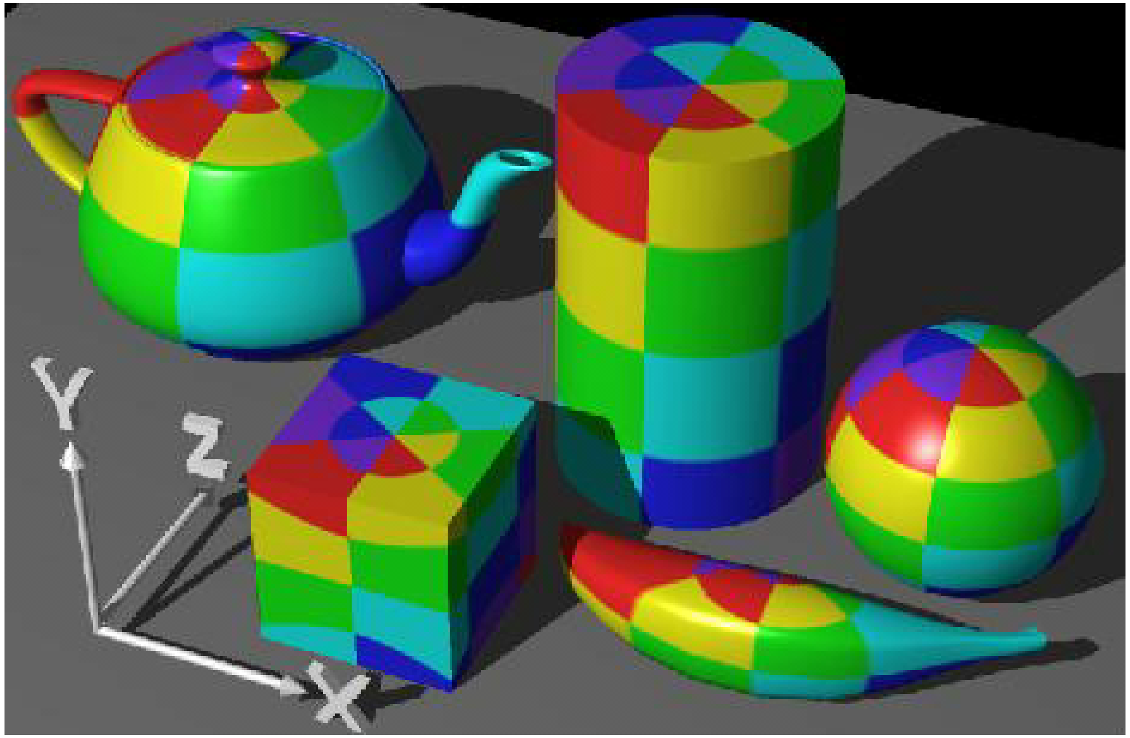
$$\boxed{(u,v)=(2p/C,2q/C) \longrightarrow (\theta, \varphi)}$$

where (θ, φ) are the equatorial and polar variables for the sphere and:

$$C=1+\mathrm{sqrt}(1+p^2+q^2)$$

$$p=\tan(\theta)\cos(\varphi)\ , \quad q=\tan(\theta)\cos(\varphi)$$





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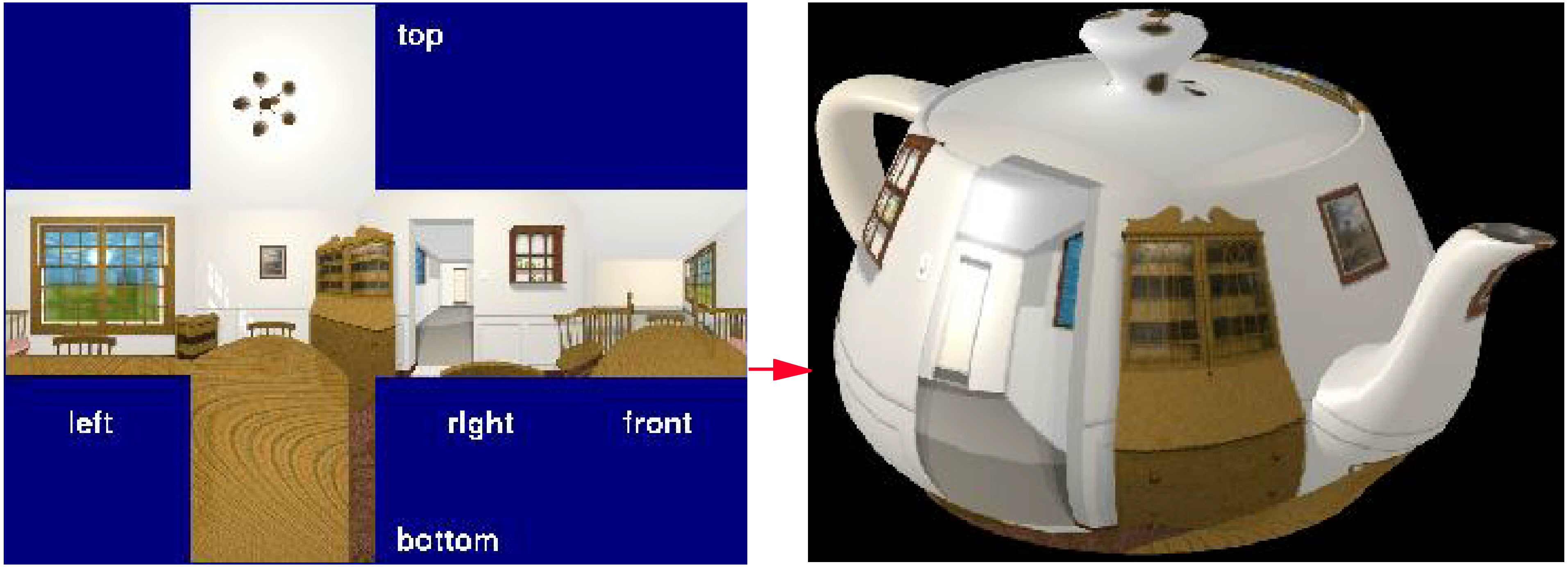
Texture

Texture mapping

Two-part mapping

4.- The faces of a cube

Interesting enough, since a box is topologically equivalent to an sphere.



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Shortcoming: nonadjacent pieces of the texture are now adjacent both on the box surface and the final three-dimensional surface, leading to possible discontinuities.

Texture

Texture mapping

Two-part mapping

For the *O mapping* we also have four mapping techniques (which map the texture from the intermediate surface to the object):

- *Reflected ray:* trace a ray from the viewpoint of the object and then trace the resulting reflected ray from the object to the intermediate surface. This is in fact the *environment mapping*.

- *Object normal:* find the intersection of the normal to the object surface with the intermediate surface.

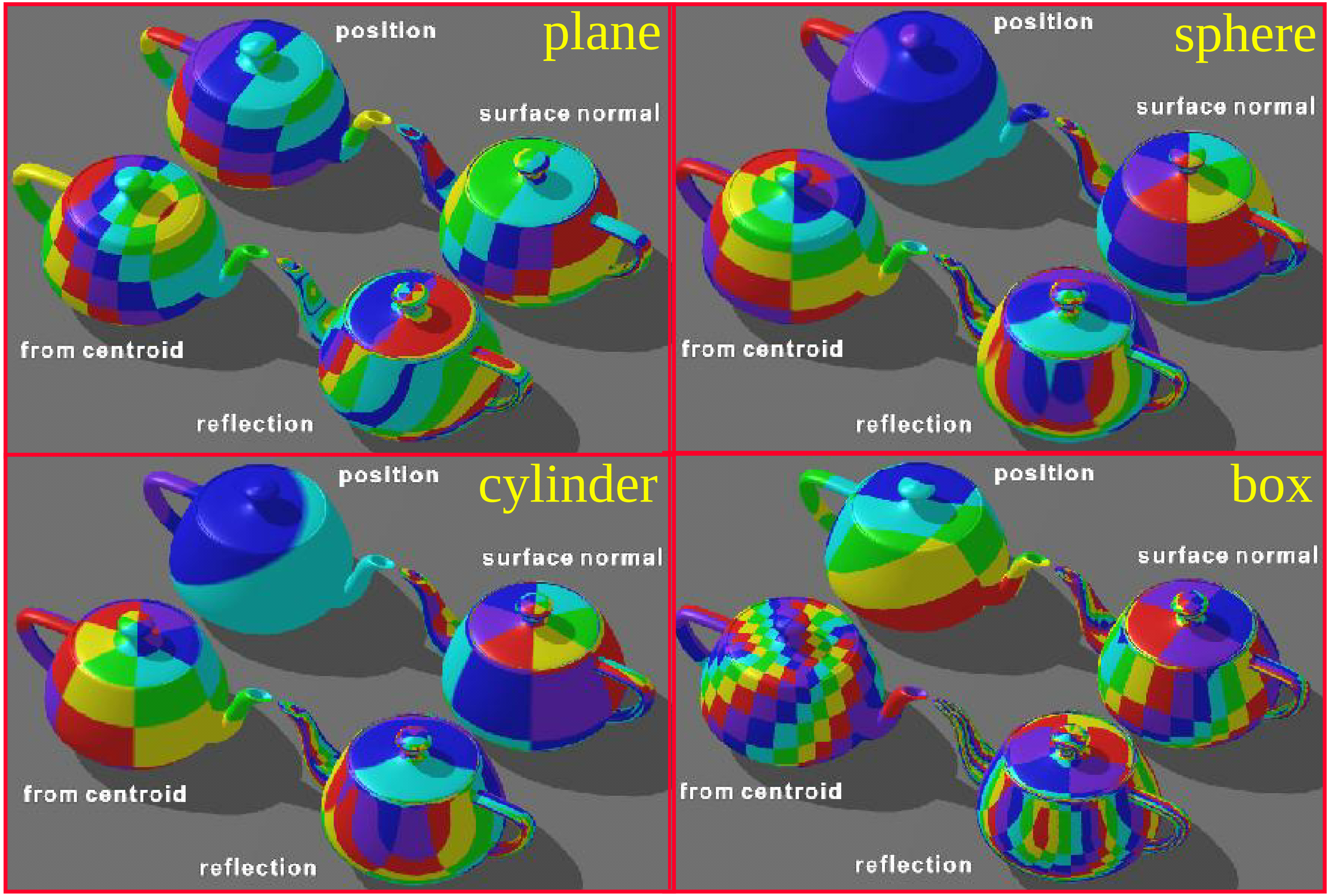
- *Object centroid:* intersect the line defined by the centroid of the object and a point on the object surface with the intermediate surface.

- *Intermediate surface normal (ISN):* trace a ray in the direction of the normal at a point on the intermediate surface to find its intersection with the object.

Reflected ray is ignored because is viewpoint dependent and not very useful.

Texture

Two-part mapping three *O mapping* x four *S mapping* = 12 combinations



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Texture

Texture mapping

Two-part mapping

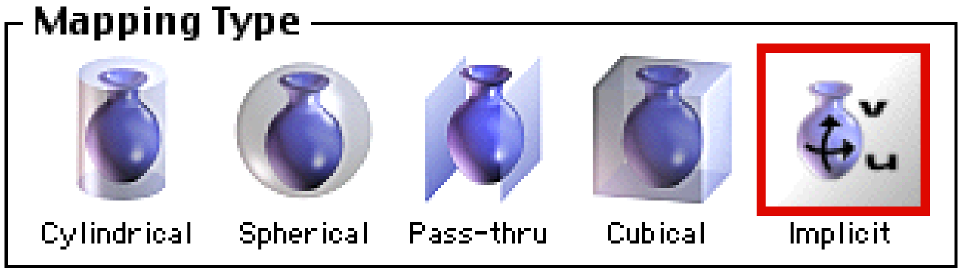
Rogers, D.F.. *Procedural Elements for Computer Graphics*, 2nd. Edition, McGraw-Hill, Boston, 1998.

However, only five mappings are really useful:

	Plane	Cylinder	Sphere	Box
Object normal	Redundant	Poor	OK	OK
Object centroid	Redundant	Poor	centroid/sphere	centroid/box
I.S.N.	slide projector	shrinkwrap	Redundant	ISN/box

Commercial software already incorporates two-part mapping techniques:

Painter 3D



Amorphium

Flat
Cylindrical
Spherical

Texture

Bump mapping

Adding texture patterns to smooth surfaces produces smooth surfaces.

Using a rough-textured pattern to add the appearance of roughness to a surface is not a good idea. Rough-textured surfaces hava a small random component in the surface normal and hence in the light reflection direction.

Blinn, J.F., *A scan line algorithm for the computer display of parametrically defined surfaces*, Comput. Graph., Vol. 12, 1978 (supplement SIGGRAPH'78).

Blinn developed a method to for perturbing the surface normal.

At any point of the surface S, the partial derivatives are S_u and S_v. The surface normal n is given by the cross-product:

$$\boxed{n = S_u \times S_v}$$

Blinn defined a new surface S' as:

$$\boxed{S'(u,v) = S(u,v) + P(u,v)\frac{n}{|n|}}$$

where P(u,v) is a perturbation function in the direction of the normal to the original surface. The new normal vector is:

$$\boxed{n' = S'_u \times S'_v}$$

Texture

Bump mapping

The perturbed normal can be written as:

$$n' = n + \frac{P_u\,(n \times S_v)}{|n|} + \frac{P_v\,(S_u \times n)}{|n|}$$

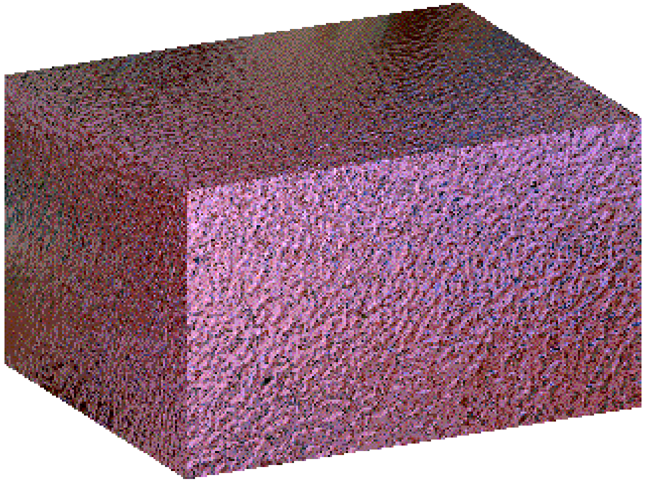
normal of the unperturbed surface

effect of the perturbation on the surface normal (hence, on the illumination model)

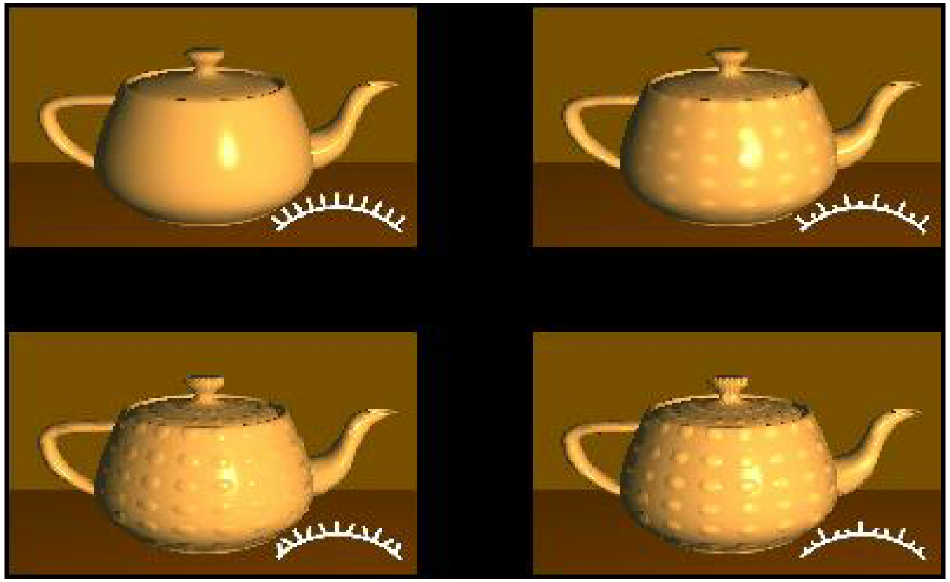
The perturbation P(u,v) can be defined either analytically or as a lookup table.

Different effects can be achieved:

random function gives rough surface



smoother functions give more regular feature



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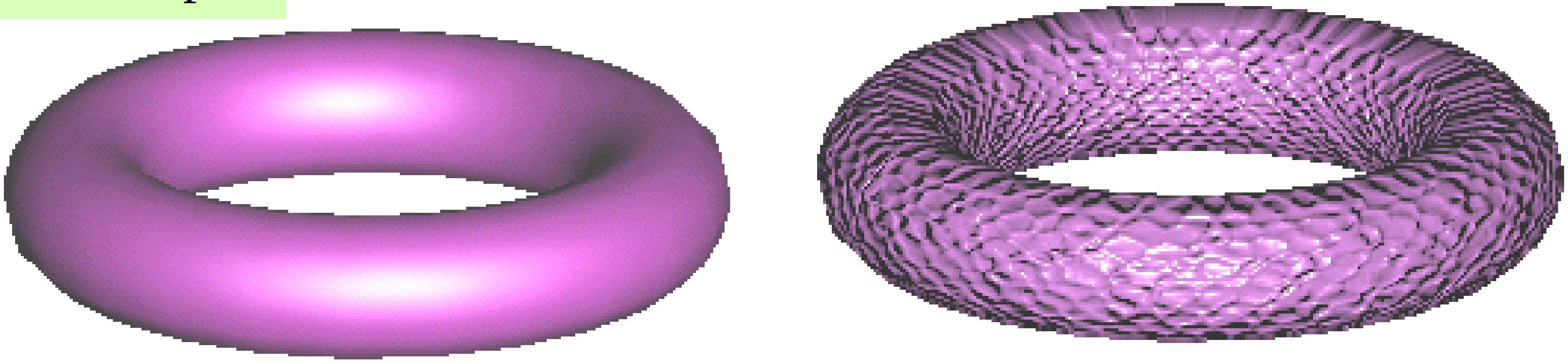
Texture

Bump mapping

An example:



Note that: *Roughening only becomes apparent when the shading model is applied*

Examples of use:

- the surface of an orange
- texture of a granitic stone
- granulated effects
- outer cover of a tyre
- etc...