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Global Illumination

Carsten Dachsbacher



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Overview

- global illumination
  - elusive goal
  - methods do not map to a GPU
- what can we do with a GPU?
  - map sub-problems to the pipeline
  - approximate:
    - indirect illumination
    - sub-surface scattering
    - caustics

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Global Illumination

- GPUs are *not* made for radiosity and ray tracing
  - random access to scene data
  - visibility/intersection computations
- pre-computed solutions
  - light maps, ambient occlusion, PRT, …

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What GPUs are made for…

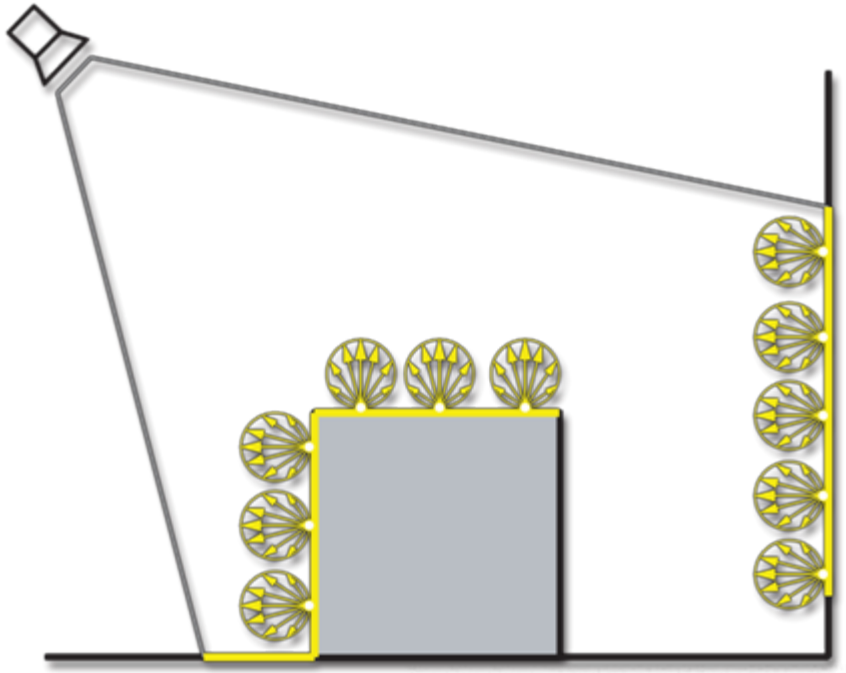
- fast rasterization of geometry
  - shadow map: sampling of lit surfaces
  - stream processing
- reformulate algorithms to exploit information from rasterized geometry
- first-order approximation of
  - one-bounce indirect illumination
  - caustics
  - not today: sub-surface scattering

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One-bounce indirect light

- single point light source
  - surfaces captured by a shadow map cause 1-bounce indirect illumination
  - extended shadow map stores required information



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Indirect Illumination

- every pixel is a small light source, ‘pixel light’
- generate extended shadow map (ESM)
  - depth value d_p
  - world space position x_p
  - light direction (normal n_p, glossy: reflection direction r_p)
  - reflected radiant flux Φ_p (+ glossiness)









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Point light sources

- radiant intensity into direction ω

$$I_p(\omega) = \Phi_p \max\{0, \langle n_p | \omega \rangle\}$$ [Watts]

- irradiance at a surface point due to pixel light p

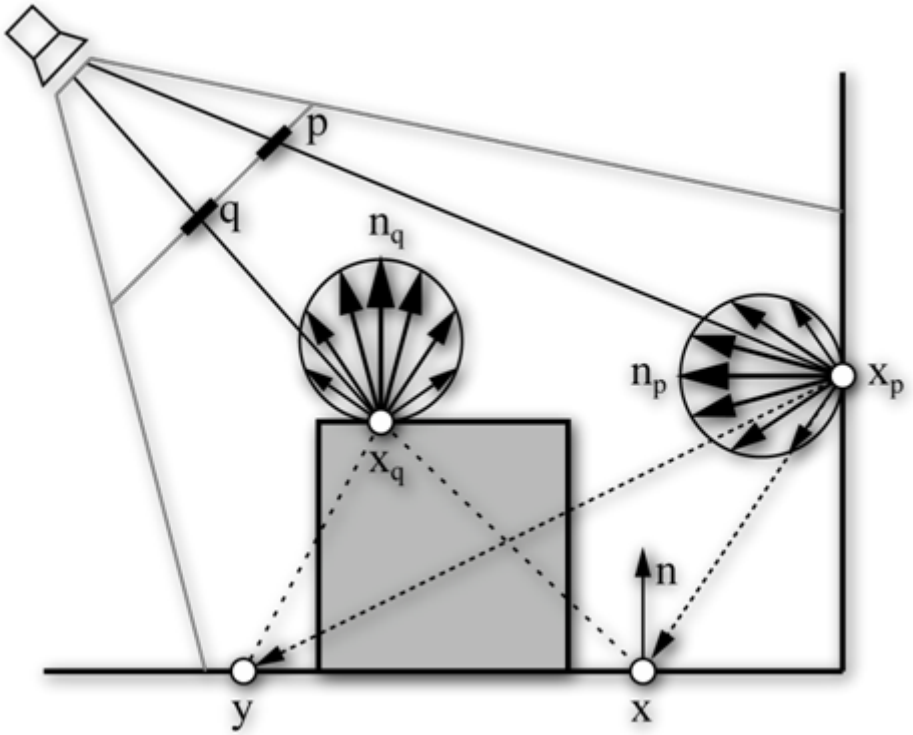
$$E_p(x,n) = \Phi_p \frac{\max\{0, \langle n_p | x - x_p \rangle\} \max\{0, \langle n | x_p - x \rangle\}}{||x - x_p||^4}$$

[Watts per m^2]

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Point light sources

- indirect irradiance from pixel lights $E(x,n) = \sum_{\text{pixels}p} E_p(x,n)$



⇨ doesn‘t consider occlusion

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What are we doing?

- ambient occlusion compensates for missing occlusion
- local illumination model:
  L=ambient+diffuse+specular
  ambient accounts for all global light transport
- now:
  L=(approx.+new_amb)+diff+spec
  closer to converged solution

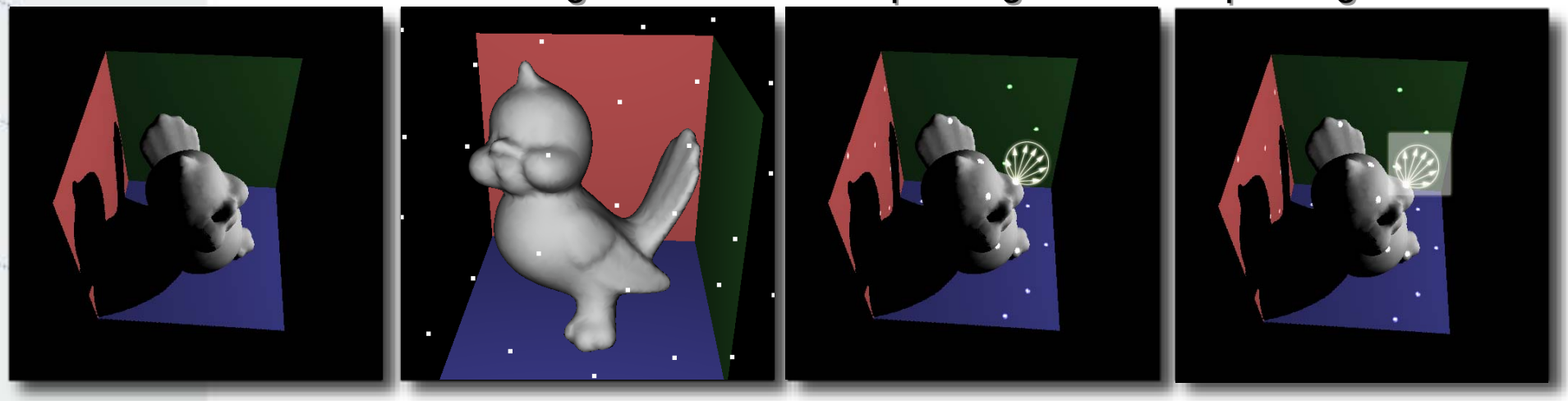


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Shooting

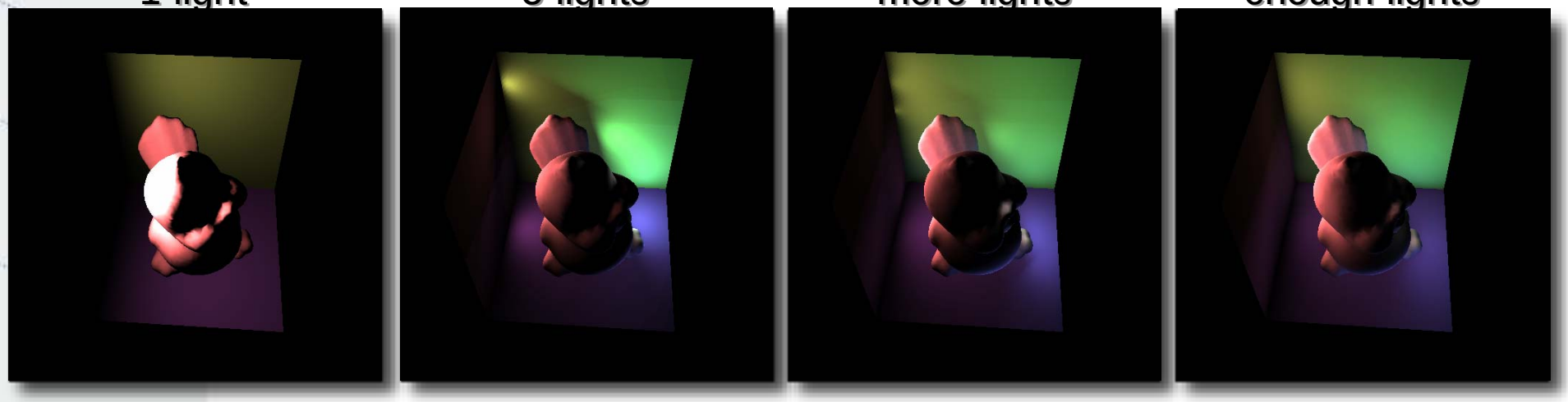
- select a subset of pixel lights
  - ESM provides sampling of lit surfaces
- account for their contribution
  - only significant nearby light source ~$1/d^2$
  - 2D AABB of significant region



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Shooting

- partial lighting computation is easy with deferred shading
- **splatting** in screen-space
  - light parameters per quad
  - surface parameters per pixel



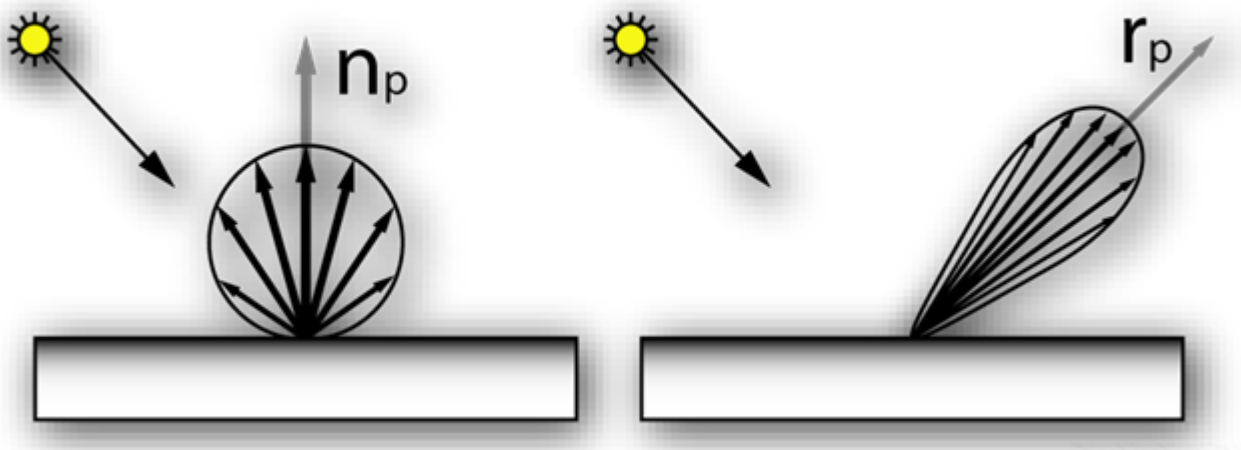
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Surface Type

- radiant intensity

  diffuse: $I_p(\omega)=\Phi_p \max\{0, n_p \circ \omega\}$

  glossy: $I_p(\omega)=\Phi_p \max\{0, r_p \circ \omega\}^P$



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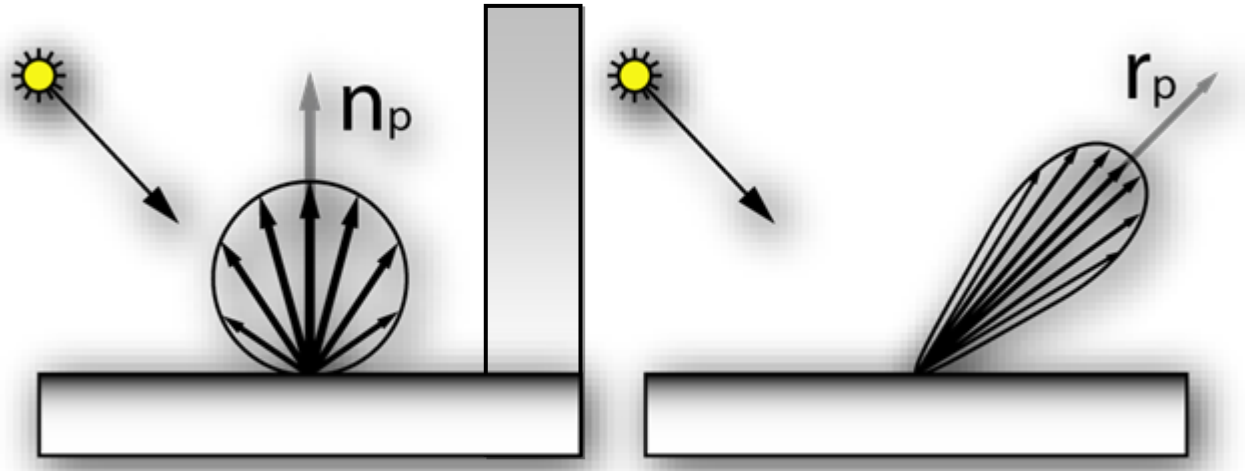
Surface Type

- radiant intensity

  diffuse: $I_p(\omega)=\Phi_p \max\{0, n_p \circ \omega\}$

  glossy: $I_p(\omega)=\Phi_p \max\{0, r_p \circ \omega\}^P$

  with distance: $P_p(\mathbf{x})=\min\{P, P\|\mathbf{x}-\mathbf{x}_p\|a\}$, $a>0$



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Spatial Attenuation

- radiance depends on distance:

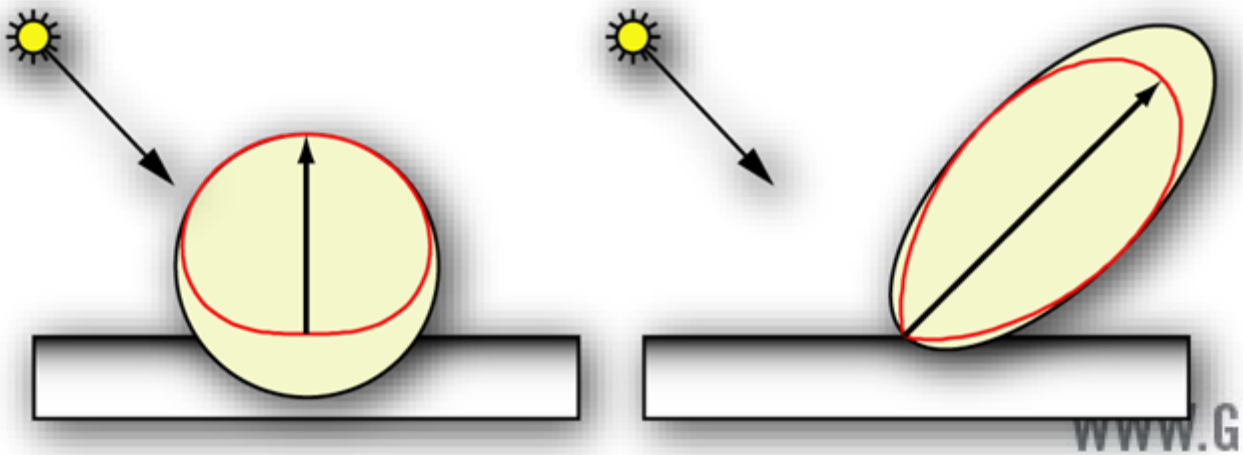
  $S(\alpha,d)=I_0\cos(\alpha)^n/d^2$

- iso-surfaces of radiance: $S(\alpha,d)=I_{low}$

  egg-shaped (diffuse n=1)

  similar to phong lobe (glossy n>1)

  choose threshold I_{low}, bound significant region

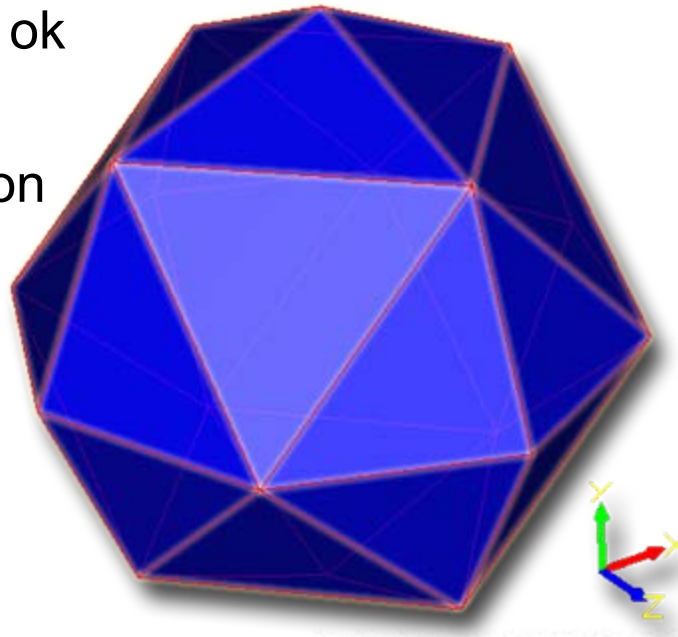


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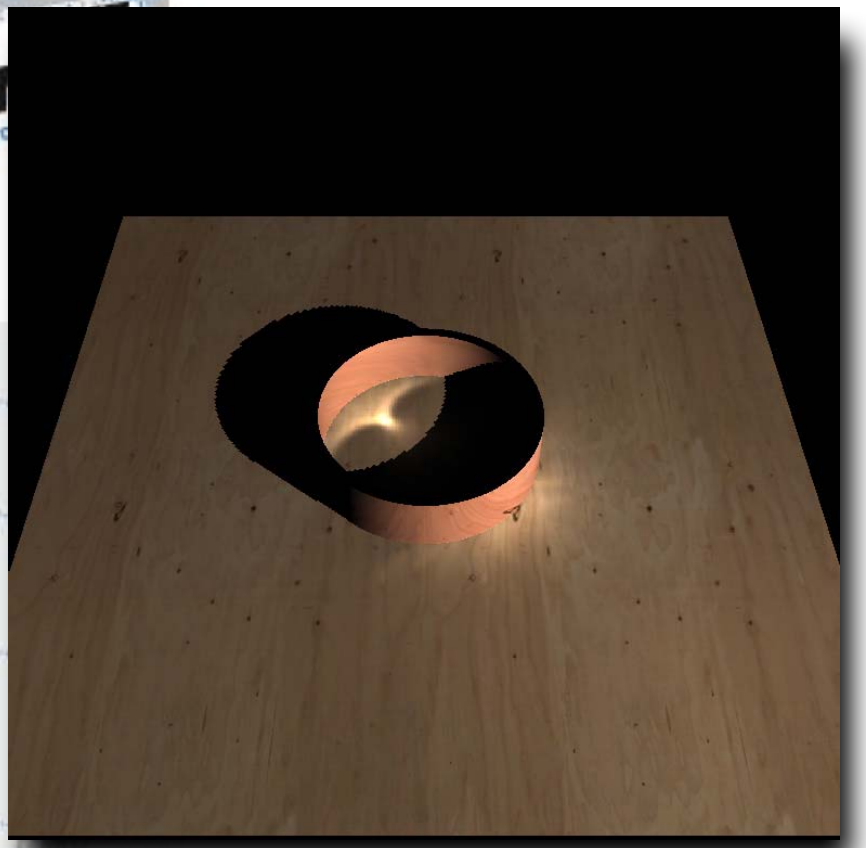
Tighter Bounding Geometry

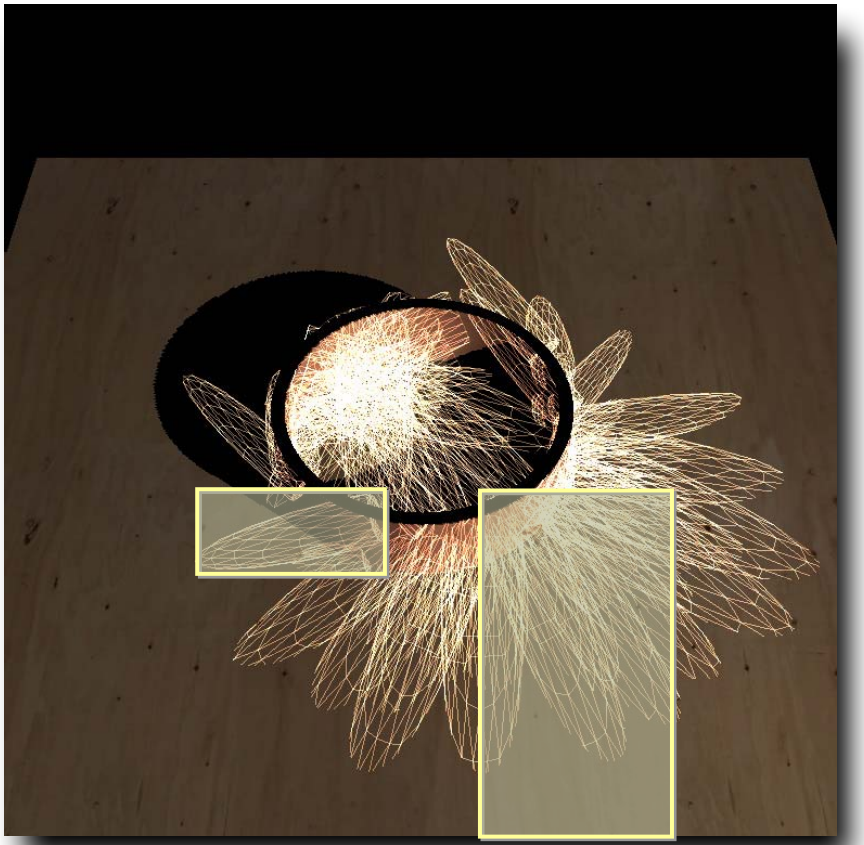
- tighter bounding geometry than 2D AABB
  - reduce fragments, more geometry
  - practicable: render ellipsoids
    - coarse meshes, but that‘s ok
    - real geometry: depth test
    - see ShaderX5 for details on ellipsoid approximation



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Tighter Bounding Geometry



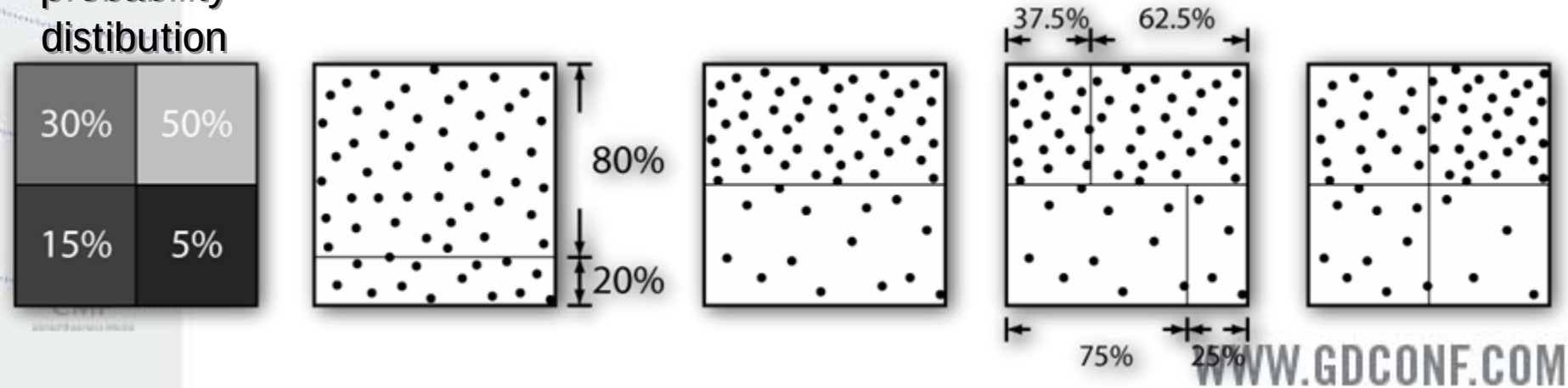


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More optimizations…

- importance sampling (details: see links)
  - place light sources – but not everywhere
  - according to
    - flux distribution
    - BRDF: more lights on glossy surfaces

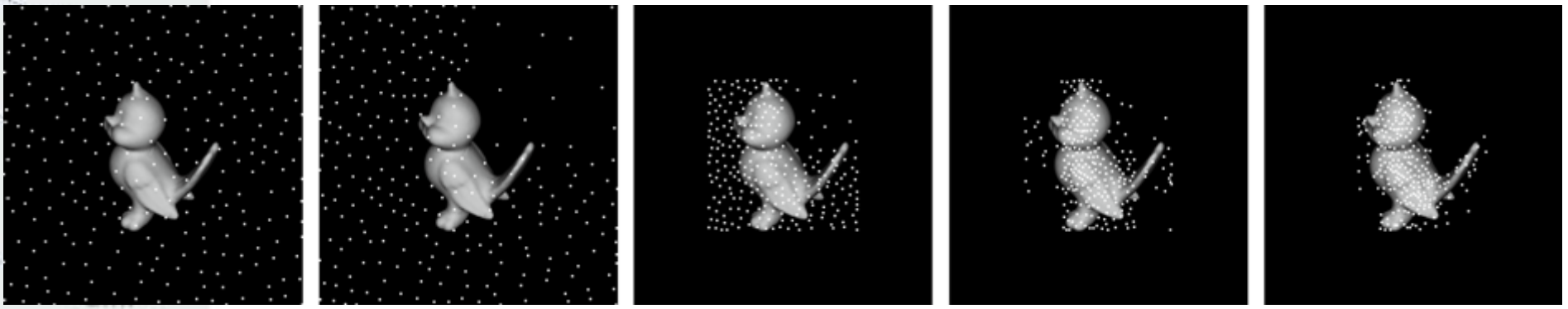
mip-map of probability distibution



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More optimizations…

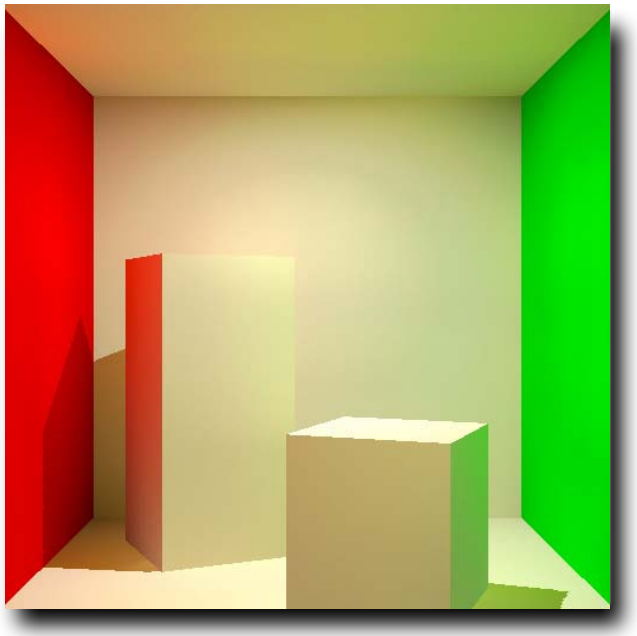
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    - flux distribution
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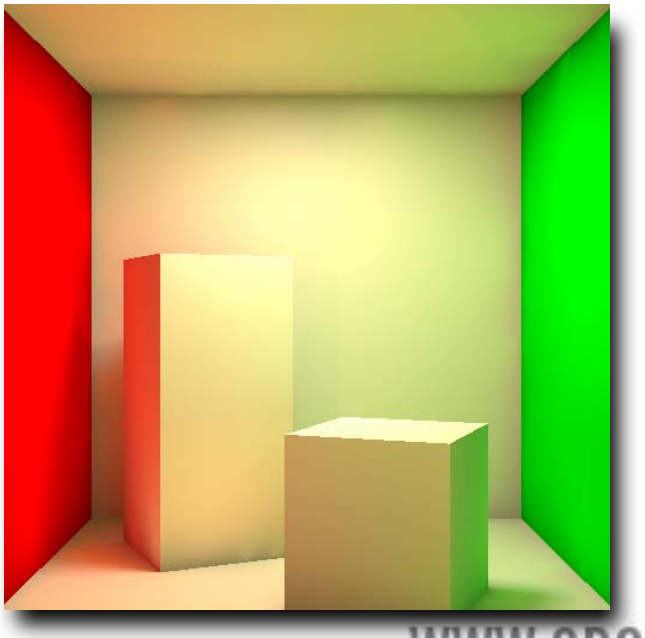
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Without ESMs

- often bsp/kd-tree of geometry available, e.g. for collision detection
- ray casting (a few hundred rays)



splatting w/ multiple bounces



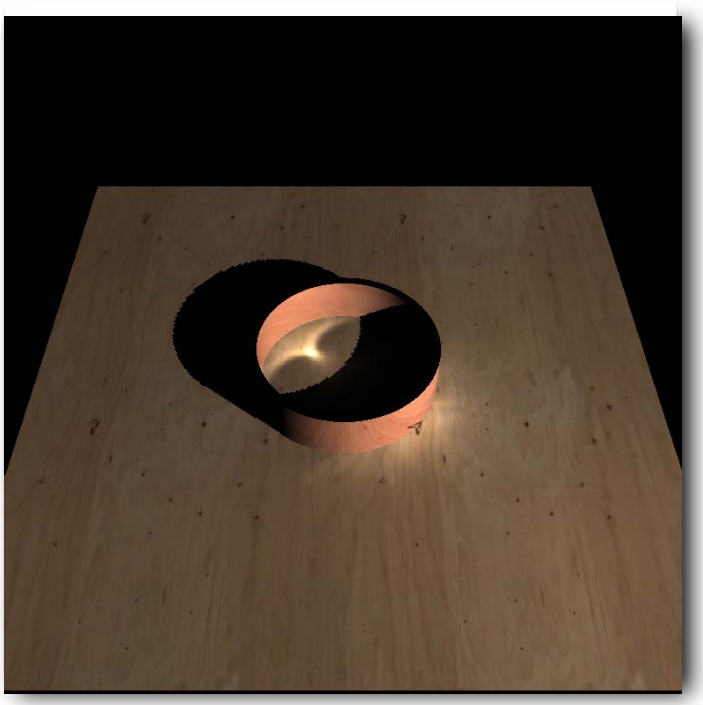
reference w/ soft-shadows

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Without ESMs

- pre-compute a set of pixel lights
  - compute direct illumination
  - splat indirect lighting
- works well for
  special objects



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Implementation (PC/GPU)

- render passes for
  - extended shadow map
  - deferred shading
  - save bandwidth
- shader model 3 (or render-to-vertex-array)
- if dynamic, sampling pattern stored as texture
  - importance sampling modifies this texture

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Geometry Processing (VS3.0)

- input:
  - sphere mesh (duplicated, better instancing)
    - to retrieve pixel light data:
      ESM coord or sampling pattern texture coord
- vertex shader:
  - read light parameters from ESM
  - construct a tangent space and elliptical approximation
    - transform mesh accordingly
  - compute texture coords for deferred shading buffers

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Fragment Processing

```
// get surface info for this pixel
float4 wsPos     = tex2Dproj( … );
float4 normal    = tex2Dproj( … ) * 2 - 1;

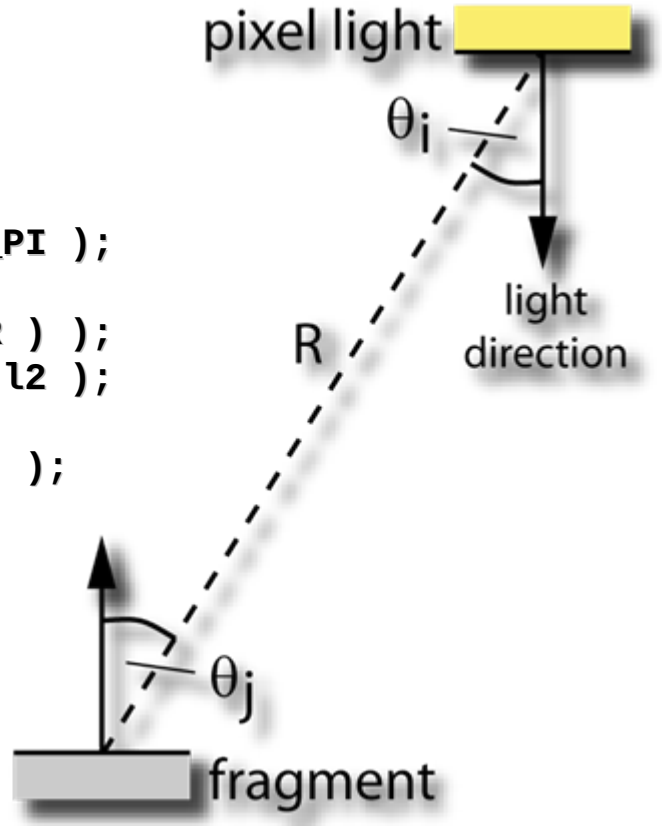
R  = lightPos - wsPos.xyz;
l2 = dot( R, R );
R *= rsqrt( l2 );

lR = 1.0f / ( bias + l2 * INV_WS_SIZE2_PI );

cosThetaI = saturate( dot( lightDir, -R ) );
cosThetaI = pow( cosThetaI, phongExp * l2 );

cosThetaJ = saturate( dot( normal,  R ) );

return lightFlux * cosThetaI *
       cosThetaJ * lR;
```



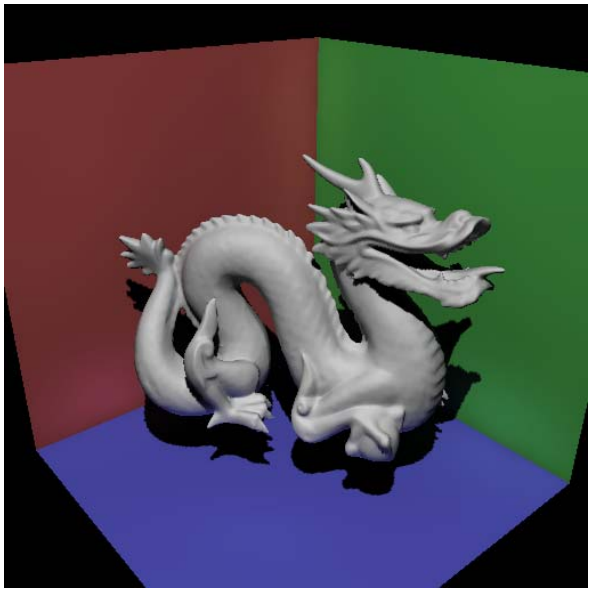
apply surface color afterwards!

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Results

- performance depends on
  - basic rule: more indirect light, more work
  - materials: diffuse surface are more expensive!
  - ⇨ highly view-dependent





GeForce 8800GTX: 130-250fps

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Results

- scalability
  - quality vs. speed
  - distance / #lights
- deferred shading



4096 light sources

GeForce 6800GT: ~100fps

GeForce 8800GTX: 150-400fps

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Detailed Caustics

- approximate refractions
  - rays change direction on interfaces (Snell's law)
  - simple methods consider one surface only
- refractive geometry: light passes through at least two surfaces
  - how determine the location of the second refraction?
  - image-space approaches, Wyman et al.



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First Refraction

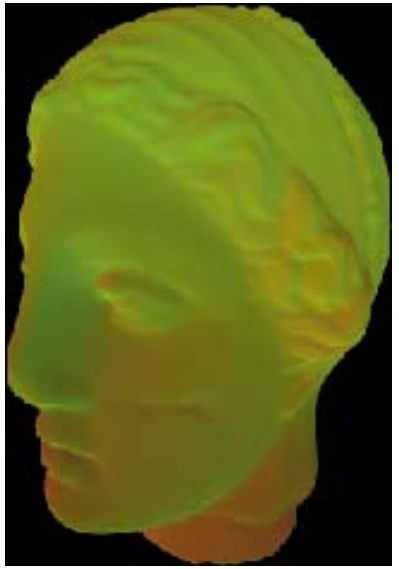
- simple rasterizer job



world space position p_1



normal



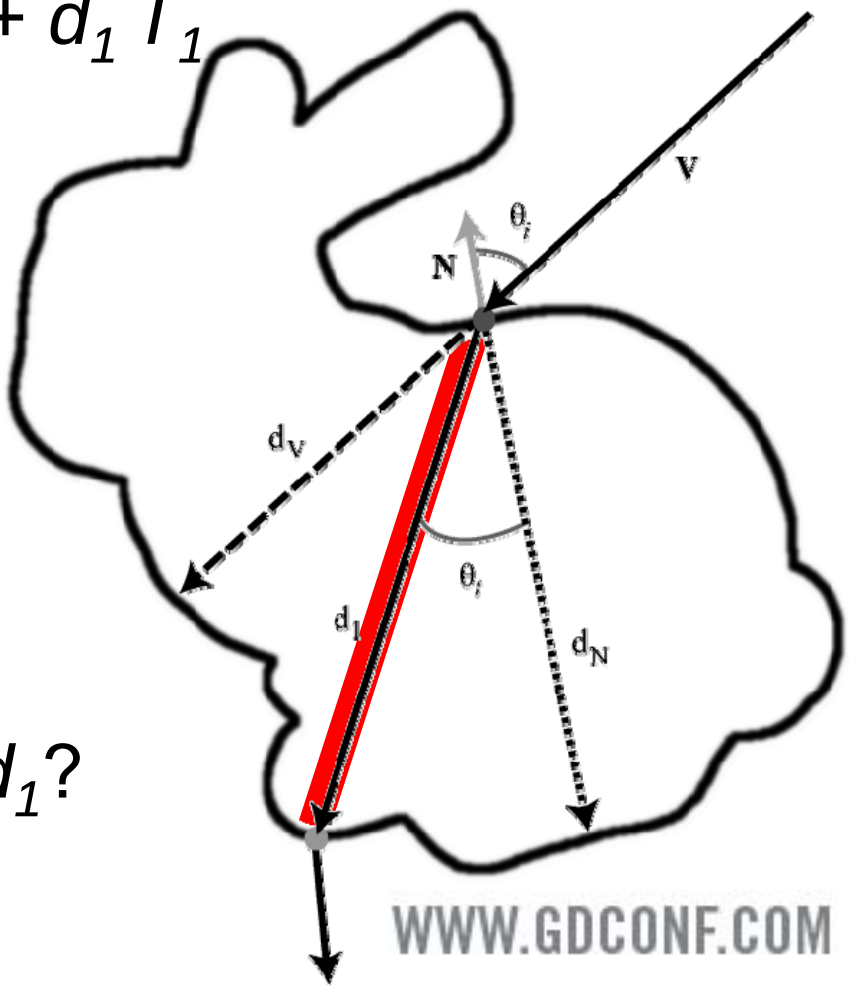
refracted direction T_1

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Second Refraction

- second refraction $p_1 + d_1 T_1$



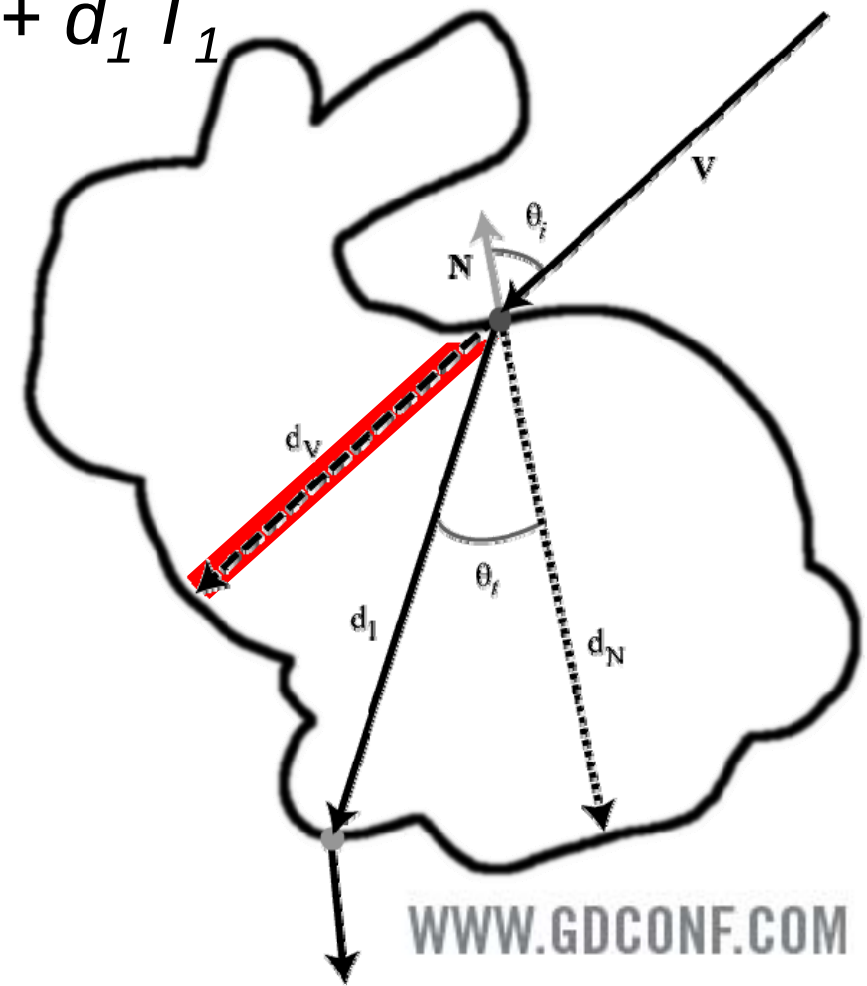
- how to approximate d_1?

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Extreme Case 1

- second refraction $p_1 + d_1 T_1$
- depth peeling d_v
- refraction indices
  - small: $n_t \approx n_i$
    - T_1 bends to d_v



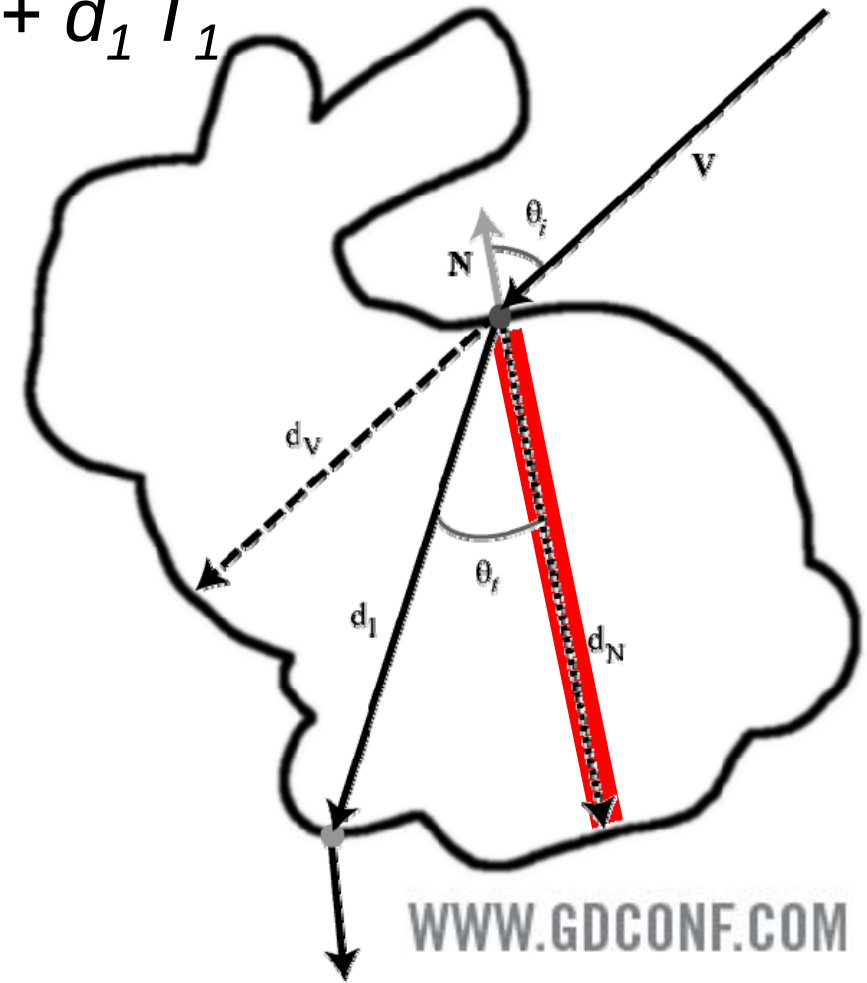
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Extreme Case 2

- second refraction $p_1 + d_1 T_1$
- depth peeling d_v
- pre-computed d_N

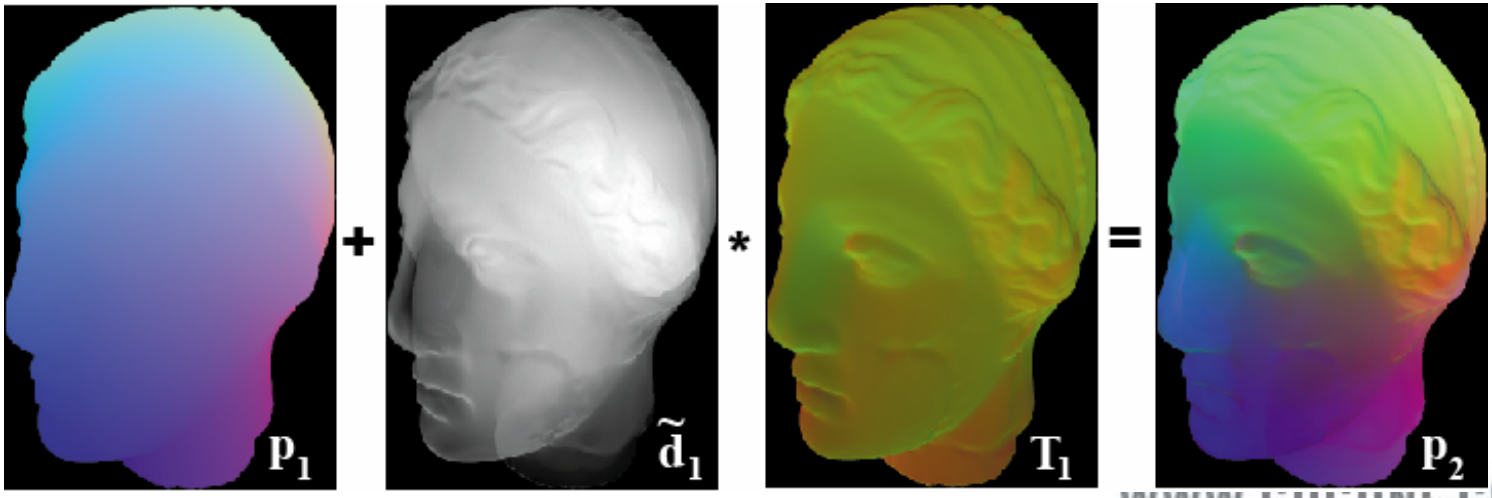
- refraction indices
  - small: $n_t \approx n_i$
    - T_1 bends to d_v
  - large: $n_t >> n_i$
    - T_1 bends to d_N



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Second Refraction by Interpolation

- interpolate based on angles between V, N and T_1: $$\tilde{d}_1 = \frac{\theta_t}{\theta_i} d_V + \left(1 - \frac{\theta_t}{\theta_i}\right) d_N$$
- get second refraction at $P_2 = p_1 + \tilde{d}_1 T_1$

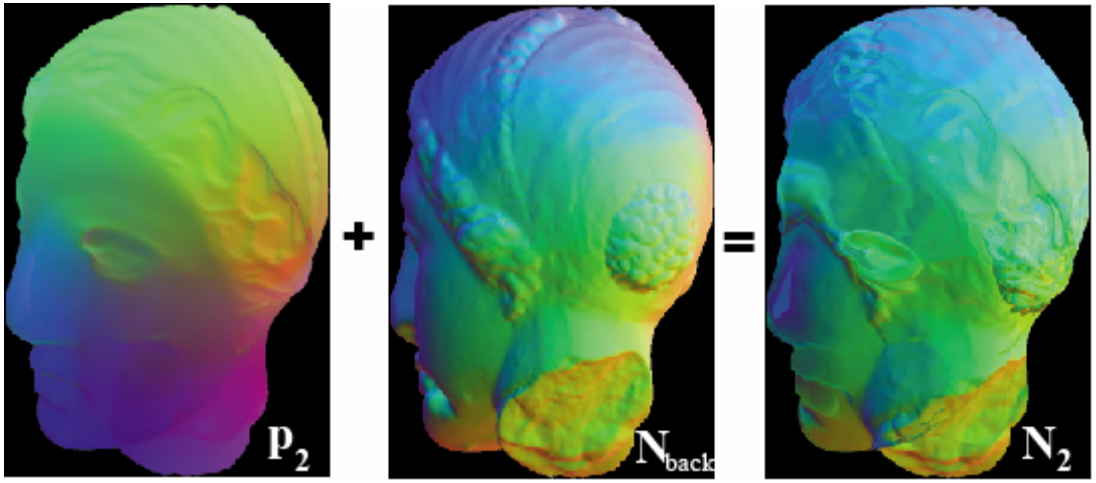


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Normals

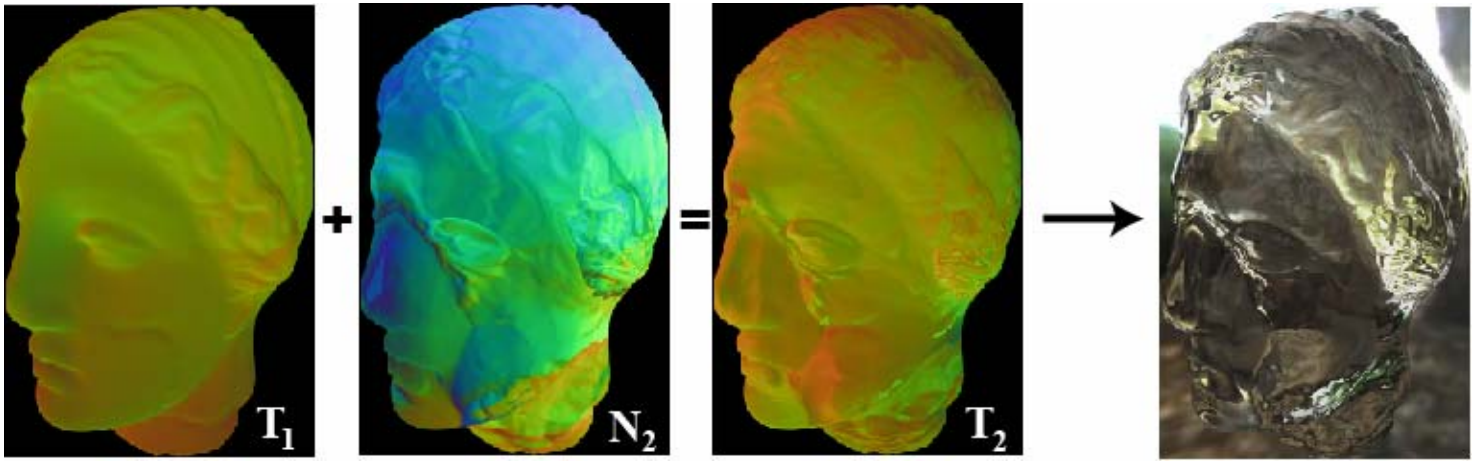
- normal at second refraction at P_2
  - render back facing normals together with d_v
  - project P_2 to retrieve normal



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Almost there…

- apply Snell's law a second time



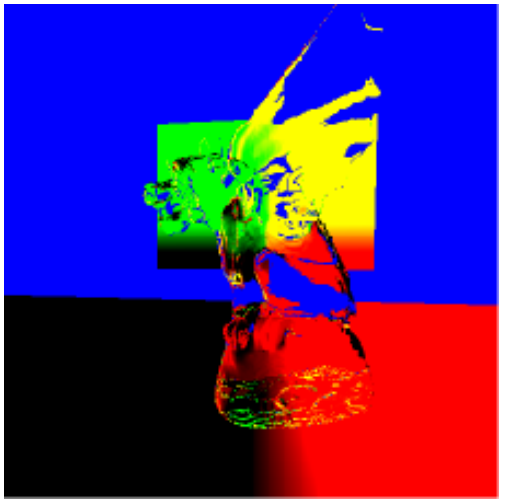
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Caustics

- and… how can we render caustics?
  - render refracted image for light view
  - store world space position, not surface color!



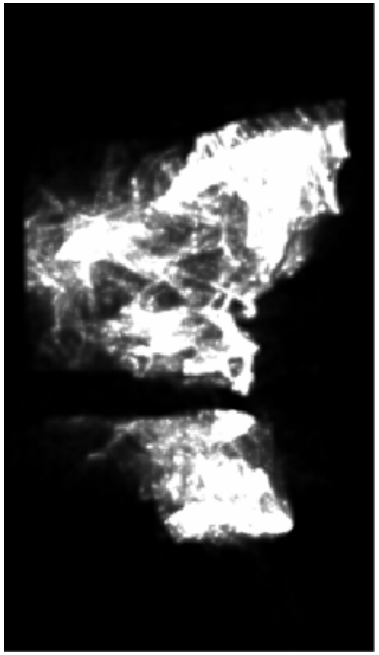


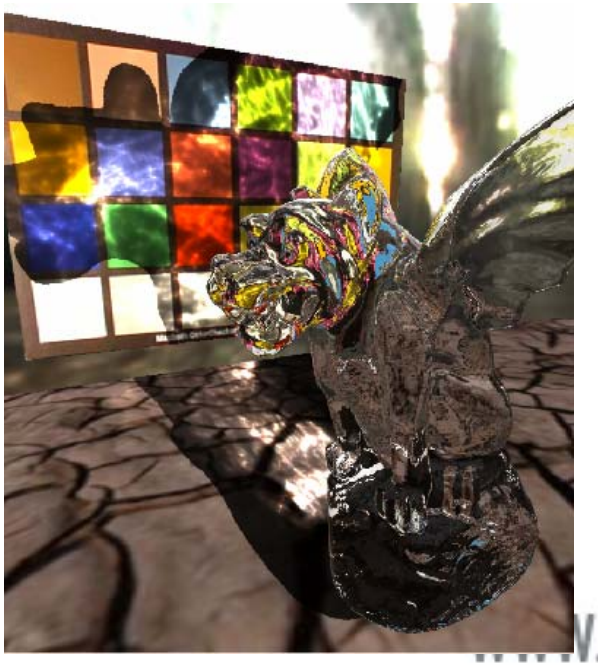


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Caustics

- world space position tells us, where “caustic photons” hit surfaces
- generate caustic map by rendering points with additive blending



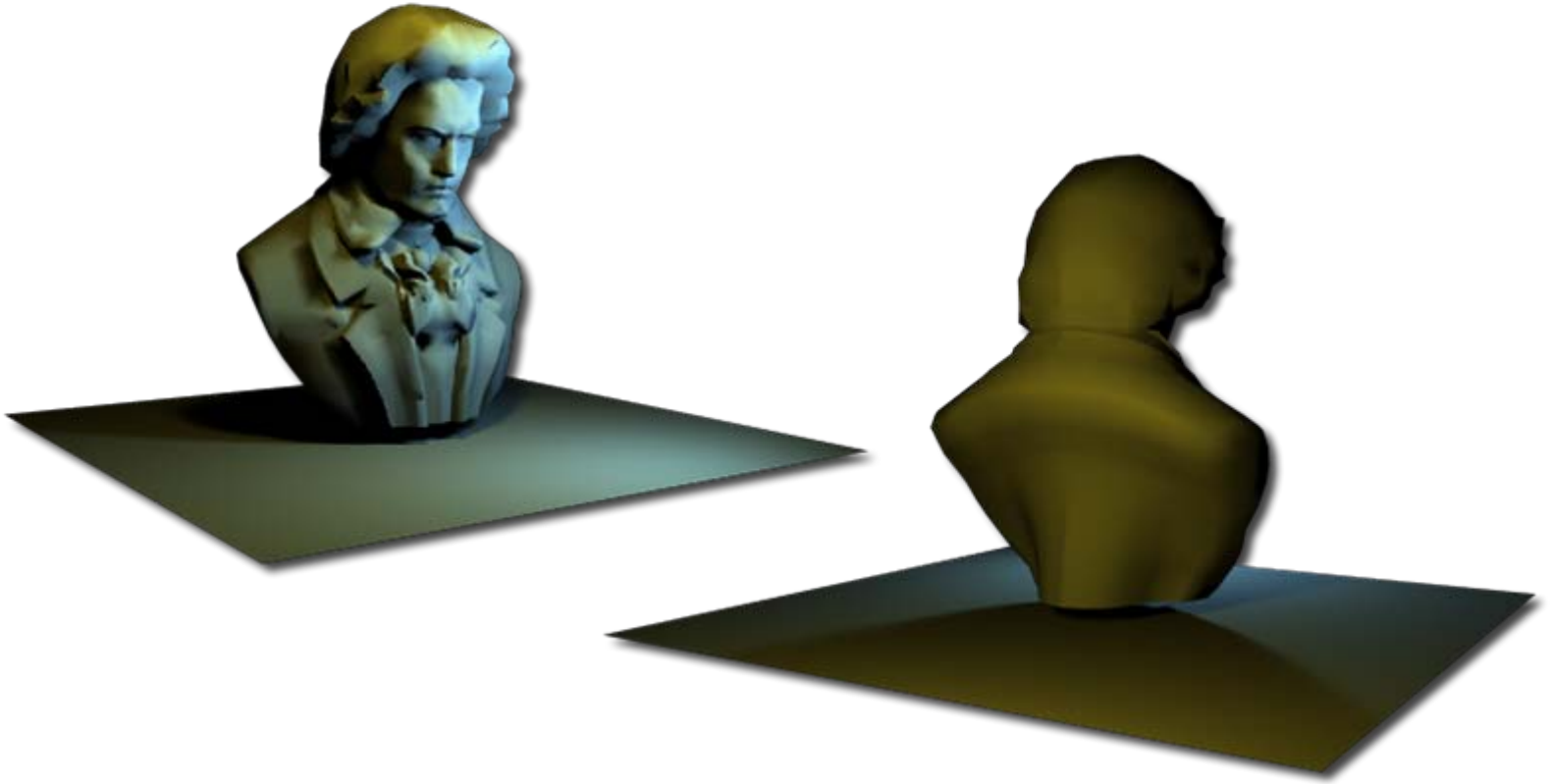


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Why two-sided refractions?

- refractive Beethoven

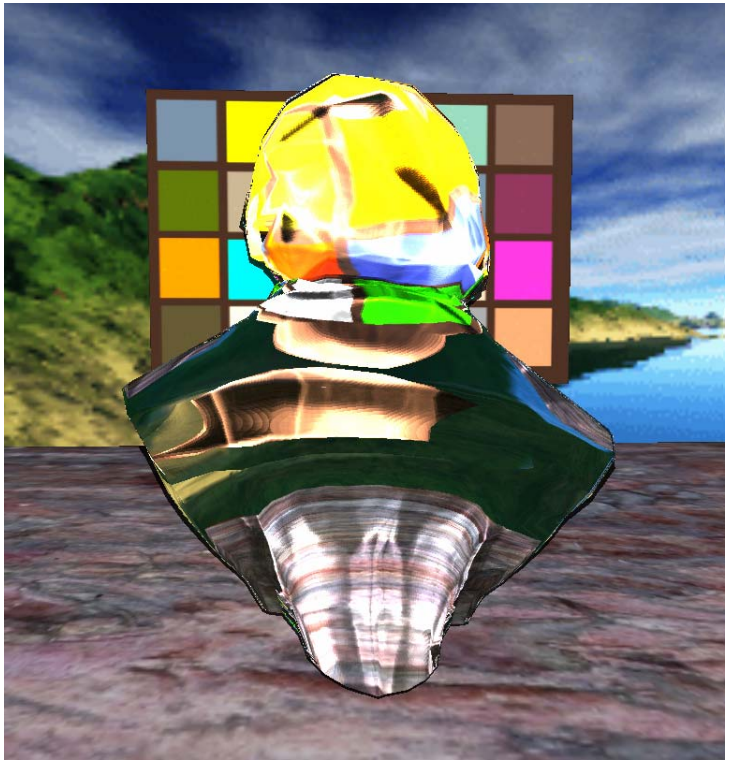


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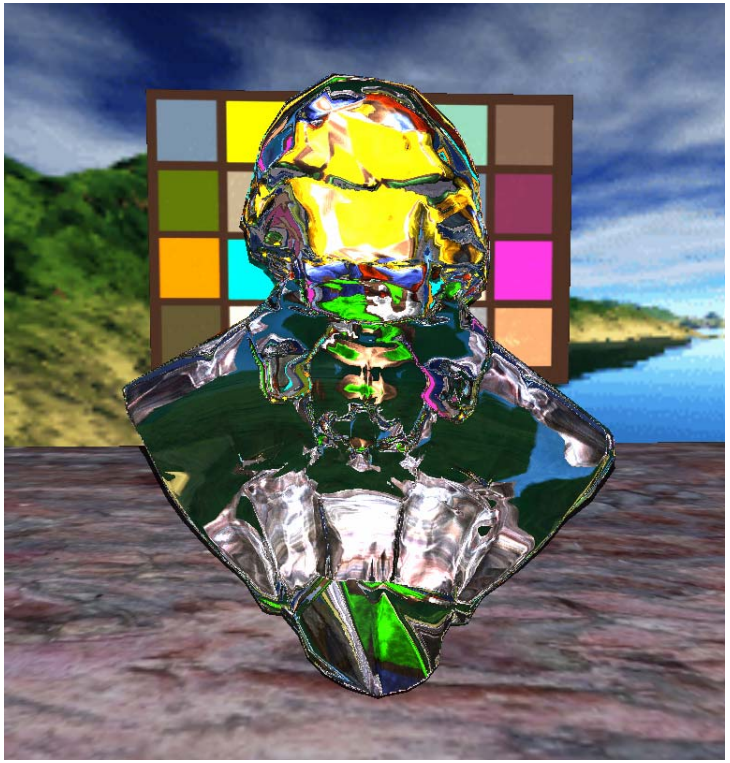
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Why two-sided refractions?

- missing detail from back sides



single-sided



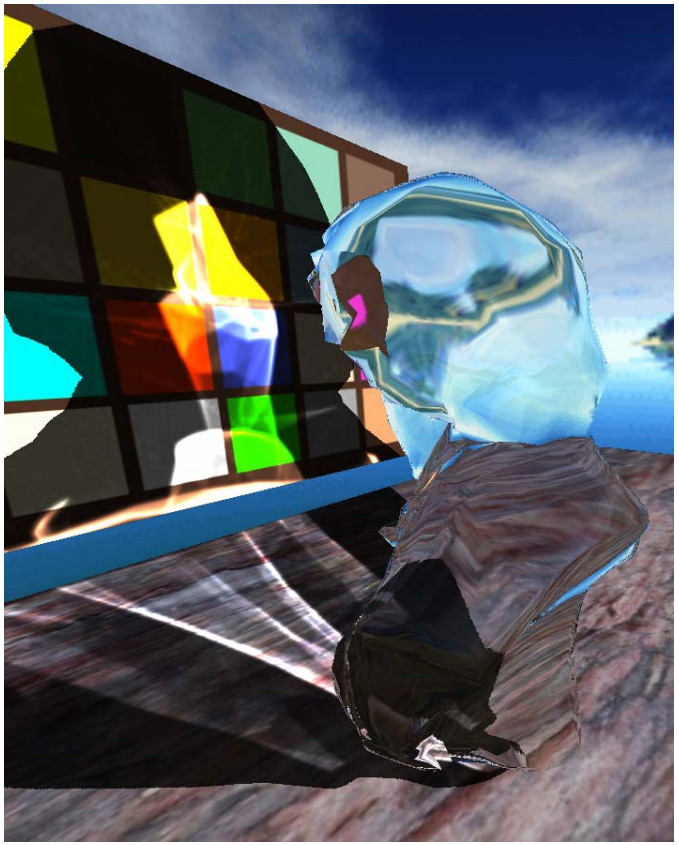
double-sided

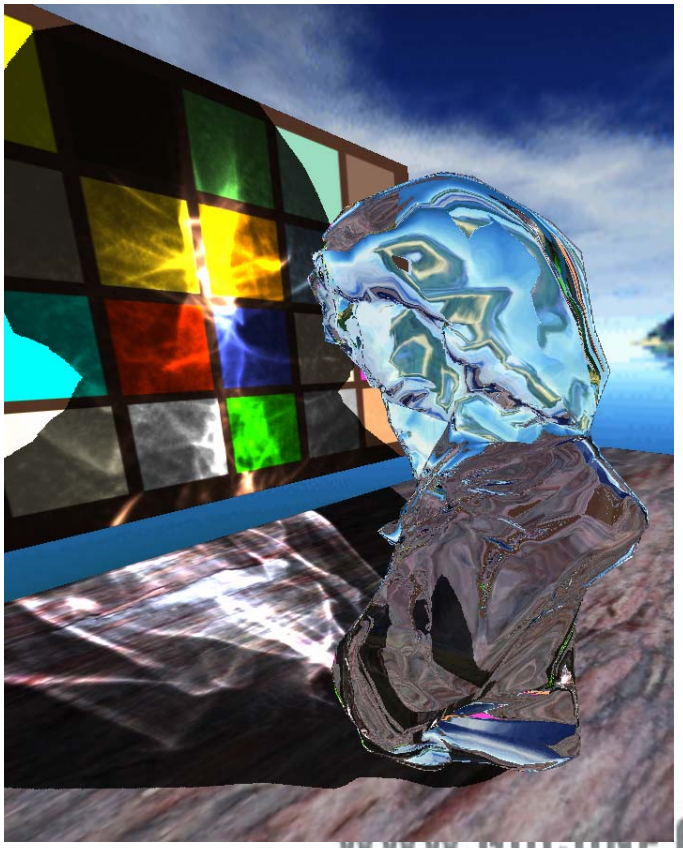
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Why two-sided refractions?

- light focusing/scattering





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Results

- performance bound by fragment processing and number of photons
  - 200fps for 256^2 (noisy), 75fps for 512^2 and 22fps for $1K^2$

  temporal filtering and more involved splatting helps

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References

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Thank you

additional info, links, code etc:

http://www-sop.inria.fr/reves/dachsbacher/GDC07/

http://www.coretechniques.info

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