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# CS482: Ray Tracing

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**Sung-Eui Yoon**  
(윤성의)

**Course URL:**  
<http://sglab.kaist.ac.kr/~sungeui/ICG/>

**KAIST**



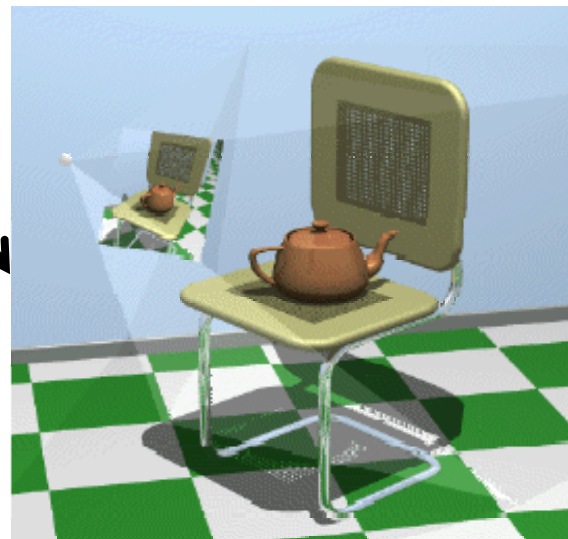
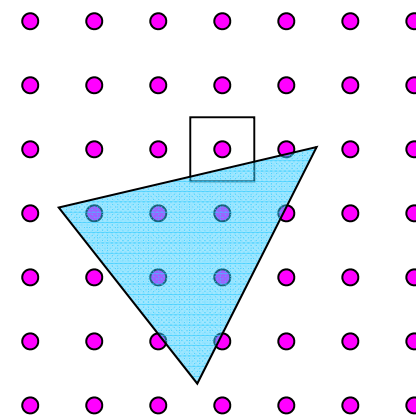
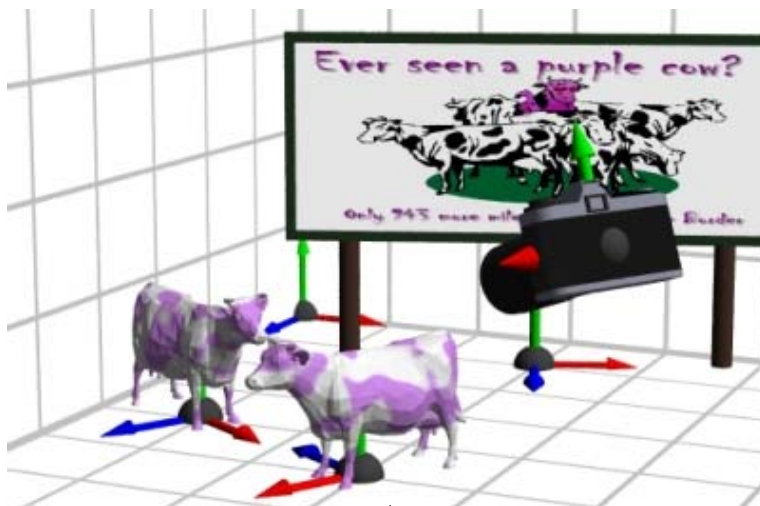
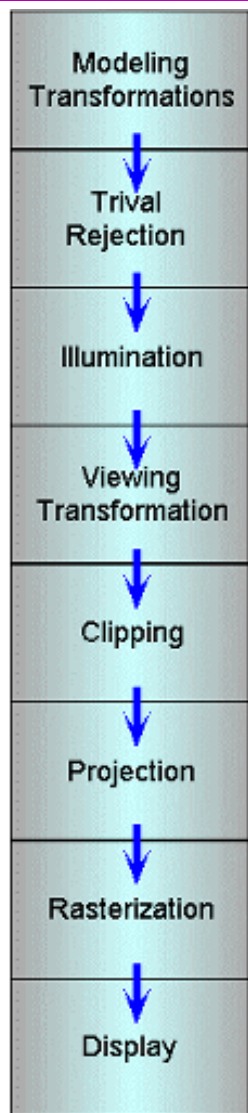
# Class Objectives

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- Understand a basic ray tracing
- Know its acceleration data structure and how to use it

# The Classic Rendering Pipeline



# Why we are using rasterization?

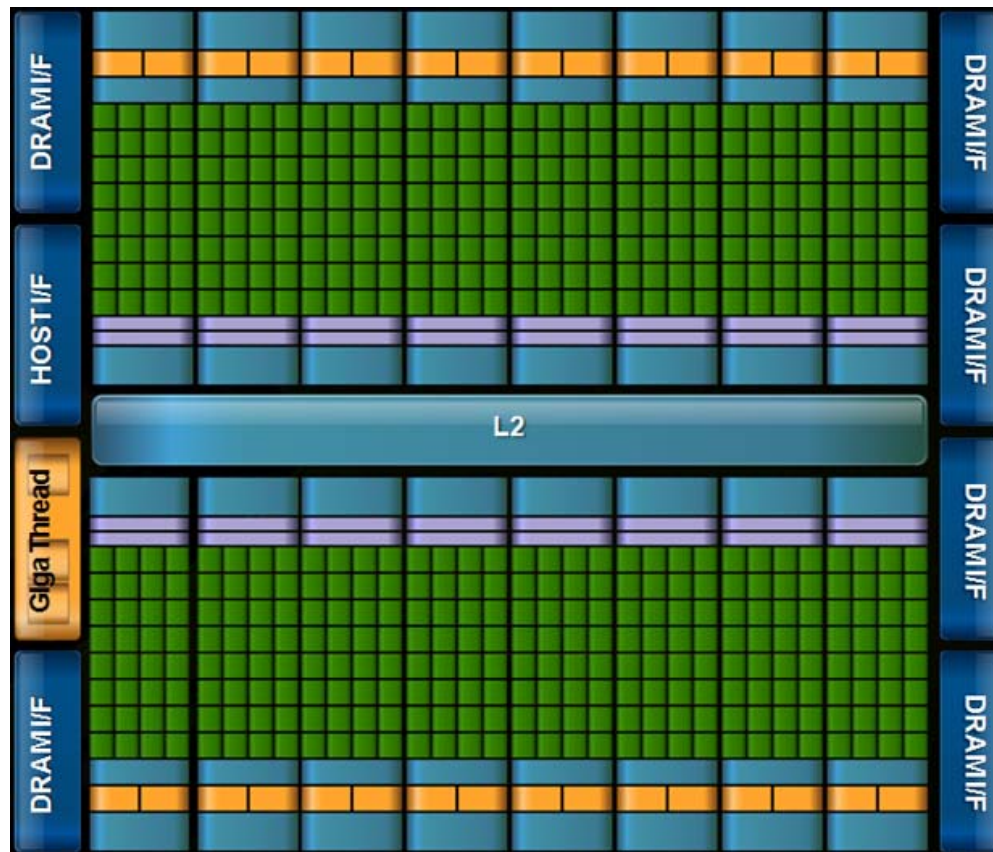
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- Efficiency
- Reasonably quality

# Fermi GPU Architecture

16 SM (streaming processors)



512 CUDA cores

Memory interfaces

# Where Rasterization Is

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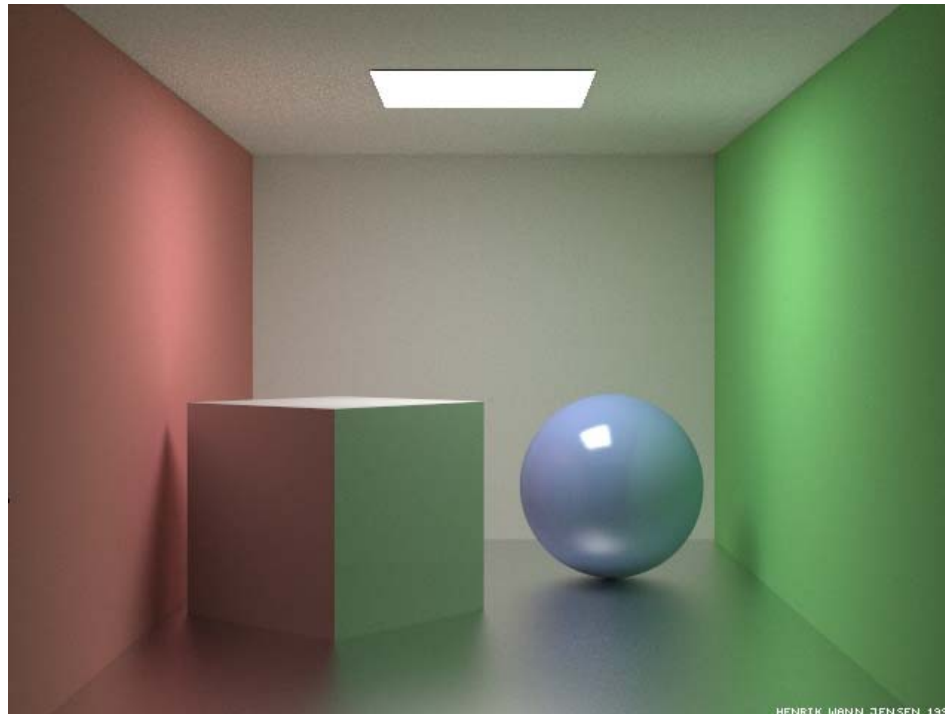
From Battlefield: Bad Company, EA Digital Illusions  
CE AB

# But what about other visual cues?

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- **Lighting**
  - **Shadows**
  - **Shading: glossy, transparency**
- **Color bleeding, etc**

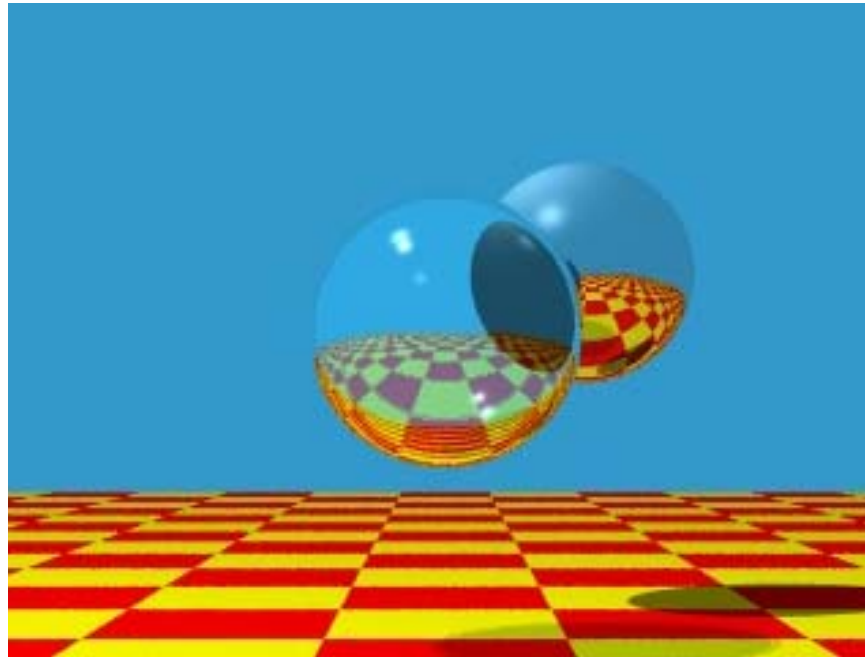


# Recursive Ray Casting

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- Gained popularity in when Turner Whitted (1980) recognized that *recursive* ray casting could be used for global illumination effects





# Ray Casting and Ray Tracing

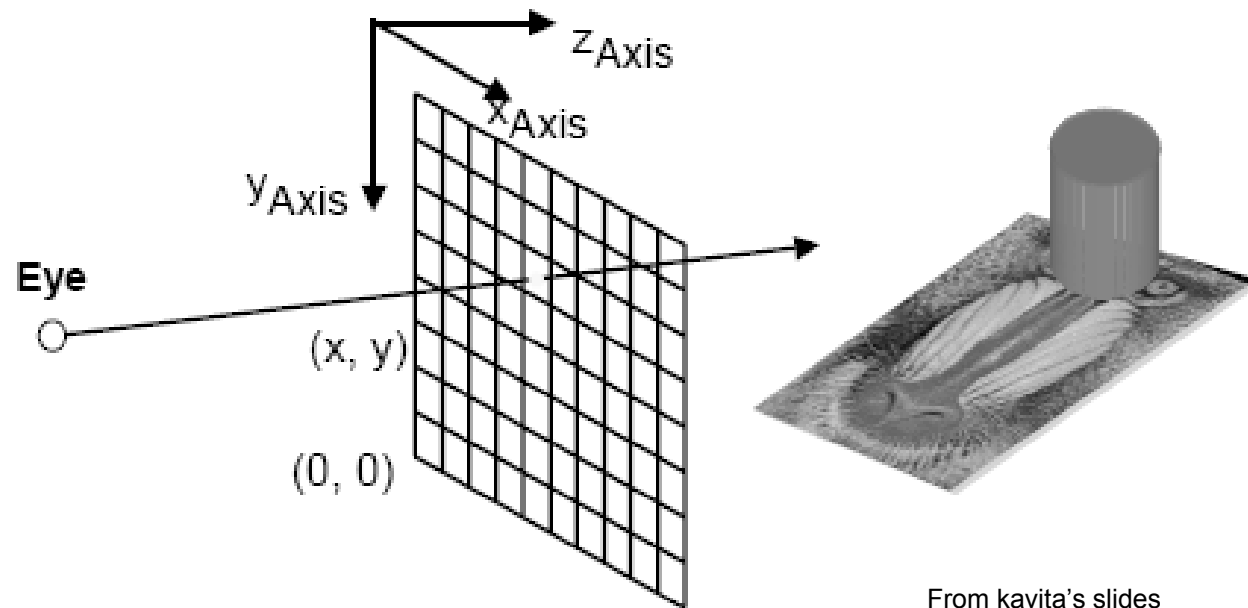
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- Trace rays from eye into scene
  - Backward ray tracing
- Ray casting used to compute visibility at the eye
- Perform ray tracing for arbitrary rays needed for shading
  - Reflections
  - Refraction and transparency
  - Shadows

# Basic Algorithms

- Rays are cast from the eye point through each pixel in the image



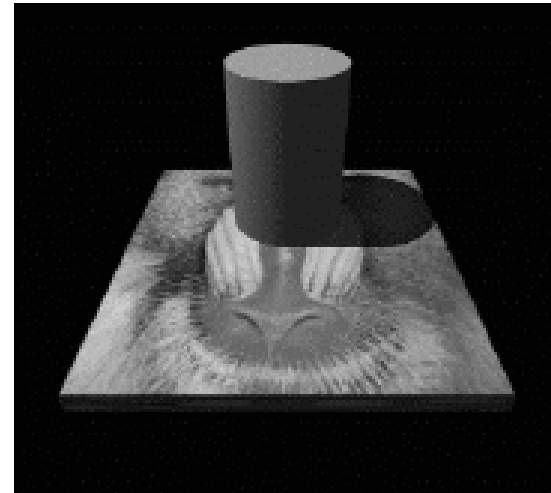
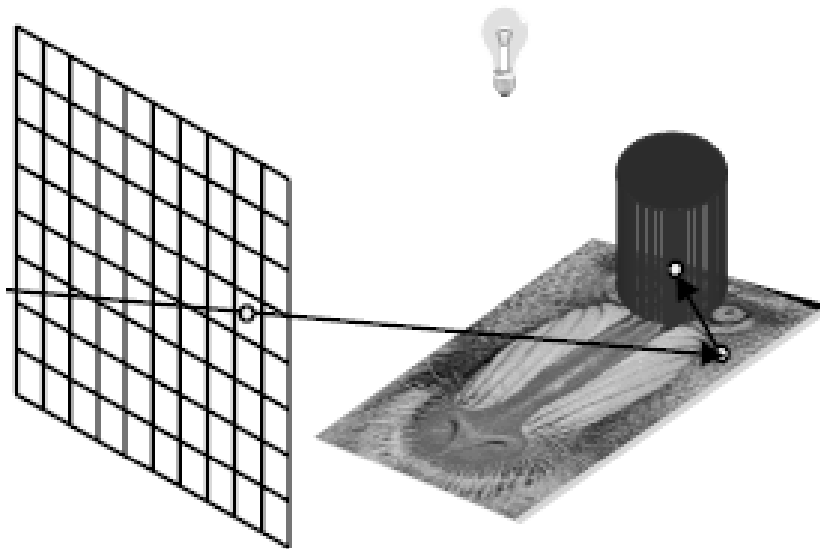
From kavita's slides

# Shadows

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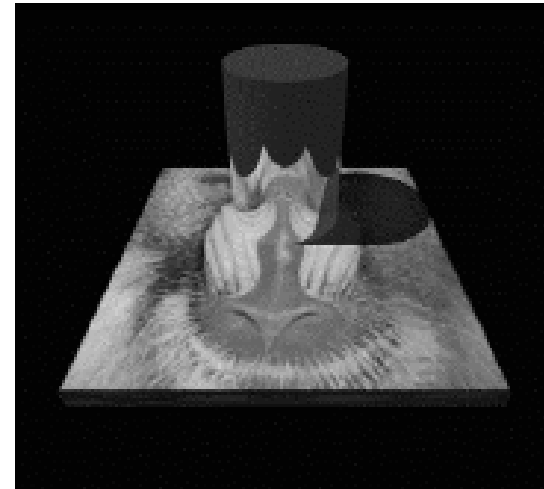
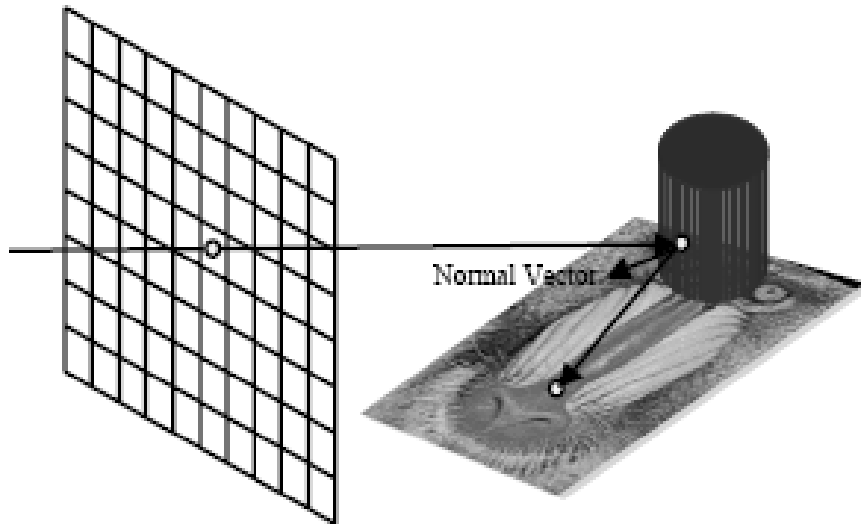
- Cast ray from the intersection point to each light source
  - Shadow rays



From kavita's slides

# Reflections

- If object specular, cast secondary reflected rays



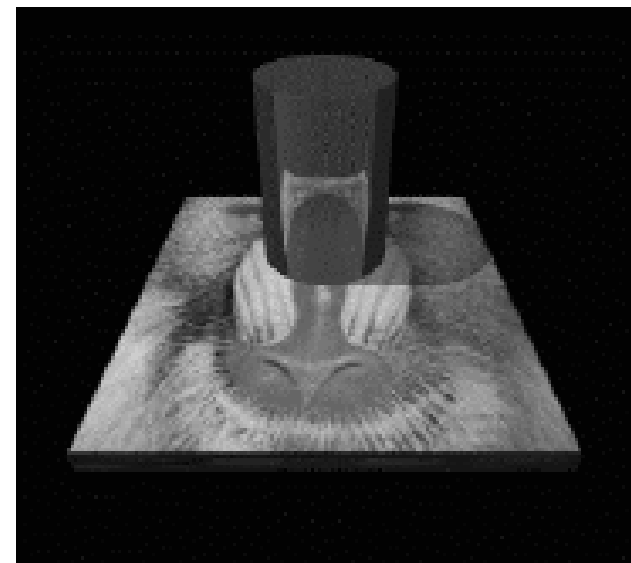
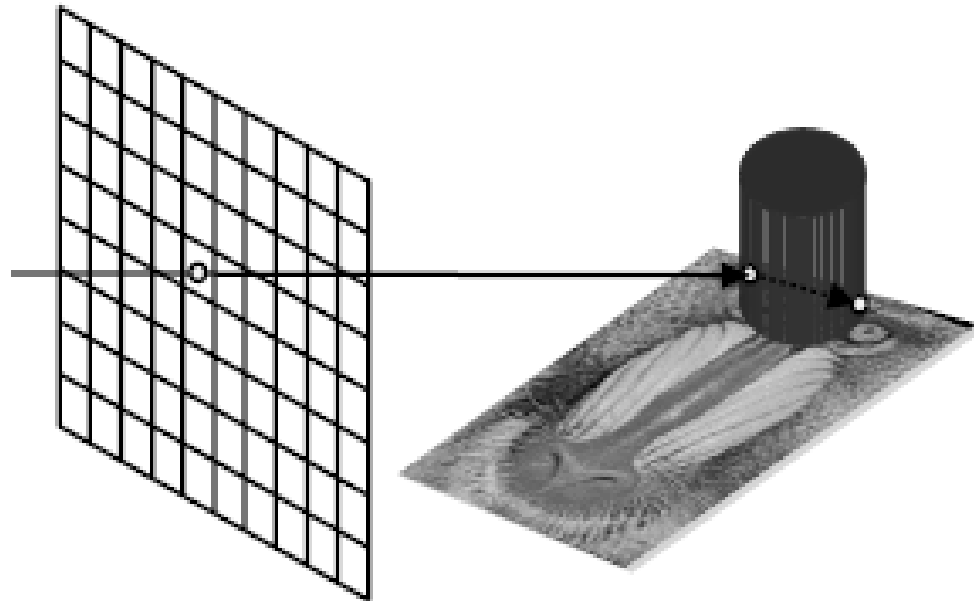
From kavita's slides

# Refractions

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- If object transparent, cast secondary refracted rays



From kavita's slides

# An Improved Illumination Model [Whitted 80]

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- Phong illumination model

$$I_r = \sum_{j=1}^{\text{numLights}} (k_a^j I_a^j + k_d^j I_d^j (\hat{N} \cdot \hat{L}_j) + k_s^j I_s^j (\hat{V} \cdot \hat{R})^{n_s})$$

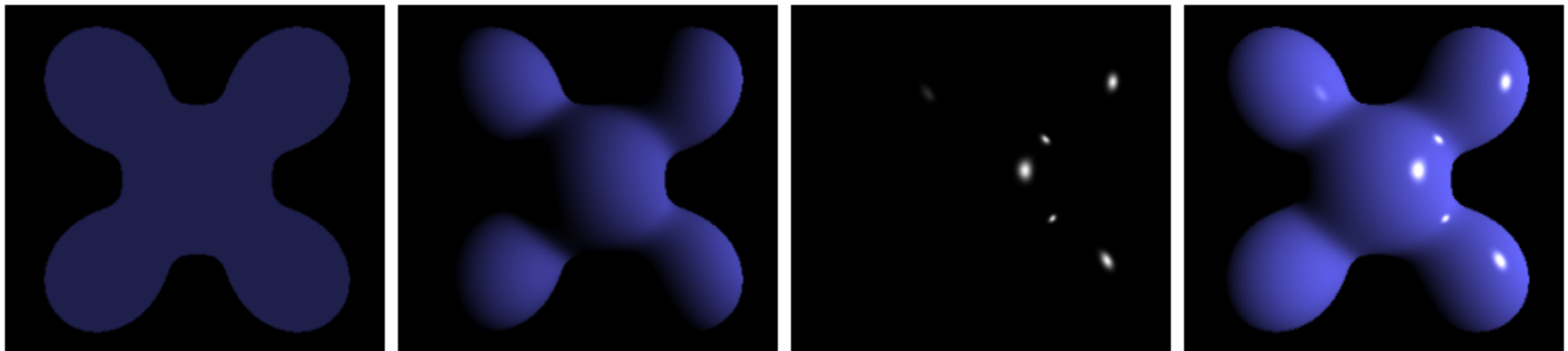
- Whitted model

$$I_r = \sum_{j=1}^{\text{numLights}} (k_a^j I_a^j + k_d^j I_d^j (\hat{N} \cdot \hat{L}_j)) + k_s S + k_t T$$

- S and T are intensity of light from reflection and transmission rays
- Ks and Kt are specular and transmission coefficient

# OpenGL's Illumination Model

$$I_r = \sum_{j=1}^{\text{numLights}} (k_a^j I_a^j + k_d^j I_d^j \max((\hat{N} \cdot \hat{L}_j), 0) + k_s^j I_s^j \max((\hat{V} \cdot \hat{R})^{n_s}, 0))$$



Ambient

+

Diffuse

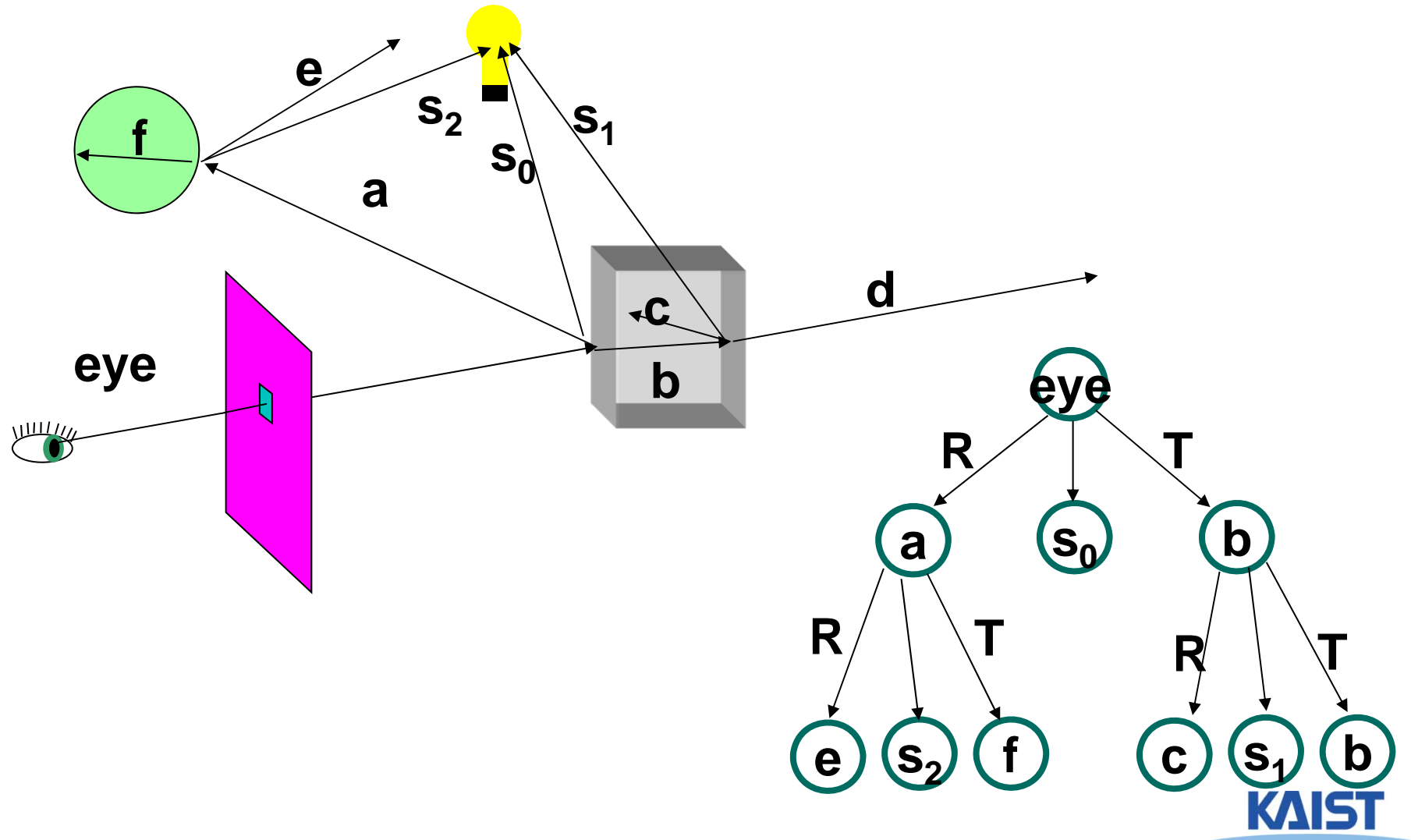
+

Specular

= Phong Reflection

From Wikipedia

# Ray Tree



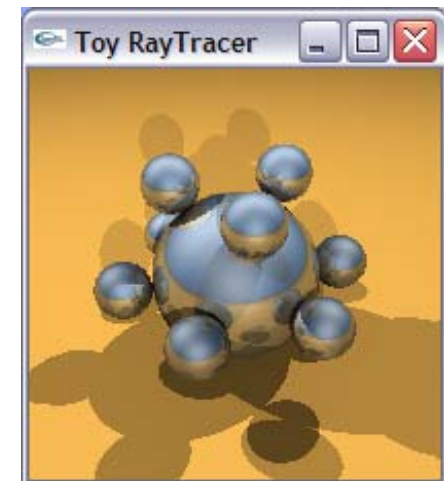


# Acceleration Methods for Ray Tracing

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- Rendering time for a ray tracer depends on the number of ray intersection tests per pixel
  - The number of pixels X the number of primitives in the scene
- Early efforts focused on accelerating the ray-object intersection tests
  - Ray-triangle intersection tests
- More advanced methods required to make ray tracing practical
  - Bounding volume hierarchies
  - Spatial subdivision (e.g., kd-trees)



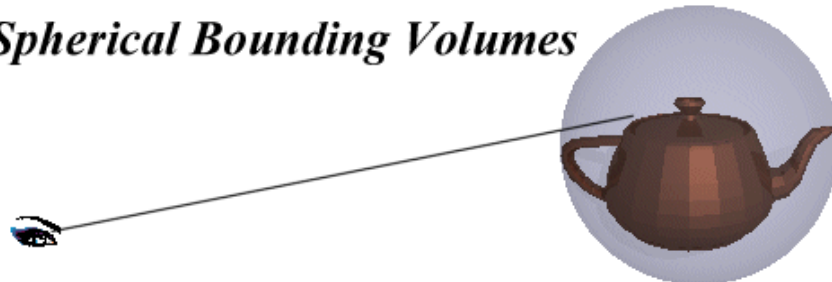
# Bounding Volumes

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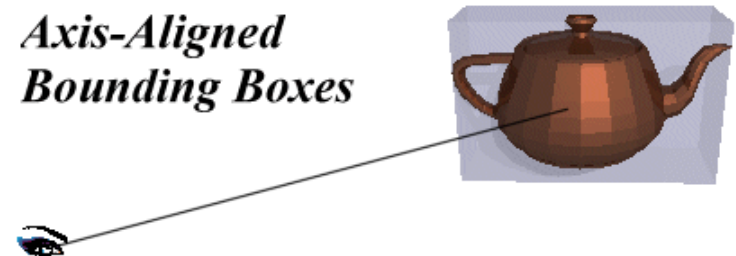
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- **Enclose complex objects within a simple-to-intersect objects**
  - If the ray does not intersect the simple object then its contents can be ignored
  - The likelihood that it will strike the object depends on how tightly the volume surrounds the object.
- **Spheres are simple, but not tight**
- **Axis-aligned bounding boxes often better**
  - Can use nested or hierarchical bounding volumes

*Spherical Bounding Volumes*



*Axis-Aligned Bounding Boxes*

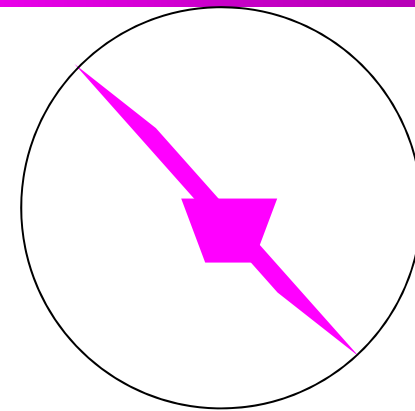


# Bounding Volumes

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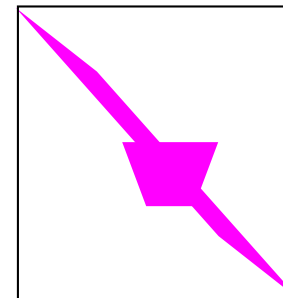
- **Sphere [Whitted80]**

- Cheap to compute
- Cheap test
- Potentially very bad fit



- **Axis-Aligned Bounding Box**

- Very cheap to compute
- Cheap test
- Tighter than sphere

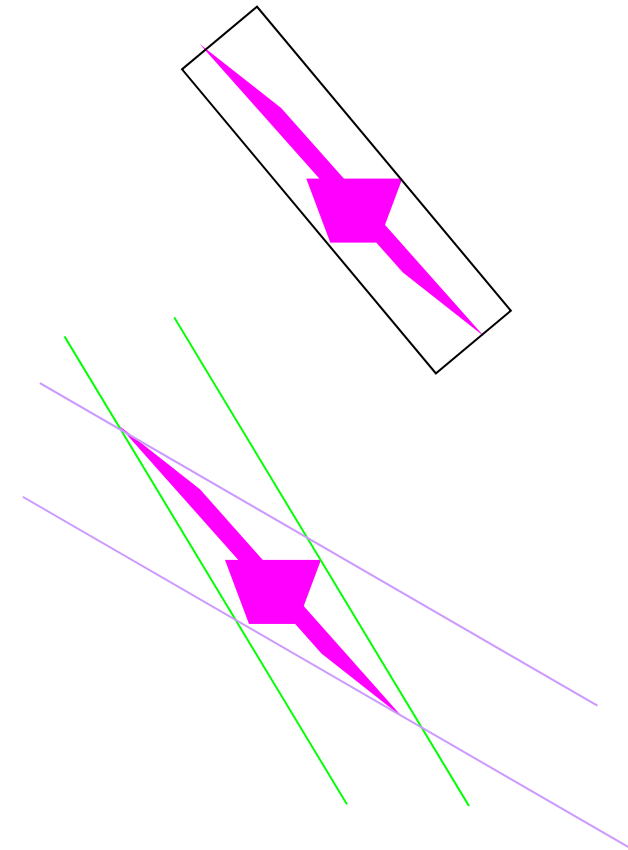


# Bounding Volumes

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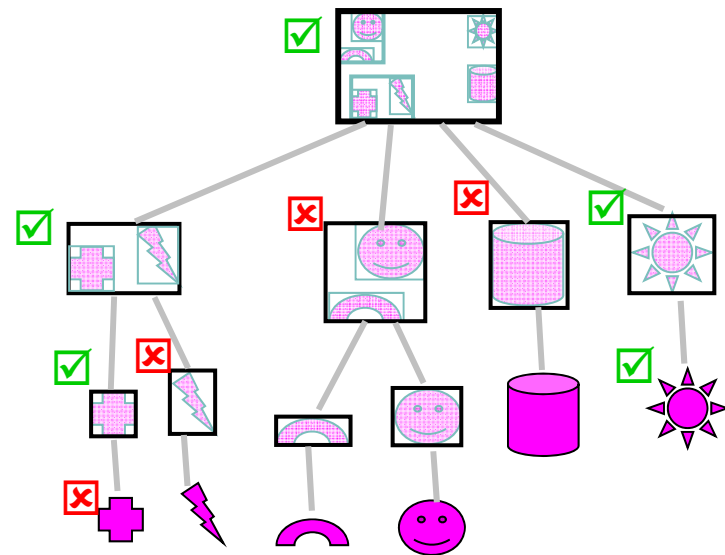
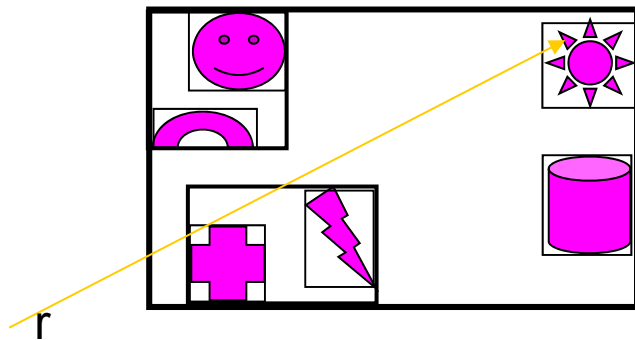
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- **Oriented Bounding Box**
  - Fairly cheap to compute
  - Fairly Cheap test
  - Generally fairly tight
- **Slabs / K-dops**
  - More expensive to compute
  - Fairly cheap test
  - Can be tighter than OBB



# Bounding Volume Hierarchy (BVH)

- Organize bounding volumes as a tree
  - Choose a partitioning plane and distribute triangles into left and right nodes
- Each ray starts with the scene BV and traverses down through the hierarchy



# Test-Of-Time 2006 Award



## RT-DEFORM: Interactive Ray Tracing of Dynamic Scenes using BVHs

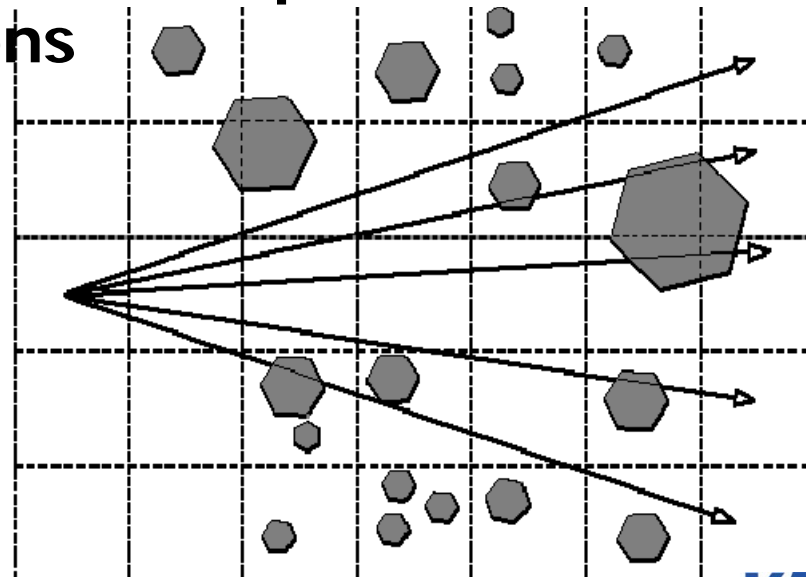
Christian Lauterbach, [Sung-eui Yoon](#),  
David Tuft, Dinesh Manocha  
IEEE Interactive Ray Tracing, 2006



# Spatial Subdivision

**Idea: Divide space in to subregions**

- Place objects within a subregion into a list
- Only traverse the lists of subregions that the ray passes through
- “Mailboxing” used to avoid multiple test with objects in multiple regions
- Many types
  - Regular grid
  - Octree
  - BSP tree
  - kd-tree



# Ray Tracing with kd-tree or BVHs

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- Goal: find closest hit with scene
- Traverse tree front to back (starting from root)
- At each node:
  - If leaf: intersect with triangles
  - If inner: traverse deeper

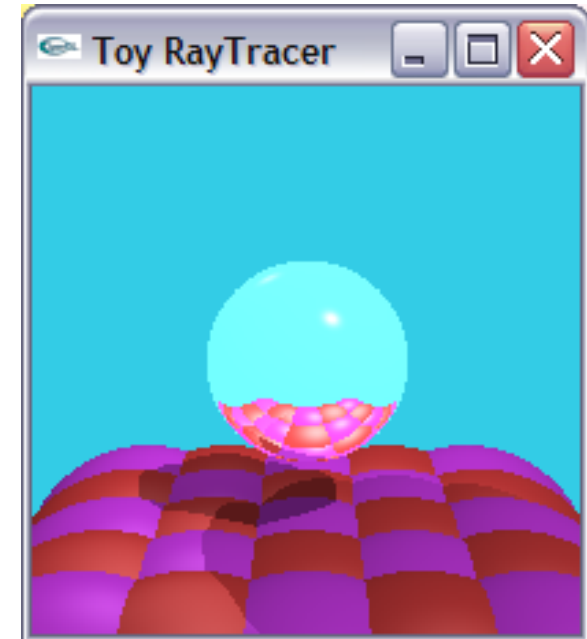


# Classic Ray Tracing

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- **Gathering approach**
  - From lights, reflected, and refracted directions
- **Pros of ray tracing**
  - Simple and improved realism over the rendering pipeline
- **Cons:**
  - Simple light model, material, and light propagation
  - Not a complete solution
  - Hard to accelerate with special-purpose H/W



# History

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- **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

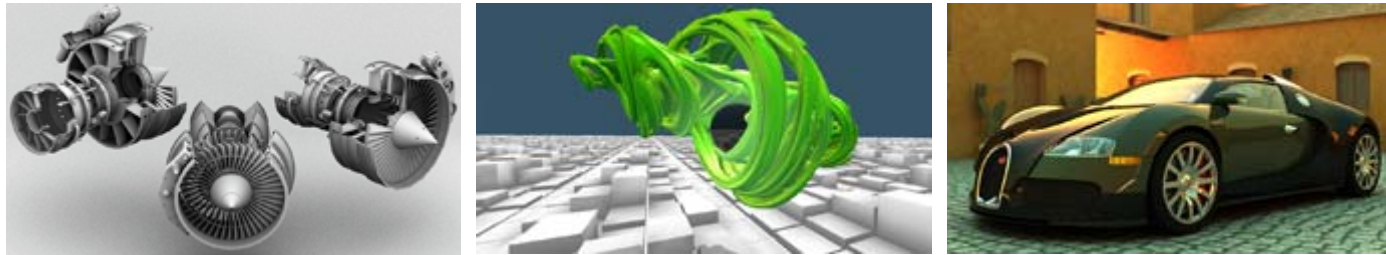
# Interactive Ray Tracing Kernels

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- **OptiX, Nvidia**

- Utilize GPU computing architectures and CUDA



- **Embree, Intel**

- Utilize CPUs (multi-threaded and SIMD)



# Class Objectives were:

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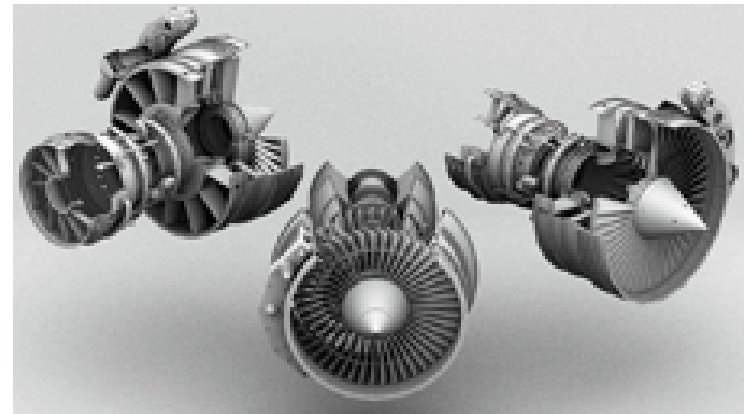
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- Understand a basic ray tracing
- Know its acceleration data structure and how to use it

# PA1

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- **Get to know OptiX or Embree**
  - Download, and compile either one of those two methods; you can just use precompiled ones
  - Try out a few scenes
  - Send images of those scenes to TA, MyungBae Sohn
- **Deadline**
  - 11:59pm on 18<sup>th</sup> of Sep.
- **Note**
  - Easy one, but start early



# Next Time

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- Radiosity

# Homework

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- **Go over the next lecture slides before the class**
- **Watch 2 SIG/I3D/HPG videos and submit your summaries every Tue. 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?

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- **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
- **Write a question more than 4 times on Sep./Oct.**
  - Online submission is available at the course webpage