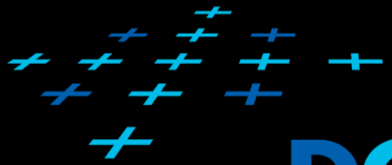

DCGI

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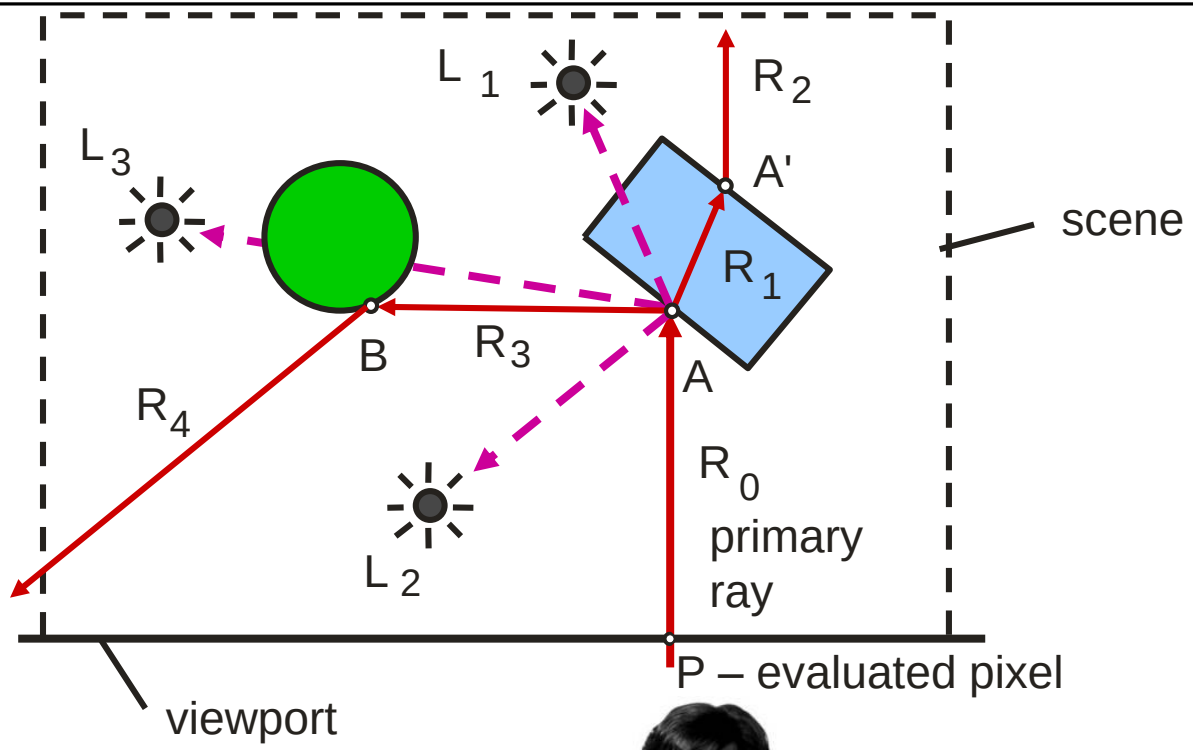
Ray Tracing

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)

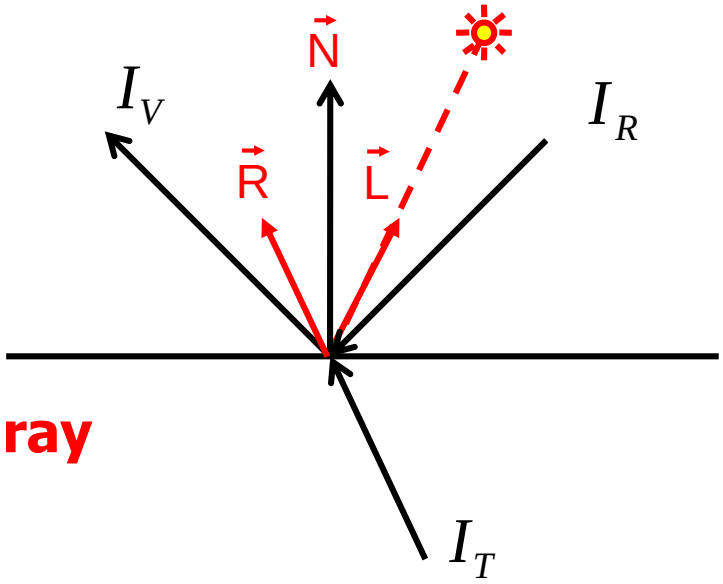
   (b) **TraceRay** (Refracted ray RT, *H* + 1)
6. Assign to R the resulting color using sum of illumination from light sources and RR and RT

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
- $I_r = k_s I_R$
- $I_t = k_t I_T$

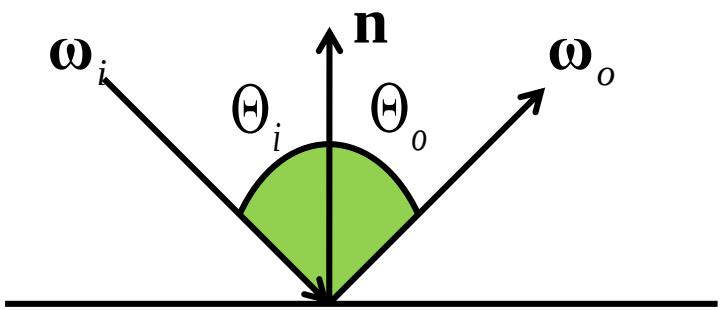
Recursion

Shadow ray



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

Direction of Reflected Ray



$$\Theta_o = \Theta_i$$

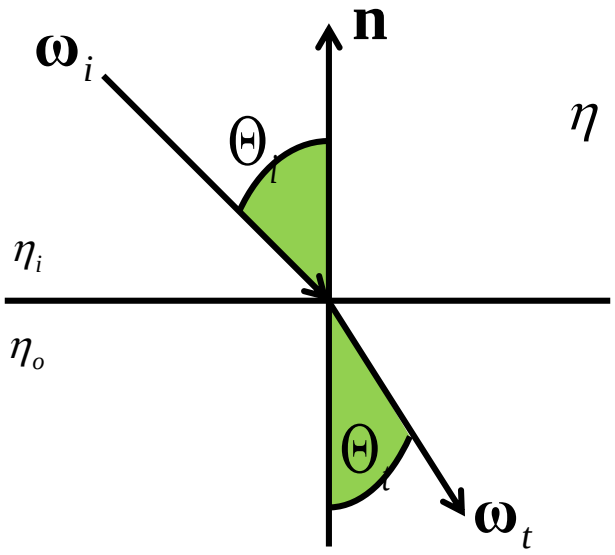
$$\boldsymbol{\omega}_o = \boldsymbol{\omega}_i + 2\cos\Theta_i \mathbf{n}$$

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

Refracted Ray

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

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

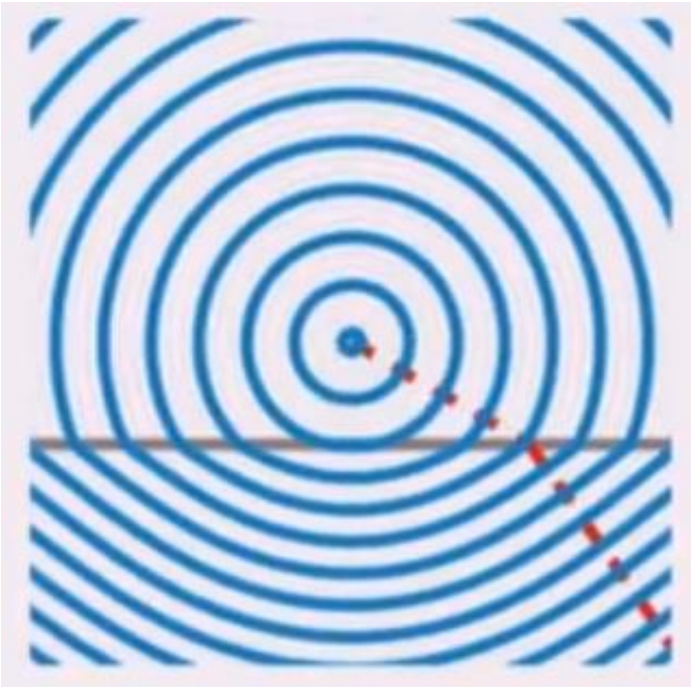


η index of refraction (air 1.000293, water 1.33, glass 1.6, diamond 2.4)

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

Total internal reflection – no refraction

Refraction - Example



Fresnel Equations

- Reflectivity / transmissivity varies with incident angle!
- Schlick approximation [1994]

$$R_0 = \left(\frac{\eta_{io} - 1}{\eta_{io} + 1} \right)^2$$

reflected $$R(\theta_i) = R_0 + (1 - R_0)(1 - \cos\theta_i)^5$$

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

Fresnel Equations

- Sem zadejte rovnici.

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

Outline

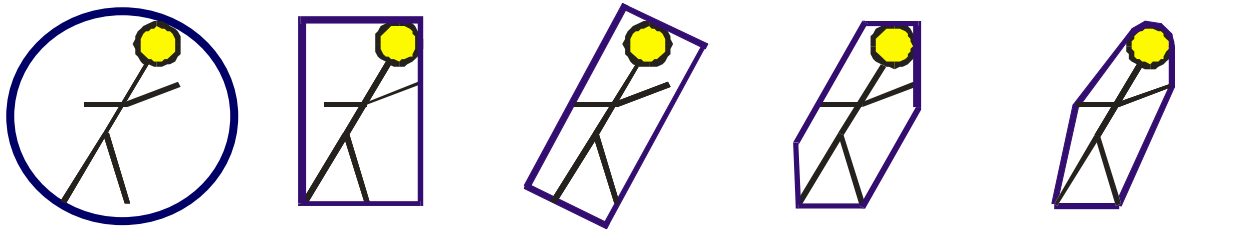
- Whitted Ray Tracing — MPG 15.9
- Ray Tracing Acceleration — MPG 15.9.3

Acceleration Methods

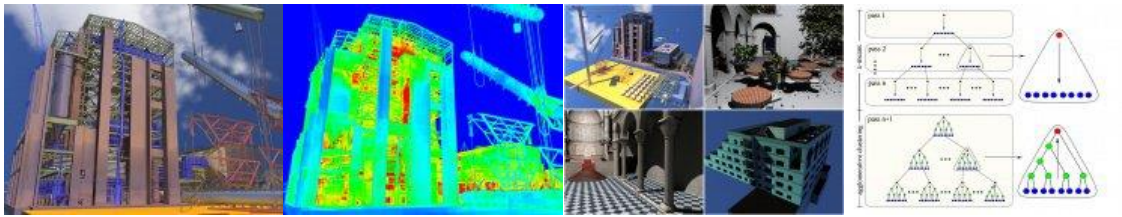
- Ray tracing is costly – must accelerate!
- Accelerating intersection computation
  - Faster ray X object intersection (fast routines with different primitives, simple bounding volumes)
  - Less ray X object intersections
    (BVH, spatial subdivison, light buffer, ray coherence)
- Less rays
  - Adaptive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

Accelerating Intersection Computation

- Bounding Volume Hierarchy

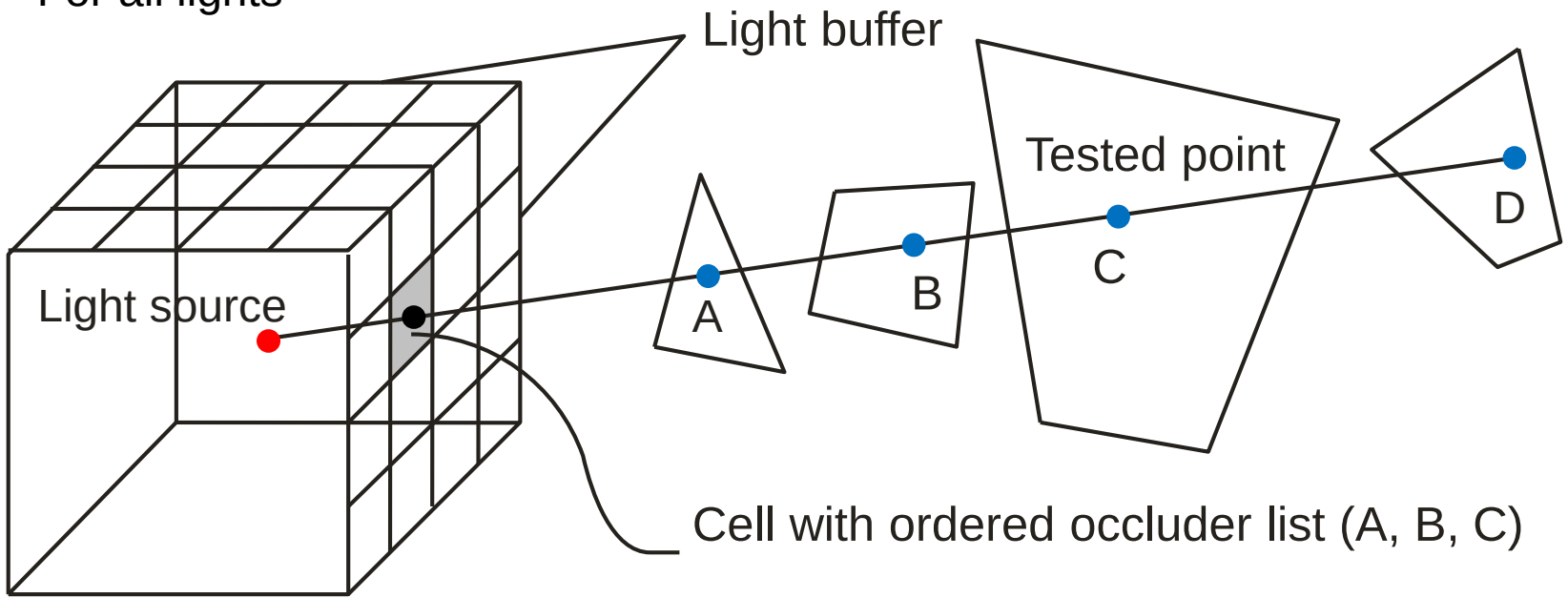


- Hot research topic at DCGI!



Accelerating Intersection Computation

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



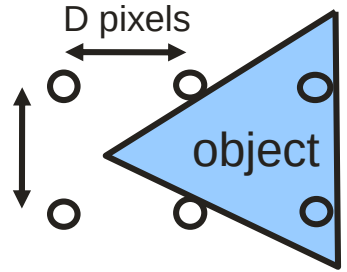
Acceleration Methods

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

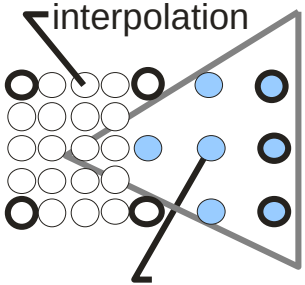
Less rays

- 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

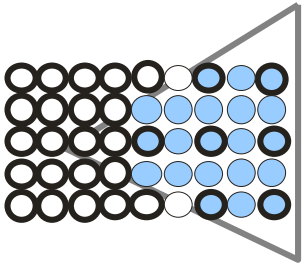
Adaptive Sampling



coarse sampling



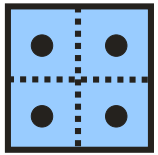
fine sampling



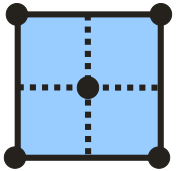
result

Supersampling

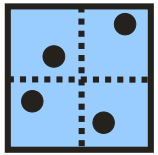
1 pixel:



subpixel centers



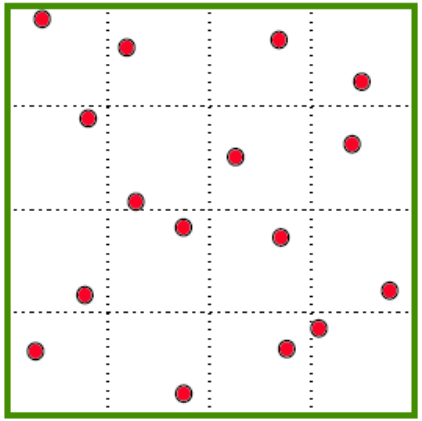
center and corners



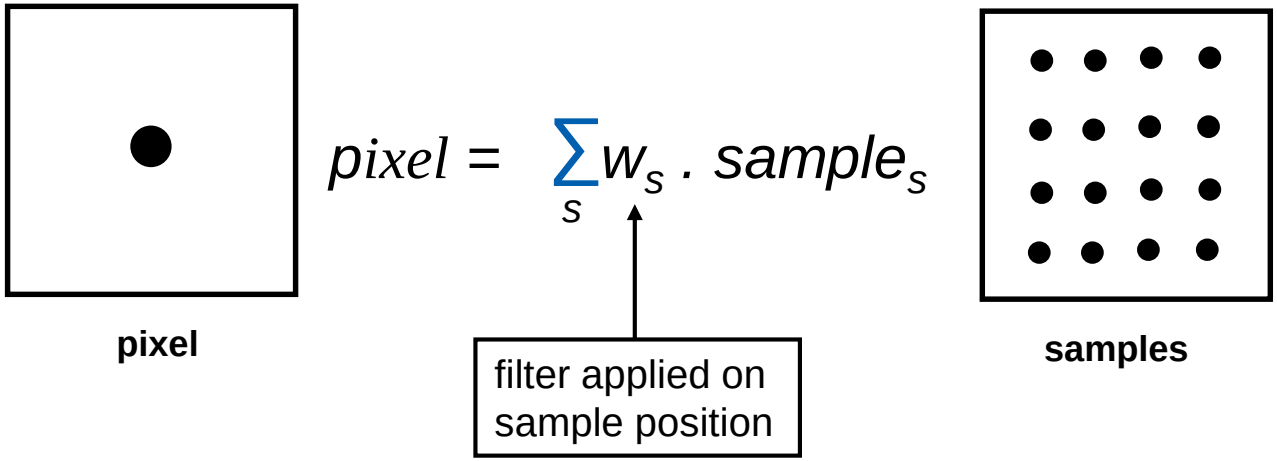
jittering

Jittering

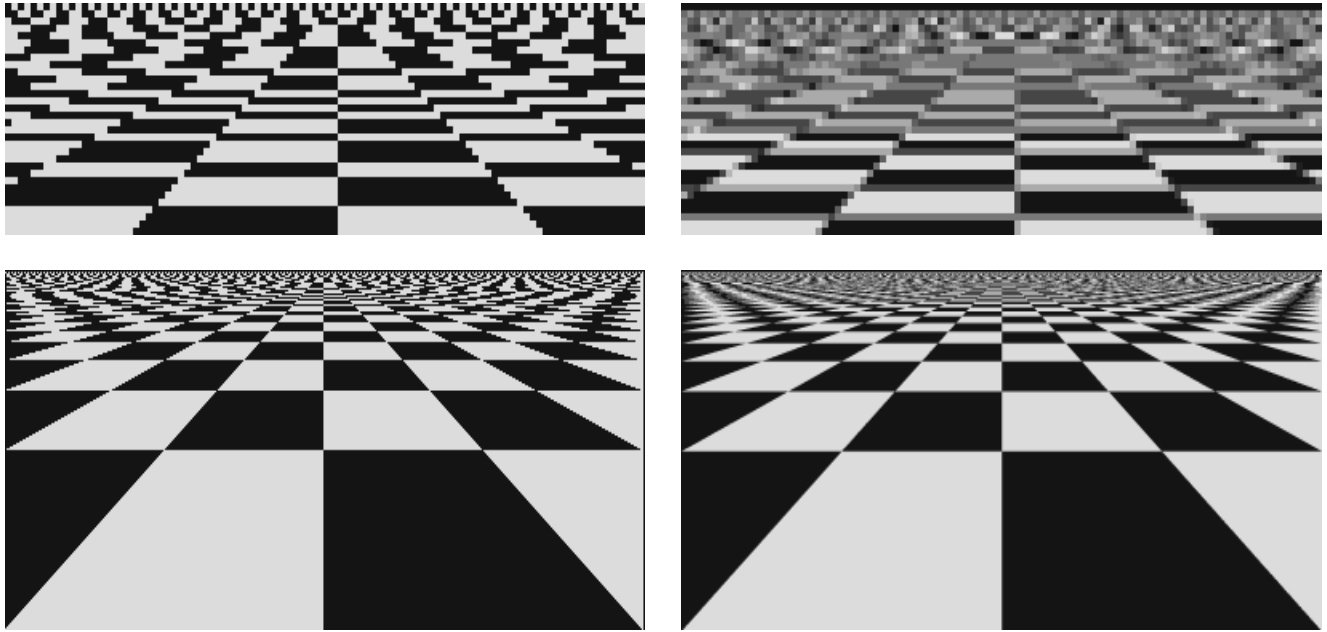
- Jittering = organized sampling in a grid
- Stratified sampling
- Avoids creating larger sample clusters
- Better distribution than random sampling
- *Disadvantage* – up to four samples can get clustered
- Sample relaxation



Antialiasing using Supersampling



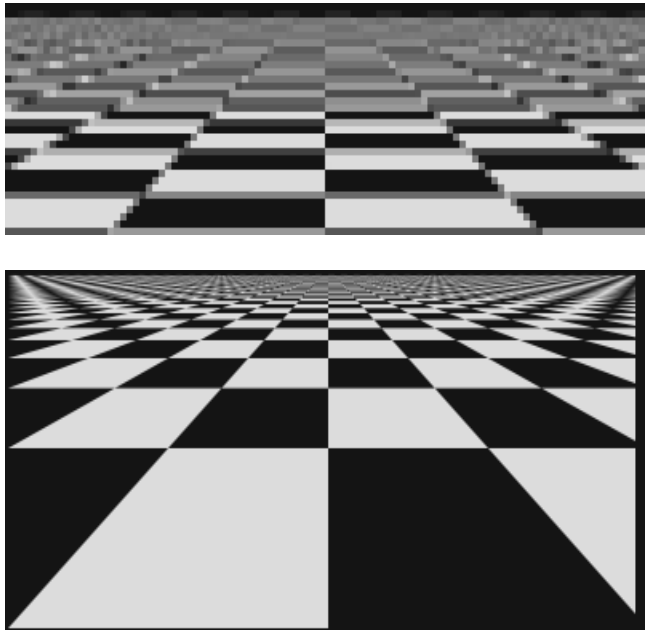
Point Sampling vs. Supersampling



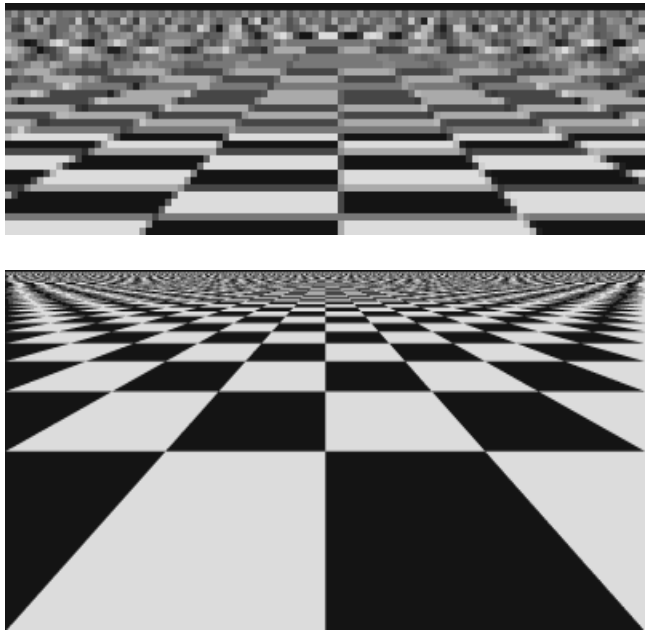
Point **Supersampling 4x4**

Checkerboard sequence by Tom Duff

Exact Solution vs. Supersampling

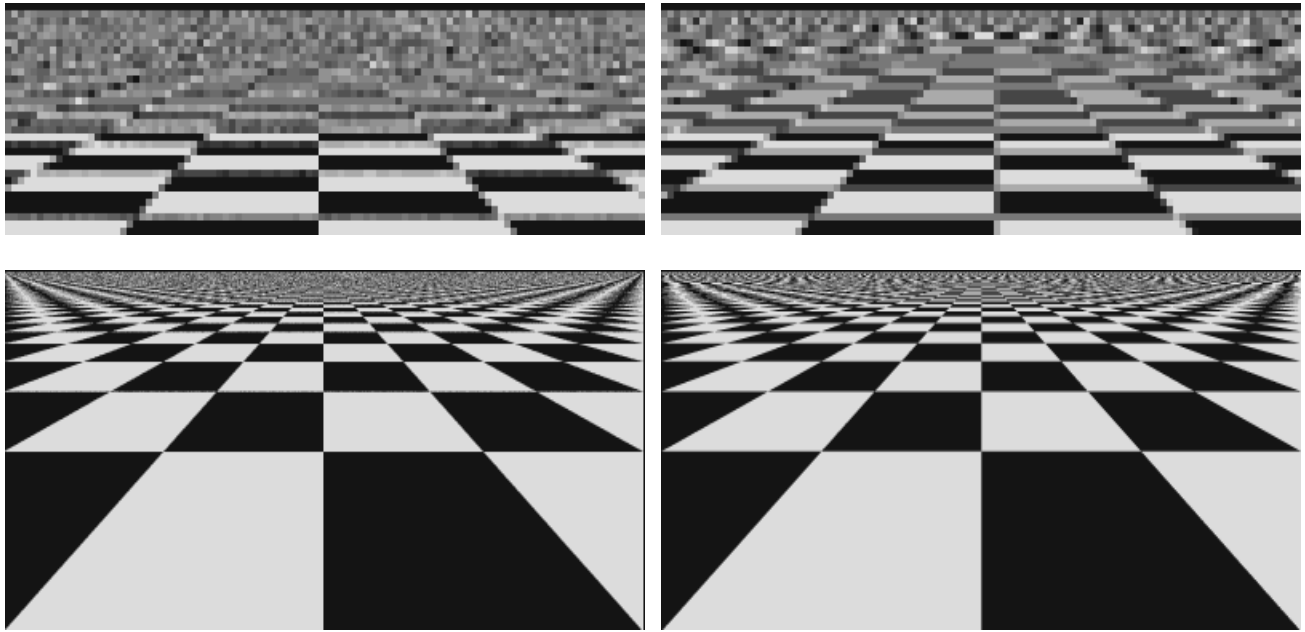


Exact visible area calculation



Supersampling 4x4

Jittering vs. Regular Supersampling



Jittering 4x4 **Supersampling 4x4**

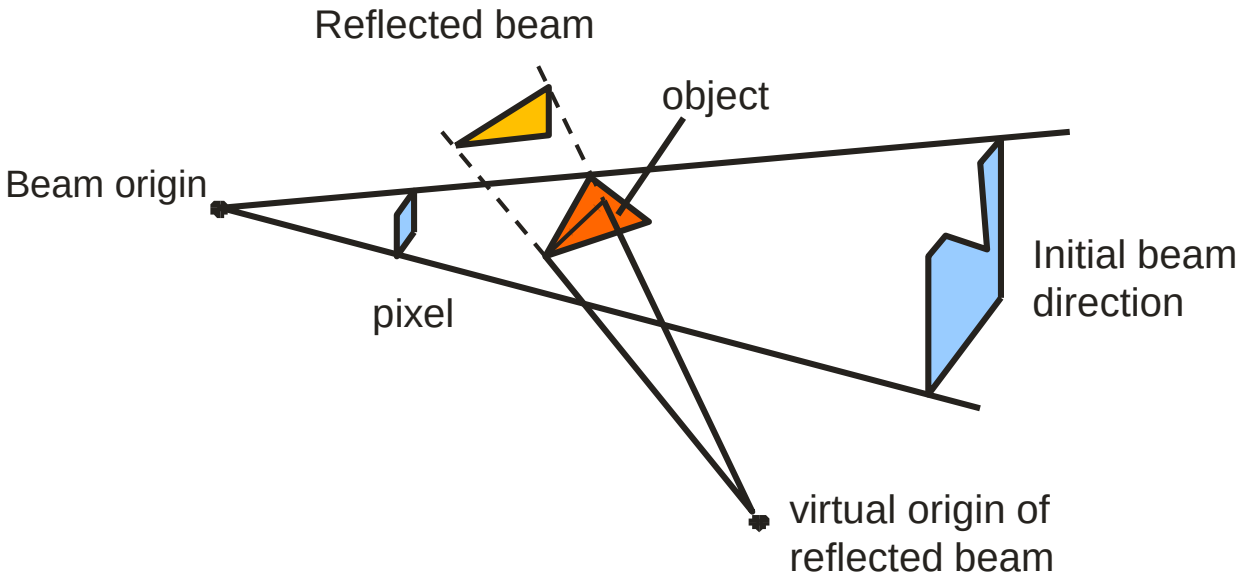
Interactive Path Tracing - Example

Acceleration Methods

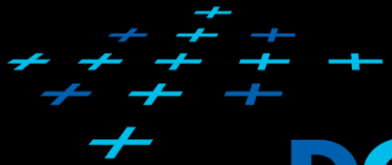
1. **Accelerating intersection computation**
   a) Faster ray X object intersection (fast routines with different primitives, simple bounding volumes)
   b) Less ray X object intersections
   (BVH, spatial subdivison, light buffer, ray coherence)
2. **Less rays**
   - Adaptive antialiasing, adaptive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

Tracing More Rays

- Beam tracing – Heckbert & Hanrahan 1986



- Packet / Bundle tracing (SSE)



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Questions?