CS4533 Lecture 13 Slides/Notes

Texture Mapping Variations (Environment, Bump, and Shadow Mapping); Ray Tracing & Radiosity (Notes, Ch 15, Notes, Ch 20)

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Mapping Techniques

1. Texture Mapping: Use an image as a texture to be "glued" (mapped) onto the surface of simple geometry to create sophisticated images.

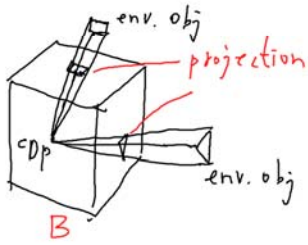
   2 main ways to produce texture images:
   ① computer programs (eg. checkerboard)
   ② digital cameras (image files)

2. Environment Mapping: For a shiny object, the environment is reflected on its surface.
   ⇒ Render the environment into an image, treat it as a texture, then map the texture onto the obj. surface.

eg. a shiny ball in the middle of a room.

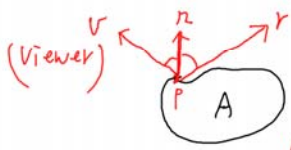
2-step Method: Let A be the shiny obj whose surface we want to perform environment mapping onto.

Step 1: Place the cop at the center of obj A, remove A.
Project the environmental objs onto an intermediate surface B.
eg. Typically we use "cube map"



* Put the viewer (cop) at the center of A. remove A. Render the environment onto the 6 faces of cube B using each face as the view plane. for each face.

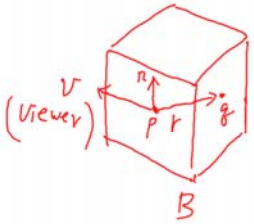
Step 2: Place obj A back. transfer the image on B onto A using texture mapping.

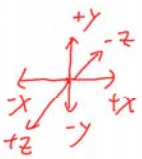


The point q of cube B where r hits, P should get the texture color of q.

Let $r = (r_x, r_y, r_z)$

① Decide which face of cube B the ray r hits.
[We will then use the texture on that face.]
To decide, look at the largest among $|r_x|, |r_y|, |r_z|$ say $|r_x|$. If $r_x > 0 \Rightarrow +x$ face
$r_x < 0 \Rightarrow -x$ face.] suppose it's +x face.

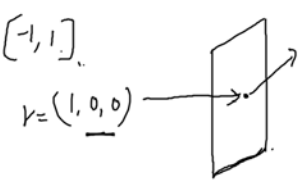


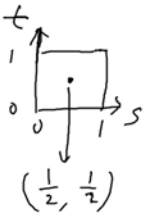


② Decide the texture coord. of q on the +x face
by $\frac{r}{|r_x|} = \left(+1, \frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) : \left(\frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) \longrightarrow (s, t)$

$\left(\frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) \in [-1,1] \times [-1,1]$

$(s,t) \in [0,1] \times [0,1]$





$\left(\frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) \rightarrow (s,t)$: origin $(0,0) \rightarrow \left(\frac{1}{2}, \frac{1}{2}\right)$

$\underbrace{[-1,1]}_{2} \rightarrow \underbrace{(0,1)}_{1}$ in both dimensions (scale by factor of $\frac{1}{2}$)

$(y \rightarrow s,\ z \rightarrow t)$

$(s,t) = \frac{1}{2}\left(\frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) + \left(\frac{1}{2}, \frac{1}{2}\right)$

verify: $\left(\frac{r_y}{|r_x|}, \frac{r_z}{|r_x|}\right) \rightarrow \left(\frac{1}{2}, \frac{1}{2}\right)$

$(0,0)$

i.e. $(0,0) \rightarrow \left(\frac{1}{2}, \frac{1}{2}\right)$ ✓

$\frac{1}{2}(-1,-1) + \left(\frac{1}{2}, \frac{1}{2}\right) = (0,0)$ i.e. $(-1,-1) \rightarrow (0,0)$

$\frac{1}{2}(1,1) + \left(\frac{1}{2}, \frac{1}{2}\right) = (1,1)$ i.e. $(1,1) \rightarrow (1,1)$

ok.

Examples of Environment Mapping (1)

Examples of Environment Mapping (2)

3. Bump Mapping: Goal: create a bumpy surface (eg. orange)

Naive attempt: Take a picture of the real bumpy obj (eg. orange) then use texture mapping to map the picture onto the obj surface (eg. sphere) (smooth).

Issue: When we move the light or rotate the obj. we will notice that it is NOT realistic looking. (eg. "shadows" corresponding to the bumps are incorrect)

Bump Mapping: We can vary the look of the shape of the surface by perturbing the normal vectors then using the perturbed normal vectors in shading computation.

Note: * The actual geometry is unchanged (still a flat polygon)

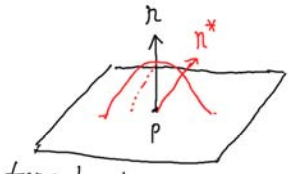
* Bump mapping does NOT change the { boundary / silhouette } of the obj

$p^* = p + d(p)\, n$ $\quad p$: original surface pt.

p^*: new surface pt displaced from p.

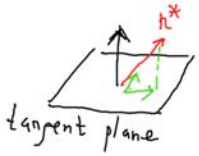
$d(p)$: displacement amount at p.

n^*: normal vector at p^*



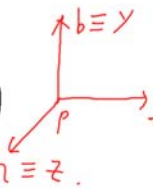
[There is a formal math derivation for n^*.
We omit it here, and only put the conclusion below:]

$\Rightarrow n^*$ is n perturbed along a direction on the tangent plane,
which can be decomposed as x & y components on the tangent plane.



$\Rightarrow$ Take t: tangent vector at p (Normalized: $|n| = |t| = 1$)

$b = n \times t$: binormal vector at p (Normalized: $|b| = 1$)



* Tangent frame:
- origin is at p
- t, b, n are 3 basis vectors

This is called the tangent frame

(also called surface local frame.) where t, b, n are in the eye frame.

Create a 3×3 matrix $M = \begin{bmatrix} [t] \\ [b] \\ [n] \end{bmatrix}$ We can use M to transform vectors from eye frame to tangent frame.

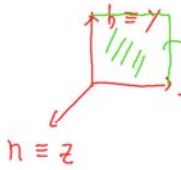
Verification: $M \cdot t = \begin{bmatrix} [t] \\ [b] \\ [n] \end{bmatrix} \underbrace{\begin{bmatrix} t \end{bmatrix}}_{\text{eye}} = \begin{bmatrix} t \cdot t \\ b \cdot t \\ n \cdot t \end{bmatrix} = \underbrace{\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}}_{\text{tangent}} \equiv x$ $\quad M \cdot b = \begin{bmatrix} [t] \\ [b] \\ [n] \end{bmatrix} \underbrace{\begin{bmatrix} b \end{bmatrix}}_{\text{eye}} = \begin{bmatrix} t \cdot b \\ b \cdot b \\ n \cdot b \end{bmatrix} = \underbrace{\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}}_{\text{tangent}} \equiv y$

Similarly $M \cdot n = \underbrace{\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}}_{\text{tangent}} \equiv z.$

Main Idea: Use matrix M to transform everything from eye frame to tangent frame, then perform shading computation in tangent frame.

* In the tangent frame: original normal $n = z = (0, 0, 1)$

perturbed normal n^* is n perturbed along x direction & y ... in the tangent frame



tangent plane is the x-y plane in the tangent frame.

* original normal $n = (0, 0, 1)$
perturbed normal $n^* = (x, y, 1)$
with $\begin{cases} x = f(s) \\ y = f(t) \end{cases}$
i.e. x, y are results of a function f on the texture coord. (s, t) of the current fragment

$n^* \leftarrow$ normalize (n^*)
Use n^* for shading computation in tangent frame.

Gouraud (Per-Vertex) Shading

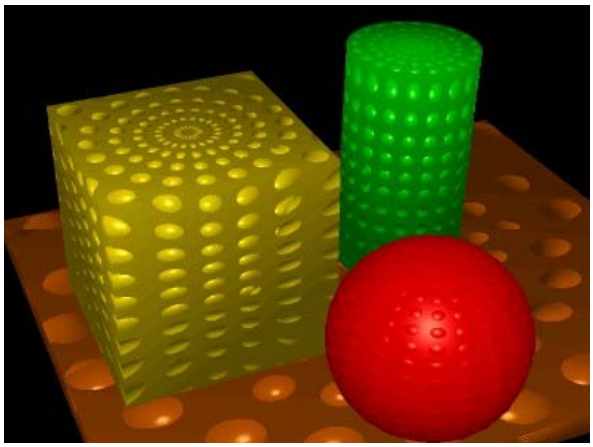
Phong (Per-Fragment) Shading

Bump Mapping (1)

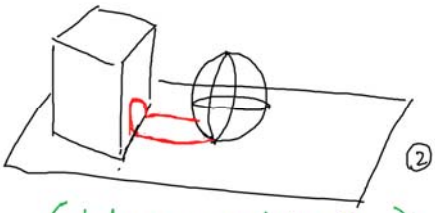
Bump Mapping (2)

Bump Mapping (3)

Bump Mapping (4)



4. Shadow Mapping:



(shadow map created in ① is stored & read as a texture)

① Put the viewer at the light position L. Render the scence to the z-buffer to create a "shadow map": The shadow map contains the z-values of all points that can be seen from L.

② Render the scene from the viewer. For each fragment f, also compute its "z-value" when viewed from L. (when rendered from L, f is at pixel p with z-value z_f)
Look at the shadow map. (in shadow map, pixel p has value M_p)

(a) if $z_f > M_p$ then f can NOT be seen from L.
$\Rightarrow$ No contribution of light L to fragment f

(b) else ($z_f == M_p$) then f can be seen from L.
$\Rightarrow$ Add contribution of L to f

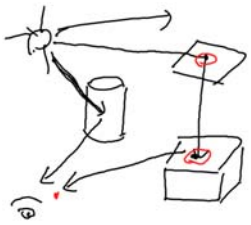
Main Issue: self shadowing

Sol: Add some tolerance ε (small and > 0):
treat $|z_f - M_p| \leq \varepsilon$ as (b)
(test case (b) first. and "else" is case (a))

Global shading: 1. Ray Tracing

2. Radiosity

1. Ray Tracing: Simulate the interactions of rays with objs where the rays are bouncing among objs.



Issues: ① Infinite # rays to trace: too slow!!

Sol: We only care about the rays coming into the eye ⇒ trace rays backwards!!

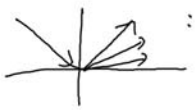
Cast rays from cop thru each pixel center into the scene. then tracy the rays there

② How do we trace the bounced rays?

(I) (i) For diffuse surface. reflected rays are along all directions.

⇒ can't trace so many rays!

(ii) For highly specular surface, reflected rays are along a narrow range of angles.



: ok to trace them.

Typically we assume to have a single reflected ray to trace

ok.

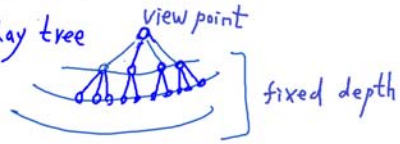
⇒ Ray tracing works mainly for highly specular surfaces

NOT for diffuse surfaces.

(II) We only trace rays with a pre-fixed # of bounces

Fixed depth of the ray tree.

Ray tree



* Every time the viewer moves or changes the viewing direction, we need to re-do the ray-tracing computation (expensive, NOT suitable for interactive applications).

2. Radiosity: Works for diffuse surfaces.

In closed environment, compute how the light energy is interacting between each pair of surface patches. (small flat polygons)

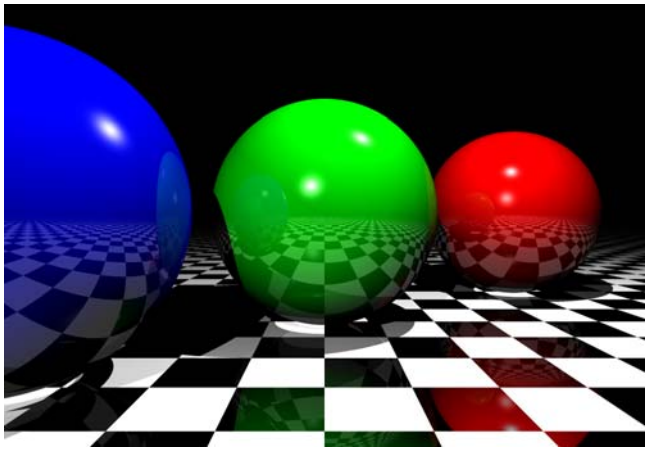
Assume: All surfaces are perfectly diffuse: reflected rays are along all directions

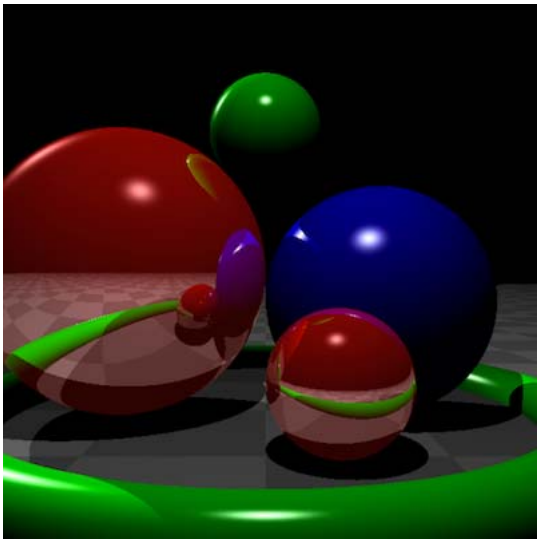
⇒ Computation is independent of the viewer position & viewing direction.

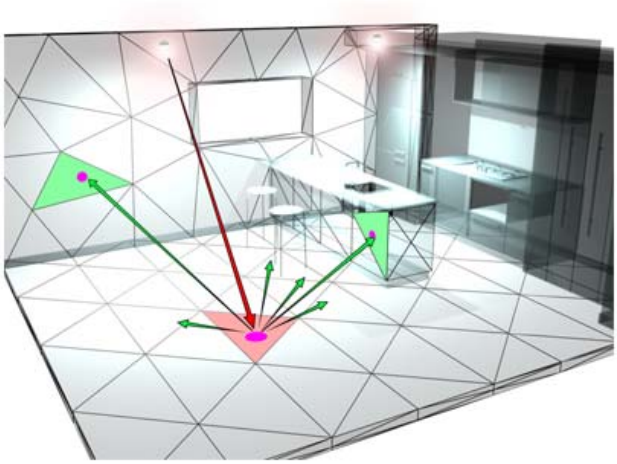
* Can be done in preprocessing (pre-computation)
* Suitable for interactive applications at run-time.

* Radiosity and ray tracing are complementary to each other.

Example Results of Ray Tracing

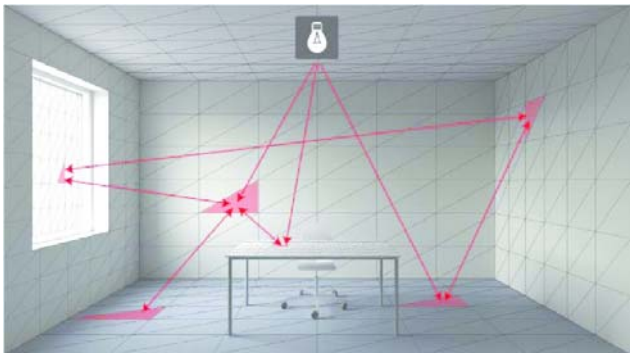


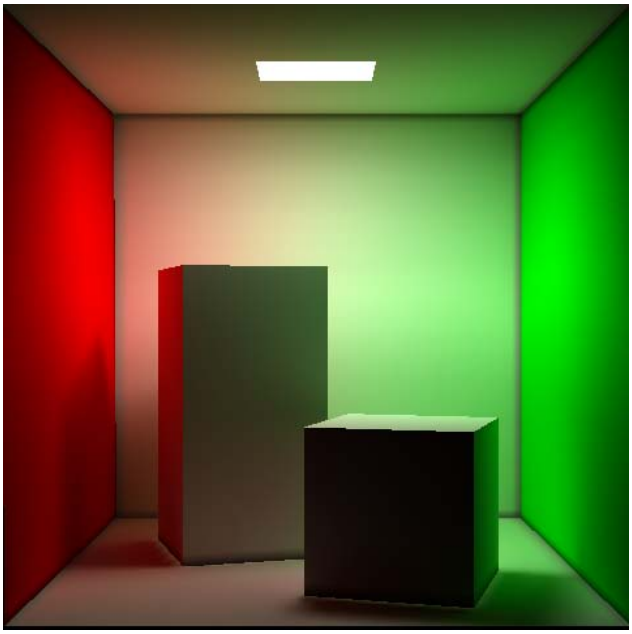




Radiosity: Concepts of the Method

Radiosity Computation: For each pair of patches, compute the light energy interactions between them





Radiosity Result:
The ``Color Bleeding'' Effect