



Lecture 33 of 41

Ray Tracing, Part 2 of 2: Distributed RT & Radiosity/RT Hybrid Systems

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KSOL course pages: <http://bit.ly/hGvXIH> / <http://bit.ly/eVizRE>
Public mirror web site: <http://www.kddresearch.org/Courses/CIS636>
Instructor home page: <http://www.cis.ksu.edu/~bhsu>

Readings:

Last class: **Ray Tracing Handout**
Today: Chapter 15, Eberly 2^o – see <http://bit.ly/ieUq45>; **Ray Tracing Handout**
Next class: **Tufte Handout 1**



Lecture Outline

- Reading for Last Class: **Ray Tracing Handout**
- Reading for Today: Chapter 15, Eberly 2^o; **Ray Tracing Handout**
- Reading for Next Class: **Tufte Handout 1**
- Last Time: Ray Tracing Lab
 - * **ACM SIGGRAPH demo**: <http://bit.ly/cilgix2>
 - * **POV-Ray**: <http://www.povray.org>
- Today: Ray Tracing, Part 2 of 2
 - * **Hybrid global illumination: RT with radiosity**
 - Calculating specular exponents
 - Pre-rendering backgrounds
 - Progressive refinement
 - * Other optimizations
- Next Class: **Visualization, Part 1 of 3 – Data**
 - * Source: *The Visual Display of Quantitative Information, 2^o*
 - * Applications: scientific visualization, information visualization



Where We Are

21	Lab 4a: Animation Basics	Flash animation handout
22	Animation 2: Rotations, Dynamics, Kinematics	Chapter 17, esp. §17.1 – 17.2
23	Demos 4: Modeling & Simulation, Rotations	Chapter 10', 13', §17.3 – 17.6
24	Collisions 1: axes, OBBs, Lab 4b	§2.4.3, 8.1, GL handout
25	Spatial Sorting, Binary Space Partitioning	Chapter 6, esp. §6.1
26	Demos 5: More CGA, Picking, HW Exam	Chapter 7'; § 8.4
27	Lab 5a: Interaction Handling	§ 8.3 – 8.4; 4.2, 5.0, 5.6, 9.1
28	Collisions 2: Dynamic, Particle Systems	§ 9.1, particle system handout
29	Lab 5b: Particle Systems	Chapters 5 – 6, 7' – 8, 12, 17
30	Animation 3: Control & IK	Particle system handout
31	Ray Tracing 1: Intersections, ray trees	§ 5.3, CGA handout
32	Lab 6a: Ray Tracing Basics with POV-Ray	Chapter 14
33	Ray Tracing 2: advanced topic survey	RT handout
34	Visualization 1: Data (Quantities & Evidence)	Ch. 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100
35	Lab 6b: More Ray Tracing	RT handout (1)
36	Visualization 2: Objects	Tufte handout (2 & 4)
37	Color Basics, Term Project Prep	Color handout
38	Lab 7: Fractals & Terrain Generation	Fractals/Terrain handout
39	Visualization 3: Processes: Final Review 1	Tufte handout (3)
40	Project presentations 1; Final Review 2	–
41	Project presentations 2	–
	Final Exam	Ch. 1 – 8, 10 – 16, 17, 20

Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.
Green, blue and red letters denote exam review, exam, and exam solution review dates.



Acknowledgements: Advanced Ray Tracing & Radiosity



David K. Buck, Aaron Collins, et al.
Developers
Persistence of Vision Raytracer (POV-Ray)
<http://www.povray.org>



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<http://pages.cpsc.ucalgary.ca/~mario/>



IMAGING EXCELLENCE FROM
CANFIELD



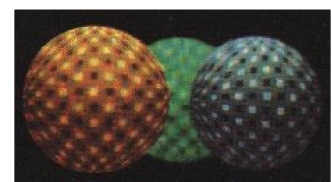
Review [1]: Recursive Ray Tracing Algorithm

- Compute 3D ray into scene for each 2D image pixel
- Compute 3D intersection point of ray with nearest object in scene
 - * Test each primitive in the scene for intersection
 - * Find nearest intersection
- Recursively spawn rays from point of intersection
 - * Shadow Rays
 - * Reflected rays
 - * Transmitted rays
- Accumulate color from each spawned ray at point of intersection

Adapted from slides © 2005 M. Thomas & C. Khambamettu, U. Del.
CISC 440/640: Computer Graphics, Spring 2005 – <http://bit.ly/hztkfu>




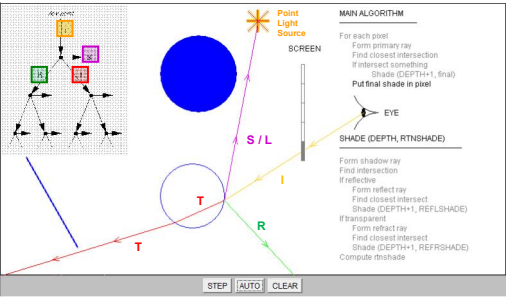
Review [2]: Distributed Ray Tracing



Adapted from slides © 2001 D. Shreiner & B. Grantham, SCU
COEN 290: Computer Graphics I, Winter 2001 – <http://bit.ly/hztkfu>



7  **Review [3]:**
Java-Based 2-D RT Demo, SIGGRAPH



MAIN ALGORITHM

```

For each pixel
  Form primary ray
  Find closest intersection
  If intersect something
    Shade (DEPTH+1, final)
    Put final shade in pixel
  
```

SHADE (DEPTH, RTNSHADE)

```

Form shadow ray
Find intersection
If reflective
  Form reflect ray
  Find closest intersect
  Shade (DEPTH+1, REFLSHADE)
If transparent
  Form refract ray
  Find closest intersect
  Shade (DEPTH+1, REFRSHADE)
Compute rshade
  
```

Screenshots from Java program © 2001 G. S. Owen & Y. Liu, GSU
ACM SIGGRAPH Ray Trace Java Demo – <http://bit.ly/clqg2>

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8  **Review [4]:**
POV-Ray




"The Wet Bird" © 2001 Gilles Tran
<http://bit.ly/vghBvdt>

"Dissolution" © 2005 Neut
<http://bit.ly/vvq64>

"Thanks for all the fish" © 2008 Robert McGregor
<http://bit.ly/REB4m>

Images © respective authors, generated using POV-Ray
© 1991 – 2011 D. K. Buck et al. – <http://www.povray.org>

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9  **Formulas:**
Ray-Object Intersection

- Intersection with plane
 - Implicit form

$$F(x, y, z) = ax + by + cz + d = \mathbf{n} \cdot \mathbf{x} + d$$
 - Intersection


$$\mathbf{n} \cdot \mathbf{S} + (\mathbf{n} \cdot \mathbf{c}) + d = 0 \Rightarrow t = \frac{-d - \mathbf{n} \cdot \mathbf{S}}{\mathbf{n} \cdot \mathbf{c}}$$
- Intersection with sphere
 - Implicit form

$$\|\mathbf{p} - \mathbf{p}_c\|^2 = r^2 \quad \mathbf{p} = (x, y, z), \mathbf{p}_c = (a, b, c)$$
 - Intersection

$$t = -\mathbf{c} \cdot (\mathbf{S} - \mathbf{p}_c) \pm \sqrt{(\mathbf{c} \cdot (\mathbf{S} - \mathbf{p}_c))^2 - \|\mathbf{c}\|^2 (\|\mathbf{S} - \mathbf{p}_c\|^2 - r^2)}$$

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10  **Formulas:**
Light Vectors aka Shadow Rays

- "Shadow feelers"
 - Spawn ray from P to each light source
 - If there is intersection of shadow ray with any object then P is in shadow
- Reflection
 - Angle of incidence = angle of reflection

$$\mathbf{m} = \left(\mathbf{a} \frac{\mathbf{n}}{\|\mathbf{n}\|} \right) \frac{(-\mathbf{n})}{\|\mathbf{n}\|} = -\frac{\mathbf{a} \cdot \mathbf{n}}{\|\mathbf{n}\|^2} \mathbf{n}$$


$$\mathbf{r} = \mathbf{e} + (-\mathbf{m}) = (\mathbf{a} - \mathbf{m}) + (-\mathbf{m}) = \mathbf{a} - 2\mathbf{m}$$

$$= \mathbf{a} - 2 \left(\frac{\mathbf{a} \cdot \mathbf{n}}{\|\mathbf{n}\|^2} \right) \mathbf{n}$$

$$= \left(\|\mathbf{n}\| \cos(180^\circ - \theta_i) \right) \hat{\mathbf{n}} = (\mathbf{a} \cdot \hat{\mathbf{n}}) \hat{\mathbf{n}}$$

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11  **Formulas:**
Refraction of Transmitted Ray

- Ray passing through two media
 - Different refractive indices
 - Ray bends towards/away from normal
- Snell's Law
 - n_i and n_r are refractive indices of two media
$$n_i \sin \theta_i = n_r \sin \theta_r$$
- Transmitted ray

$$\mathbf{T} = \frac{n_r}{n_i} \mathbf{u} - \left(\cos \theta_i - \frac{n_r}{n_i} \cos \theta_r \right) \mathbf{n}$$

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12  **Speeding Up RT Using Extents/BVs [1]:**
Motivation

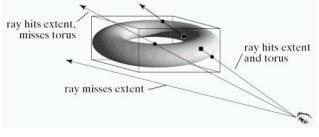
- Ray tracing slow, performs same functions repeatedly
- Most time spent in computing intersections
 - Each ray should be intersected with every object in scene
 - Each ray spawns out reflected/transmitted rays which have to be interested with objects in scene

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13  **Speeding Up RT Using Extents/BVs [2]: Definition & Basic Idea**

- **Extent (aka bounding volume)** of object: shape that encloses it
- Compute complicated intersections if and only if ray hits extent
- Two shapes most commonly used as extents
 - * Sphere – specified by center and radius (C, r)
 - * Box – specified by sides aligned to coordinate axis
 - Axis-aligned bounding box (AABB) – more typical for RT
 - Oriented bounding box (OBB)

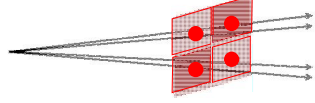


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14  **Super-Sampling**

- Instead of shooting one ray per pixel, shoot four rays through corners of pixel
- Adaptive super-sampling (Whitted's approach)
 - * Shoot more rays through corners with higher intensity variation
 - * Compute final color as weighted average rather than regular average



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15  **Advanced Topics in RT: Road Map**

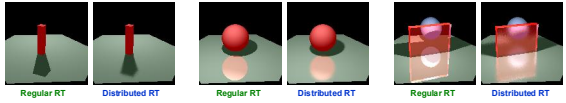
- Monte Carlo Methods: Distributed RT
- Bidirectional Ray Tracing: Caustics
- POV-Ray
- Hybrid Global Illumination
 - * RT: good for
 - Specular highlights (highlights)
 - Point-to-point interobject reflectance, shadows
 - * Radiosity: good for
 - Diffuse reflectance (matte effects)
 - Patch-to-patch interobject reflectance
 - * Best of both worlds
 - RT for exponents
 - Radiosity for backgrounds

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16  **Distributed Ray Tracing [1]: What Is It?**


- Distributed ray tracing: not RT on distributed systems!
- Ray tracing method
 - * based on randomly distributed oversampling
 - * to reduce aliasing artifacts
 - * in rendered images
- Reference
 - * Allen Martin, Worcester Polytechnic Institute (WPI)
 - * Examples for shadows, reflection, transparency




"Distributed Ray Tracing" © 1995 A. Martin – <http://bit.ly/ex5ZUm>

Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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17  **Distributed Ray Tracing [2]: From Stochastic RT to Distributed RT**



- **Distributed ray tracing** is an elegant technique that tackles many problems at once
 - Stochastic ray tracing: distribute rays stochastically across pixel
 - Distributed ray tracing: distribute rays stochastically across everything

Adapted from slide ♥ 2005 D. Luebke, University of Virginia
CS 551-0003/651-0001: Advanced CG, Spring 2005 – <http://bit.ly/eTWYAO>


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18  **Distributed Ray Tracing [3]: Stochastic Oversampling (Cook, 1984)**

- Developed by Cook et al. ("*Distributed Ray Tracing*", *Computer Graphics*, vol. 18, no. 3, pp 137-145, 1984)
- Stochastic Oversampling: <http://bit.ly/eTWYAO>
 - * Pixel for antialiasing
 - * Light source for soft shadows
 - * Reflection function for soft (glossy) reflections
 - * Time for motion blur
 - * Lens for depth of field

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19  **Distributed Ray Tracing [4]: Gloss**

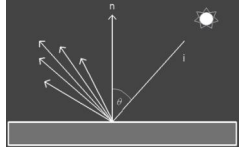
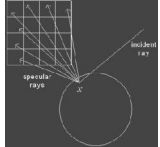
- Partially reflecting surfaces
- Traditional ray tracing
 - reflections look identical to scene they are reflecting
 - reflections are always sharp
- Randomly distributing rays reflected by surface
- Send out packet of rays around reflecting direction
- Actual value of reflectance is statistical mean of the values returned by each of these rays

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20  **Distributed Ray Tracing [5]: Perturbing Specular Reflection Ray**


- Distributing set of reflection rays by randomly perturbing ideal specular reflection ray
- Spread of distribution determines glossiness where wider distribution spread models rougher surface

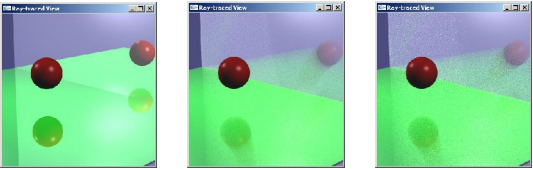



"Realistic Raytracing" © 2003 Z. Waters & E. Agu, WPI
<http://bit.ly/gUNeGr>

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21  **Distributed Ray Tracing [6]: Multiple Reflected Rays**



- First image is from traditional ray tracer
- Second one uses 16 rays in place of single reflected ray
- Third image uses 64 rays

"Monte Carlo Ray Tracing"
© 2005 D. Strock, University of Wisconsin Milwaukee
<http://bit.ly/ISiYAL>

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22  **Distributed Ray Tracing [7]: Soft Shadows & Reflection**



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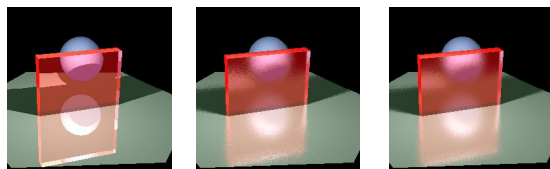
23  **Distributed Ray Tracing [8]: Fuzzy Translucency**

- Same as glossy reflections, but jitter refracted ray
- Analytical function similar to shading
 - Transmission function is used instead of reflectance function
 - Light is gathered from other side of surface.
- Cast randomly distributed rays in general direction of transmitted ray from traditional ray tracing
- Average value computed from each of these rays: true translucent component

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24  **Distributed Ray Tracing [9]: Soft Reflection & Transparency**



- First image is obtained from traditional ray tracer
- Second image uses 10 rays for transmitted ray
- Third image uses 20 rays

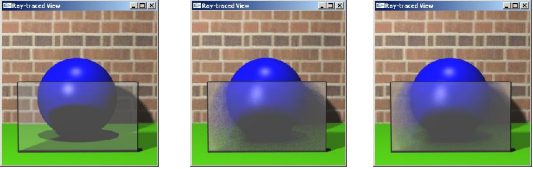
"Distributed Ray Tracing" © 1995 A. Martin – <http://bit.ly/ex5ZUm>

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Distributed Ray Tracing [10]: Shadows, Reflection, Transparency



- First image is from traditional ray tracer
- Second one uses 16 rays in place of single reflected ray
- Third image uses 64 rays

"Monte Carlo Ray Tracing"
© 2005 D. Strock, University of Wisconsin Milwaukee
<http://bit.ly/1S1Tsk>

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Distributed Ray Tracing [11]: Penumbrae (Soft Shadows)

- Traditional ray tracing shadows: discrete
 - Shadow feelers used to check if point is in shadow with respect to point light source
- Incorrect for large light sources and/or light sources that are close to object
- Transition from fully shadowed to partially shadowed is gradual
 - Due to finite area of real light sources
 - Also due to scattering of light of other surfaces

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Distributed Ray Tracing [12]: Tracing Penumbrae (Soft Shadows)

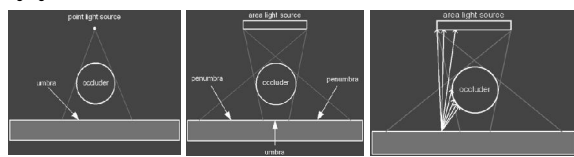
- Set of rays cast about projected area of light source
 - Projected area helps tackle large area light source
- Amount of light transmitted by: ratio of number of rays that hit source to number of rays cast

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Distributed Ray Tracing [13]: Shadow Feelers & Penumbrae



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<http://bit.ly/gUteGr>

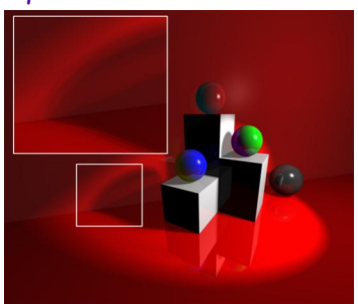
- In case of point source, occluder would create sharp shadow boundary
- In area light source or if light source is closer to object
 - Creation of penumbra region
- Sending out shadow feelers to capture penumbra region

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Distributed Ray Tracing [14]: Example – Transitions inside Penumbra



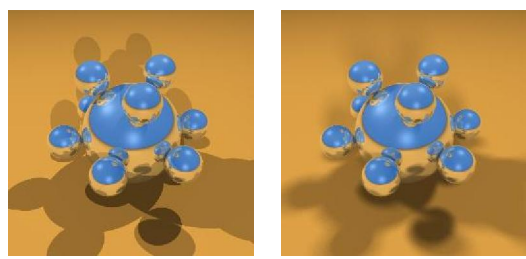
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Distributed Ray Tracing [15]: Example – Soft Shadows




Regular RT Distributed RT

♥ 2000 A. G. Zafearakis, UNC Chapel Hill
COMP 238, Advanced Image Generation – <http://bit.ly/GYzaw/> <http://bit.ly/8NQt8H>

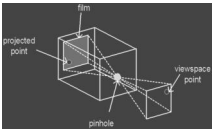
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Distributed Ray Tracing [16]: Depth of Field


- Distance at which objects appear in focus
- Objects too far away or too close appear unfocused, blurry
- Pinhole camera model does not truly mimic real world
 - * Pinhole assumed to be infinitely small
 - * Changing focal length changes field of view but does not change focus



"Realistic Raytracing" © 2003 Z. Waters & E. Agu, WPI
<http://bit.ly/9aUHeGr>

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Distributed Ray Tracing [17]: Creating Depth of Field

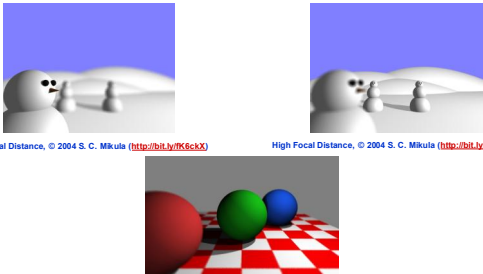
- Distributed RT: places artificial lens in front of view plane
- Randomly distributed rays: used once again to simulate blurring of depth of field
 - * First ray cast not modified by lens
 - * Focal point of lens is at fixed distance along this ray
 - * Rest of rays sent out for same pixel scattered about surface of lens
 - * Points in scene close to focal point of lens: in sharp focus
 - * Points closer or further away: blurred

Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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Distributed Ray Tracing [18]: Example – Depth of Field



Low Focal Distance, © 2004 S. C. Mikula (<http://bit.ly/K6ckX>)


High Focal Distance, © 2004 S. C. Mikula (<http://bit.ly/7SA3b3>)

Intermediate Focal Distance, © 2003 A. Bair (<http://bit.ly/faxUPh>)

♥ 2001-2006 respective authors, University of Illinois at Urbana-Champaign
CS 419, Advanced Computer Graphics – <http://bit.ly/9aUHeGr>

Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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Distributed Ray Tracing [19]: Motion Blur

- Temporal sampling rather than spatial sampling
- Frame represents average of scene during time that camera shutter is open
- Before each ray is cast, objects are translated or rotated to their correct position for that frame
- Rays are averaged to give actual value
- Objects with most motion will have most blurring in rendered image

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Distributed Ray Tracing [20]: Example – Motion Blur



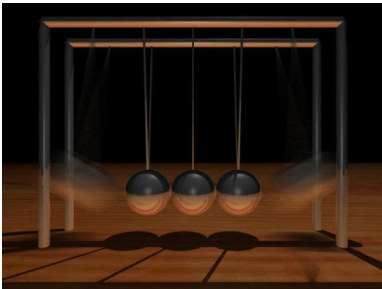
♥ 2005 C. M. Cameron, University of Illinois at Urbana-Champaign
CS 419, Advanced Computer Graphics – <http://bit.ly/9aUHeGr>

Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
CISC 440/640: Computer Graphics, Spring 2005 – <http://bit.ly/hz1kftU>

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Distributed Ray Tracing [21]: Example – Soft Shadows



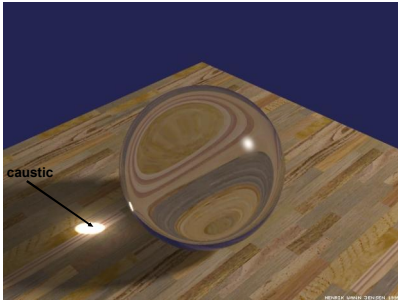
♥ 2005 M. A. Townsend, University of Illinois at Urbana-Champaign
CS 419, Advanced Computer Graphics – <http://bit.ly/9aUHeGr>

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Bidirectional Ray Tracing [1]: Example – Caustic



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<http://graphics.ucsd.edu/~henrik/>

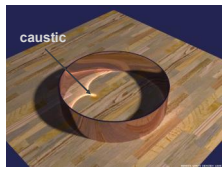
Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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Bidirectional Ray Tracing [2]: Example – Caustic

- **Caustic** – (concentrated) specular reflection/refraction onto diffuse surface
- Standard ray tracing cannot handle caustics



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<http://graphics.ucsd.edu/~henrik/>

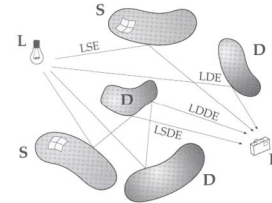
Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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Light Paths: Abbreviated Notation

- Shown: interactions of light ray
- Can be expressed using regular expressions
 - * L: light source
 - * E: eye/camera
 - * D: diffuse surface
 - * S: specular surface



Sillion, F. X. & Puech, C. (1994). *Radiosity and Global Illumination*. San Francisco, CA: Morgan-Kaufmann.
Amazon: <http://amazon.to/vhNBjH>

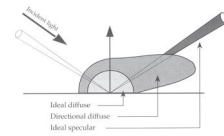
Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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BRDF Revisited: Diffuse Surfaces [1]

- Uncertainty in direction photon will take for diffuse surfaces
- Specular surfaces: **Bidirectional Reflectance Distribution Function** (probability that incoming photon will leave in particular direction) has thin profile
 - * Can predict direction of outgoing photon
- For ideal diffuse surfaces, BRDF would be spherical
 - * Photon can travel along any direction with equal probability



Sillion, F. X. & Puech, C. (1994). *Radiosity and Global Illumination*. San Francisco, CA: Morgan-Kaufmann.
Amazon: <http://amazon.to/vhNBjH>

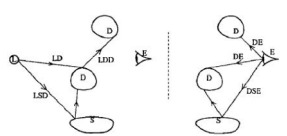
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BRDF Revisited: Diffuse Surfaces [2]

- Idea: Trace forward light rays into scene as well as backward eye rays
 - * At diffuse surfaces, light rays additively “deposit” photons in radiosity textures, or “rexes”, where they are picked up by eye rays
- Rays of forward and backward pass “meet in middle” to exchange information



Heckbert, P. S. (1990). “Adaptive radiosity textures for bidirectional ray tracing”, *Proceedings of the 17th Annual Conference on Computer Graphics and Interactive Techniques* (Scott 1990).

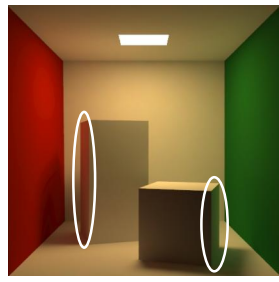
Adapted from slides ♥ 2005 M. Thomas & C. Khambamettu, U. Del.
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Radiosity

- Handling cases such as LD^*E
- “Color Bleeding”



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Software Packages

- Two excellent, full-featured rendering & modeling packages
- POV-Ray** (<http://www.povray.org/>)
 - * Persistence of Vision Ray Tracer
 - * Free rendering tool (not modeling tool)
 - * Uses text-based scene description language (SDL)
 - * Available on Windows, Linux, Mac OS
- Blender** (<http://www.blender3d.org>)
 - * Modeling, animation, rendering tool
 - * Especially useful in 3-D game creation
 - * Available for Windows, Linux, Irix, Sun Solaris, FreeBSD or Mac OS X under GPL

Adapted from slides ♥ 2005 M. Thomas & C. Kambamettu, U. Del.
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Radiosity [1]: Basic Idea

- "Radiosity" method: basis is field of thermal heat transfer
- Heat transfer theory describes radiation as transfer of energy from surface when that surface has been thermally excited

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Radiosity [2]: Derivation of Radiosity Equation

- Radiosity equation** describes **amount of energy** which can be emitted from surface, as sum of
 - * energy inherent in surface (e.g., light source)
 - * energy which strikes surface, being emitted from some other surface
- Energy which leaves surface j and strikes another surface i is attenuated by two factors
 - * "form factor" between surfaces i and j , which accounts for physical relationship between two surfaces
 - * the **reflectivity** of surface i , which will absorb some percentage of light energy striking surface

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Radiosity [3]: Radiosity Equation

$$B_i = E_i + \rho_i \sum B_j F_{ij}$$

Diagram illustrating the Radiosity Equation:

- B_i : Radiosity of surface i
- E_i : Emissivity of surface i
- ρ_i : Reflectivity of surface i
- B_j : Radiosity of surface j
- F_{ij} : Form Factor of surface j relative to surface i

Annotations:

- Form Factor of surface j relative to surface i
- accounts for physical relationship between two surfaces
- will absorb certain percentage of light energy which strikes surface


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Radiosity [4]: Implementation, Pros & Cons

- Classic radiosity = finite element method
- Assumptions
 - * Diffuse reflectance
 - * Usually polygonal surfaces
- Advantages
 - * Soft shadows and indirect lighting
 - * View independent solution
 - * Precompute for set of light sources
 - * Useful for walkthroughs



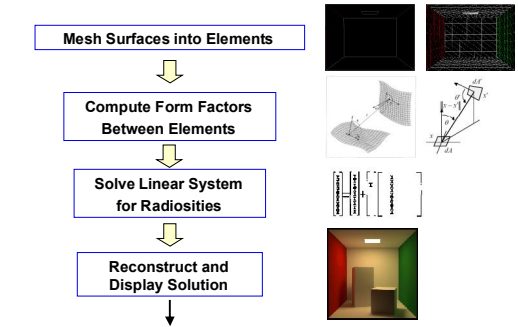
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Radiosity [5]: Classic Radiosity Algorithm

- Mesh Surfaces into Elements
- Compute Form Factors Between Elements
- Solve Linear System for Radiosities
- Reconstruct and Display Solution



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Radiosity [6]: Form Factors Illustrated

Purely geometric relationship, independent of viewpoint or surface attributes

Surface j

Surface i

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Radiosity [7]: Formula – Form Factor

differential area of surface i, j

angle between Normal, and r

angle between Normal, and r

$$F_{dA_j, dA_i} = \frac{\cos \theta_i \cos \theta_j}{\pi |r|^2}$$

vector from dA_i to dA_j

Surface j

Surface i

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Radiosity [8]: Formula – Overall Form Factor

Overall form factor between i and j is found by integrating

$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos \theta_i \cos \theta_j}{\pi |r|^2} dA_i dA_j$$

Surface j

Surface i

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Radiosity [9]: Progressive Refinement

- Each element in scene maintains two energy values
 - Accumulated
 - Residual ("unshot")
- Choose one element as shooter
- Test visibility of every other element from this shooter
 - If visible, calculate shooter-to-receiver energy transfer
 - Based on shooter's residual, receiver's reflectance
- Progressive refinement: reset residual, repeat with new shooter
- Terminate when shooter residuals below threshold

Adapted from GPU Gems 2, Chapter 39, "Global Illumination Using Progressive Refinement Radiosity", © 2005 G. Coombe & M. Harris, nVidia Corporation - <http://bit.ly/hXQ8Zd>

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Radiosity [10]: Example – Progressive Refinement

2 seconds

30 seconds

100 seconds

940 seconds

Myszkowski, K. (2001). *Efficient and Predictive Realistic Image Synthesis*. Habilitation thesis, Warsaw University of Technology - <http://bit.ly/qi9k6>

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Radiosity [11]: Example – Cornell Box

- This simulation of the Cornell box was done by Michael F. Cohen and Donald P. Greenberg for the 1985 paper *The Hemi-Cube, A Radiosity Solution for Complex Environments*, Vol. 19, No. 3, July 1985, pp. 31-40.
- The hemi-cube allowed form factors to be calculated using scan conversion algorithms (which were available in hardware), and made it possible to calculate shadows from occluding objects.


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Radiosity [12]: Example – Discontinuity Meshing

- Dani Lischinski, Filippo Tampieri and Donald P. Greenberg created this image for the 1992 paper *Discontinuity Meshing for Accurate Radiosity*.
- It depicts a scene that represents a pathological case for traditional radiosity images, many small shadow casting details.
- Notice, in particular, the shadows cast by the windows, and the slats in the chair.




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Radiosity [13]: Example – Focused Opera Lighting

- This scene from *La Bohème* demonstrates the use of focused lighting and angular projection of predistorted images for the background.
- It was rendered by Julie O'B. Dorsey, Francois X. Sillion, and Donald P. Greenberg for the 1991 paper *Design and Simulation of Opera Lighting and Projection Effects*.




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Radiosity [14]: Formula – Overall Form Factor

- These two images were rendered by Michael F. Cohen, Shenchang Eric Chen, John R. Wallace and Donald P. Greenberg for the 1988 paper *A Progressive Refinement Approach to Fast Radiosity Image Generation*.
- The factory model contains 30,000 patches, and was the most complex radiosity solution computed at that time.
- The radiosity solution took approximately 5 hours for 2,000 shots, and the image generation required 190 hours; each on a VAX8700.




Adapted from slides ♥ 2001 - 2005 M. C. Sousa, University of Calgary
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Radiosity [15]: Example – Cornell Virtual Museum

- Most of the illumination that comes into this simulated museum arrives via the baffles on the ceiling.
- As the progressive radiosity solution executed, users could witness each of the baffles being illuminated from above, and then reflecting some of this light to the bottom of an adjacent baffle.
- A portion of this reflected light was eventually bounced down into the room.
- The image appeared on the proceedings cover of SIGGRAPH 1988.



© 1988-1989 E. Chen & M. Cohen, Cornell University – <http://bit.ly/87YTL>
Cornell University Department of Computer Science

Adapted from slides ♥ 2001 - 2005 M. C. Sousa, University of Calgary
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Summary

- Reading for Last Class: **Ray Tracing Handout**
- Reading for Today: Chapter 15, Eberly 2nd; **Ray Tracing Handout**
- Reading for Next Class: **Tufte Handout 1**
- Last Time: Ray Tracing Lab
 - * ACM SIGGRAPH demo: <http://bit.ly/cllgx2>
 - 2-D "screen"
 - Moveable objects: transparent, opaque (both reflective)
 - * POV-Ray (<http://www.povray.org>) Example Renderings
- Next Class: Visualization Part 1 of 3

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Terminology

- **Caustic**: Envelope of Light Rays Reflected/Refracted by Curved Object
- **RT Direction**
 - * **"Forward" RT**: Light-to-Scene, Scene-to-Eye (Only for Caustics)
 - * **"Backward" RT**: Eye-to-Scene, Scene-to-Light (Typical Order)
 - * **Bidirectional RT**: both directions (meet in middle)
- **Stochastic Jitter**: Local Random Perturbations of Traced Rays
- **Distributed RT**: Nonlocal Randomization
- **Penumbra**: Region Where Only Part of Light Source Blocked
- **Blurring**
 - * **Soft shadows**: blurred penumbras (achieved using shadow feelers)
 - * **Gloss**: property of smooth surface material (multiple reflected rays)
 - * **Reflections**: soften (also distributed RT)
 - * **Transparency**: lensed caustic effect (also distributed RT)
- **Form Factor**: Fraction of Energy Leaving Surface i That Reaches j
- **Radiosity**: Heat Transfer-Based Global Illumination Method

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