DCGI

KATEDRA POČÍTAČOVÉ GRAFIKY A INTERAKCE

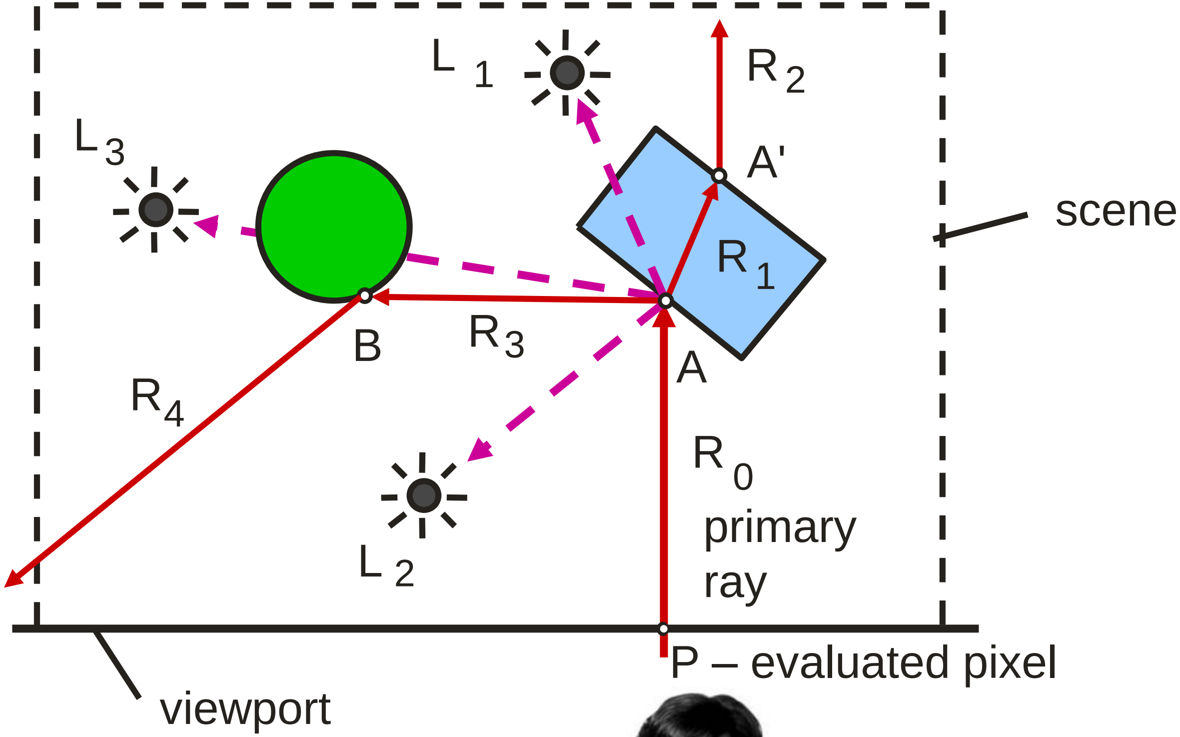
Ray Tracing

Jiří Bittner

Outline

- Whitted Ray Tracing MPG 15.9
- Ray Tracing Acceleration MPG 15.9.3

Ray Tracing Principle



[Whitted 1980]

(Backward) Ray Tracing - Algorithm

TraceRay (Ray *R*, recursion depth *H*)

1. Find intersection P of R with the nearest object

2. If no intersection // ray leaves the scene

   assign R background color and terminate

3. For all light sources:

   cast a **shadow ray** from *P.*

   if the shadow ray reaches the light source mark it visible

4. Evaluate light contribution at P from all **visible light sources**

5. If H < max depth :

   (a) **TraceRay** (Reflected ray *RR*, *H* + 1)

   (b) **TraceRay** (Refracted ray RT, *H* + 1)

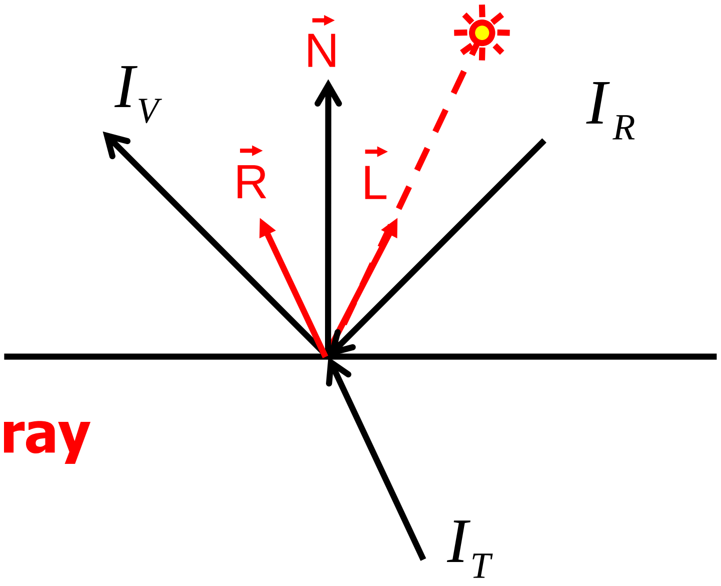
6. Assign to R the resulting color using sum of illumination from light sources and RR and RT

Extending Illumination Model

- $I_V = I_a + I_r + I_t + \sum I_d + I_s$
- I_a ambient component
- I_d diffuse component
- I_s specular component
- $I_r = k_s I_R$
- $I_t = k_t I_T$

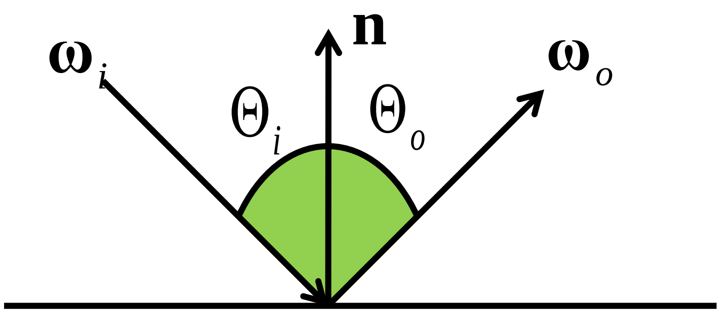
Recursion

Shadow ray



- k_s ... specular coef.
- k_t ... transmittance coef.

Direction of Reflected Ray



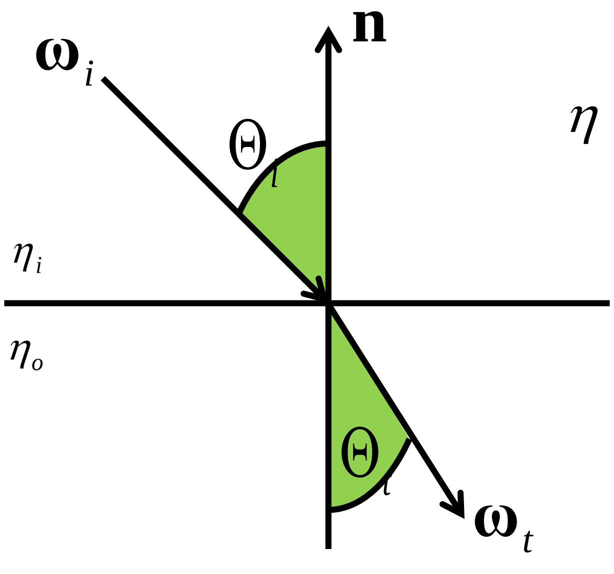
$$\Theta_o = \Theta_i$$

$$\boldsymbol{\omega}_o = \boldsymbol{\omega}_i + 2\cos\Theta_i \mathbf{n}$$
$$\boldsymbol{\omega}_o = \boldsymbol{\omega}_i - 2(\boldsymbol{\omega}_i \circ \mathbf{n})\mathbf{n}$$

Refracted Ray

$$\eta_i \sin\theta_i = \eta_o \sin\theta_t$$ Snell's law

$$\boldsymbol{\omega}_t = \eta_{io}\boldsymbol{\omega}_i - [\sqrt{1-\eta_{io}^2(1-\cos^2\theta_i)} + \eta_{io}cos\theta_i]\,\mathbf{n} \qquad \eta_{io} = \frac{\eta_i}{\eta_o}$$

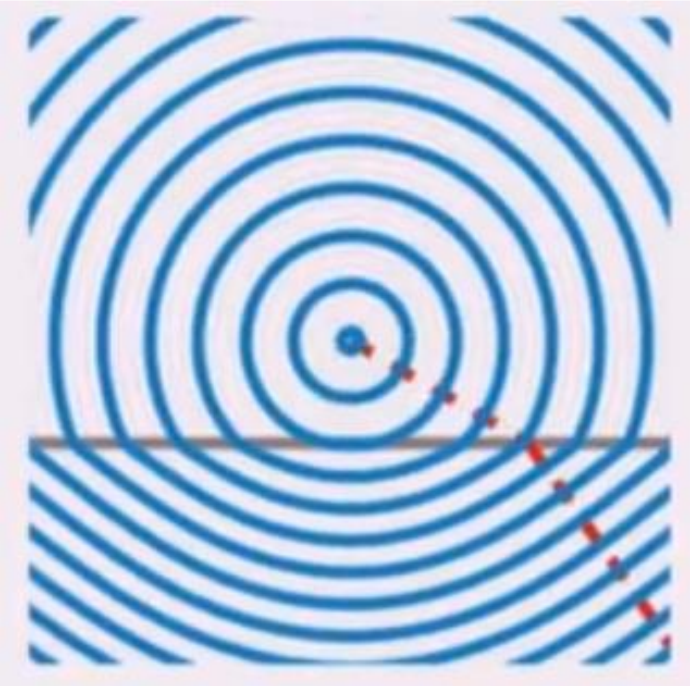


η index of refraction (air 1.000293, water 1.33, glass 1.6, diamond 2.4)

$$\sin^2\theta_t = \eta_{io}^2(1-\cos^2\theta_i) > 1$$

Total internal reflection – no refraction

Refraction - Example



Fresnel Equations

- Reflectivity / transmissivity varies with incident angle!
- And reflection / transmition different for polarized light

reflected $$R(\theta_i) = \left| \frac{\eta_{io} cos\theta - \sqrt{1 - (\eta_{io} sin\theta)^2}}{\eta_{io} cos\theta + \sqrt{1 - (\eta_{io} sin\theta)^2}} \right|^2$$

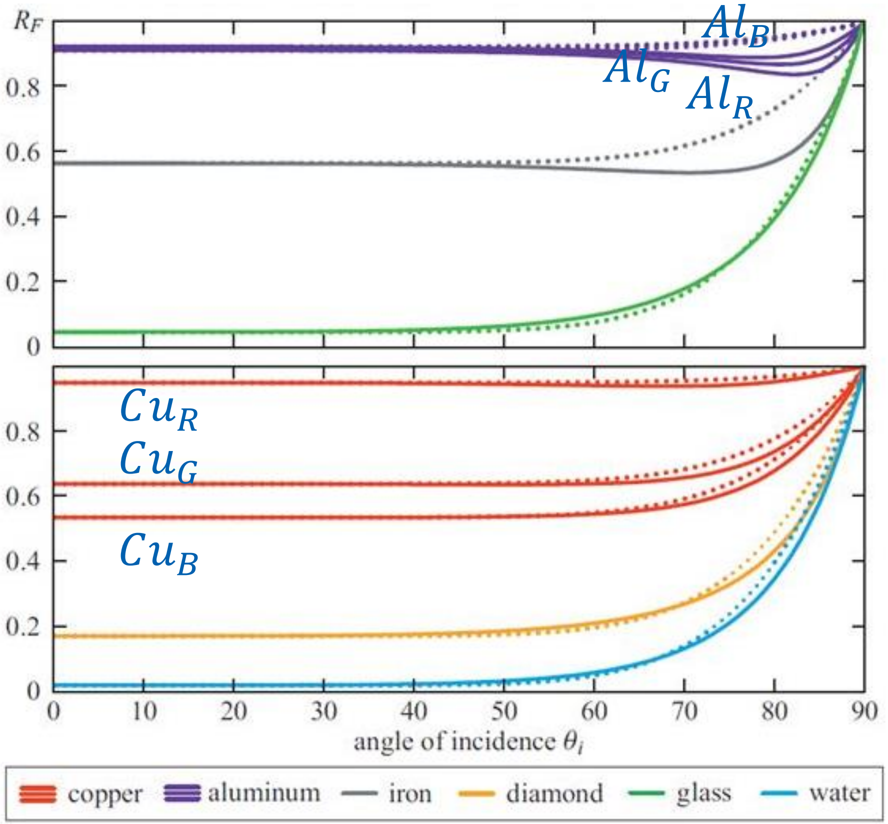
transmitted $$T(\theta_i) = 1 - R(\theta_i)$$

- Schlick approximation [1994]

$$R(\theta_i) = R_0 + (1 - R_0)(1 - \cos\theta_i)^5 \qquad R_0 = \left(\frac{\eta_{io} - 1}{\eta_{io} + 1} \right)^2$$

Examples

solid = Fresnel
dotted = Schlick



Source: Möller et al. RTR 3ed.

Outline

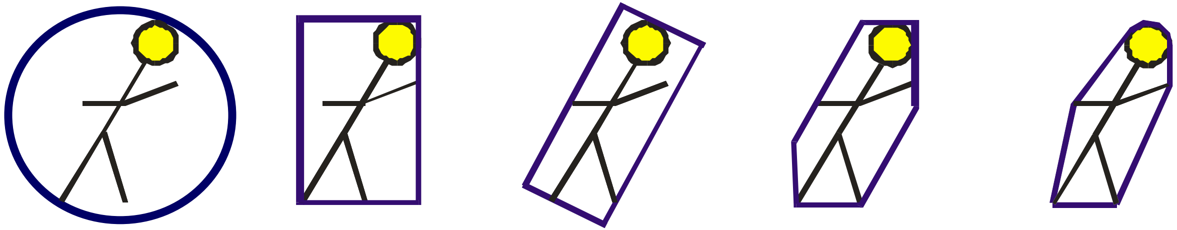
- Whitted Ray Tracing MPG 15.9
- Ray Tracing Acceleration MPG 15.9.3

Acceleration Methods

- Ray tracing is costly – must accelerate!
- Accelerating intersection computation
  - Faster ray X object intersection (fast routines with different primitives, simple bounding volumes)
  - Less ray X object intersections
    (BVH, spatial subdivison, light buffer, ray coherence)
- Less rays
  - Adaptive antialiasing, adaptive depth of recursion, …
- Tracing more rays
  - Ray packets/ bundles

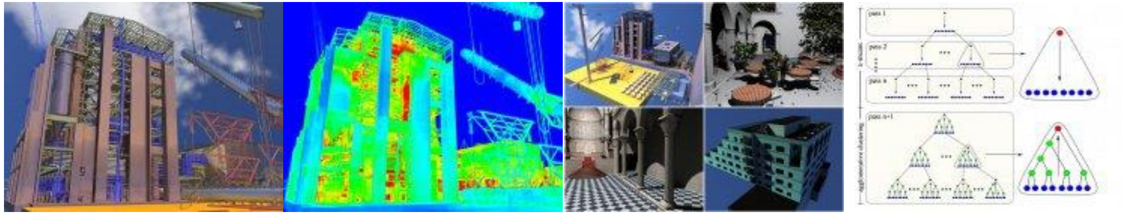
Accelerating Intersection Computation

- Bounding Volume Hierarchy



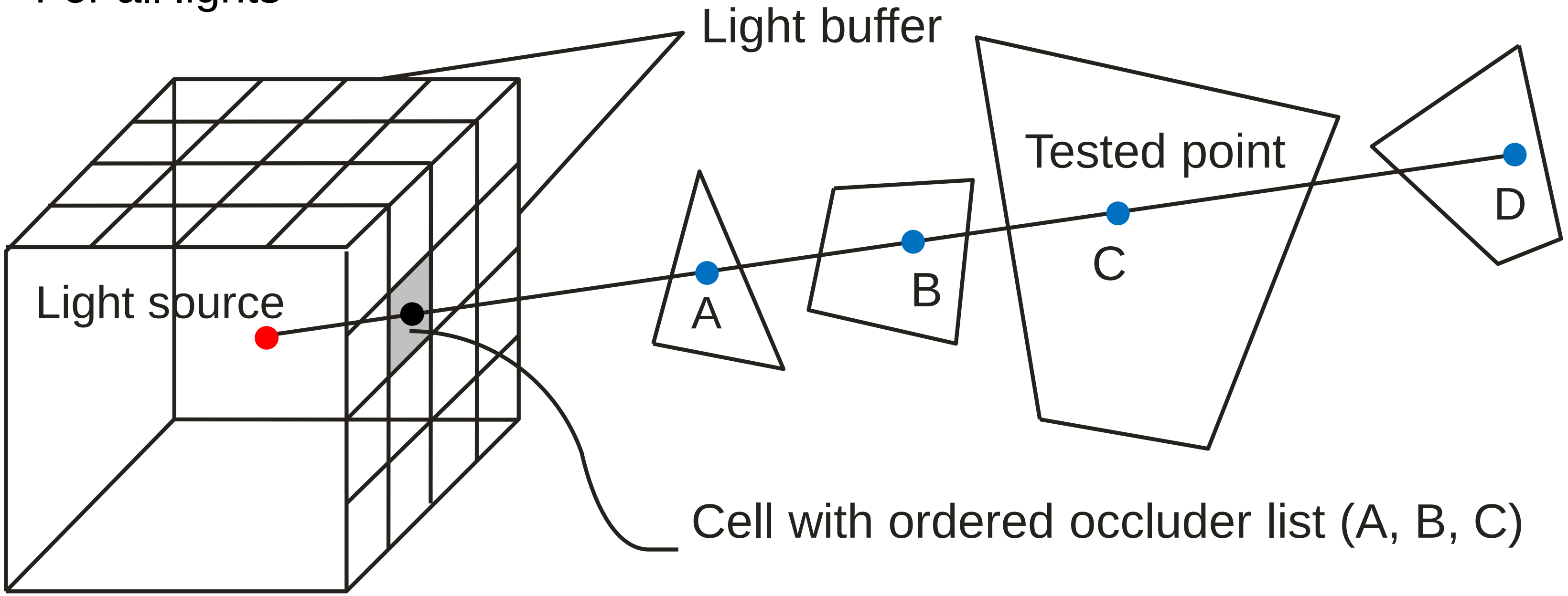
Sphere | AABB | OBB | Polytope (6-DOP) | Convex Hull

- Hot research topic at DCGI!



Accelerating Intersection Computation

- Light buffer [Haines & Greenberg 1986]
  - Faster shadow rays
  - For all lights



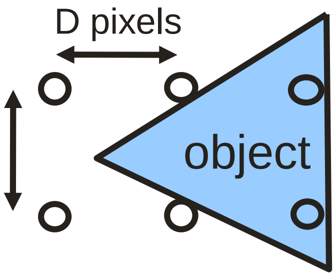
Acceleration Methods

1. **Accelerating intersection computation**
   a) Faster ray X object intersection (fast routines with different primitives, simple bounding volumes)
   b) Less ray X object intersections
   (BVH, spatial subdivison, light buffer, ray coherence)
2. **Less rays**
   - Adaptive antialiasing, adaptive depth of recursion, …
3. **Tracing more rays**
   - Ray packets/ bundles

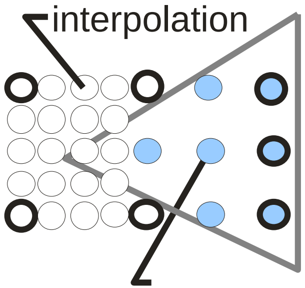
Less rays

- Controlling recursion depth
  - Static using a constant (e.g. 5)
    - too deep for non reflecting surfaces
  - Adaptive using importance of contribution
    - Initial contribution 100%, reflection/refraction multiply with rs (<1)
- Adaptive sampling

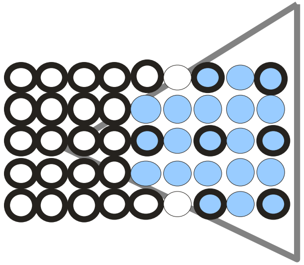
Adaptive Sampling



coarse sampling



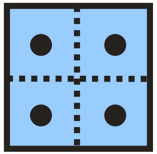
fine sampling



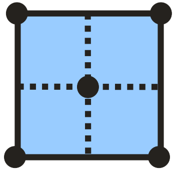
result

Supersampling

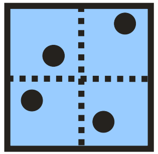
1 pixel:



subpixel centers



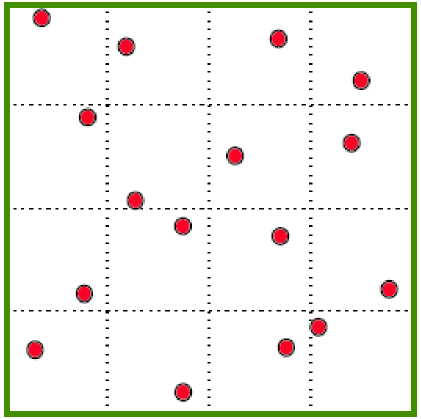
center and corners



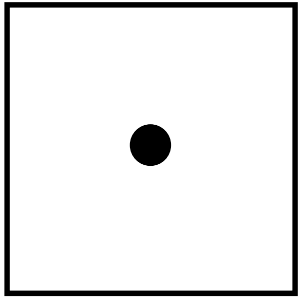
jittering

Jittering

- Jittering = organized sampling in a grid
- Stratified sampling
- Avoids creating larger sample clusters
- Better distribution than random sampling
- *Disadvantage* – up to four samples can get clustered
- Sample relaxation



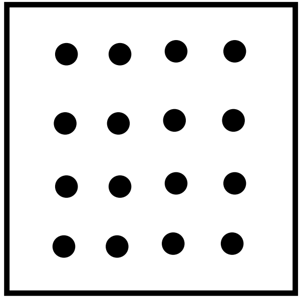
Antialiasing using Supersampling



pixel

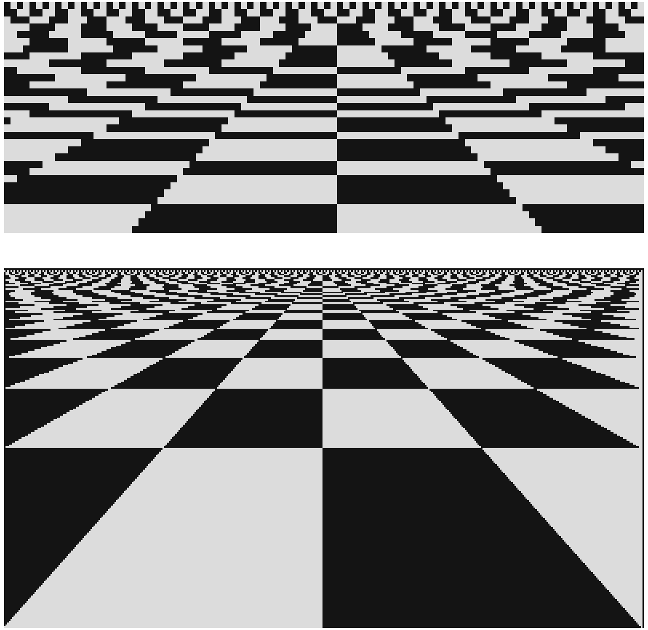
$$pixel = \sum_{s} w_s \cdot sample_s$$

filter applied on sample position

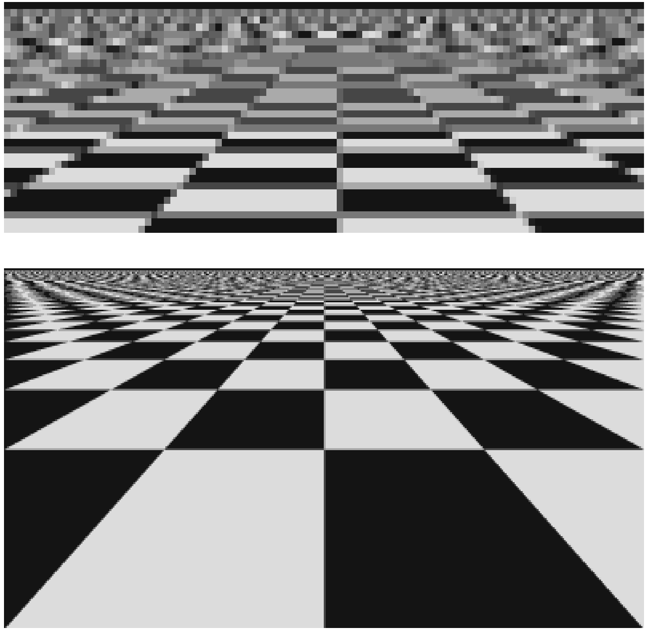


samples

Point Sampling vs. Supersampling



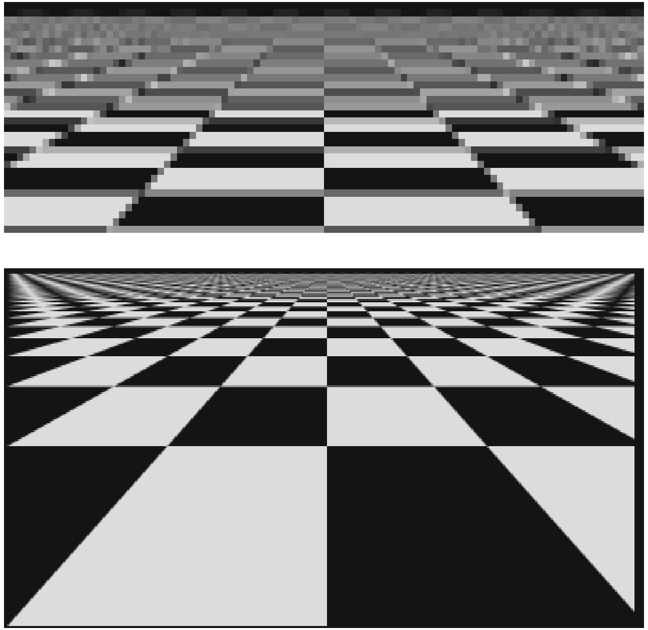
Point



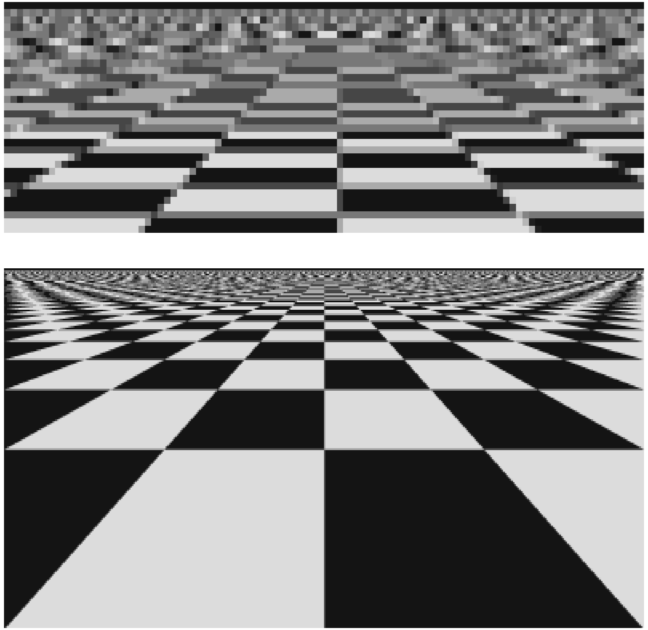
Supersampling 4x4

Checkerboard sequence by Tom Duff

Exact Solution vs. Supersampling

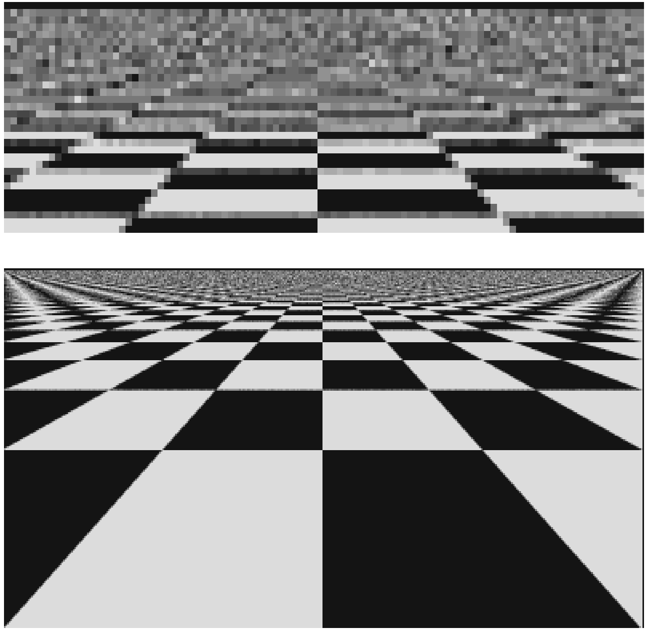


Exact visible area calculation

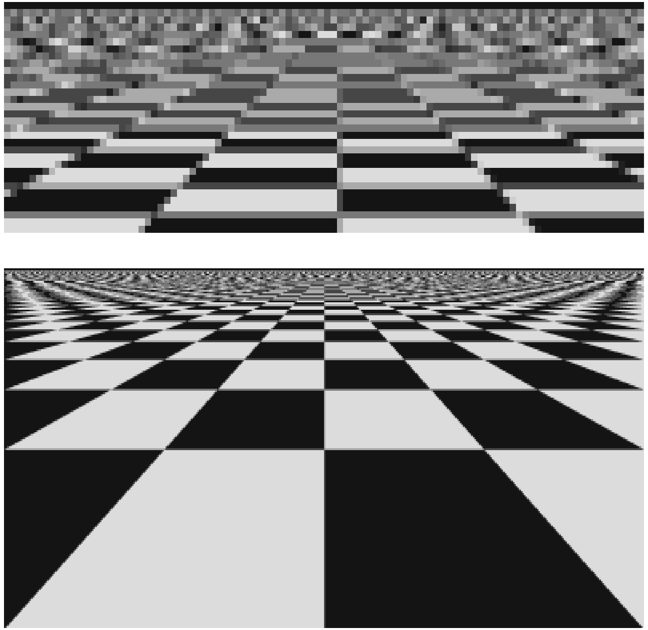


Supersampling 4x4

Jittering vs. Regular Supersampling



Jittering 4x4



Supersampling 4x4

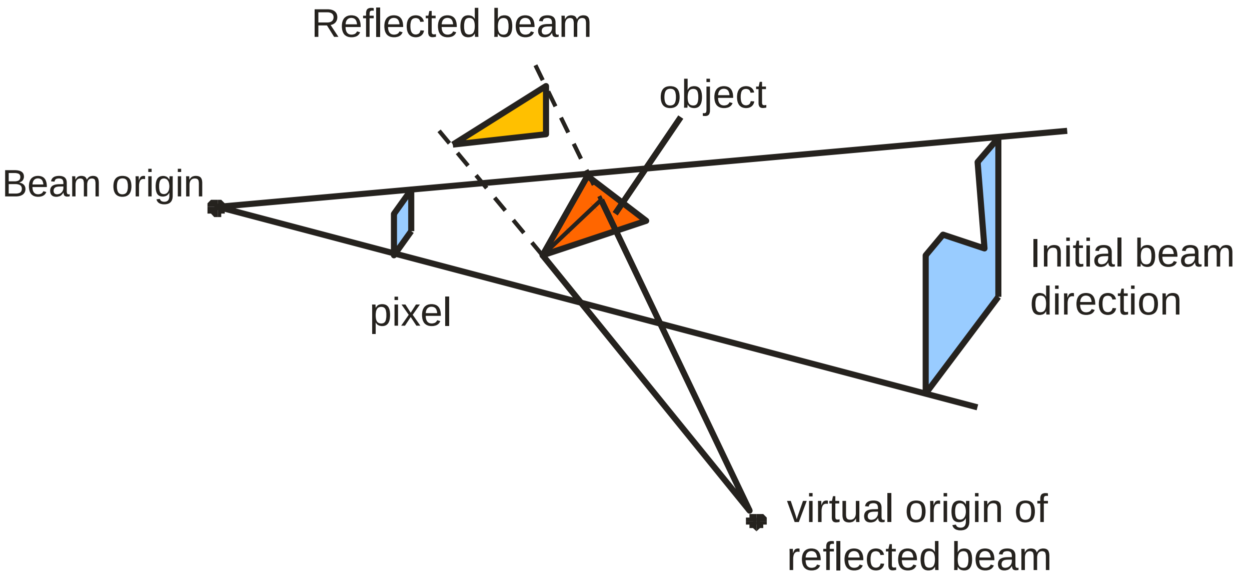
Interactive Path Tracing - Example

Acceleration Methods

1. **Accelerating intersection computation**
   a) Faster ray X object intersection (fast routines with different primitives, simple bounding volumes)
   b) Less ray X object intersections
   (BVH, spatial subdivison, light buffer, ray coherence)
2. **Less rays**
   - Adaptive antialiasing, adaptive depth of recursion, …
3. **Tracing more rays together**
   - Ray packets/ bundles

Tracing More Rays

- Beam tracing – Heckbert & Hanrahan 1986



- Packet / Bundle tracing (SSE)

Outline

- Whitted Ray Tracing MPG 15.9
- Ray Tracing Acceleration MPG 15.9.3

DCGI

KATEDRA POČÍTAČOVÉ GRAFIKY A INTERAKCE

Questions?