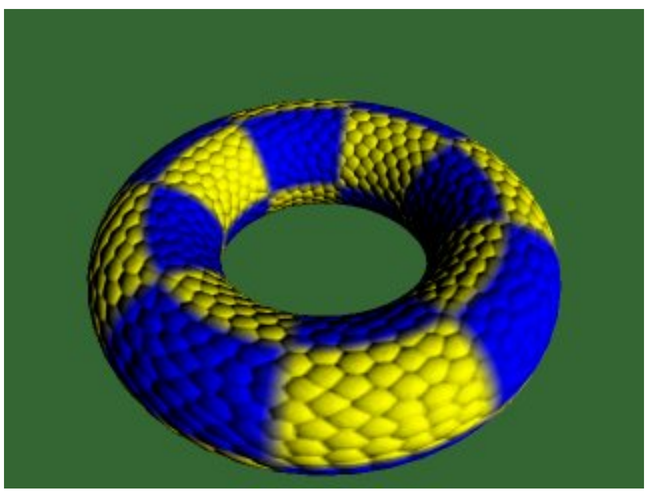
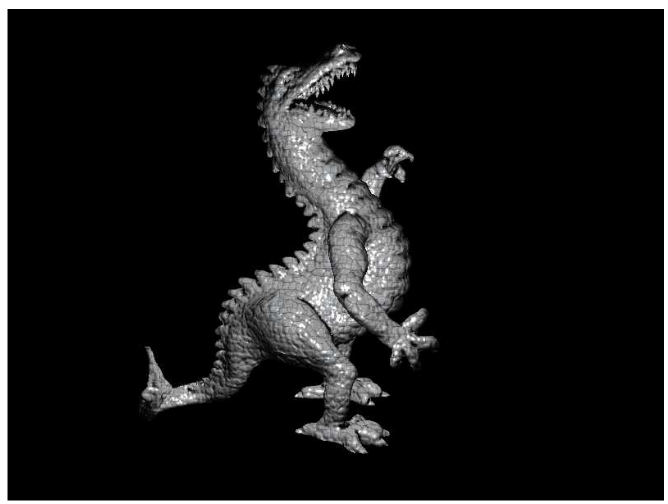
Bump Mapping

CSE 781 Winter 2010





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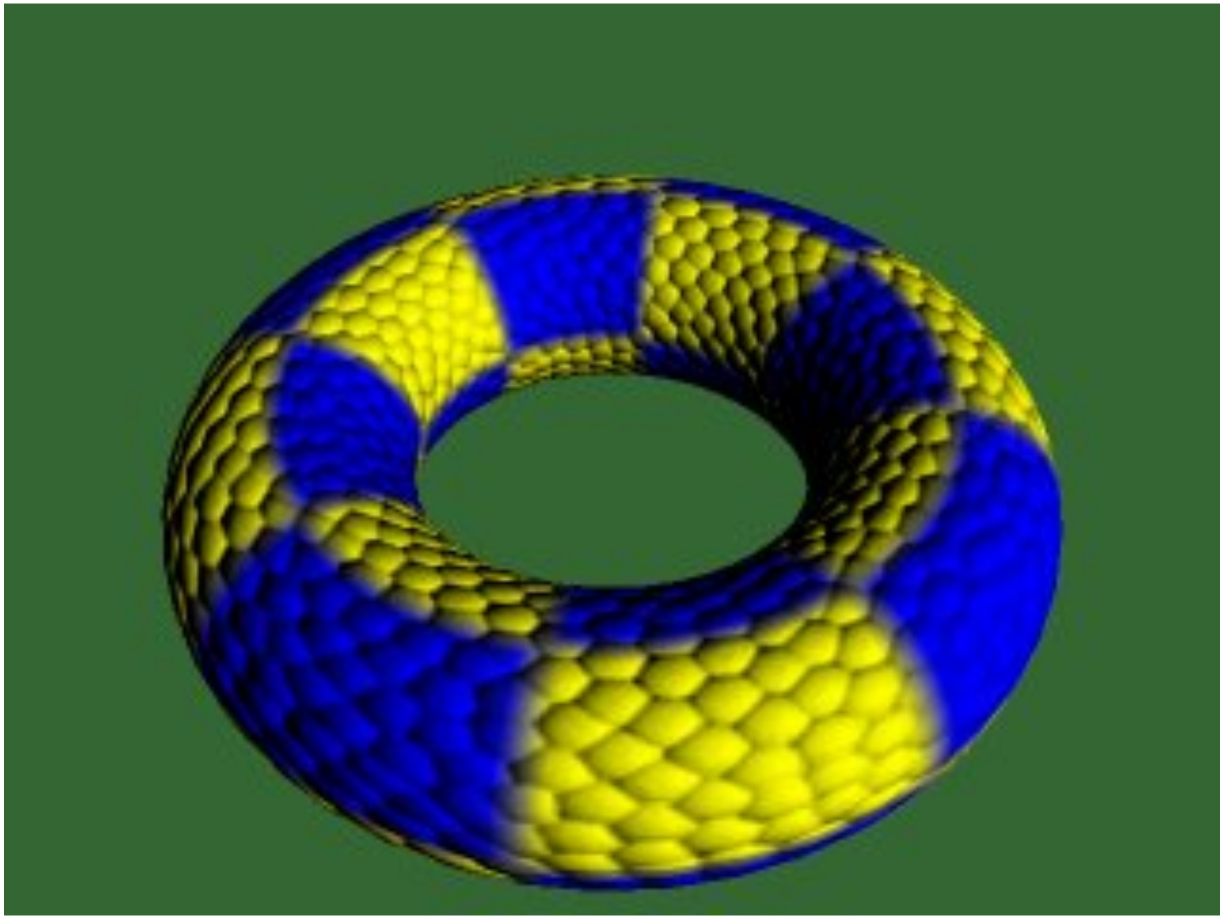
Bump Mapping

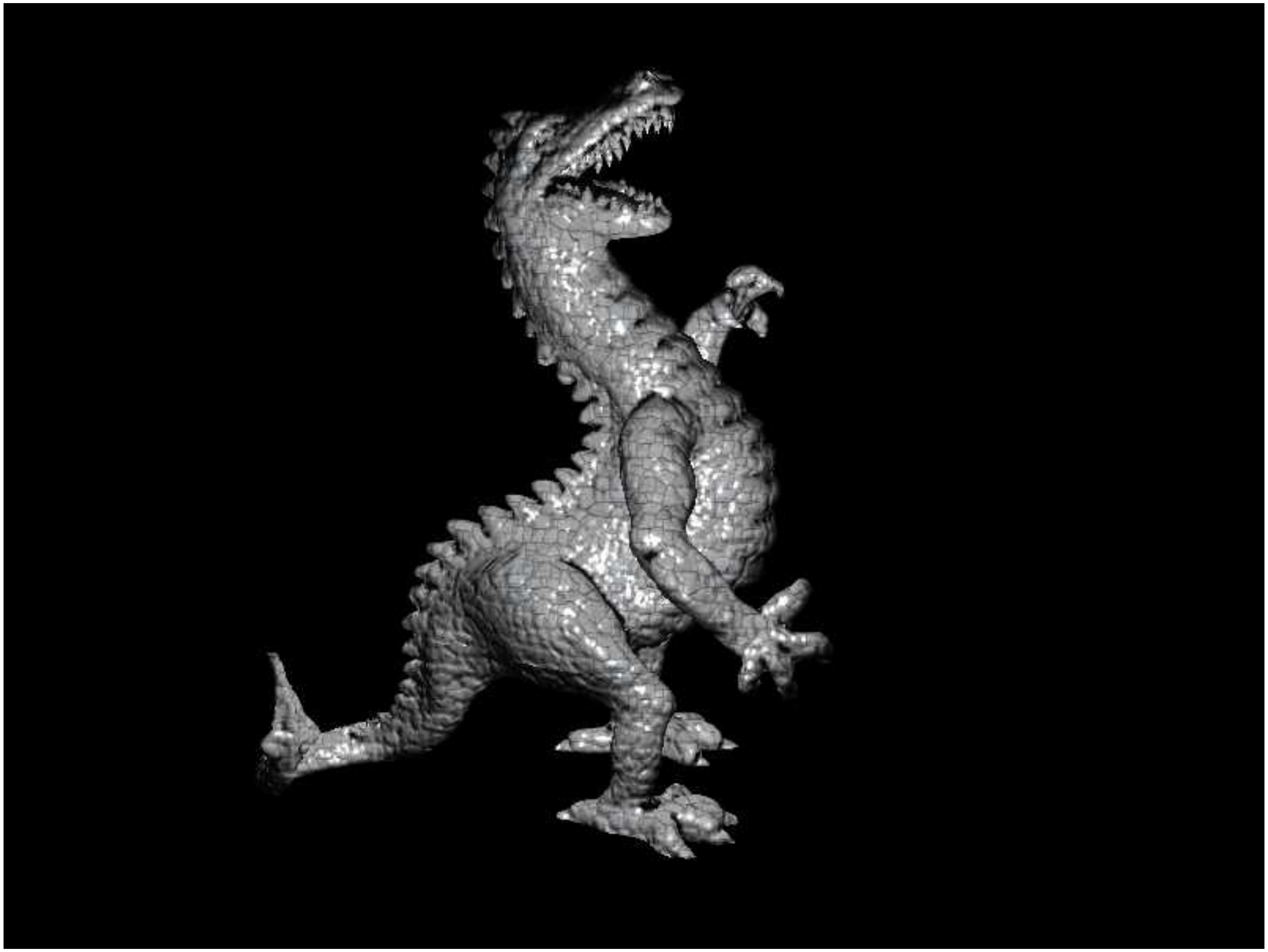
- Many textures are the result of small perturbations in the surface geometry
- Modeling these perturbations would result in an explosion in the number of geometric primitives
- Bump mapping is a cheap way to alter the lighting across a polygon to provide the illusion of surface displacement
- The algorithm is applied at the fragment level

Bump Mapping

- Example

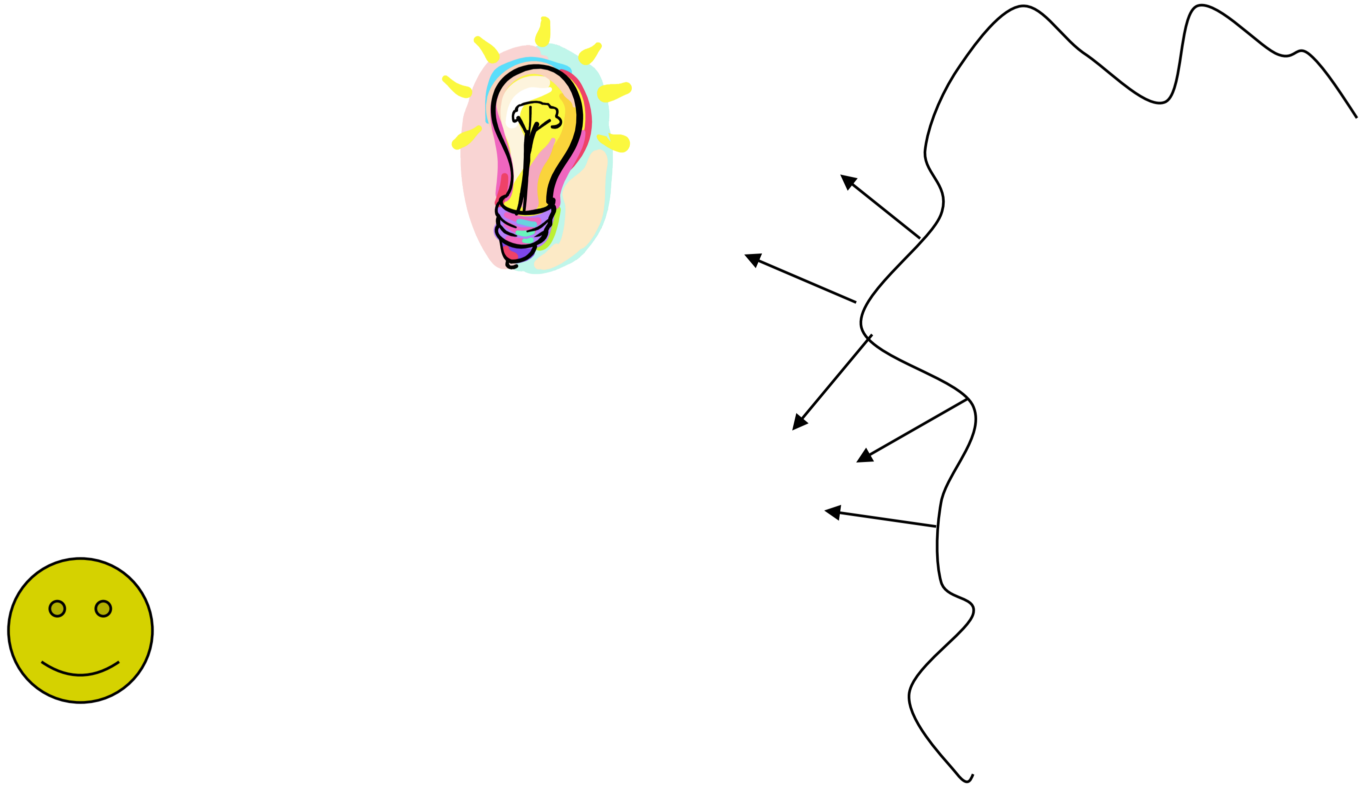


Bump Mapping



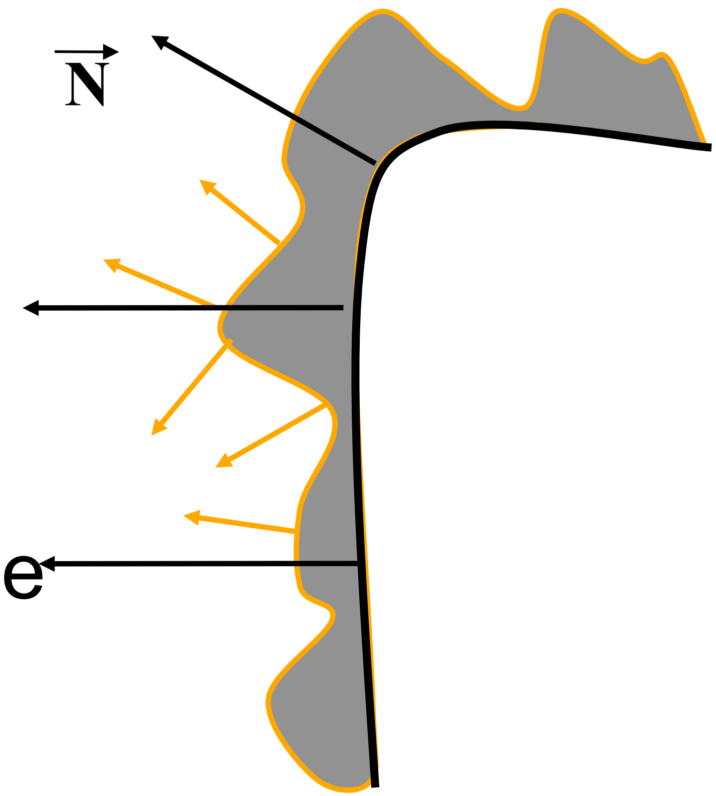
Basic Idea

- Consider the lighting for a bumpy surface.



Basic Idea

- We can model a bumpy surface as deviations from a base surface.
- The question is then how these deviations change the lighting.
- Remember we do not want to create the actual geometry

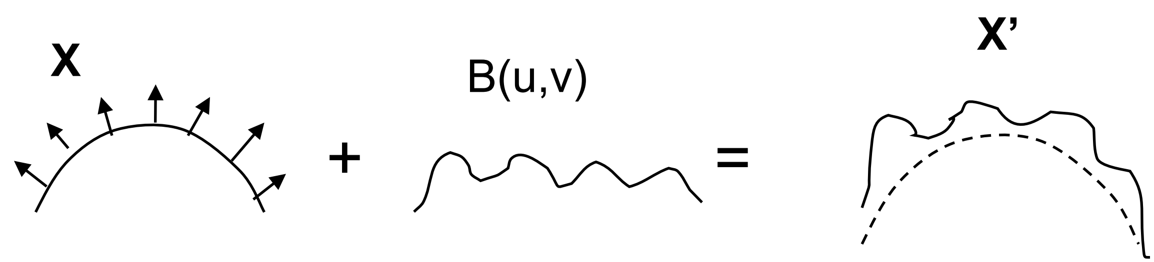


Surface Displacement

- Bumps: small deviations along the normal direction from the surface.

$$\vec{\mathbf{X}}' = \vec{\mathbf{X}} + B\,\vec{\mathbf{N}}$$

Where B is the amount of surface displacement, defined as a 2D function parameterized over the surface:

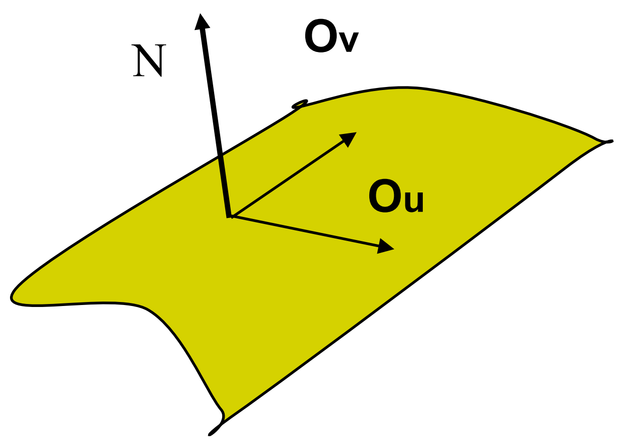


Surface Parameterization

- B(u,v) is the displacement in a 2D parameterized surface at the point (u,v) along the normal direction
- Surface parameterization: (x,y,z) <-> (u,v)
  - We can get the surface point (x,y,z) from the parameterization: x(u,v), y(u,v), z(u,v), or **O**(u,v) (**O** = (x,y,z))
  - The transformation between (x,y,z) and (u,v) is given in parametric surfaces, but can be also derived for other analytical surfaces.
- (u,v) can be seen as the texture coordinates
- Assuming such a parameterization already exists, let's see how to calculate the new normal given B(u,v)

The Original Normal

- Define the tangent plane to the surface at a point (u,v) by using the two vectors O_u and O_v, resulting from the partial derivatives.
- Analytic derivatives or, you can compute them using central difference:
  - $O_u = (\mathbf{O}(u+1,v) - \mathbf{O}(u-1,v)) /2$
  - $O_u = (\mathbf{O}(u,v+1) - \mathbf{O}(u,v-1)) /2$
- The normal at **O** is then given by:
  - $\mathbf{N} = \mathbf{O}_u \times \mathbf{O}_v$



The New Normal

- The new surface positions are given by:
  - $\mathbf{O}'(u,v) = \mathbf{O}(u,v) + B(u,v)\,\mathbf{N}$
  - **Where, N = N / |N|**
- We need to get the new normal after the displacement. Differentiating of O'(u,v) leads to:
  - $\mathbf{O}'_{\mathbf{u}} = \mathbf{O}_{\mathbf{u}} + B_u\,\mathbf{N} + B\,\mathbf{N}_u \quad \approx \mathbf{O}'_{\mathbf{u}} = \mathbf{O}_{\mathbf{u}} + B_u\,\mathbf{N}$
  - $\mathbf{O}'_{\mathbf{v}} = \mathbf{O}_{\mathbf{v}} + B_v\,\mathbf{N} + B\,\mathbf{N}_v \quad \approx \mathbf{O}'_{\mathbf{v}} = \mathbf{O}_{\mathbf{v}} + B_v\,\mathbf{N}$

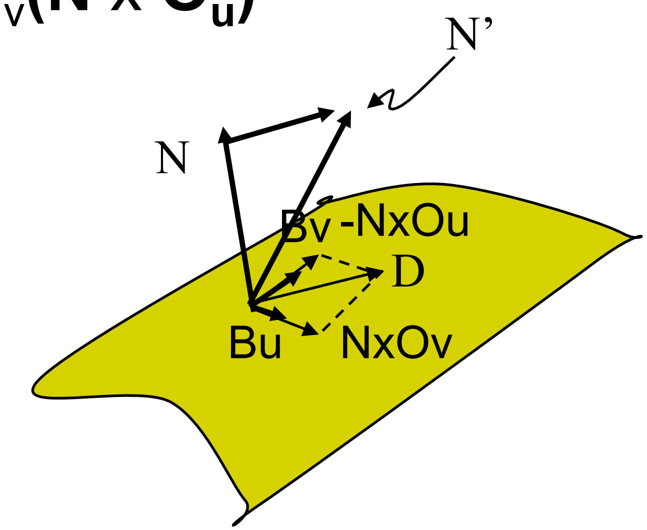
If B is small.

Bump Mapping

- This leads to a new normal:
  - $\mathbf{N'}(u,v) = \mathbf{O_u} \times \mathbf{O_v} + B_u(\mathbf{N} \times \mathbf{O_v}) - B_v(\mathbf{N} \times \mathbf{O_u})$
    $+ B_u B_v(\mathbf{N} \times \mathbf{N})$

    $= \mathbf{N} + B_u(\mathbf{N} \times \mathbf{O_v}) - B_v(\mathbf{N} \times \mathbf{O_u})$

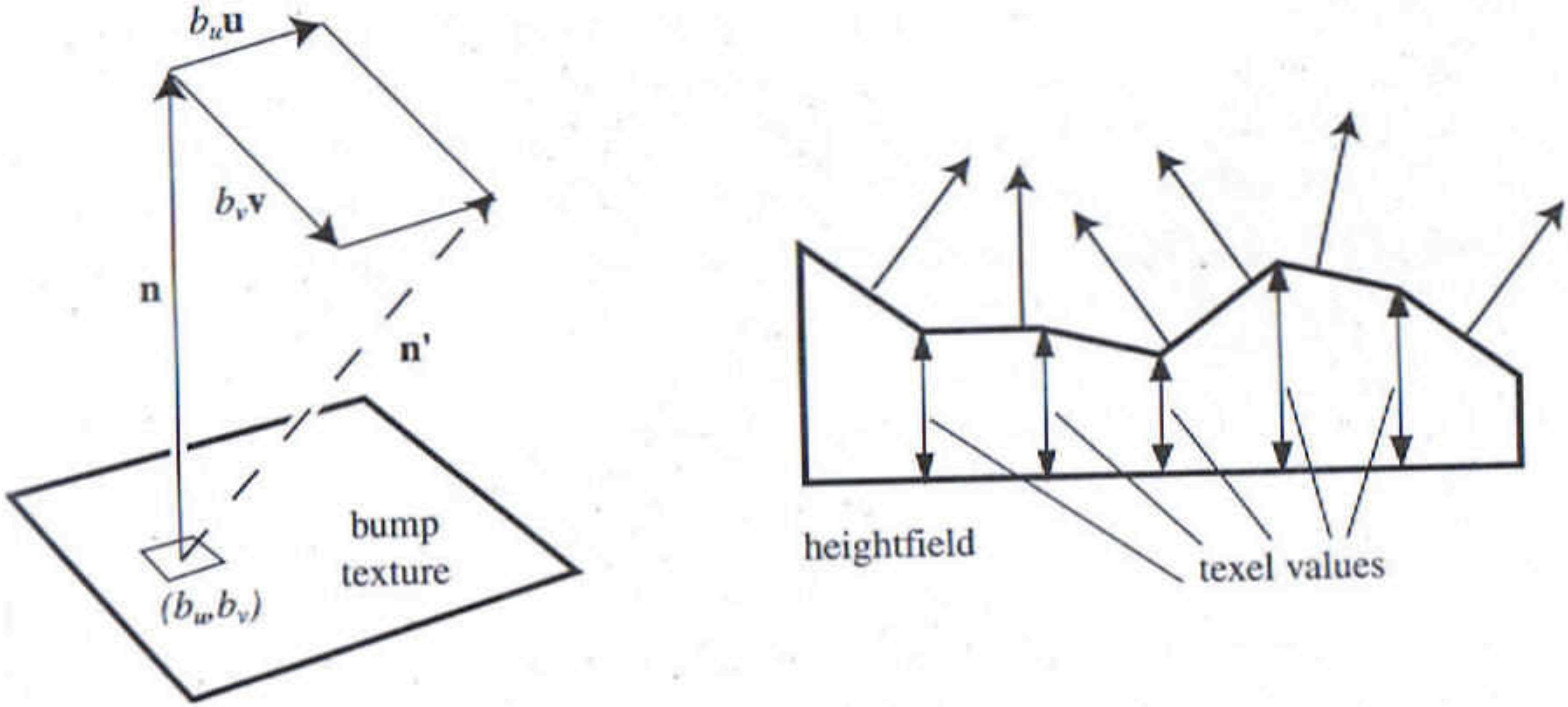
    $= \mathbf{N} + \mathbf{D}$



Bump Mapping Representation

- For efficiency, we can store B_u and B_v in a 2-component texture map.
  - This is commonly called a *offset vector* map.
  - Note: Bu and Bv are oriented in tangent-space
- B_u and B_v are used to modify the normal N
- Another way is to represent the bump as a high field
  - The high field can be used to derive Bu and Bv (using central difference)
- See Figure in the next page

Bump Map Representation



Bump Mapping Representation

- An alternative representation of bump maps can be viewed as a *rotation* of the normal.
- The rotation axis is the cross-product of N and N'.

$$\vec{A} = \vec{N} \otimes \vec{N}' = \vec{N} \otimes \left(\vec{N} + \vec{D}\right) = \vec{N} \otimes \vec{D}$$

Bump Mapping Representation

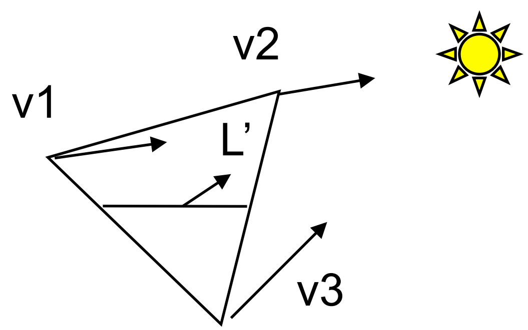
- In sum, we can store:
  - The height displacement
  - The offset vectors in tangent space
  - The rotations in tangent space
    - Matrices
    - Quaternians
    - Euler angles

Bump Mapping in Graphics Hardware

- The primary method for modern graphics hardware (also called dot product bump mapping)
- The bump map texture stores the actual normals to be used for bump mapping for the surface (defined in the fragment's tangent space)
- Lighting for every fragment is calculated by eavulating N.L (for diffuse) and (N.H)^8 (for specular)

Dot3 Bump Mapping

- The lighting is calculated in the tangent space – we need to transform the light vector of very vertex to the vertex’s tangent space
- The light vector for each fragment is obtained by interpolation using graphics hardware (pass the light vector as the vertex color)

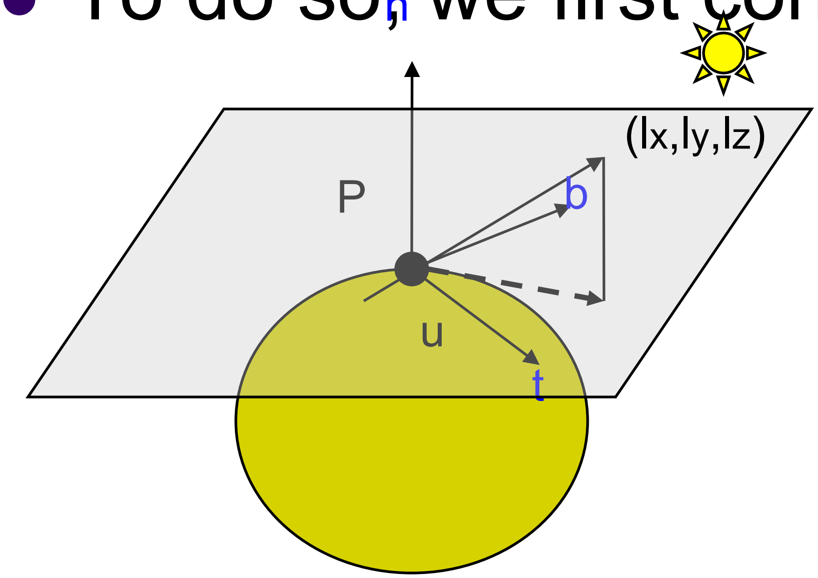


L’ = lerp (L at V1, L at V2, L at V3)

** Remember L’ has to be normalized for lighting calculation – how?

Light Vector in Tangent Space

- Transform the light vector to the tangent plane of the surface point – remember different surface point has different tangent plane
- To do so, we first construct a tangent space



- t is the tangent vector follows the texture parameter u direction
- n is the surface normal
- b is another tangent vector perpendicular to t and n (b = n x t)

Then t, n, b form a coordinate frame for the point P – called tangent space

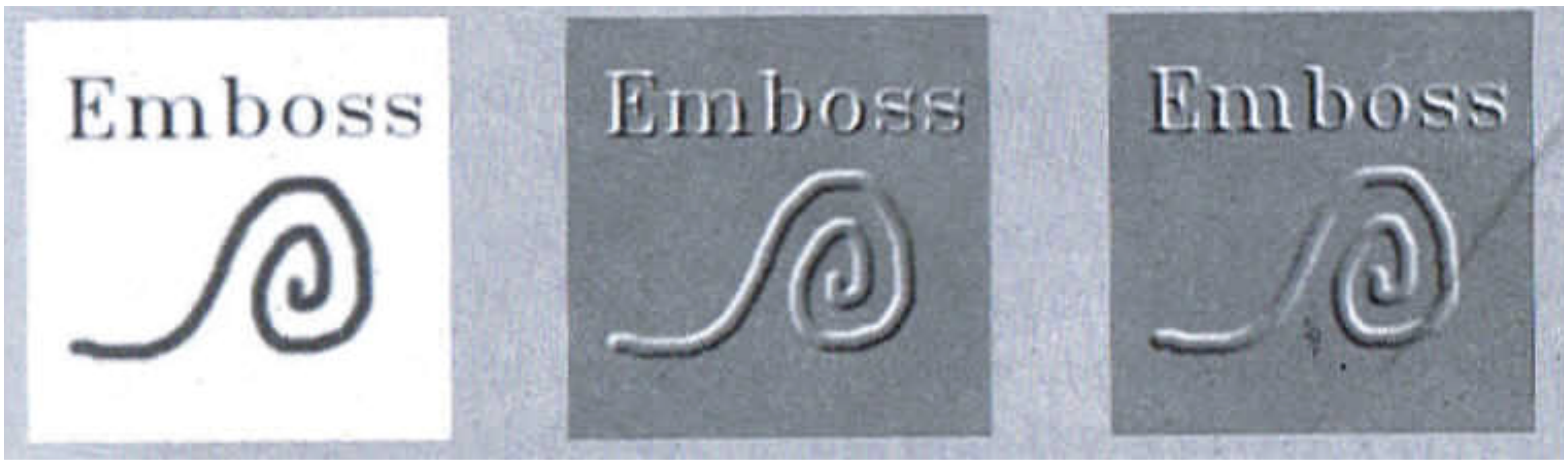
Shifting (u,v) in the light direction? (II)

- After we know t, b, n (the basis vector of the tangent space), we can transform the light vector to the tangent space using the transformation matrix M : (lx', ly', lz',0) = M * (lx,ly,lz,0)

$$M = \begin{vmatrix} tx & ty & tz & 0 \\ bx & by & bz & 0 \\ nx & ny & nz & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Emboss Bump Mapping

- A cheap bump mapping implementation (but not really bump mapping)
- Image embossing – shift to the light and then subtract

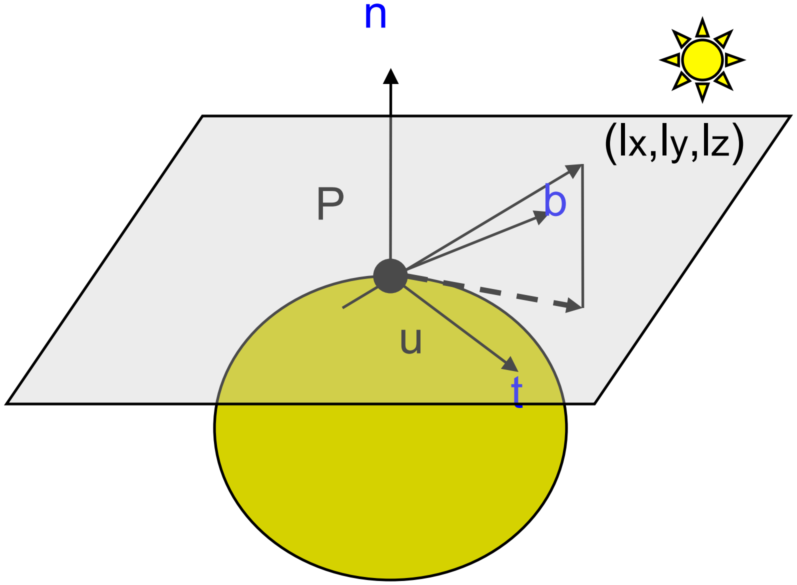


Emboss Bump Mapping

- The same idea can be applied to 3D surfaces
- Basic idea: Apply the input texture to the surface twice
  - First pass – use the input texture as before
  - Second pass – shift the texture coordinates of each vertex in the direction of light, render it, and then subtracting it from the result of the first pass
  - Then you can render the surface using regular lighting and add it to the result

Shifting (u,v) in the light direction?

- Project the light to the tangent plane of the surface point – remember different surface point has different tangent plane
- To do so, we first construct a tangent space



- t is the tangent vector follows the texture parameter u direction
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Then t, n, b form a coordinate frame for the point P – called tangent space

Shifting (u,v) in the light direction? (II)

- After we know t, b, n (the basis axes of the tangent space), we can transform light to the tangent space using the transformation matrix M : (lx', ly', lz',0) = M * (lx,ly,lz,0)

$$M = \begin{vmatrix} tx & ty & tz & 0 \\ bx & by & bz & 0 \\ nx & ny & nz & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

- Normalize (lx', ly') and then multiple both by 1/r (texture resolution), Add these two numbers to the texture coordinate (u, v) – done.