CS580:
Radiosity

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(윤성의)

Course URL:
http://sgvr.kaist.ac.kr/~sungeui/GCG

Tentative Schedule

- 30 → 16 → 9 students (as of 9/8)
- Oct-20 (mid-term exam)
- Oct. 27, 29: Students Presentation 1, 2 (2 talks per each class)
- Nov 3, 5: SP 3, 4

- Nov 10, 12: Mid-term project presentation
- Nov 17, 19 Students Presentation 5, 6 (2 talks per each
- Nov 24 26; SP 7, 8

- Dec 1, 3 Final-term presentation
- Dec 8, 10 reservation for now (no class for now)

Announcements

- **Make a project team of 1 or 2 persons for your final project**
  - Each student has a clear role
  - Declare the team at the KLMS by Sep-23; you don't need to define the topic by then
- **Each student (or team)**
  - Present one lecture and a paper related to the project in each talk
  - 15 min for each talk; we will have 5 min Q&A
- **Each team**
  - Give a mid-term review presentation for the project
  - Give the final project presentation

Deadlines

- Declare project team members
  - By 9/23 at KLMS
  - Confirm schedules of paper talks and project talks at 9/24

- Declare a student lecture topic and a paper for student presentations
  - by 9/30 at KLMS
  - Discuss them at the class of 10/1

- **Physically Controllable Relighting of Photographs**
- **Chris Careaga, Yagiz Aksoy | SIGGRAPH | 2025**

- **The paper describes a novel method to synthesize a realistic image with arbitrary lighting given the original image. The first step is to remove existing illumination in the image to get a delit version to be able to add a new illumination later on, which is achievable by Colorful Intrinsic Decomposition method (CID). Actually, CID allows us to obtain the diffuse image D using the diffuse reflectance A and diffuse shading S. Secondly, the 3D shape of the scene is estimated using Monocular Geometry Estimation method (MoGe). This monocular geometry and diffuse reflectance A are used to reconstruct a textured 3D mesh of the scene, M. This textured mesh, along with parametric light sources (position, color, and intensity), forms the input to a differentiable renderer. By optimizing these illumination**

- **Splatter Image: Ultra-Fast Single-View 3D Reconstruction**
- **Stanislaw Szymanowicz, Christian Rupprecht, Andrea Vedaldi. CVPR, 2024**
- 이 논문은 단일 이미지로부터 초고속 3D 재구성을 수행하는 Splatter Image라는 방식을 제안한다. 핵심 아이디어는 입력 이미지의 각 픽셀을 3D Gaussian 하나로 매핑하여, 이미지 전체를 "3D Gaussian 집합"으로 바꾸는 것이다. 이렇게 하면 일반적인 2D U-Net 기반 네트워크만으로 학습이 가능하고, Gaussian Splatting 기반 렌더링 덕분에 38FPS 추론, 588FPS 렌더링이라는 매우 빠른 속도를 달성한다. 성능도 ShapeNet, CO3D, Objaverse 등 다양한 데이터셋에서 PSNR·LPIPS 등에서 기존 방법보다 우수하거나 비슷한 결과를 내면서 학습/추론 비용은 훨씬 적다. 장점은 단일 GPU로도 대규모 학습이 가능할 정도로 효율적이며, 속도와 품질을 동시에 달성했다는 점이다. 단점은 복잡한 장면보다는 객체 중심(single object-centric) 재구성에 초점이 맞춰져 있어 일반 장면(scene-level) 확장은 제한적일 수 있다는 점이다.

Class Objective (Ch. 11)

- **Understand radiosity**
  - **Radiosity equation**
  - **Solving the equation**

History

- Problems with classic ray tracing
  - Not realistic
  - View-dependent

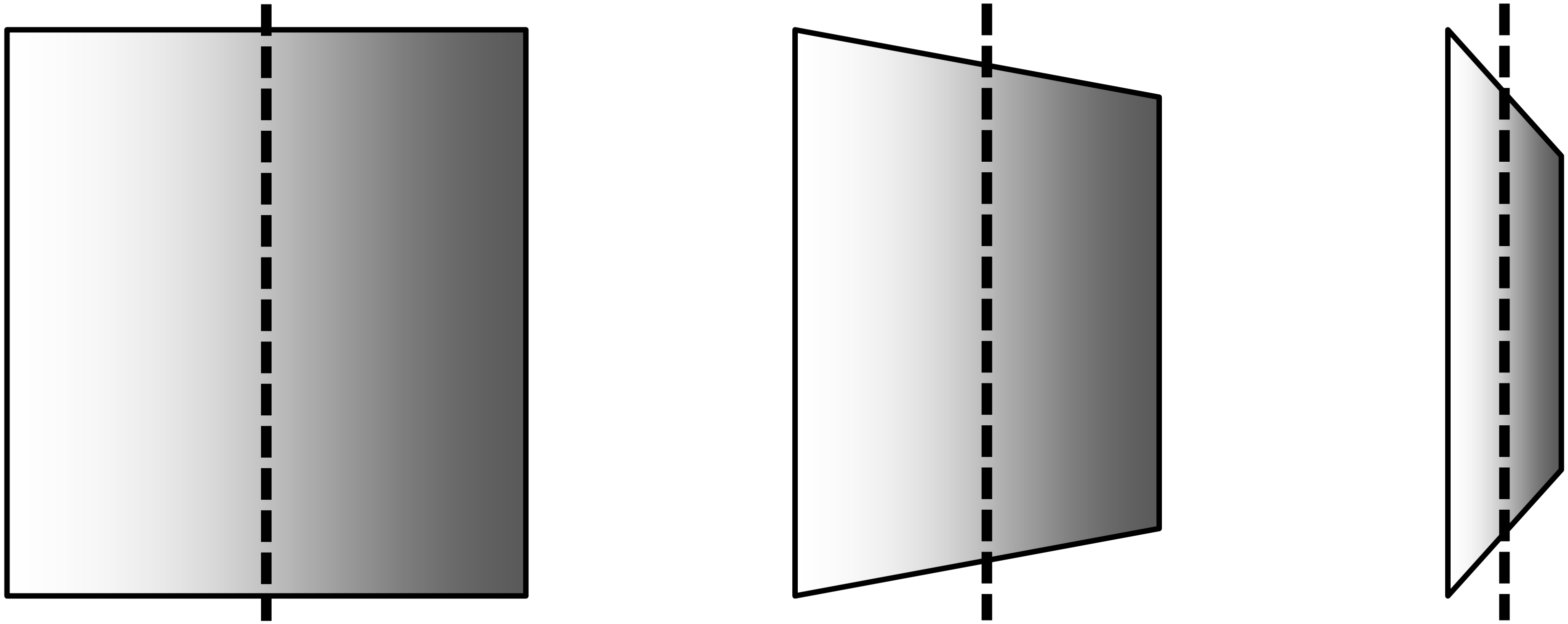
- Radiosity (1984)
  - Global illumination in diffuse scenes

- Monte Carlo ray tracing (1986)
  - Global illumination for any environment

Radiosity

- **Physically based method for diffuse environments**
  - **Support diffuse interactions, color bleeding, indirect lighting and penumbra**
  - **Account for very high percentage of total energy transfer**
  - **Finite element method**

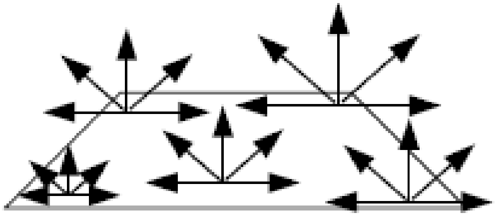
Key Idea #1: Diffuse Only



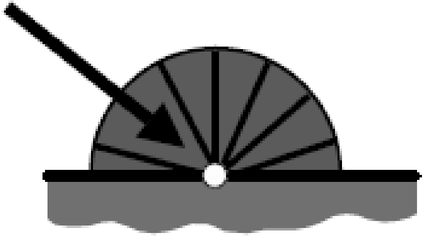
- **Radiance independent of direction**
  - **Surface looks the same from any viewpoint**
  - **No specular reflection**

Diffuse Surfaces

- **Diffuse emitter**
  - $L(x \rightarrow \Theta)$ **= constant over** Θ



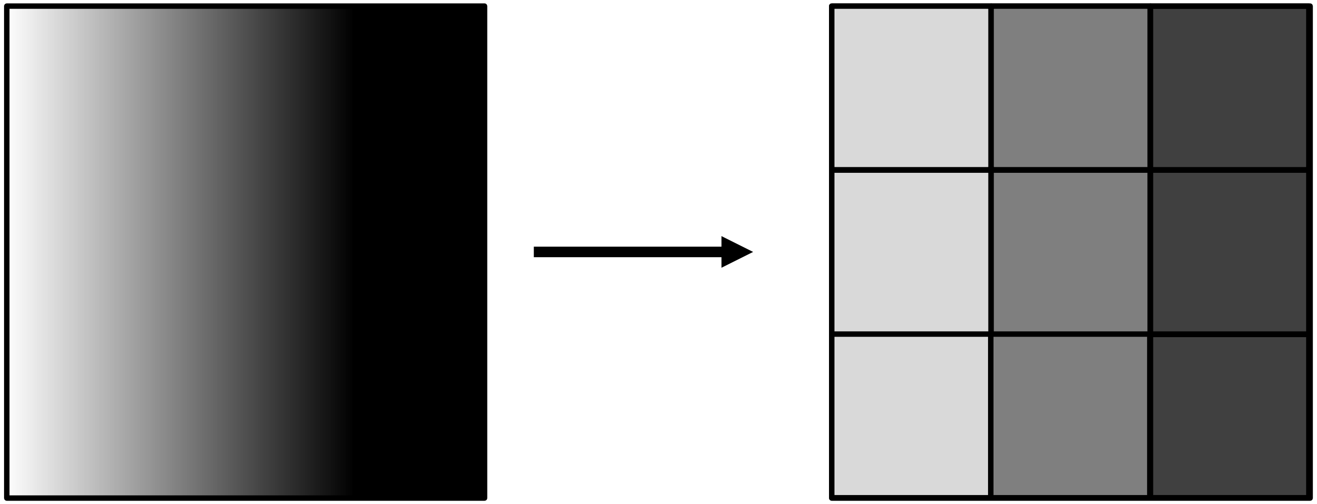
- **Diffuse reflector**
  - **Constant reflectivity**



From kavita's slides

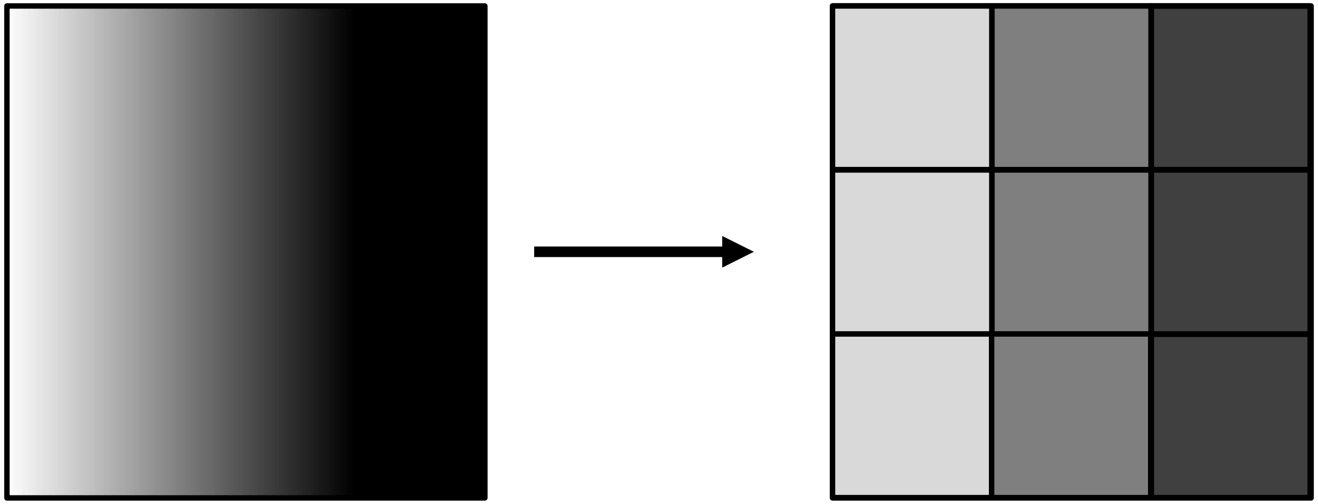
Key Idea #2: Constant Polygons

- Radiosity is an approximation
  - Due to discretization of scene into patches



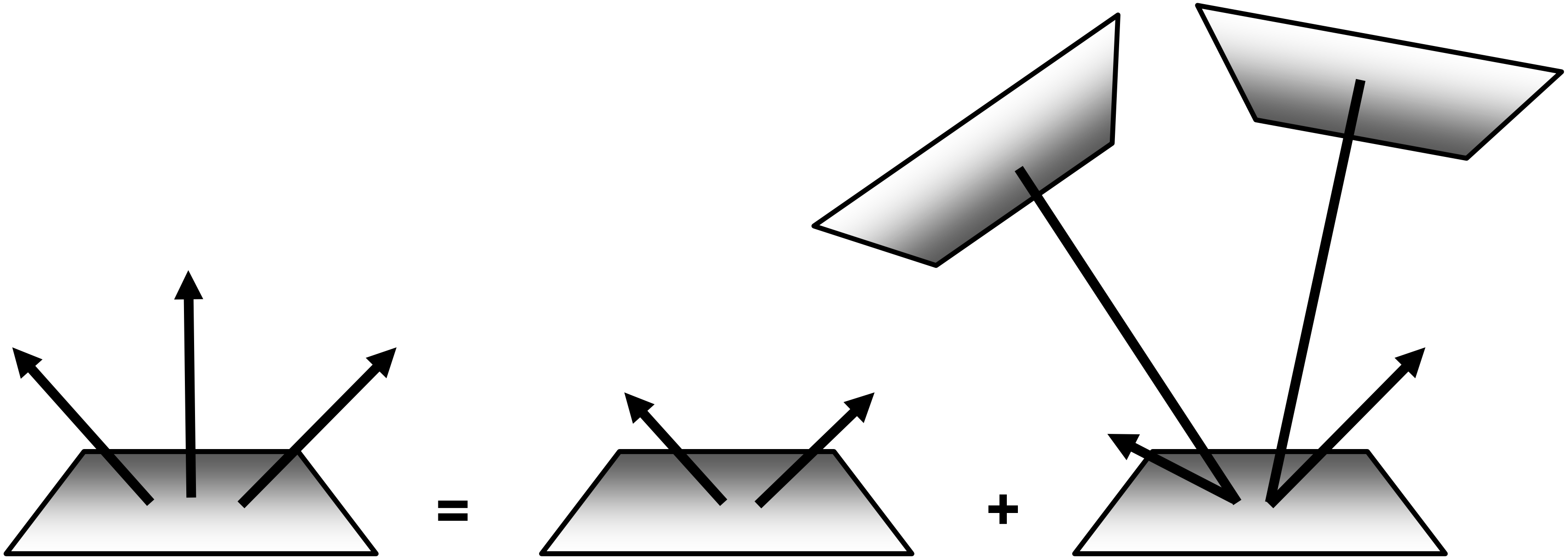
  - Subdivide scene into small polygons

Constant Radiance Approximation



- **Radiance is constant over a surface element**
  - **L(x) = constant over x**

Radiosity Equation



Radiosity

Self-emitted radiosity

Reflected radiosity

$$Radiosity_i = Radiosity_{self,i} + \sum_{j=1}^{N} a_{j\rightarrow i}\, Radiosity_j$$

Radiosity Equations

- **Radiosity for each polygon i**

$$Radiosity_1 = Radiosity_{self,1} \quad + \quad \sum_{j=1}^{N} a_{j \to 1}\, Radiosity_j$$

$$\vdots$$

$$Radiosity_i = Radiosity_{self,i} \quad + \quad \sum_{j=1}^{N} a_{j \to i}\, Radiosity_j$$

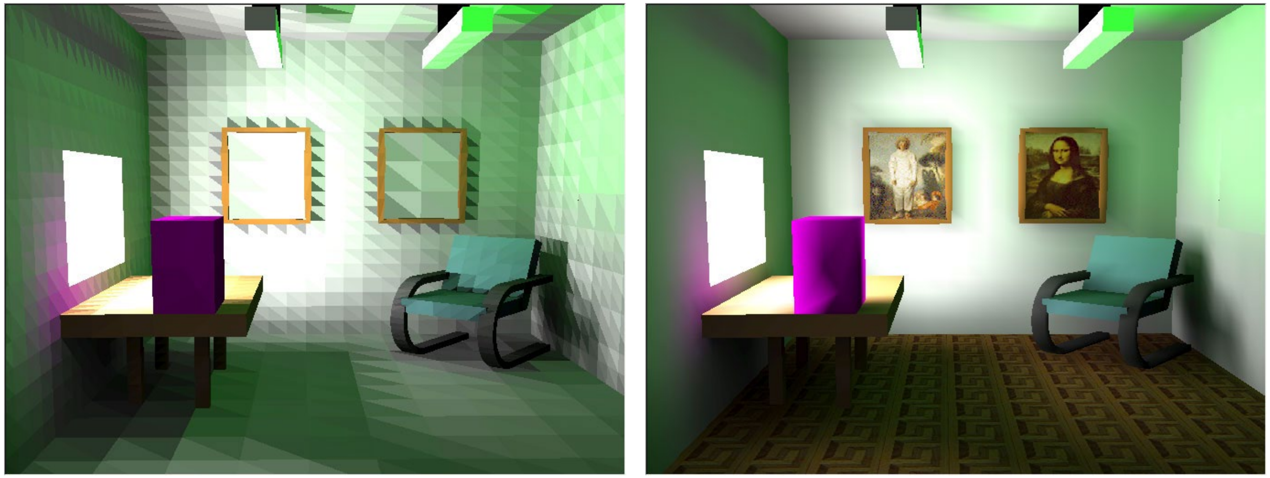
$$\vdots$$

$$Radiosity_N = Radiosity_{self,N} \quad + \quad \sum_{j=1}^{N} a_{j \to N}\, Radiosity_j$$

- **N equations and N unknown variables**

Radiosity Algorithm

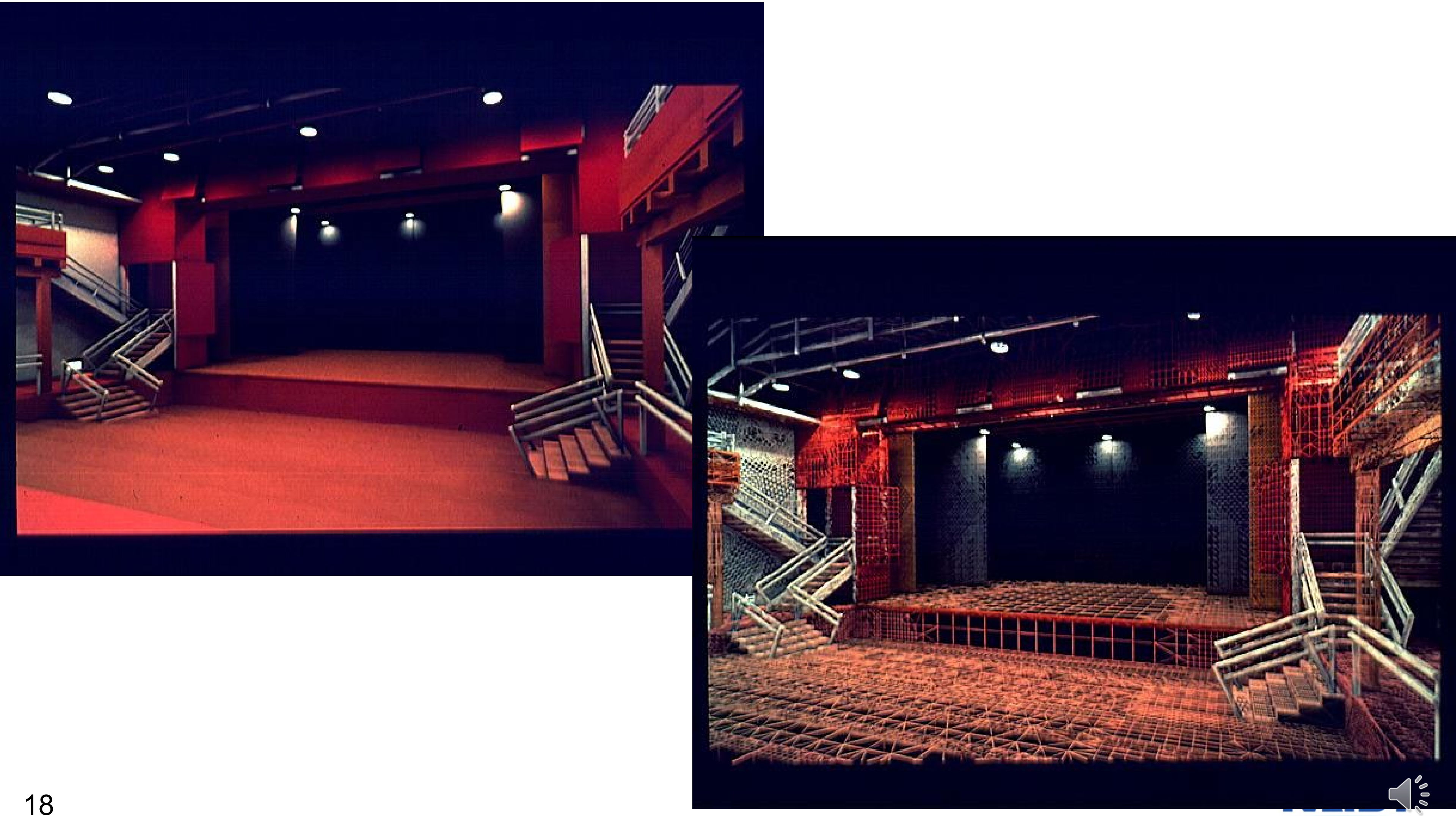
- Subdivide the scene in small polygons
- Compute a constant illumination value for each polygon
- Choose a viewpoint and display the visible polygon
    - Keep doing this process



From Donald Fong's slides

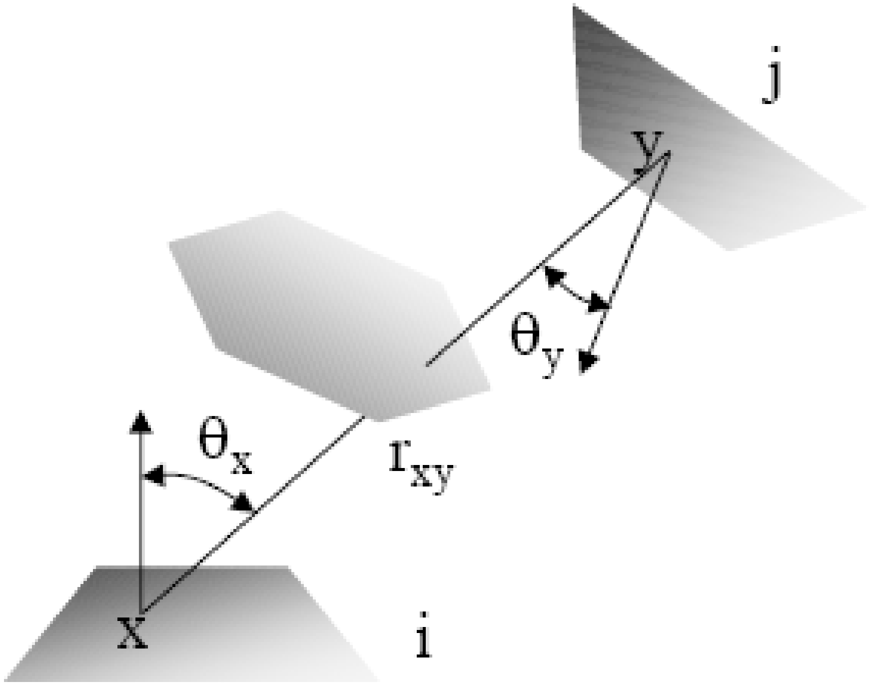
Radiosity Result

Theatre Scene



Compute Form Factors

$$F(j \rightarrow i) = \frac{1}{A_j} \int_{A_i} \int_{A_j} \frac{\cos\theta_x \cdot \cos\theta_y}{\pi \cdot r_{xy}^2} \cdot V(x,y) \cdot dA_y \cdot dA_x$$



Radiosity Equation

- **Radiosity for each polygon *i***

$$B_i = B_{e,i} + \rho_i \sum_j B_j F(i \to j)$$

- **Linear system**
  - B_i : radiosity of patch i (unknown)
  - $B_{e,i}$: emission of patch i (known)
  - ρ_I : reflectivity of patch i (known)
  - $F(i\to j)$: form-factor (coefficients of matrix)

Linear System of Radiosity

Known **Known**

$$\begin{bmatrix} 1-\rho_1 F(1\rightarrow 1) & -\rho_1 F(1\rightarrow 2) & \ldots & -\rho_1 F(1\rightarrow n) \\ \vdots & \vdots & \ddots & \vdots \\ -\rho_n F(n\rightarrow 1) & -\rho_n F(n\rightarrow 2) & \ldots & 1-\rho_n F(n\rightarrow n) \end{bmatrix} \begin{bmatrix} B_1 \\ \vdots \\ B_n \end{bmatrix} = \begin{bmatrix} B_{e,1} \\ \vdots \\ B_{e,n} \end{bmatrix}$$

$\uparrow$

Unknown

How to Solve Linear System

- **Matrix inversion**
  - **Takes O(n^3)**

- **Gather methods**
  - **Jacobi iteration**
  - **Gauss-Seidel**

- **Shooting**
  - **Southwell iteration**

Iterative Approaches

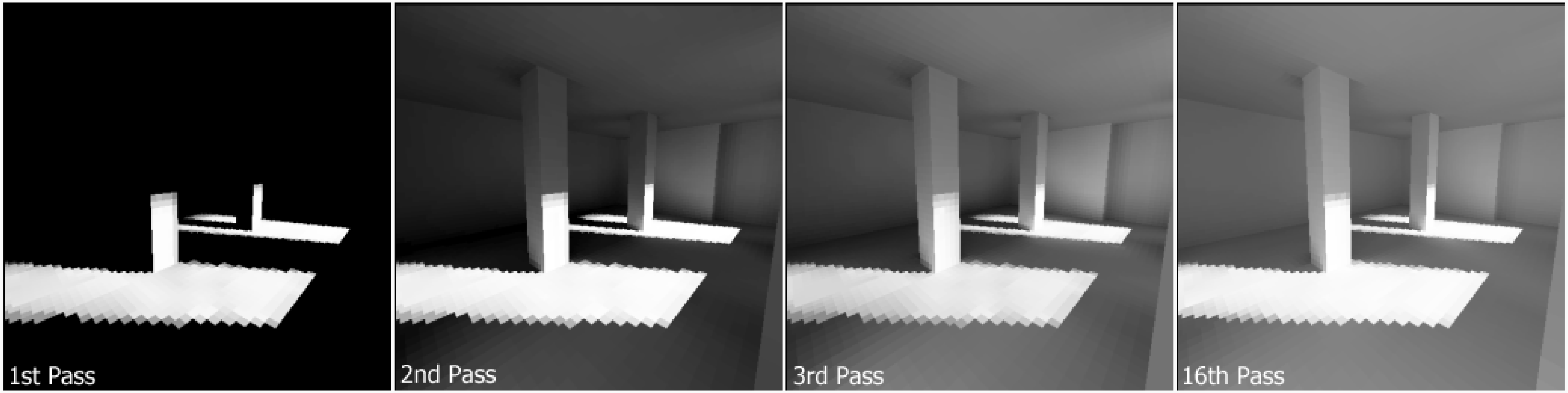
- **Jacobi iteration**
  - **Start with initial guess for energy distribution (light sources)**
  - **Update radiosity of all patches based on the previous guess**

$$\underset{\nwarrow\,\text{New values}}{B_i} = B_{e,i} + \rho_i \sum_j \underset{\nwarrow\,\text{Old values}}{B_j} F(i \rightarrow j)$$

  - **Repeat until converged**
- **Guass-Seidel iteration**
  - **New values used immediately**

Progress of Update Steps

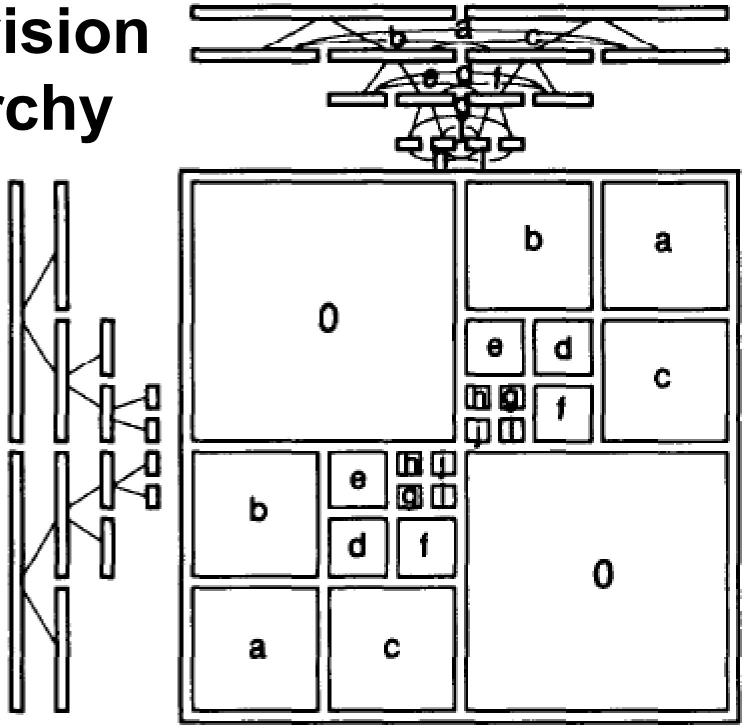
- **Update step supports the light bounce**



Multi-Resolution Approach

- **A Rapid Hierarchical Radiosity Algorithm, Hanrahan, et al, SIGGRAPH 1991**

Subdivision hierarchy

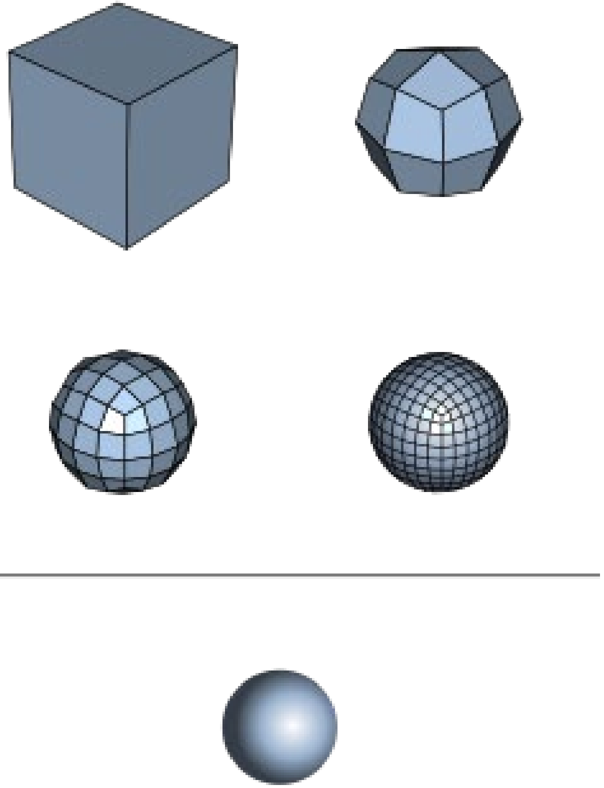


Block diagram of the form factor matrix

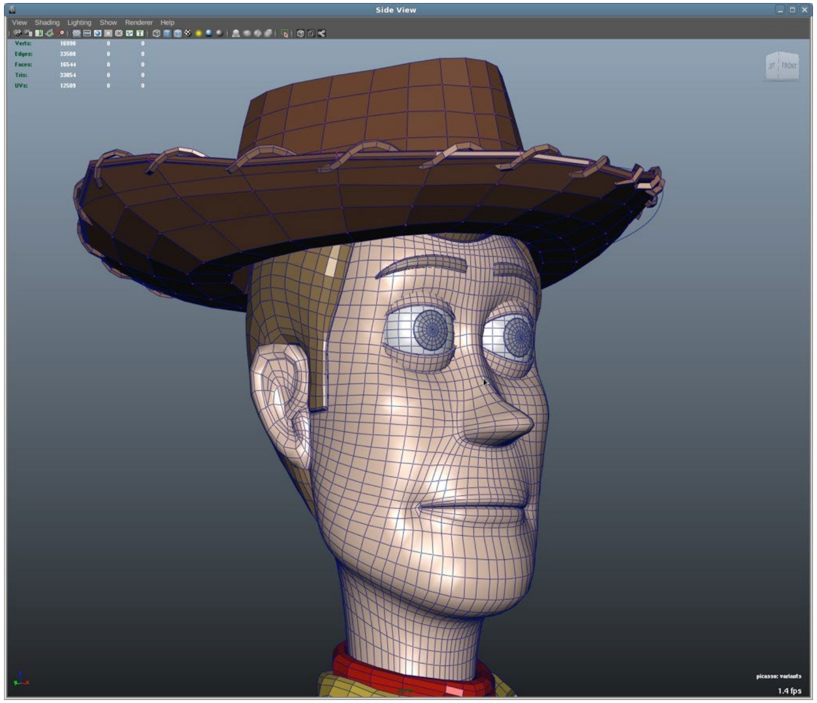
- **Refine triangles only if doing so improves the foam factor accuracy above a threshold**

Catmull-Clark Subdivision

- **Pixar Pioneers Win $1 Million Turing Award, 2020**



wiki



Verts:	16990	0	0
Edges:	33508	0	0
Faces:	16544	0	0
Tris:	33054	0	0
UVs:	12509	0	0

Hybrid and Multipass Methods

- **Ray tracing**
  - **Good for specular and refractive indirect illumination**
  - **View-dependent**

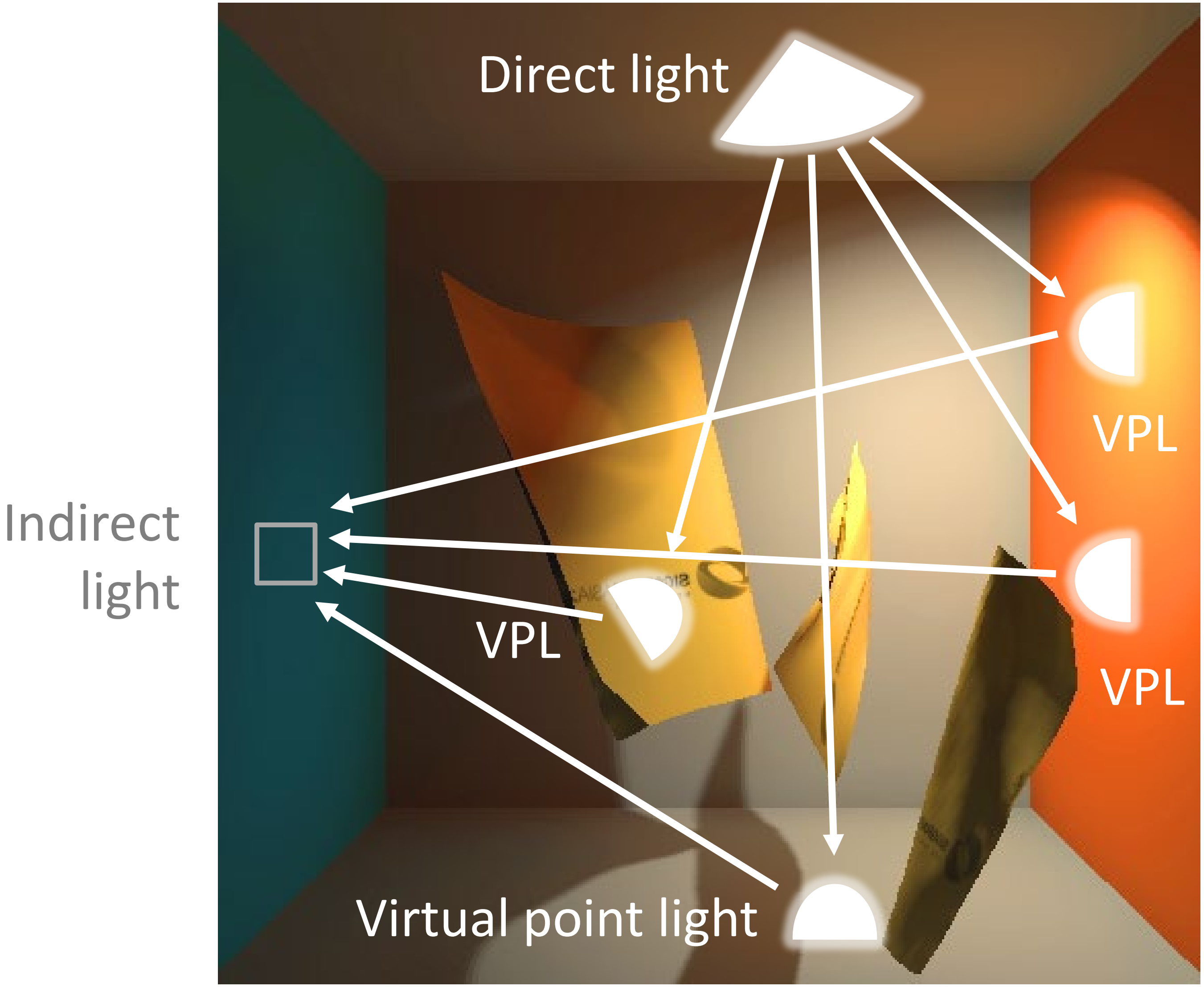
- **Radiosity**
  - **Good for diffuse**
  - **Allows interactive rendering**
  - **Does not scale well for massive models**

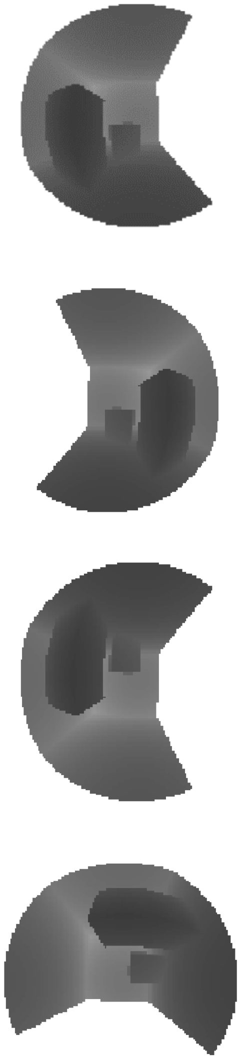
- **Hybrid methods**
  - **Combine both of them in a way**

Instant Radiosity

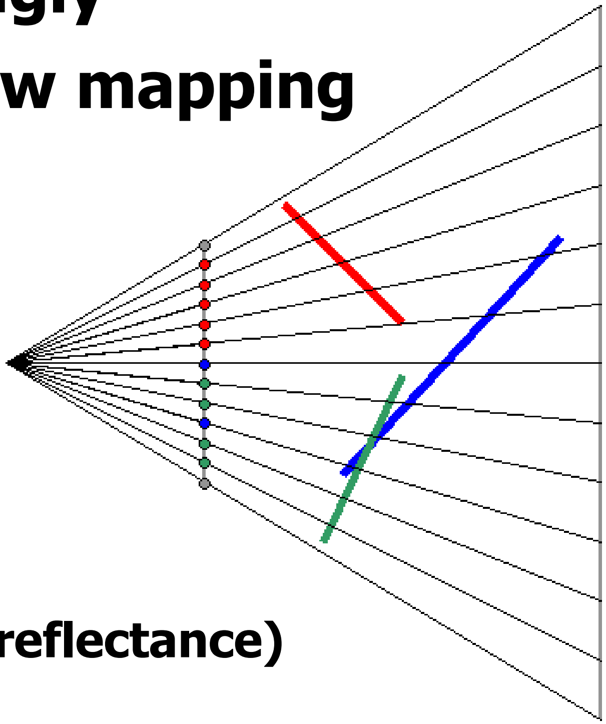
- Use the concept of radiosity
- Map its functions to those of classic rendering pipeline
  - Utilize fast GPU
- Additional concepts
  - Virtual point lights
  - Shadow maps

Instant Radiosity





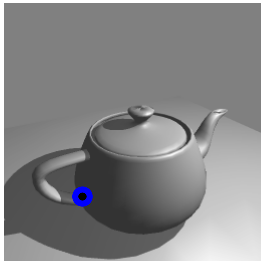
Ray Casting



- For each pixel, find closest object along the ray and shade pixel accordingly
- Produce similar results to shadow mapping

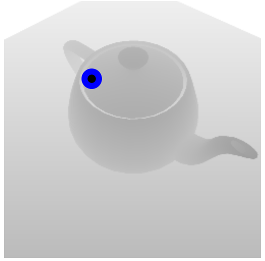
- Advantages
  - Conceptually simple
  - Can support CSG
  - Can take advantage of spatial coherence in scene
  - Can be extended to handle global illumination effects (ex: shadows and reflectance)
- Disadvantages
  - Renderer must have access to entire retained model
  - Hard to map to special-purpose hardware
  - Visibility computation is a function of resolution

Shadow Maps

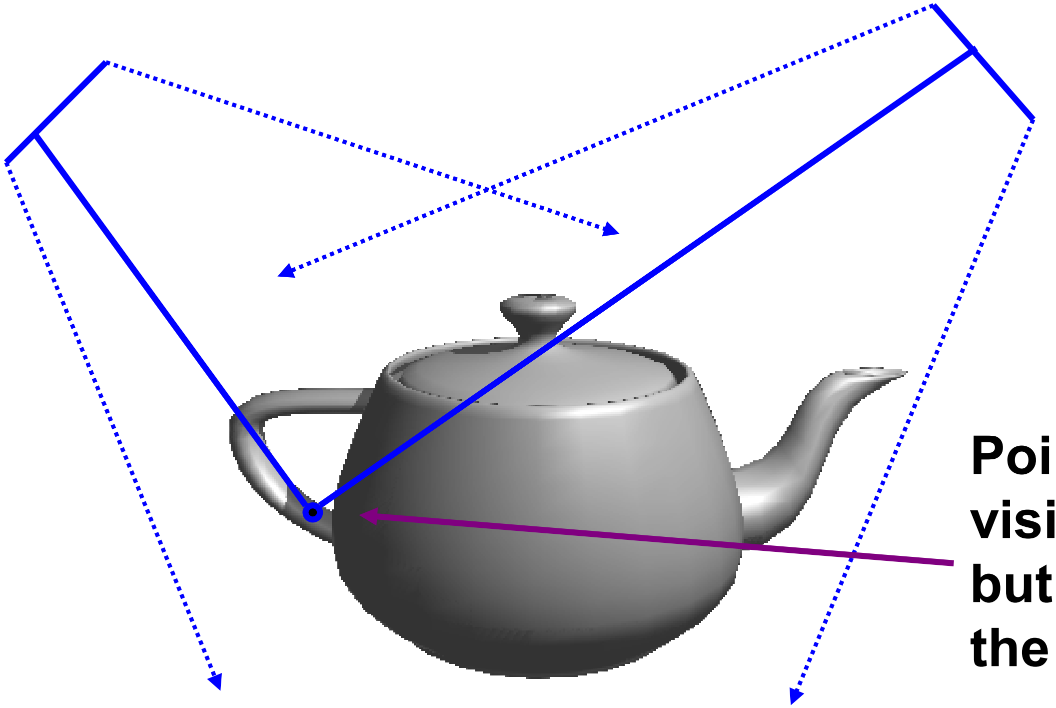


Eye

Use the depth map in the light view to determine if sample point is visible



Light



Point in shadow visible to the eye, but not visible to the light

Class Objectives were:

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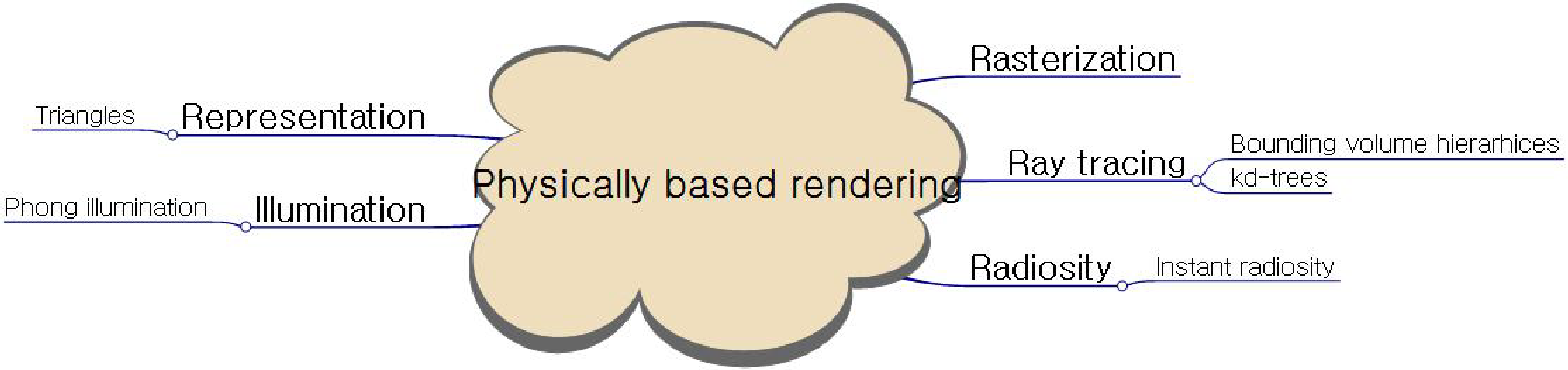
  - **Radiosity equation**
  - **Solving the equation**



Homework

- **Go over the next lecture slides before the class**
- **Watch 2 paper videos and submit your summaries every Mon. class**
  - **Just one paragraph for each summary**

Example:

Title: XXX XXXX XXXX

Abstract: this video is about accelerating the performance of ray tracing. To achieve its goal, they design a new technique for reordering rays, since by doing so, they can improve the ray coherence and thus improve the overall performance.

Any Questions?

- **Submit three times before the mid-term exam**
- **Come up with one question on what we have discussed in the class and submit at the end of the class**
  - 1 for typical questions
  - 2 for questions that have some thoughts or surprise me

Next Time

- **Radiometry and rendering equation**