Grafické systémy, vizualizácia a multimédiá

2 / 1

Letný semester 2006

Photorealism

Graficke systemy, vizualizacia a multimedia

Reality versus Synthesis

Photograph

Rendering using the deterministic method

„Computer Graphics...

- ... can be formulated as a radiometrically „weighted“ counterpart of computational geometry…
- ... rendering is done through the application of a simulation process to quantitative models of light and materials to predict/synthesize appearance“
-
- D. Dobkin & S. Teller

Computer Graphics...

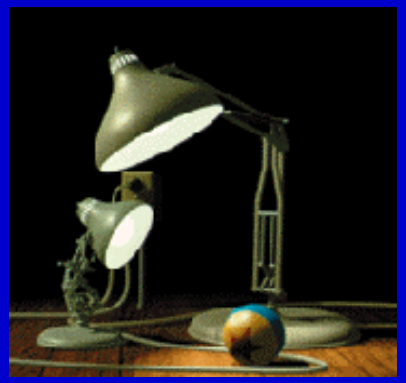
- ... must account geometry
- material properties: reflectance/color, refractive index, opacity, and (for light sources) emmisivity
- radiometry
- output for viewing: explicitly or implicitly psychophysics

- by D. Dobkin & S. Teller

Agenda - Photorealism

- (Polygonize, generate the mesh)
- Classic Local Illumination Models
- Definition of Light Sources
- Rendering & Light Simulation
- Material & Light Interaction

What means Photorealism?



Reality versus Synthesis

Photograph

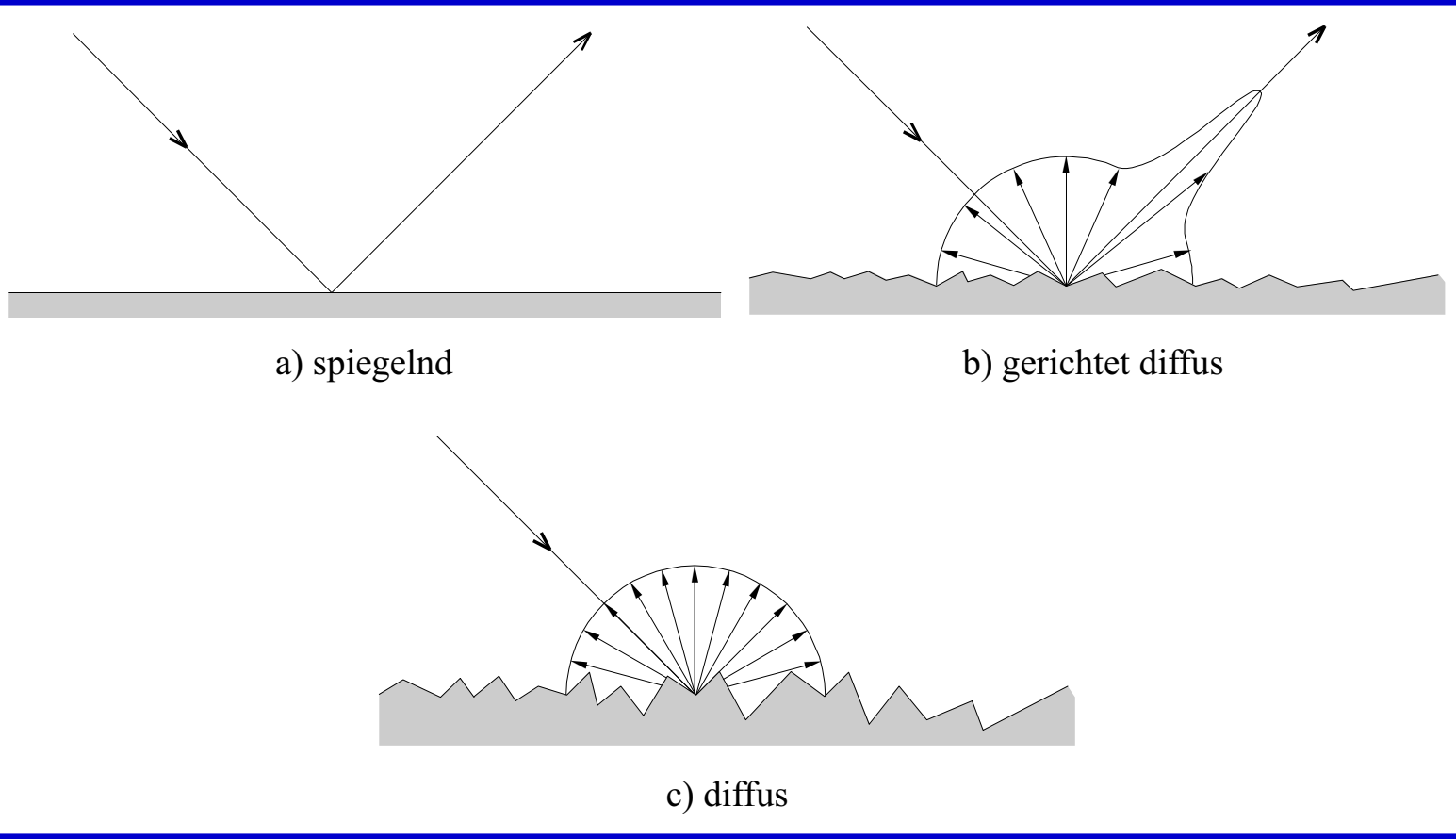
Rendering using the deterministic method

Simulation of the Office

Illumination Models

- **Local Illumination Models (first order)**
  - Empiric Models (feasible)
  - Physical Models (possible, but expensive)
- **Globale Illumination Models (second order)**
  - Ray-Tracing (photons)
  - Radiosity (waves, „key is the light“)

Reflexion Properties



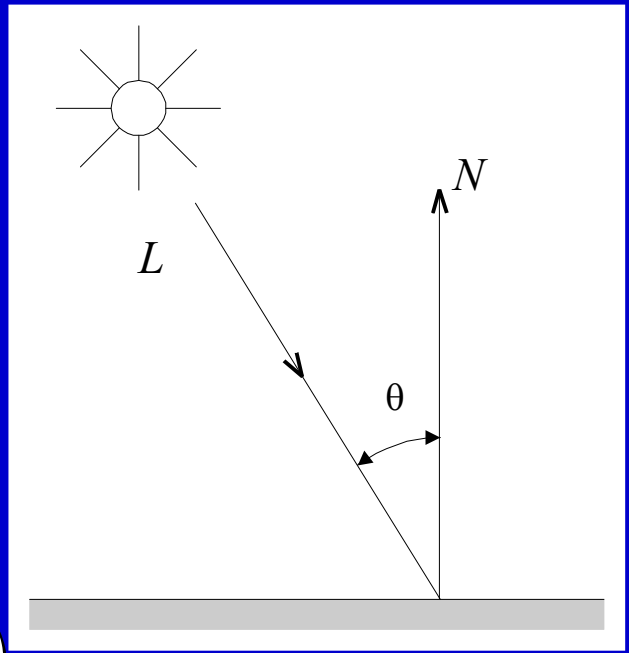
Ambient Light

- Daylight (diffuse, undirected) lightsource
- Intensity in the given scene constant
- Multiple reflexions on surfaces in the scene
- Trivial Illumination Model: $I = I_a k_a$

I_a intensity of ambient light
k_a ambient reflexion coeficient

Lambertian Illumination Model

- Directional lightsource(s) added
- Diffuse reflection: independent from the camera position
- Illumination Model:
  $I = I_p\, k_d \cos\theta = I_p\, k_d\, (N \bullet L)$



I_p Intensity of directional lightsource, point

k_d diffuse reflexion coeficient

Intensity attenuation

- **Intensity contribution:**
  d_L lightsource distance

$$f_{att} = \frac{1}{d_L^2}$$

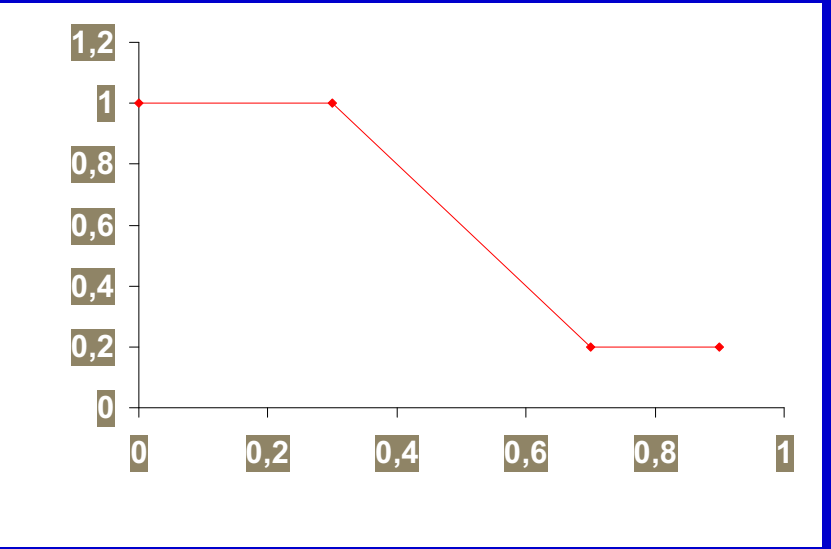
- **Alternative representation:**

$$f_{att} = \min\left(\frac{1}{c_1 + c_2 d_L + c_3 d_L^2}, 1\right)$$

- **Lighting model:** $I = I_a k_a + f_{att} I_p k_d (N \bullet L)$

Depth-cueing

- Distant objects appear darker (optionally „color-shift“, too)
- „Atmospheric perspective“



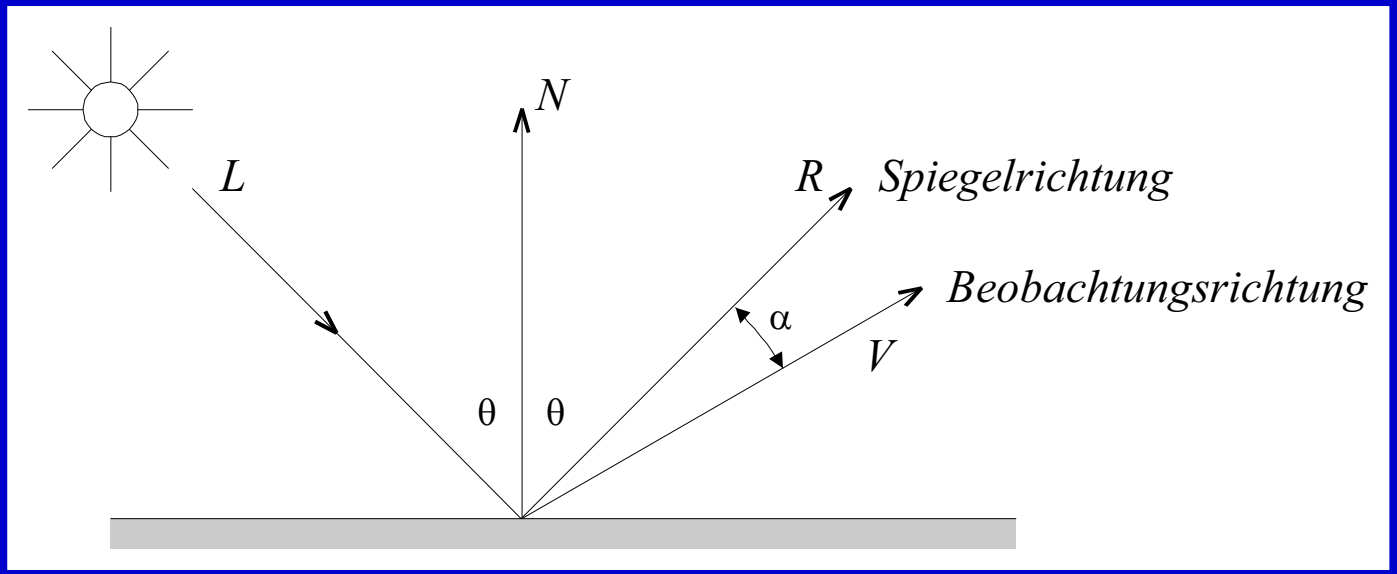
- Linear interpolation: $I' = s_0 I_f + (1- s_0) I_b$
- Scaling between „front/backplane“

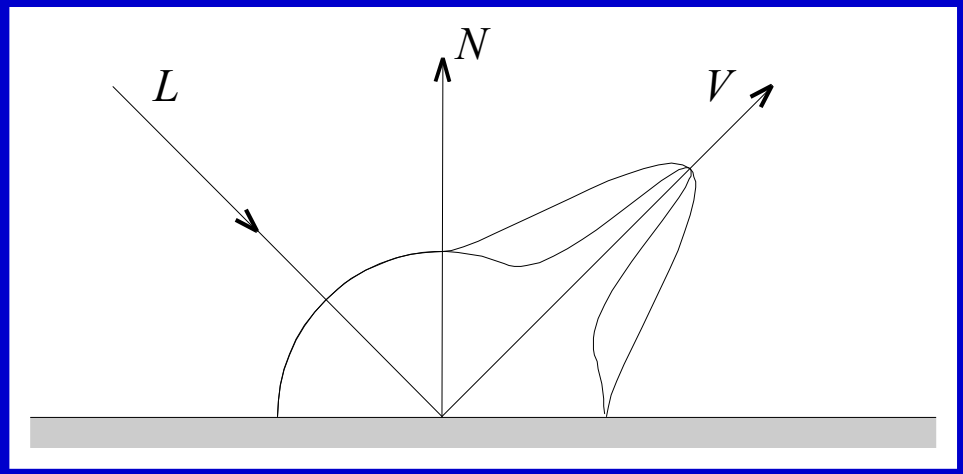
Phong Illumination Model

- Adding specular reflection (depends on camera position)
- New Illumination Model:

$$I = I_a k_a + f_{att} I_p (k_d \cos\theta + k_s \cos^n \alpha) =$$
$$I_a k_a + f_{att} I_p [k_d (N \bullet L) + k_s (R \bullet V)^n]$$

k_d, diffuse reflection coeficient
n (*Spiegelneigung*), „shininess“parameter
R Reflected photon direction vector
V Viewer/Camera direction vector


N
L
R
Spiegelrichtung
Beobachtungsrichtung
α
V
θ
θ


N
L
V

Shaders, shading models

- **Fill polygons after transformations and rasterization by color values**
- **Flat-Shading:**
  - *Lamberts Illumination Model*
  - *single color value for each polygon/triangle*
  - *advantage: very fast*
  - *drawbacks: Mach-bands, causing nonrealistic appearance*
- *Better ones: Gouraud-, Phong-Shading*

Rendering Polygonal Scene

- 1. Extract Polygons from the Database
- 2. Transform to WC and VRC
- 3. Backface Culling and Visibility
- 4. Clip against the visible volume
- 5. Projection of clipped polygons
- 6. Shading by Incremental Shader:
  - 1. Rasterize,
  - 2. Depth and visibility, (z-buffer)
  - 3. Shading (constant, Gouraud, Phong…)

Local Illumination Summary

- Empirical Shading Models
  - constant, Gouraud, Phong...
- Ambient, diffuse and specular reflection
- Light Rays only
- Polygonal Scenes
- Rendering Summary (Polygonal Case)
- More: transparency, bumpy surfaces, textures, global illumination, animation...

Local Illumination Online

- *Applet by Patrick Min at*

  http://www.cs.princeton.edu/~min/cs426/classes/light.html

- *http://www.siggraph.org/education/materials/HyperGraph/illumin/illum0.htm*
- *http://www.siggraph.org/education/materials/HyperGraph/illumin/vrml/pellucid.html*

Definition of Light Sources

- Point light source
- Multiple point sources… area
- 4 abstract lightsources - ambient, directional, point, flood
- intensity/fog = I/(a*d*d…*d + b)
- flood: powers of cosine (Phong)

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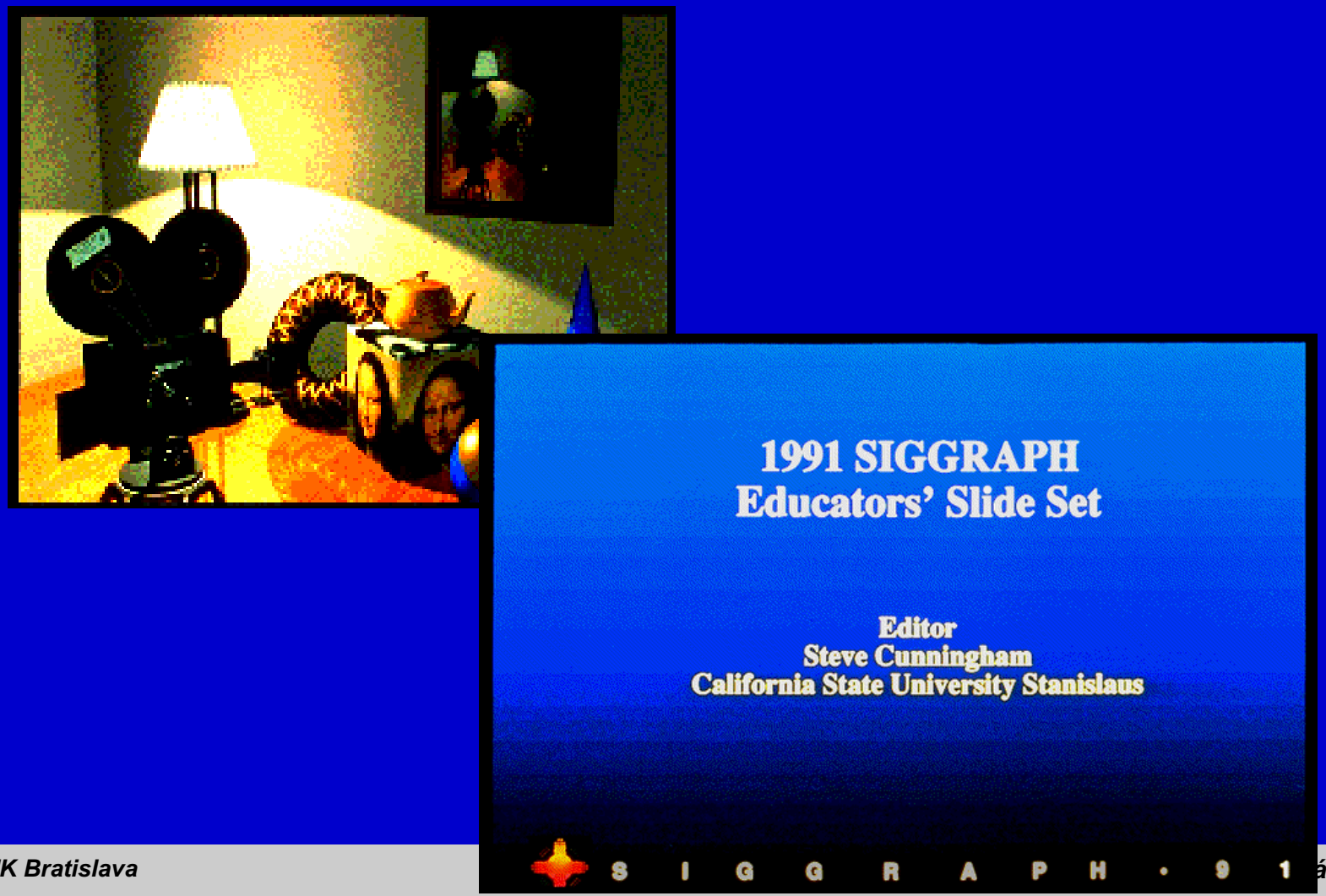
SIGGRAPH Slide Show

- 

The Shutterbug Rendering Progression

This sequence illustrates the progressive refinement of rendering algorithms.

The images range from wire frames to photo-realistic renditions including reflections and shadows.

The rendering algorithm affects the quality and information conveyed by the image, independent of the underlying three-dimensional model.

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ShutterBug Credits

Produced by Tom Williams and H. B. Siegel, with the assistance of M. W. Mantle

All images rendered with PhotoRealistic RenderMan 3.2

Produced for Computer Graphics, Principles and Practice, Second Edition, by Foley, van Dam, Feiner, and Hughes

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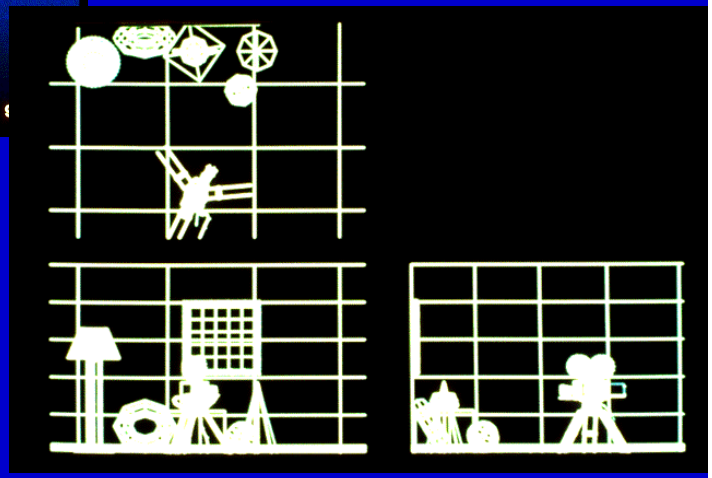
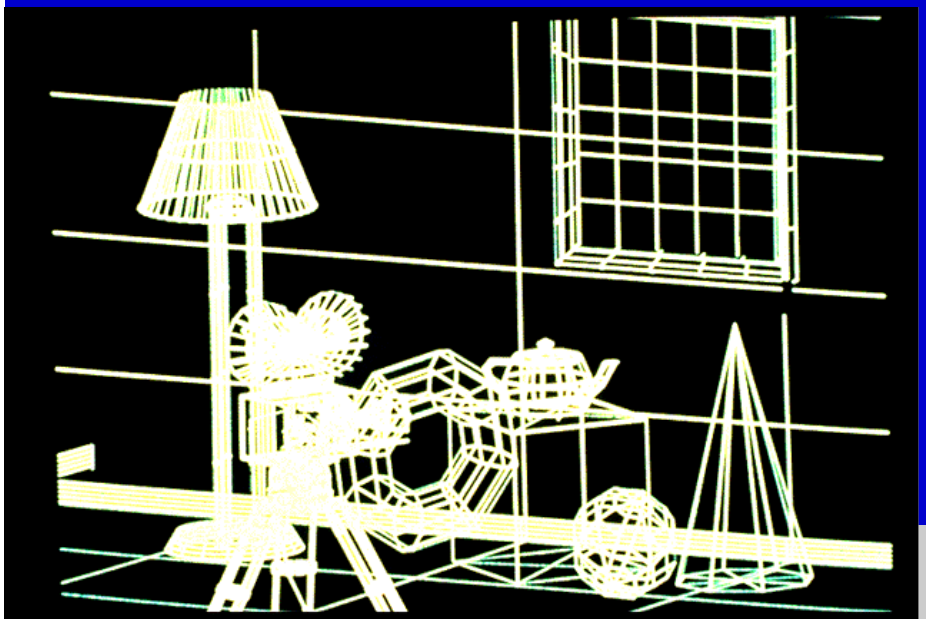
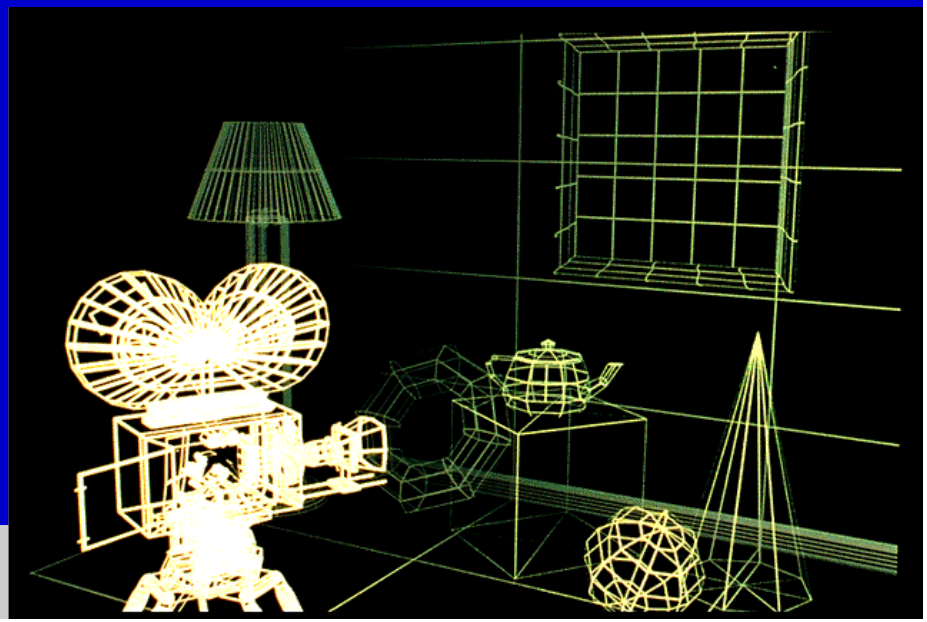
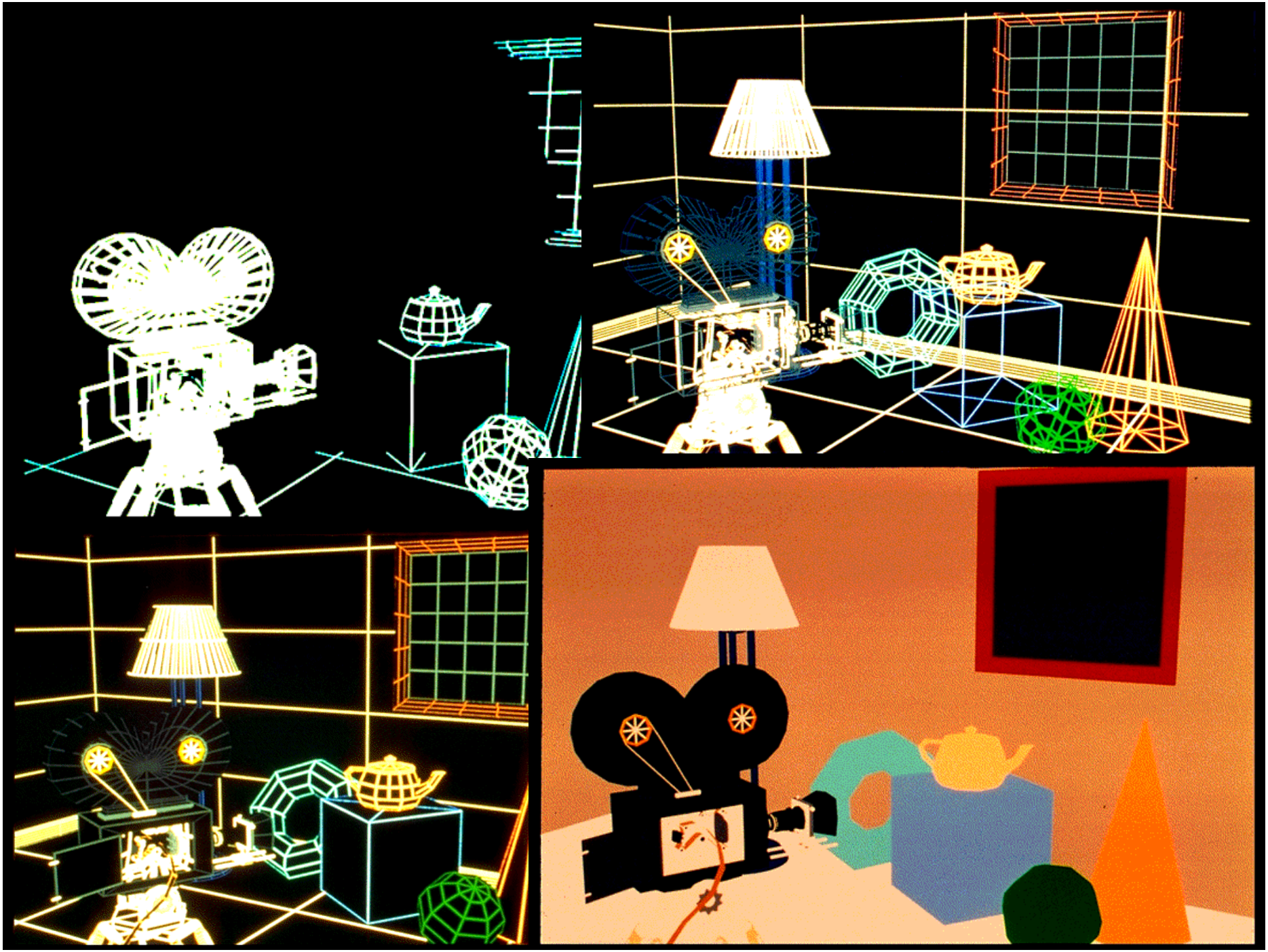
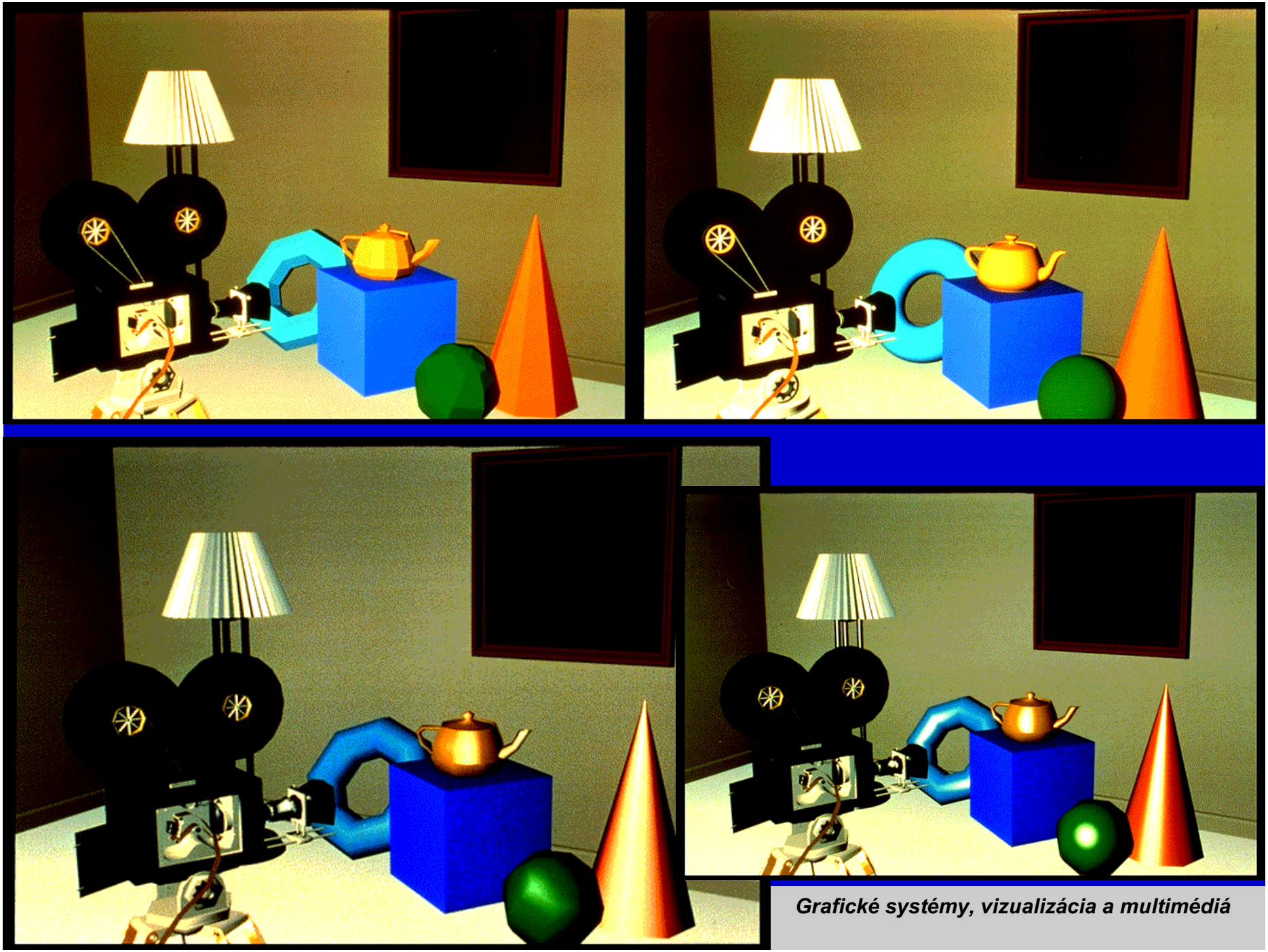
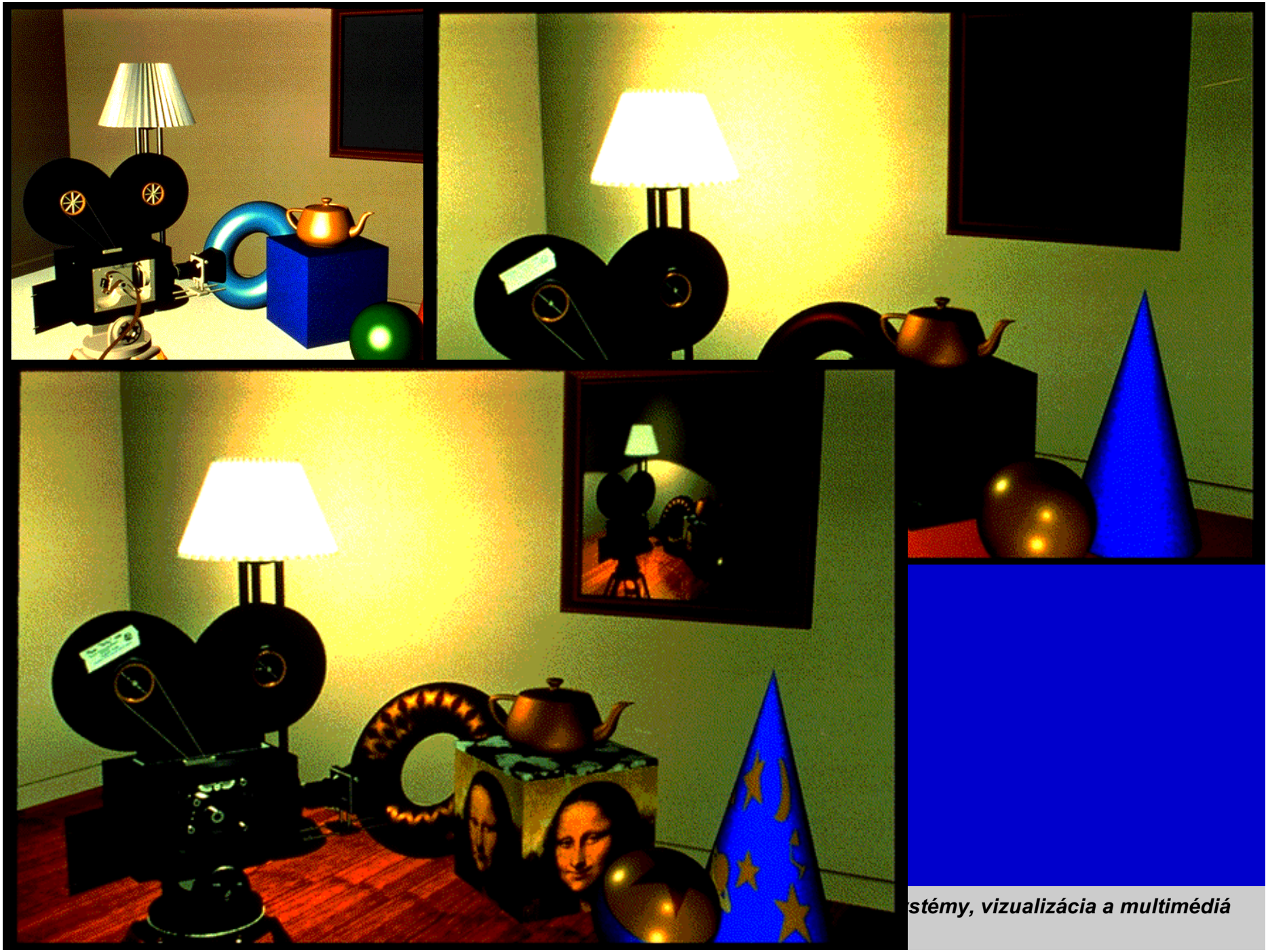


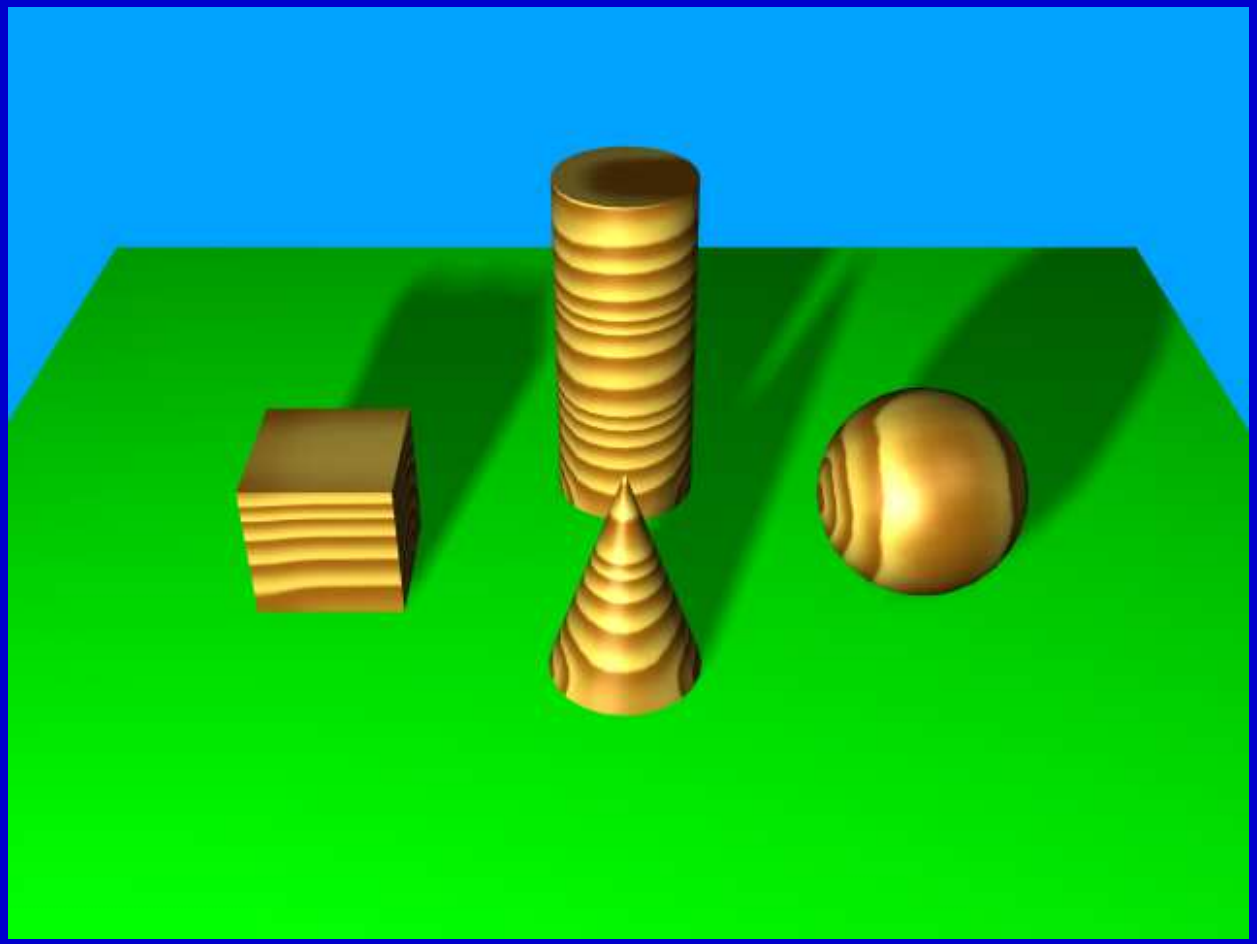












Ray Tracing

Standard Global Illumination Method

Ray Tracing Preview

- *Early Use - Descartes (1637) - rainbow*
- *Optics, geometry for lens systems*
- *Reflection and refraction*
- *Three Ray Tracings:*
  - *Visibility method*
  - *Recursive Ray Tracing for Global Illumination*
  - *Volume Rendering Method*
- *http://www.acm.org/tog/resources/bib/*

Forward and Backward RT

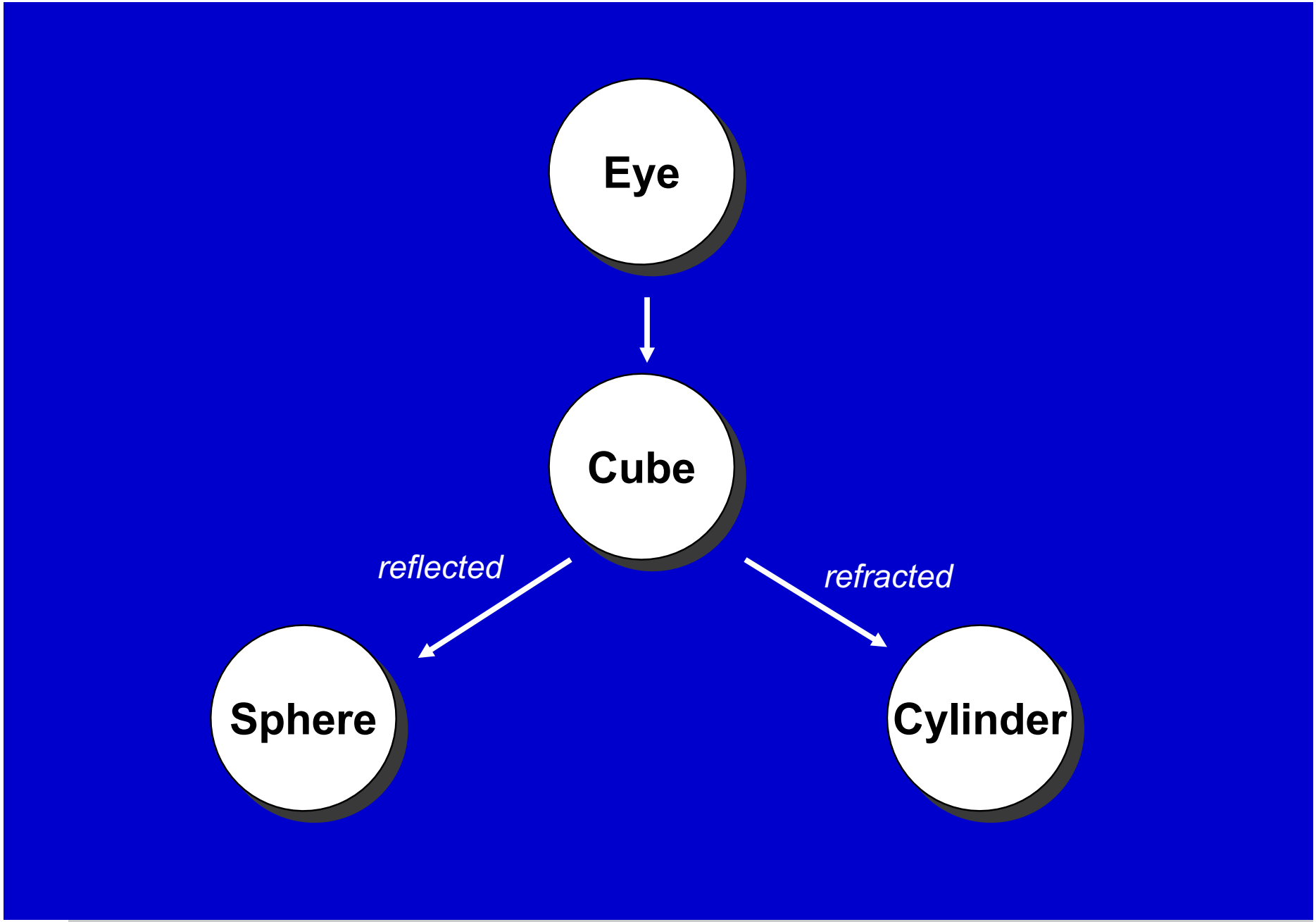
- *2D case by F. S. Hill, Jr.*
- *Pinhole camera model...*
- *… extended camera model (TU Wien)*
- *Pixels & rays (photon vibrations, RGB)*
- *Forward Ray Tracing*
- *Lightsource -> Image Plane, unfeasible*
- *Better one: Eye rays, pixel rays… light*
- *Shadow and Illumination Rays*

Ray Classification & Numbers

- Primary Rays (Visibility <-> Shadow)
- Reflection and Refraction Rays
- Binary tree model
- 100 W bulb/sec about 10E42 photons
- Computer 10E7 initial particles :-(
- Time and memory (Terraflop Club)
- Standard free software is POVRay
- **www.povray.org**

Recursive Ray Tracing

- **Illumination Model**
  - *Visibility/Shadows computation*
  - *Reflexion/Refraction of light*
  - *Global mirror reflection*
- **Ray Distribution**
  - *Indirectly through transparent object*
  - *Directly (local illumination)*
  - *Multiple reflexions*


Eye
Cube
reflected
refracted
Sphere
Cylinder

Recursive Ray Tracing

1) Visibility algorithm for primary rays
(eye -> pixel center)

- *Visible Object Intersection*
- *Background (Color setting)*

2) Recursive tracing of rays

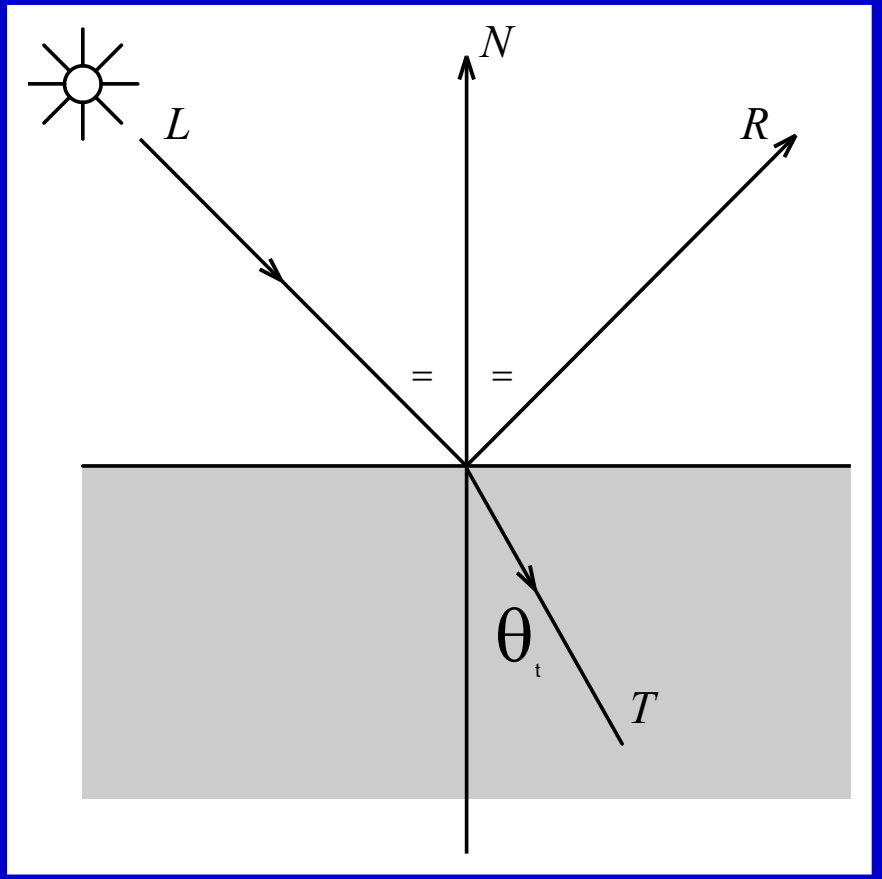
- *Lightsource hit*
- *Intensity increase until* $< \varepsilon$

```
FOR every pixel p DO
1.  trace primary ray
    find closest intersection s
2.  FOR every light source l DO
      trace shadow feeler l -> s
      IF no intersection THEN
          illumination += influence of l
3.  IF surface of s is reflective THEN
      trace secondary ray
      illumination += influence of reflection
    IF surface of s is transparent THEN
      trace secondary ray
      illumination += influence of refraction
```

Reflection & Refraction Vector

$$\vec{R} = 2\left(\vec{N} \cdot \vec{L}\right)\vec{N} - \vec{L}$$

$$\vec{T} = \frac{n_1}{n_2}\vec{L} - \left(\cos\theta_t + \left(\vec{L} \cdot \vec{N}\right)\right)\vec{N}$$



Illumination Model

- **Point Intensity:**

  $I = I_{local} + k_{rg}\, I_{reflected} + k_{tg}\, I_{transmitted}$

- **Local (Phong extended):**

  $I_{local} = I_a\, k_a + I_p\, [k_d\, (N \bullet L) + k_{rl}\, (N \bullet H)^n + k_{tl}\, (N \bullet H')^n]$

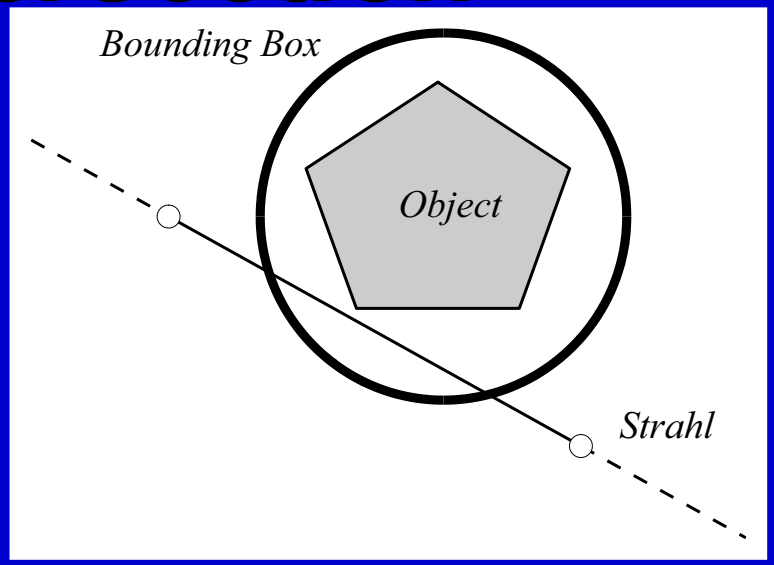
- **Recursive Definition:**

  $I(P) = I_{local} + k_{rg}\, I(P_r) + k_{tg}\, I(P_t)$

Intersection Computations

- Ray-Scene Intersections (Sphere!)
- Multiple Intersections Possible
- Usable for B-Rep´s
  (95% of Time Consumption)
- Problem Formulation
  - Efficient Intersection Algorithm (stability)
  - Alternative Strategies
    (Bounding Box Checks, Space Subdivisions etc.)

Ray-Sphere Intersection



1) Define the Bounding Box (Sphere)
2) Ray&Sphere Query
3) If YES
   then Ray-Object Intersection (triangles: barycentric hint)

Pros:

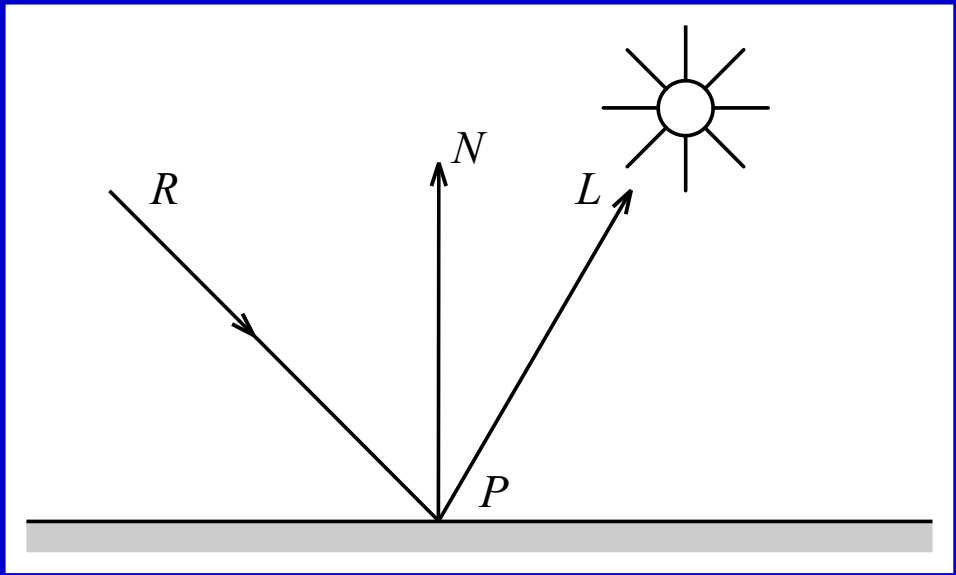
- Simple Bbox Definition
- Efficient Calculation of Intersections

Shadow Feeler

Ray = P + t (L - P)

- P… Surface Point
- t … Parameter of Representation for Shadow Feeler

If (Intersection for 0 < t < 1) then no Impact of the given Lightsource



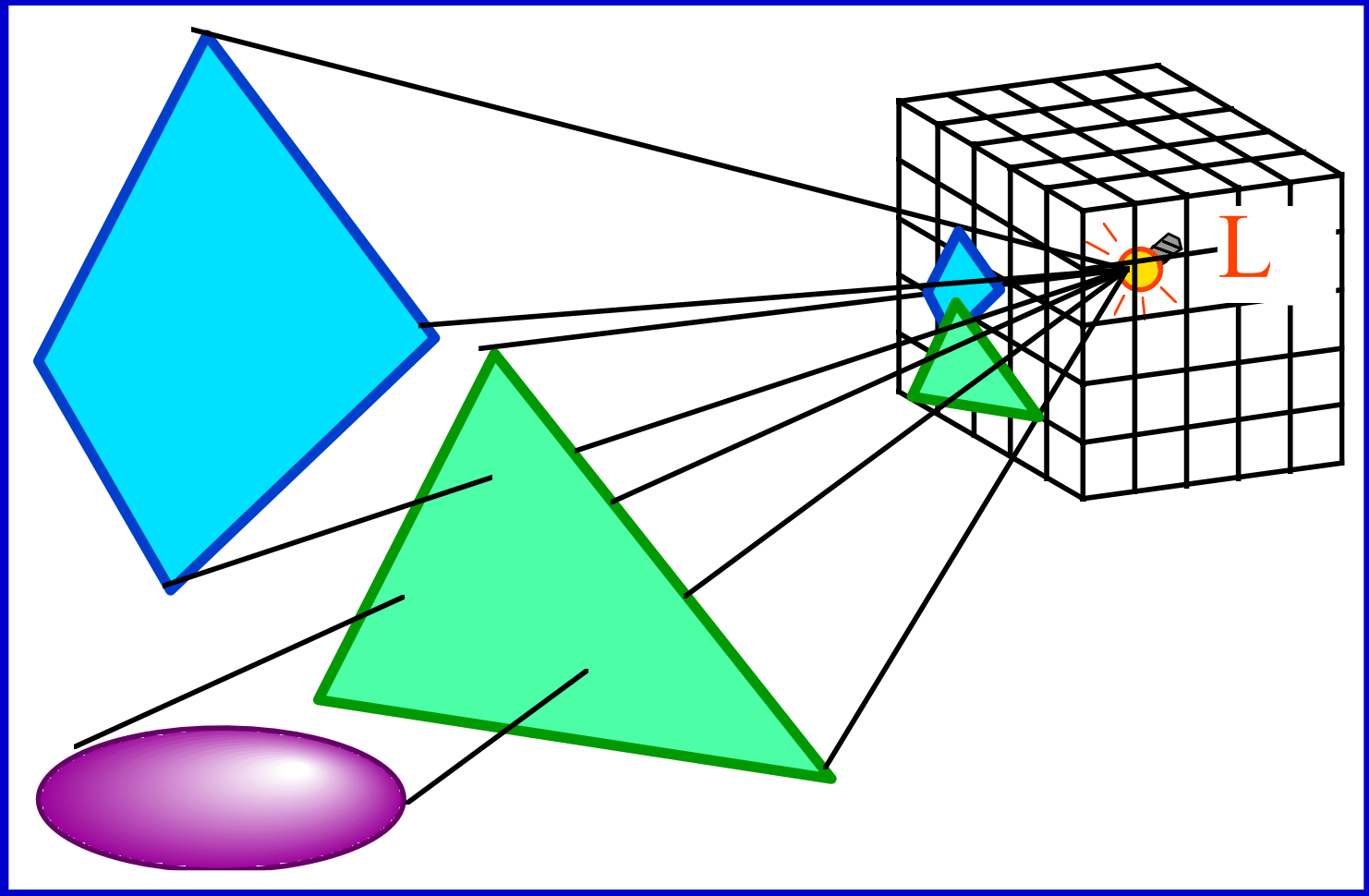
Disadvantages

- ***High complexity, too many rays (and intersections)***
- ***Restricted „globality“ for mirror reflection and refraction (no global diffuse illumination)***
- ***View dependent & visual drawbacks***
  - *Anti-Aliasing*
  - *Sharp shadow borders*
  - *Depth of field problem*

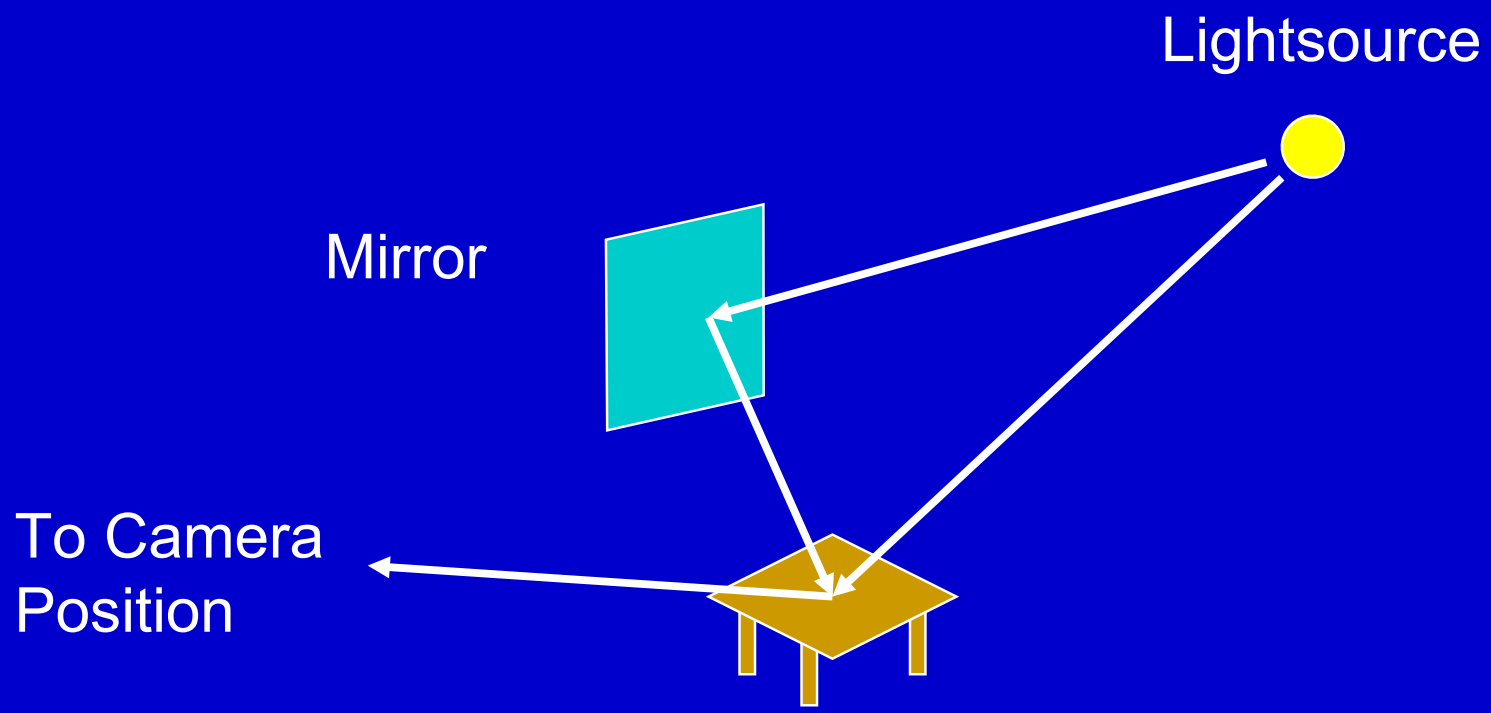
Optimisation Ideas

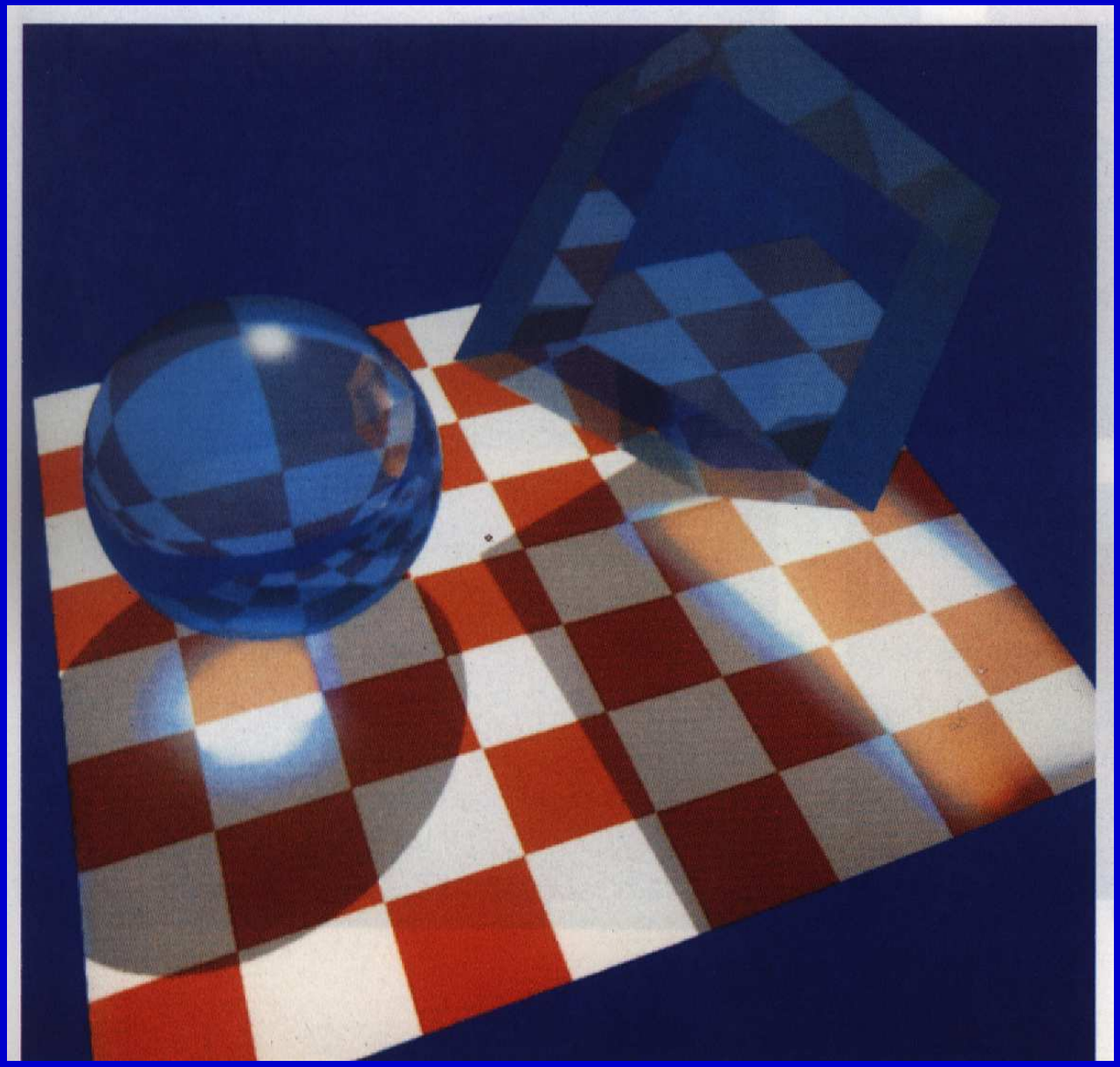
- z-buffer for primary rays
- Recursion depth limit
  - fixed depth
  - given quality, threshold (ε)
- Hierarchic object neighbourhoods
- Space subdivision
- Light-Buffer, Ray Coherence, Ray Classification
- Generalized Rays and Cone Tracing

Light-Buffer by Haines&Greenberg



Backwards Ray Tracing





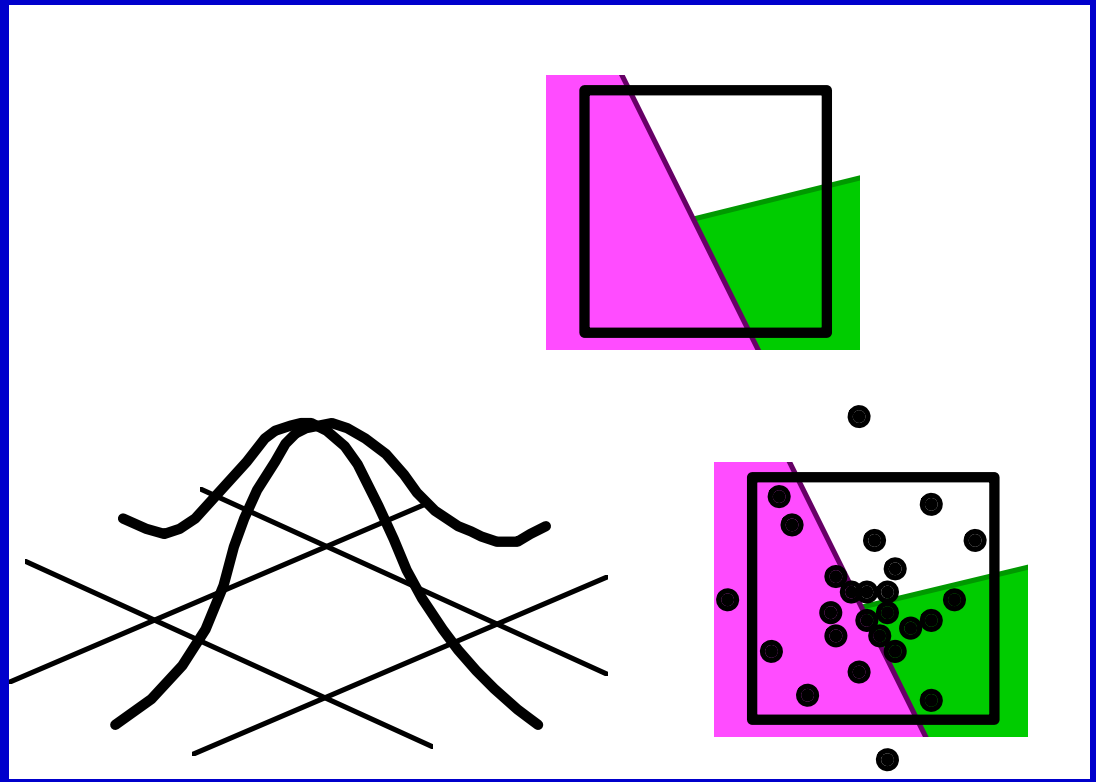
Distributed Ray Tracing

Provides these effects:

- *Aliasing*
- *Diffuse mirror case*
- *Milk-glass effect*
- *Soft shadows*
- *Depth of field*
- *Motion blurr*

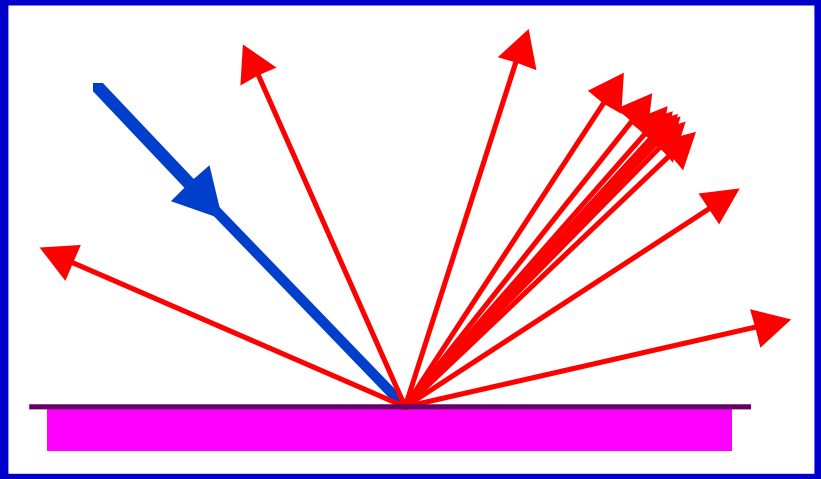
Anti-Aliasing

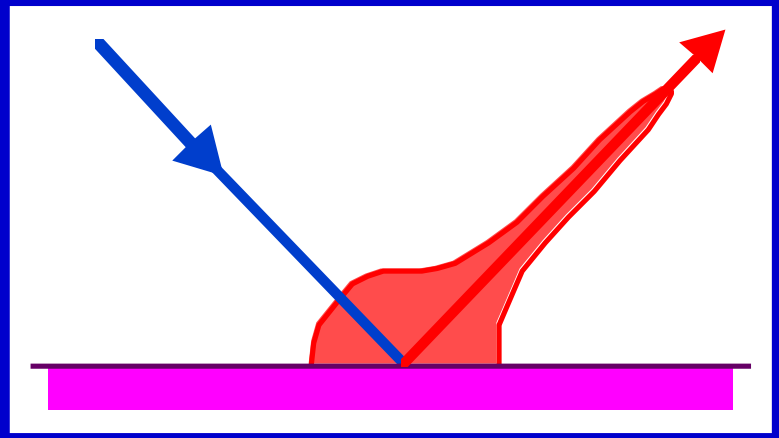
Stochastic sampling with Gaussian distribution



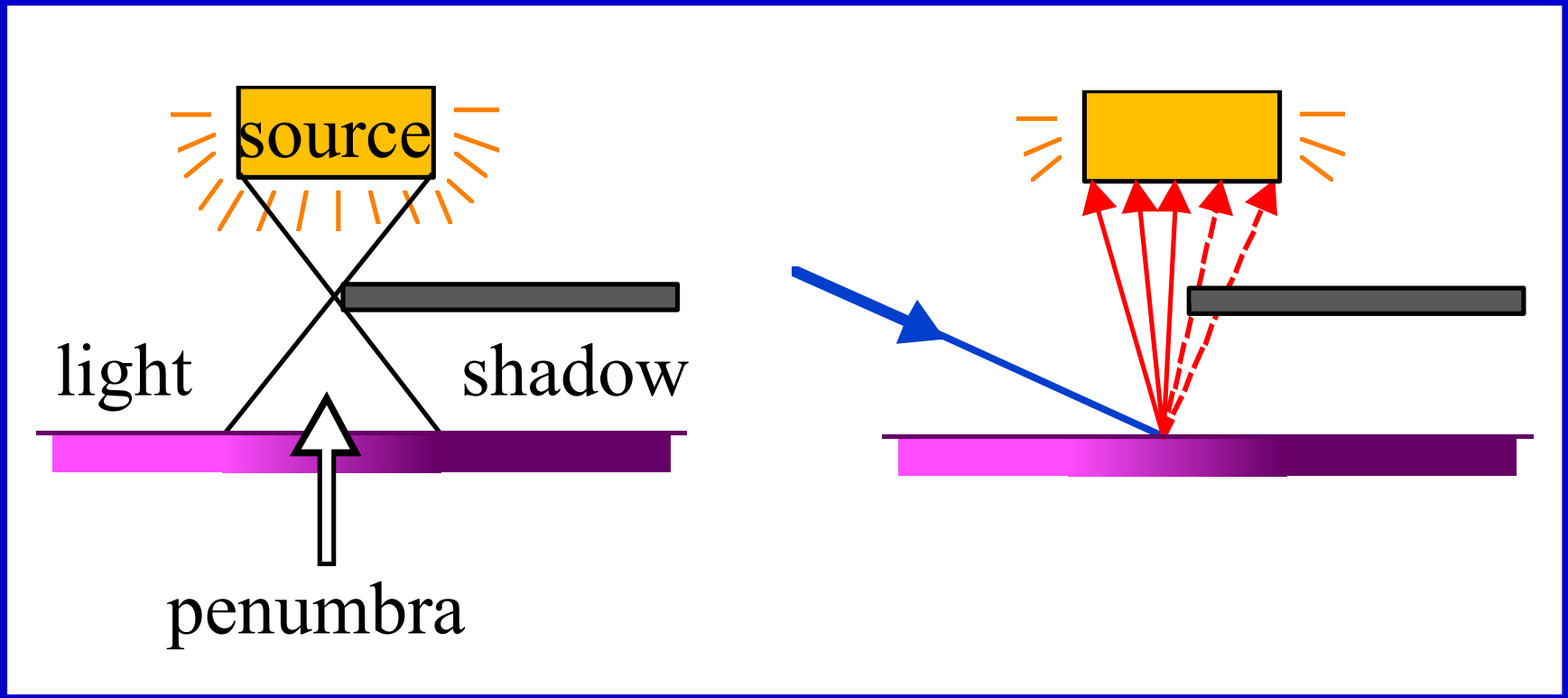
Diffuse Mirror Case

Simulation of directed-diffuse reflection using the variation of reflection angles



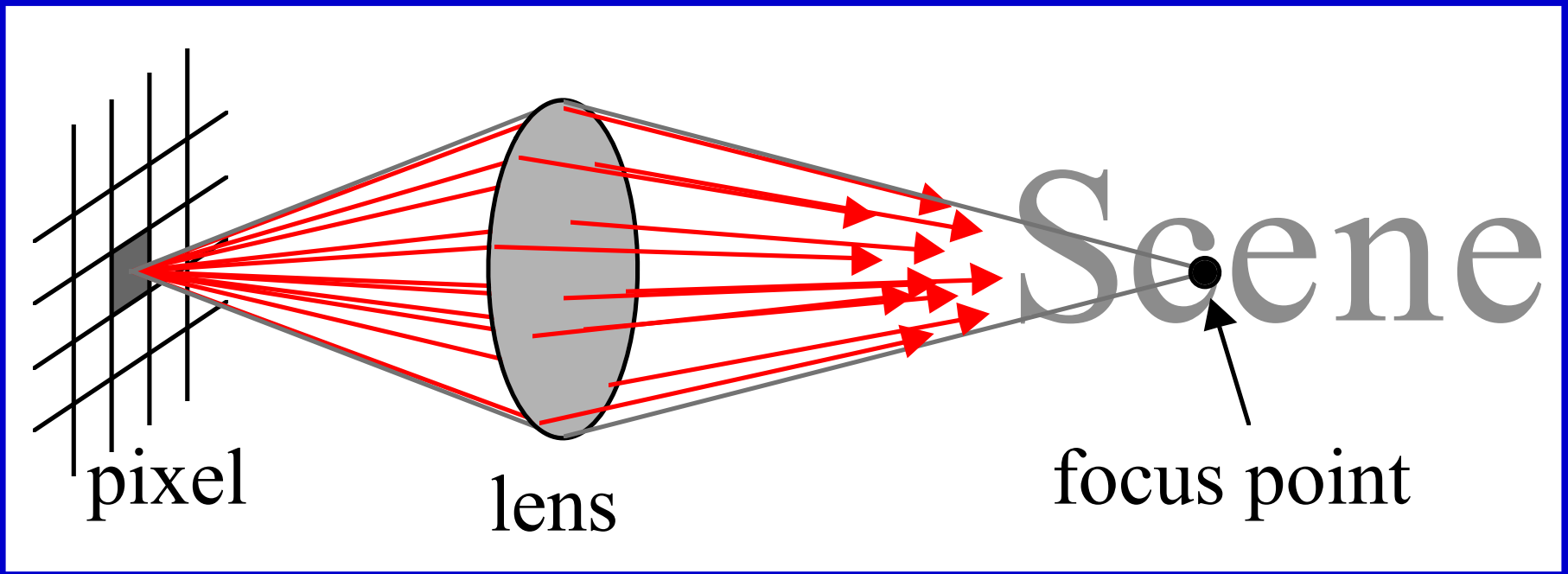


Soft Shadows



Depth of field

Depends on the lens parameters, out of the pinhole camera model, distortion



Algorithm
(Distributed Ray Tracing)

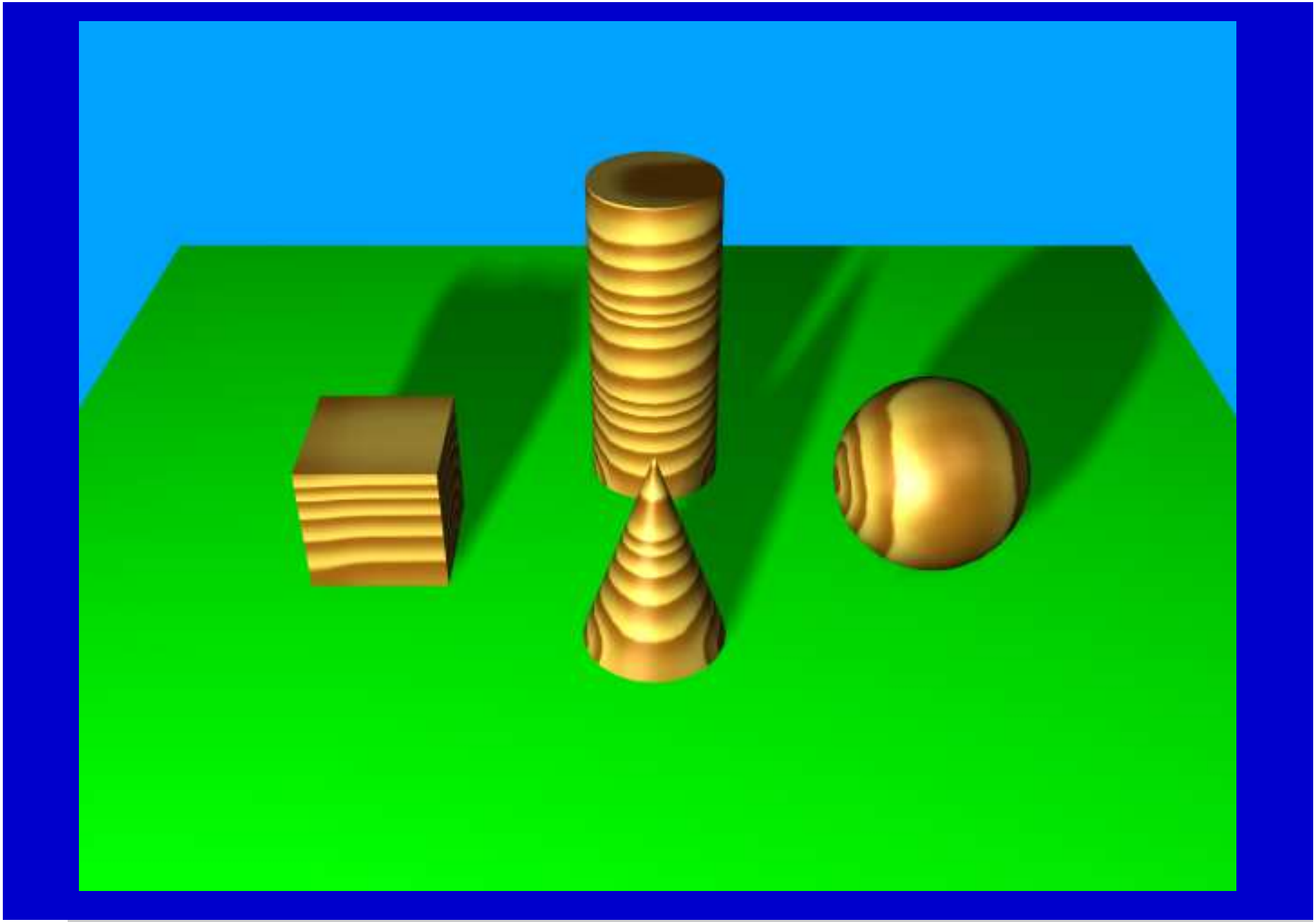
- **Huge set of rays - but:**
- **Monte-Carlo integration possible**
  - *One ray traced only*
  - *Integrated bundles of rays*
- **Necessary rays (per pixel):**
  - *Minimum: 5-10*
  - *Good quality: 10-20 (for one effect)*
  - *Exellent quality: 20-60*

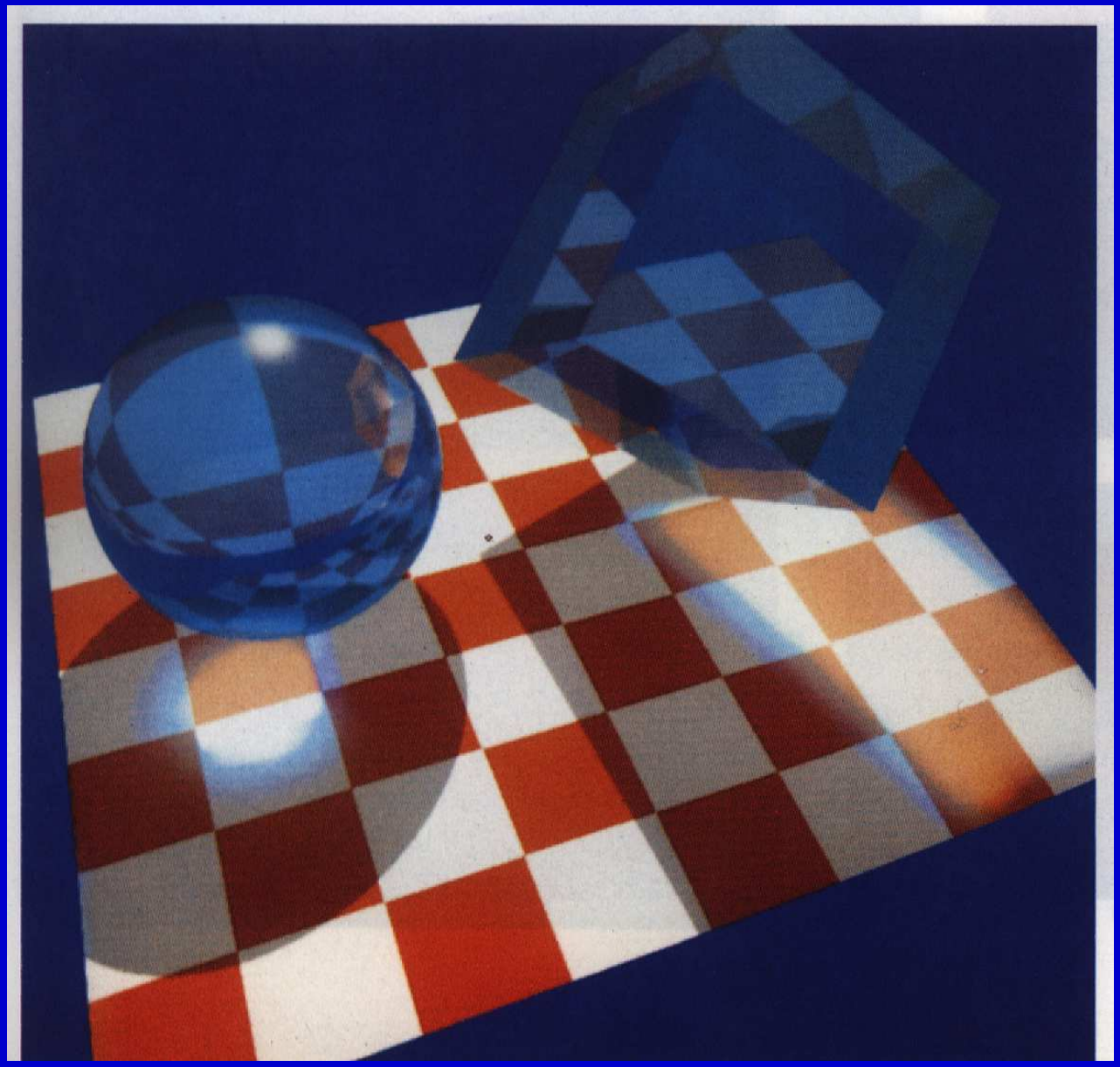
Ray Tracing Summary

- Very old geometric model
- Industrial standard and POVRay
- Computationally expensive
- Many improvements published:
- www.acm.org/tog/resources/bib/
- Parallelisation, ray space, random walk, two-pass methods, instant radiosity by Keller, … research...

Radiosity

Global Illumination Method for Diffuse Environments





Simulation of the Office

Radiosity

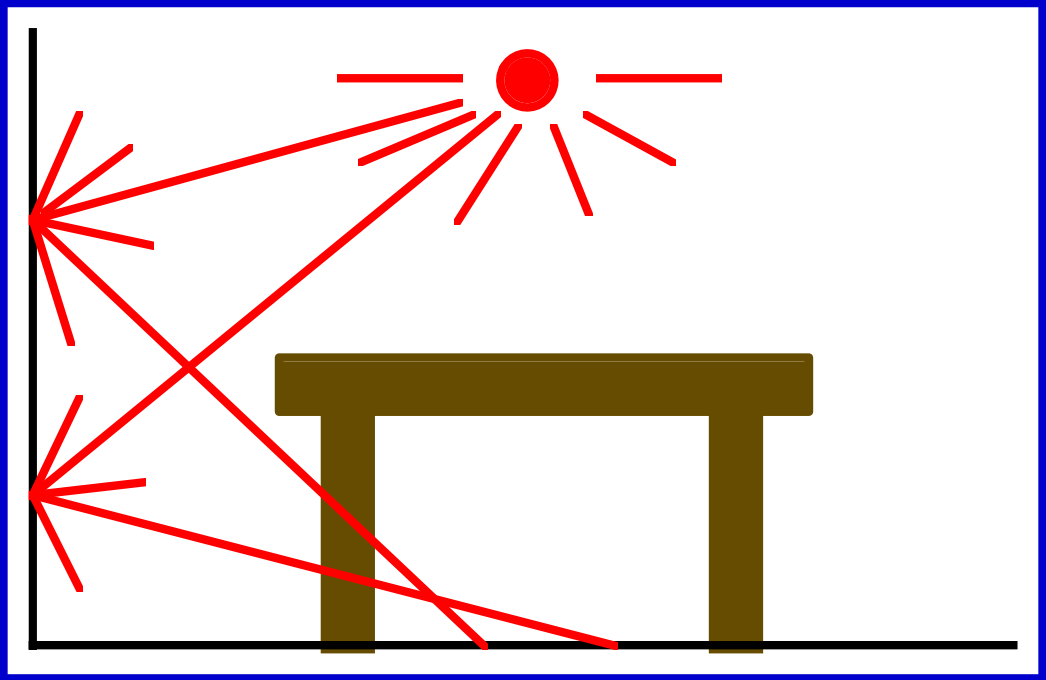
- Solution for global diffuse illumination of closed systems
- Very suitable for interior scenes
- Algorithmisation and rendering completely differs from Ray Tracing
- Cornell, Fukuyama, Hiroshima Universities (1984 -)

Radiosity Idea

Lightsources & surfaces are equally active areas. They the light energy both:

- ***reflect***
- ***emit***

Energy is radiated in the space.



„Radiosity“ of a Patch

- **Total energy (continuous case):**

$$B_i dA_i = E_i dA_i + \rho_i \int_j B_j dA_j F_{dAjdAi}$$

B_i … Radiosity of Patch

E_i … Emitted Energy from Patch

ρ_i … Coefficien t of Reflexivit y

F_{dAjdAi} … Formfactor $dA_j - dA_i$

- **Total energy (discrete case):**

$$B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{ji}$$

- **Reciprocity of Formfactors:**

$$F_{ij} A_i = F_{ji} A_j \rightarrow F_{ij} = F_{ji} \frac{A_j}{A_i}$$

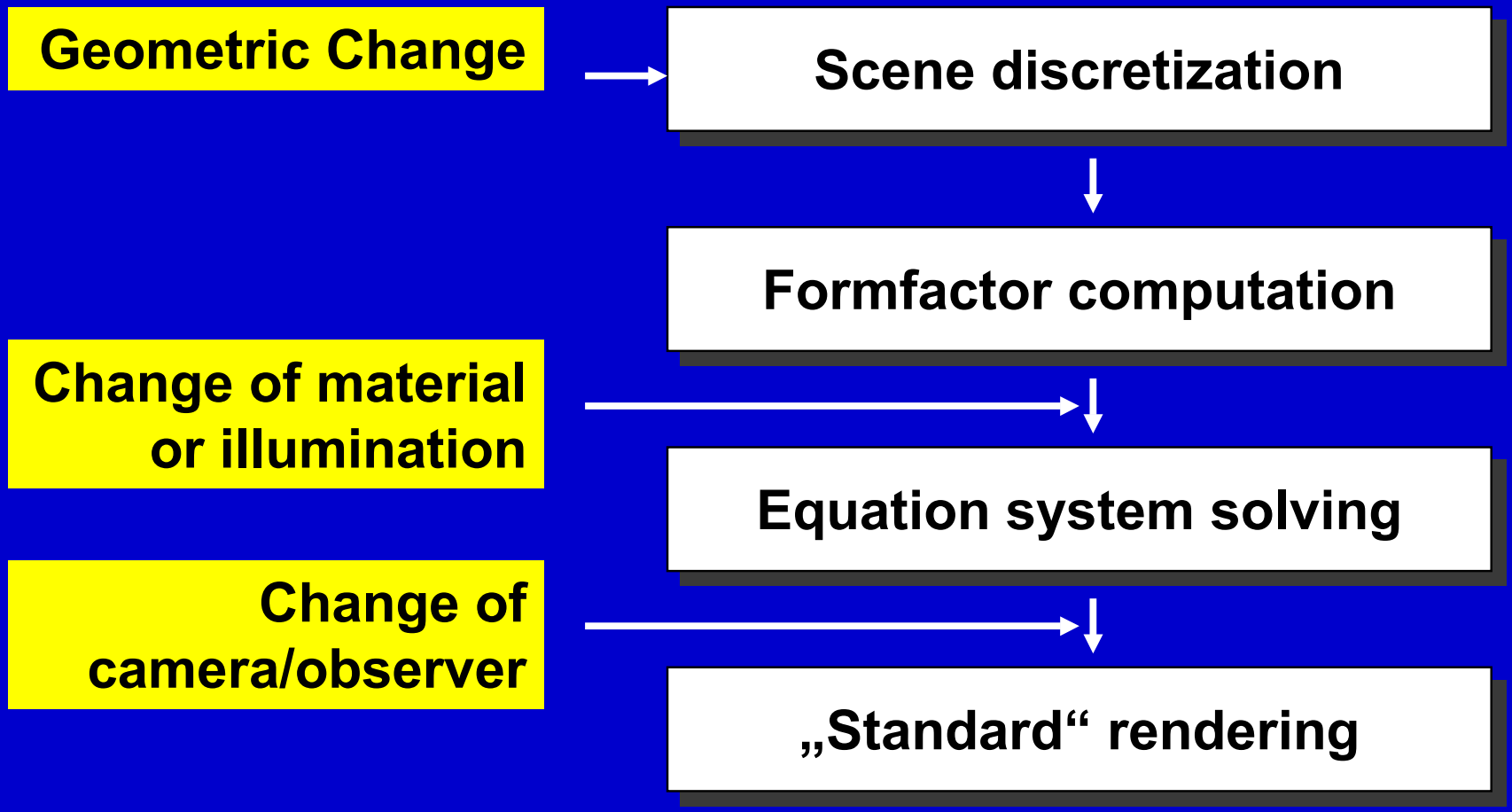
- **Based on „Radiosity Equation“:**

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

- **Radiosity system of equations:**

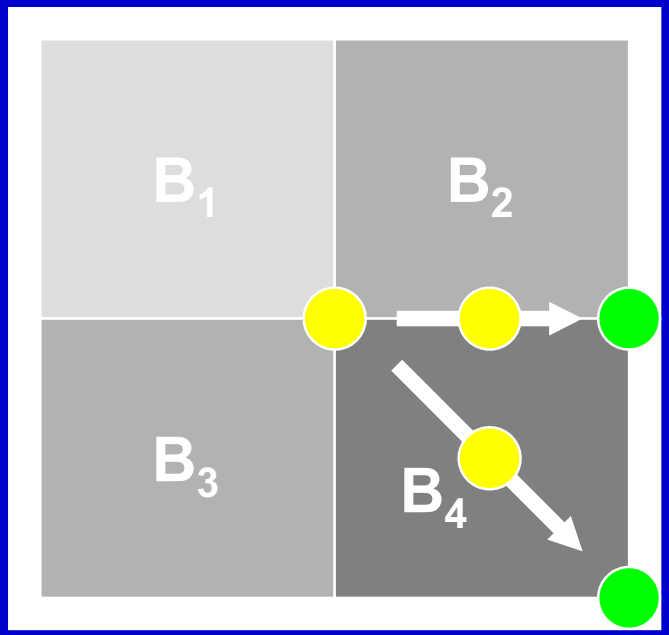
$$\begin{bmatrix} 1-\rho_1 F_{11} & -\rho_1 F_{12} & \cdots & -\rho_1 F_{1n} \\ -\rho_2 F_{21} & -\rho_2 F_{22} & \cdots & -\rho_2 F_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ -\rho_n F_{n1} & -\rho_n F_{n2} & \cdots & -\rho_n F_{nn} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ . \\ . \\ . \\ B_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ . \\ . \\ . \\ E_n \end{bmatrix}$$

Algorithm
(Radiosity)



Color Processing

- B_i's define the color
- shader uses Gouraud-shading and special edge processing.



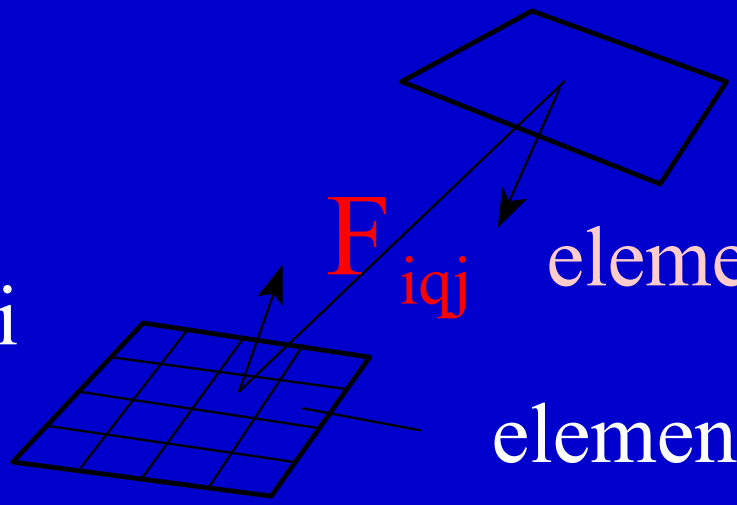
Radiosity with Substructuring

1. Element formfactor computation F_{iqj}
2. Patch formfactor computation F_{ij}
3. Equation system for B_i with F_i solving
4. Element radiosity evaluation B_{iq}

$$B_{iq} = E_i + \rho_i \sum_j B_j F_{iqj}$$

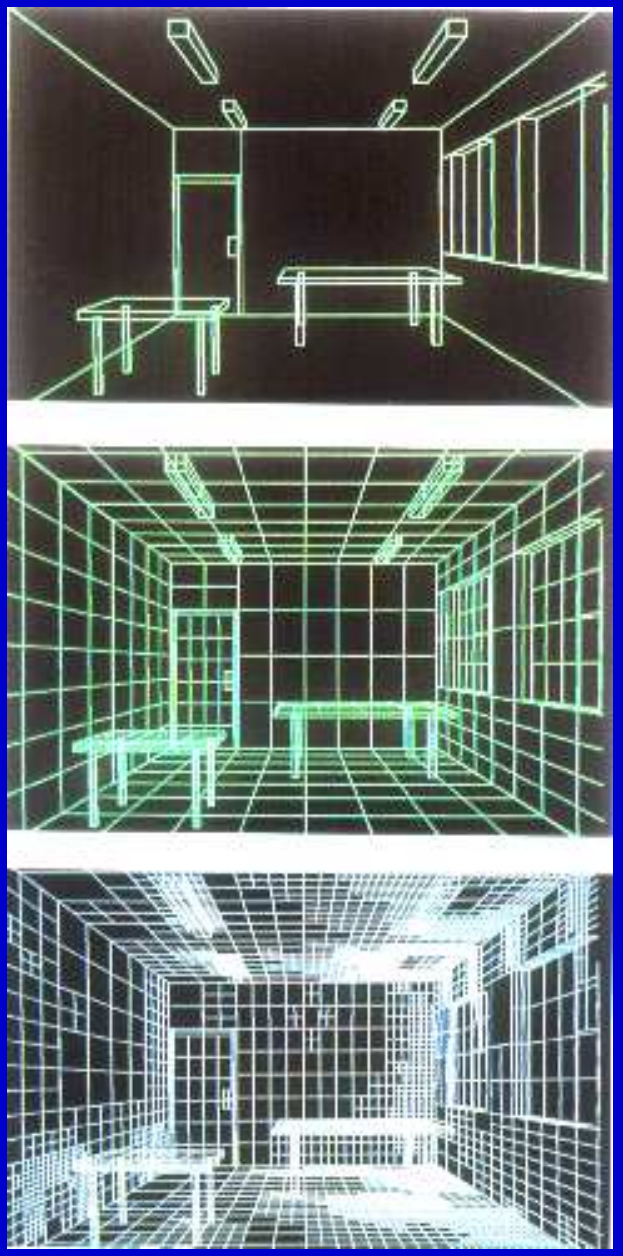
reduction of high intensity differences

$\Rightarrow$ finer subdivision of the surfaces



patch-formfactor $F_{ij} = \frac{1}{A_i} \sum_{q=1}^{R} F_{iqj} A_q$

Substructuring
(Selective Refinement)



Progressive Refinement

General Method:

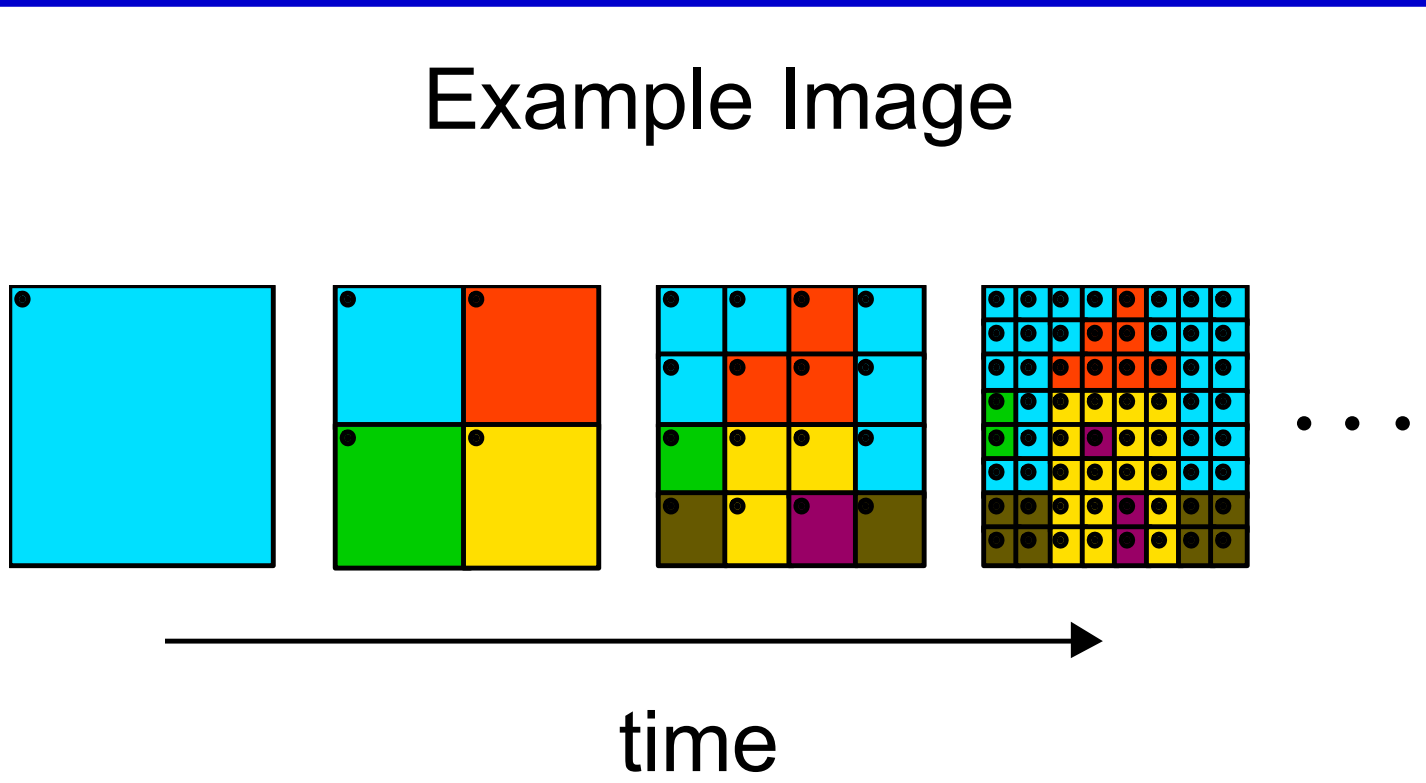
- First the approximate (cheaper) solution
- Subsequent refining the solution until done

Used in:

Ray Tracing: spacial refinement
Radiosity: radiometric refinement

Progressive Refinement

(Ray Tracing)



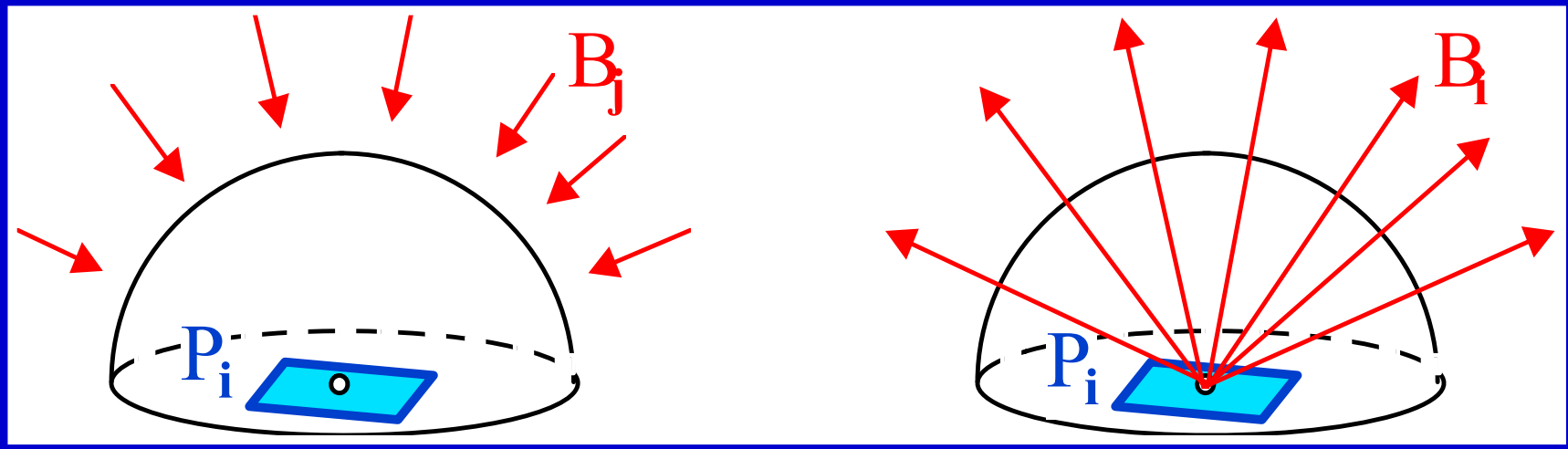
Gathering vs. Shooting

- *Gathering:*
  - *Solution of the system of equations (Gauss-Seidel)*
  - *Start: B_i's = 0, except the lightsources*
  - *Change single patch pro one iteration*
- *Shooting:*
  - *Select the patch with maximum energy*
  - *Energy emission within the scene*
  - *Change all patches in one iteration*

Progressive Refinement
(Radiosity)

Collect all contributions

Radiosity spread



Algorithm

1. Select the maximum energy patch
2. Compute the row of formfactors
3. Actualise the radiosity of receivers
4. Repeat until convergence

Form Factor Computation

- **Problem:**
  - Compute A_I - A_J :

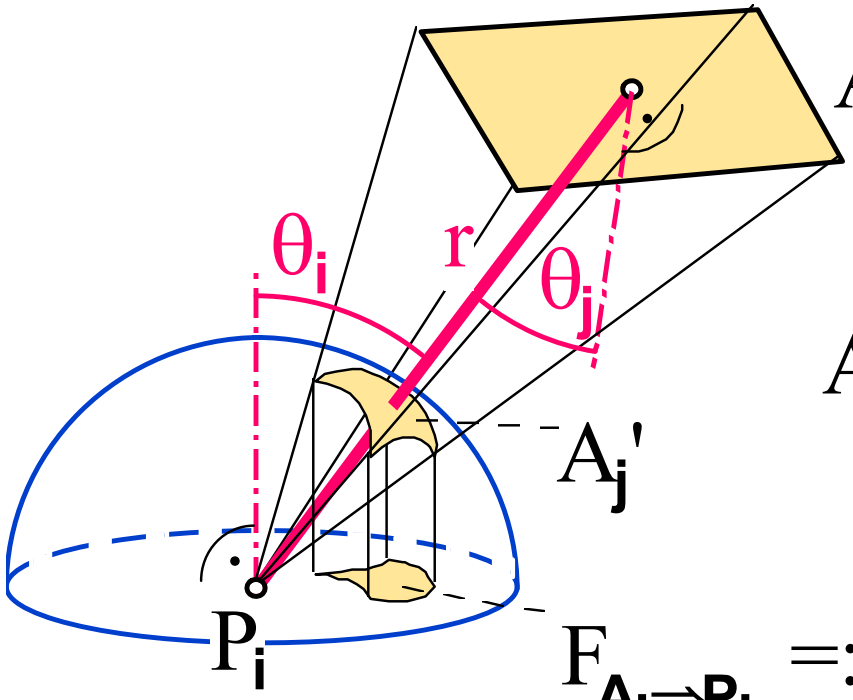
$$F_{ii} = \frac{1}{A_i} \int_{Ai} \int_{Aj} \frac{\cos\phi_i \cos\phi_j}{\pi r^2} dA_j dA_i$$

  - Obstacles, open problem of area-area visibility
  - Memory complexity
- **Special cases:**

$$F_{ii} = 0$$

$$F_{ij} = F_{ji} \frac{A_j}{A_i}$$

Form Factor Evaluation



$$A_j' = \frac{A_j \cdot \cos\theta_j}{r^2}$$

$$F_{A_j \Rightarrow P_i} =: F_{ij} = \frac{A_j' \cdot \cos\theta_i}{\pi}$$

$$F_{ij} = \frac{A_j \cdot \cos\theta_j \cdot \cos\theta_i}{r^2 \pi}$$

Radiosity - Properties

+ Arbitrary area lightsources
+ Global diffuse illumination
+ Shadows & soft shadows effects
+ Viewing direction independent
– No specular reflection,
– no transparency

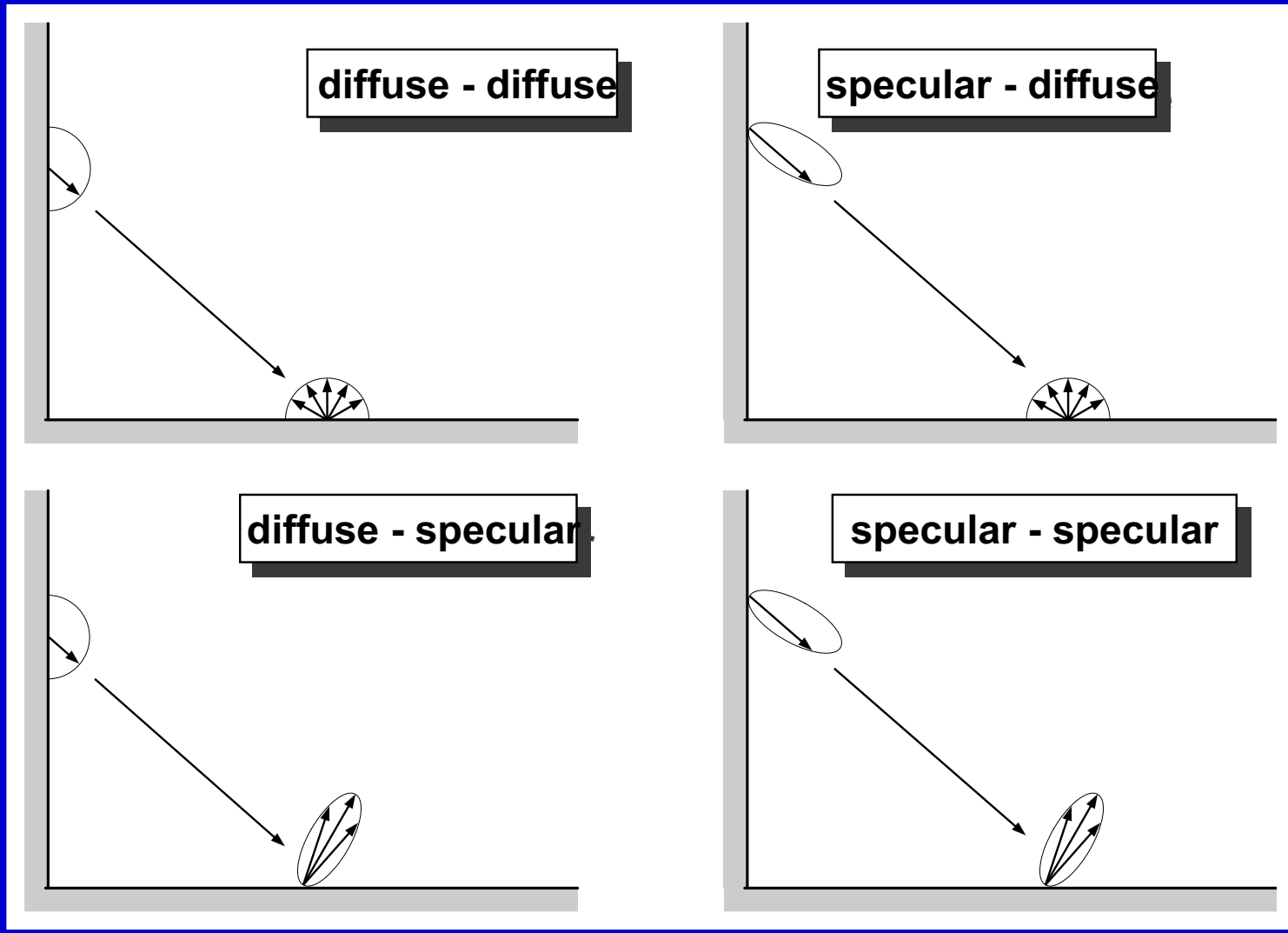
Ray Tracing vs. Radiosity

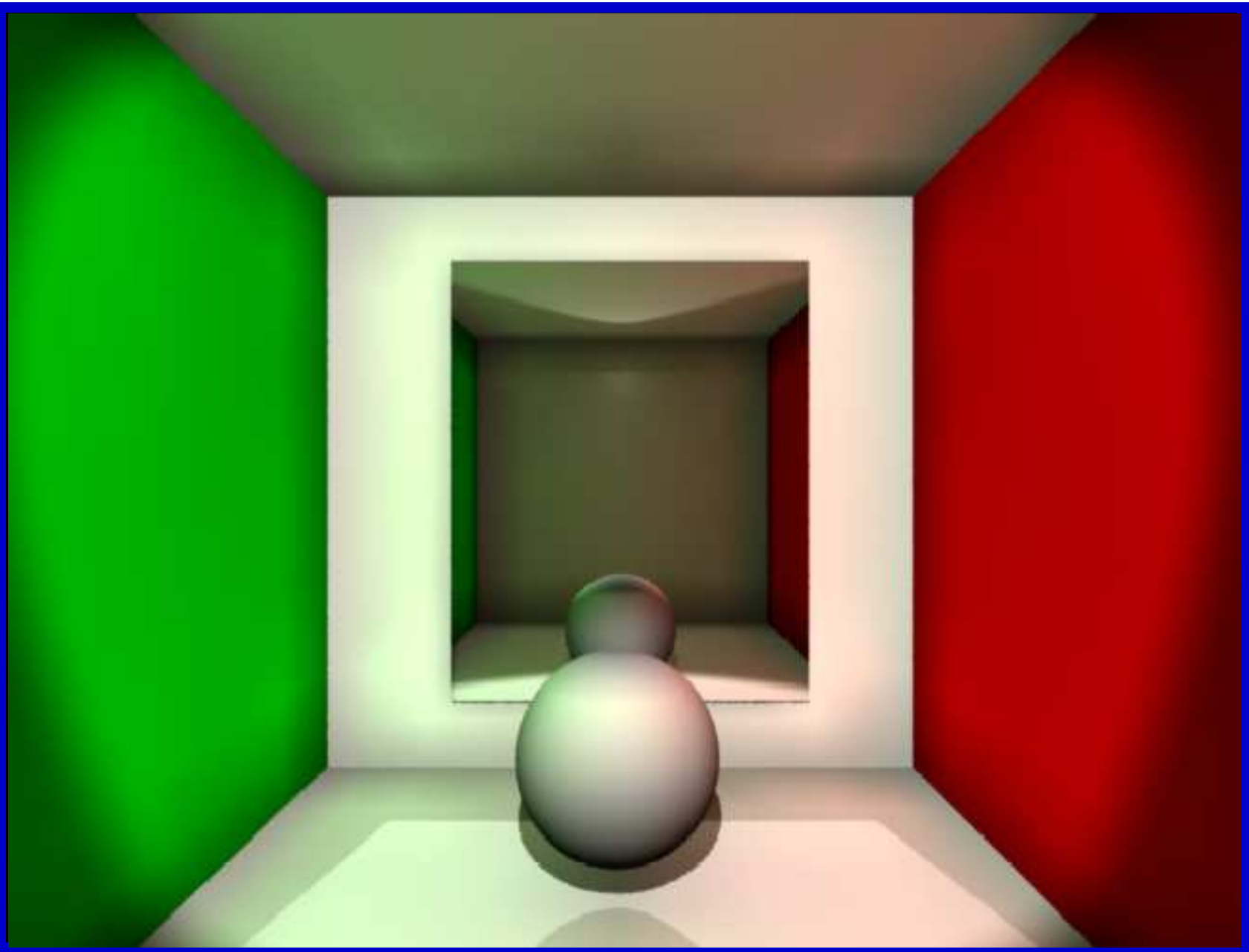
Towards Two-Pass Methods

Ray Tracing versus Radiosity

Ray Tracing	Criterion	Radiosity
dependent	View Direction	independent
specular	Suitable for Reflexion Type	diffuse
any	Scene Description	B-Rep
Each Picture	Higher Time Complexity	Each Scene

Global Illumination Effects





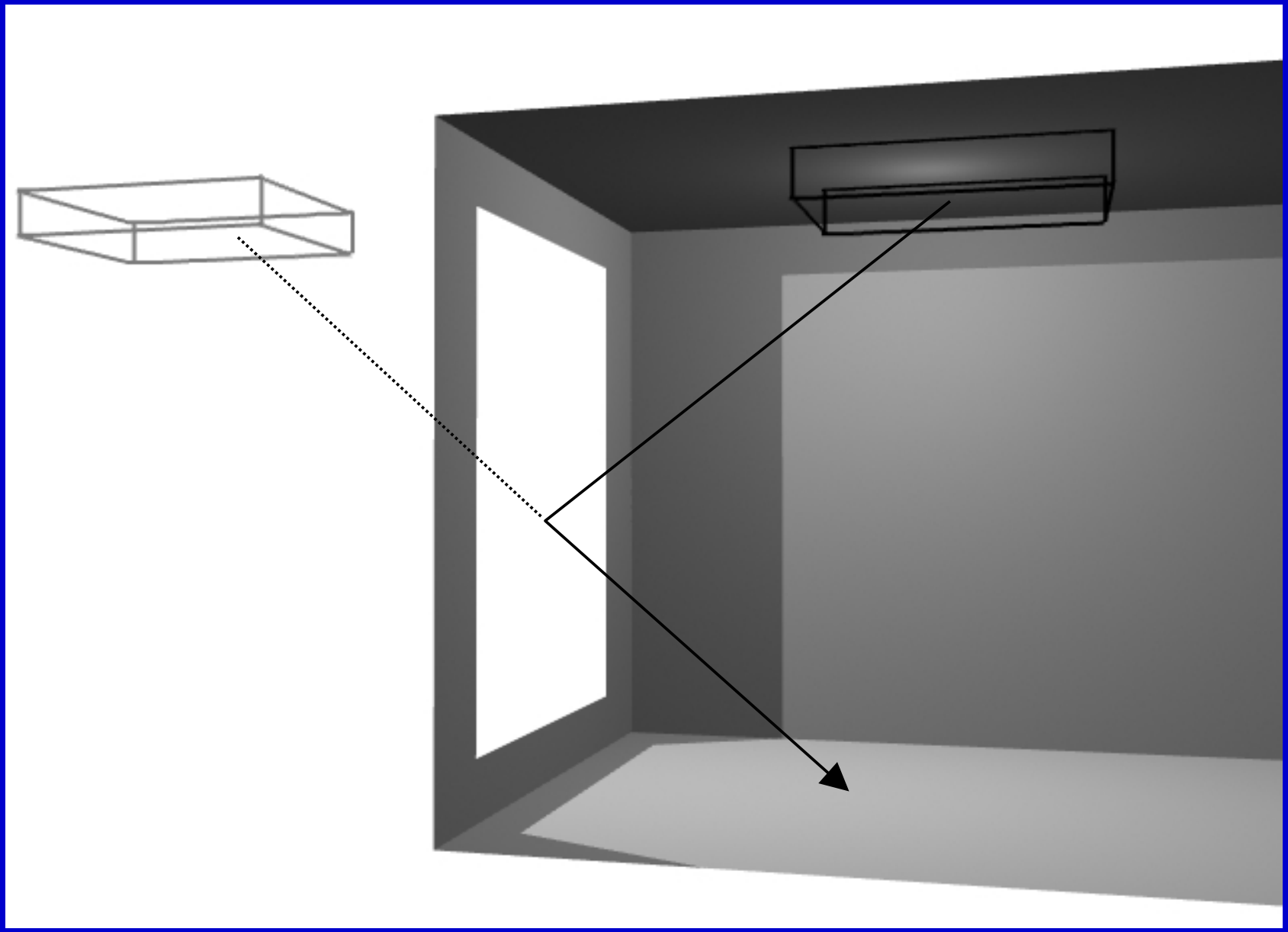
Combining both Methods

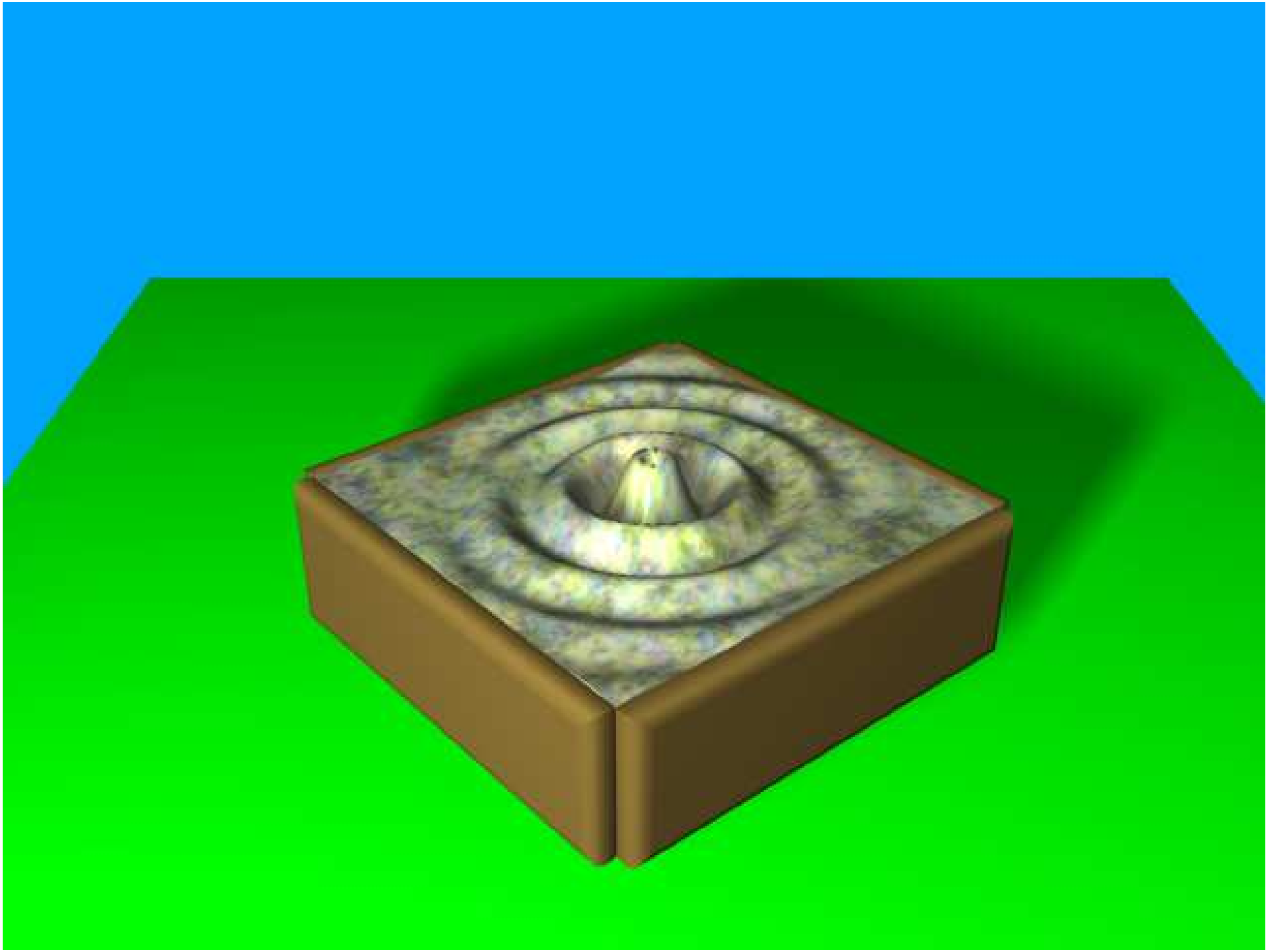
2-Pass Method for General Solution of Global Ilumination

- Step 1: Solution for Cases 1 & 2
  - Radiosity computation
  - Specular-diffuse Interaction Added
- Step 2: Solution for Cases 3 & 4
  - Ray Tracing computation
  - Integration of Step 1 Solution

Extending Radiosity

- **Standard -Radiosity Limitations:**
  - Scene Discretising
  - One Patch One Color
- **Extension:**
  - Specular surfaces provide formfactors of „Virtual Mirrorworld“
  - Discretising of single patch
  - Specular-diffuse interactions





Radiosity On-line

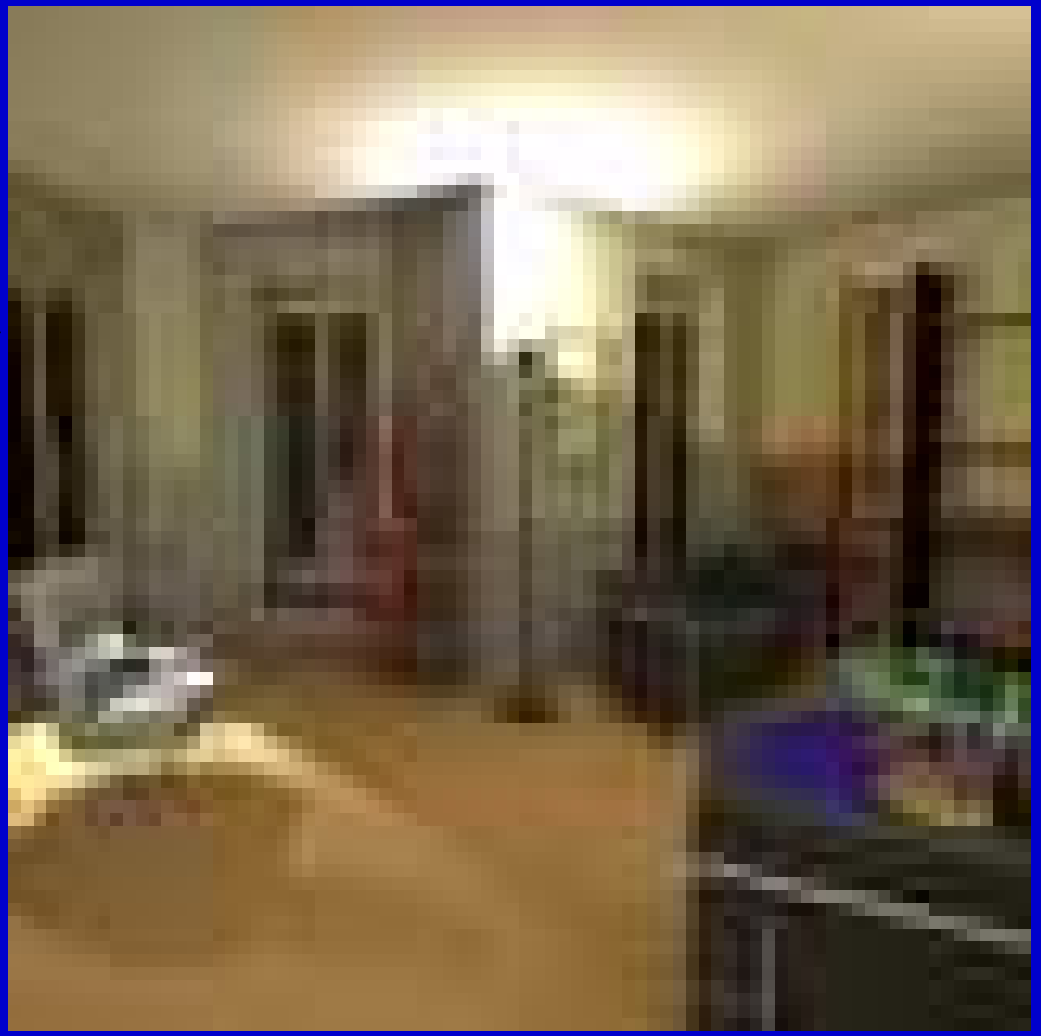
- *SOFTWARE: http://www.informatik.uni-dortmund.de/~kohnhors/radiosity.html#SOFTWARE*
- *http://www-2.cs.cmu.edu/afs/cs/user/ajw/www/software/index.html#Radiator*
- *IMAGES: http://www.graphics.cornell.edu/online/research/ and many others*
- *http://www.upb.de/cs/plachetk/HIQOS/TOPUBLISH/HAUS6/haus6_en.html*

Rendering Server Idea

- *Parallel Computing*
- *& Web: HiQoS*

- *http://www.upb.de/cs/*
- *plachetk/HIQOS/*
- *TOPUBLISH/*
- *HAUS6/*
- *haus6_en.html*

- ***Courtesy T. Plachetka***
- ***Uni Paderborn 2001***



Three Open Problems

- All optical paths bearing radiance greater than given threshold:
- A. with respect to viewpoint
- B. no viewpoint restriction
- Inverse problem. Vision comprises the product of irradiance and reflection. Deduce BRDF (reflection only).
- By Dobkin&Teller (1999)

Radiosity Summary

- Well working heat transfer model
- Lightning only standard
- Computationally very expensive
- Many improvements published:
- http://www.geocities.com/ResearchTriangle/Lab/1851/abs-mnu.htm
- More: two-pass methods, importance idea, instant radiosity by Keller, … research...

Back to Rendering Equation

- Heat transfer model and photons
- LIGHT: direct, indirect, shadows & participating media
- Known solutions for few cases
- Monte Carlo methods
- Metropolis Light Transfer
- Stochastic Optimisations…
- IBR surprise!!!

Chatam Sófer M. by J. Krizik

- WCH?

Image Based Rendering

Alternative Method for Photorealistic Scenes

IBR Idea

- 1995: set of 2D stills
- 2001: QuicktimeVR industry
- Cylindric and Spheric Panoramas
- Limited movement applications
- Open problem: minimum

IBR Open Problem

- Dobkin&Teller (1999)
- Given a 3D polygonal model
- Generate a minimal set of images:
- for all subsequent query viewpoints recover the correct image

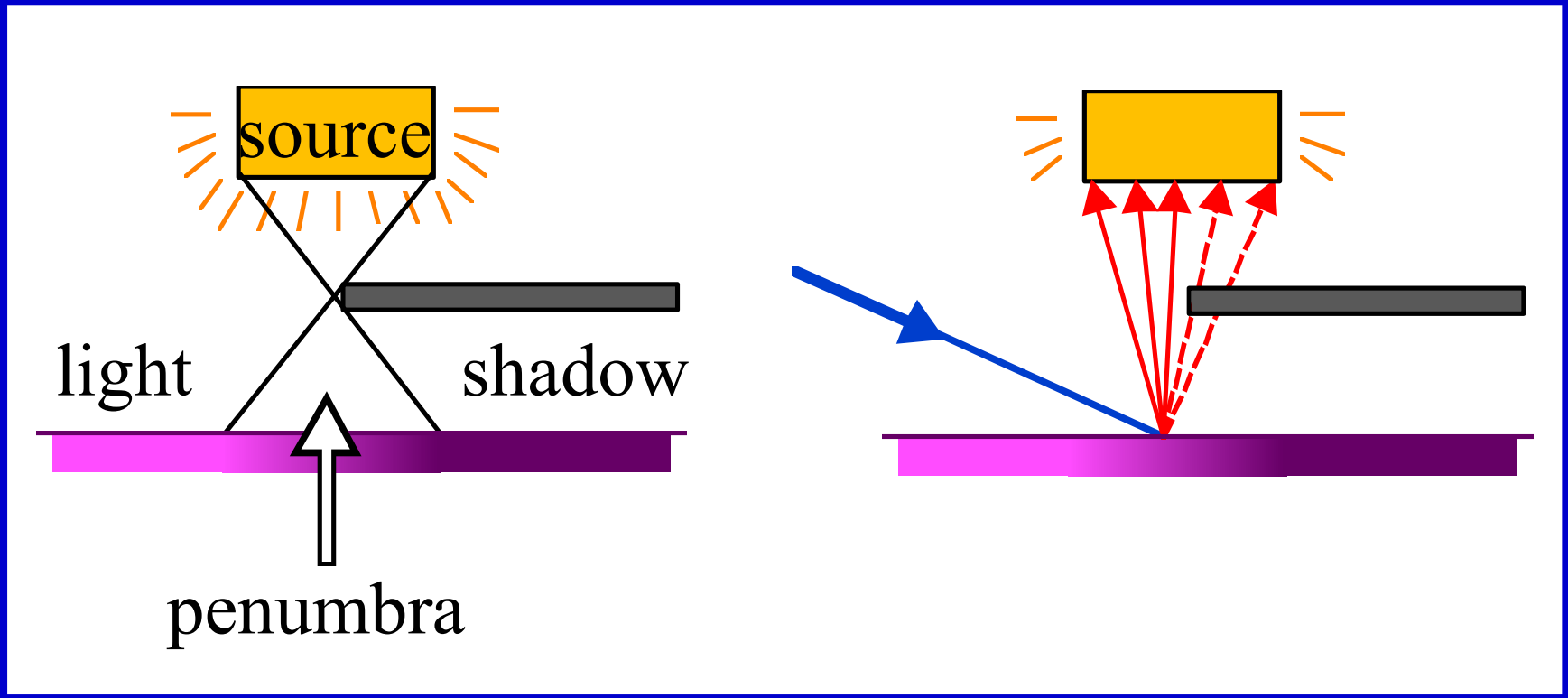
PHOTOREALISM (2)
Defining Light Sources

More Realism

Recall (Lightsources)

- **Local Illumination Models**
  - Ambient Light
    - Parameter: I_a
    - no spatial dependecies
  - Point Lightsource
    - Parameter: I_p , I_{near} , I_{far}
    - Intensity depends on the distance (spheric waves, fog, intensity attenuation)
  - Parallel Light Source

Soft Shadows



- **Global Illumination Models**
  - Ray Tracing:
    - Recursive Ray Tracing: Point light sources like locale Illumination Models
    - Distributed Ray Tracing: area lightsources, new dependecies through visibility (soft shadows)
  - Radiosity:
    - only area light sources (point sources using approximation)
    - Parameter: Energy E instead of I
    - dependecies: implicitly in Form-Faktor computation

RT Illumination Model

- **Point Intensity:**

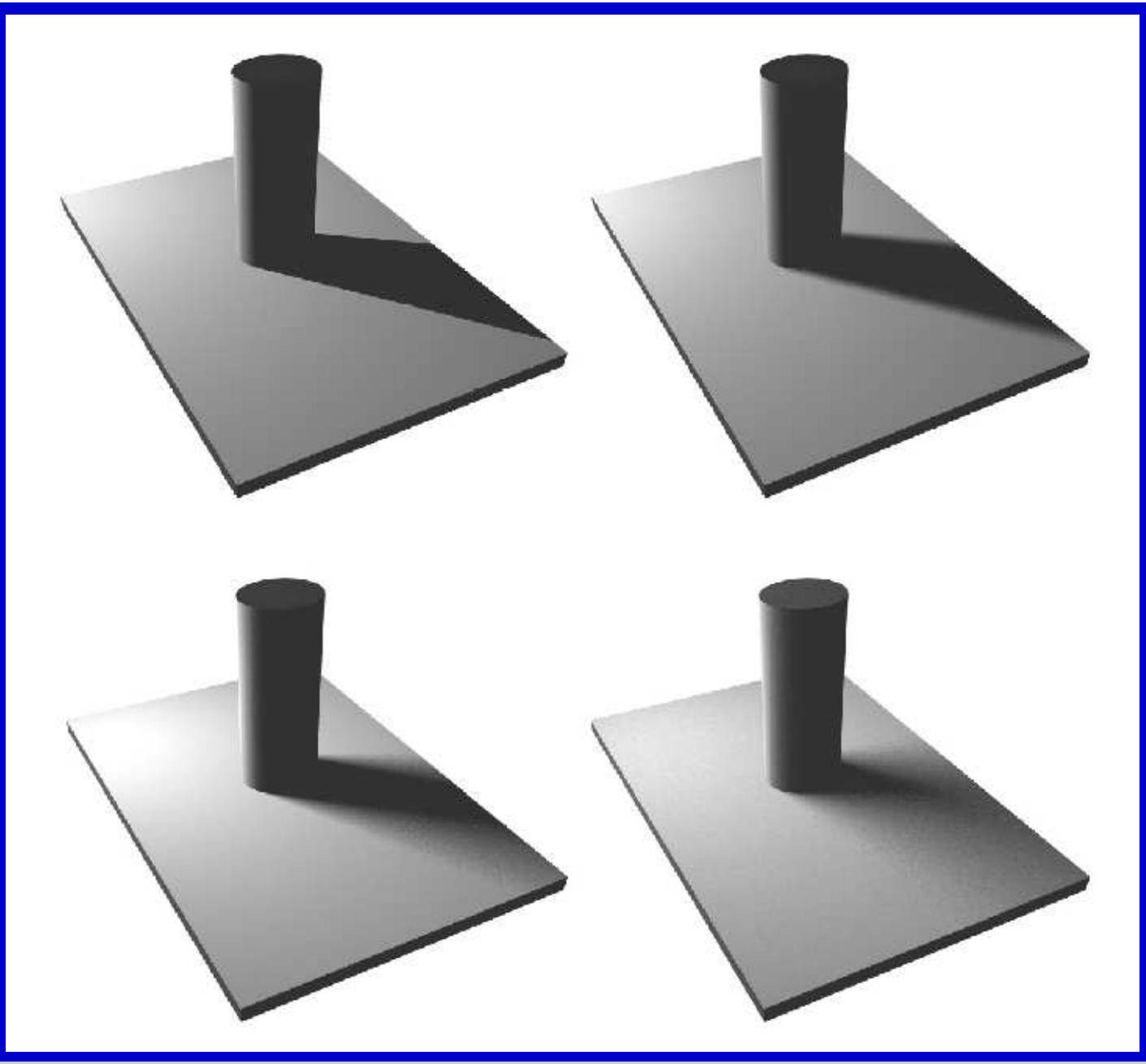
  $I = I_{local} + k_{rg}\, I_{reflected} + k_{tg}\, I_{transmitted}$

- **Local (Phong extended):**

  $I_{local} = I_a\, k_a + I_p\, [k_d\, (N \bullet L) + k_{rl}\, (N \bullet H)^n + k_{tl}\, (N \bullet H')^n]$

- **Recursive Definition:**

  $I(P) = I_{local} + k_{rg}\, I(P_r) + k_{tg}\, I(P_t)$



Standardisation

- **New Form of Definition**
  - Geometric Description
    - Lamp
    - Usage
    - Elektric Properties
  - Photometric Description (Goniogram)
- **Standards:**
  - IES (Illumination Engineering Society)
  - CIE

Goniometric Configuration

- Local Coordinate System (Euklidean - 3D)
- Measuring Coordinate System:
  - spheric one
- Configuration:
  - Main axis containing both poles
  - 3 possibilities
  - Configuration & 2 angles identify the direction for measuring in a unique way

IES(NA)

- **Text file (editable)**
  - catalogued geometric description
- **Content**
  - main block (mit „keywords“)
  - photometry block (ohne „keywords“)
    - # Lamps
    - Input energy
    - Geometric openess of the light construction
    - Configuration
    - Measures

```
IESNA91
[TEST]              Luminaire C6567681
[MANUFAC]           Deep 13 Labs
[LUMCAT]            27599-3175
[LUMINAIRE]         Portable searchlight.
[LAMPCAT]           MST-3K
[LAMP]              Headmount
TILT=INCLUDE
1                   # configuration
5                   # measures
0     30    90    120   180
1.0   0.95  0.92  0.75  0.65
```

PHOTOREALISM (3)

Rendering & Lighting Simulation

Special methods

„Computer Graphics...

- ... can be formulated as a radiometrically „weighted“ counterpart of computational geometry…
- ... rendering is done through the application of a simulation process to quantitative models of light and materials to predict/synthesize appearance“
-
- D. Dobkin & S. Teller

Computer Graphics...

- ... must account geometry
- material properties: reflectance/color, refractive index, opacity, and (for light sources) emmisivity
- radiometry
- output for viewing: explicitly or implicitly psychophysics

- by D. Dobkin & S. Teller

Material Description

Geometric Description

Light Sources Description

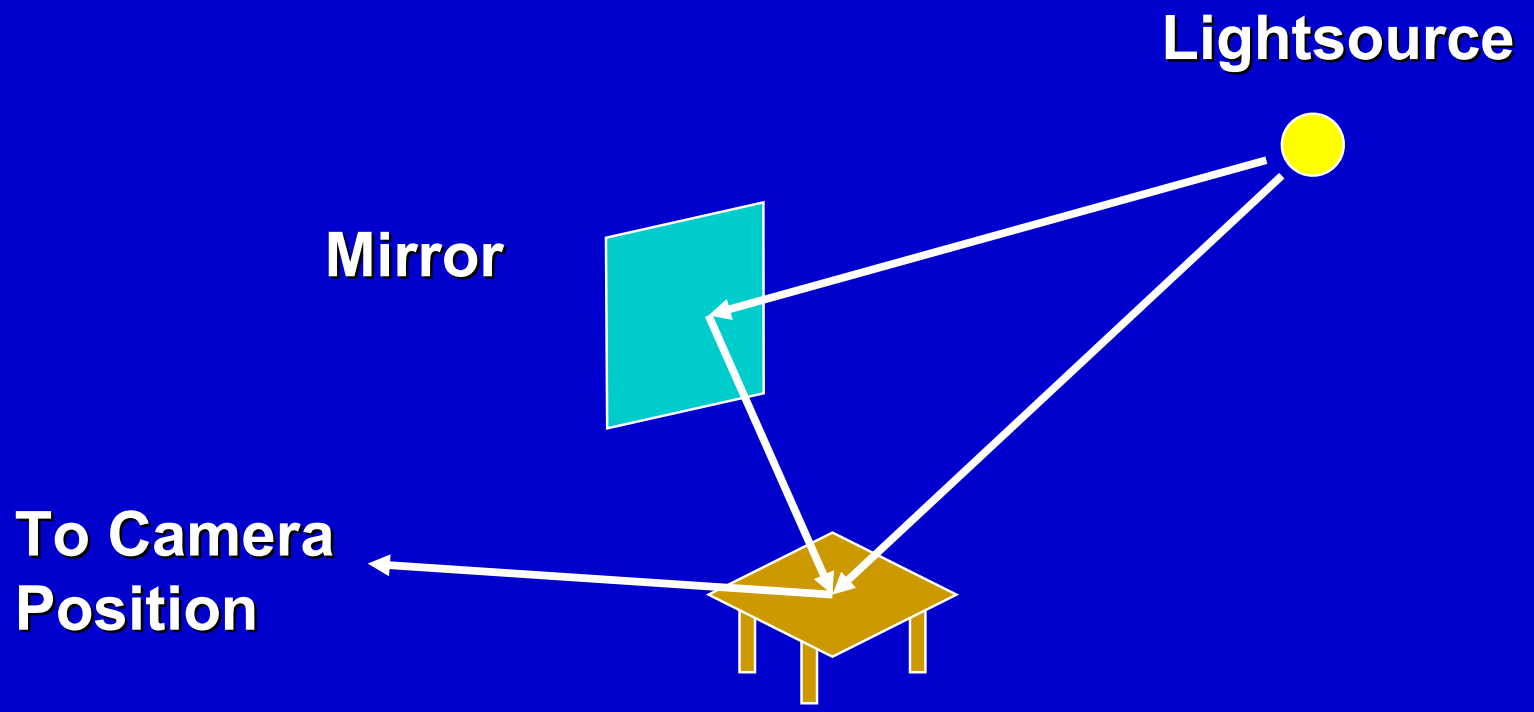
Image Synthesis (Rendering Algorithm)

Requirements

The Lighting Simulation:

- exact
- general
- practic

Backwards Ray Tracing



Ray Tracing Summary

- Very old geometric model
- Industrial standard and POVRay
- Computationally expensive
- Many improvements published:
- www.acm.org/tog/resources/bib/
- Parallelisation, ray space, random walk, two-pass methods, instant radiosity by Keller, … research...

Ray Tracing - Disadvantages

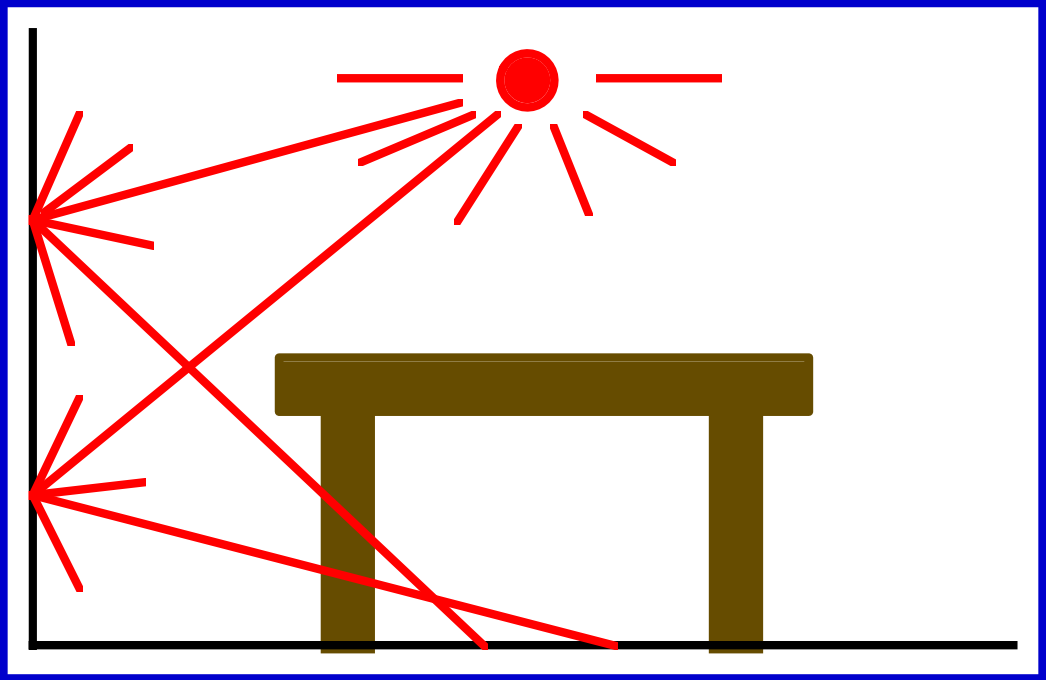
- No global diffuse lighting
- Improvements:
  - Monte Carlo Sampling
  - extremely high time consumption
  - aliasing

Radiosity Idea

Lightsources & surfaces are equally active areas. They the light energy both:

- ***reflect***
- ***emit***

Energy is radiated in the space.



Radiosity Summary

- Well working heat transfer model
- Diffuse lightning only standard
- Computationally very expensive
- Many improvements published:
- http://www.geocities.com/ResearchTriangle/Lab/1851/abs-mnu.htm
- More: two-pass methods, importance idea, instant radiosity by Keller, … research...

Radiosity - Disadvantages

- Complex Scenes
- Discretisation, meshing
- Illumination Model:
  - global diffuse model only
  - mirror reflections, high computational complexity
- No general object representation

IBR Idea

- 1995: set of 2D stills
- 2001: QuicktimeVR industry
- Cylindric and Spheric Panoramas
- Limited movement applications
- Open problem: minimum

RADIANCE ® - System Design

Goals:

- the exact lighting computation
- simulation of daylight and artificial light
- different reflexion models used
- complex geometry
- direct CAD systems input/output

- http://radsite.lbl.gov/radiance/

Figure 12. A still life image showing examples of procedural and scanned textures and patterns.

Back to Rendering Equation

- Heat transfer model and photons
- LIGHT: direct, indirect, shadows & participating media
- Known solutions for few cases
- Monte Carlo methods
- Metropolis Light Transfer
- Stochastic Optimisations…
- IBR surprise!!!

Approach

Alternative form of Rendering Equation:

$$L_r(\theta_r,\phi_r) = L_e(\theta_r,\phi_r) + \int_0^{2\pi}\int_0^{\pi} L_i(\theta_i,\phi_i) f_r(\theta_i,\phi_i,\theta_r,\phi_r)\left|\cos\theta_i\right|\sin\theta_i d\theta_i d\phi_i$$

Naive Approach: Monte Carlo Methods (Distributed Ray Tracing)

Hybrid Approach

Idea: Combination of both stochastic and deterministic ray distribution.

Deterministic:

- highlights in L_i distribution using lightsources
- highlights in reflexion distribution of mirror surfaces

Stochastic:

- for diffuse interreflexion
- this means more rays

Diffuse Interreflexion

Observation: Ambient light part differs only gradually within the surface.

Naive Approach: Use the constant.

Radiance:

- Identify diffuse Interreflexion in a small number of surface points
- smooth distribution of points with respect to pixels

Method

1) direct and mirror contributions for pixel

2) diffuse (hemispheral) contributions:

- *search-like (Stichproben)*
- *approx. 100 rays pro hemisphere (normally distributed)*
- *caching ofr „Irradiance Gradients“*
- *interpolating the values using computed quantities and gradient evaluation*

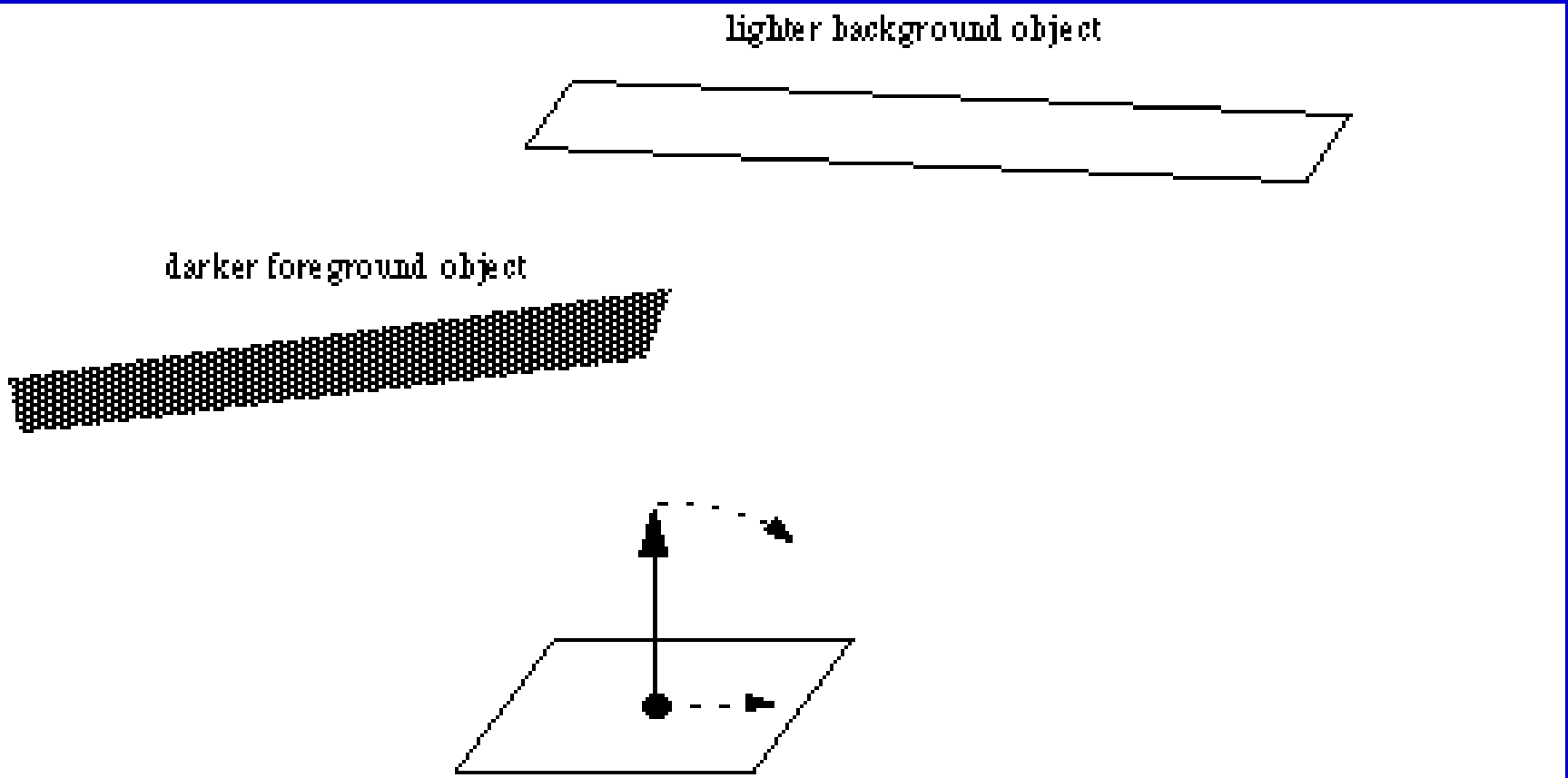


Figure 2: Irradiance gradients due to bright and dark objects in the environment.

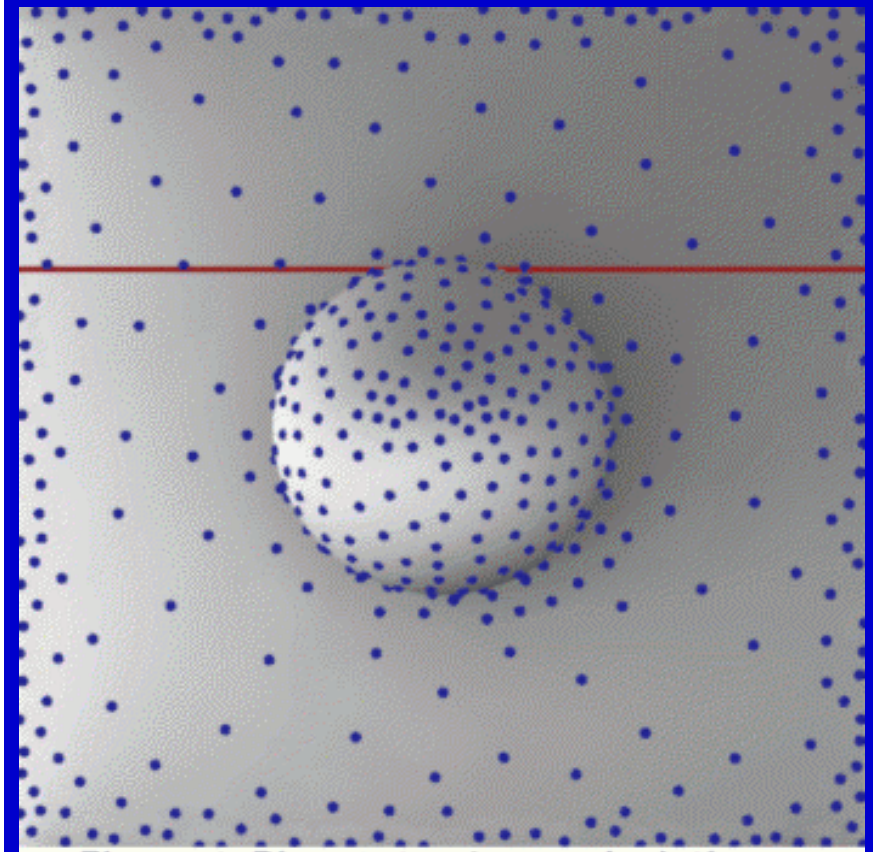
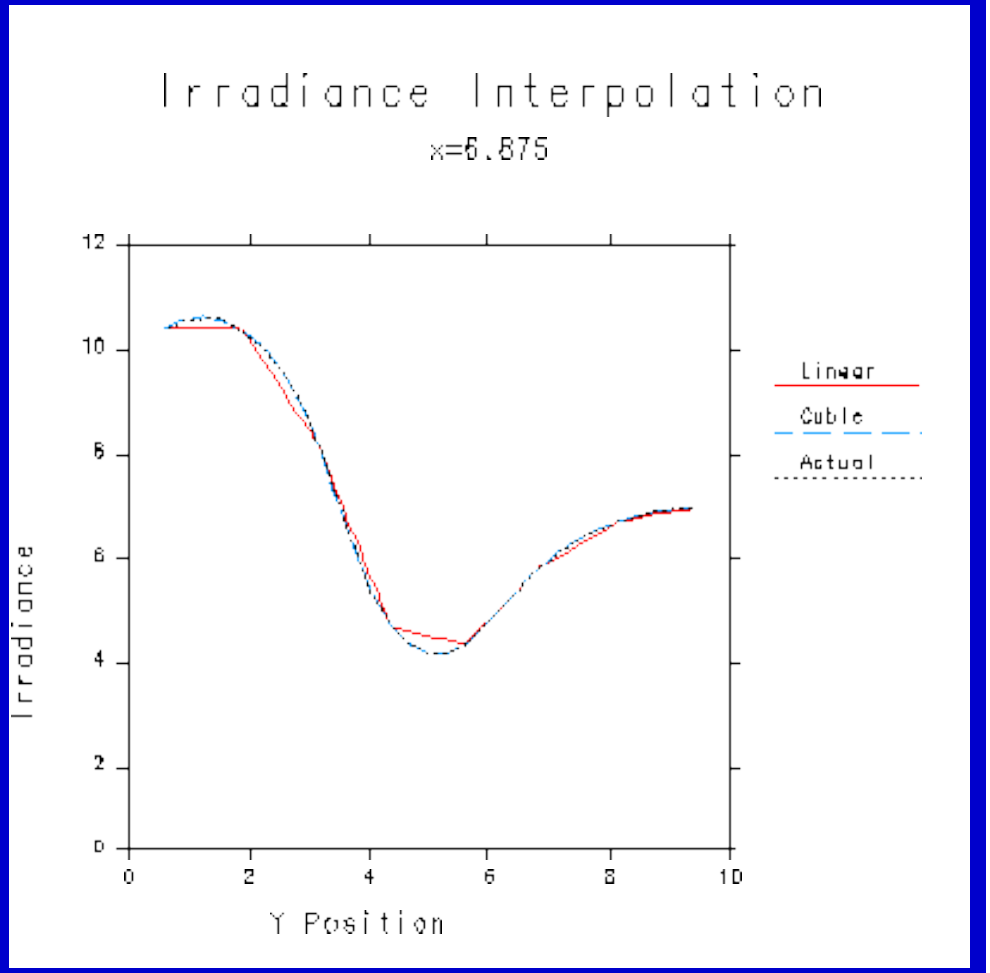


Figure 1. Blue dots show calculation points for diffuse interreflection. (See Figure 3 regarding red line.)



Caching indirect irradiances

Advantages:

- *no meshing*
- *diffuse illumination computed only for visible part of the scene (re-usable for other views)*
- *reducing the Sampling-Rate in more deep recursion-planes.*
- *adaptive illumination because of adaptive sampling-rate (gradients)*

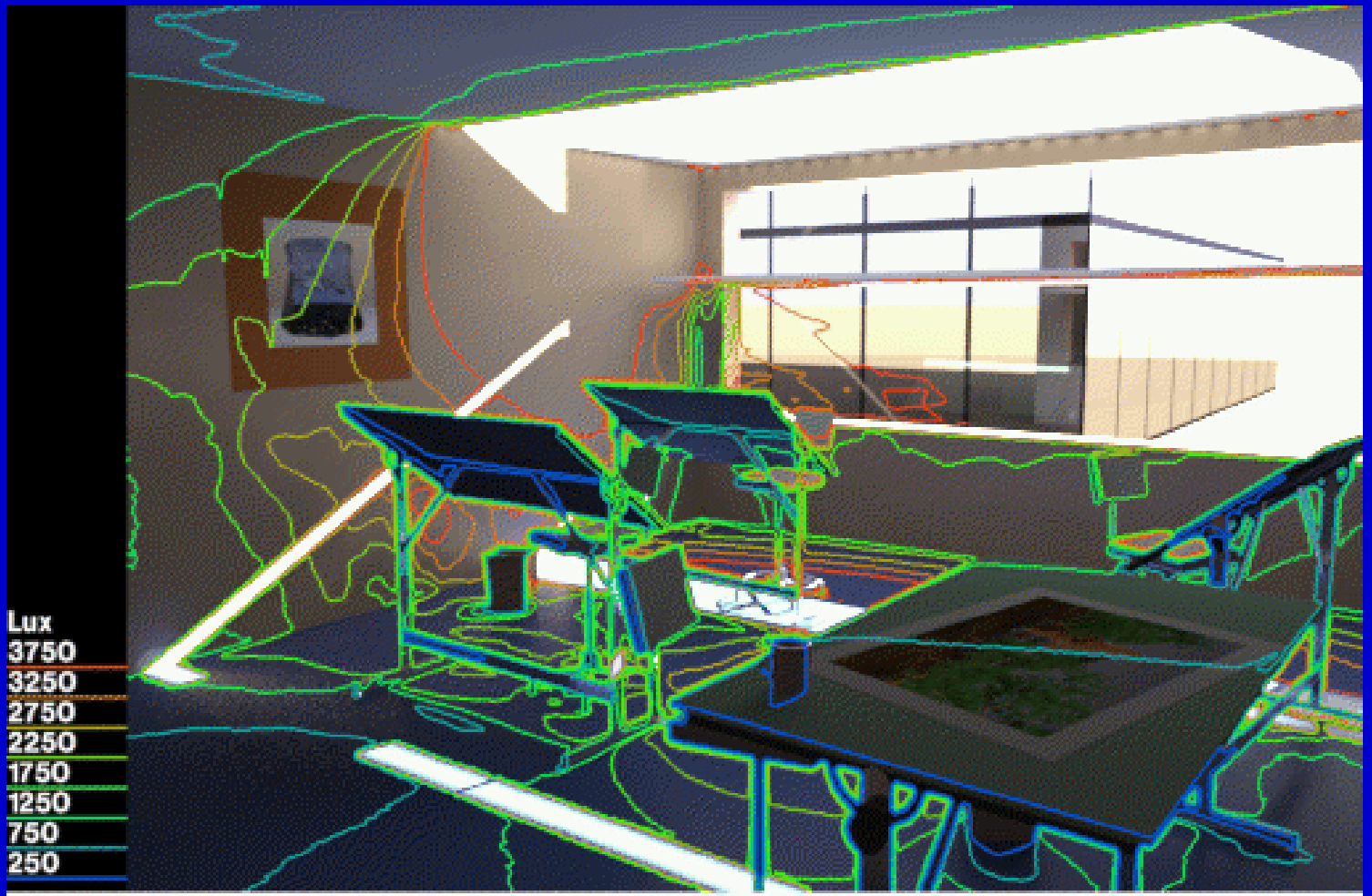


Figure 9c. A visualization of the illuminance levels on the room surfaces in the drafting office.

IBR-like Idea

- Use photographs of lightsources
- 2001: SIGGRAPH Award for Paul Debevec
- IMAGE-BASED LIGHTING
- www.debevec.com
- movies

IMAGE-BASED LIGHTING

- 2001: Paul Debevec, CVPR 2001 Short Course, 3.5 hours
- IMAGE-BASED LIGHTING:
- „integrating computer-generated imagery with live action photography that use measurements of real-world lighting to illuminate CG objects“

IBL Survey

- High-dynamic range images HDRI
- lighting acquisition (M. Gross)
- IBL and compositing
- real-time techniques
- software (Radiance, Maya...) and research

Rendering & Lighting Simulation
Summary

- Point lightsource .. Photographs
- Radiance approach
- IBL idea
- Out of standard textbooks .. IBL
- Computationally very expensive
- http://www.debevec.com
- HOT research topic: conference papers

PHOTOREALISM (4)

Material & Light

Exact Approach

Material Description

Geometric Description

Light Sources Description

Image Synthesis (Rendering Algorithm)

RADIANCE

- *The 4 basic steps were:*
- *modelling the office using AutoCAD*
- *radiometric modelling of the room (i.e. determine color, specularity & roughness of all surfaces)*
- *add light to the scene (natural and/or artificial)*
- *raytrace the whole scene:* ***RADIANCE***

RADIANCE

RADIANCE 2

Light & Energy

- CG: Simulation of light distribution
- Physical phenomena:
  - reflexion, refraction
  - wave nature of light (Huygens, 1600)
  - polarisation
  - interference
- Wave nature of ligh
  - electromagnetic waves:

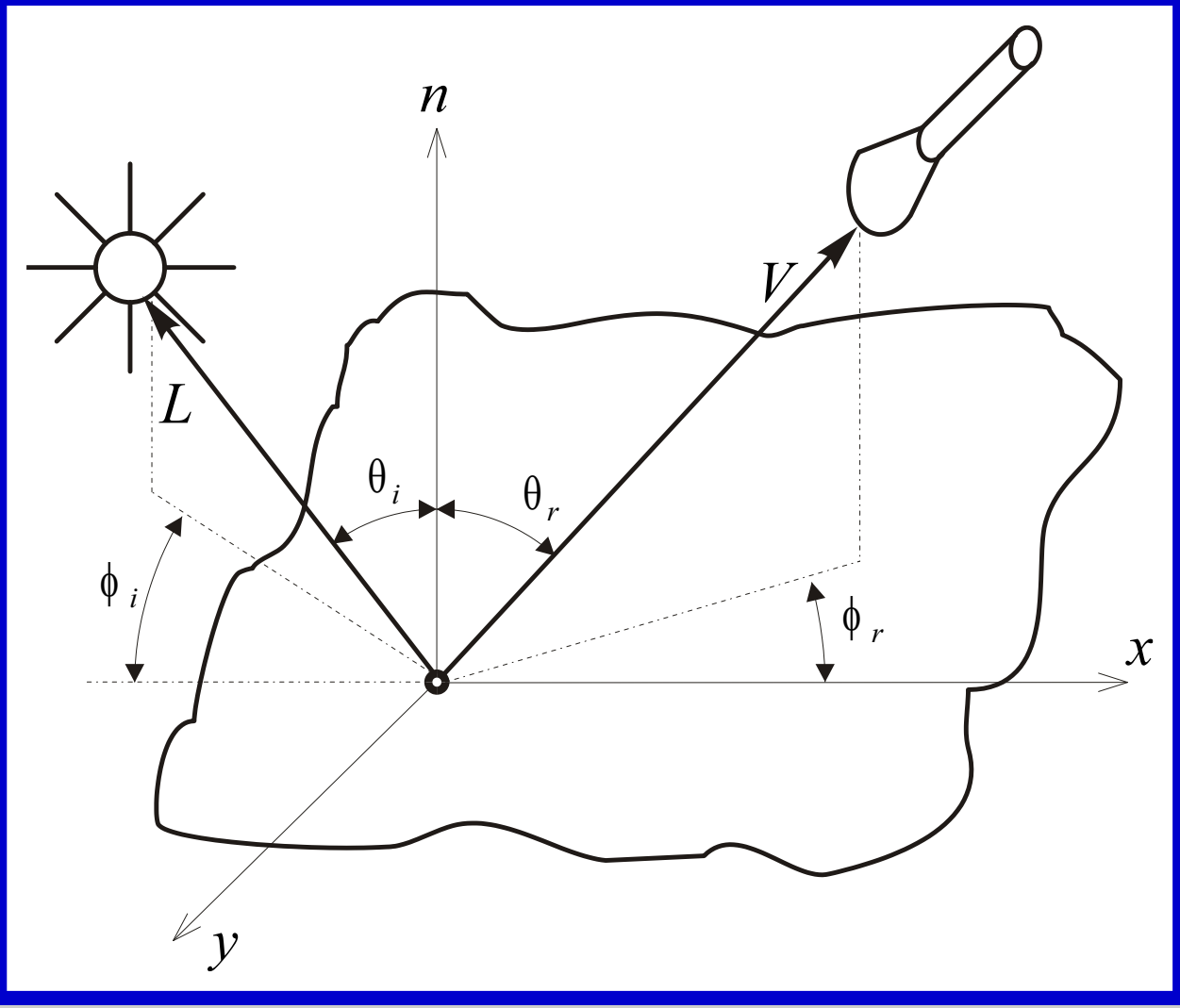
Particle-Wave Duality

- **Alternative representation:**
  - Fundamentals: Quantum-Physics (Optics)
  - Particle distribution
  - Intensities: collecting „wavepackets“
- **Pros and Cons:**
  - Approach using geometric optics
  - polarisation, interfering and other properties/behaviours are not respected

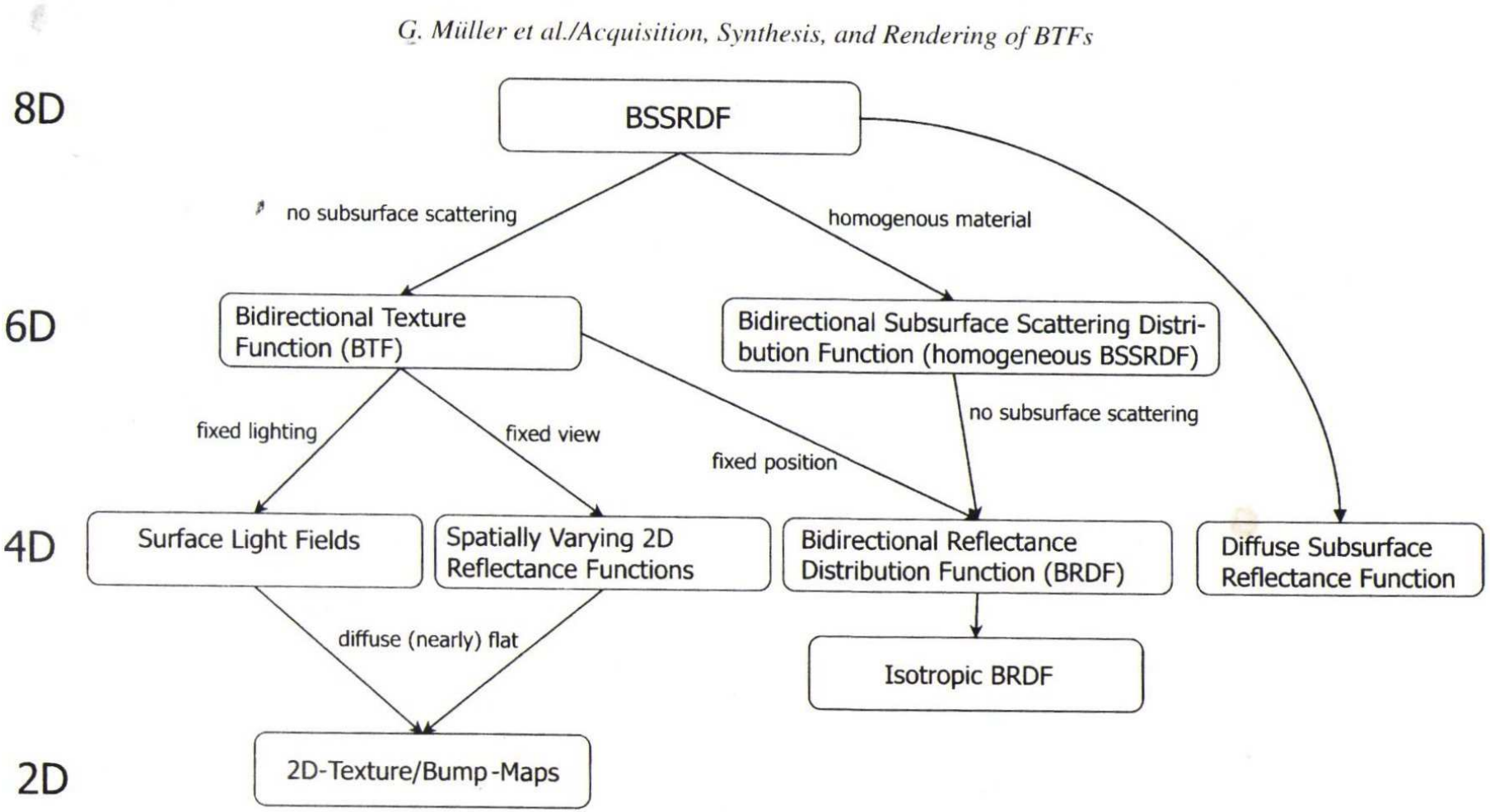
Energy Transport

- **Model:**
  Particles transport
- **Radiometry**
  Measure intensities
- **Photometry**
  Adapt to the „standard-observer“

BRDF



BSSRDF


G. Müller et al./Acquisition, Synthesis, and Rendering of BTFs
8D
BSSRDF
no subsurface scattering
homogenous material
6D
Bidirectional Texture Function (BTF)
Bidirectional Subsurface Scattering Distribution Function (homogeneous BSSRDF)
fixed lighting
fixed view
fixed position
no subsurface scattering
4D
Surface Light Fields
Spatially Varying 2D Reflectance Functions
Bidirectional Reflectance Distribution Function (BRDF)
Diffuse Subsurface Reflectance Function
diffuse (nearly) flat
Isotropic BRDF
2D
2D-Texture/Bump-Maps

Reflexion Models

- Simulation of particles transport
- Additional Simulation of Polarisation
- Empiric Models (i. e., Ward)
- Statistic Models (BRDF Hemisphere Sampling)

Closed Form Solution

- $$f_{r,iso} = \frac{\rho_d}{\pi} + \rho_s \frac{1}{\sqrt{\cos\theta_i \cos\theta_r}} \frac{\exp\left(-\tan^2 \delta / \alpha^2\right)}{4\pi\alpha^2}$$

  δ *Angle between N and H*

- ***For anisotropic Materials:***
  - ***additional model parameter:*** $\alpha \rightarrow \alpha_x, \alpha_y$
  - ***additional variable:*** ϕ

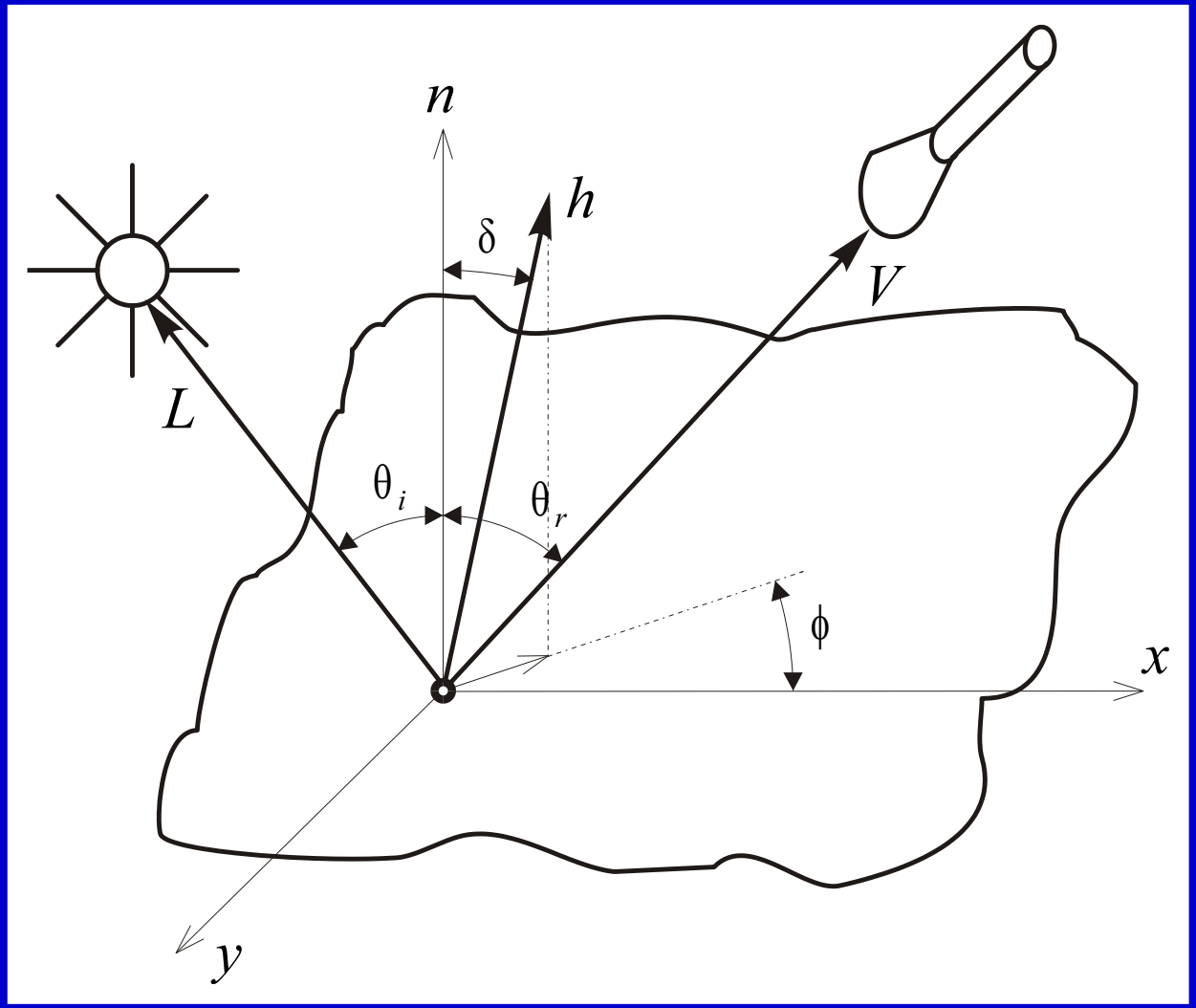
Measurement Method

- **Sampling of BRDF-measured points**

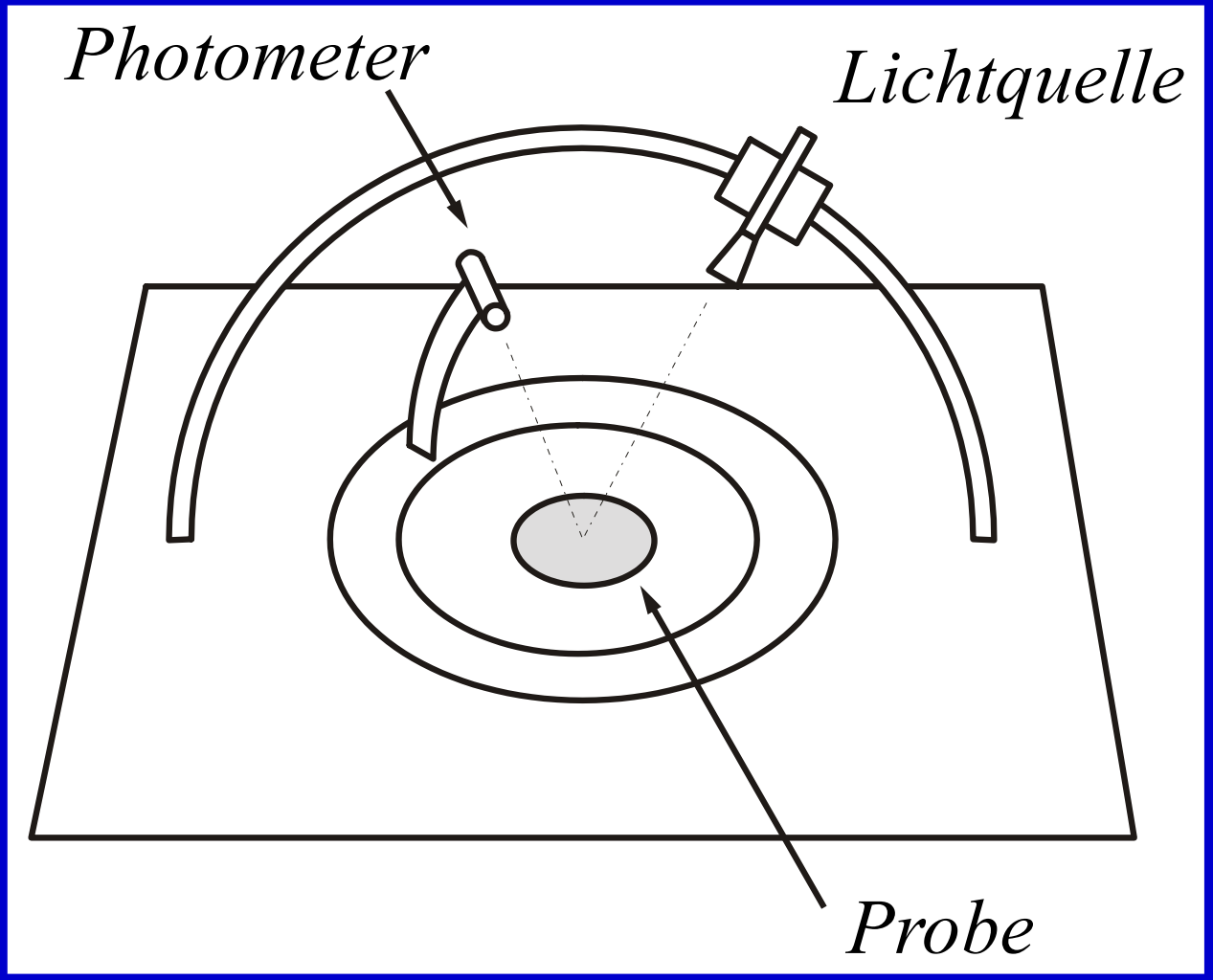
$$f_r(\theta_i, \phi_i, \theta_r, \phi_r); \qquad f_r(\theta_i, \theta_r, \phi)$$

- **Adaptation of the given reflexion model (tune the specific parameters)**
  - **select model**
  - **Least-Mean / Least-Median -Squares**

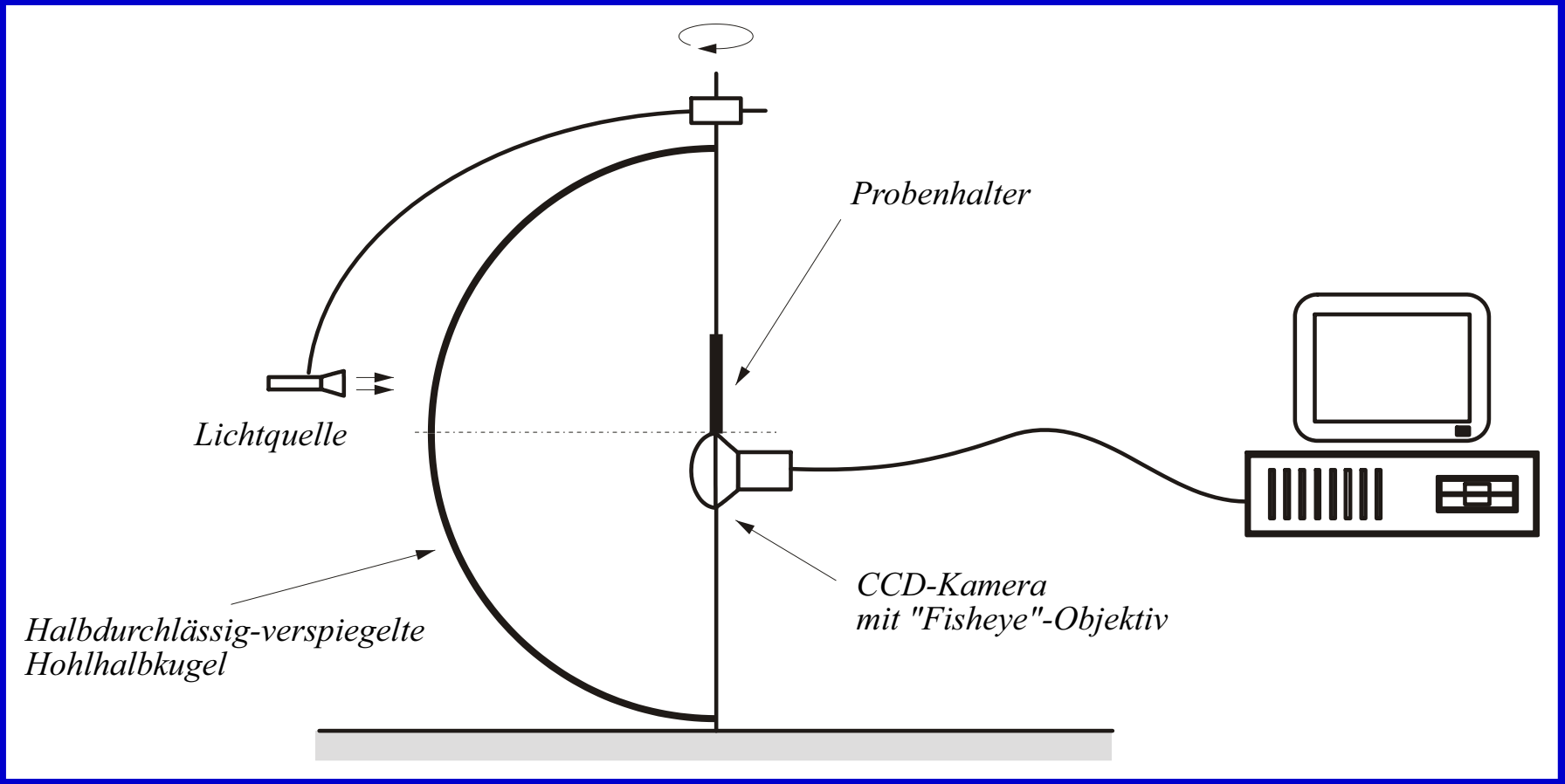
Problem Setting



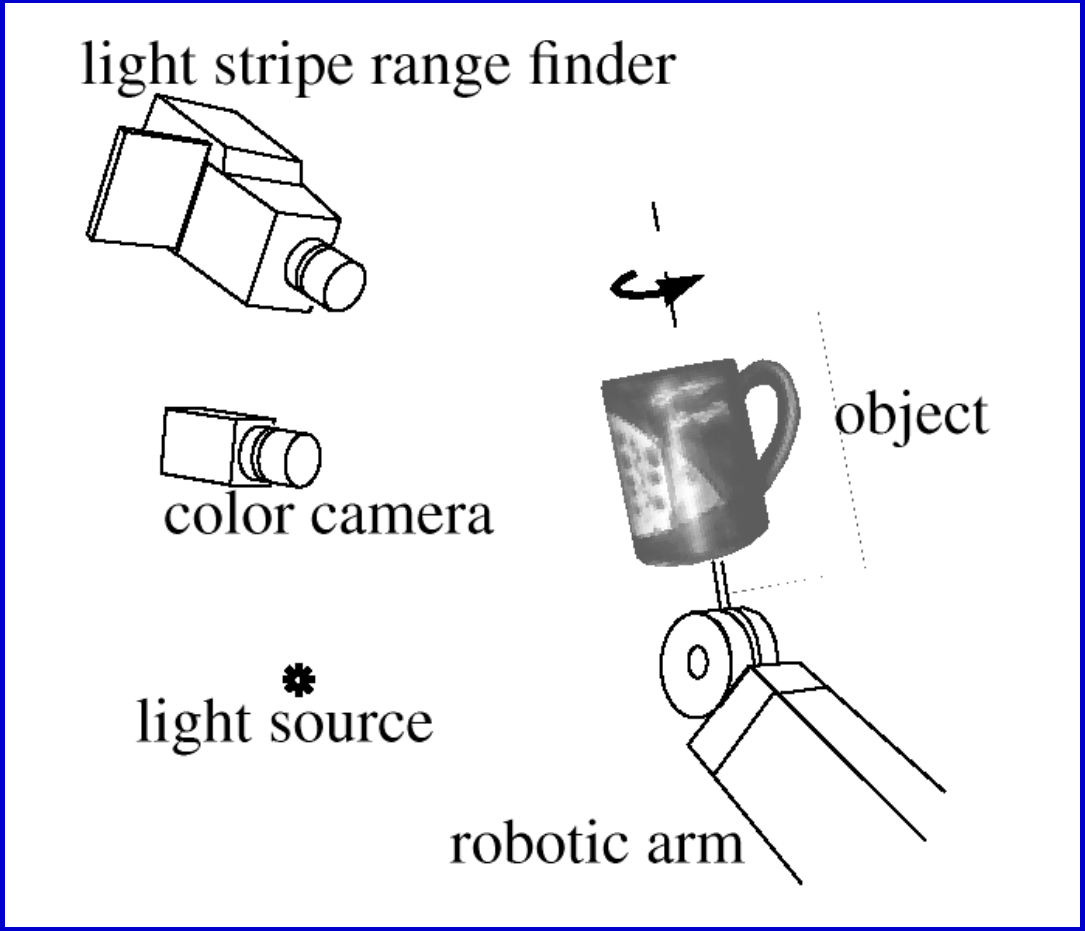
Photogoniometer

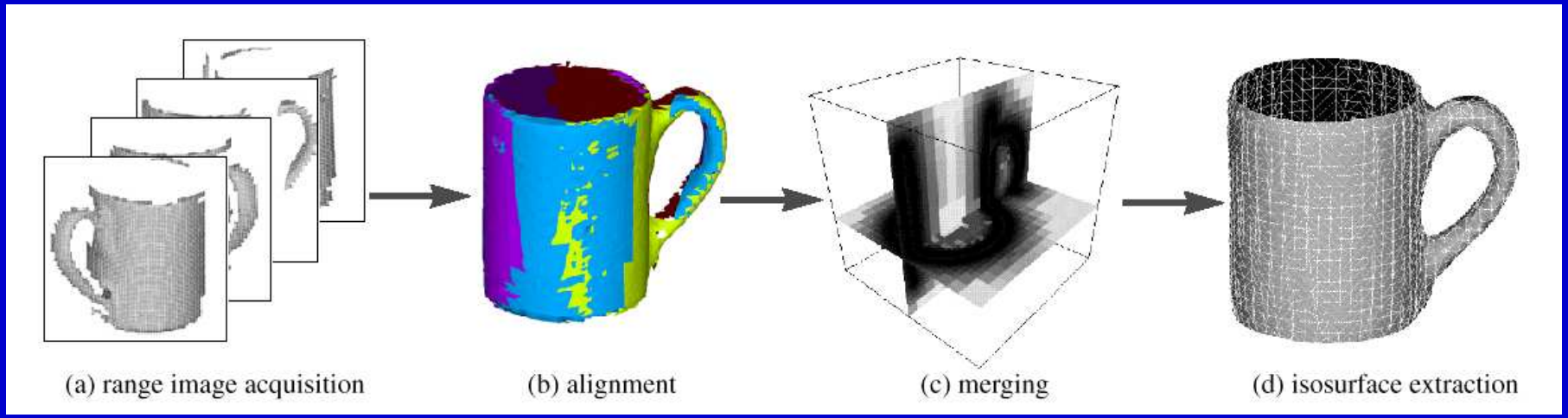


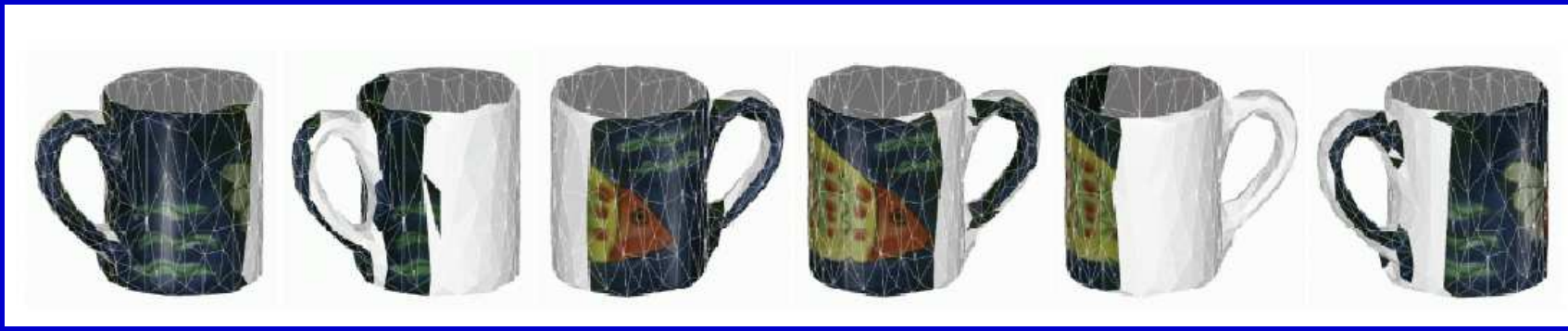
Imaging Reflectometer



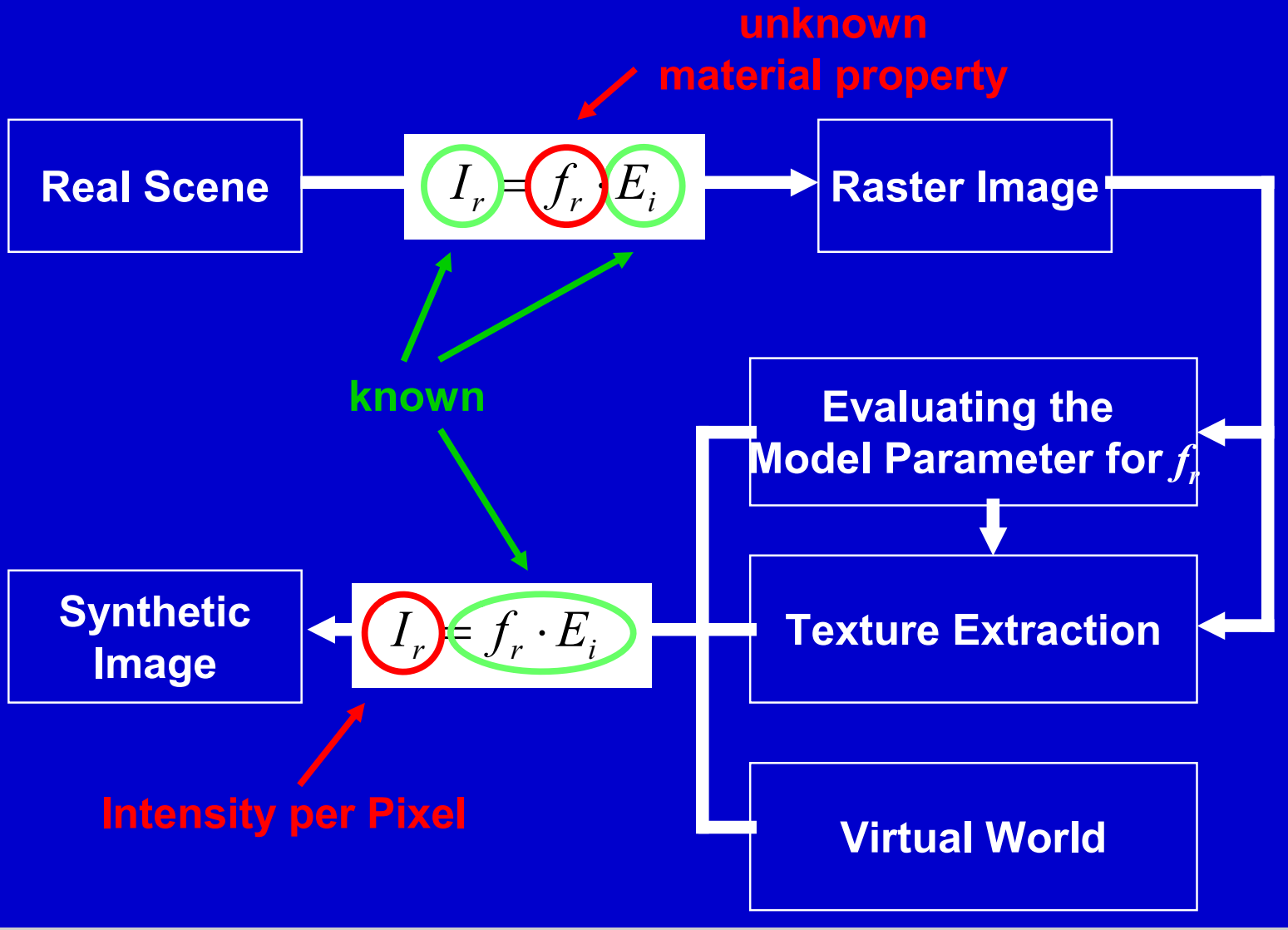
Method by Sato & Wheeler



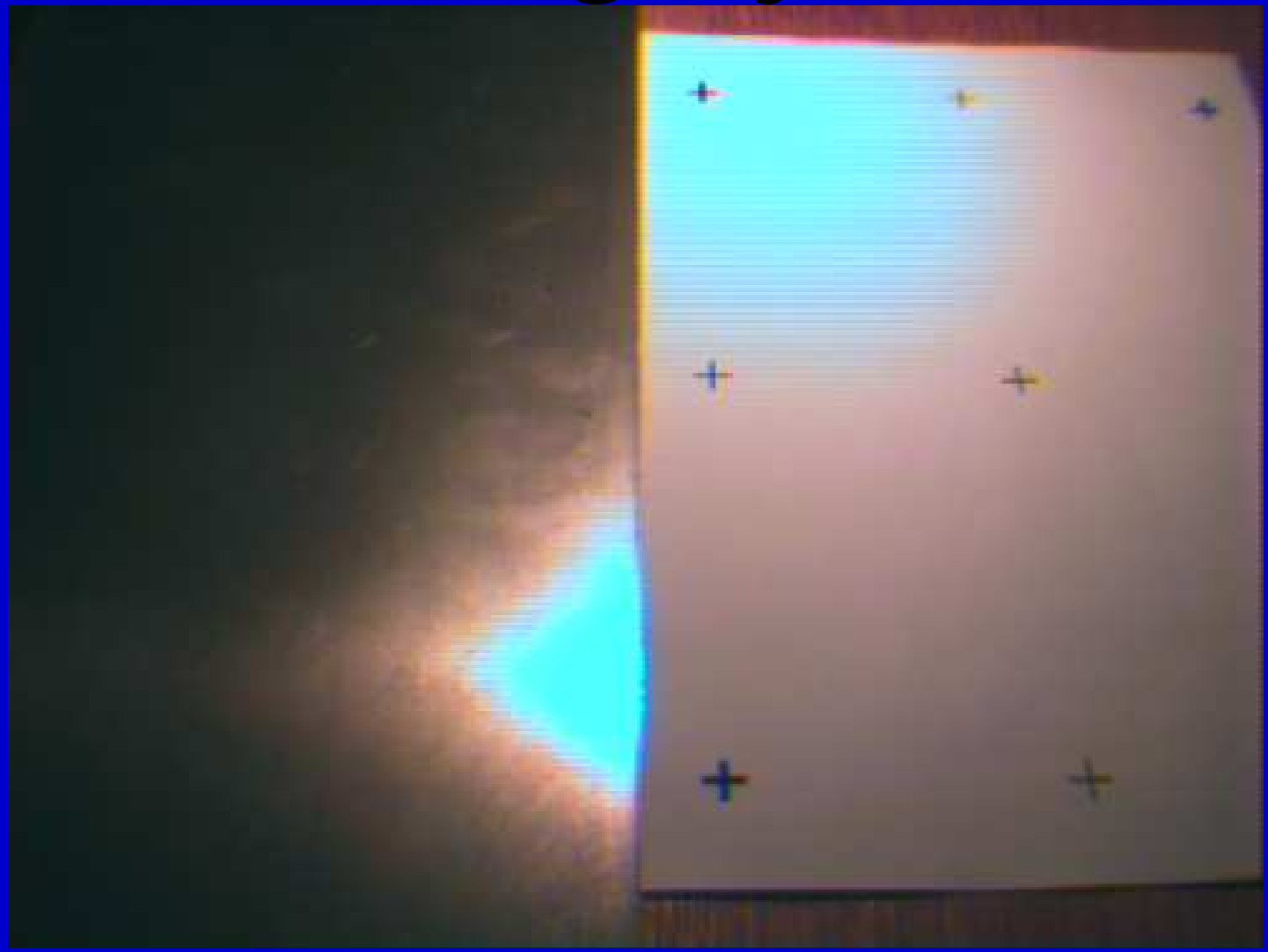

(a) range image acquisition
(b) alignment
(c) merging
(d) isosurface extraction



Images -> Material Properties -> Images



Scanning System



Pros & Cons

- **Pro:**
  - Only for symmetric lightsources
  - Elimined adventitious light (Streulicht)
  - Calibration (linear error only)
  - Measured values distributed on object surface
- **Contra:**
  - known dynamics of CCD-cameras

Separating Texture & Mirror Reflection

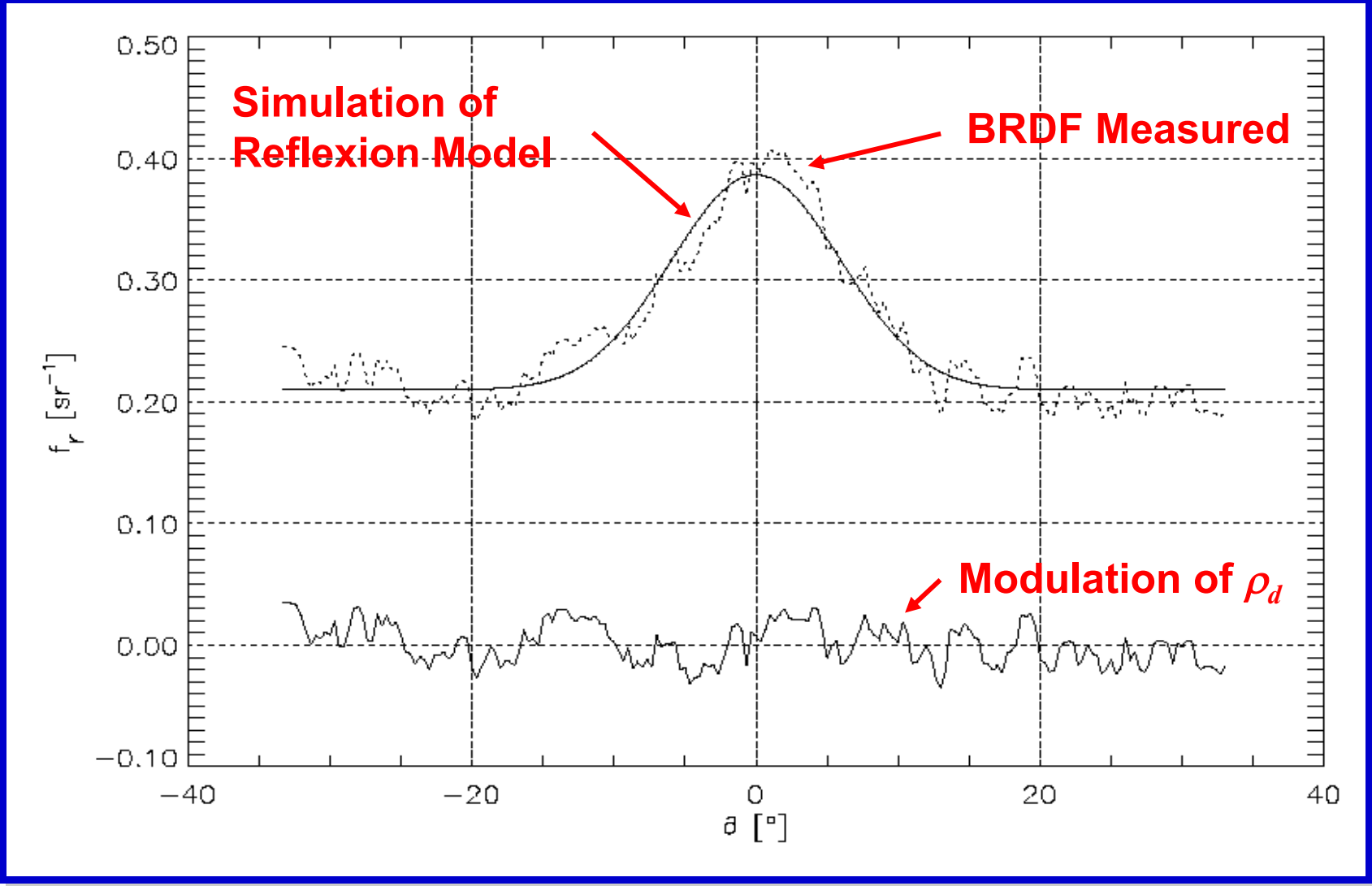
Parametric model for directed-diffuse reflexion: (Mikrofacetten-Modell)

from parameter evaluation (Least-Squares)

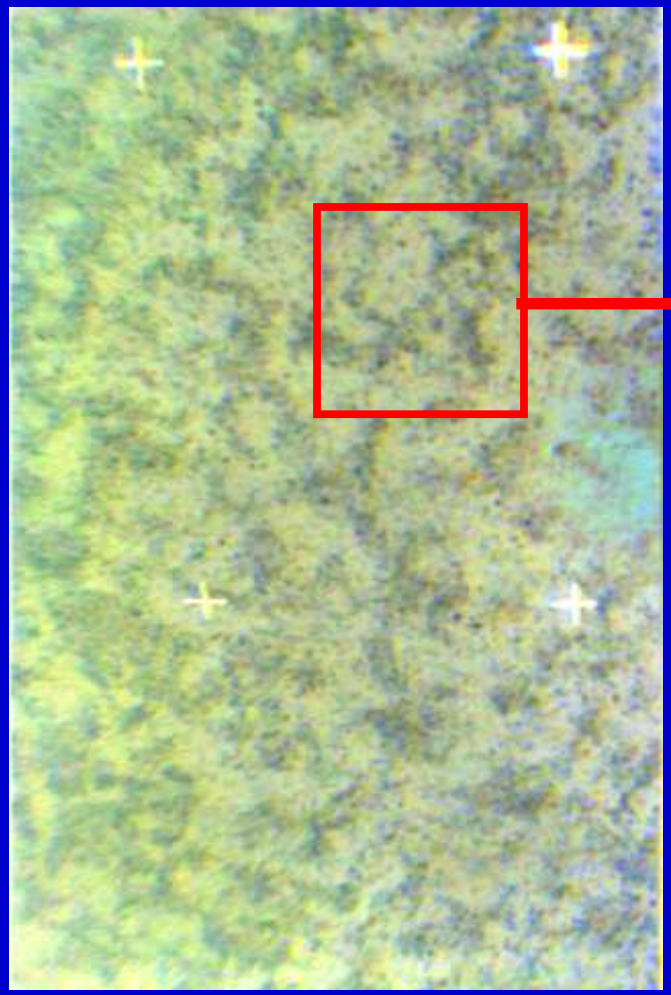
$$f_{r,iso} = \frac{\rho_d}{\pi} + \rho_s \frac{1}{\sqrt{\cos\theta_i \cos\theta_r}} \frac{\exp\left(-\tan^2 \delta / \alpha^2\right)}{4\pi\alpha^2}$$

Modulation of ρ_d = Textur

BRDF (f_r) of a row of pixels



Parametric Texture Description

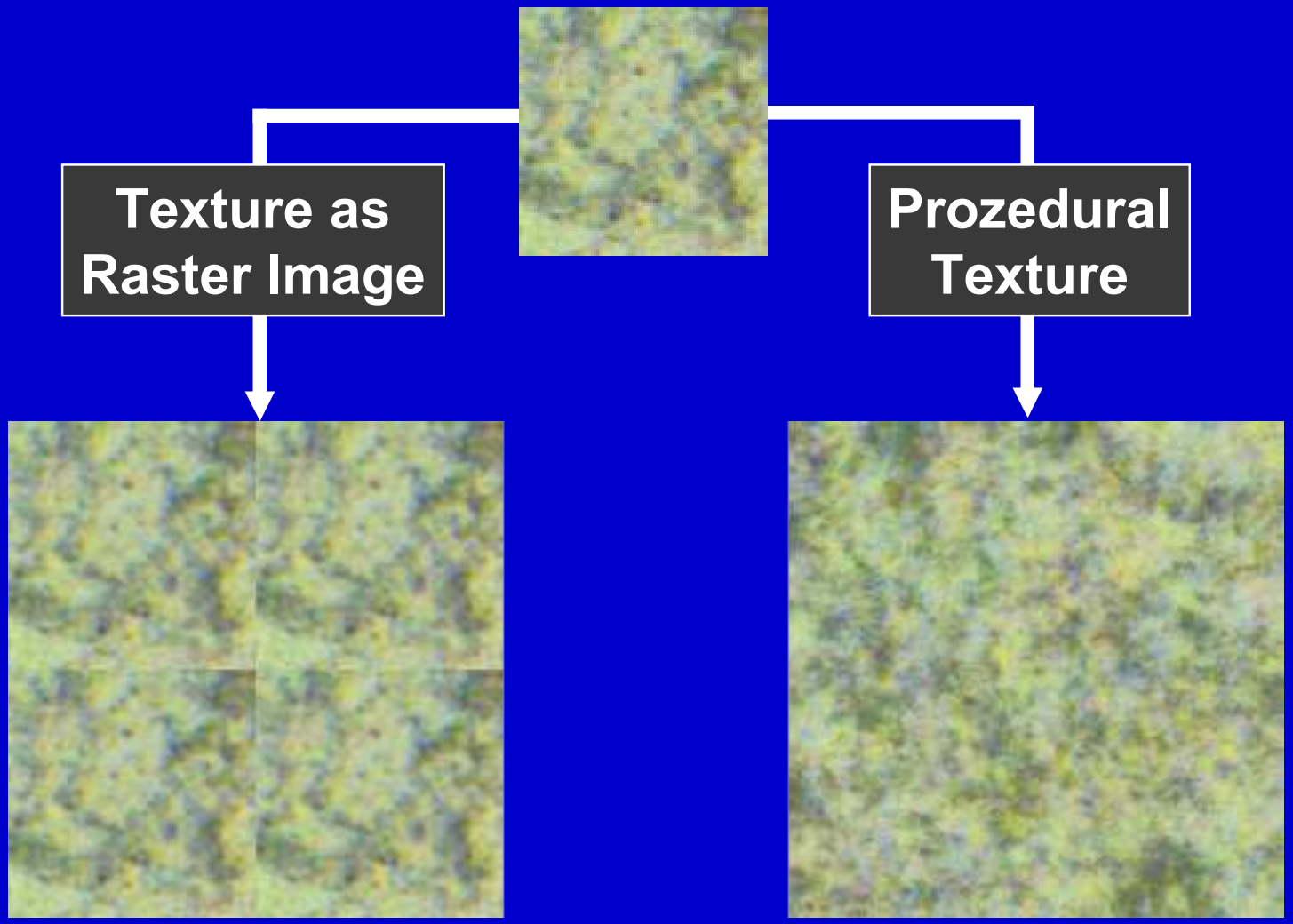


Output Image for Analysis

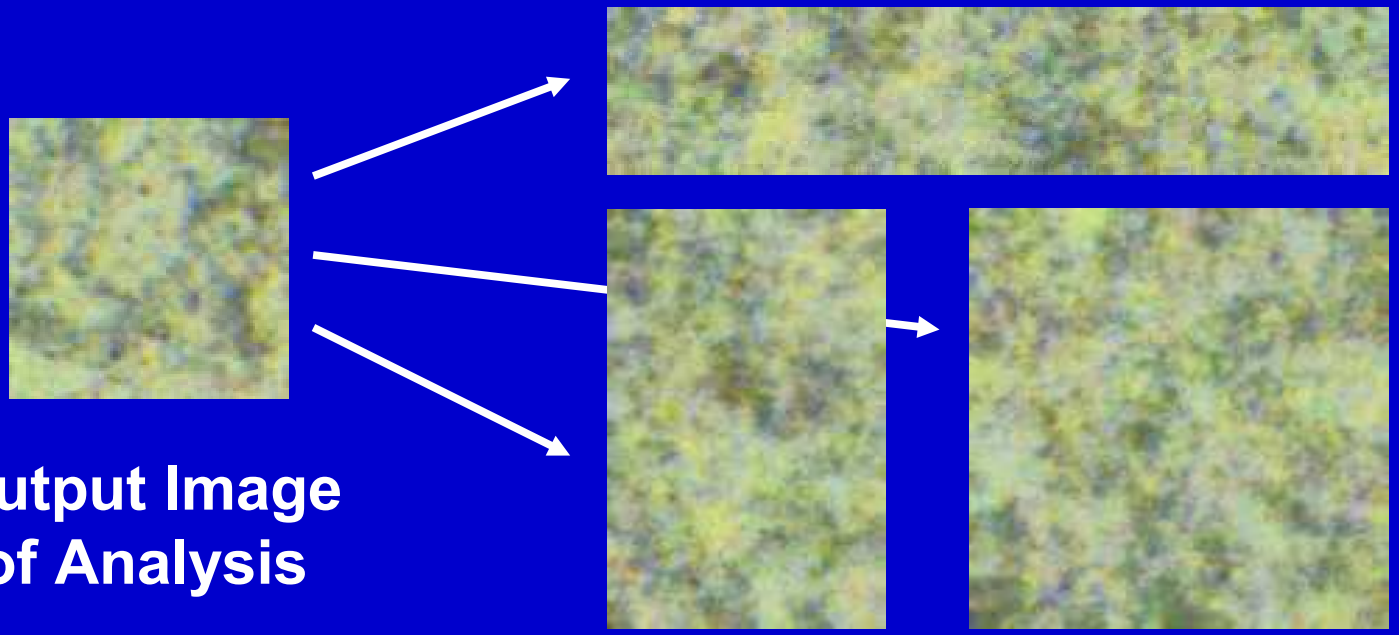
Usage of prozedural textures gives:

- ***Seamless Textures***
- ***Arbitrary*** *extension* ***and proportions***

Tiling vs. Seamless Textures

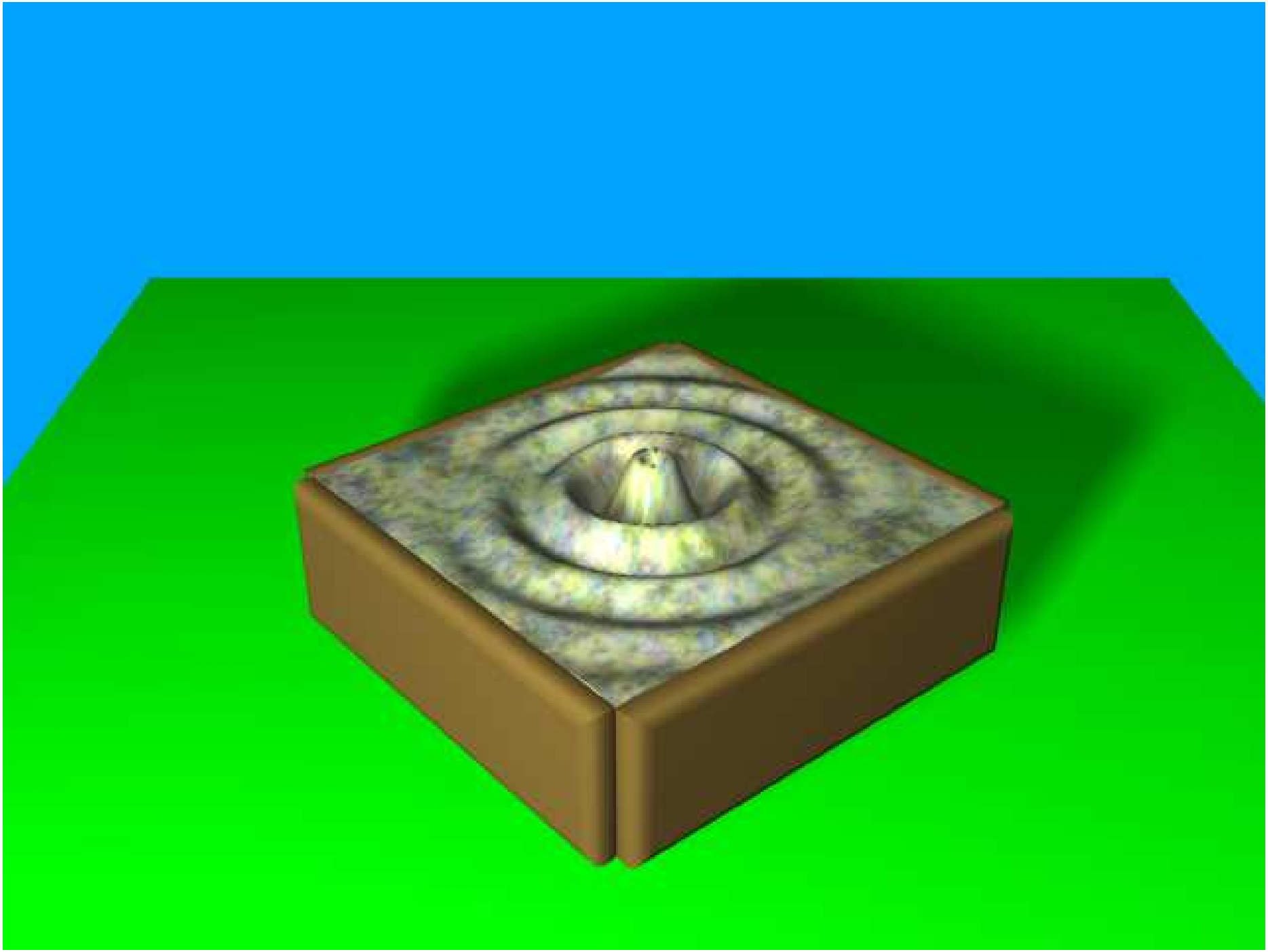


Proportions & Extension

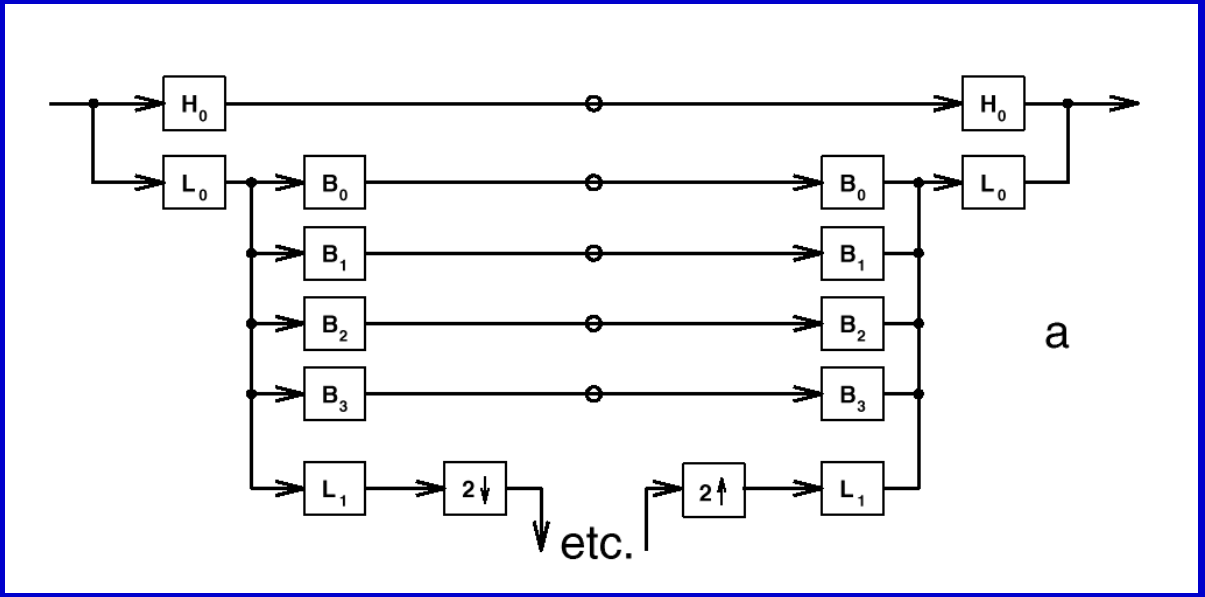


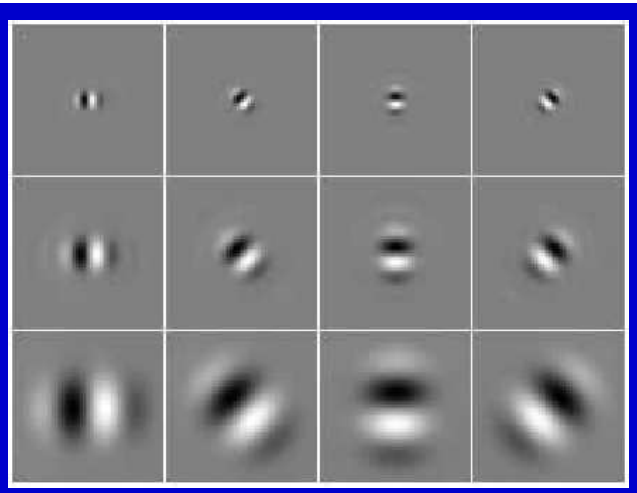
Output Image of Analysis

Synthesis of raster images with different proportions

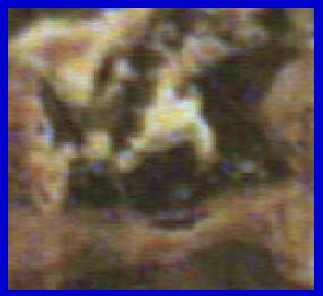


LaPlace / Steerable Pyramid





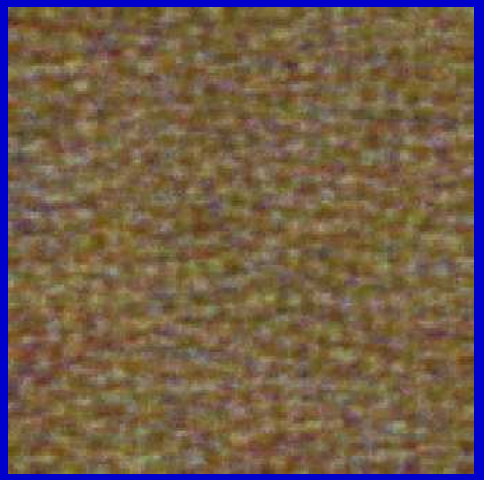
Output Image for Analysis



Synthesis

Output Image for Analysis

Synthesis



Future Work, Open Problems

- **Problems with:**
  - inhomogeneous textures
  - quasi-periodic and mosaic-like textures
  - local surface deformations (bump / displacement maps)
- **Improvement:**
  - Texture separation from surface deformations = Normal vektors displacmenet

Chatam Sófer M. by J. Krizik

- WCH?

Grafické systémy, vizualizácia a multimédiá

2 / 1

Letný semester 2006