Global Illumination

(BRDFs, Ray Tracing)

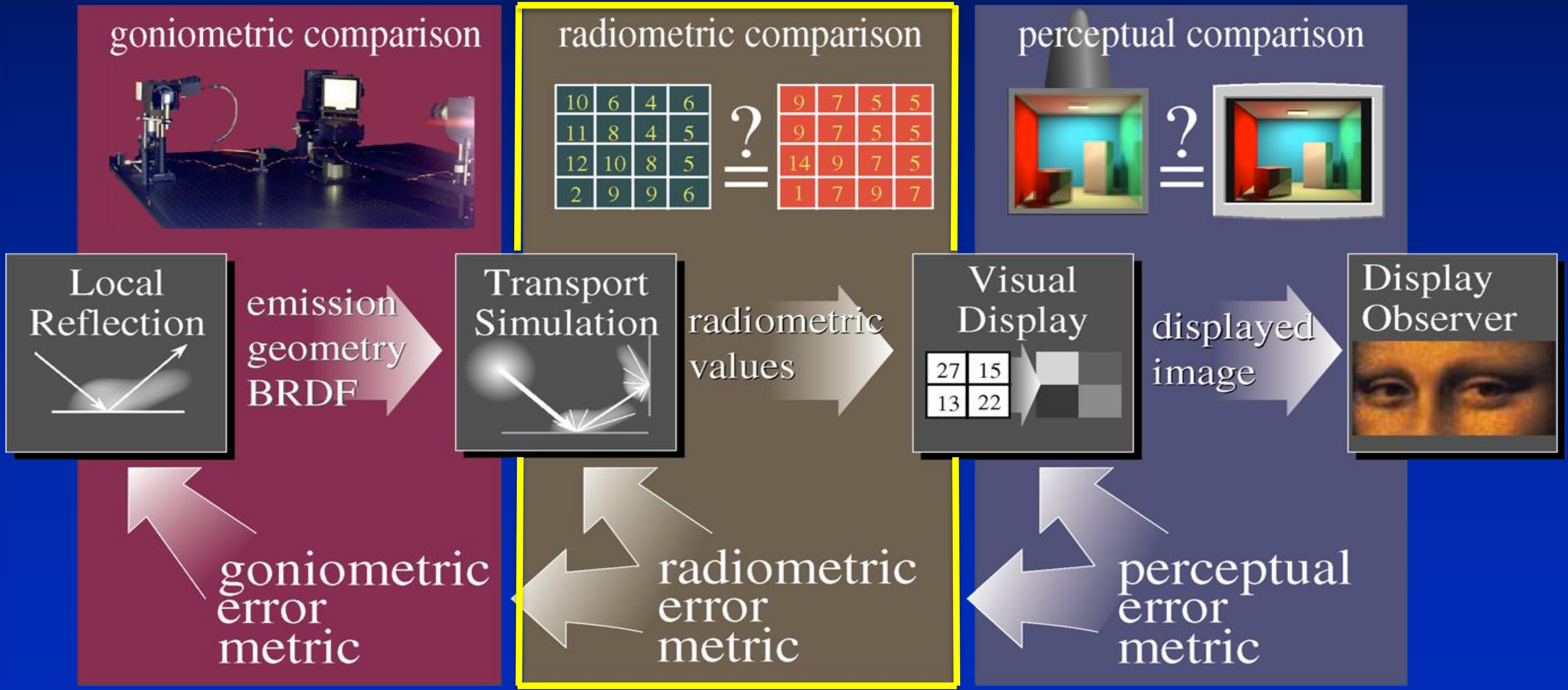
Visual Imaging in the Electronic Age

Donald P. Greenberg

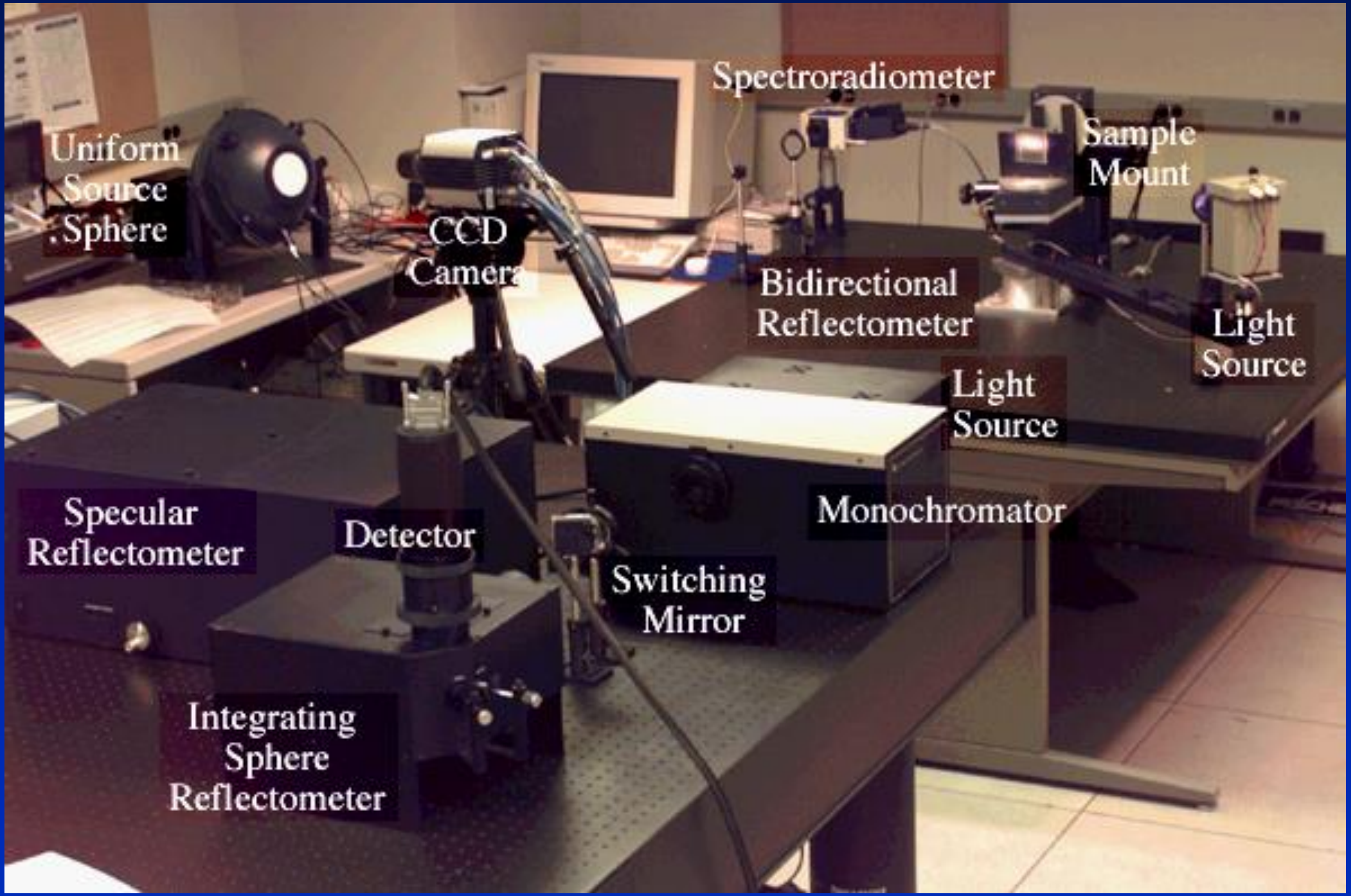
October 29, 2020

Lecture #16

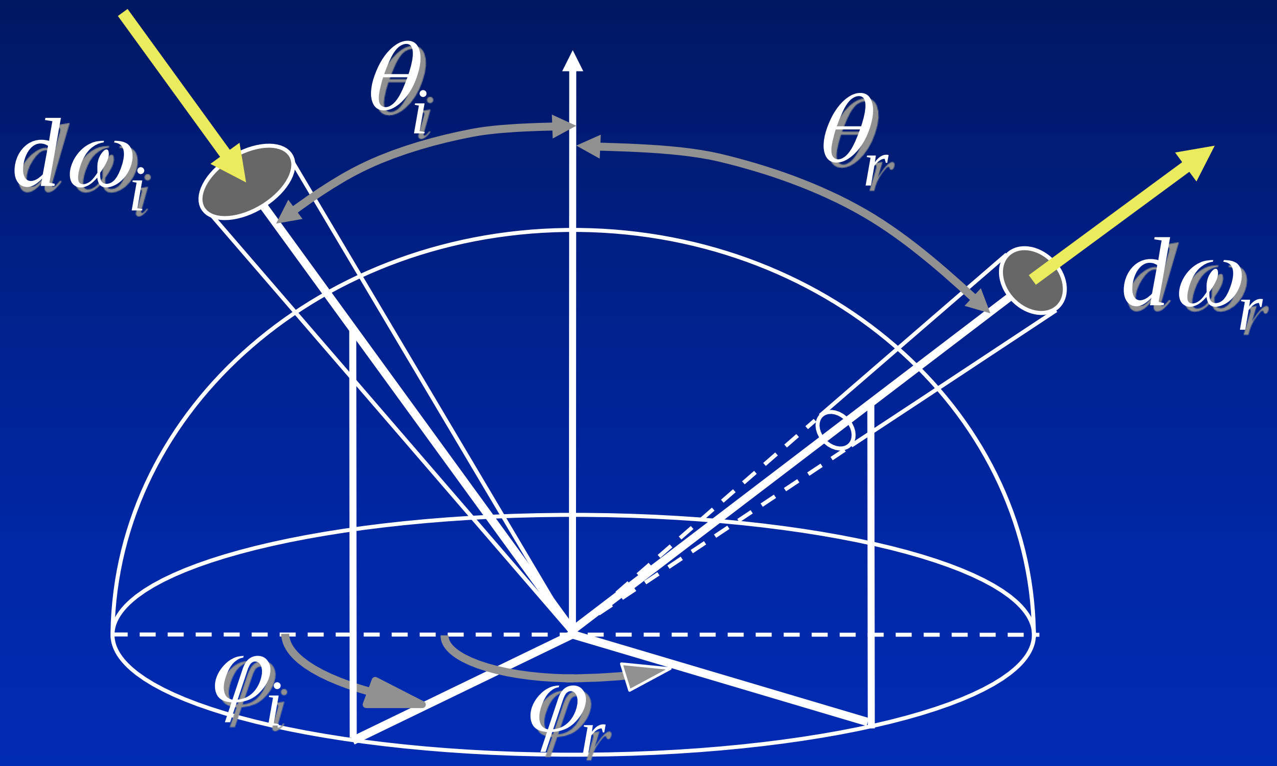
Rendering Framework 1997



Light Measurement Laboratory

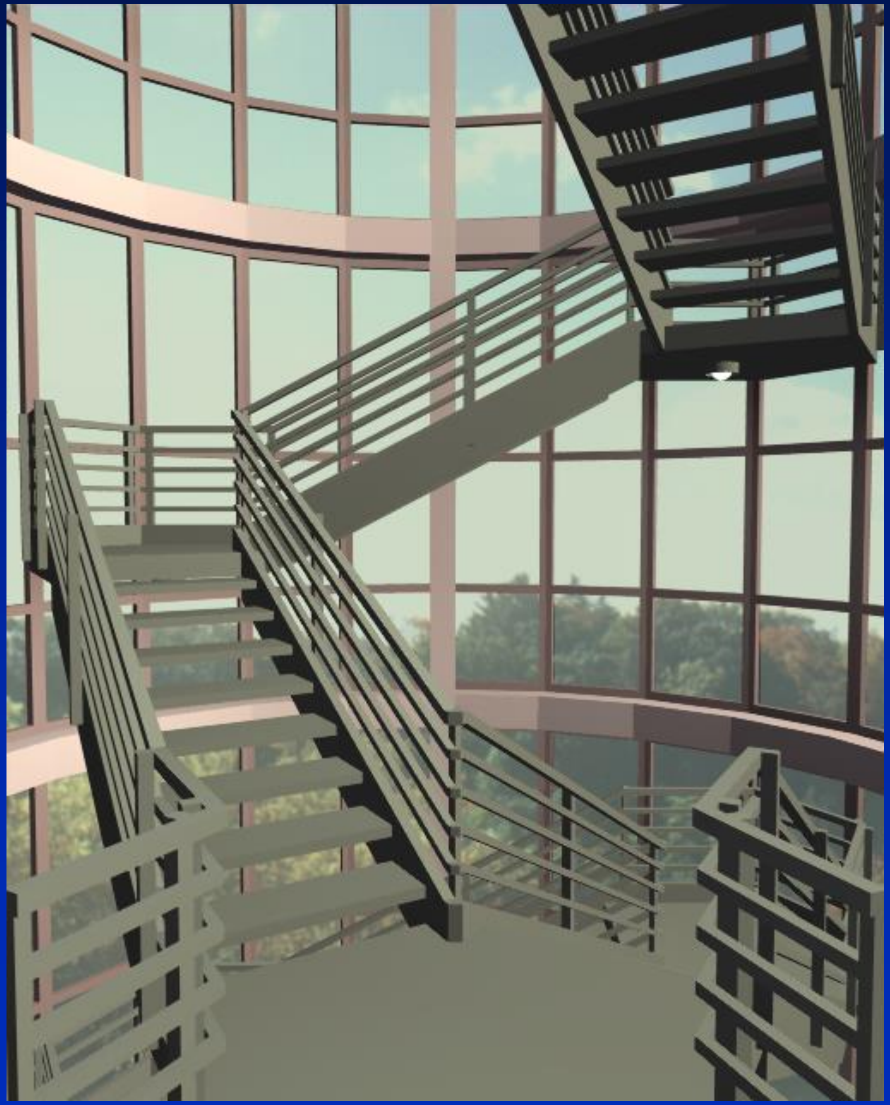


Reflection Geometry (BRDF)



Bidirectional Reflection Distribution Function

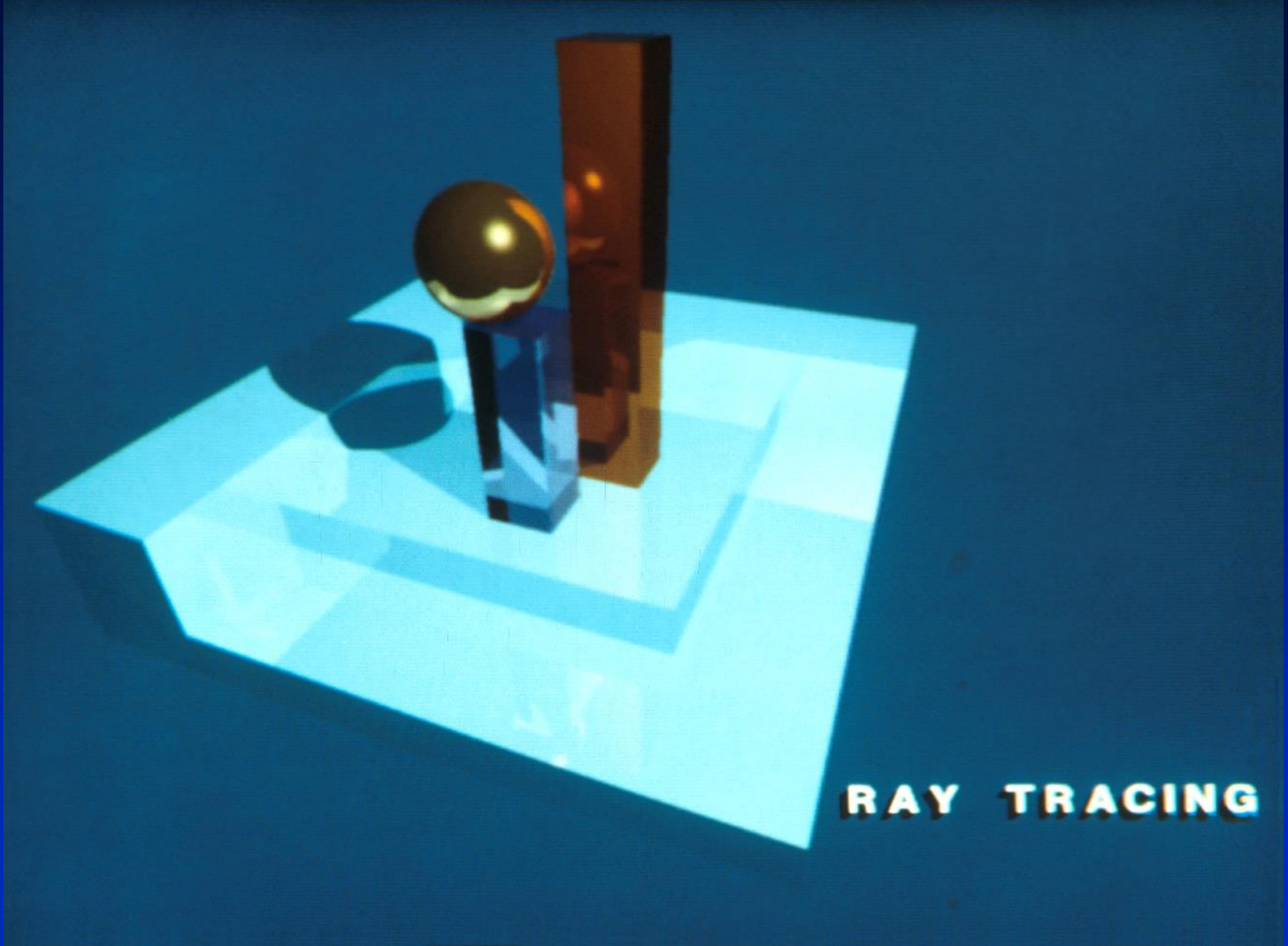
Direct Lighting Only



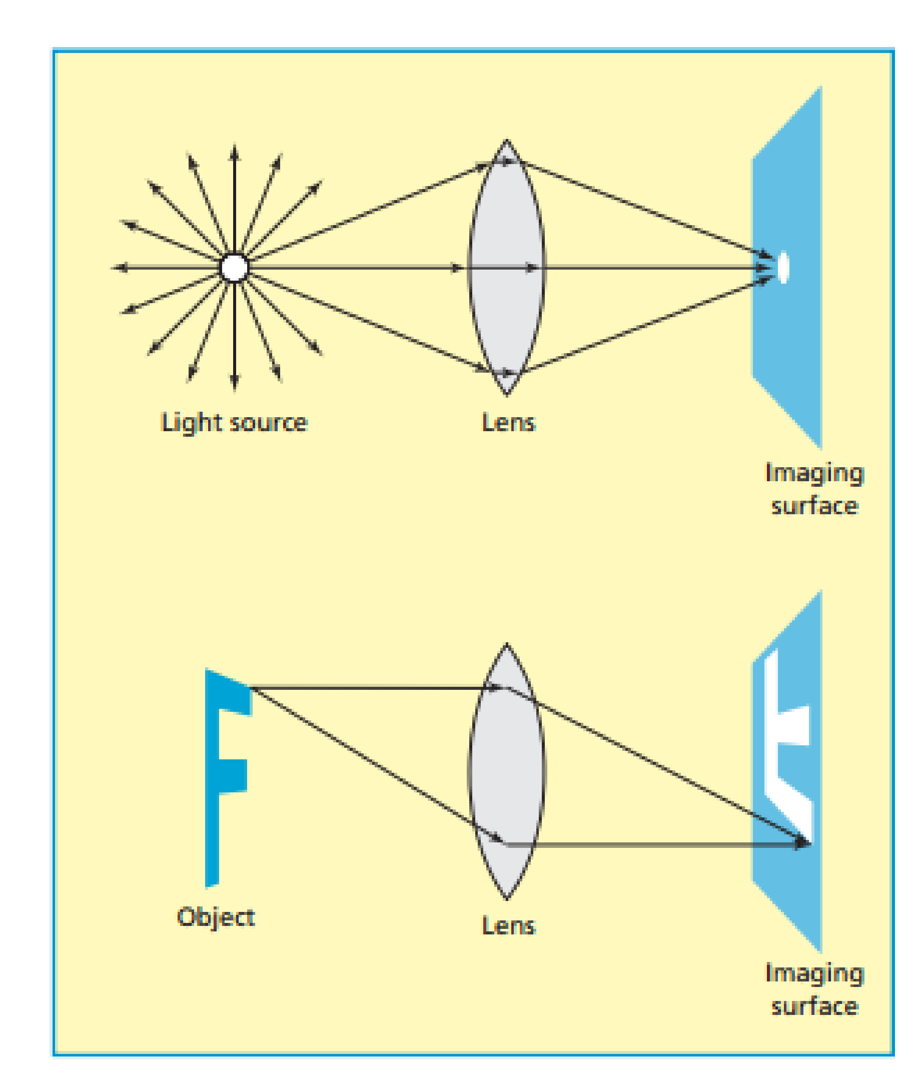
Global Illumination

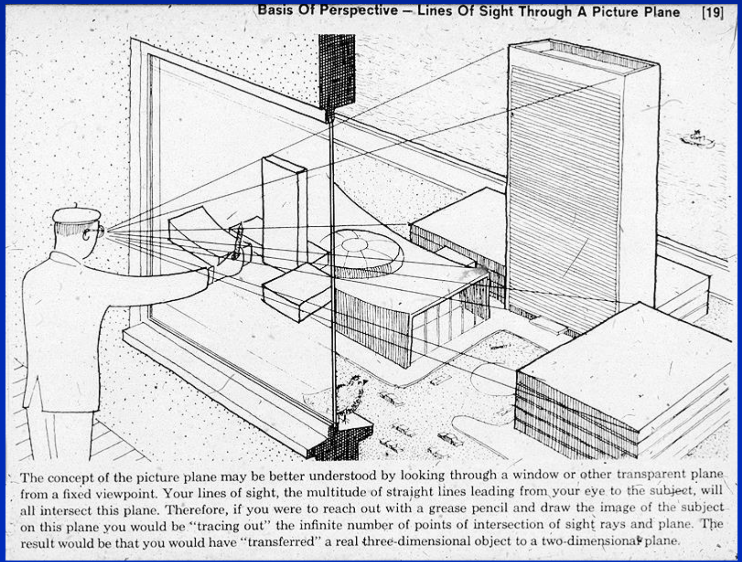
Global Illumination Methods

- Ray Tracing
- Radiosity
- Path Tracing

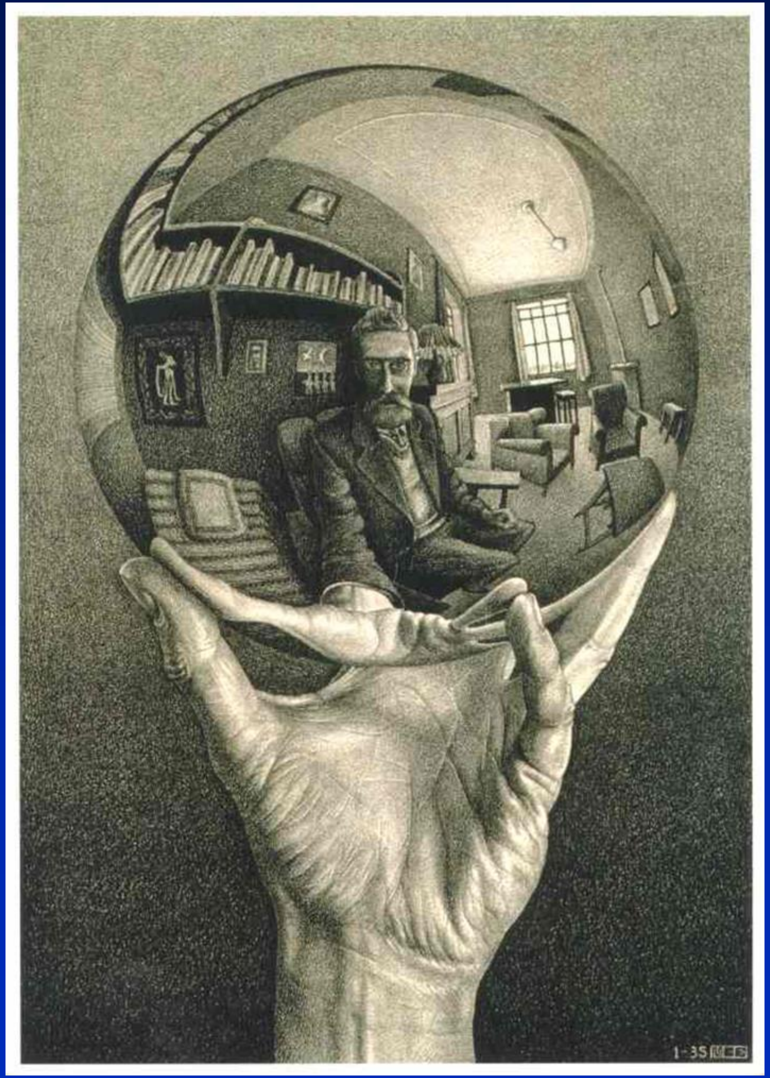

RAY TRACING

Light as Rays

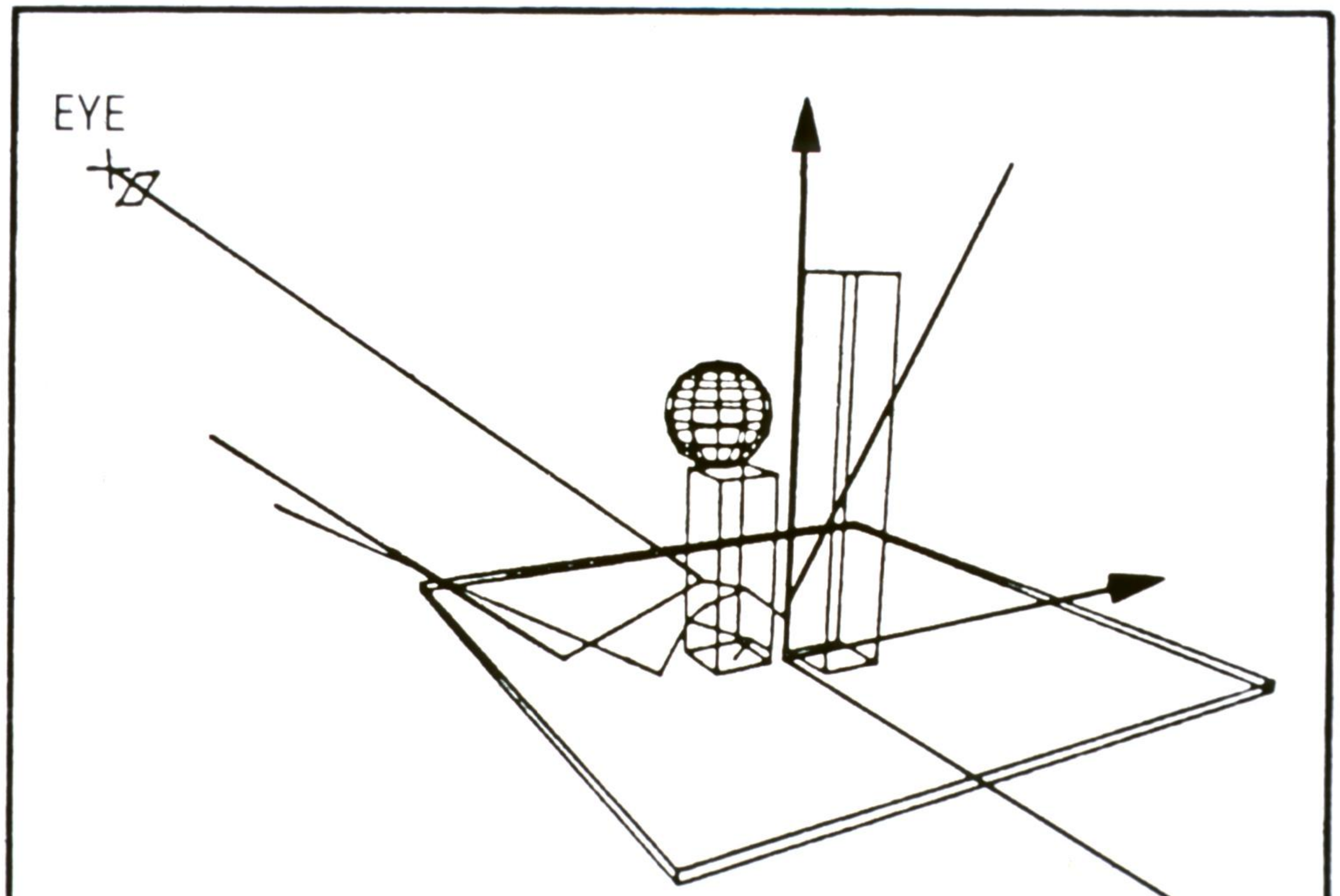





Escher 1935 Caillebotte 1875

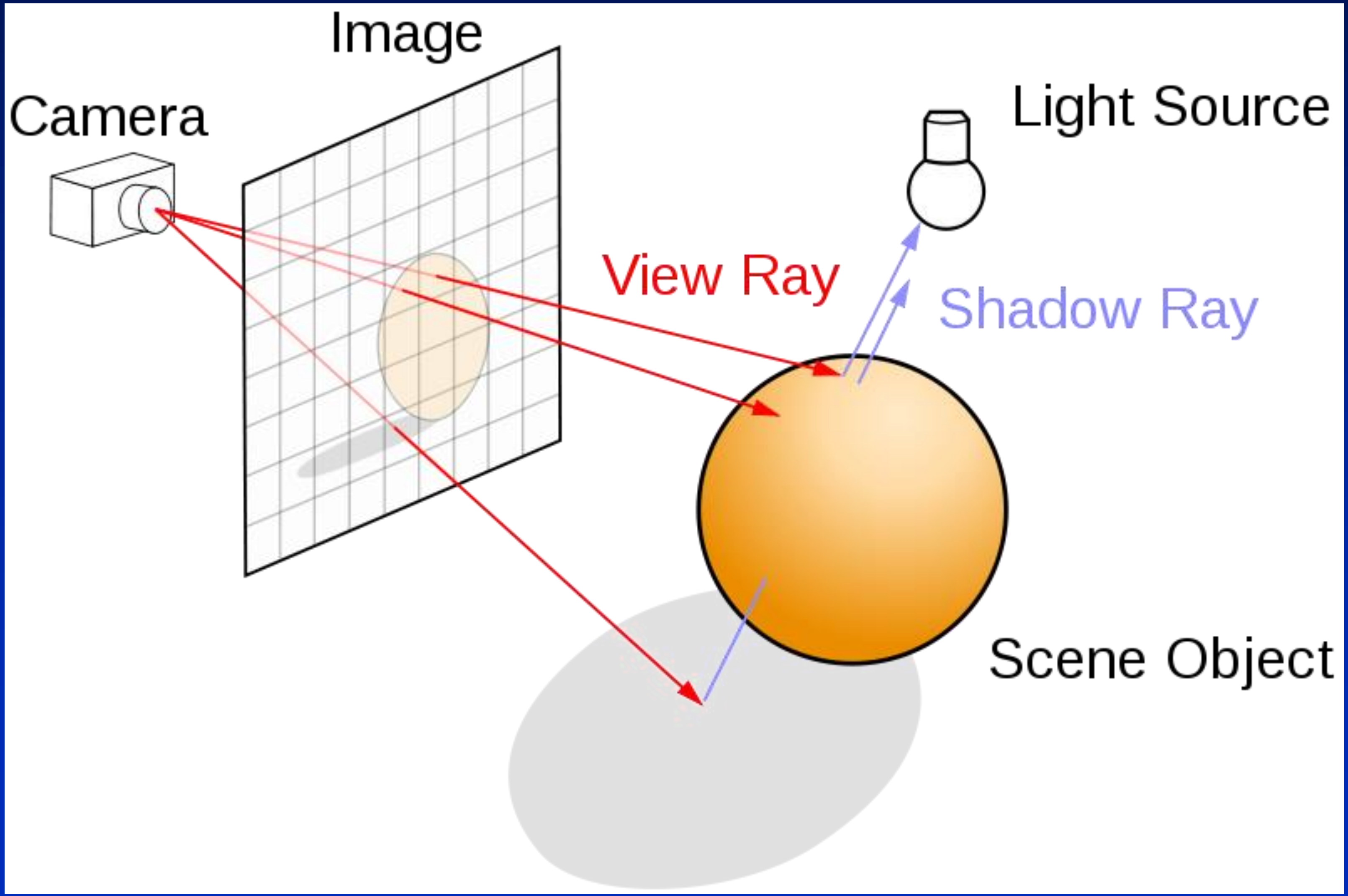


Ray Tracing



Note: Point Sampling at center of each pixel

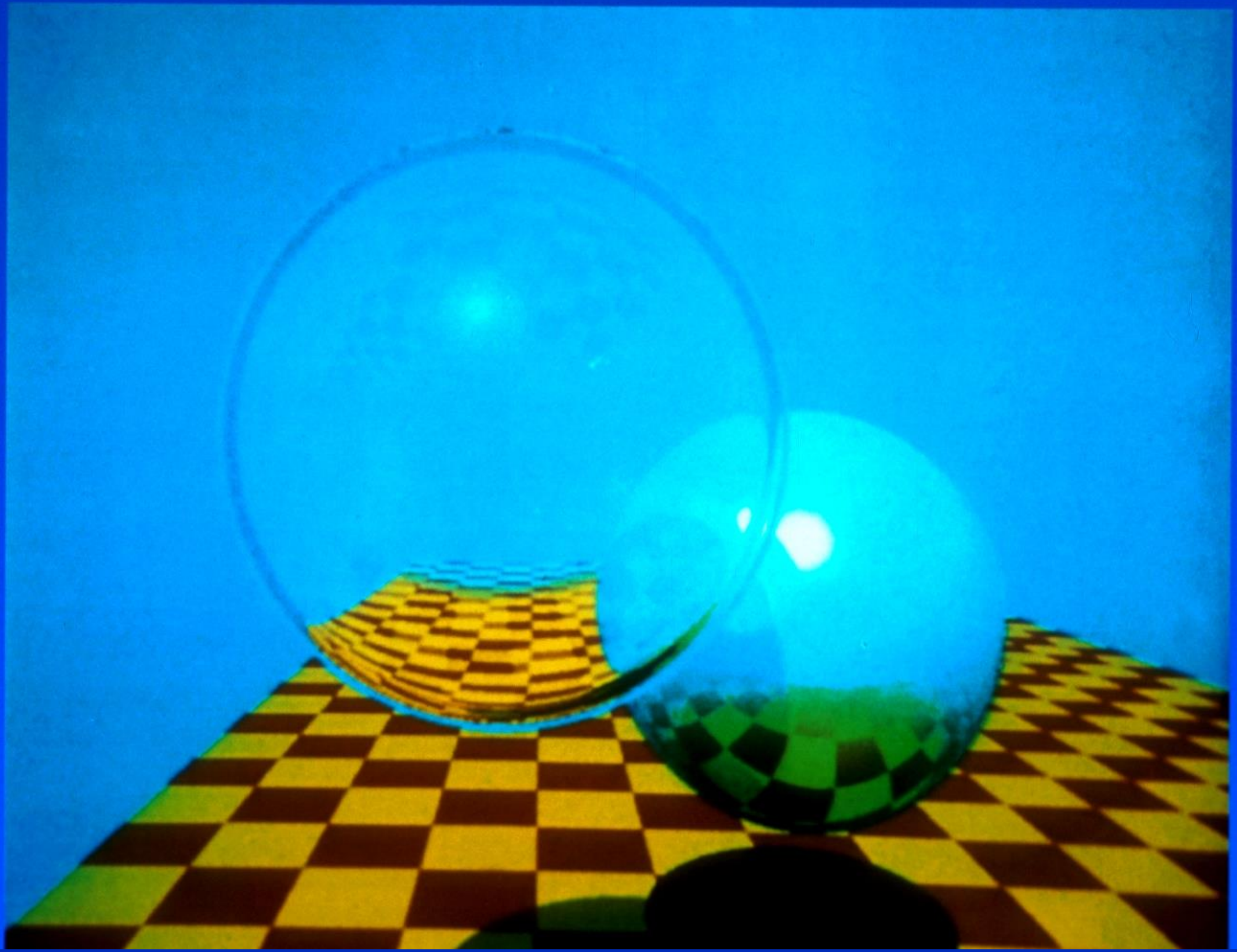
Ray Tracing



Ray Tracing Whitted 1979

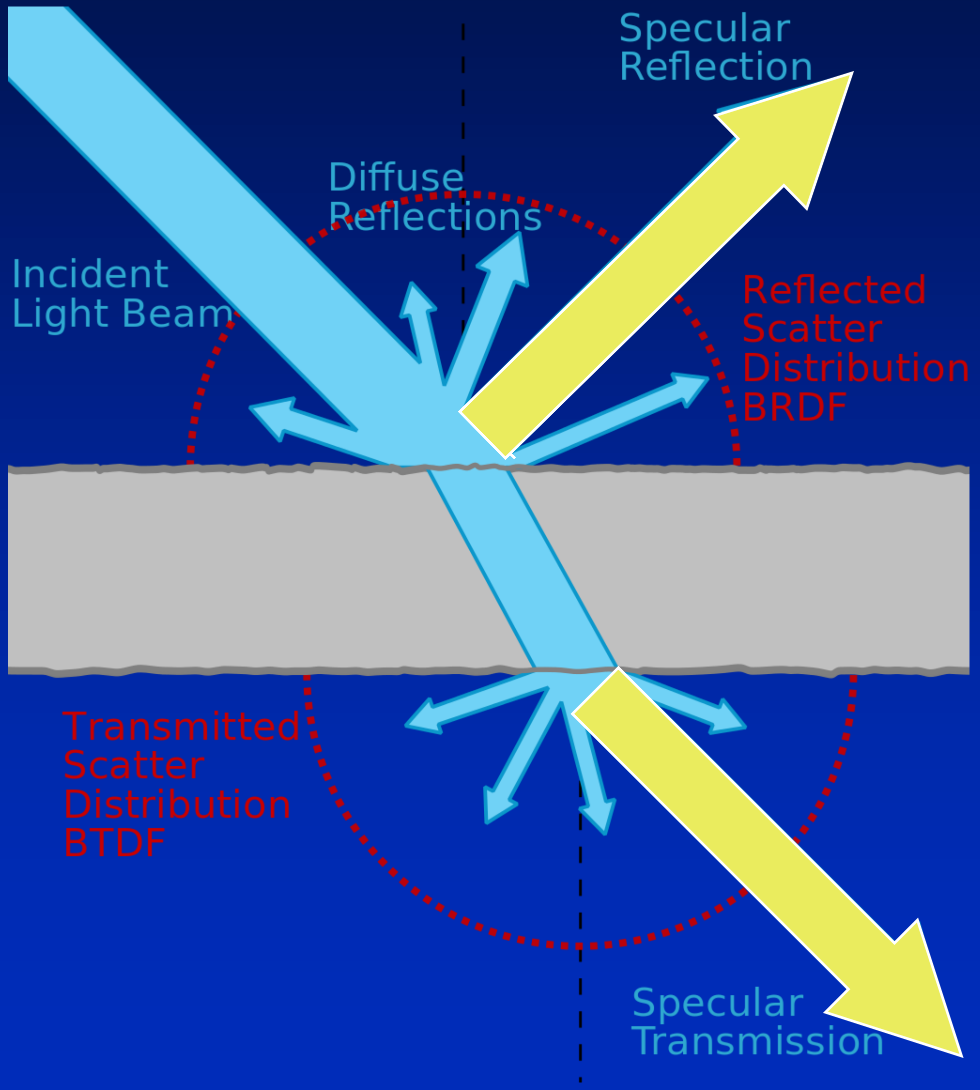
- Assumptions:
  - Light Source
    - > point light source
  - Material
    - > diffuse with specular spike (e.g., Phong Model)
  - Light Propagation
    - > occluding objects (shadows, but no penumbra)
    - > no attenuation
    - > Specular inter-reflections only (trace rays in mirror reflection direction only)

Ray Tracing
Turner Whitted, 1979



Doug Kay Cornell 1979

Ray Tracing Specular Directions



Ray Tracing Model Whitted 1979

$$I = \underbrace{k_d \sum_{i=1}^{l} (\overline{N} \cdot \overline{L})}_{\text{direct diffuse}} \text{(object color)} \quad \underbrace{+ k_s \sum_{i=l}^{l} (\overline{N} \cdot \overline{H})^n}_{\text{direct specular}} \text{(light color)}$$

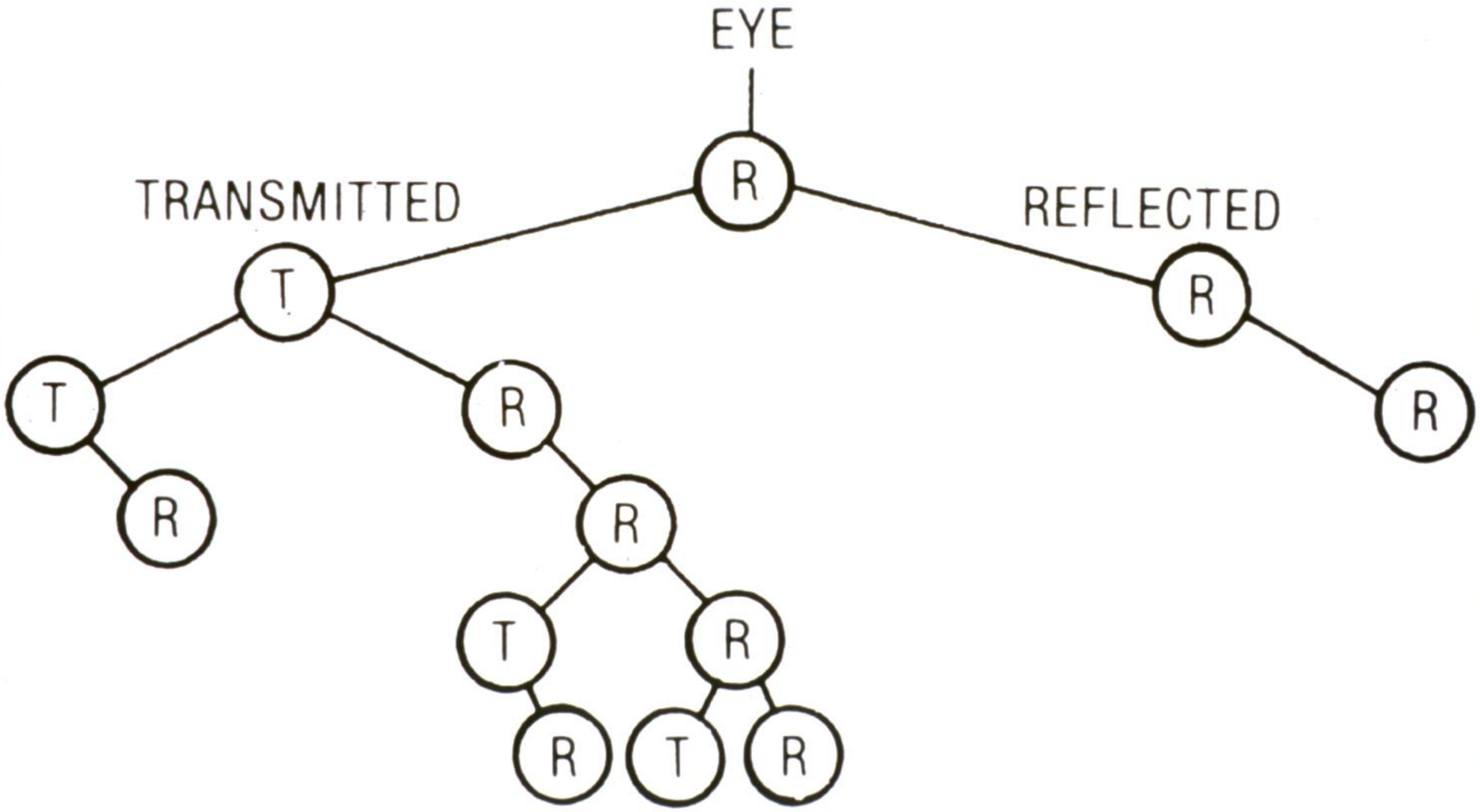
$$+ \underbrace{I_a}_{\text{global diffuse}} + \underbrace{k_s I_r}_{\text{global specular reflected}} + \underbrace{k_t I_t}_{\text{global specular transmitted}}$$

global diffuse

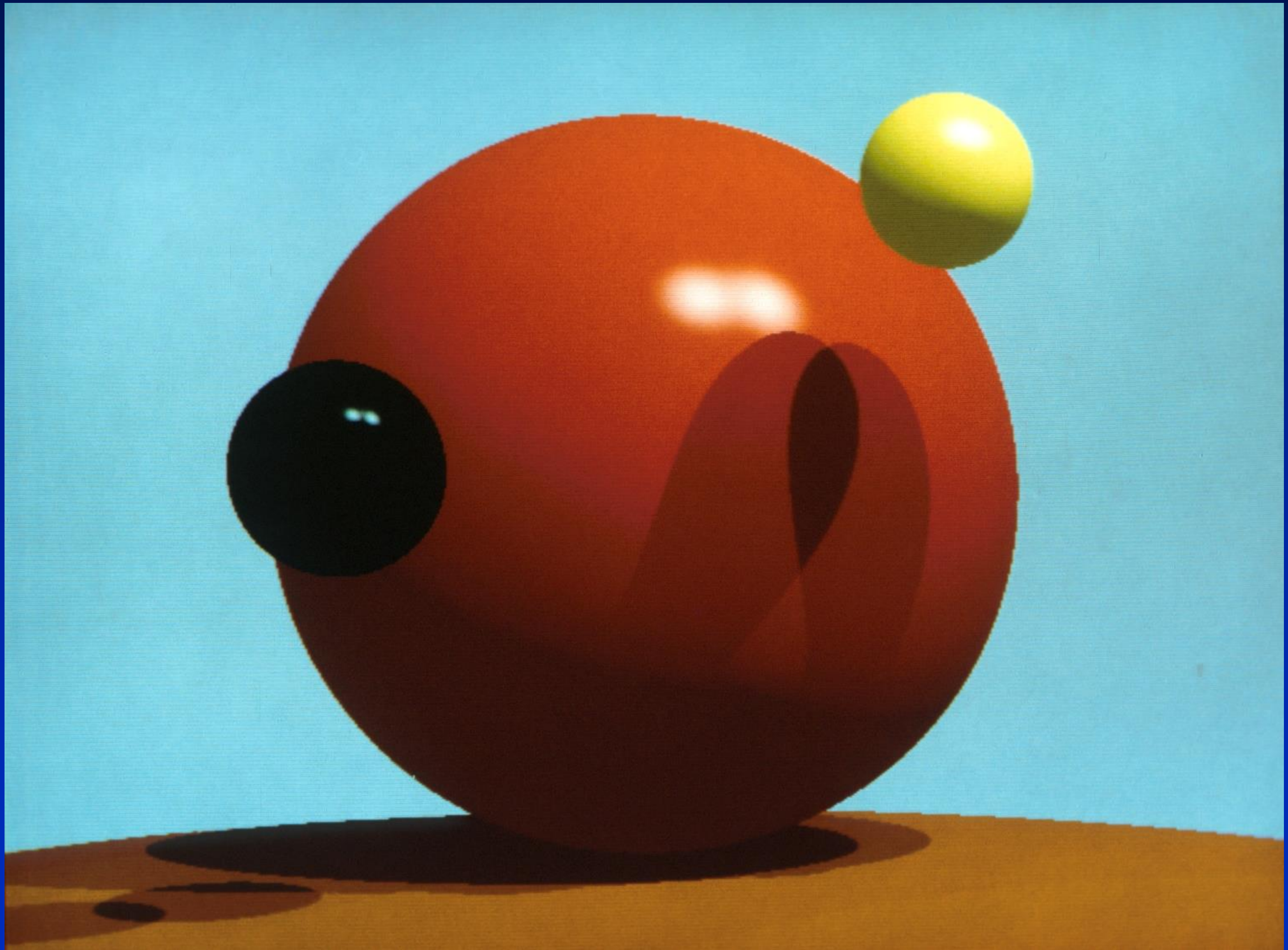
global specular reflected

global specular transmitted

Ray Tracing Tree

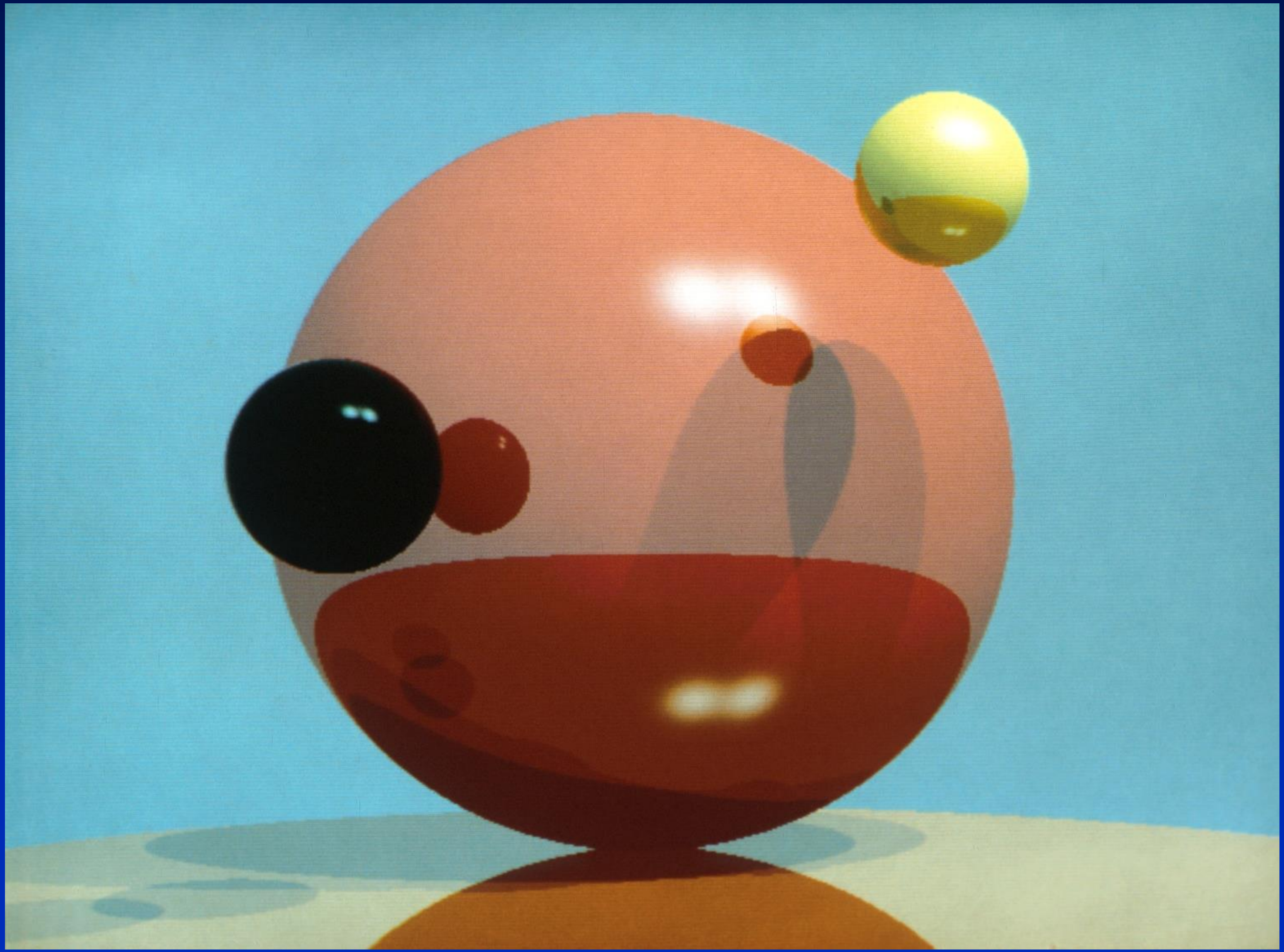


First Reflection



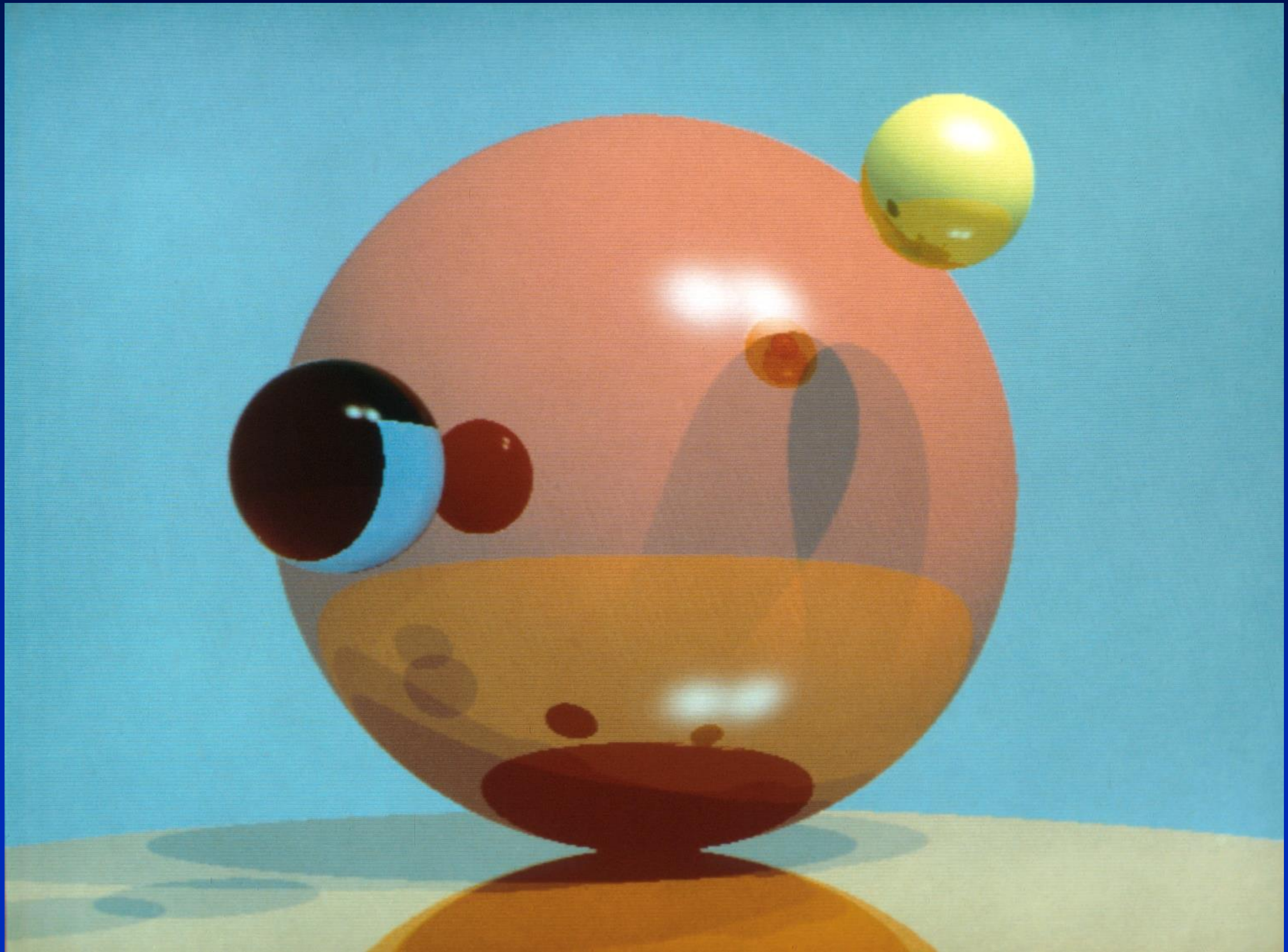
Roy Hall

Two Reflections



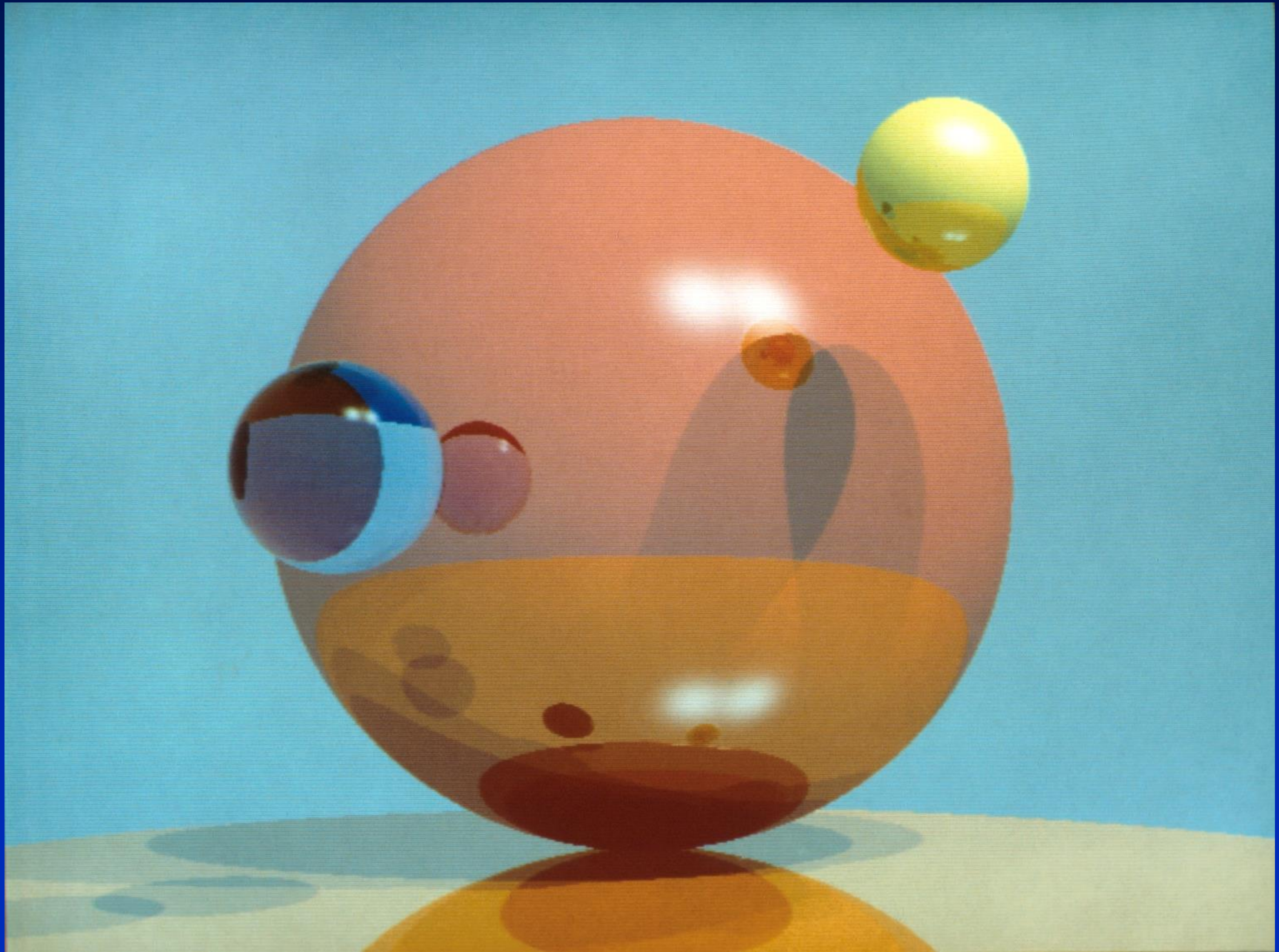
Roy Hall

Three Reflections



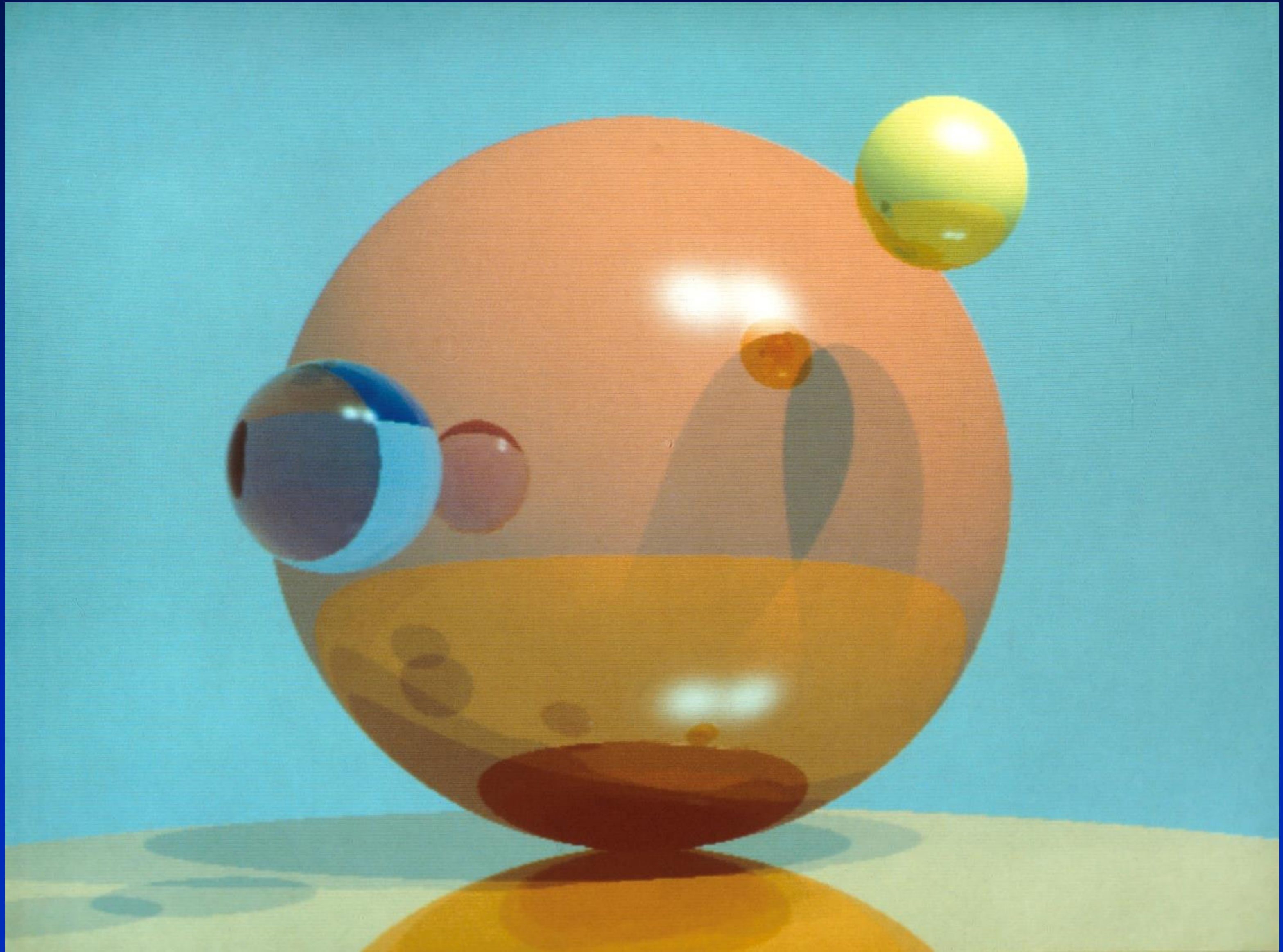
Roy Hall

Four Reflections



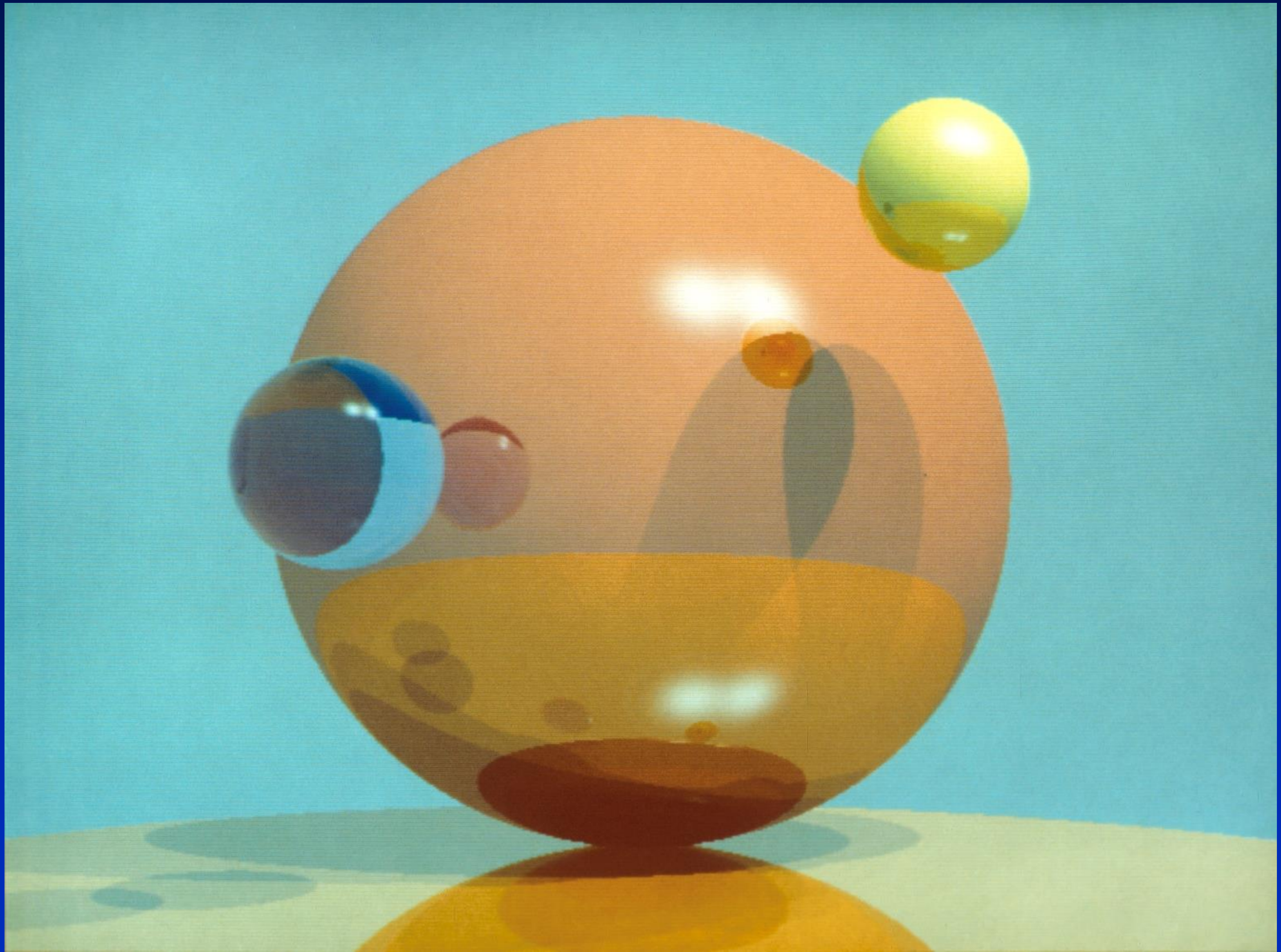
Roy Hall

Five Reflections

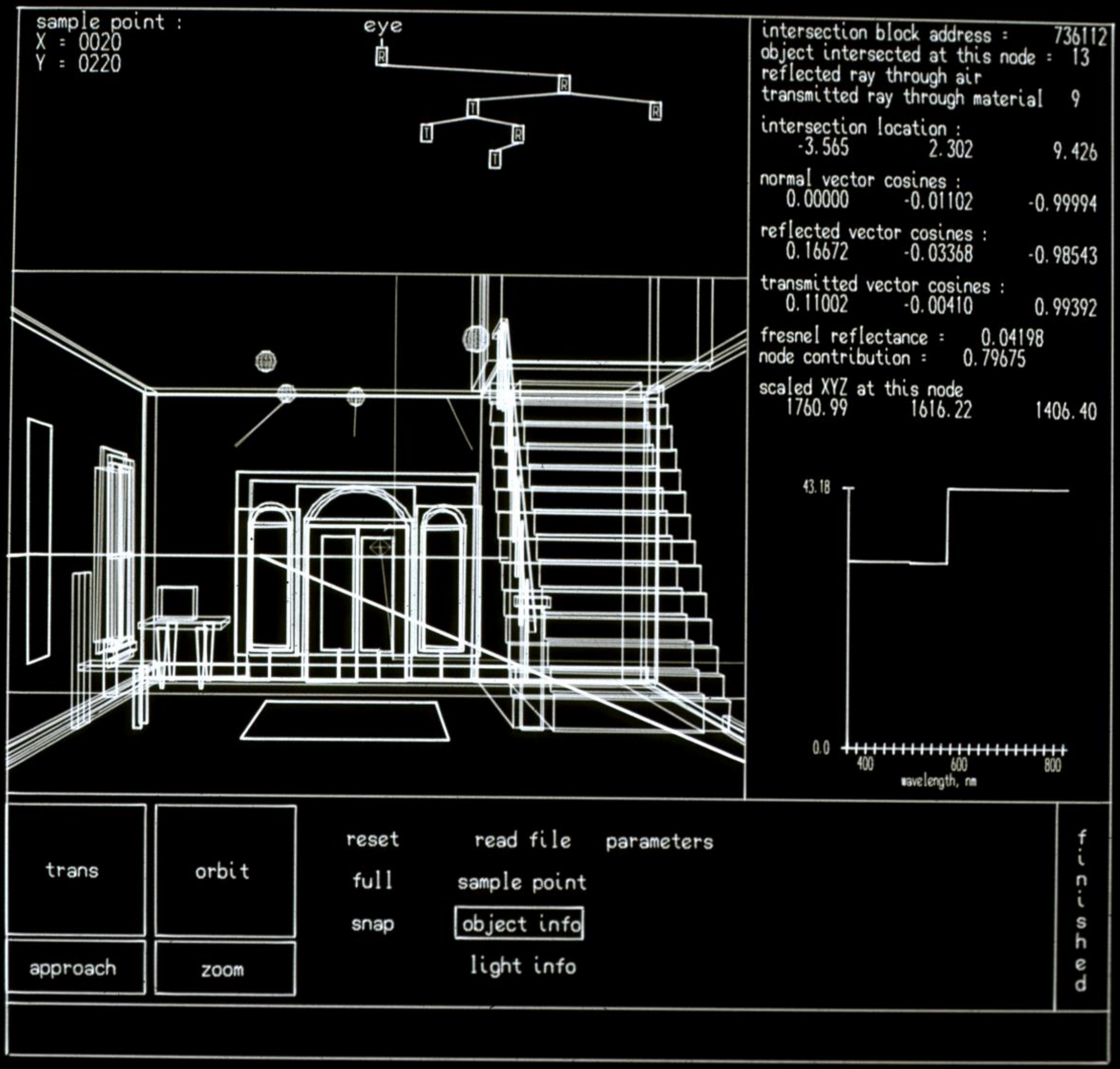


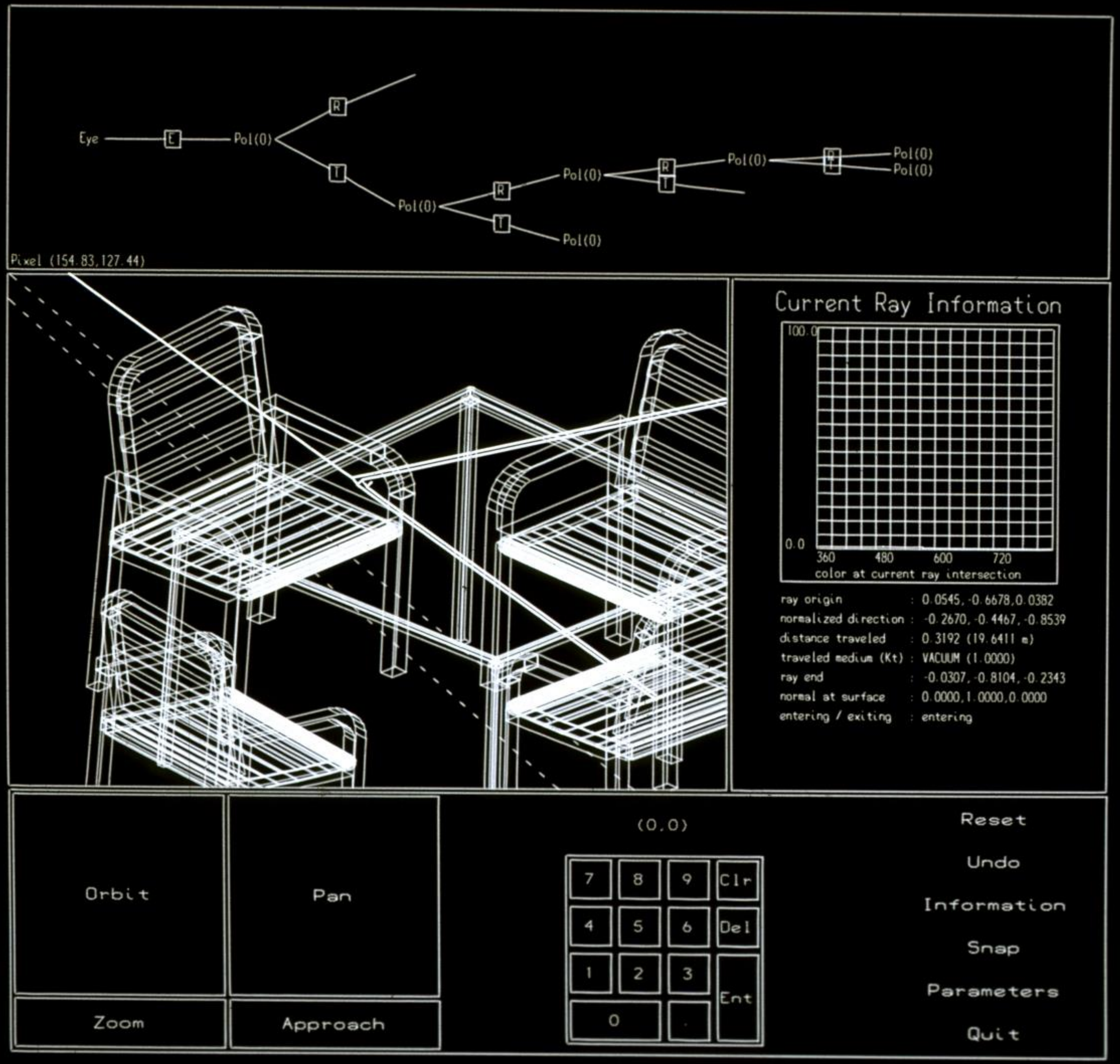
Roy Hall

Six Reflections

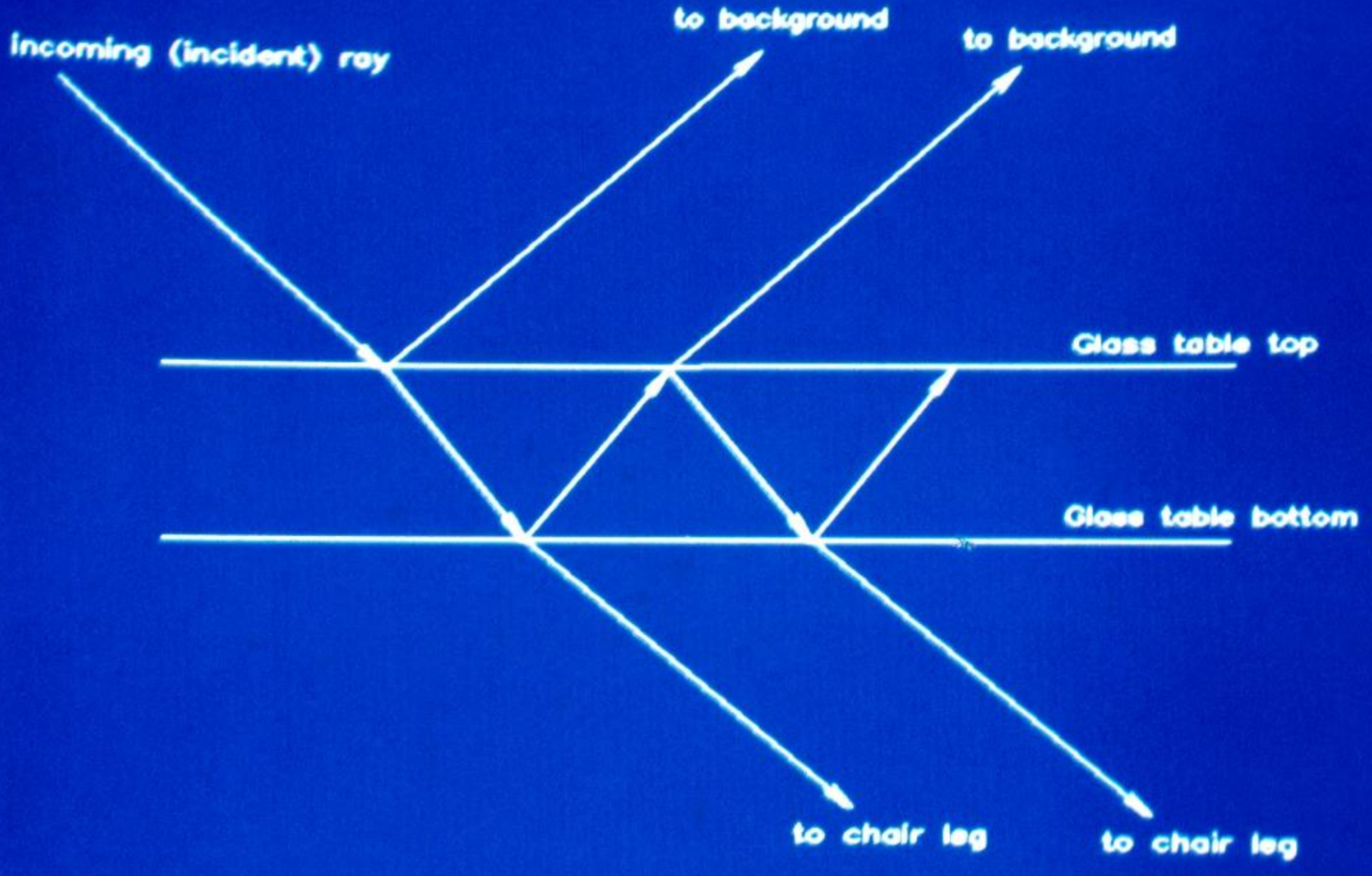


Roy Hall


sample point :
X = 0020
Y = 0220
eye
intersection block address : 736112
object intersected at this node : 13
reflected ray through air
transmitted ray through material 9
intersection location :
-3.565 2.302 9.426
normal vector cosines :
0.00000 -0.01102 -0.99994
reflected vector cosines :
0.16672 -0.03368 -0.98543
transmitted vector cosines :
0.11002 -0.00410 0.99392
fresnel reflectance : 0.04198
node contribution : 0.79675
scaled XYZ at this node
1760.99 1616.22 1406.40
43.18
0.0
400
600
800
wavelength, nm
trans
orbit
approach
zoom
reset
full
snap
read file
sample point
object info
light info
parameters
finished



Eye
Pol(0)
Pol(0)
Pol(0)
Pol(0)
Pol(0)
Pol(0)
Pol(0)
Pixel (154.83,127.44)
Current Ray Information
100.0
0.0
360
480
600
720
color at current ray intersection
ray origin : 0.0545,-0.6678,0.0382
normalized direction : -0.2670,-0.4467,-0.8539
distance traveled : 0.3192 (19.6411 m)
traveled medium (Kt) : VACUUM (1.0000)
ray end : -0.0307,-0.8104,-0.2343
normal at surface : 0.0000,1.0000,0.0000
entering / exiting : entering
Orbit
Pan
Zoom
Approach
(0,0)
7
8
9
Clr
4
5
6
Del
1
2
3
Ent
0
Reset
Undo
Information
Snap
Parameters
Quit



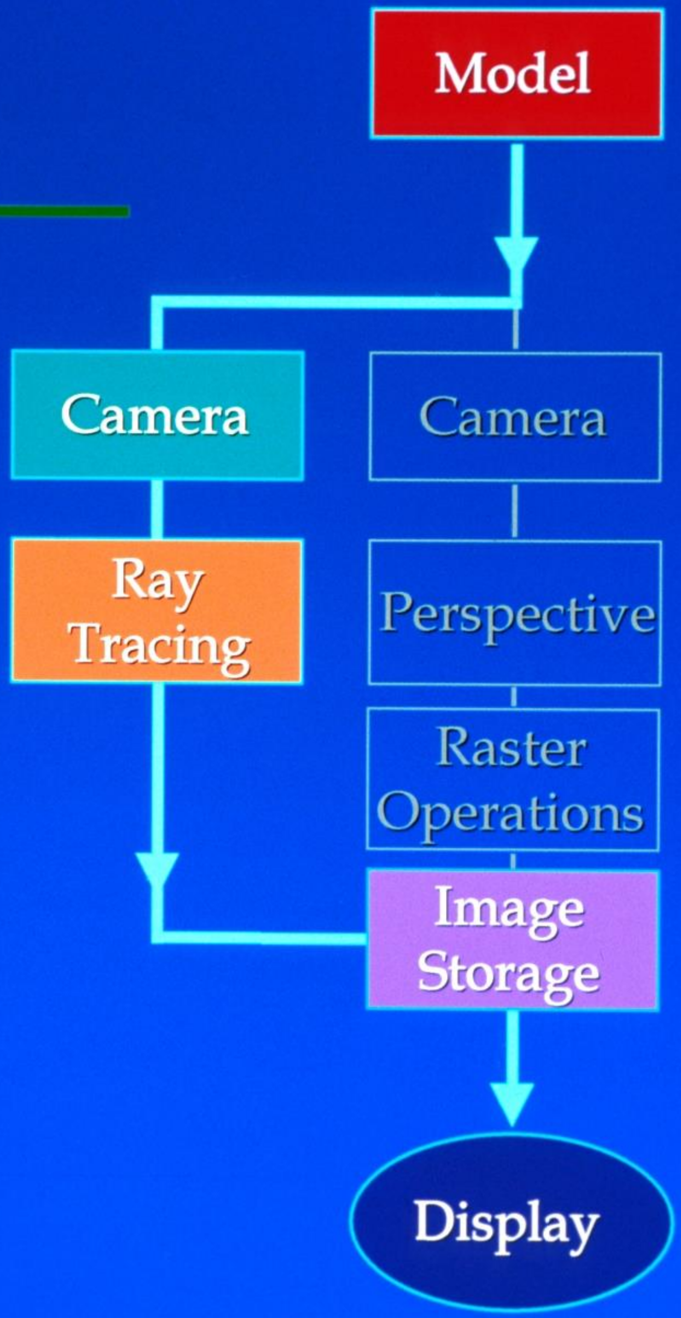
RAY INTERSECTION DIAGRAM

Eric Haines

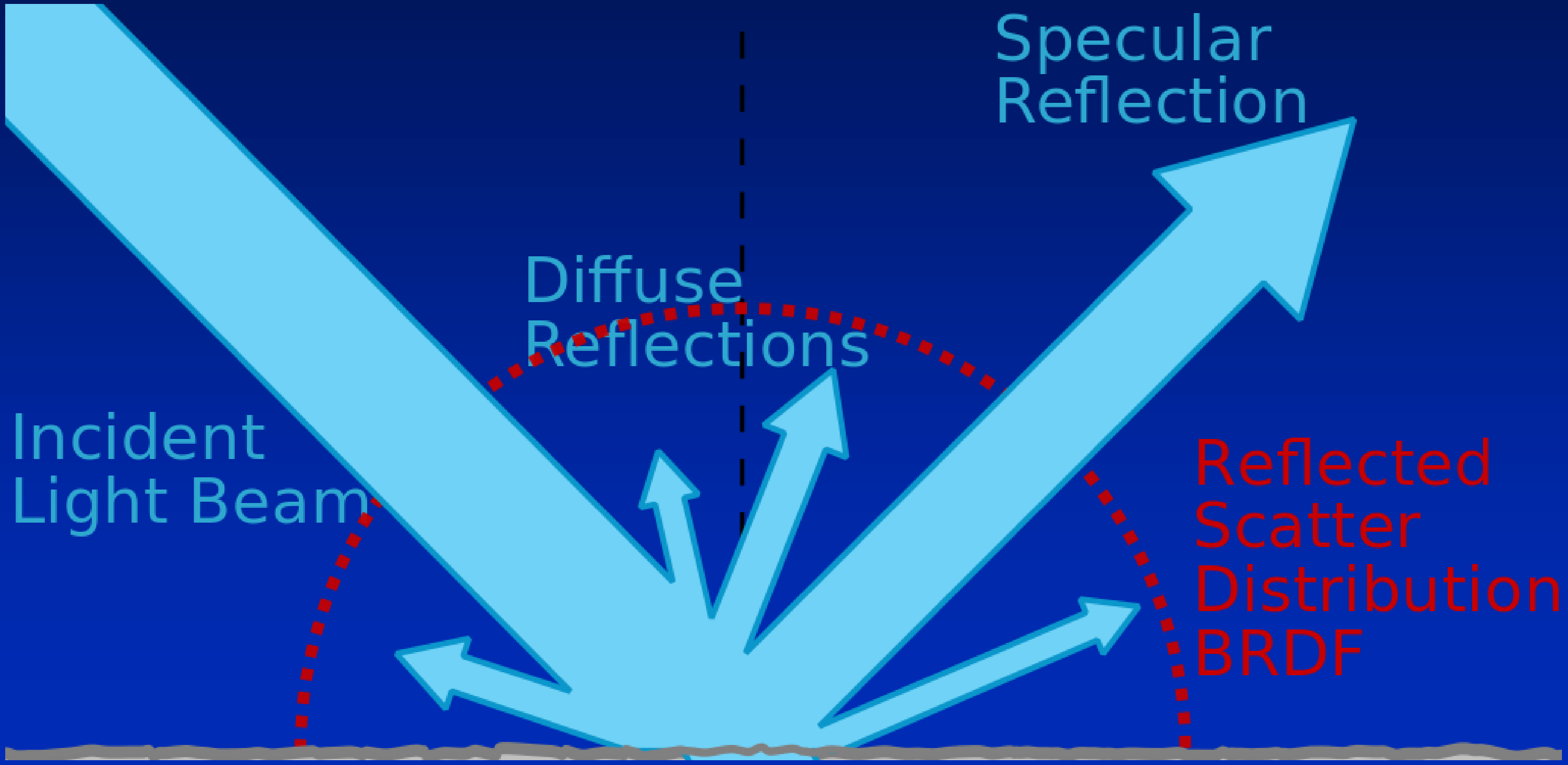
Eric Haines

Jason Ardizzone-West
1995

Ray Tracing

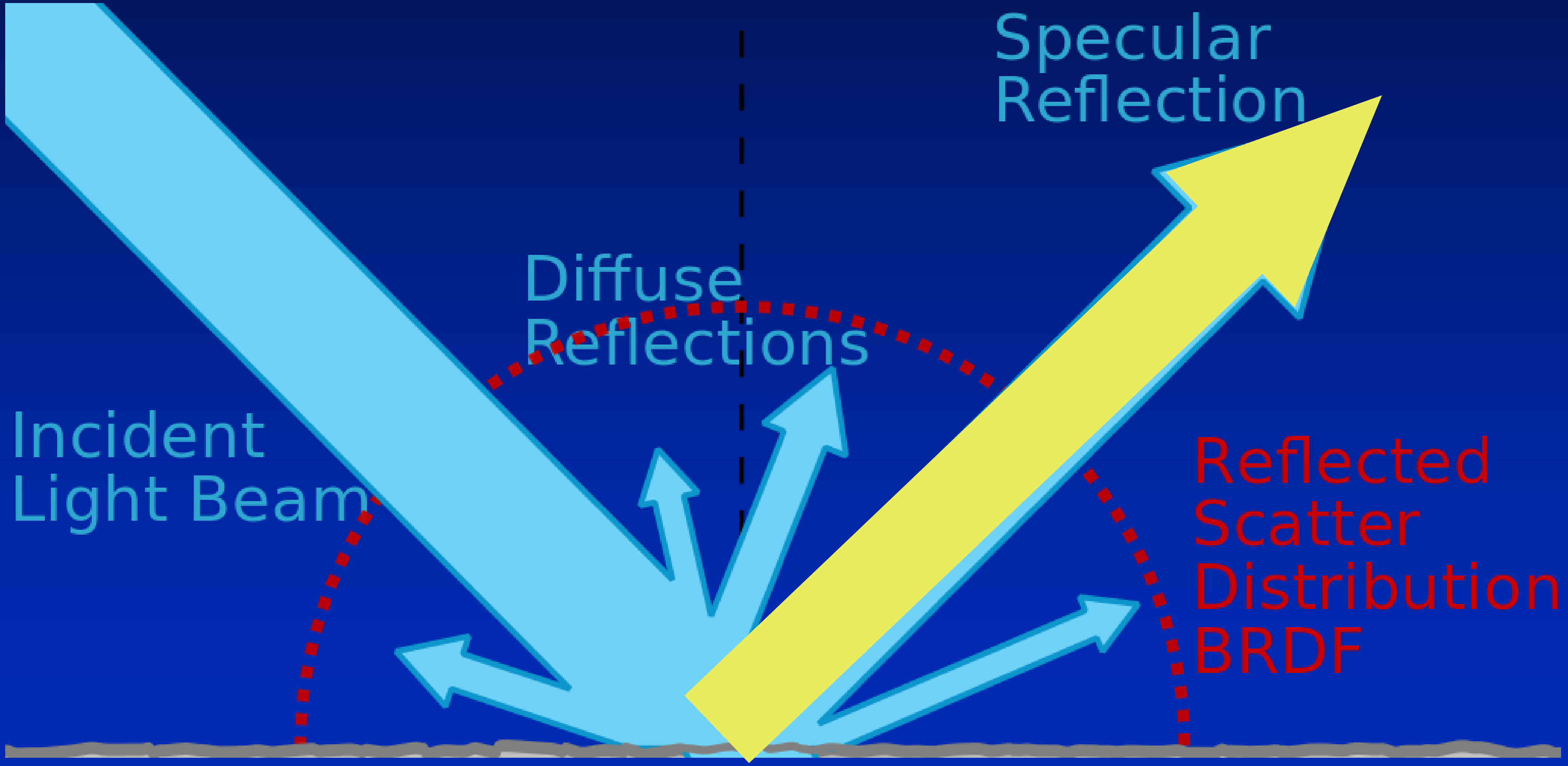

Model
Camera
Camera
Ray Tracing
Perspective
Raster Operations
Image Storage
Display

Surface Reflectance



For simplicity transmitted directions are not shown.

Ray Tracing



For simplicity transmitted directions are not shown.

Weghorst Bounding Sphere 1984

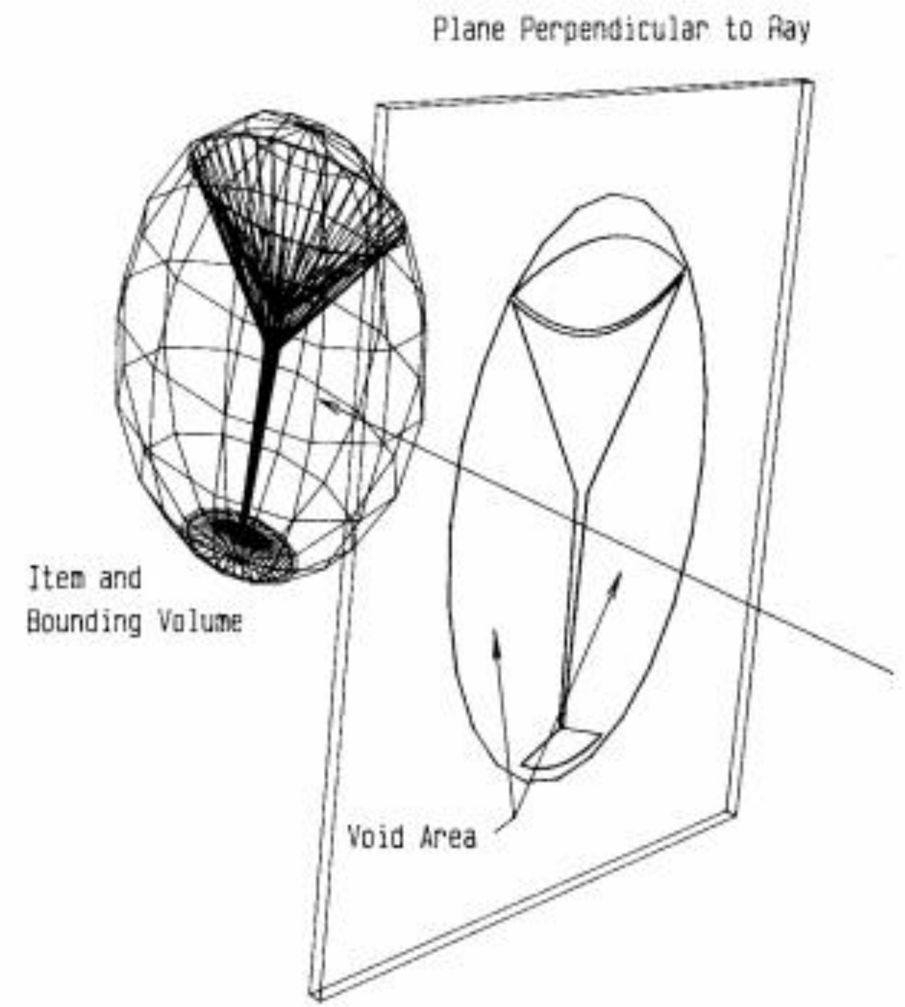


Fig. 1. Projected area of item and its bounding volume.

Office Weghorst 1984

Fig. 8. Office Scene.

Resolution =256 x240
CPU hrs. = 14.6

Pool Room Weghorst 1984

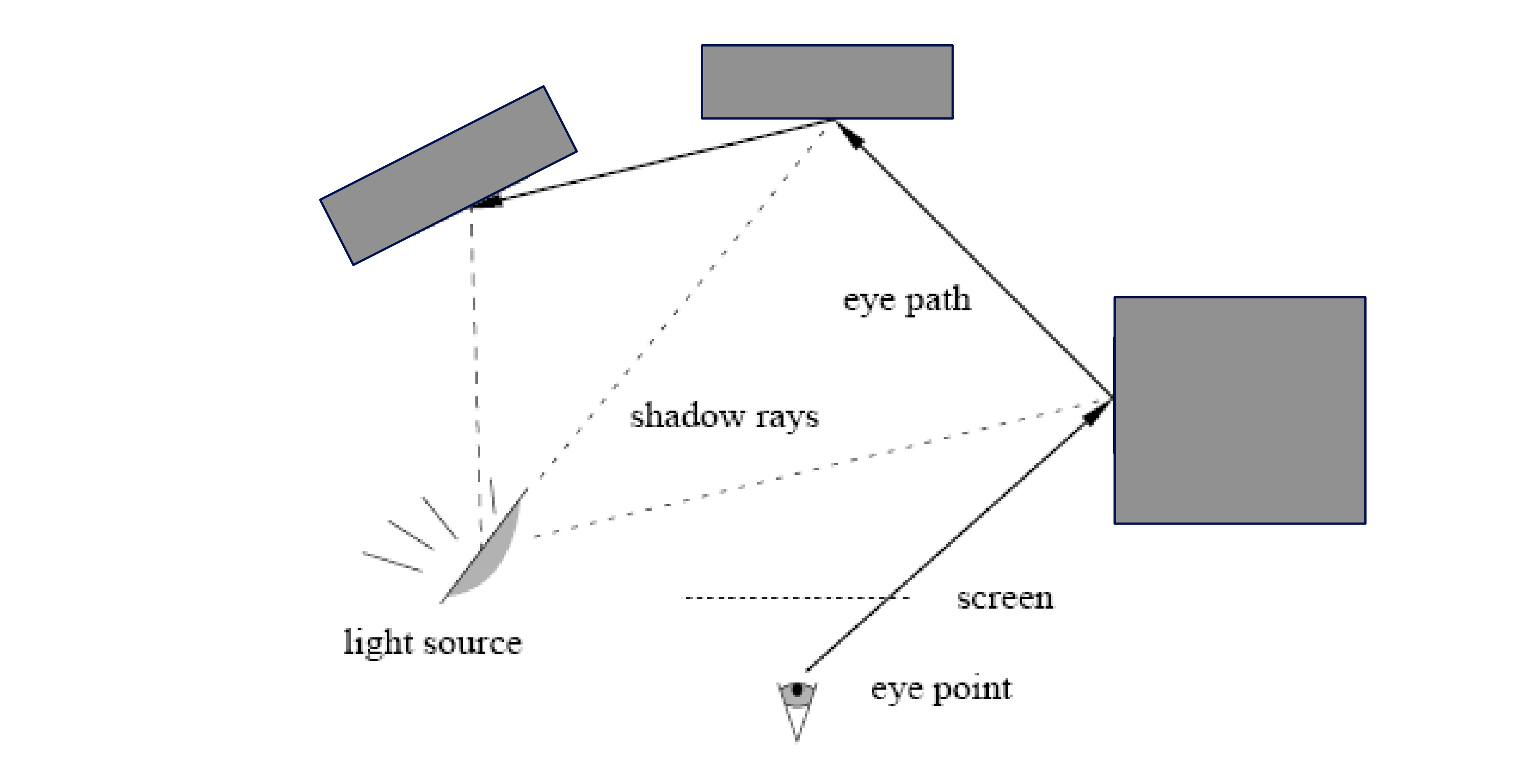
Fig. 9. Pool Room.

Resolution =256 x240
CPU hrs. = 14.33

Path Tracing

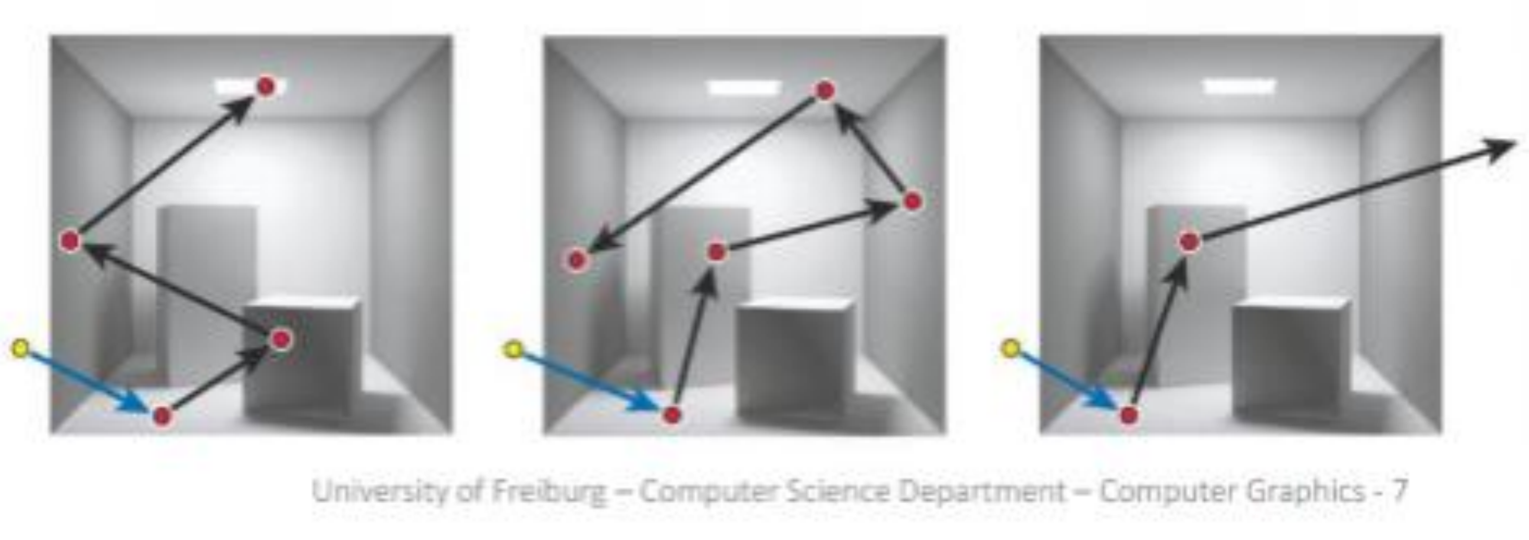
- Path Tracing is similar to ray tracing except that many rays are sent for each pixel.
- Rays are sent out on a probabilistic basis depending on the reflectance (transmittance) distributions of each surface that is struck.
- Computations can be accelerated by using “importance sampling”, where the ray directions are dependent on the magnitude of the potential effects.

Path Tracing

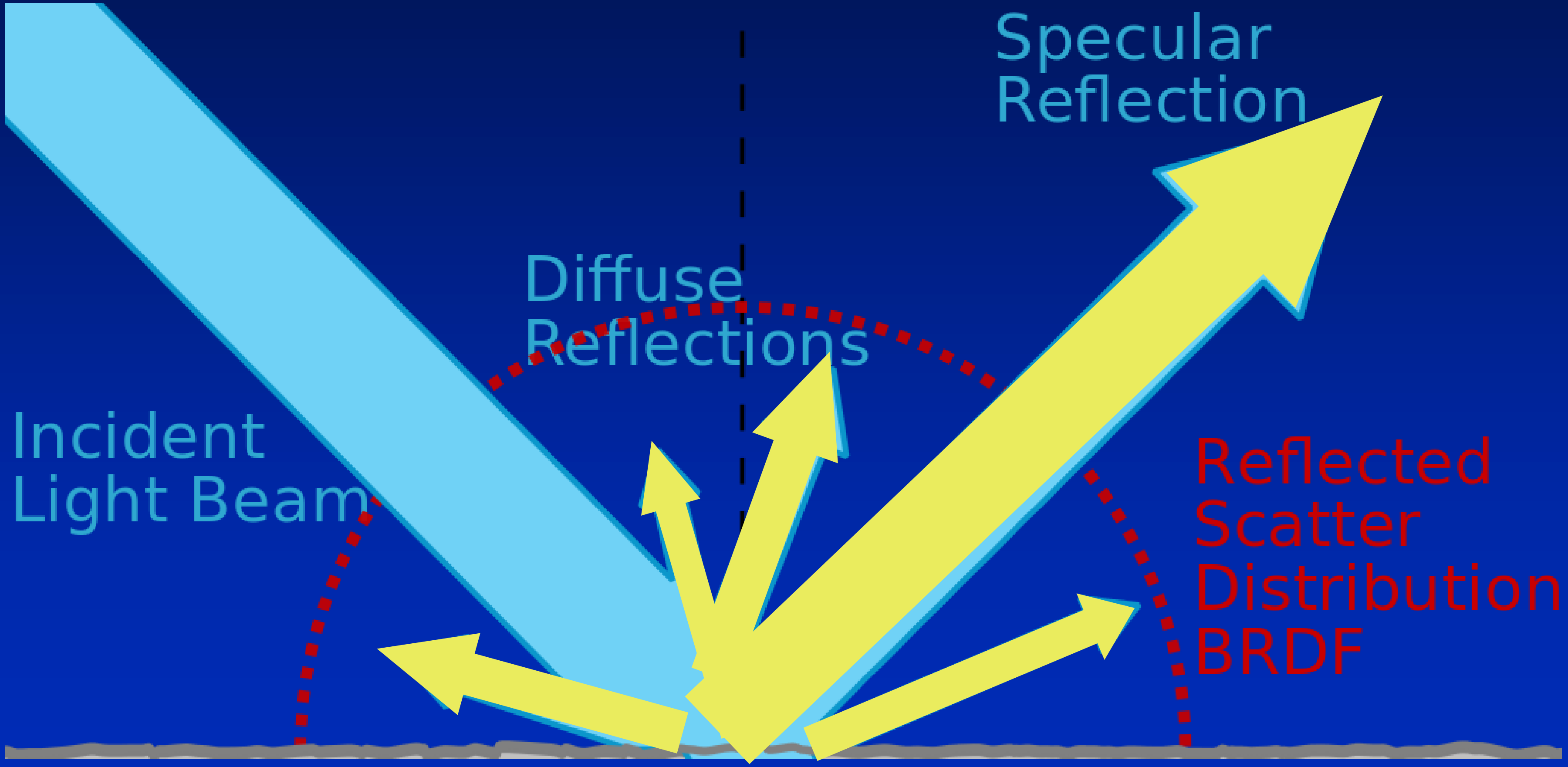


Path Tracing

- Rays are cast to estimate the transported radiance.
- Recursion stops if
  - A light source is hit
  - A maximum depth/minimum radiance is reached
  - The ray leaves the scene/hits the background

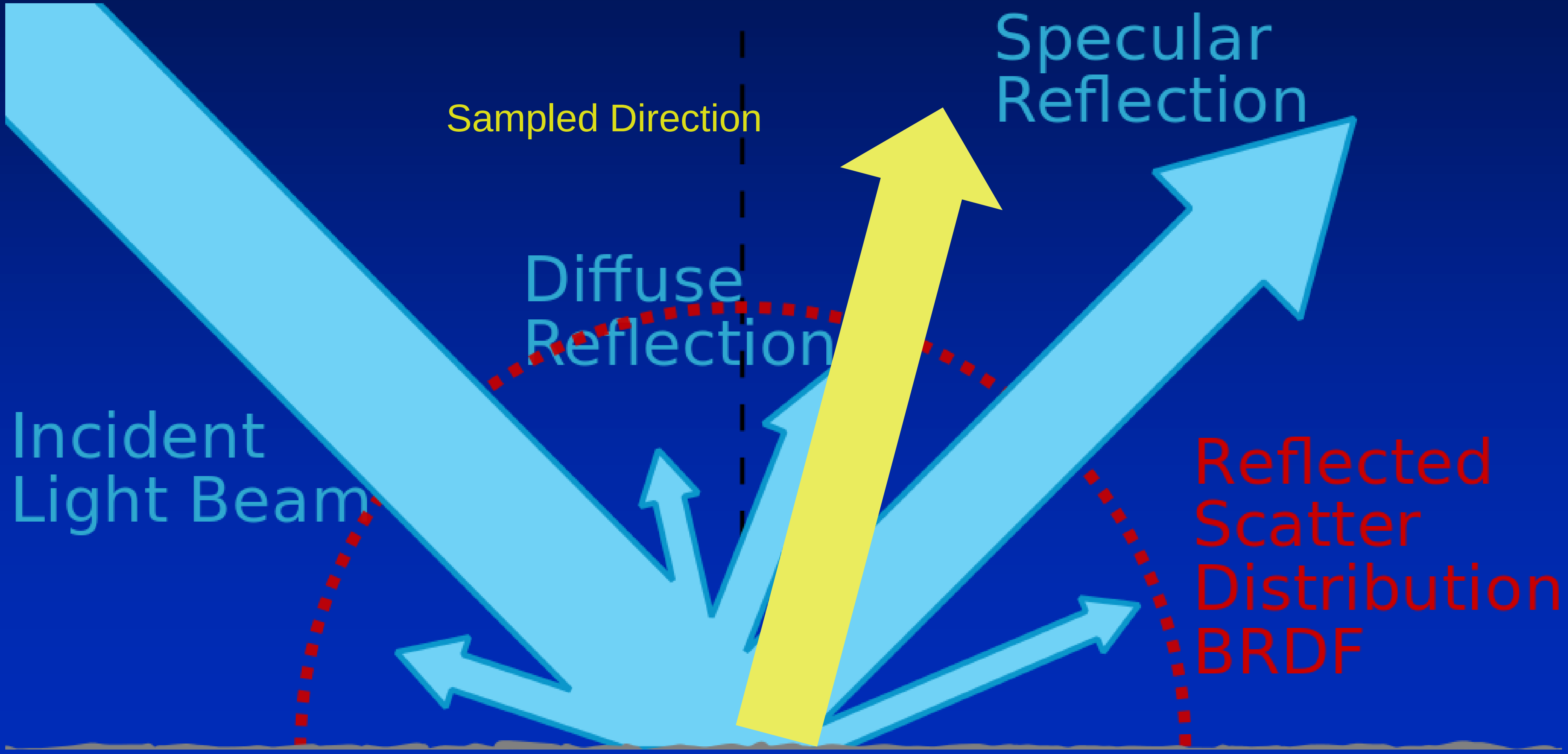


Path Tracing



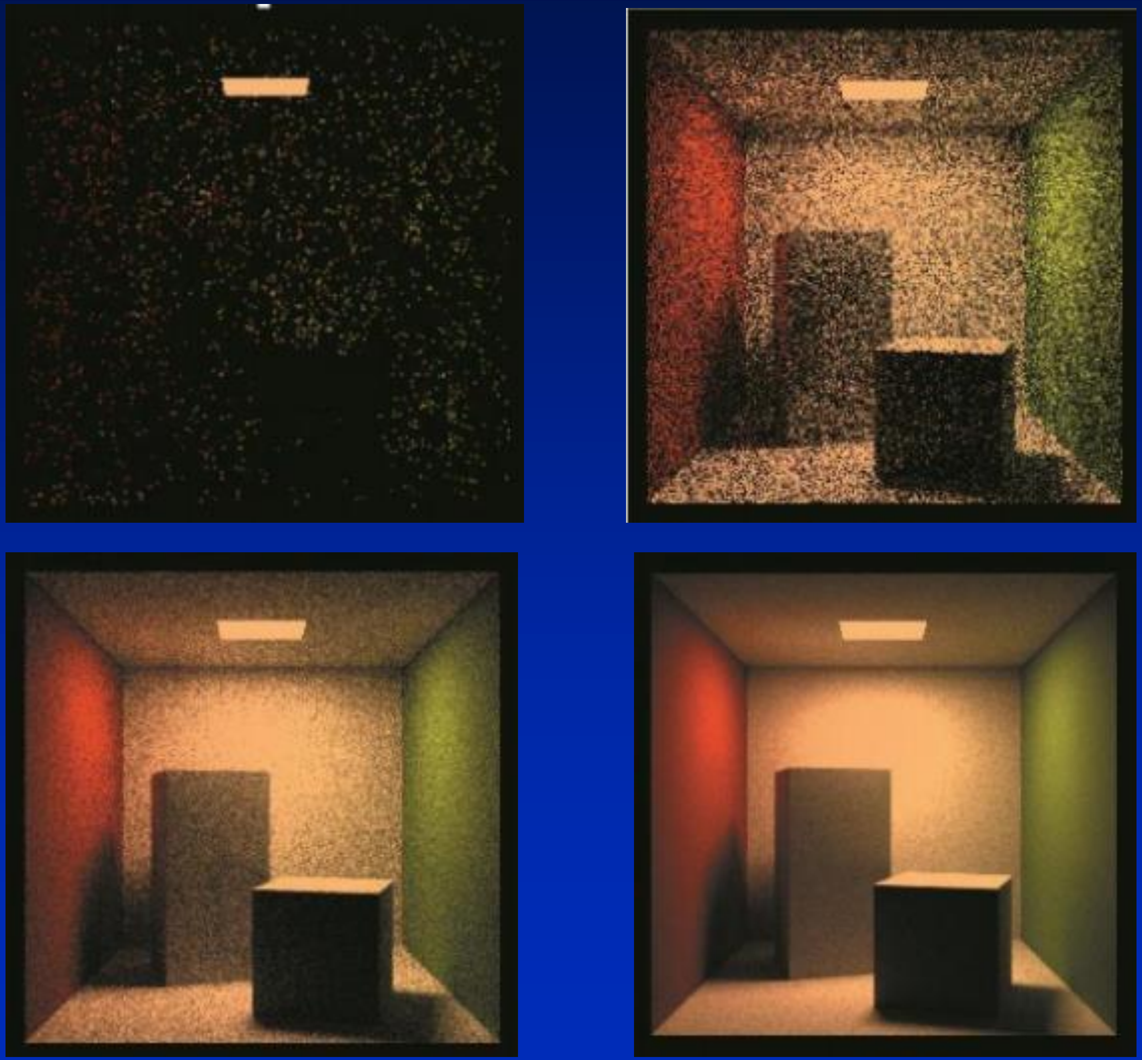
For simplicity transmitted directions are not shown.

Probabilistic Sample Direction for Path Tracing



For simplicity transmitted directions are not shown.

Path Tracing



1 sample/pixel

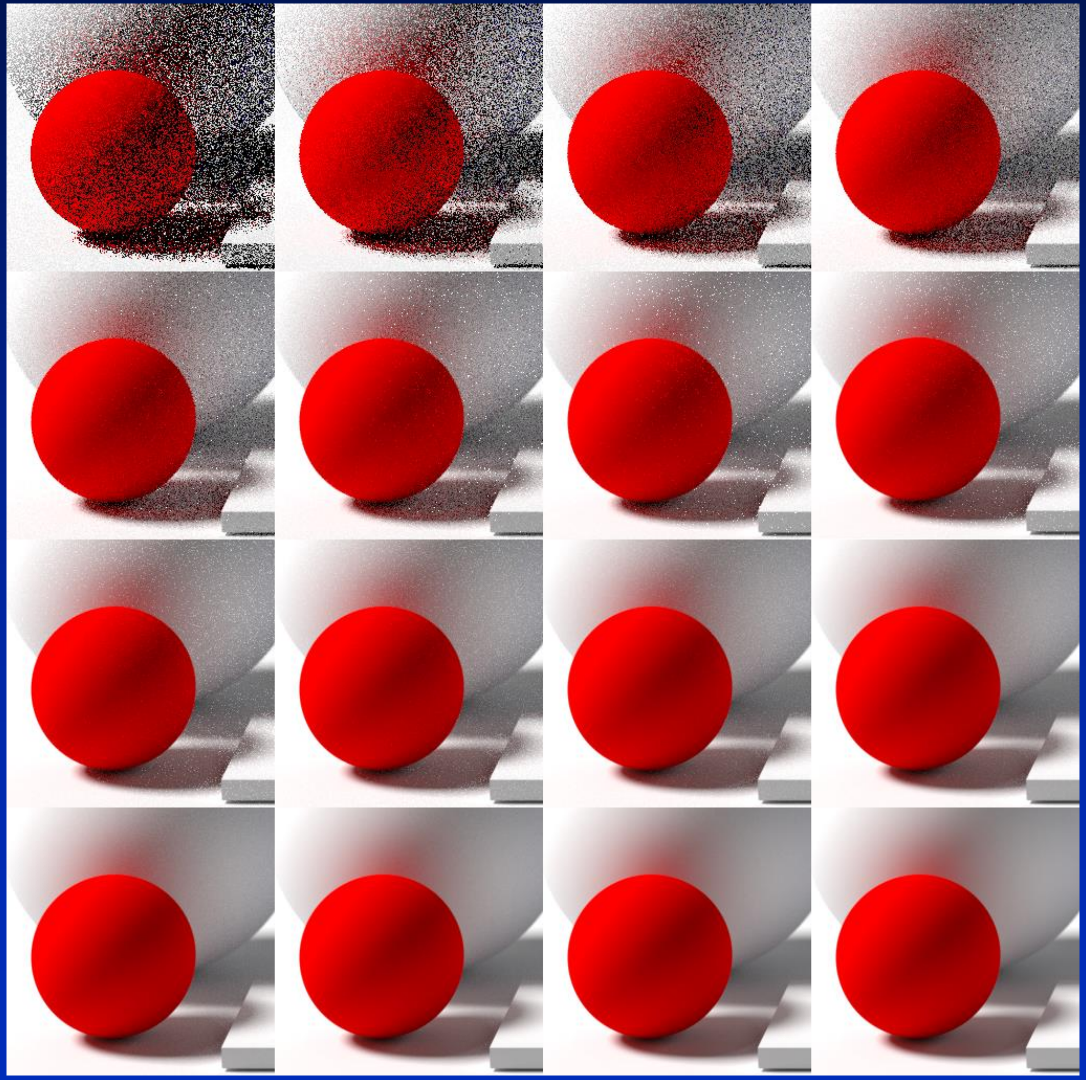
100 samples/pixel

1,000 samples/pixel

10,000 samples/pixel

Path Tracing samples/pixel

Noise decreases as the number of samples per pixel increases. The top left shows 1 sample per pixel, and doubles from left to right each square.

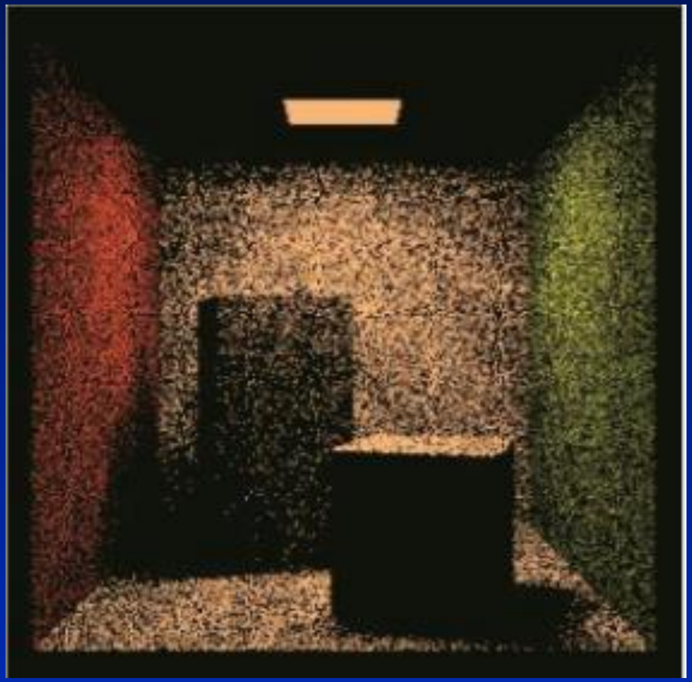


https://en.wikipedia.org/wiki/Path_tracing

Nvidia 2018

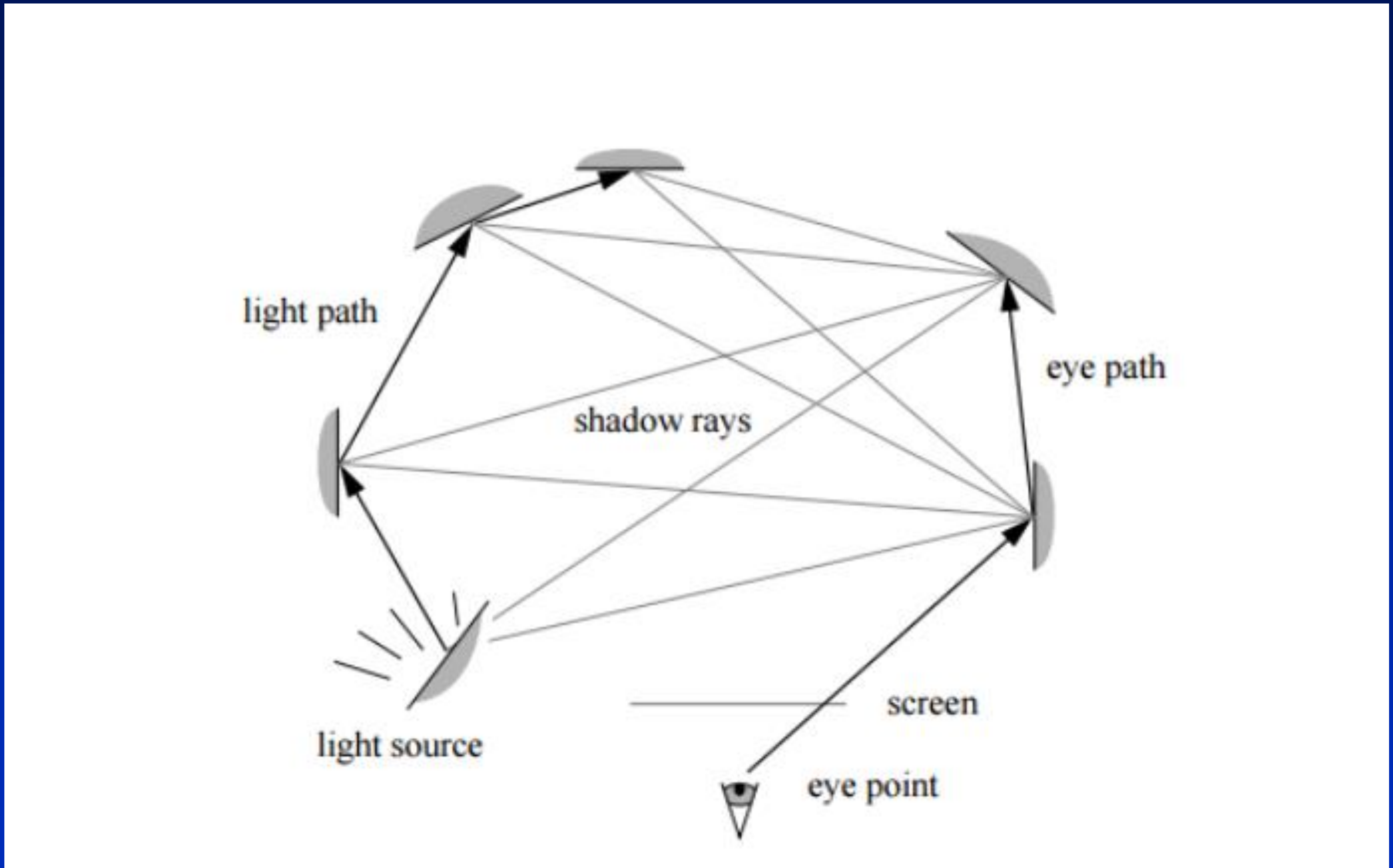
Path Tracing

1 sample/light source
100 samples/pixel

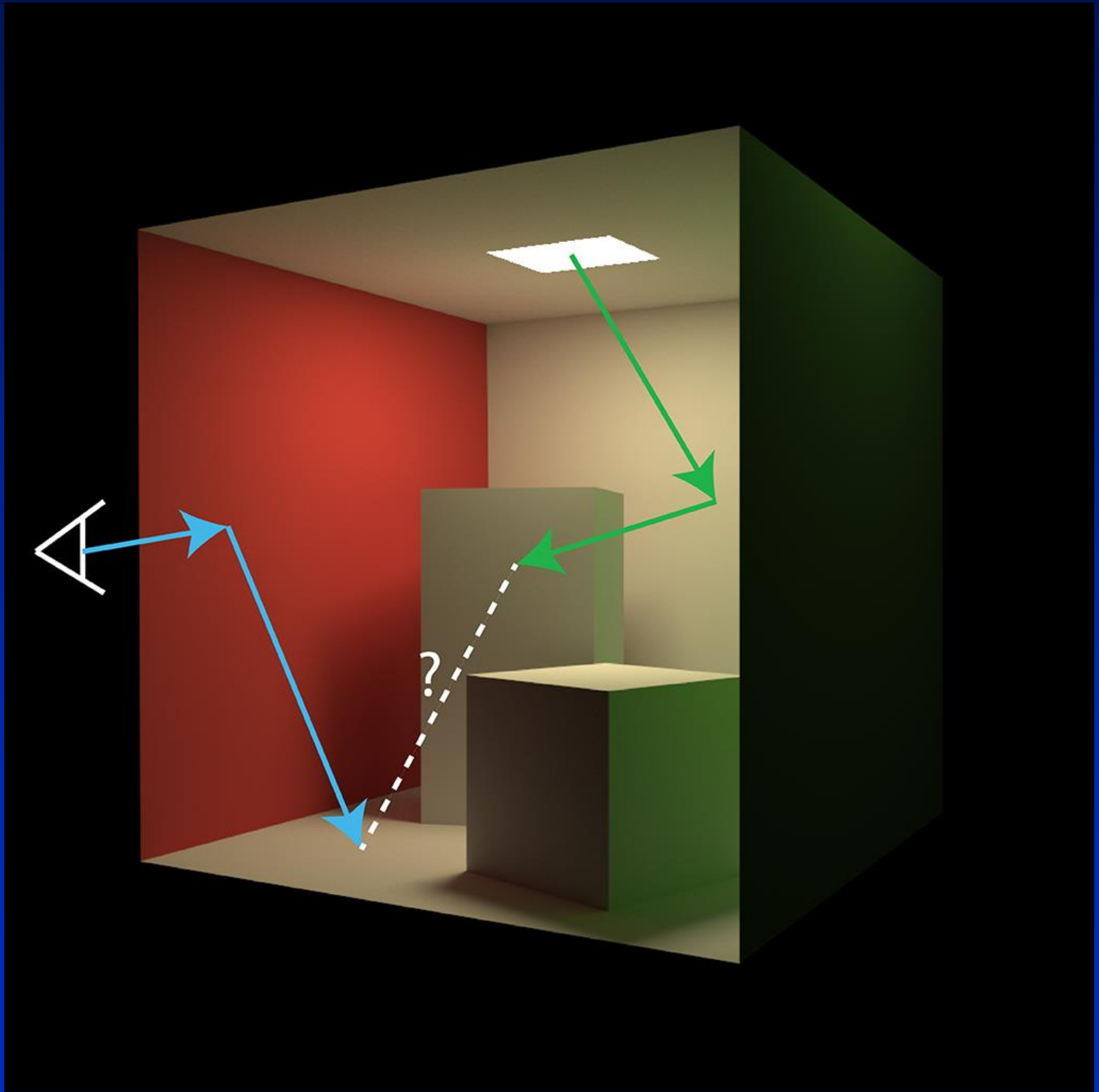


100 samples/light source
100 samples/pixel

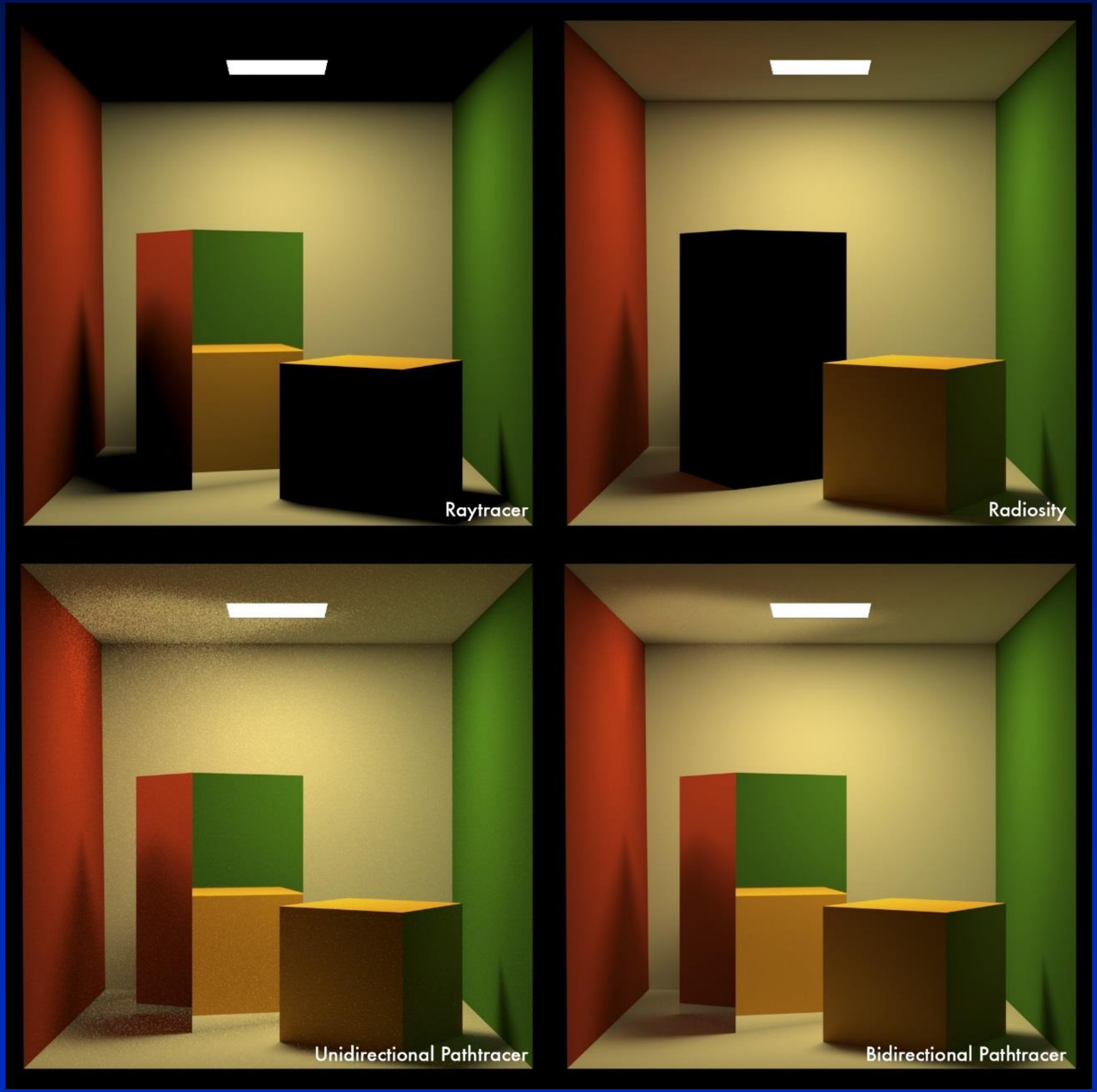
Bi-directional Path Tracing



Bi-Directional Path Tracing

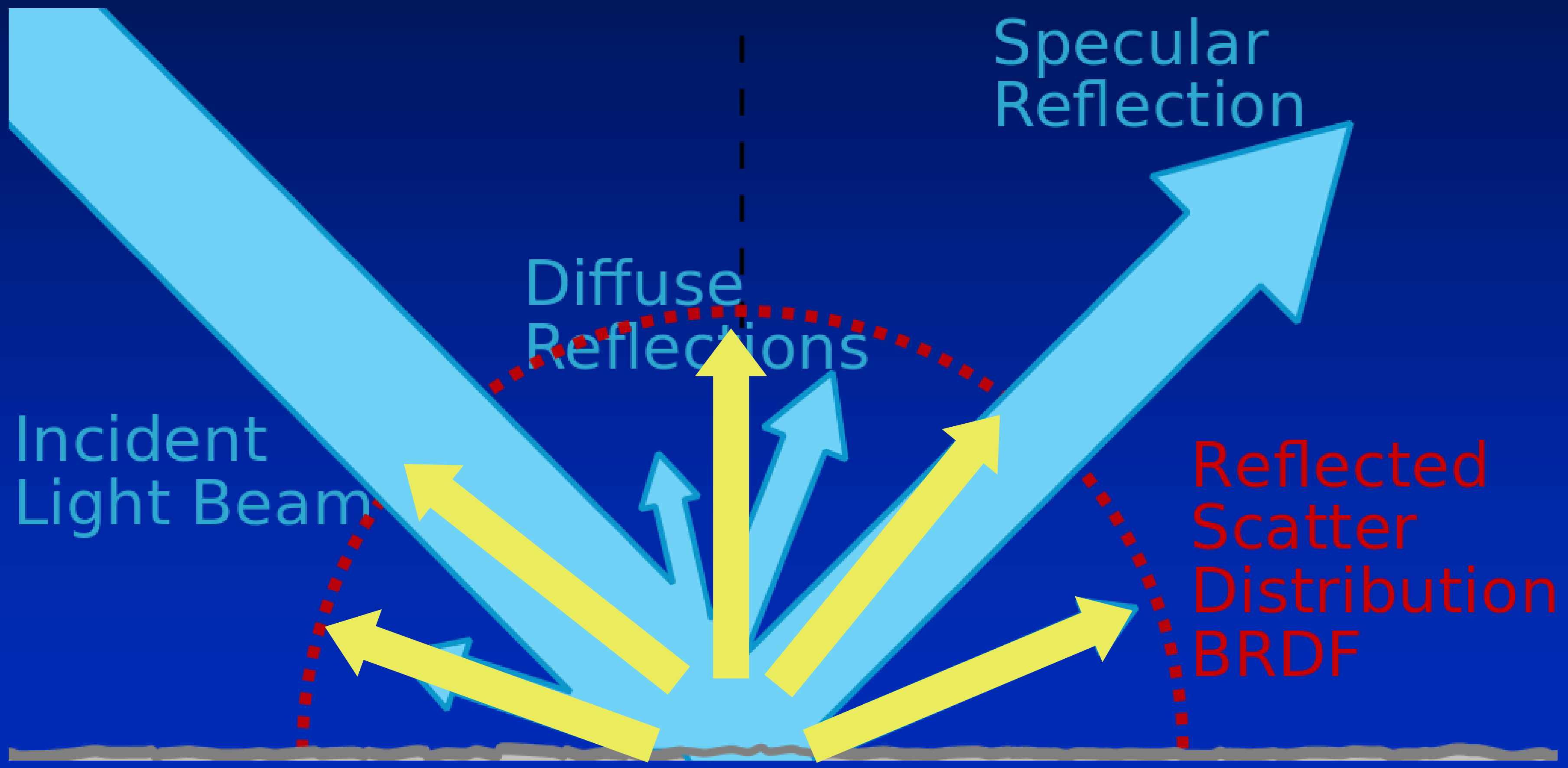


Bi-directional Path Tracing

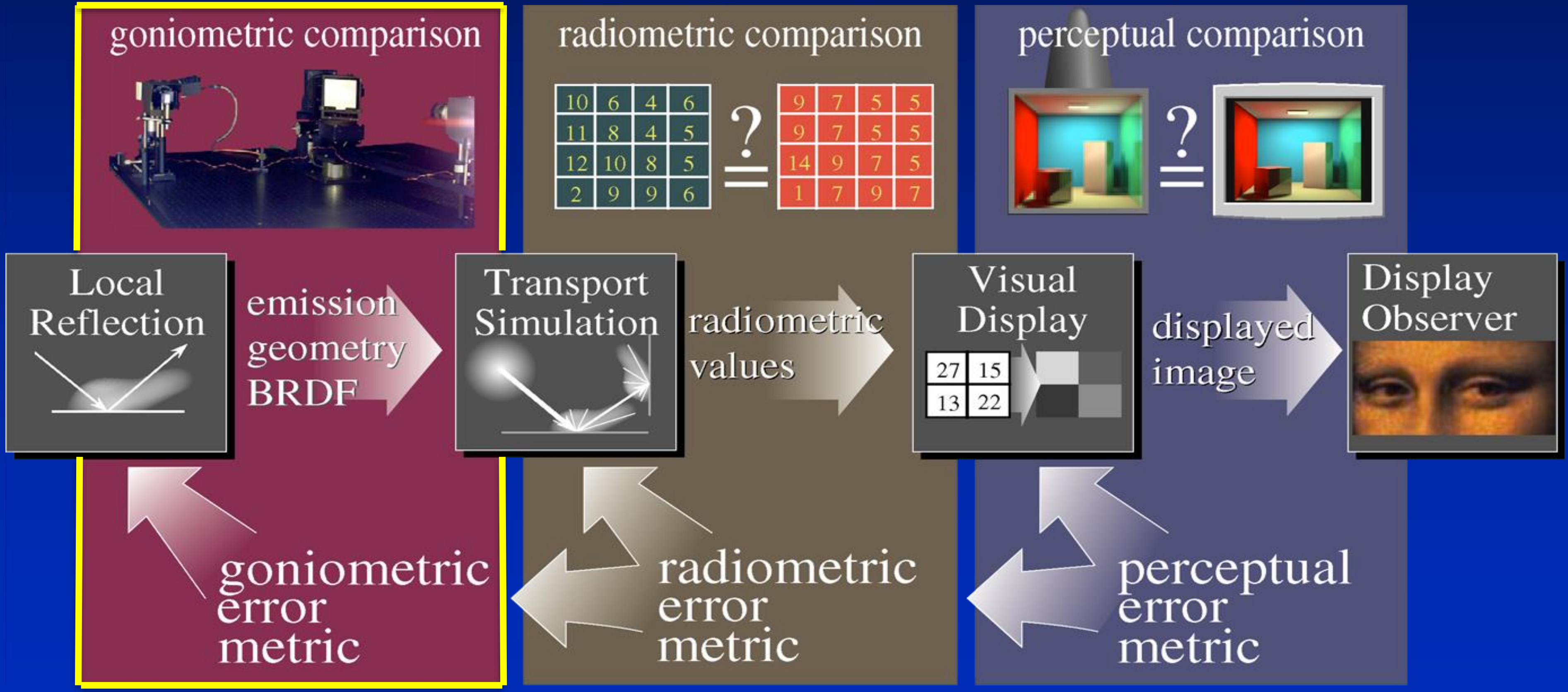


End

Radiosity

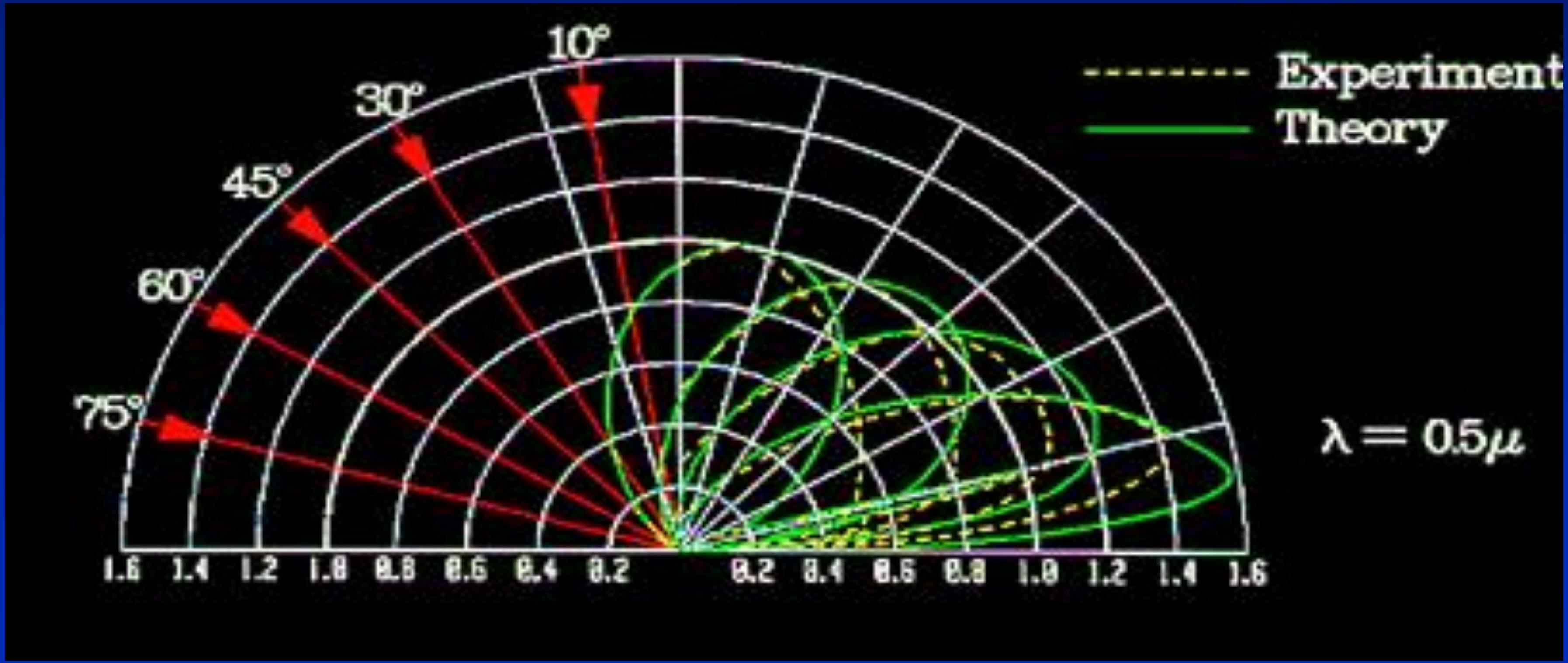

Specular
Reflection
Diffuse
Reflections
Incident
Light Beam
Reflected
Scatter
Distribution
BRDF

Rendering Framework 1997



Comparison of experiment and theory

Aluminum $\sigma_0 = 0.28\mu, \quad \tau = 1.77\mu$



Video: Material Science

Predicting Surface Appearance
from
Measured Microgeometry

PaperID: 0582

Total Cost of Intersection Operation

Why Triangles?

Monte Carlo Ray Tracing

Ray Tracing Model Whitted 1979

$$\underbrace{I = k_d \sum_{i=1}^{l} \left(\overline{N} \cdot \overline{L}\right) \qquad \text{(object color)}}_{\text{direct diffuse}}$$

(object color)

$$\underbrace{+ k_s \sum_{i=l}^{l} \left(\overline{N} \cdot \overline{H}\right)^n}_{\text{direct specular}} + \underbrace{I_a}_{\text{global diffuse}} + \underbrace{k_s I_r}_{\text{global specular reflected}} + \underbrace{k_t I_t}_{\text{global specular transmi tted}}$$