

# CS-C3100 Computer Graphics

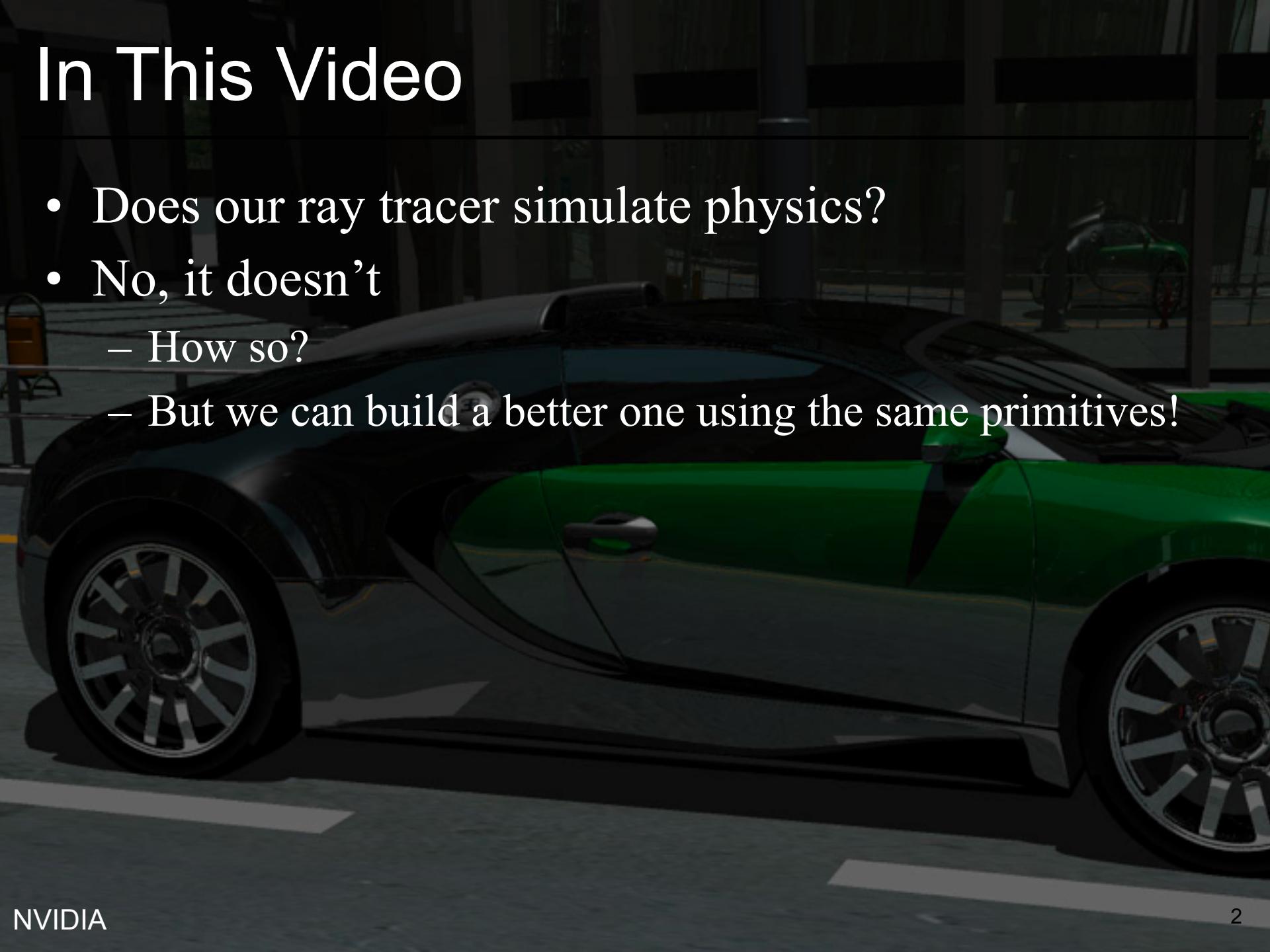
## 13.3 Analysing Our Simple Ray Tracer



Jaakko Lehtinen  
with lots of material from Frédo Durand

# In This Video

- Does our ray tracer simulate physics?
- No, it doesn't
  - How so?
  - But we can build a better one using the same primitives!



# Today – Ray Tracing

(Indirect illumination)

Reflections

Refractions

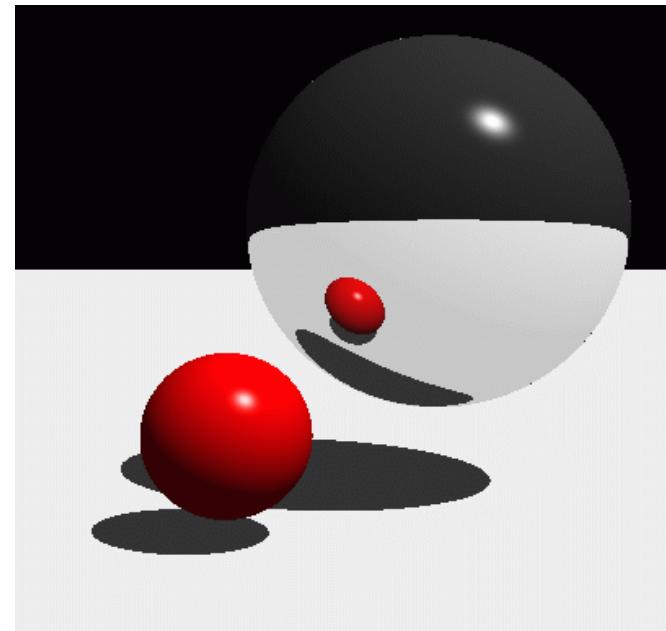
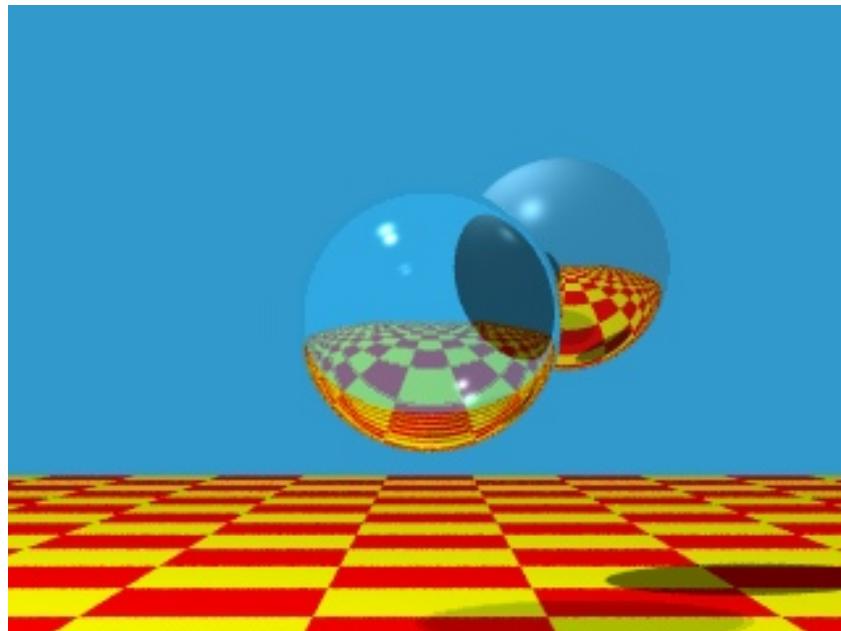
Shadows

(Caustics)

# Let's Pause for a Moment...

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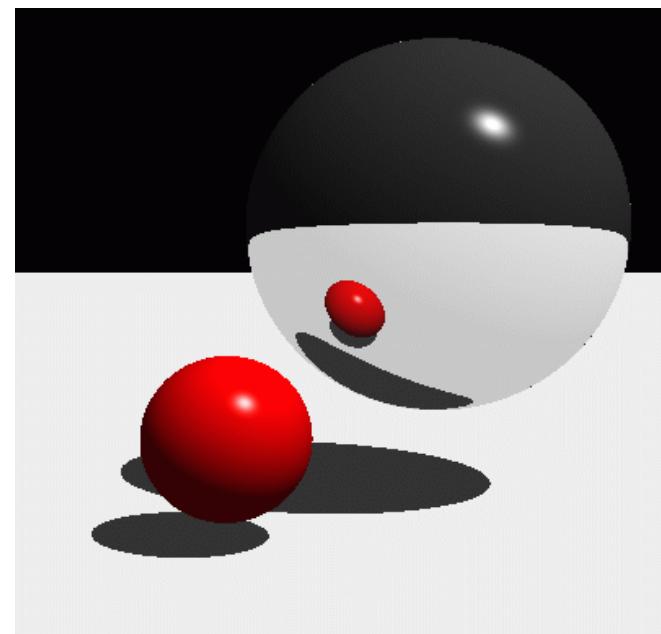
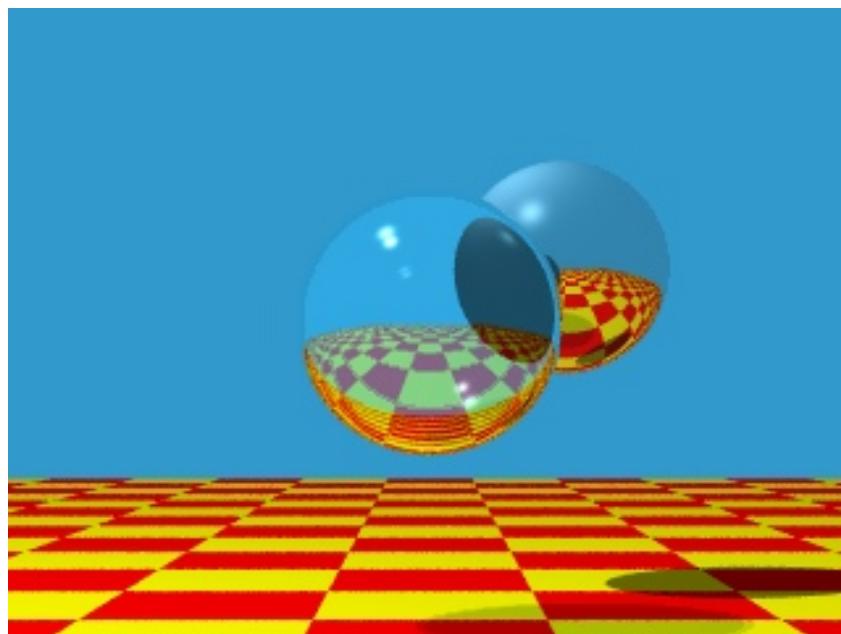
- Do these pictures look real?
- At least they don't look like the previous slide..



# What's Wrong then?

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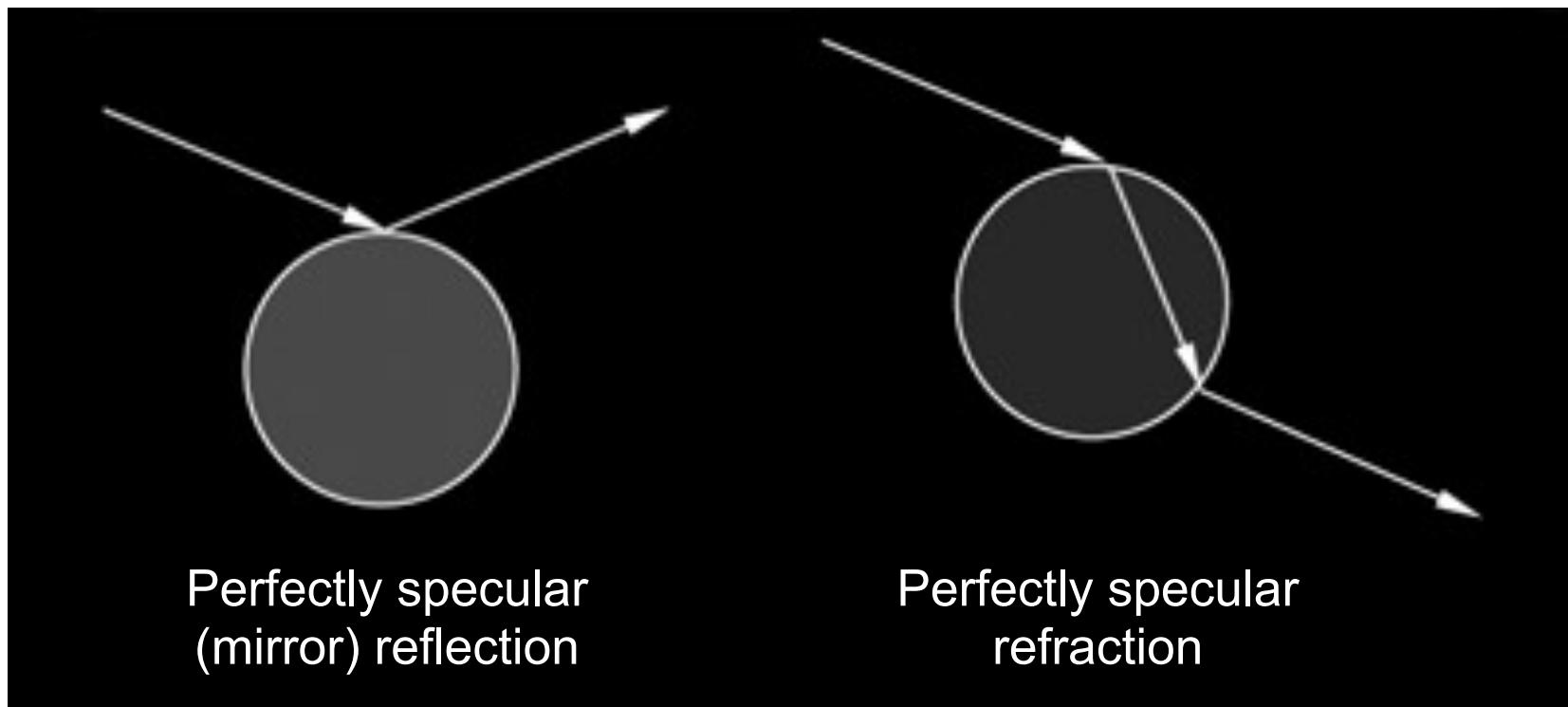
- No surface is a perfect mirror,  
no material interface perfectly smooth



# What's Wrong then?

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- No surface is a perfect mirror,  
no material interface perfectly smooth

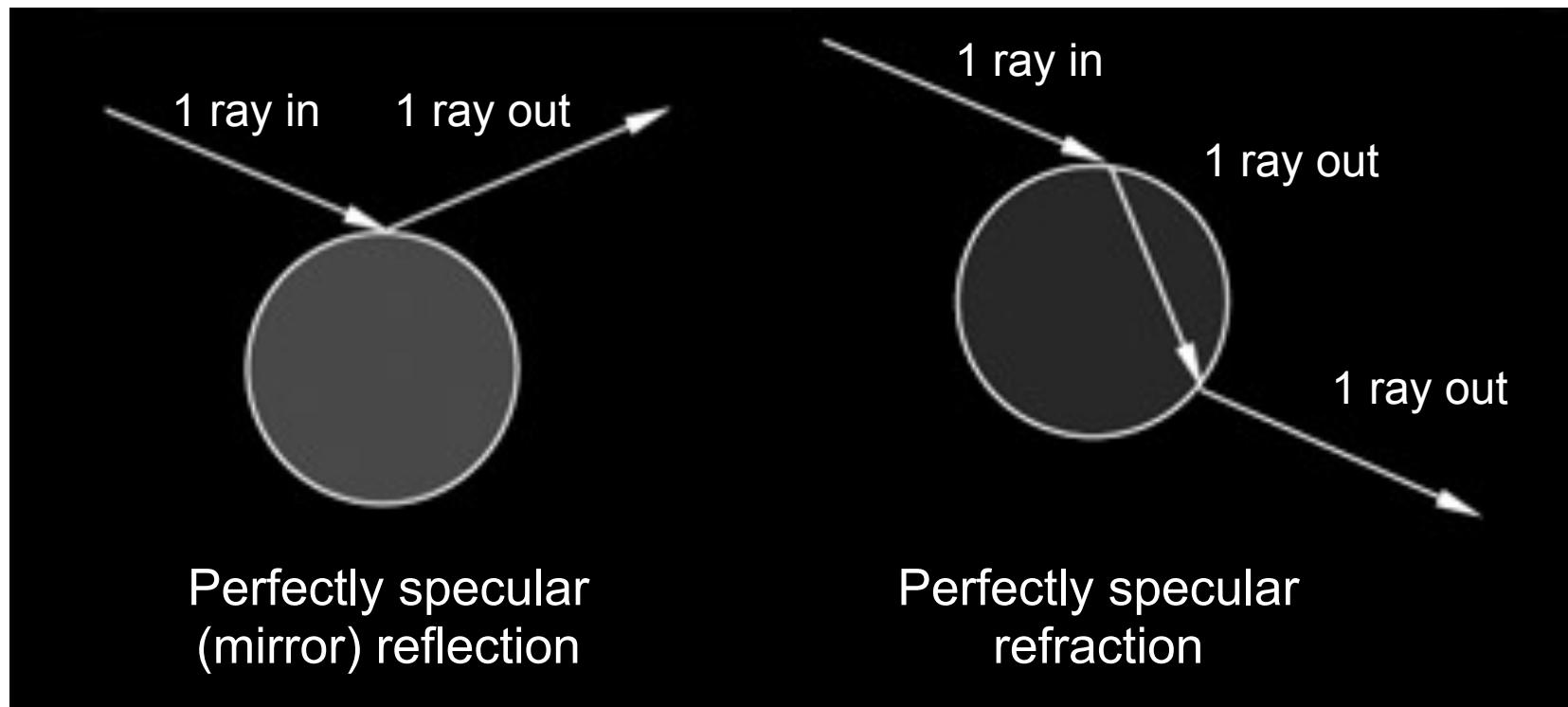


Adapted from [blender.org](http://blender.org)

# What's Wrong then?

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- No surface is a perfect mirror,  
no material interface perfectly smooth

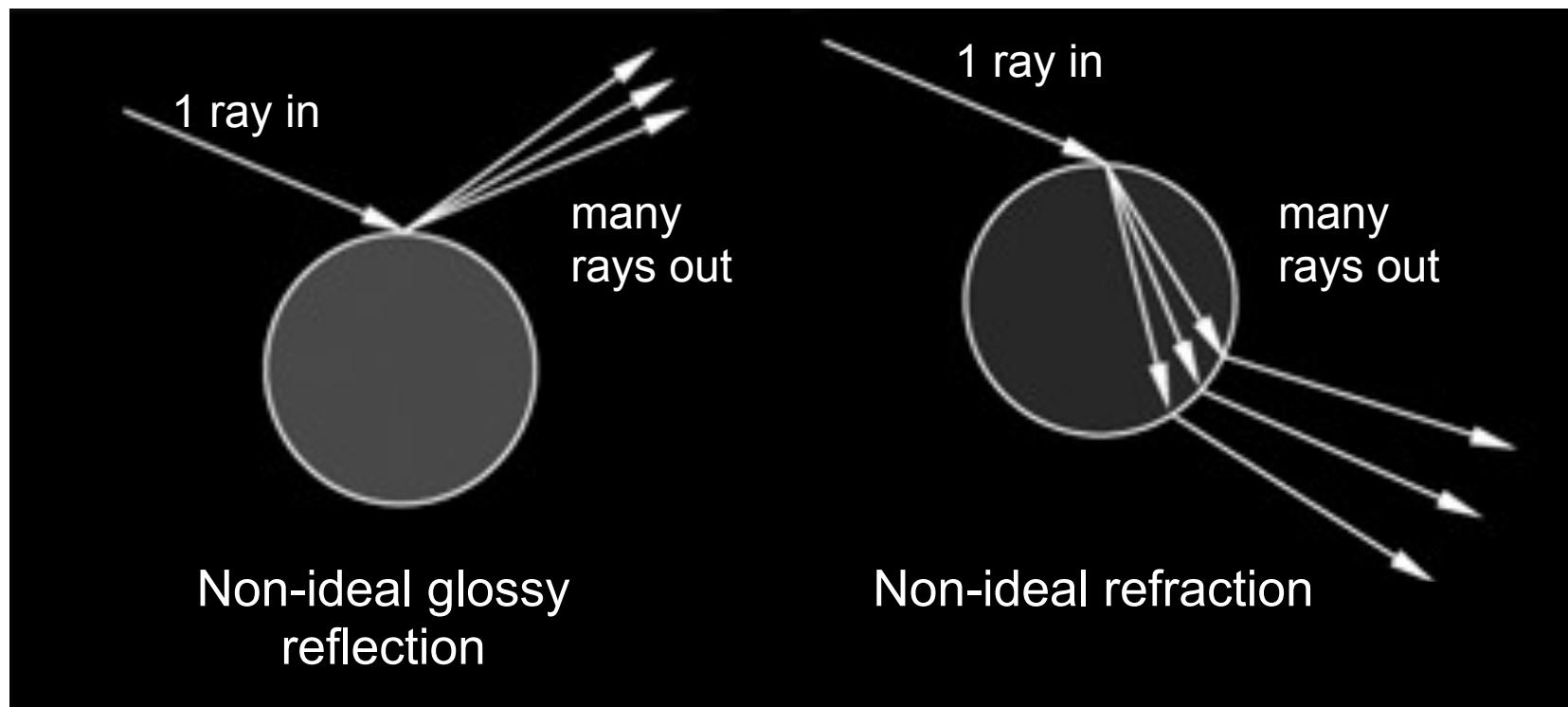


Adapted from [blender.org](http://blender.org)

# Non-Ideal Reflection/Refraction

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- No surface is a perfect mirror,  
no material interface perfectly smooth



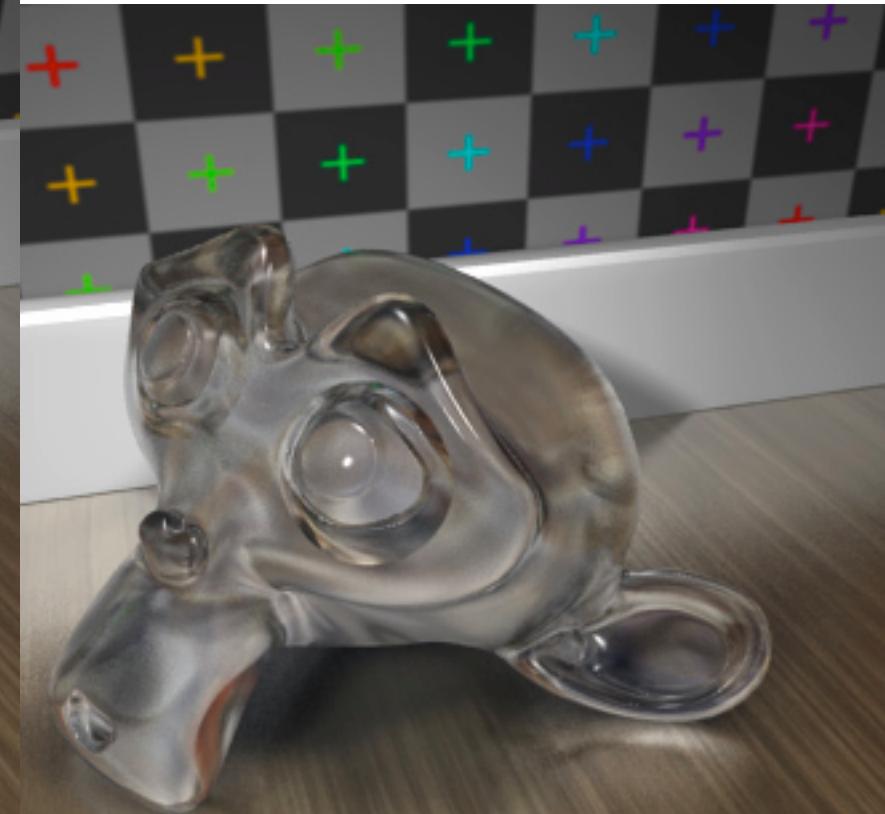
Adapted from [blender.org](http://blender.org)

# Non-Ideal Reflection/Refraction

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Glossy (as opposed to mirror) reflection

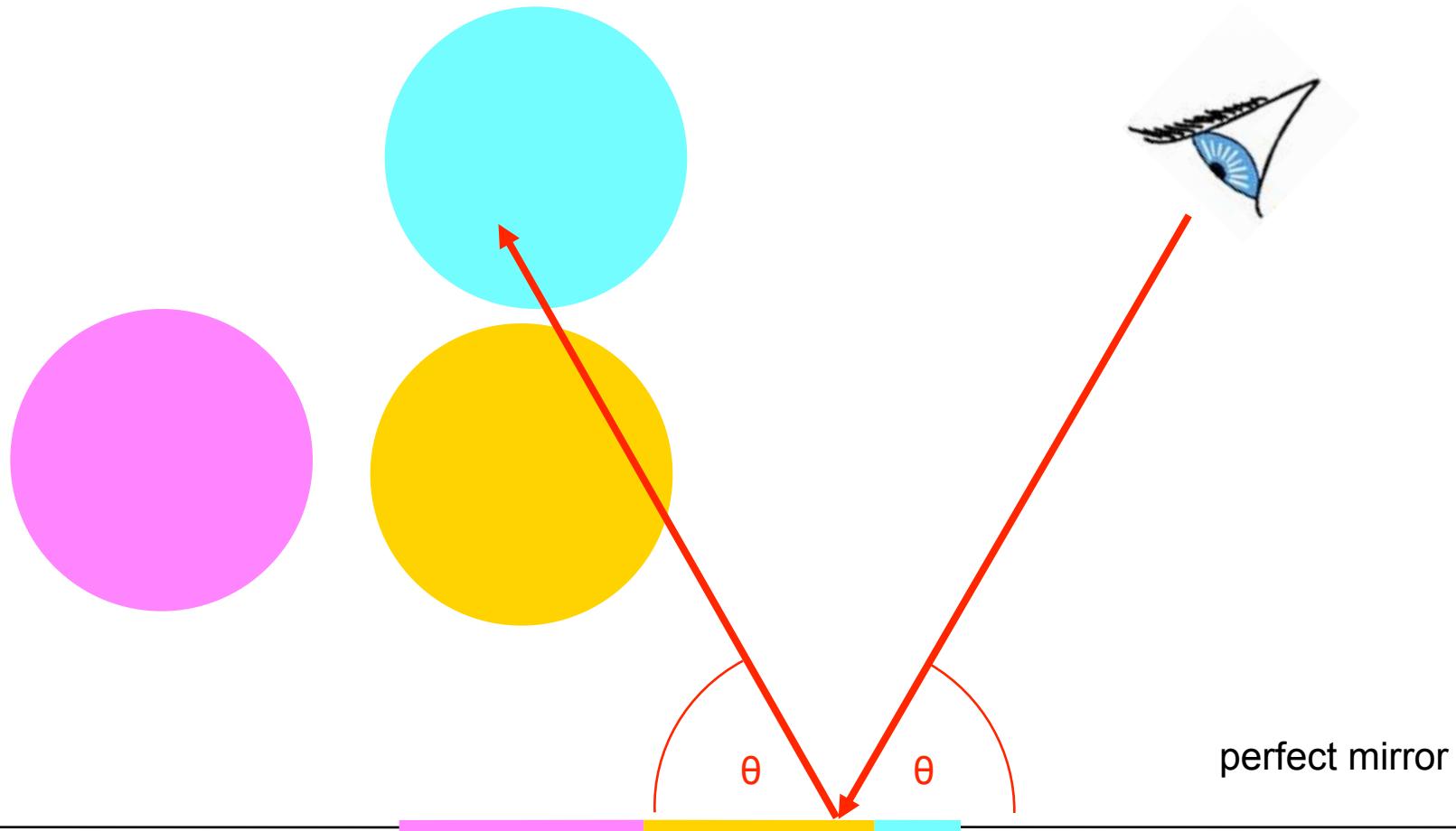


Glossy (as opposed to perfect) refraction

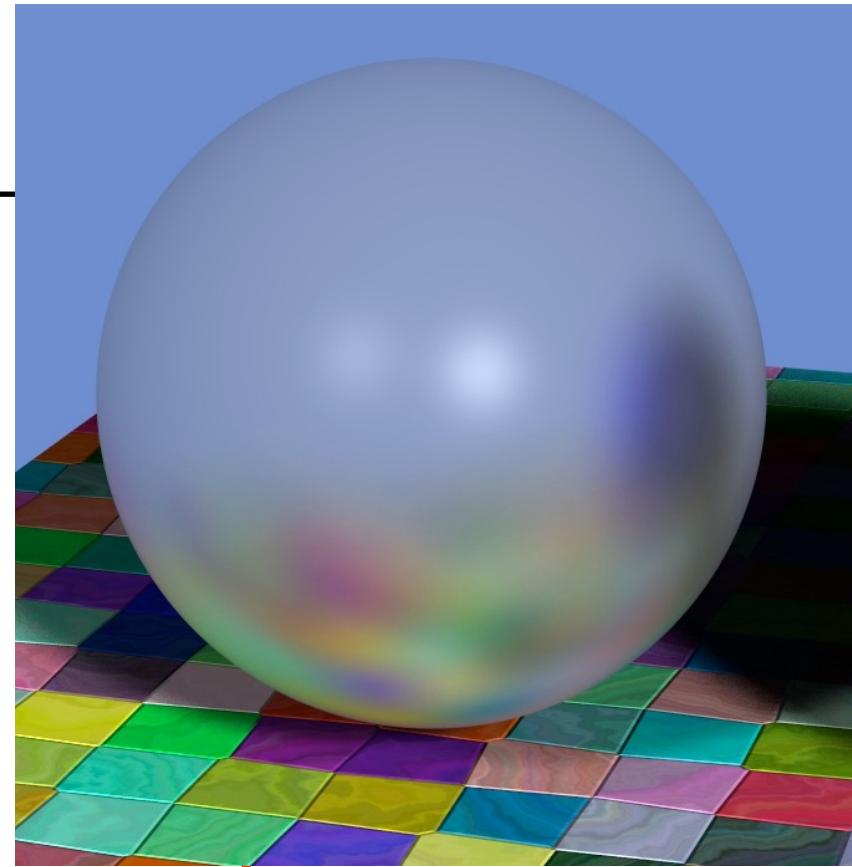
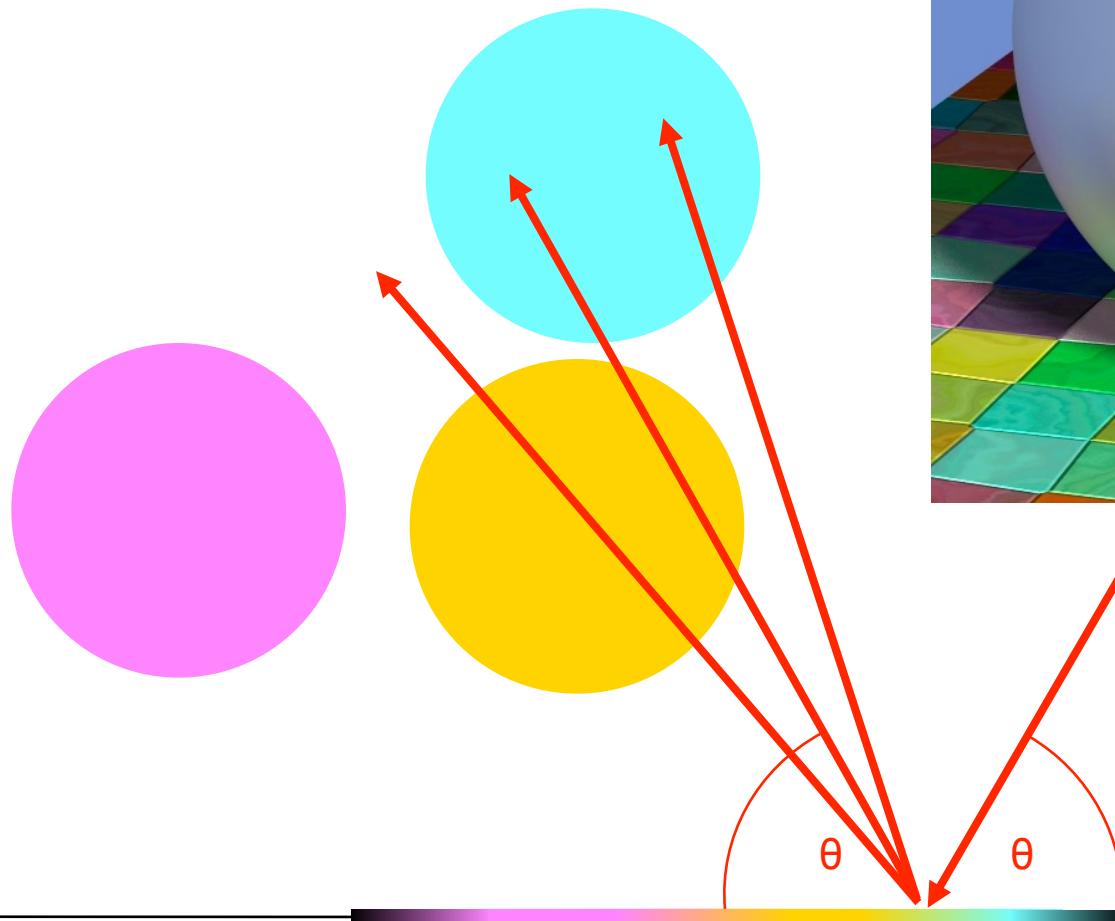
# Reflection

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- One reflection ray per intersection



# Glossy Reflection

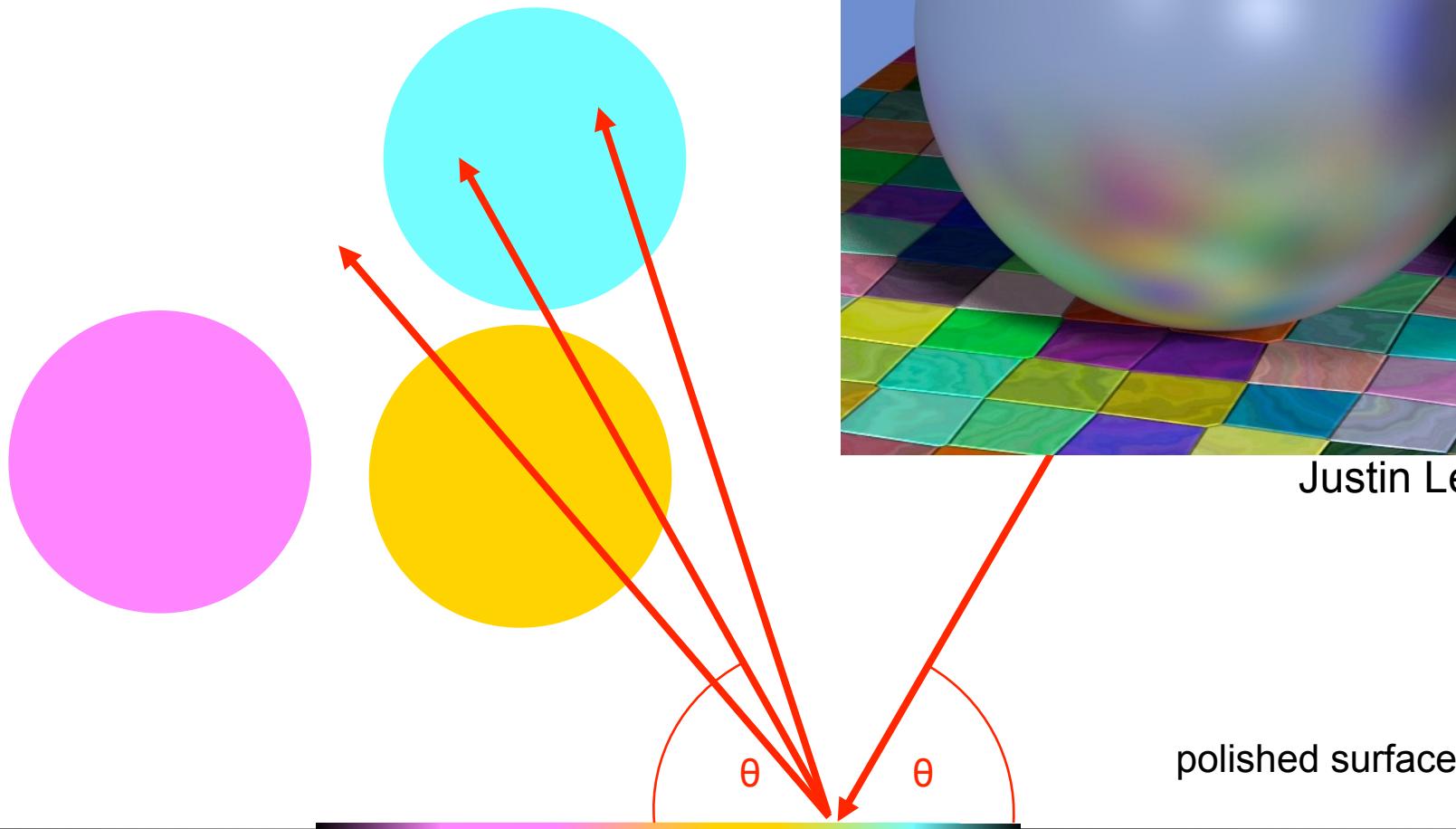


Justin Legakis

polished surface

# Glossy Reflection

- Multiple reflection rays

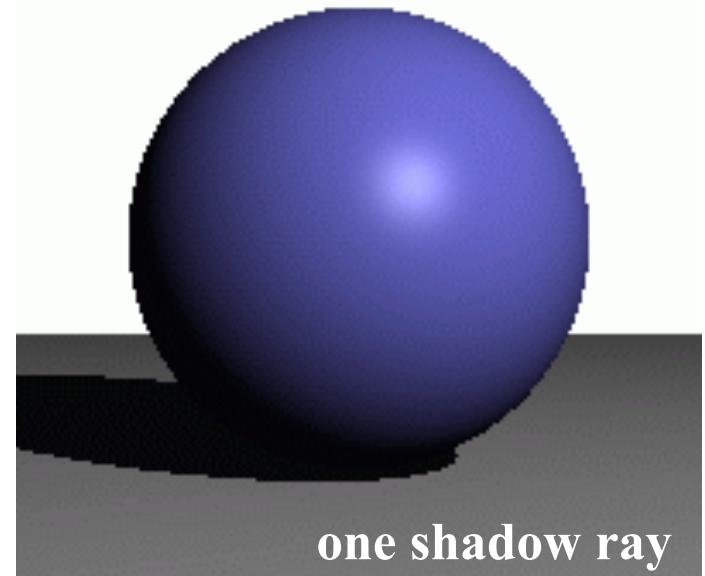
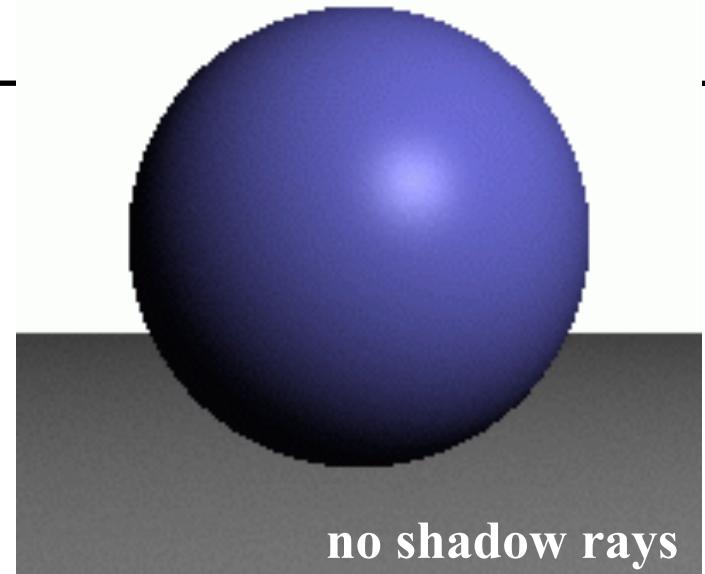
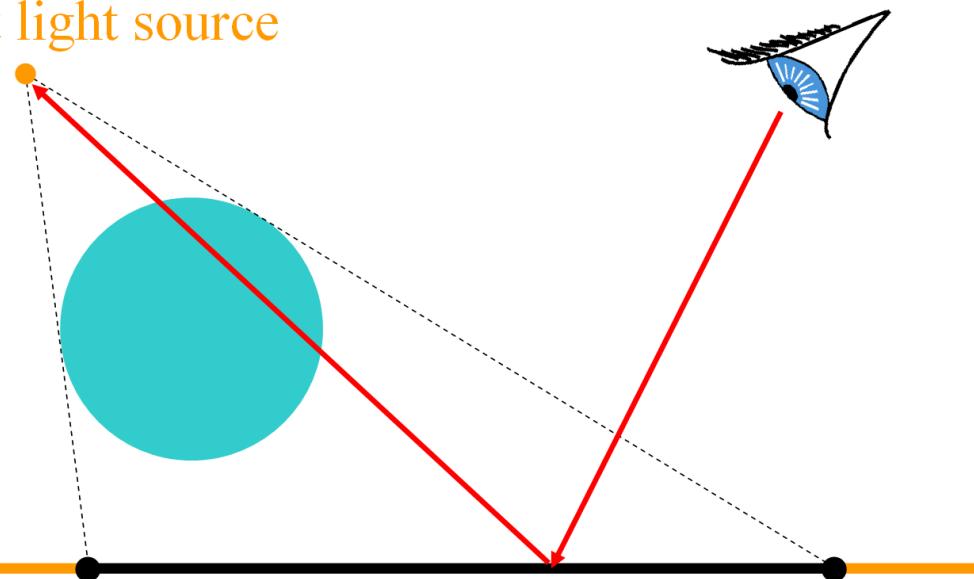


polished surface

# Shadows

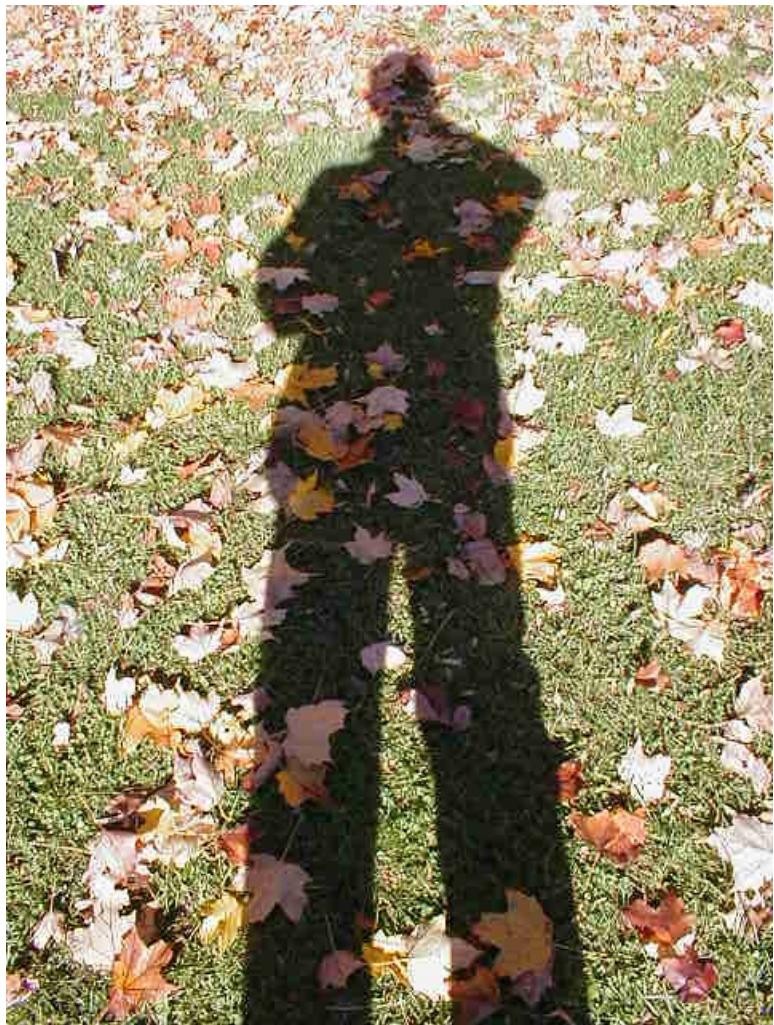
- One shadow ray per intersection per point light source

point light source



# Shadows & Light Sources

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[http://3media.initialized.org/photos/2000-10-18/index\\_gall.htm](http://3media.initialized.org/photos/2000-10-18/index_gall.htm)



<http://www.davidfay.com/index.php>



clear bulb

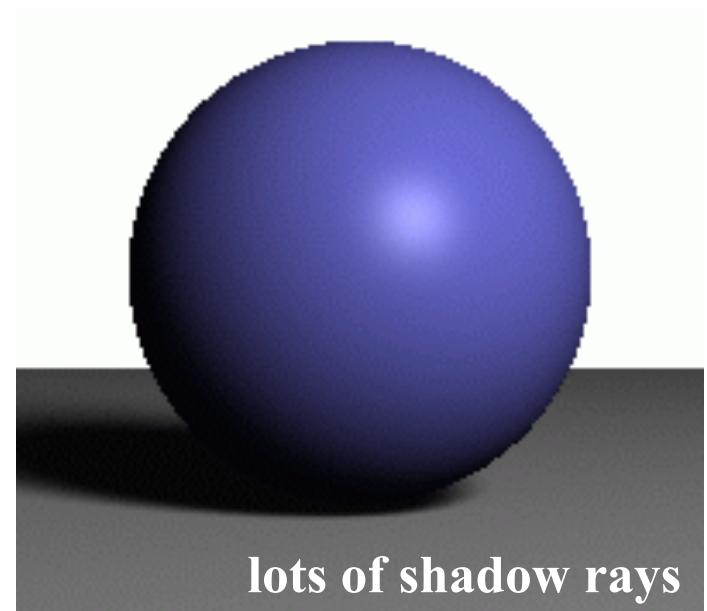
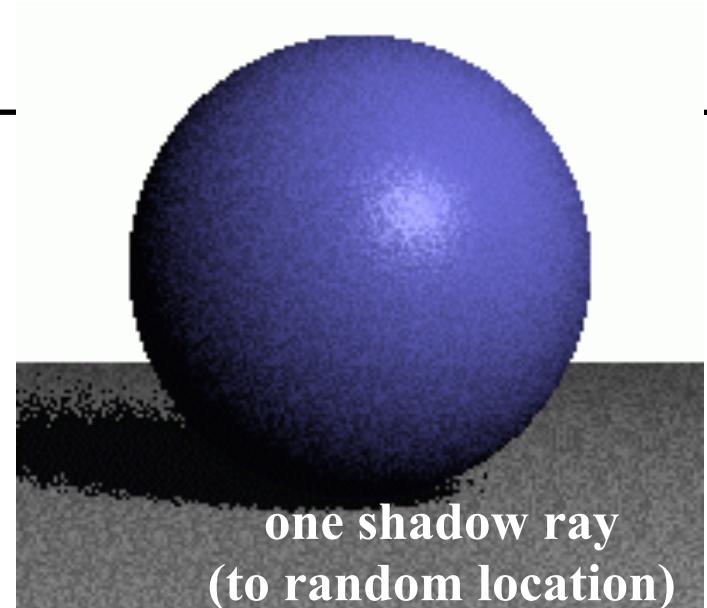
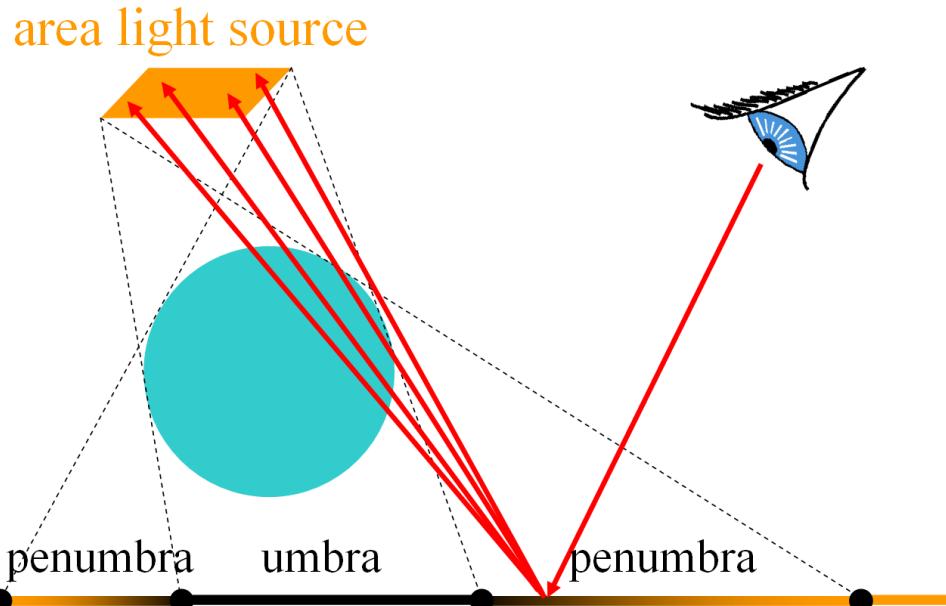


frosted bulb

<http://www.pa.uky.edu/~sciworks/light/preview/bulb2.htm>

# Soft Shadows

- Multiple shadow rays to sample area light source

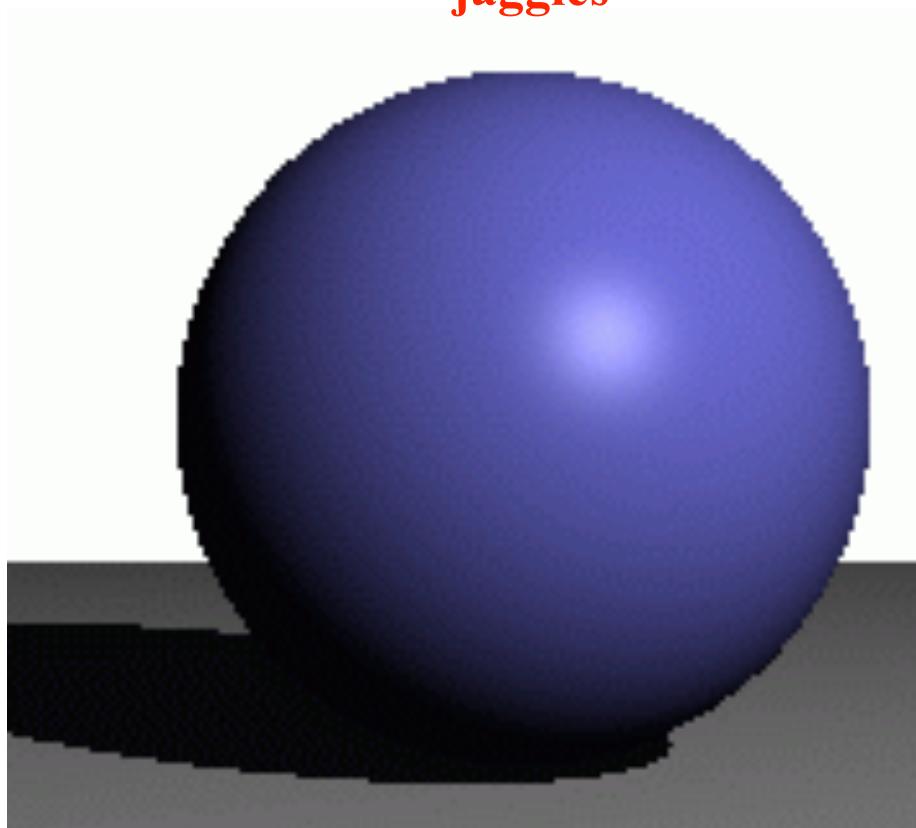


# Antialiasing – Supersampling

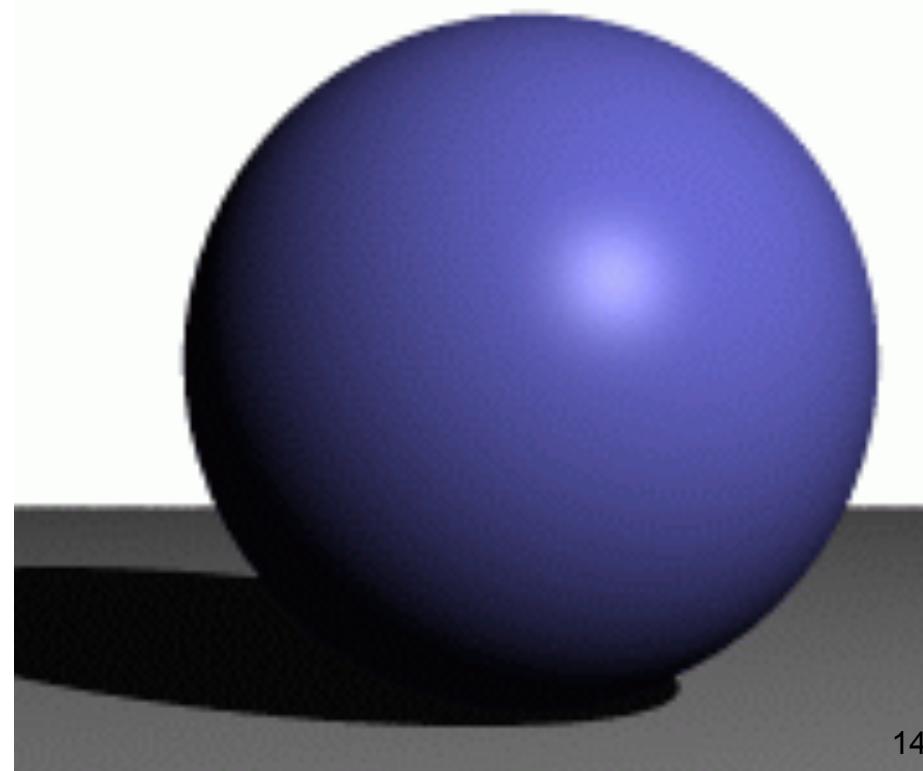
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- Multiple rays per pixel

jaggies



w/ antialiasing



# Motion Blur

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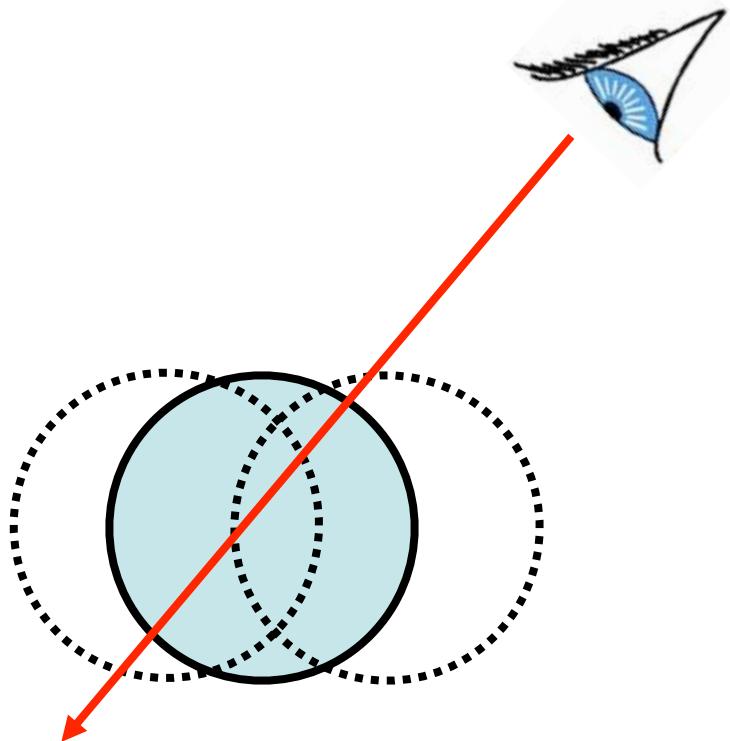


Rob Cook

# Motion Blur

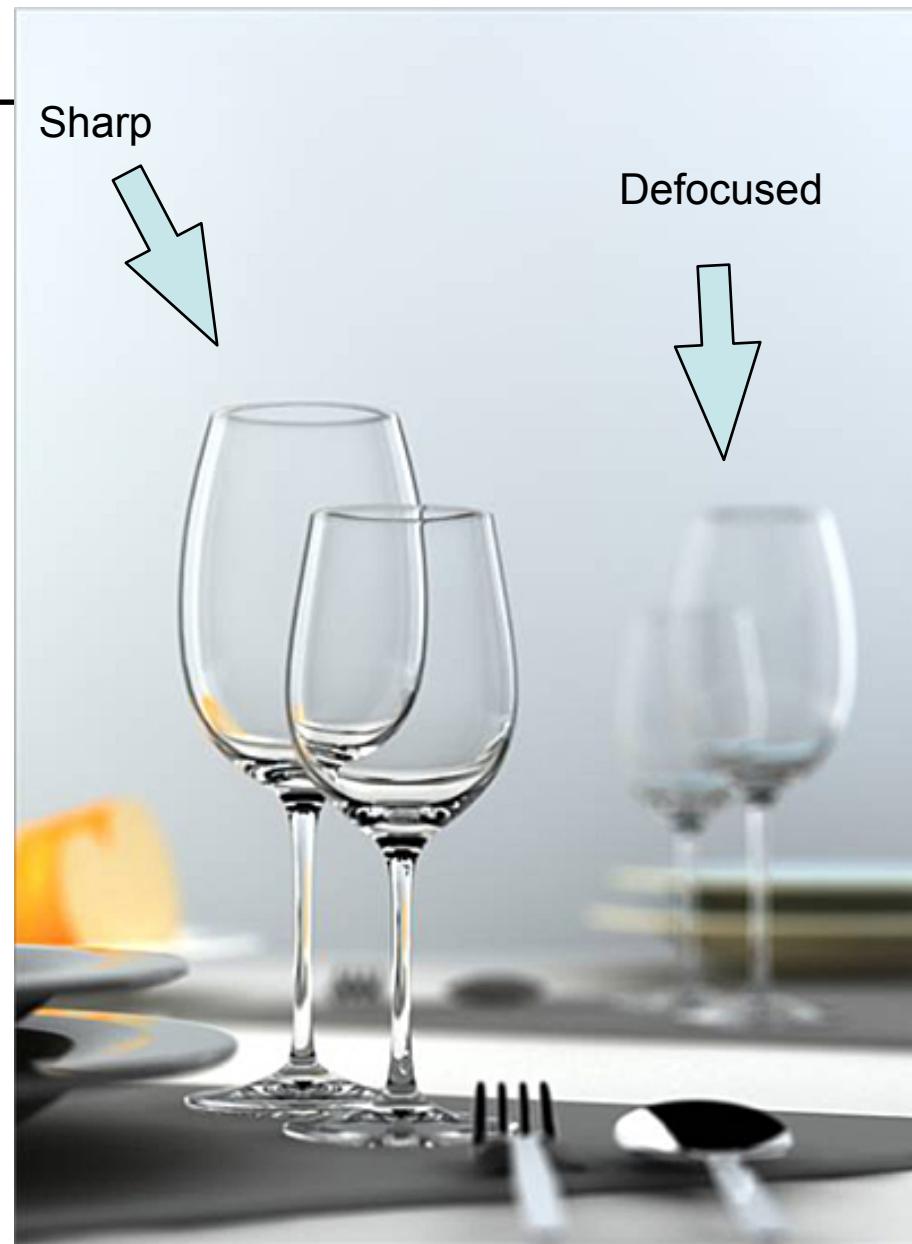
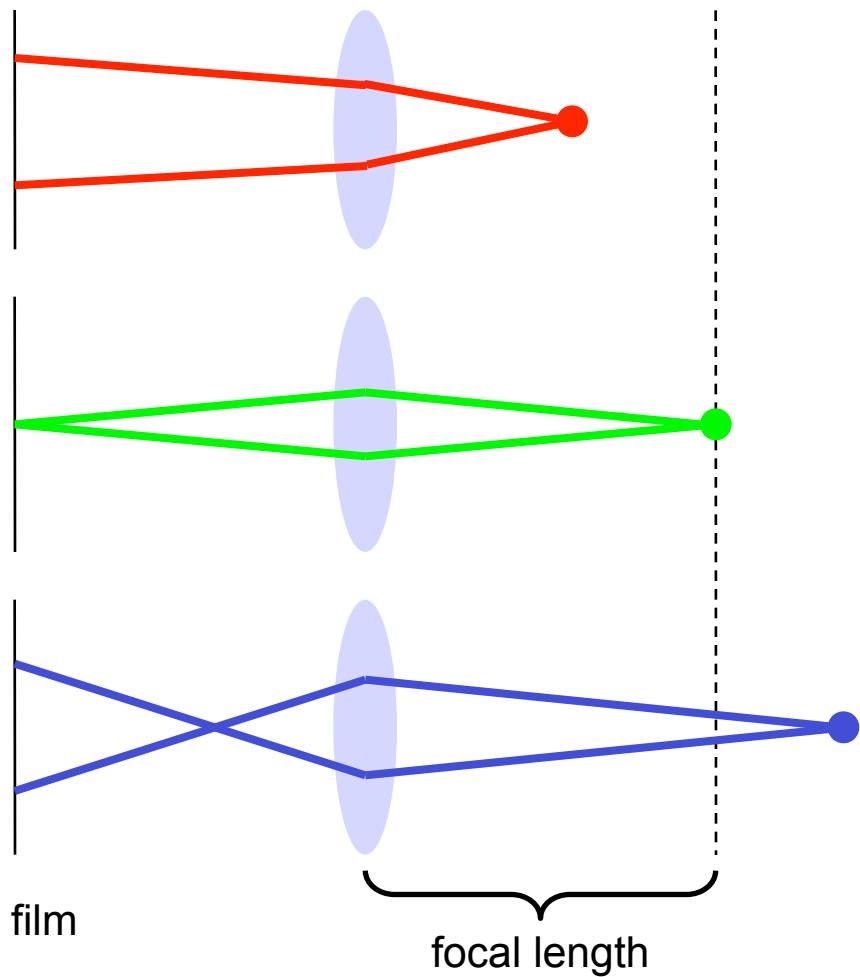
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- Sample objects temporally over time interval



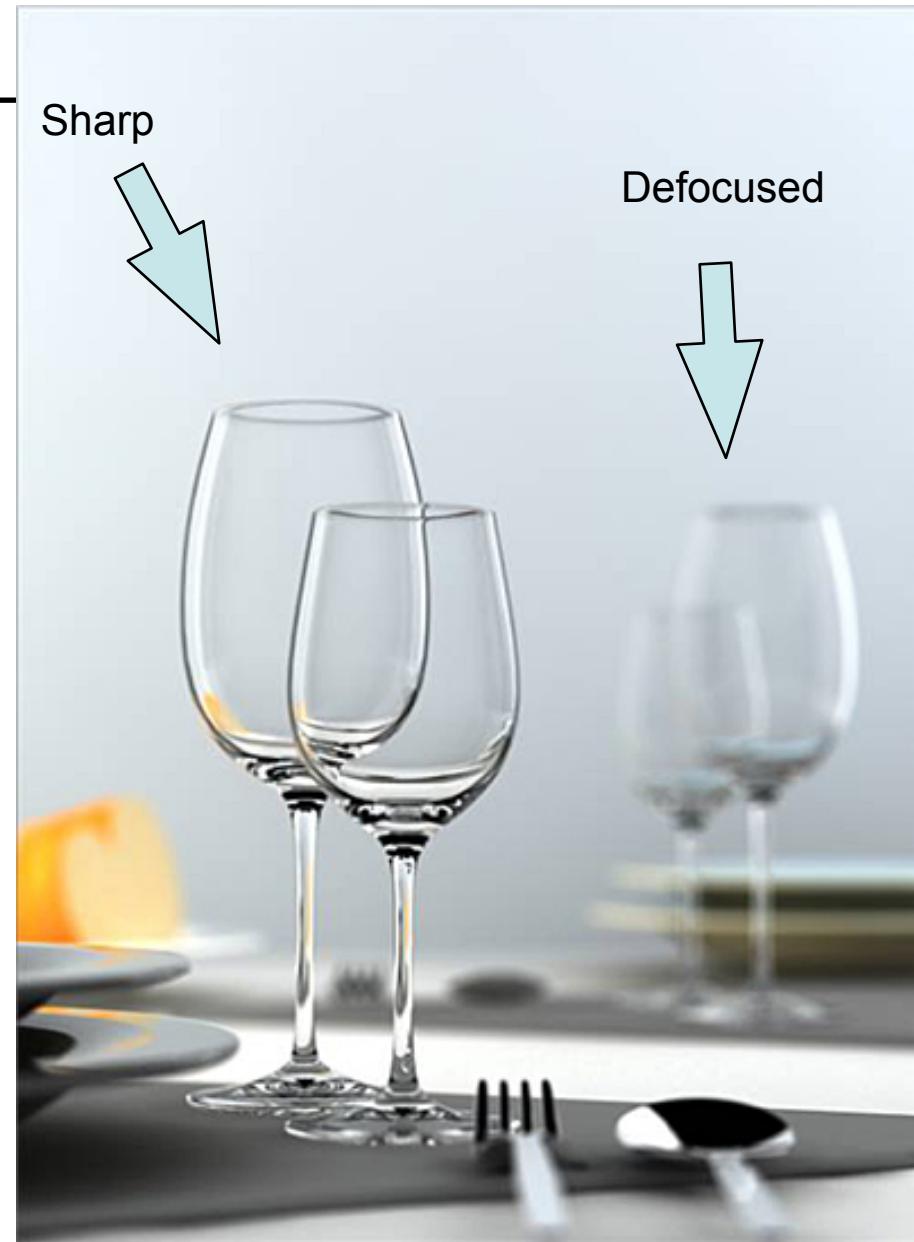
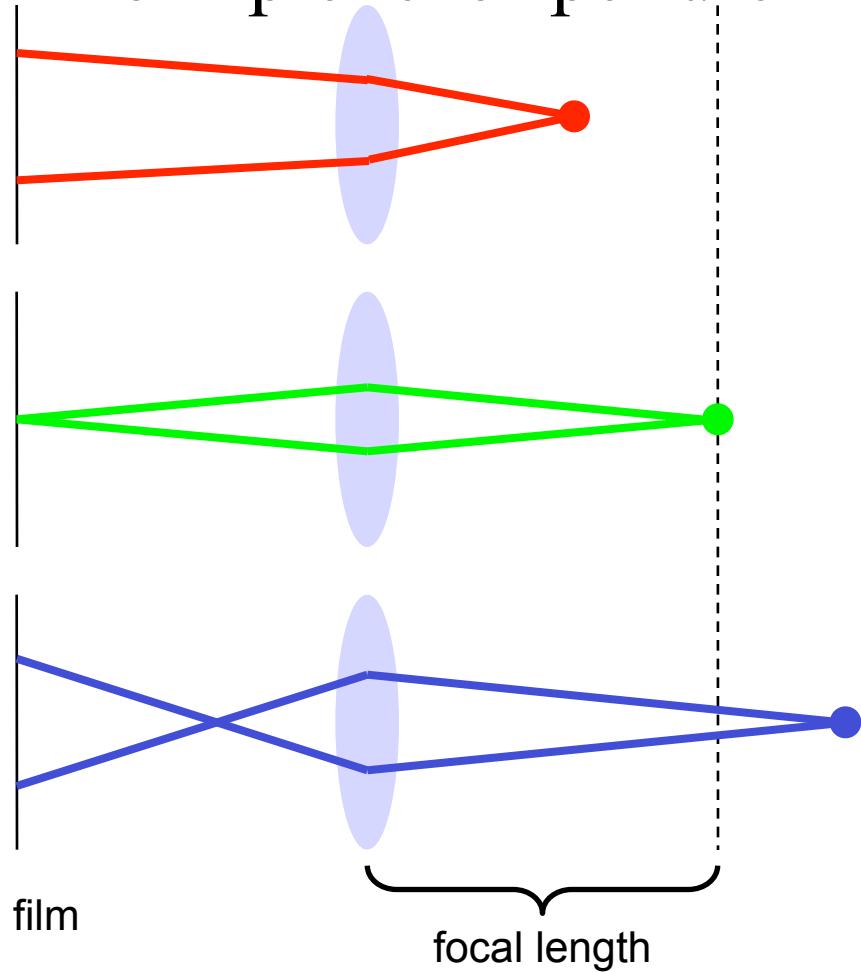
Rob Cook

# Depth of Field



# Depth of Field

- Multiple rays per pixel:  
sample lens aperture



# Aside: Smart Depth of Field

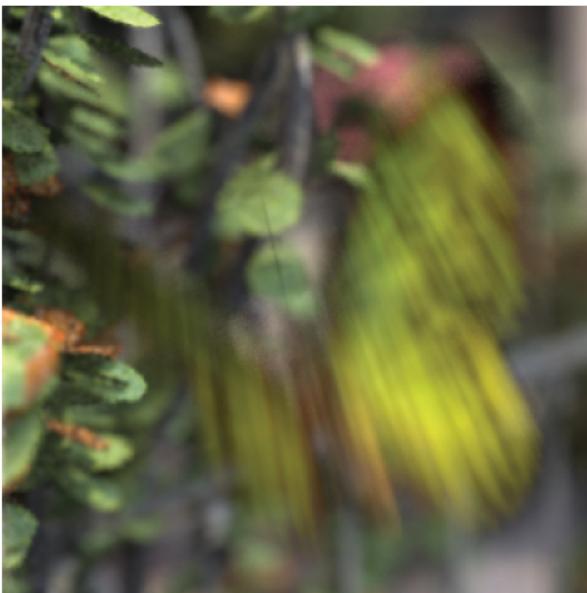
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Lehtinen et al. 2011

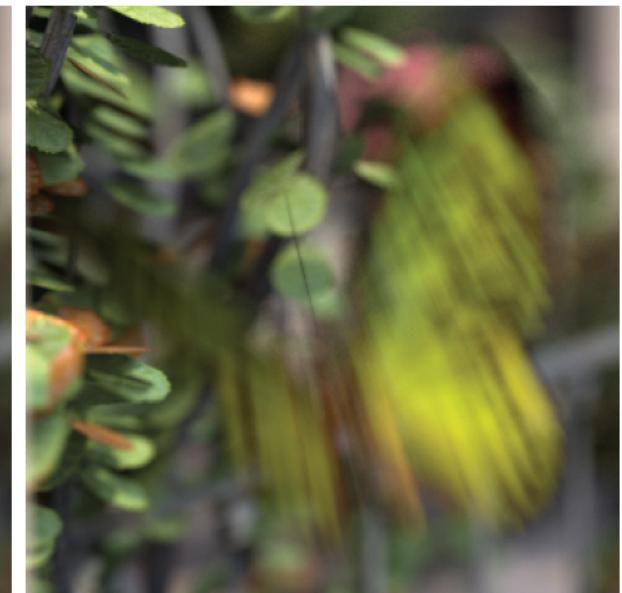
- (also video)



Input: 1 sample/pixel



Our result

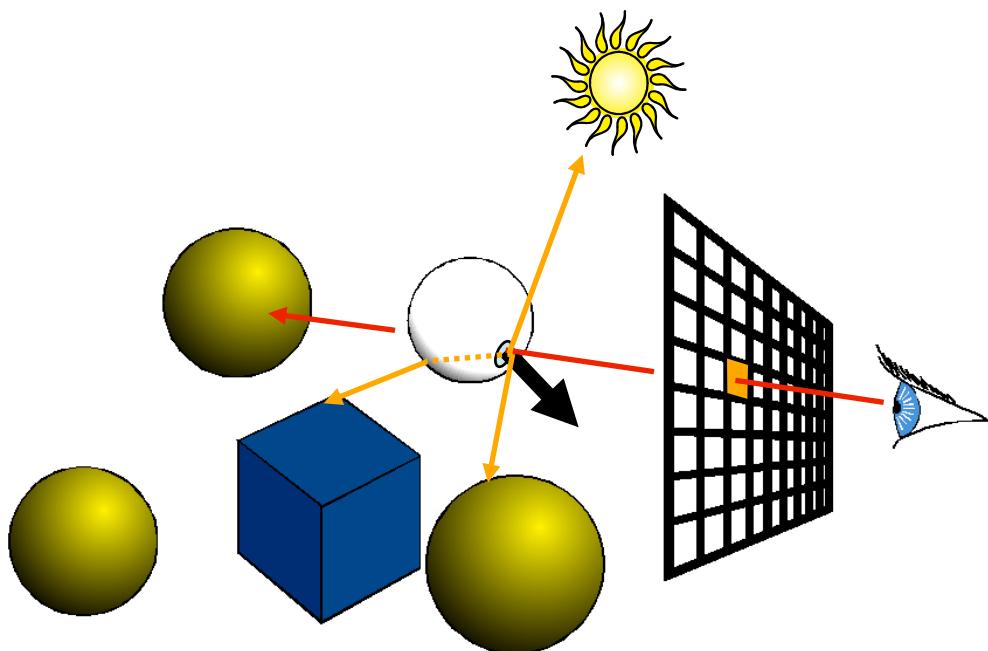


Ground truth

# Does Ray Tracing Simulate Physics?

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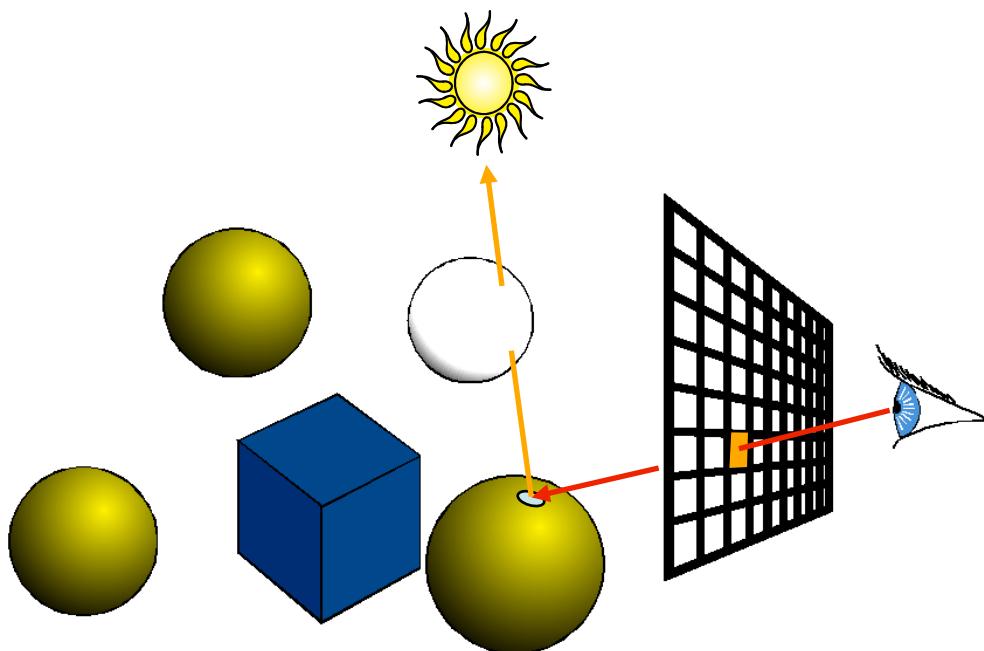
- Photons go from the light to the eye,  
not the other way
  - What we do is *backward ray tracing*.



# Does Ray Tracing Simulate Physics?

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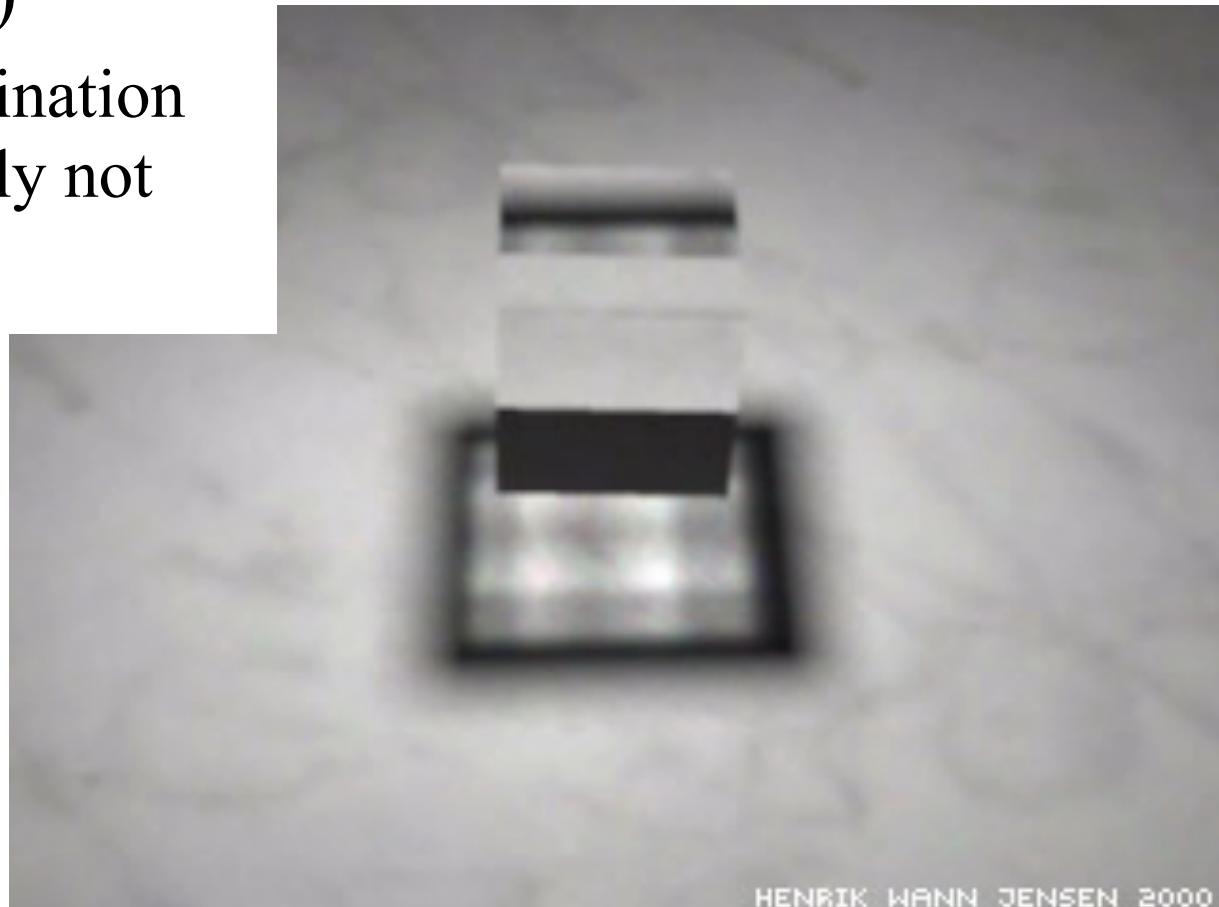
- Ray Tracing is full of dirty tricks
- For example, shadows of transparent objects
  - Opaque? Surely not..
  - Multiply by transparency color?  
(ignores refraction & does not produce caustics)



# Correct Transparent Shadow

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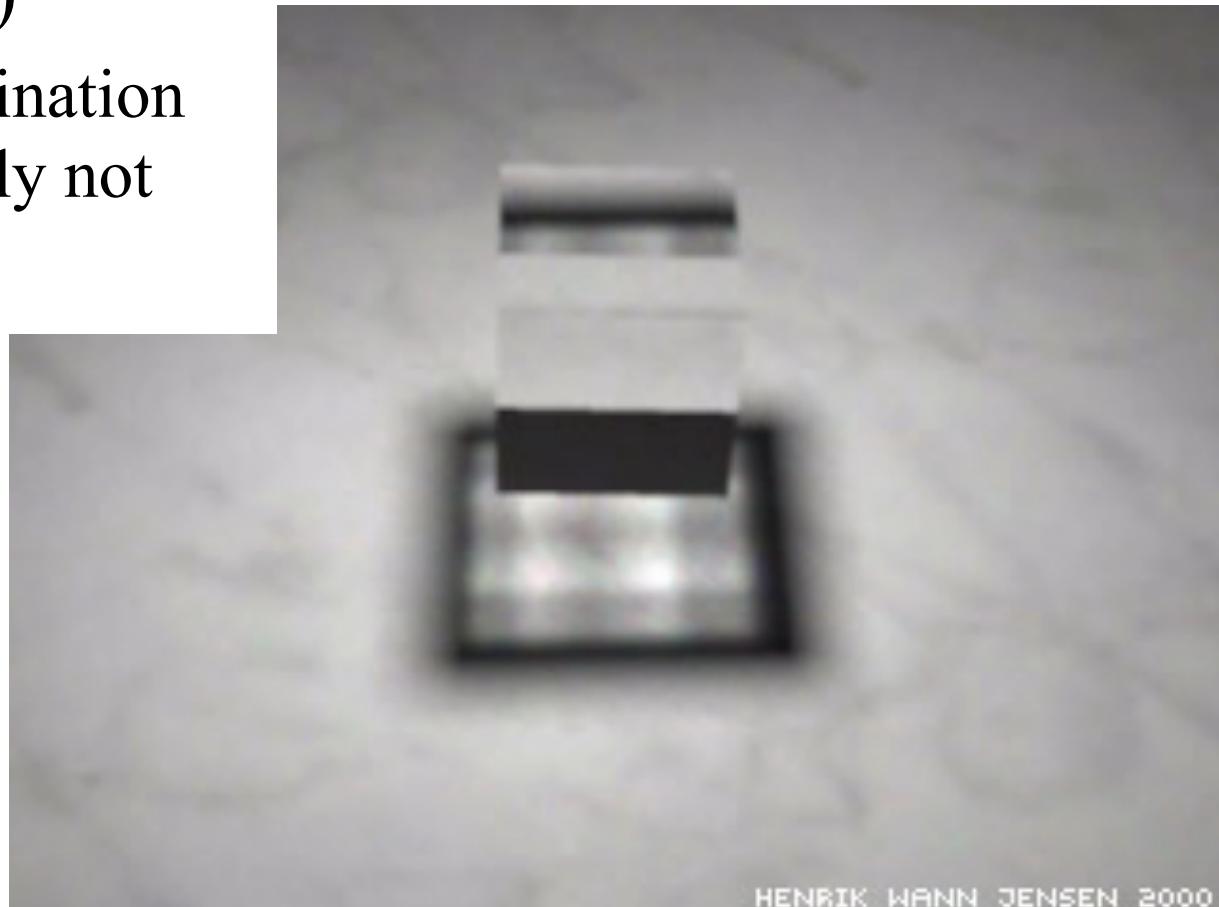
- Using advanced refraction technique (photon mapping)
  - Refraction for illumination (“caustics”) is usually not handled that well



# Correct Transparent Shadow

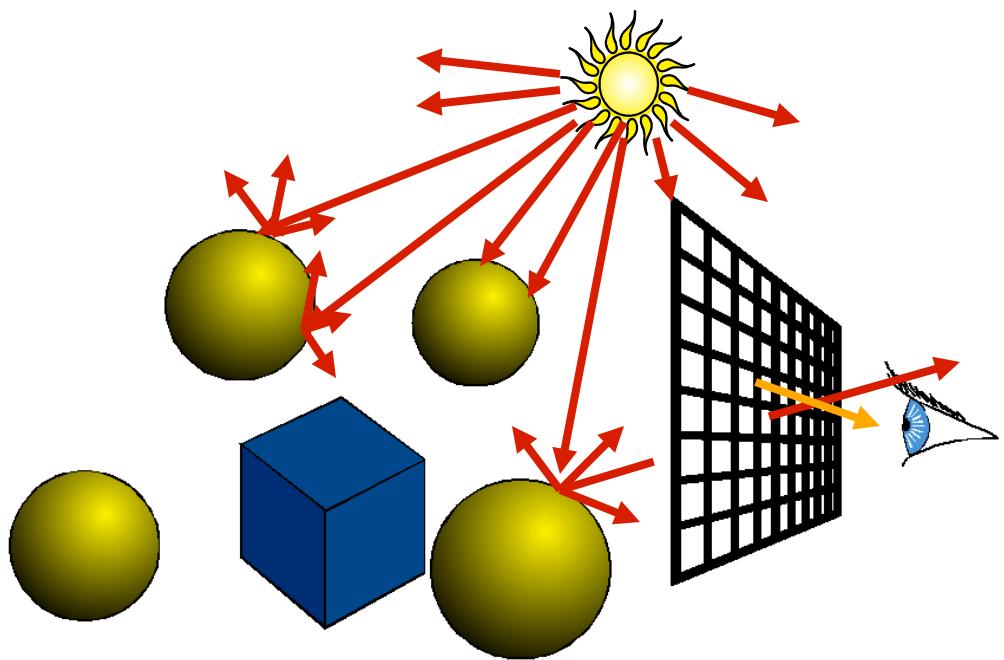
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- Using advanced refraction technique (photon mapping)
  - Refraction for illumination (“caustics”) is usually not handled that well



# “Forward” Ray Tracing

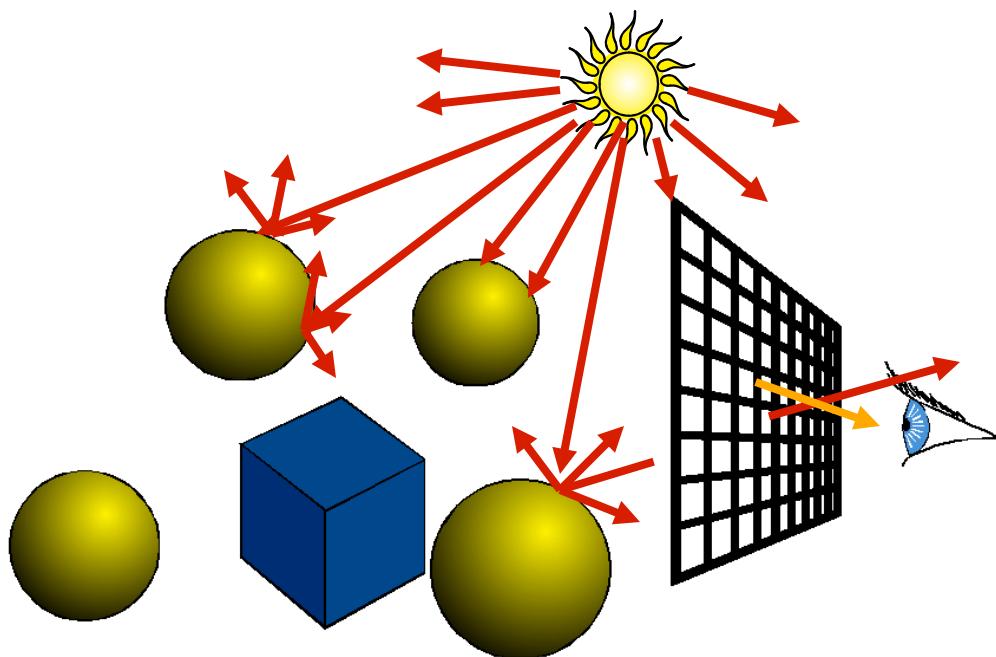
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# “Forward” Ray Tracing

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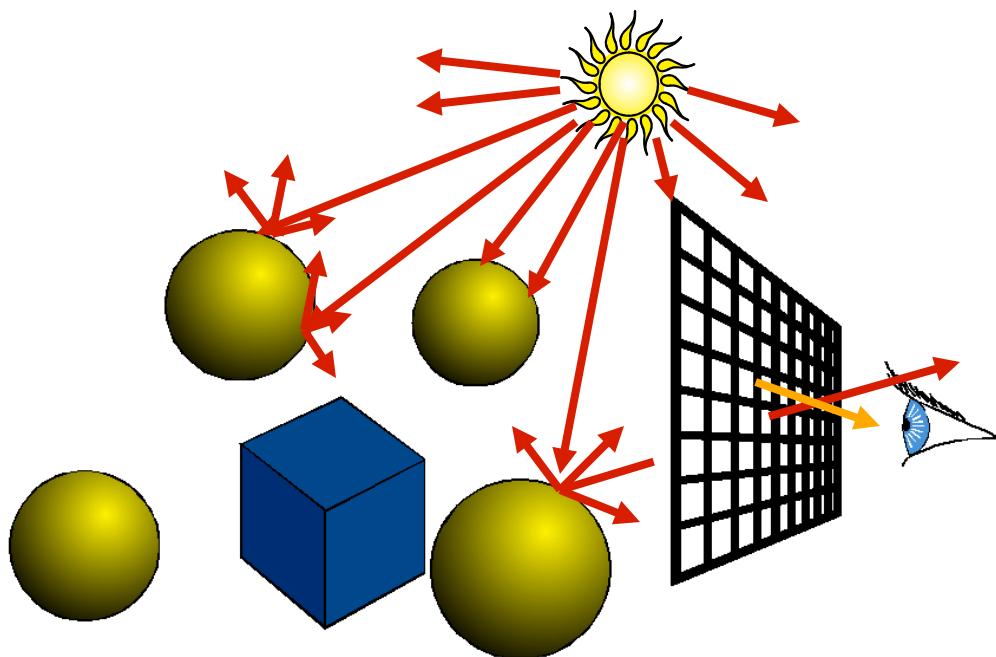
- Start from the light source: Shoot lots of “photons”



# “Forward” Ray Tracing

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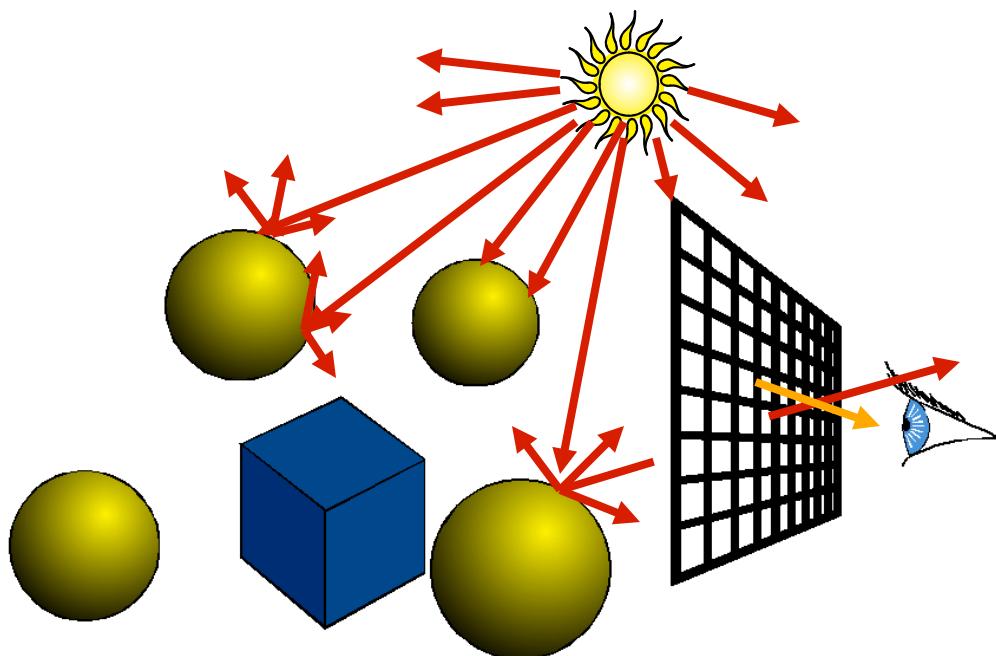
- Start from the light source: Shoot lots of “photons”
  - Very, very low probability to reach the eye/camera!



# “Forward” Ray Tracing

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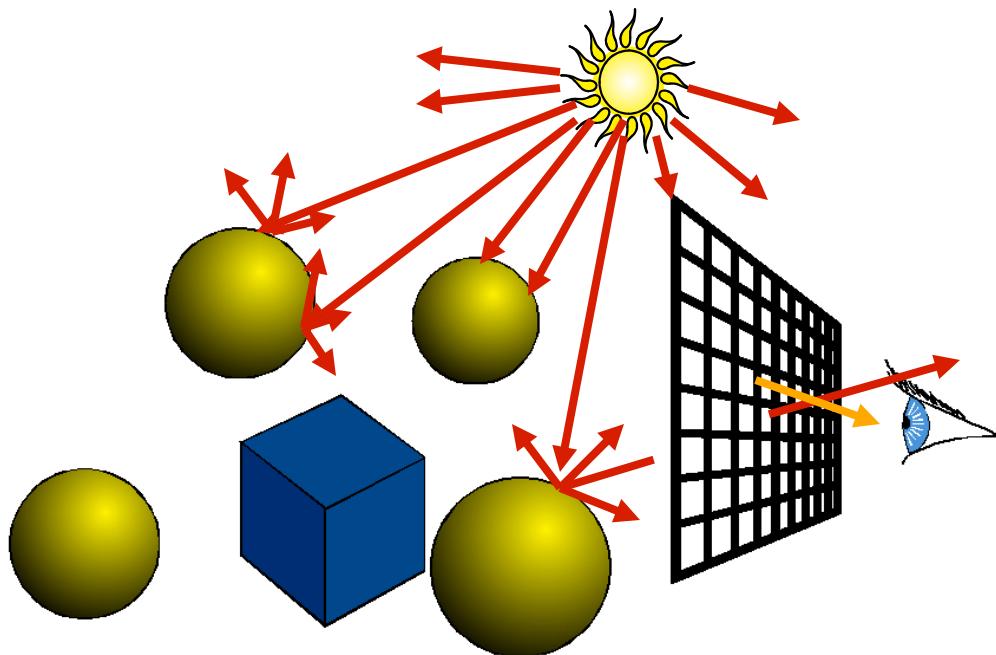
- Start from the light source: Shoot lots of “photons”
  - Very, very low probability to reach the eye/camera!
- What can we do about it?



# “Forward” Ray Tracing

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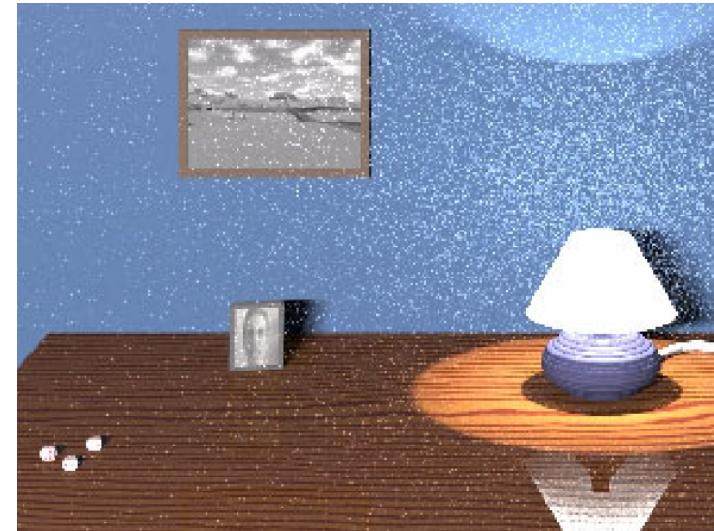
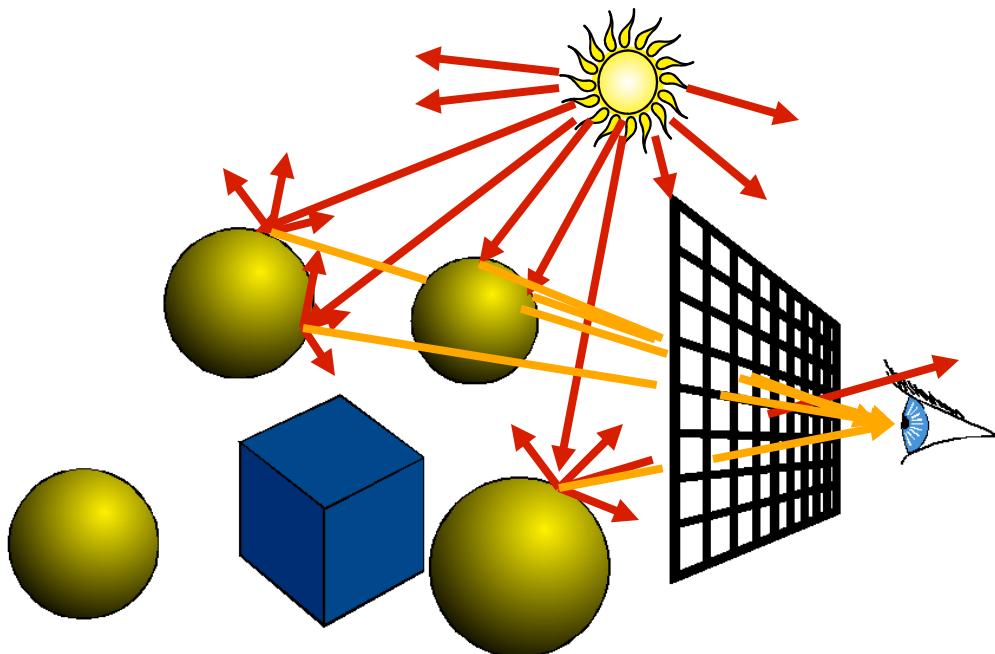
- Start from the light source: Shoot lots of “photons”
  - Very, very low probability to reach the eye/camera!
- What can we do about it?
  - Always send a ray to the eye.... still not efficient



# “Forward” Ray Tracing

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- Start from the light source: Shoot lots of “photons”
  - Very, very low probability to reach the eye/camera!
- What can we do about it?
  - Always send a ray to the eye.... still not efficient
  - More solutions later

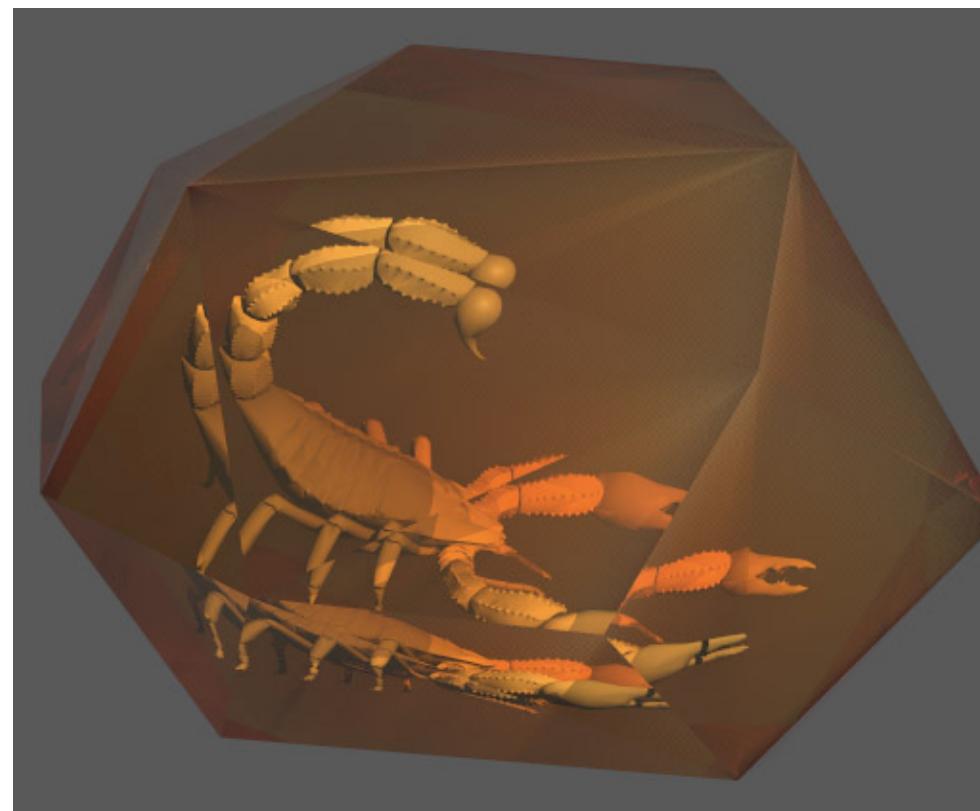


# Forward vs. Backward Ray Tracing

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- A word of warning:  
The terms “forward”  
and “backward” are  
not quite standard
  - Some texts use  
“backward” when  
they mean “forward”  
in our sense
  - And vice versa

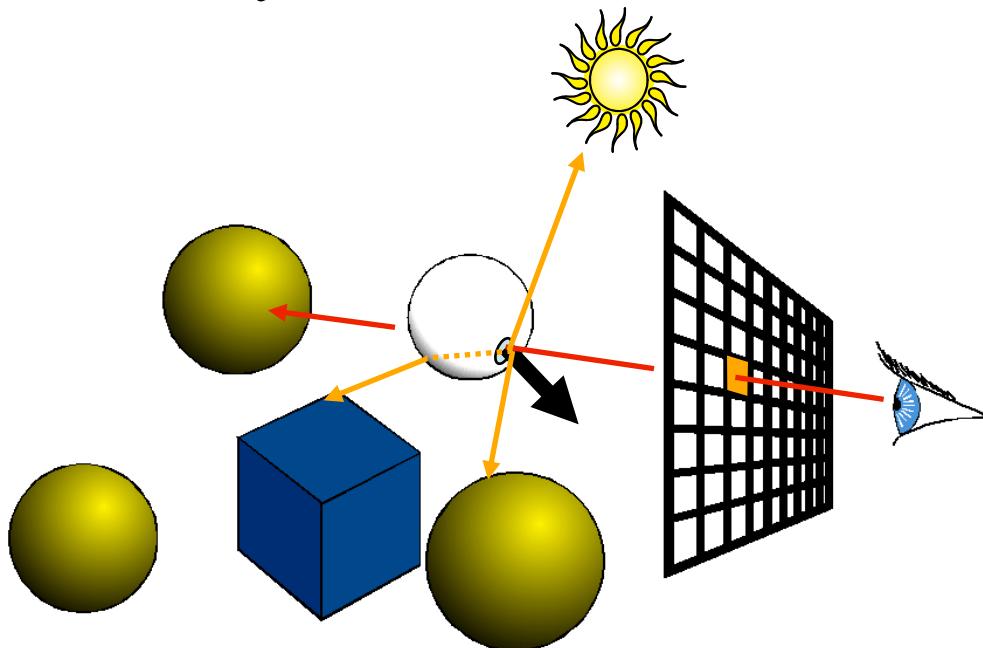
Walter et al., Single Scattering in Refractive Media with Triangle Mesh Boundaries, SIGGRAPH 2009



# Does Ray Tracing Simulate Physics?

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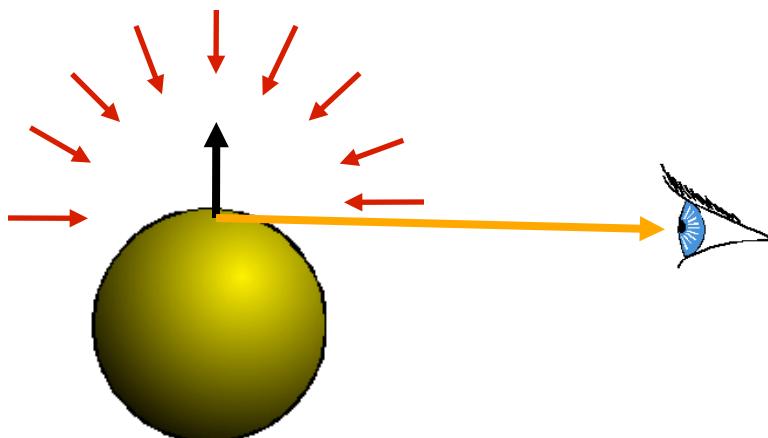
- We do backward ray tracing
- Fortunately, it turns out that there is a mathematical justification to going from eye towards the scene
  - (Monte Carlo path tracing & variants)
- In any case, the real world doesn't consist  
of just mirrors :-)



# The Rendering Equation

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- Clean mathematical framework for light transport simulation ([Kajiya, 1986](#))
- We'll see this later
  - You can take a peek [here](#) or [here](#) for a preview.
- At each point, outgoing light in one direction is the integral of incoming light in all directions multiplied by material reflectance



The Rendering  
Equation is a  
physically-based  
model that is valid  
in lots of cases.

# Stack Studios, Rendered using Maxwell



Stack Studios, Rendered using Maxwell



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Markus Otto/Winzenrender, Rendered using Maxwell



winzenrender

Stack Studios, Rendered using Maxwell



Stack Studios, Rendered using Maxwell

Yep, the Rendering  
Equation works!



Stack Studios, Rendered using Maxwell

# That's All for Today

Further reading:

- Shirley: Realistic Ray Tracing
- Dutre et al.: Advanced Global Illumination
- Physically-based rendering, 3rd ed.