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CS300
Bump Mapping & Normal Mapping

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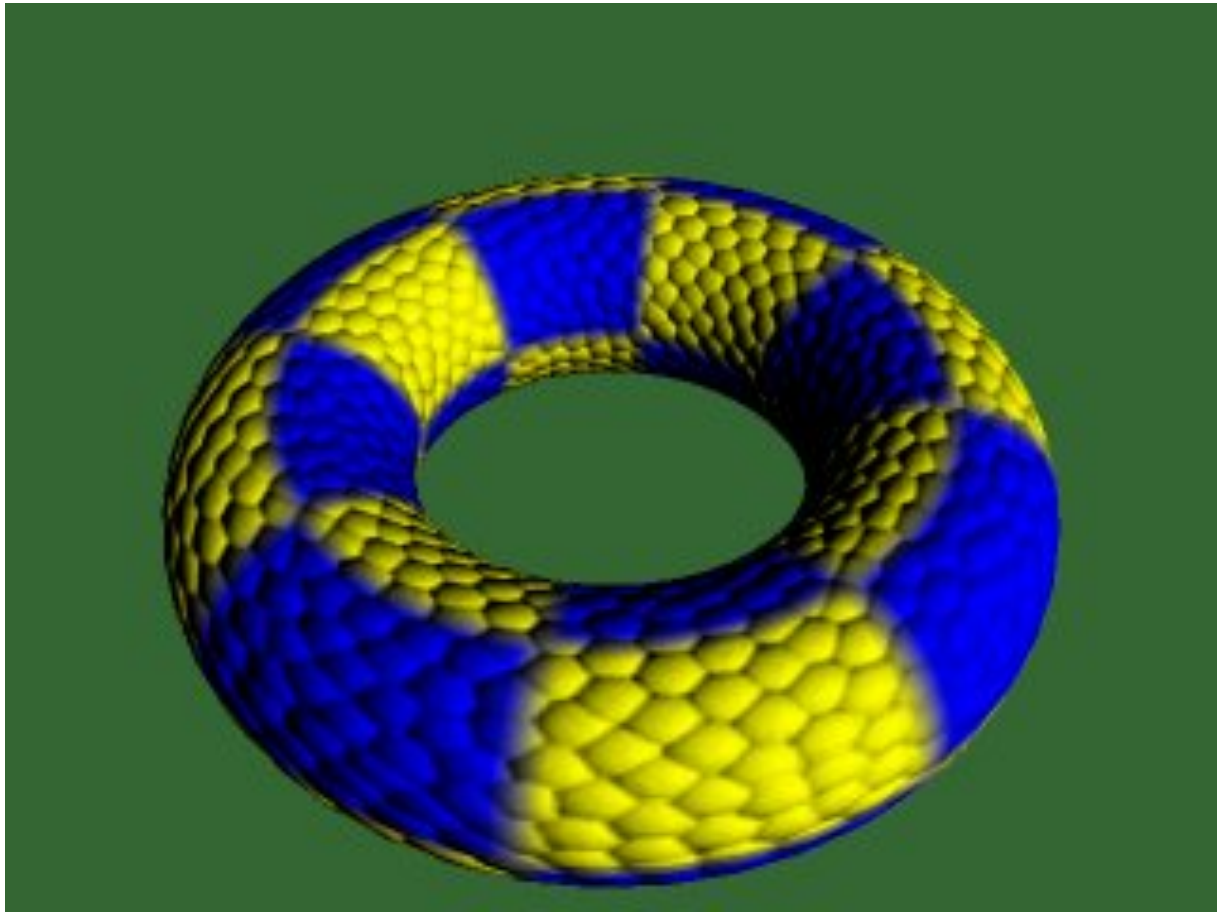
Bump Mapping



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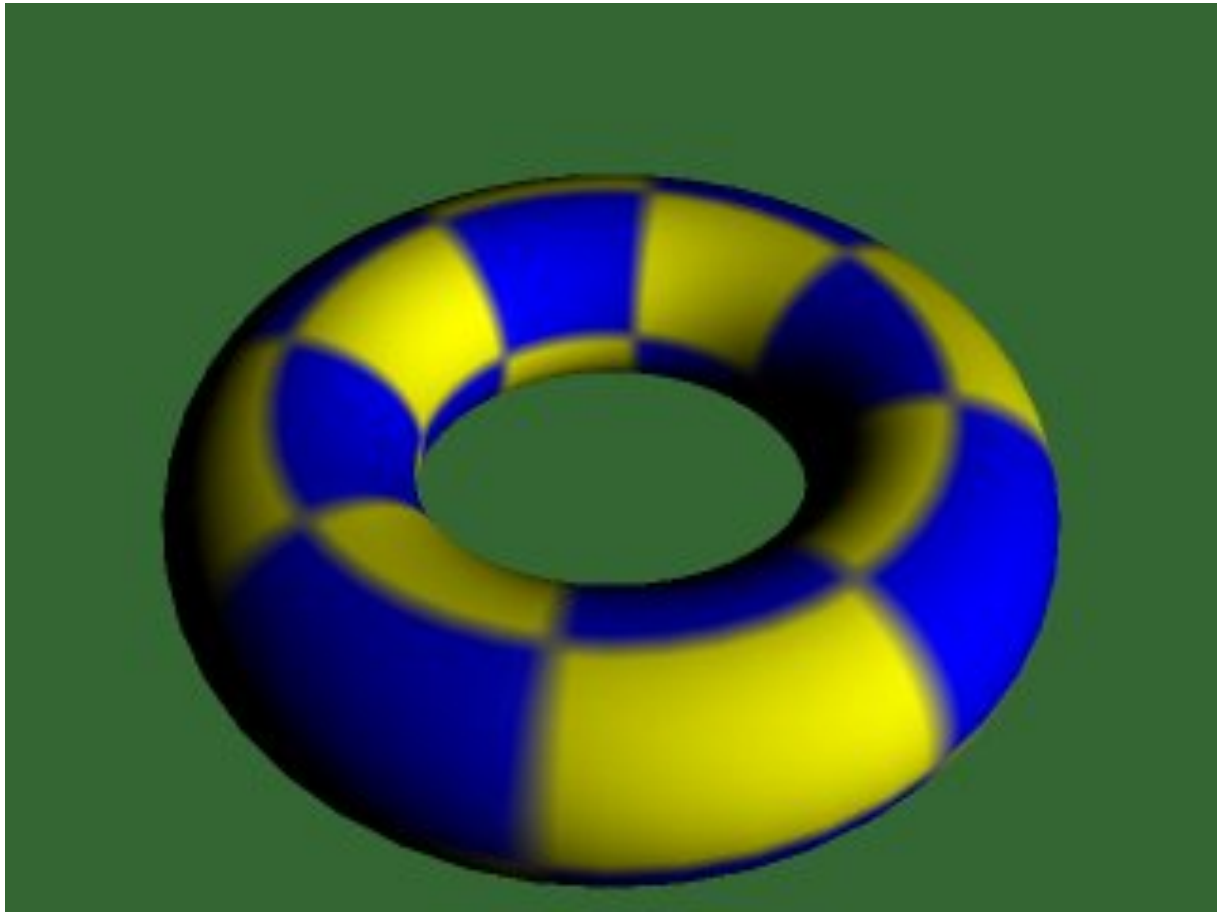
Bump Mapping



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Bump Mapping

- Bump mapping is a technique developed by James Blinn (1978)
  - "Simulation of wrinkled surfaces," SIGGRAPH 1978
- The method allows a surface to appear wrinkled or dimpled without the need to model these depressions geometrically.
- To achieve this effect, the surface normal at every pixel is modified according to the information supplied in a height map.

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Bump Mapping *(cont'd)*

- Key Idea
  - Surface variations **do not exist in the model**, causing the illusion to break around the silhouette of objects.

- At these edges the viewer notices that there are no real bumps but just smooth outlines.

- Good to use when the bump is 'small' relative the surface size.

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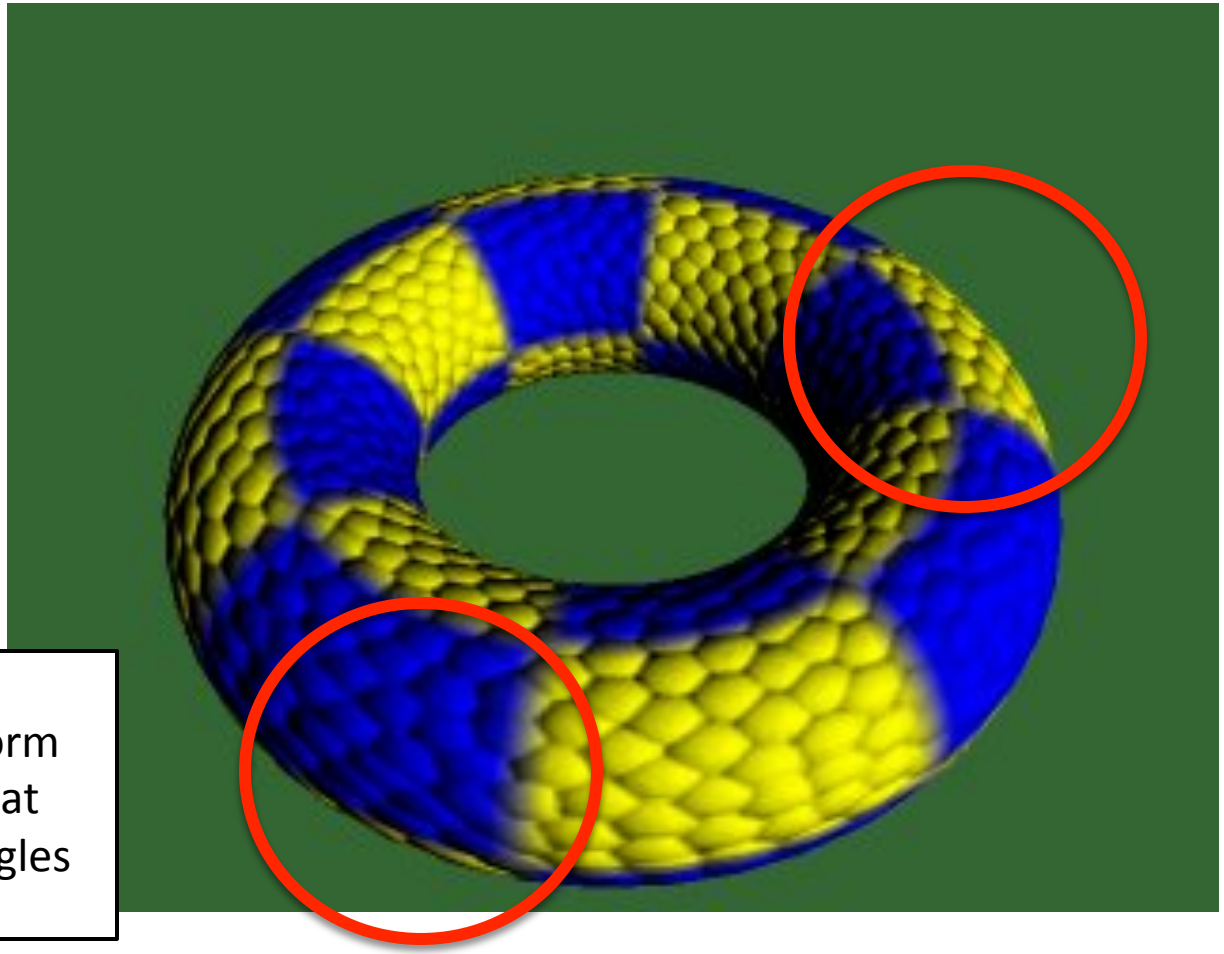
Bump Mapping



Smooth Silhouette

Non-uniform features at grazing angles

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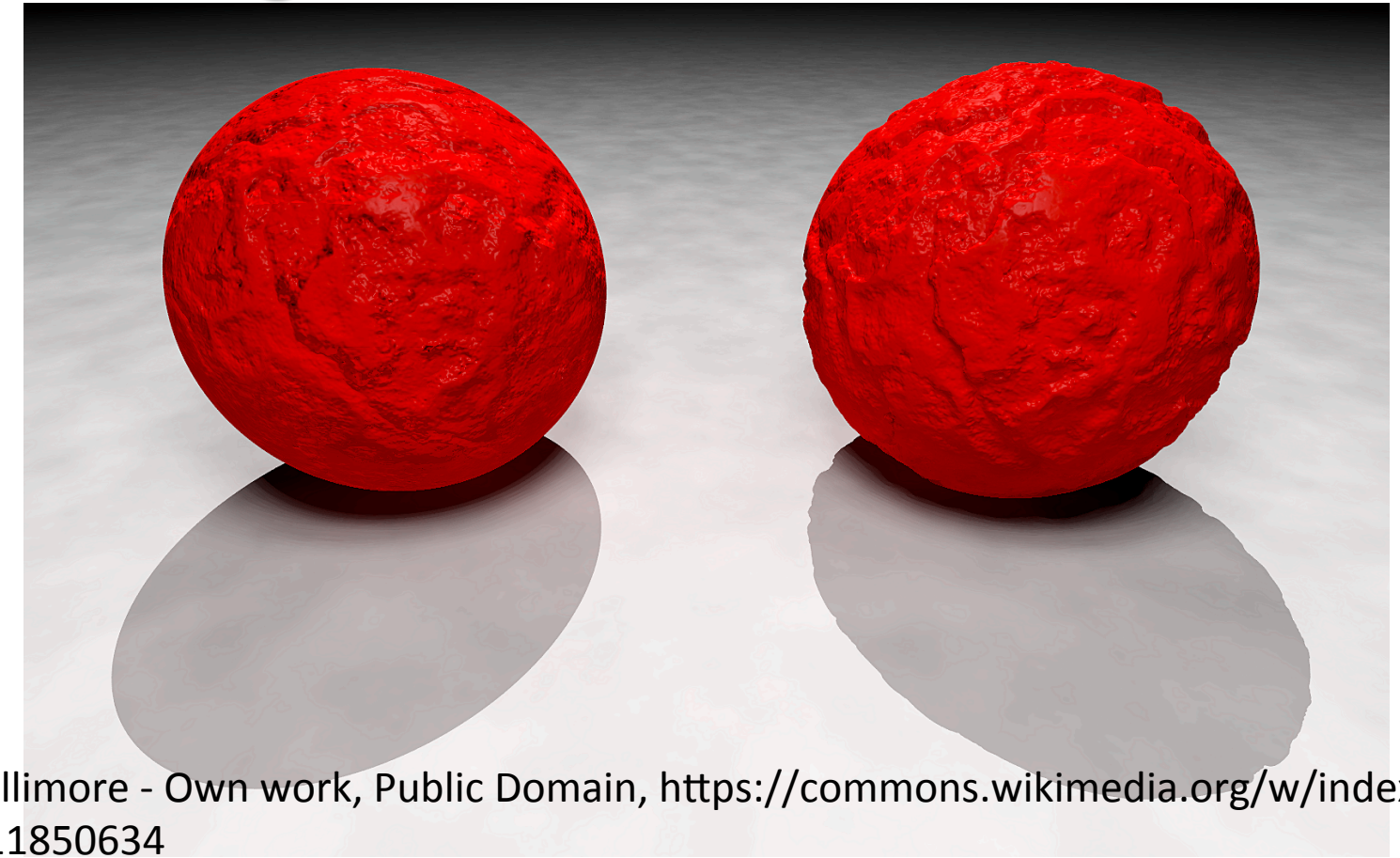
Bump Mapping Vs Volume-based Rendering



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OpenGL Lighting Model

- What components of the light model determine the color at a point on the surface?
  - Light vector (position of the light)
  - Surface normal (local surface features)
- We trick the user by manipulating the lighting model components
  - Which one can we (reliably, consistently & efficiently) change?

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Bump Mapping Calculations

- What do we need?
  - Light position (defined per scene - uniform)
  - Surface normal (defined per vertex – attribute/out)
  - View vector (defined per fragment - out)

- Let us try the naïve approach
  - Change the normal in the fragment shader
  - Use this normal in the lighting equation

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Lighting Model Redux

- Phong lighting model relies on dot products to simulate illumination distribution across a surface
- Our vectors are all in the same space when we compute the fragment color (Eye space)

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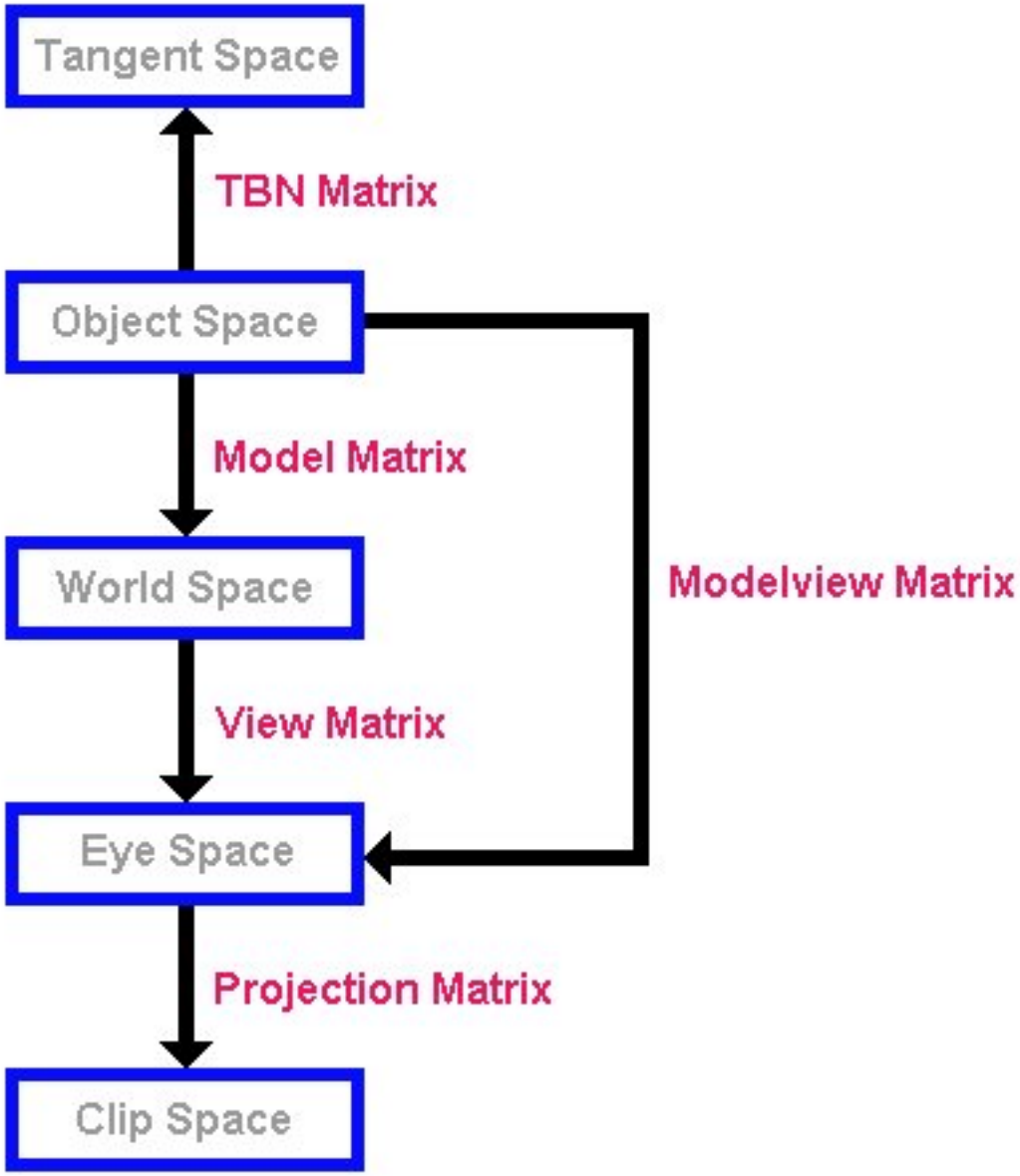

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Tangent Space

- Is uniquely defined for EVERY POINT on the surface
- Is represented by 3 axes in 3D
  - Similar to X, Y and Z axes in Object Space
- Simpler interpretation
  - Z = N, the normal (the outward direction)
- What about the corresponding “X” and “Y” axes?

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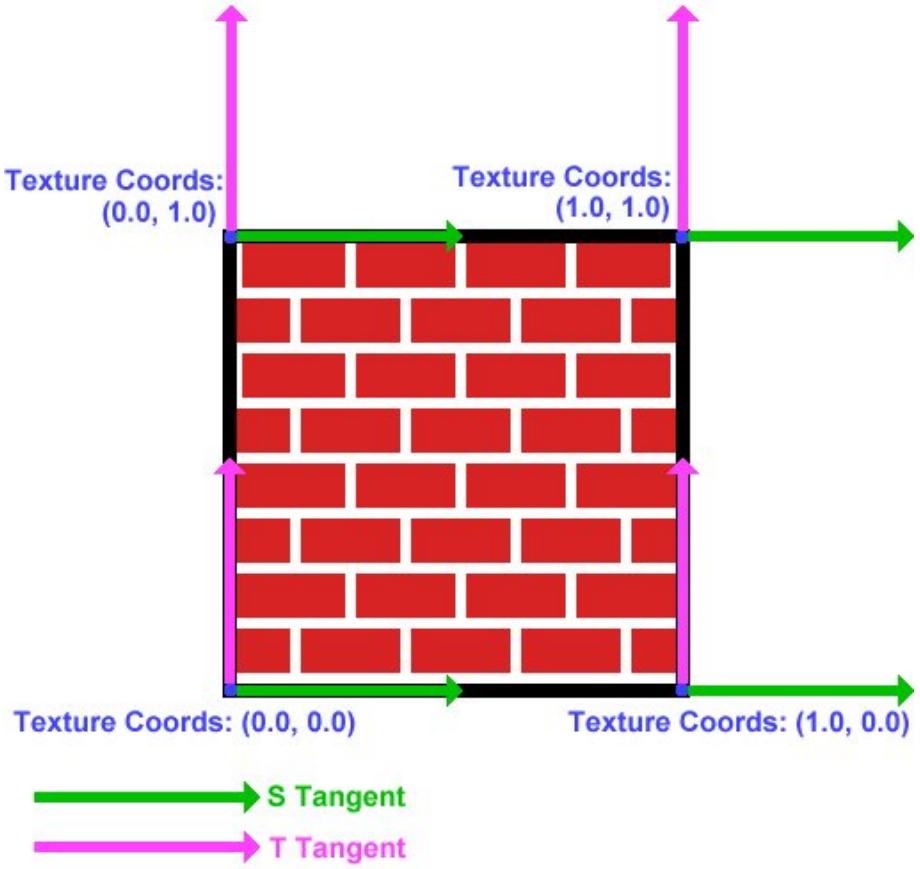
Tangent Space Representation



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Calculating lighting equation in Tangent Space

- Convert the Light vector (L) and View direction (V) to the tangent space
- Apply the transformations to the normal
  - Or lookup a new value for the normal
- Perform the lighting calculations with the new normal

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Transforming L into the TBN space

$$\begin{bmatrix} L'x \\ L'y \\ L'z \end{bmatrix} = \begin{bmatrix} Sx & Sy & Sz \\ Tx & Ty & Tz \\ Nx & Ny & Nz \end{bmatrix} \begin{bmatrix} Lx \\ Ly \\ Lz \end{bmatrix}$$

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Bump Mapping *(cont'd)*

- The technique converts a two-dimensional height field B(u, v), called the bump map, which represents some desired surface displacements, into appropriate perturbations of the local surface normal.

- When this surface normal is used in the shading equation, the reflected light calculations vary as if the surface had been displaced.

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Bump Mapping *(cont'd)*

- Consider a point P(u, v) on a parameterized surface, we define the surface normal at the point to be

$$N = \frac{\partial P}{\partial u} \times \frac{\partial P}{\partial v} \qquad N = P_u \times P_v$$

- Where P_u and P_v are the partial derivatives lying in the tangent plane to the surface at point P(u, v)

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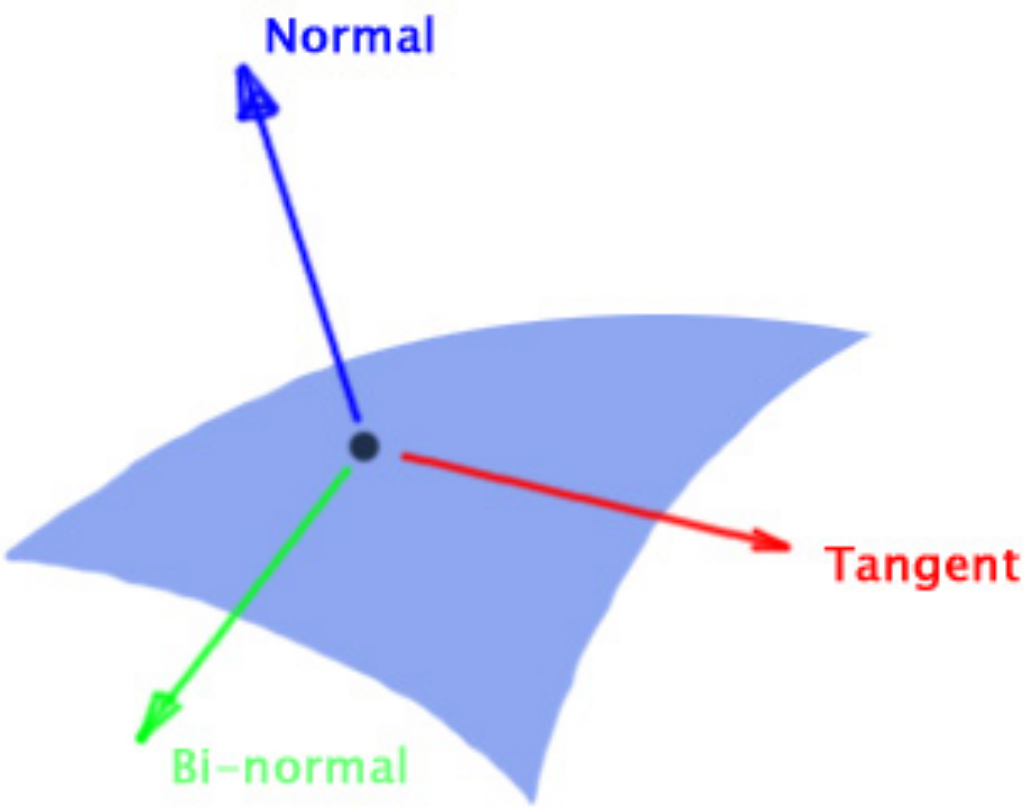
TBN Space



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Bump Mapping *(cont'd)*

- What we want to do is to have the same effect as displacing the point P along the surface normal at that point by an amount B(u, v)

- We get the new surface P' defined by

$$P'(u,v) = P(u,v) + B(u,v)N$$

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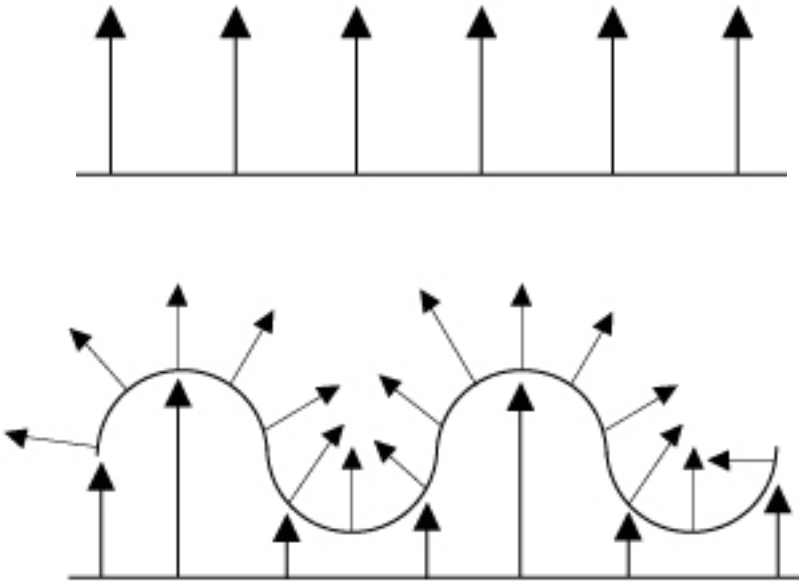
Bump Mapping *(cont'd)*

- The figure below shows a one-dimensional analogue to the process



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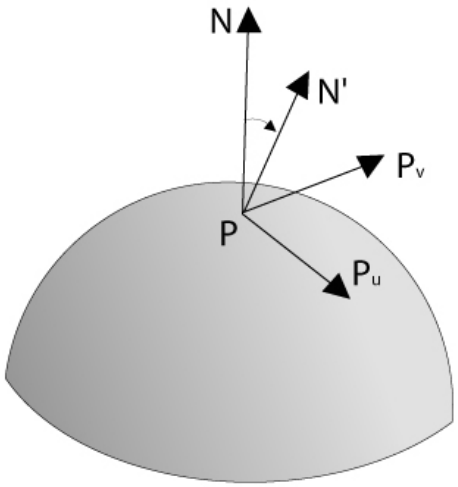
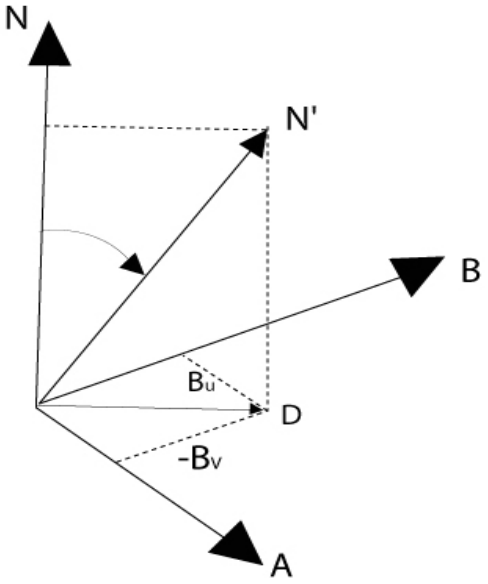
Bump Mapping *(cont'd)*





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Bump Mapping *(cont'd)*

- Now we need to find the new normal N' to the surface P' at every point (u, v) of the surface, this is done as follows

$$N' = P'_u \times P'_v$$

$$P'_u = P_u + B_u N + B(u,v) N_u$$

$$P'_v = P_v + B_v N + B(u,v) N_v$$

- N_u and N_v is assumed to be zero because we assumed that the normal to vary very little on the surface.

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Bump Mapping *(cont'd)*

$$N' = N + B_u N \times P_v + B_v P_u \times N$$

$$N' = N + B_u N \times P_v - B_v N \times P_u$$

$$N' = N + (B_u A - B_v B)$$

$$N' = N + D$$

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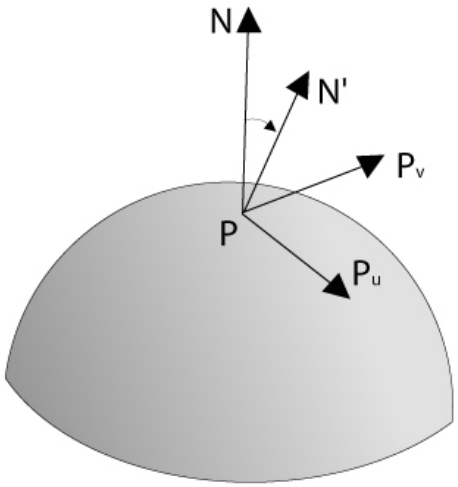
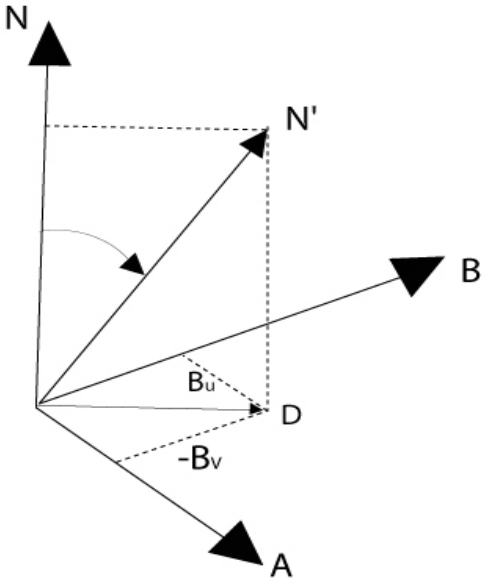
Bump Mapping *(cont'd)*





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Bump Mapping *(cont'd)*

- For every point (u, v) on the surface represented by P, we use the new normal N' in the illumination calculations.

- This will create the bumpy surface we are looking for.

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Normal Mapping

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Normal Mapping

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Normal Mapping

- Normal mapping is just another form of Bump Mapping.
- Instead of storing heights in a bump map, we will store normals in a normal map.
- Depending on how the normals are measured and stored, normal mapping comes in two varieties:
  - Object-space normal mapping
  - Tangent-space normal mapping

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Normal Mapping

I. Constructing normal maps from height maps

II. Constructing normal maps from high polygon models

III. Tangent Space

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Constructing normal maps from height maps

- Given a height map H(i,j), where H represents the height at any pixel (i, j), a normal map can be derived by considering the tangents or partial derivatives in the u and v directions.

- The normal to the pixel is formed by taking the vector resulting from the cross product of the two tangents.

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Constructing normal maps from height maps *(cont'd)*

- First we need to find the two tangents at any pixel (i, j).
- Let S(i, j) be the tangent in the u direction and T(i, j) be the tangent in the v direction

$$S(i,j) = \langle 1, 0, aH(i+1,j) - aH(i-1,j) \rangle$$

$$T(i,j) = \langle 0, 1, aH(i,j+1) - aH(i,j-1) \rangle$$

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Constructing normal maps from height maps *(cont'd)*

- The constant "a" is a scale factor that can be used to vary the range of the height, making the perturbed normals more or less pronounced.
- To calculate the normal vector N at the point (i, j) we take the cross product of S and T at that point:

$$N(i,j) = \frac{S(i,j) \times T(i,j)}{\| S(i,j) \times T(i,j) \|}$$

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Constructing normal maps from height maps *(cont'd)*

- The normalized vector N needs to be stored within the normal map.
- We know that each components of the vector vary between -1 and 1.
- And the texture (assuming it is an RGB texture with 8-bits per component) can store a number between 0 to 255 per component.
- We need to map the [-1,1] range to [0,255].

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Constructing normal maps from height maps *(cont'd)*

- The equation to map the x coordinate to the red channel:

$$R = 255 * 0.5 * (N_x + 1)$$

- It is customary to store the x coordinate in the red channel, the y coordinate in the green channel and the z coordinate in in blue channel.

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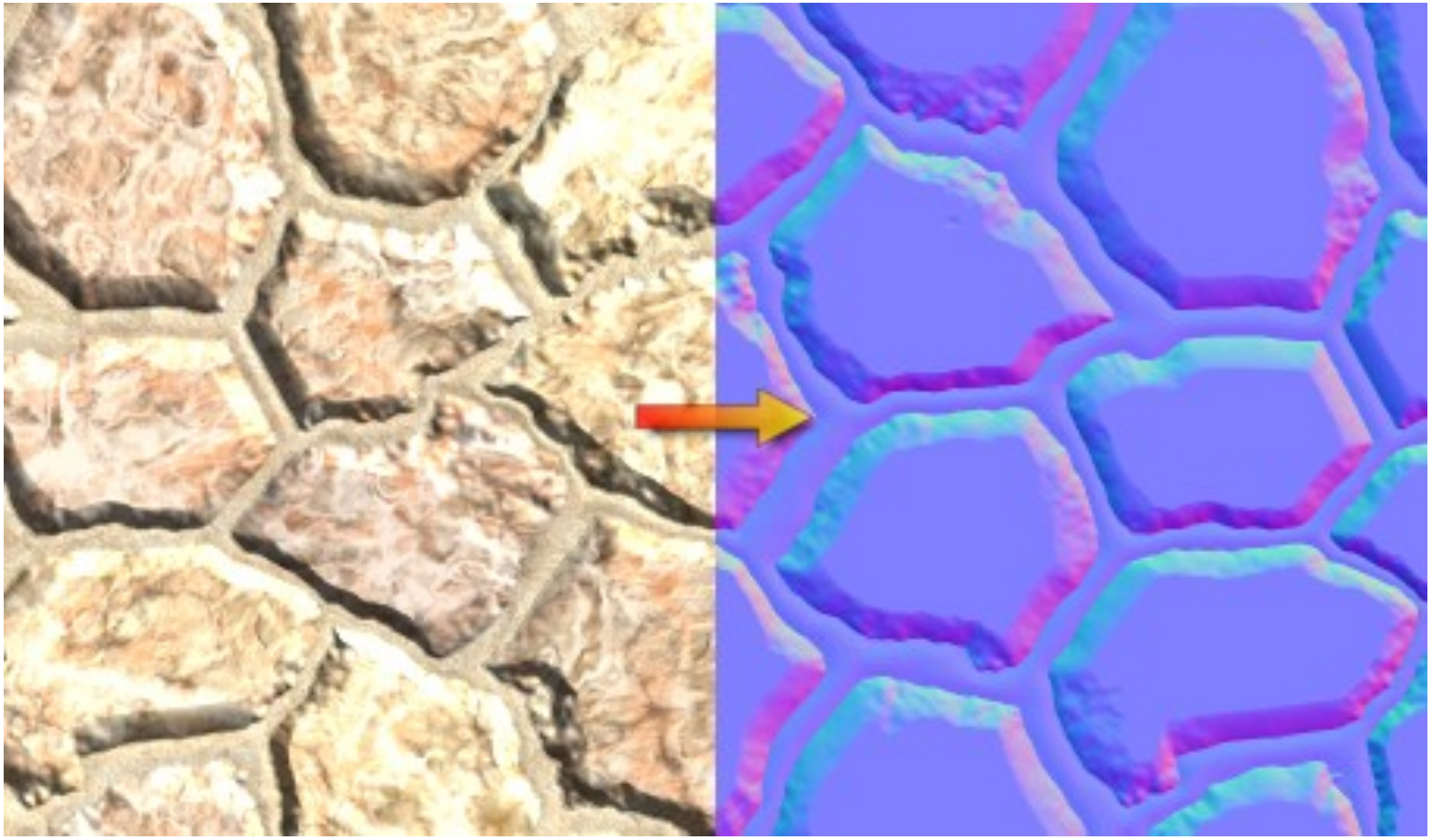
Example Normal Map



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Using Maps to encode surface

Texture
(shading and lighting)

Flat walls

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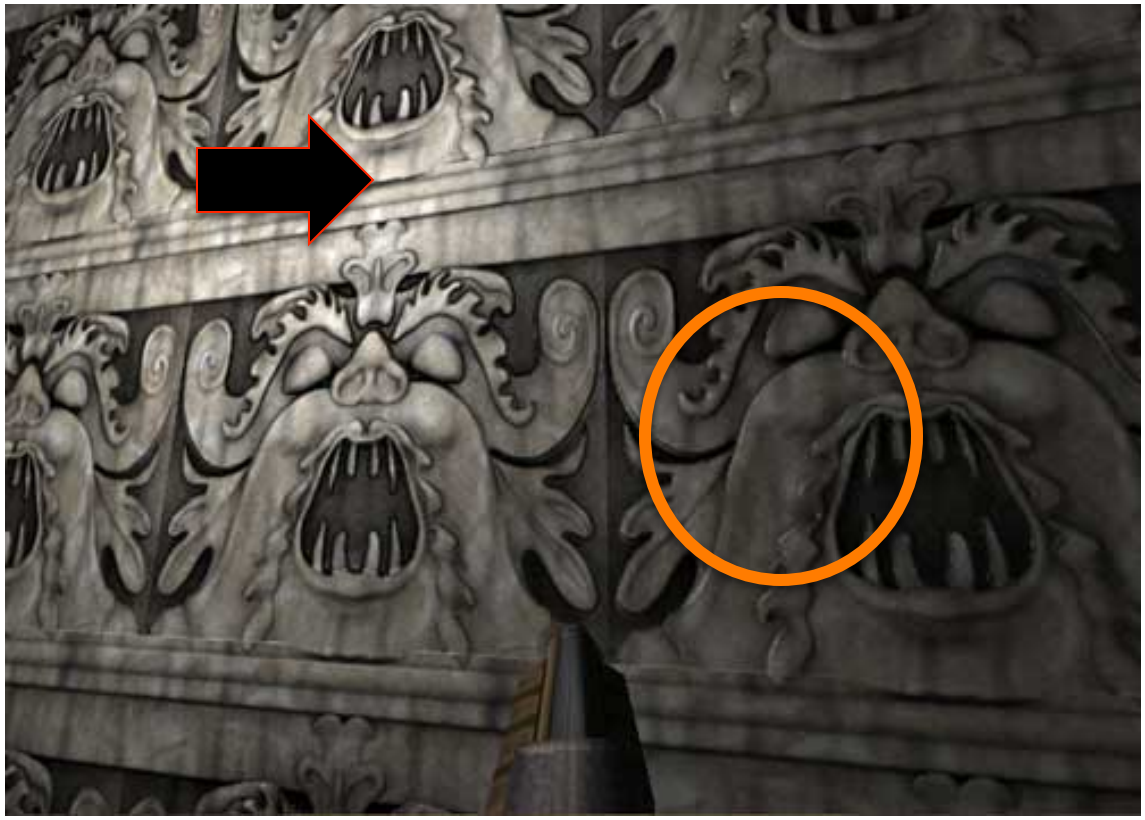
Building Height Maps (Bump Mapping)

Bump Map



Better lighting, but still feels flat

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Normal Map

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Normal Map Dissected

Red

Green

Blue

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Normal Map Vs Bump Map

http://www.zarria.net/nrmphoto/nrmphoto.html

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II. Constructing normal maps from high polygon models

- The goal of normal mapping is to allow low polygon models to appear as though they were more detailed.
- We need to create two versions of the same model, a high polygon version and a low polygon version.

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II. Constructing normal maps from high polygon models *(cont'd)*

- Afterwards, we cast rays from the low polygon version to the high polygon version, and we return the normal that collided with each ray.
- The normals are then mapped from the [-1, 1] range to the [0, 255] range and saved in the normal map.
- The number of rays sent is determined by the size of the normal map, which is usually the same size as the texture map.

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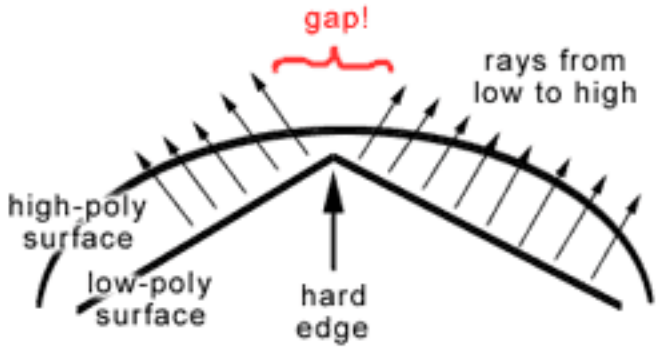
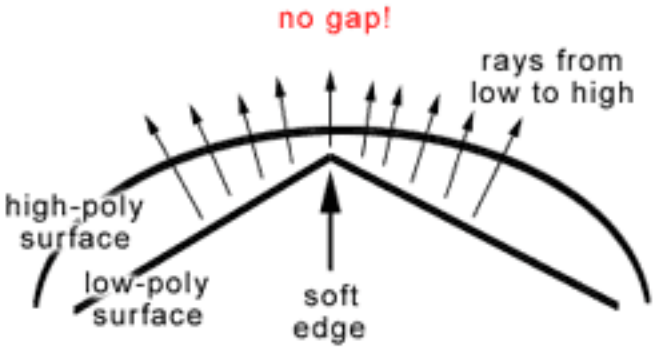
Gotcha!





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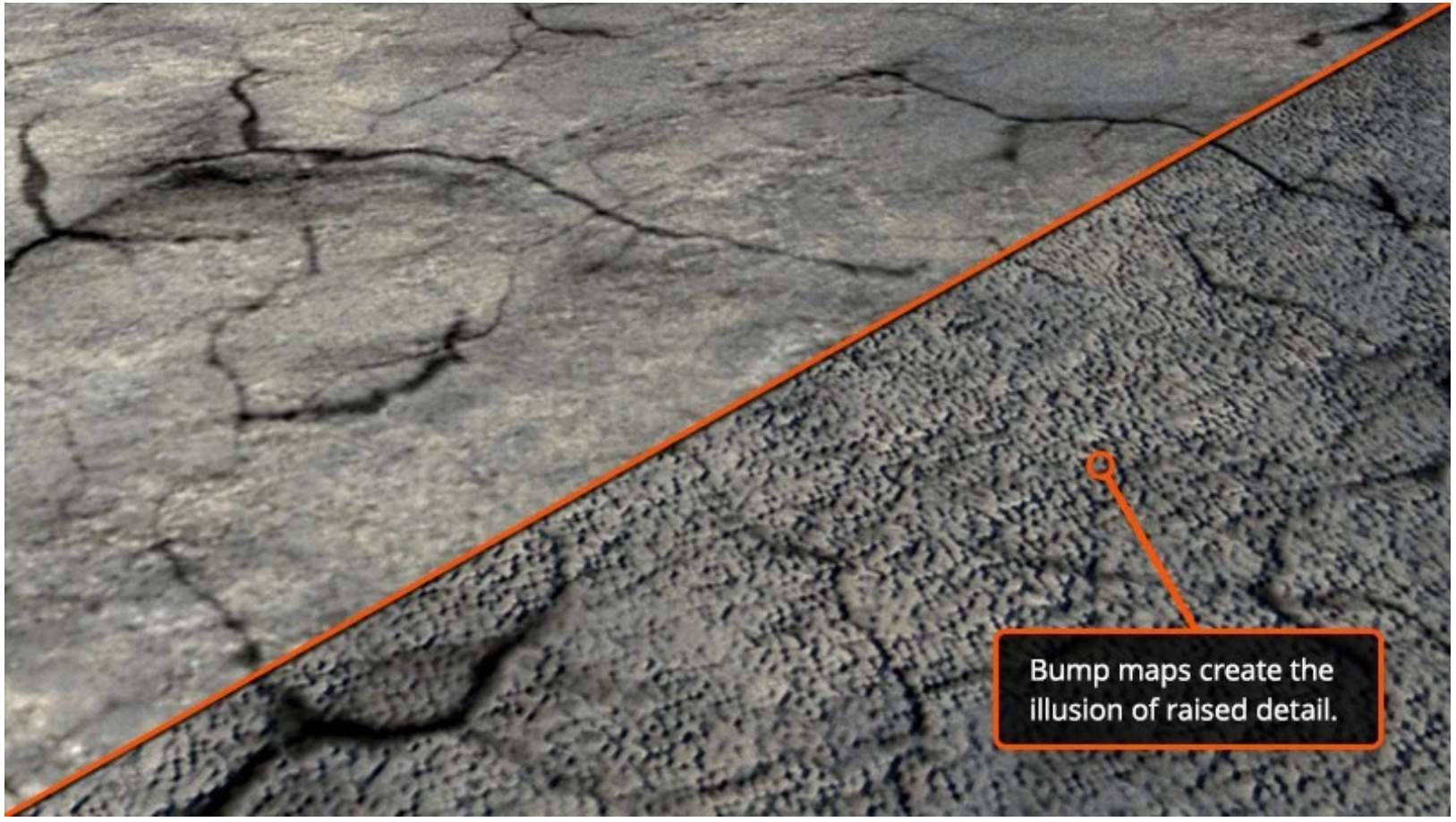
Bump Map (Summary)



http://blog.digitaltutors.com/bump-normal-and-displacement-maps/

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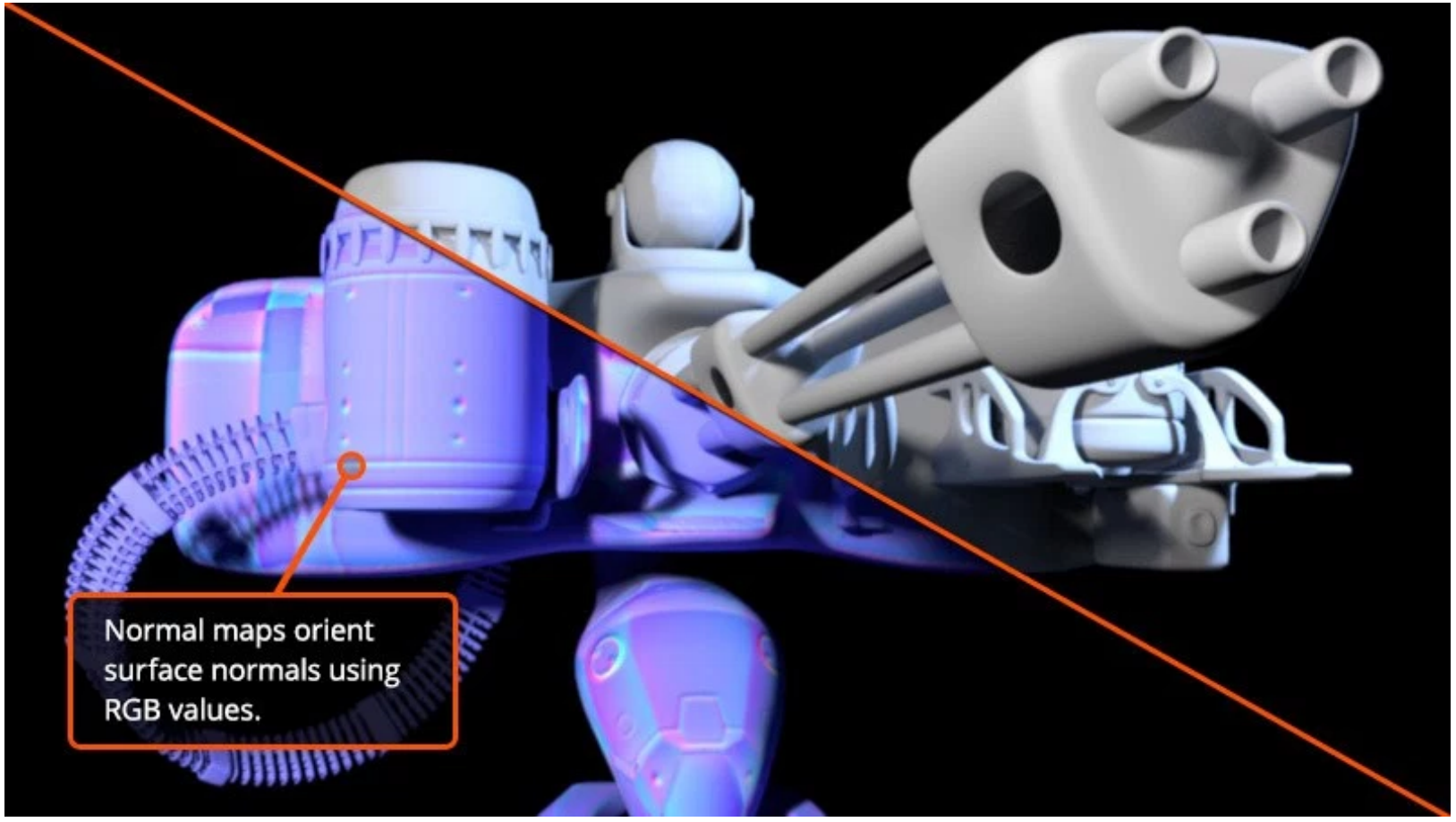
Normal Map (Summary)



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Next step?

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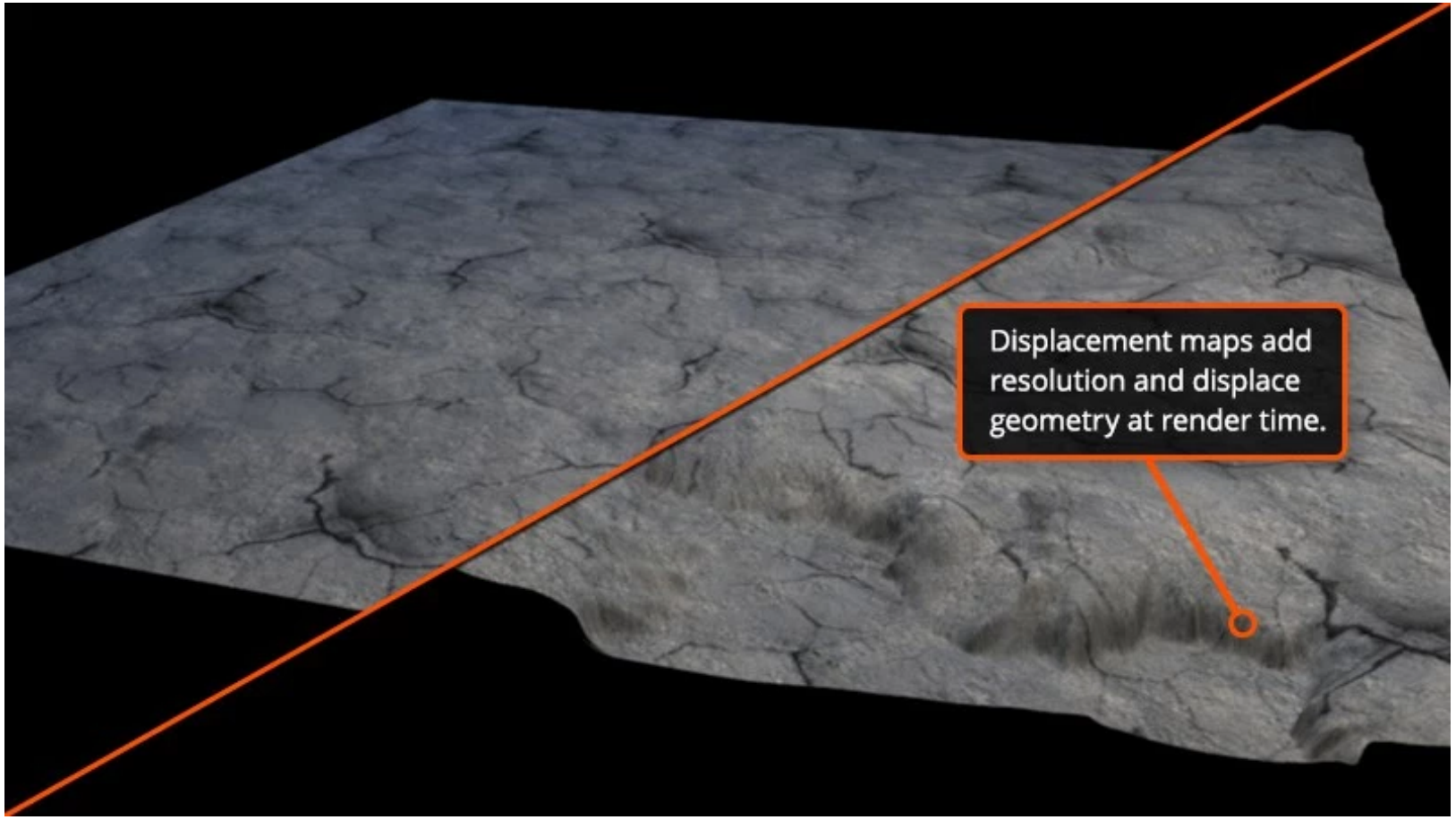
Displacement Maps (no fake geometry)



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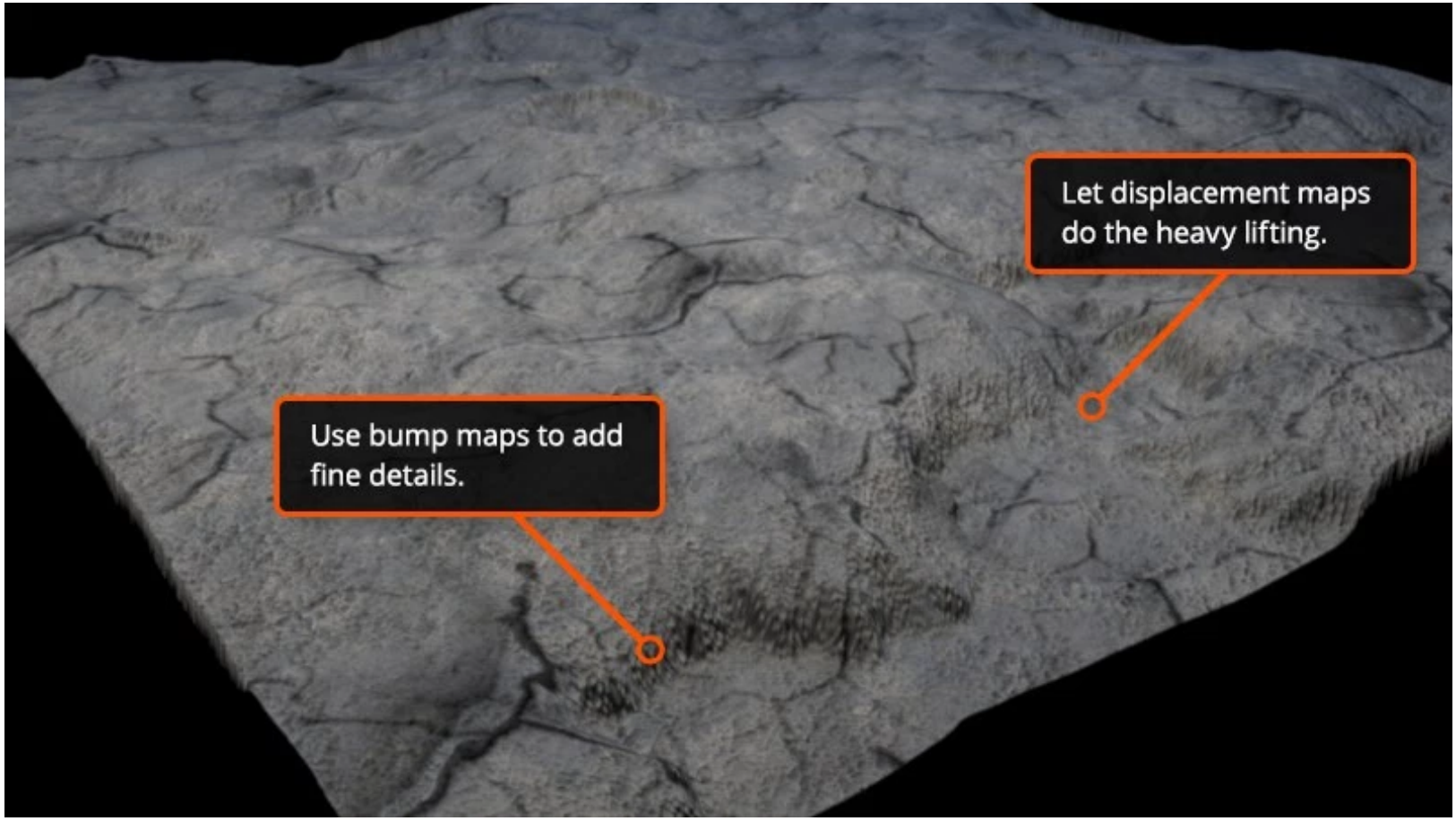
Combining maps for realistic details



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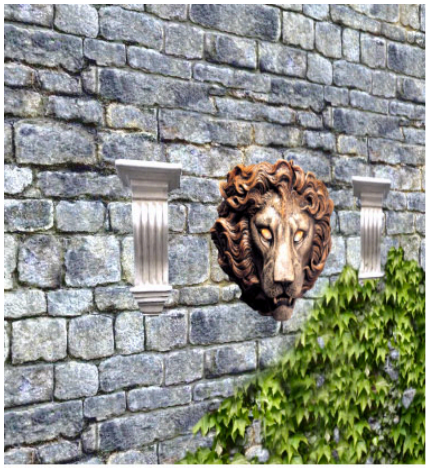
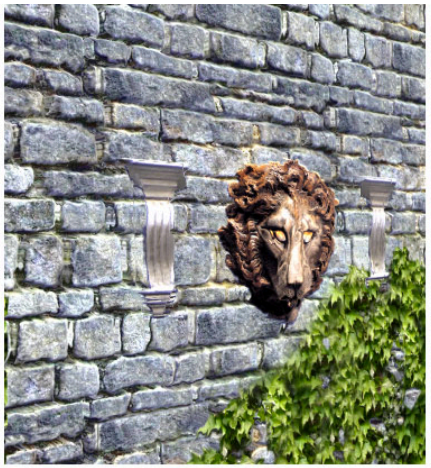
Comparison



Texture Mapped

Normal Mapped



Parallax Mapped

Steep Parallax Mapped

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III. Tangent Space

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III. Tangent Space

- Given a vertex V having a normal N, we need to construct a coordinate system at that vertex such that the value (0,0,1) taken from a normal map corresponds to the normal N.
- This can be achieved by constructing a coordinate system in which the vertex normal always points along the positive z-axis.
- In addition to the normal vector, we need two vectors parallel to the surface and aligned to the texture space of the normal map.

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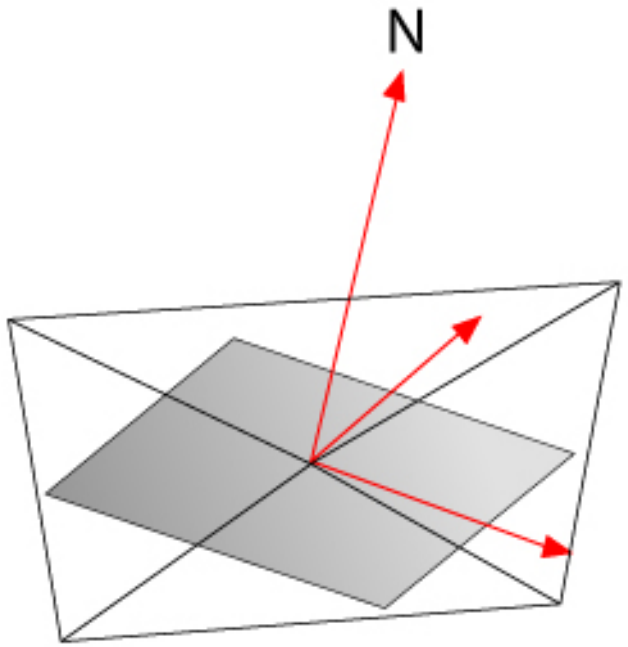
III. Tangent Space *(cont'd)*

- The resulting coordinate system is called tangent space and is shown in the figure below:



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III. Tangent Space *(cont'd)*

- Once the tangent-space coordinate system is established at each vertex of a triangle, the light vector L is computed and transformed into tangent space.

- Afterwards all what we need to do is to interpolate the vector across the surface and get the result of N.L where N represents the normal at the pixel fetched from the normal map.

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III. Tangent Space *(cont'd)*

- Our tangent space is formed by the three axes described by the vectors:
  - N is the normal to the surface
  - T (tangent) is parallel to the surface and in the direction of increasing s (or u)
  - B (bitangent) is parallel to the surface and in the direction of increasing t (or v).

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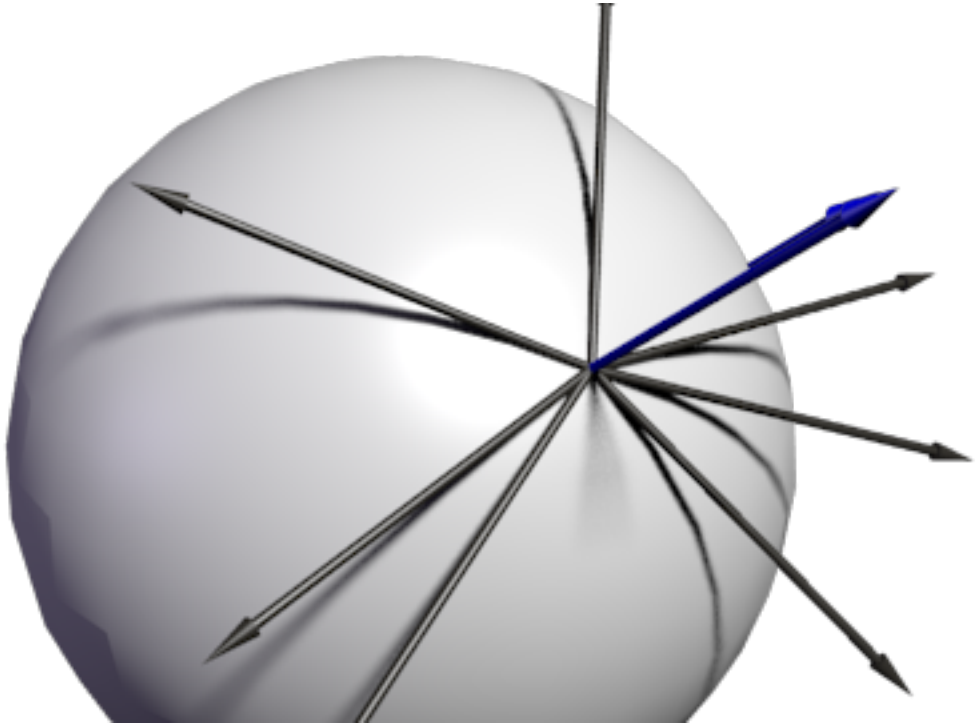

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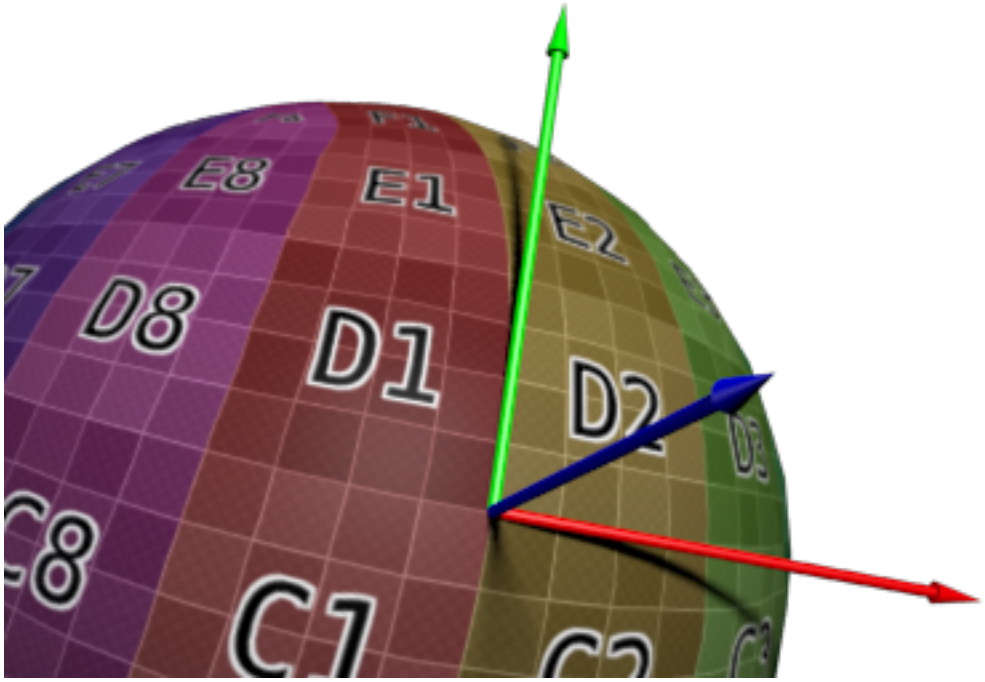

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III. Tangent Space *(cont'd)*

- Any vector V (s, t) belonging to the face can be written as:

$$V = sT + tB$$

where (s, t) are the texture coordinates describing the vector

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III. Tangent Space *(cont'd)*

- Given a triangle's vertices and texture coordinates, our goal is to find the vectors T and B in order to build our tangent space.
- Consider a triangle having as vertices E, F and G.
- The texture coordinates corresponding to those vertices are (s_e, t_e), (s_f, t_f) and (s_g, t_g) respectively.

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III. Tangent Space *(cont'd)*

- Let P and Q be the vectors formed by:

$$P = F - E$$

$$Q = G - E$$

and

$$(s_1, t_1) = (s_f - s_e, t_f - t_e)$$

$$(s_2, t_2) = (s_g - s_e, t_g - t_e)$$

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III. Tangent Space *(cont'd)*

- We need to solve the following equations for T and B:

$$P = s_1 T + t_1 B$$
$$Q = s_2 T + t_2 B$$

- This is a linear system with six unknowns and six equations (corresponding to the x, y and z coordinates of T and B).

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III. Tangent Space *(cont'd)*

- Solving the system will give us the tangent vector T and bitangent vector B corresponding to the triangle EFG.

- To find the tangent vector to a single vertex, we need to average the tangents of all the triangles sharing that vertex.

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III. Tangent Space *(cont'd)*

- The resulting tangent and bitangent are most likely not unit vectors and they should NOT be normalized as they contain the scaling (bumpiness) information.

- However, the normal vectors are typically normalized to ensure the height of the bump surface across the object surface is uniform.

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III. Tangent Space *(cont'd)*

- The following matrix will transform a point in a tangent space back to the model space.

$$\begin{bmatrix} T_x & B_x & N_x \\ T_y & B_y & N_y \\ T_z & B_z & N_z \end{bmatrix}$$

- Use its inverse to transform from the model space to the tangent space

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III. Tangent Space *(cont'd)*

- Keep in mind that the light vectors are described in view space and the calculated T and B are in model space.
- So, transform T and B to view space before constructing the matrix. This way, the matrix will transform the sampled normal directly to view space.

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Thank You.