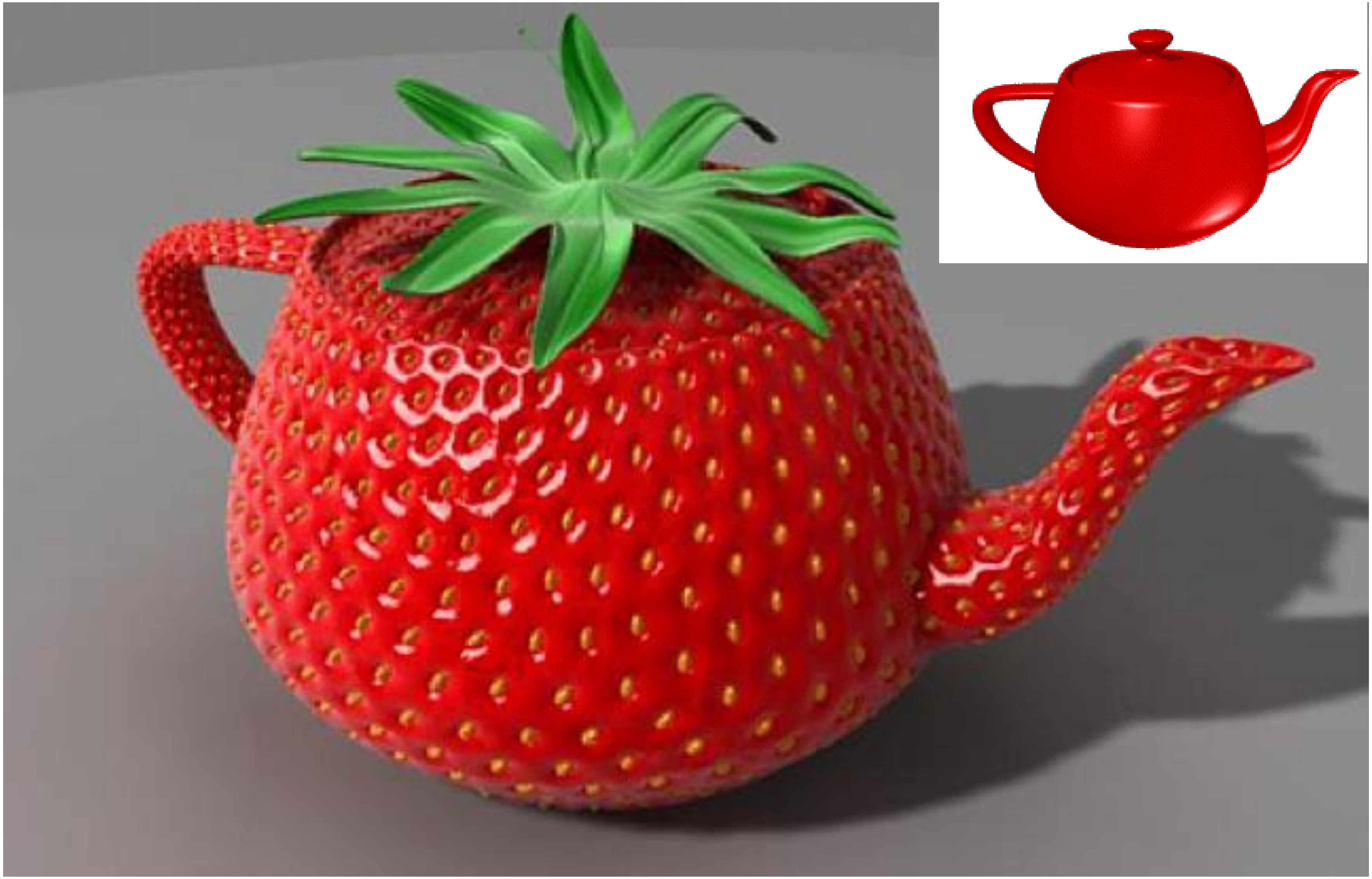
Topic 12:

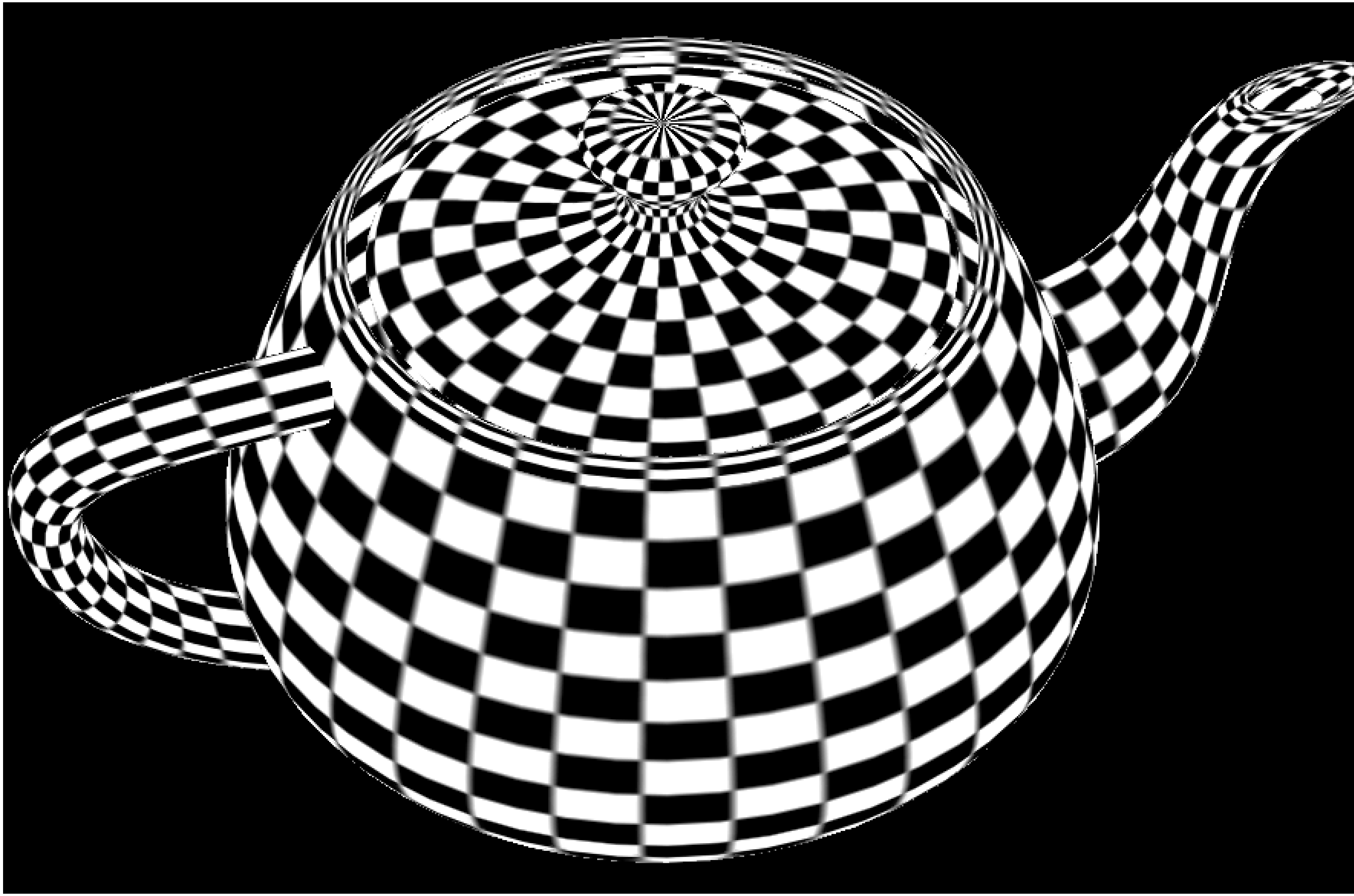
Texture Mapping

- Motivation
- Sources of texture
- Texture coordinates
- Bump mapping, mip-mapping & env mapping



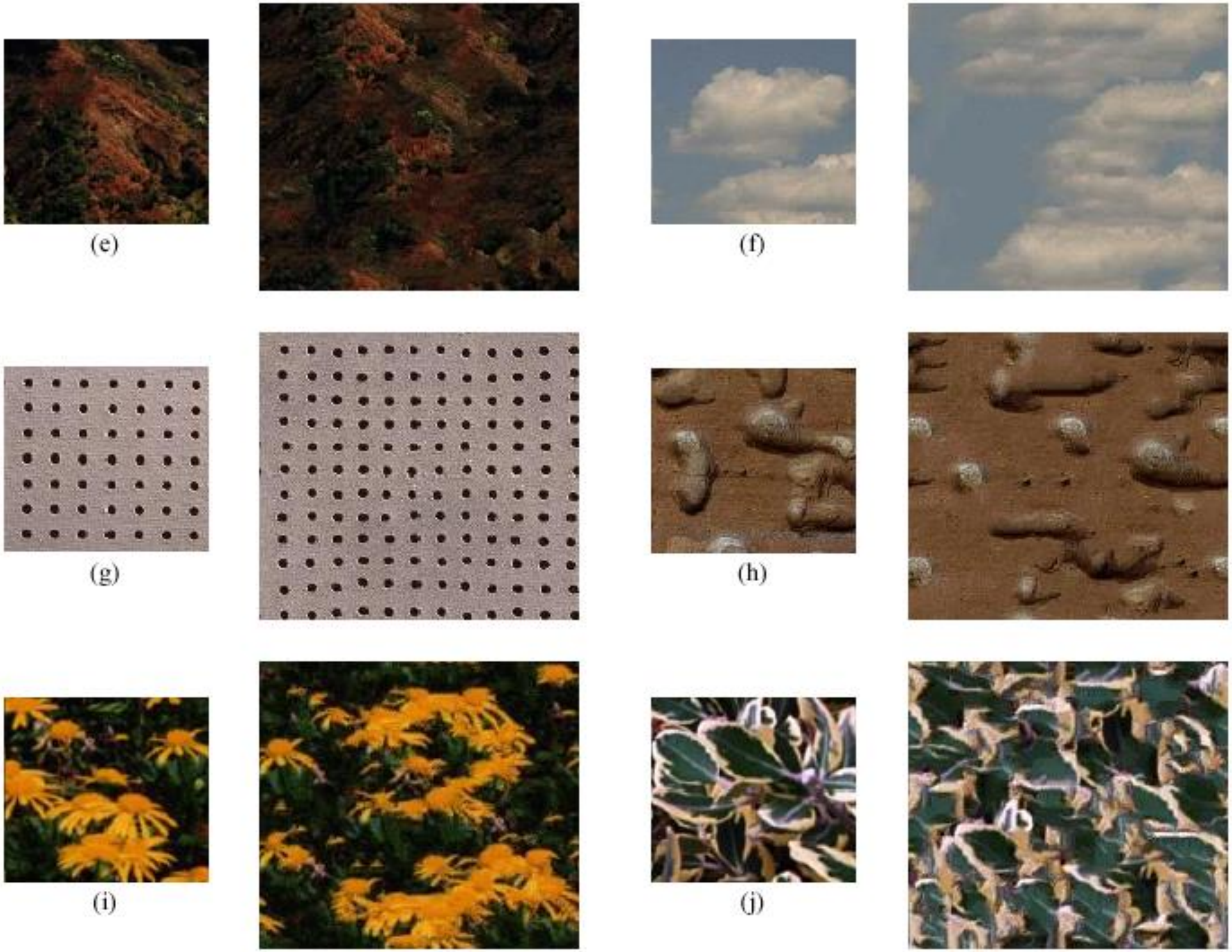
Texture sources: Photographs

Texture sources: Procedural



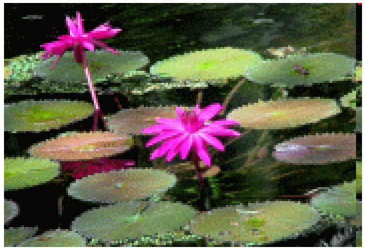
Texture sources: Solid textures

Texture sources: Synthesized



[redacted]

Original



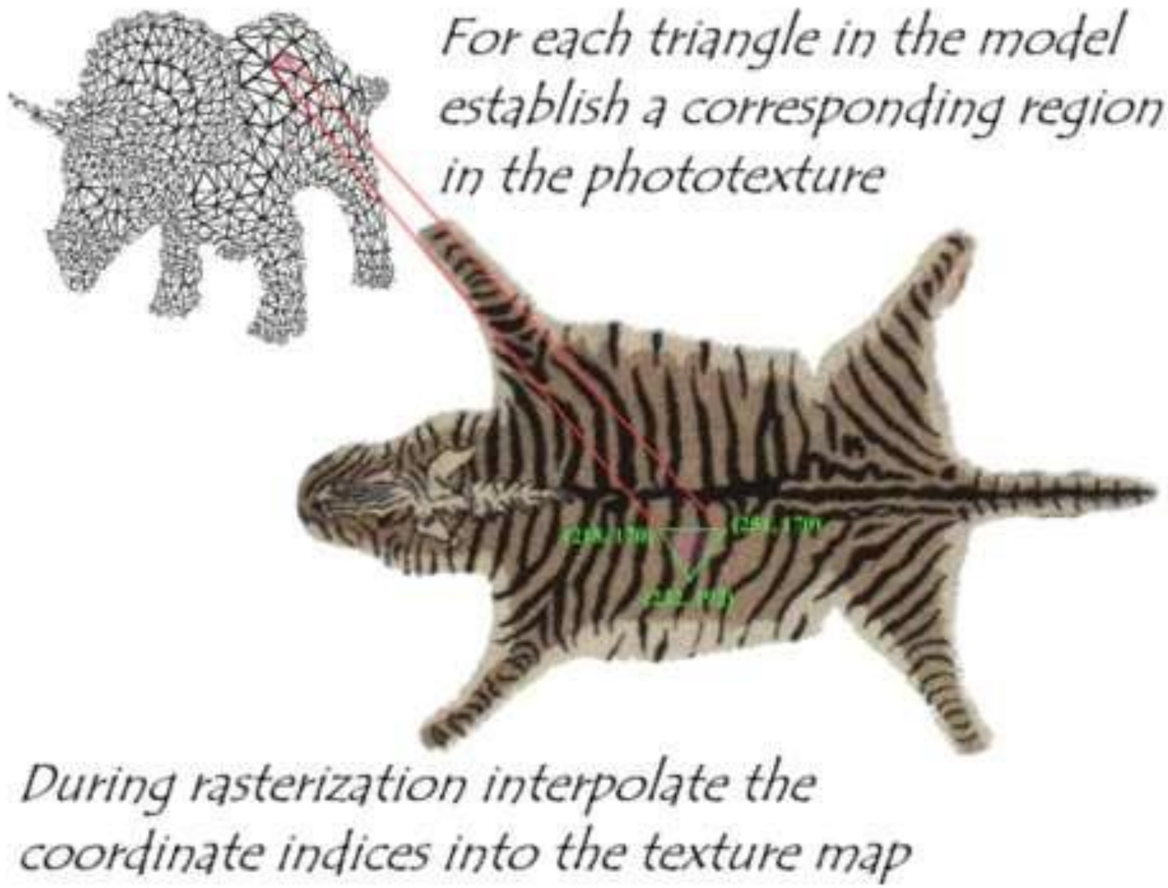
Synthesized

Original

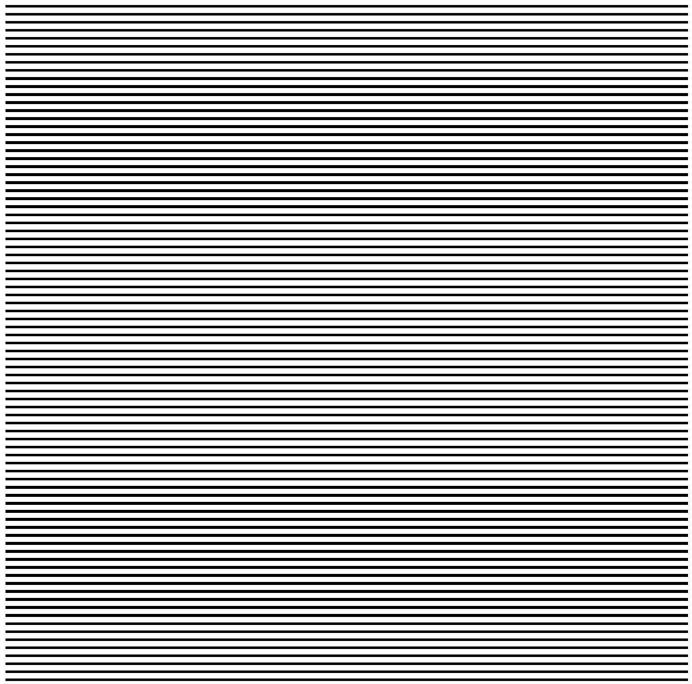
Synthesized

Texture coordinates

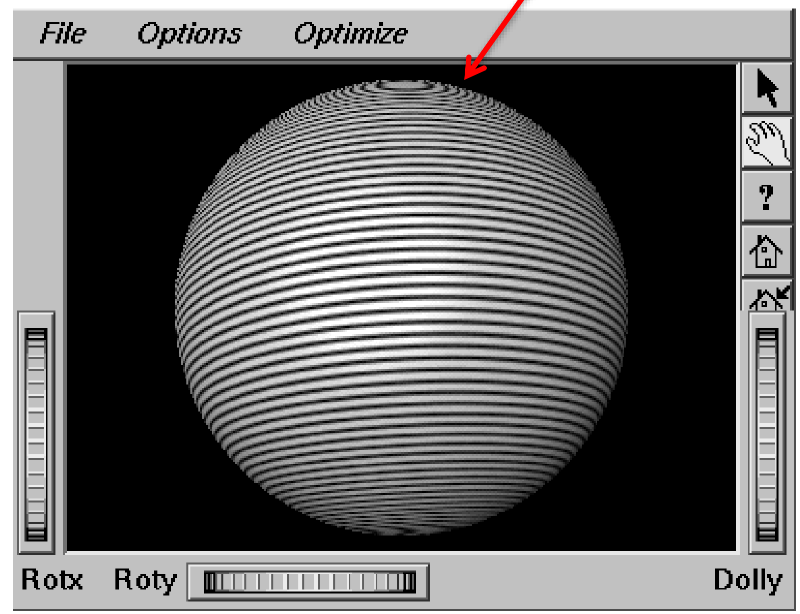
How does one establish correspondence? (UV mapping)



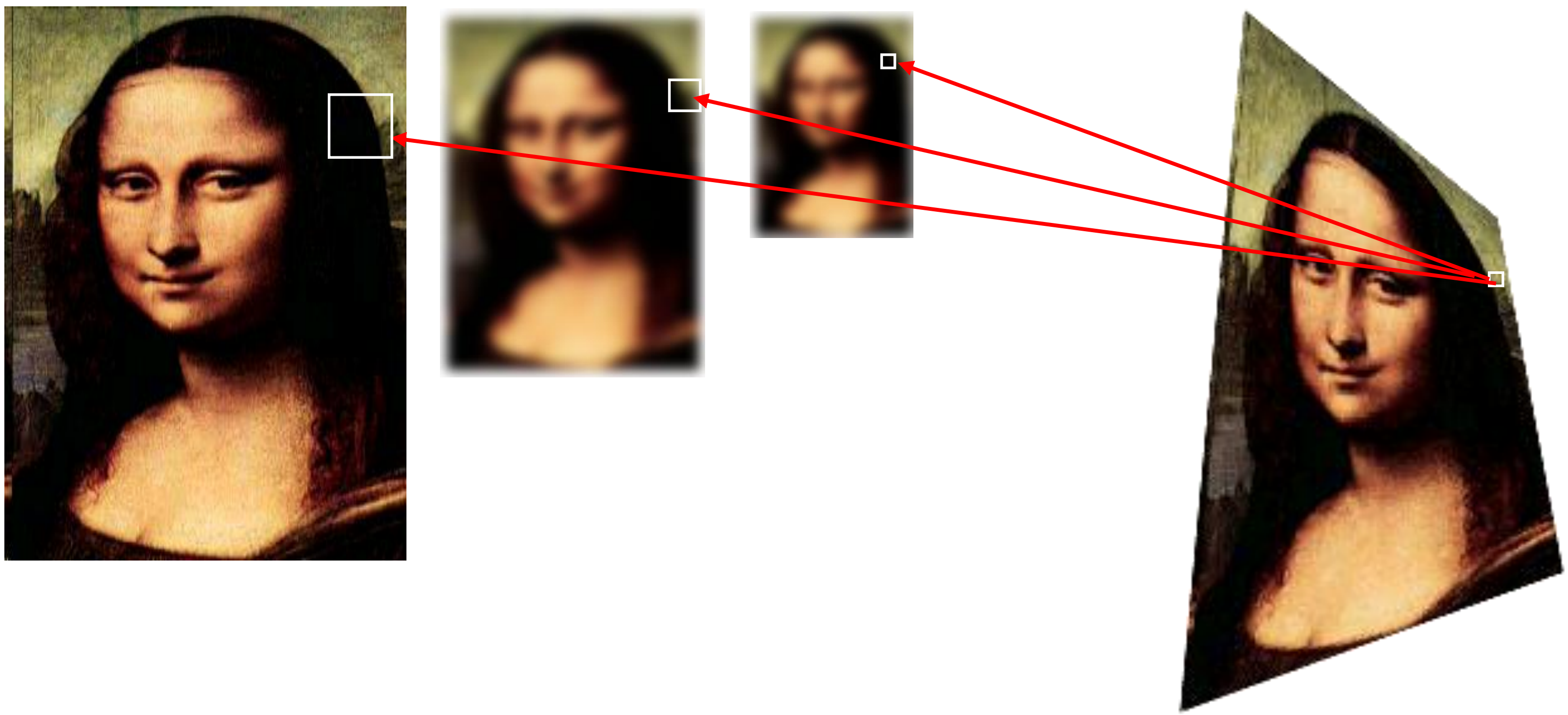
Aliasing During Texture Mapping



aliasing

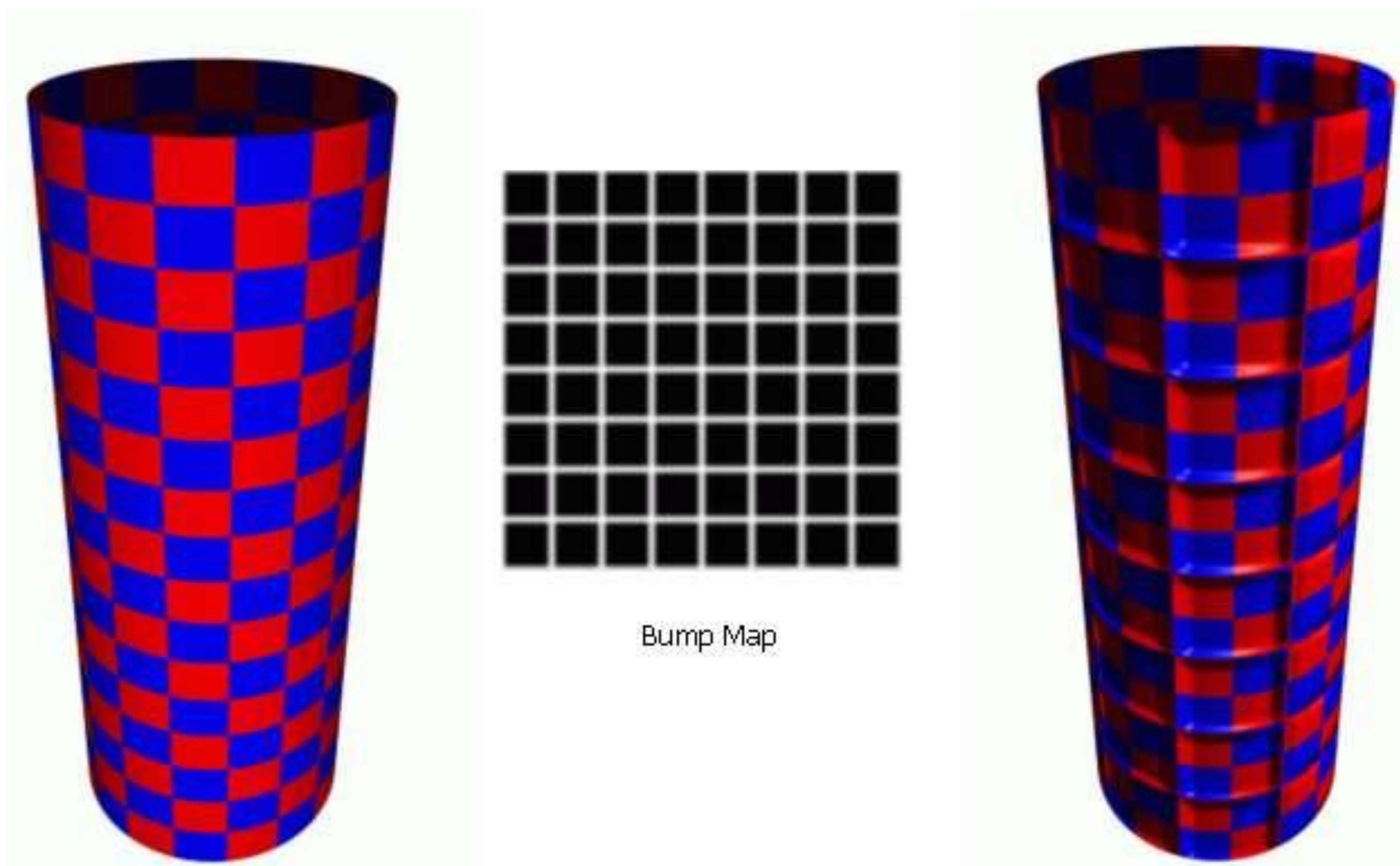


MIP-Mapping: Basic Idea

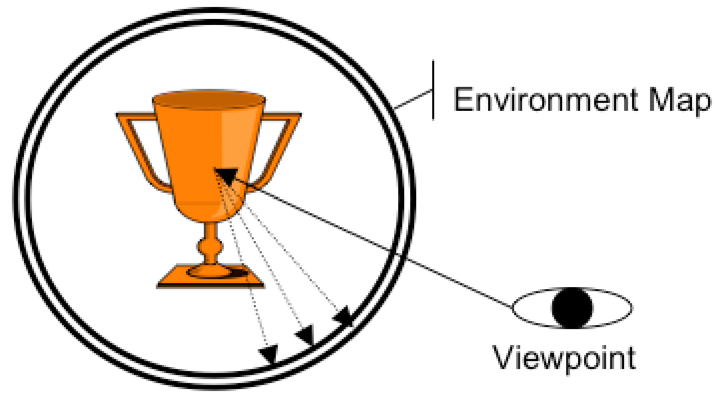


Given a polygon, use the texture image, where the projected polygon best matches the size of the polygon on screen.

Bump mapping

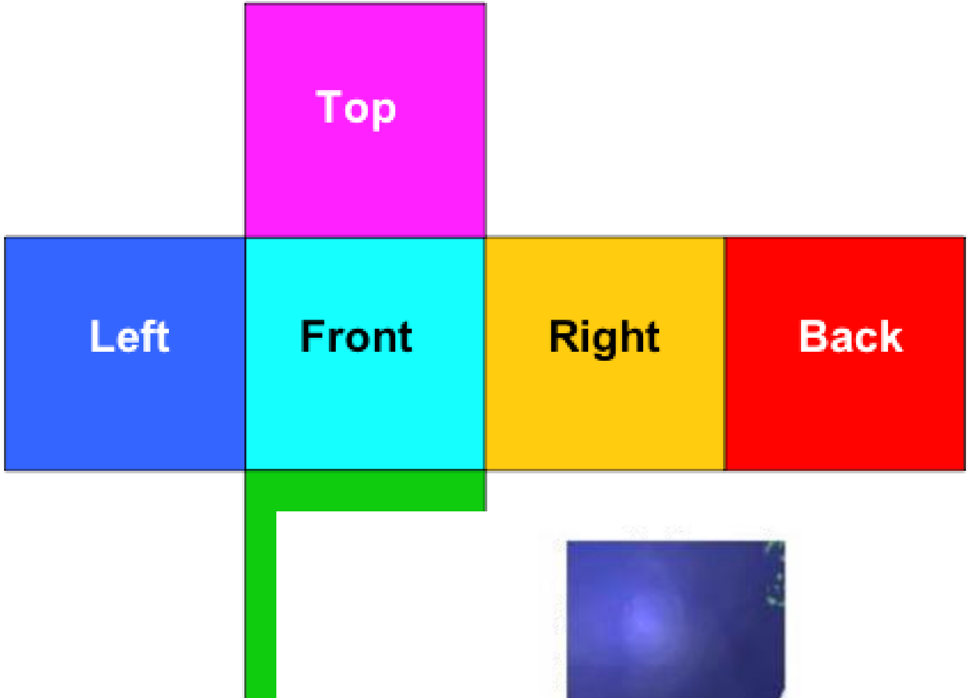


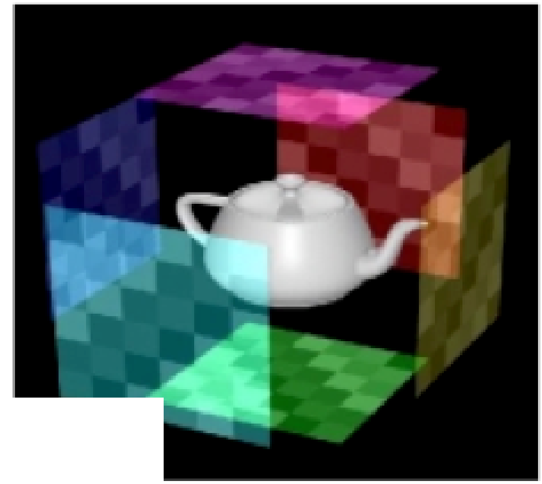
Environment Map



Render a 3D scene as viewed from a central viewpoint in all directions (as projected onto a sphere or cube).
Then use this rendered image as an environment texture…
an approximation to the appearance of highly reflective objects.

Environment Mapping Cube





Environment Mapping

Local vs. Global Illumination

Local Illumination Models

e.g. Phong

- Model source from a light reflected once off a surface towards the eye
- Indirect light is included with an ad hoc “ambient” term which is normally constant across the scene

Global Illumination Models

e.g. ray tracing or radiosity (both are incomplete)

- Try to measure light propagation in the scene
- Model interaction between objects and other objects, objects and their environment

All surfaces are not created equal

Specular surfaces

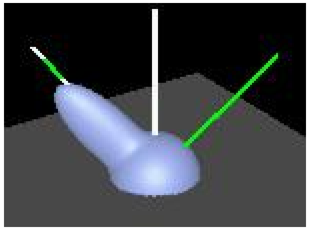
- e.g. mirrors, glass balls
- An idealized model provides 'perfect' reflection

  Incident ray is reflected back as a ray in a single direction

Diffuse surfaces

- e.g. flat paint, chalk
- Lambertian surfaces
- Incident light is scattered equally in all directions

General reflectance model: **BRDF**



Categories of light transport

Specular-Specular

Specular-Diffuse

Diffuse-Diffuse

Diffuse-Specular

Ray Tracing

Traces path of specularly reflected or transmitted (refracted) rays through environment

Rays are infinitely thin

Don't disperse

Signature: shiny objects exhibiting sharp, multiple reflections

Transport E - S – S – S – D – L.

Ray Tracing

Unifies in one framework

- Hidden surface removal
- Shadow computation
- Reflection of light
- Refraction of light
- Global **specular** interaction

Topic 13:

Basic Ray Tracing

- Introduction to ray tracing
- Computing rays
- Computing intersections
  - ray-triangle
  - ray-polygon
  - ray-quadric
- Computing normals
- Evaluating shading model
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  - refraction
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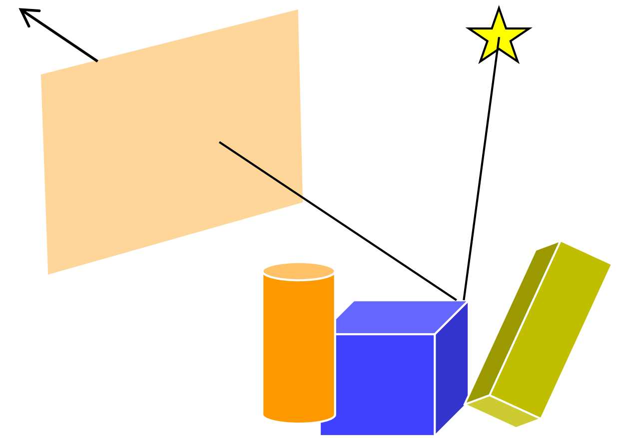
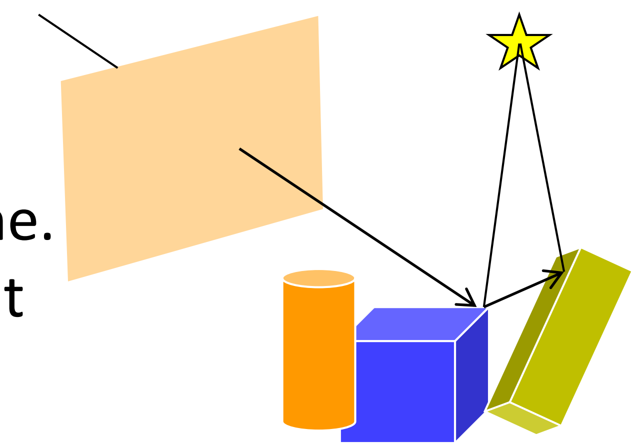
Rasterization vs. Ray Tracing

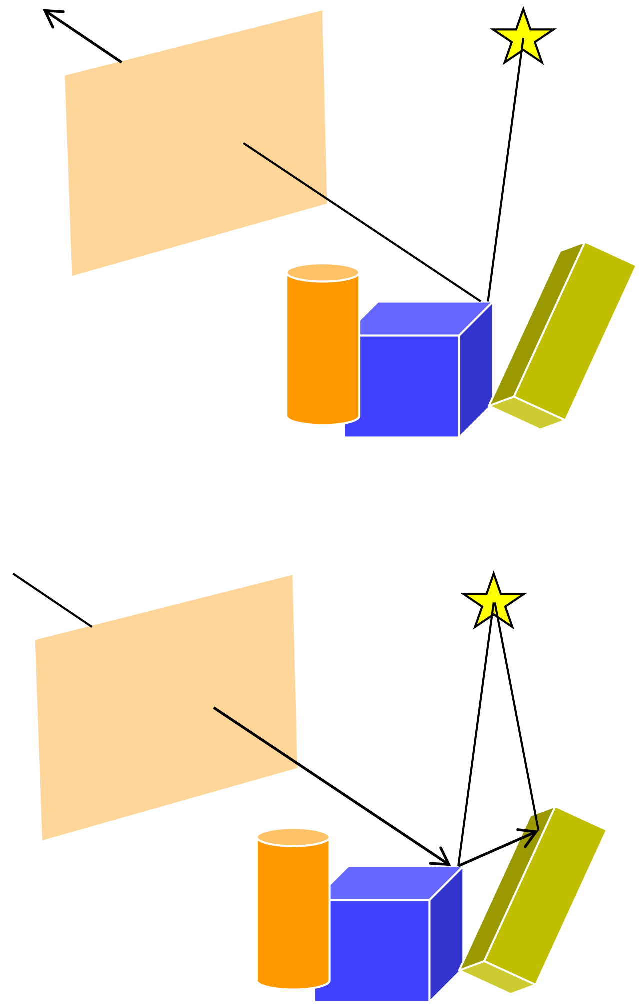
Rasterization:
-project geometry onto image.
-pixel color computed by local illumination
 (direct lighting).



Ray-Tracing:
-project image pixels (backwards) onto scene.
-pixel color determined based on direct light
as well indirectly by recursively following
promising lights path of the ray.



Ray Tracing: Basic Idea



Ray Tracing: Advantages

- **Customizable:** modular approach for ray sampling, ray object Intersections and reflectance models.

- **Variety of visual effects:** shadows, reflections, refractions, indirect illumination, depth of field etc.

- **Parallelizable:** each ray path is independent.

- **Speed vs. Accuracy trade-off:** # and recursive depth of rays cast.

Ray Tracing: Basic Algorithm

For each pixel *q*
{
  compute ***r***, the ray from the eye through ***q***;
  find first intersection of ***r*** with the scene, a point ***p***;
  estimate light reaching ***p;***
  estimate light transmitted from ***p*** to ***q*** along ***r***;
}

Ray Tracing Imagery

Ray Tracing vs. Radiosity

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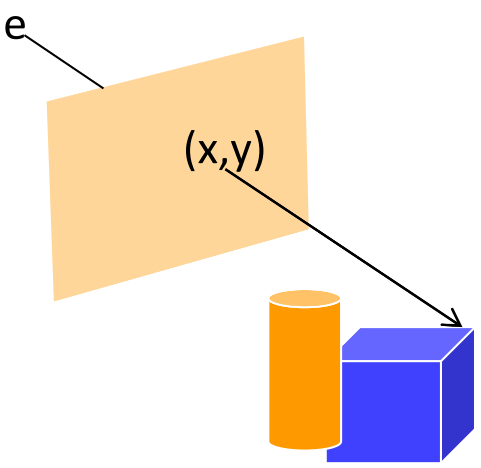
Computing the Ray Through a Pixel: Steps



Pixel **q** in local camera coords $\mathbf{[x,y,d,1]}^T$

Let **C** be camera to world transform

Sanity check $\mathbf{e} = \mathbf{C}\ \mathbf{[0,0,0,1]}^T$

pixel **q** at **(x,y)** on screen is thus $\mathbf{C}\ \mathbf{[x,y,d,1]}^T$

Ray **r** has origin at **q** and direction **(q-e)/|q-e|**.

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Computing Ray-Triangle Intersections

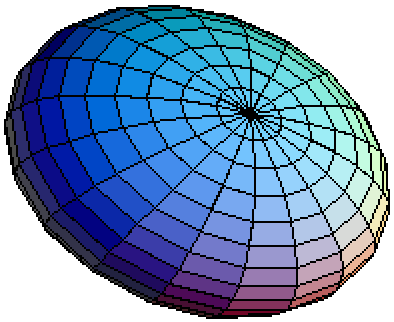
Let ray be defined parameterically as **q**+**r**t for t>=0.

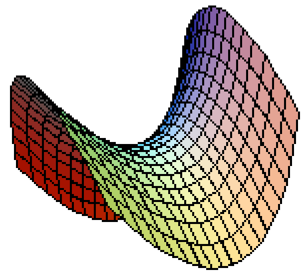
Compute plane of triangle **<p1,p2,p3>** as a point **p1** and normal **n= (p2-p1)x(p3-p2)**. Now **(p-p1).n=0** is equation of plane.

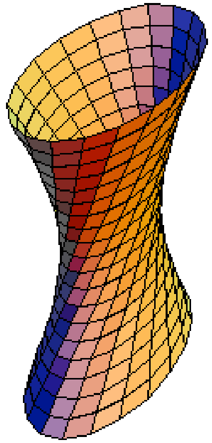
Compute the ray-plane intersection value t by solving
(q+rt-p1).n=0 => t= (p1-q).n /(r.n)

Check if intersection point at the **t** above falls within triangle.

Computing Ray-Quadric Intersections







Implicit equation for quadrics is

$\mathbf{p}^T\mathbf{Q}\mathbf{p} = \mathbf{0}$ where $\mathbf{Q}$ is a 4x4 matrix of coefficients.

Substituting the ray equation $\mathbf{q}+\mathbf{r}t$ for $\mathbf{p}$ gives us a quadratic equation in t, whose roots are the intersection points.

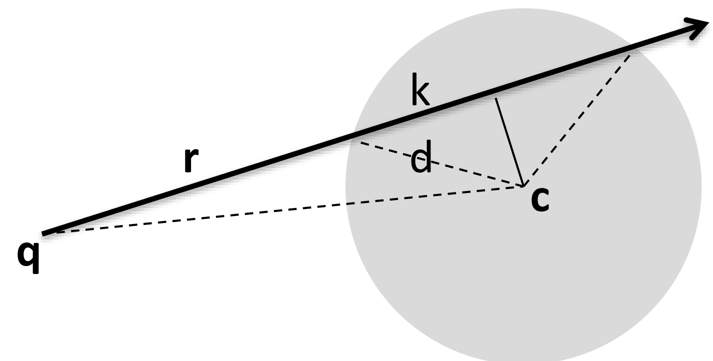
Computing Ray-Sphere Intersections

$(\mathbf{c}-\mathbf{q})^2 - ((\mathbf{c}-\mathbf{q}).\mathbf{r})^2 = d^2 - k^2$

Solve for k, if it exists.

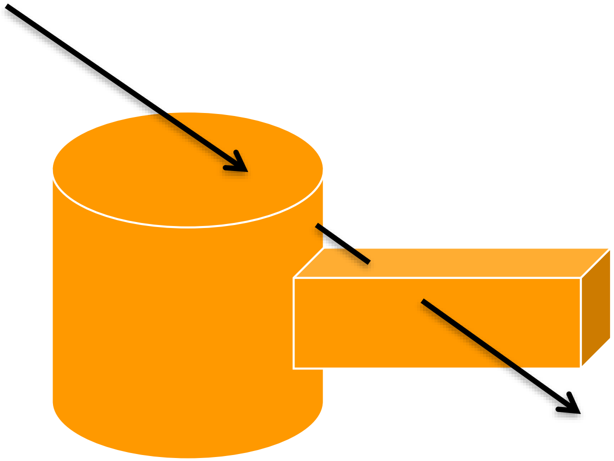
Intersections:

$\mathbf{q}+\mathbf{r}((\mathbf{c}-\mathbf{q}).\mathbf{r} \;+/-\; k)$

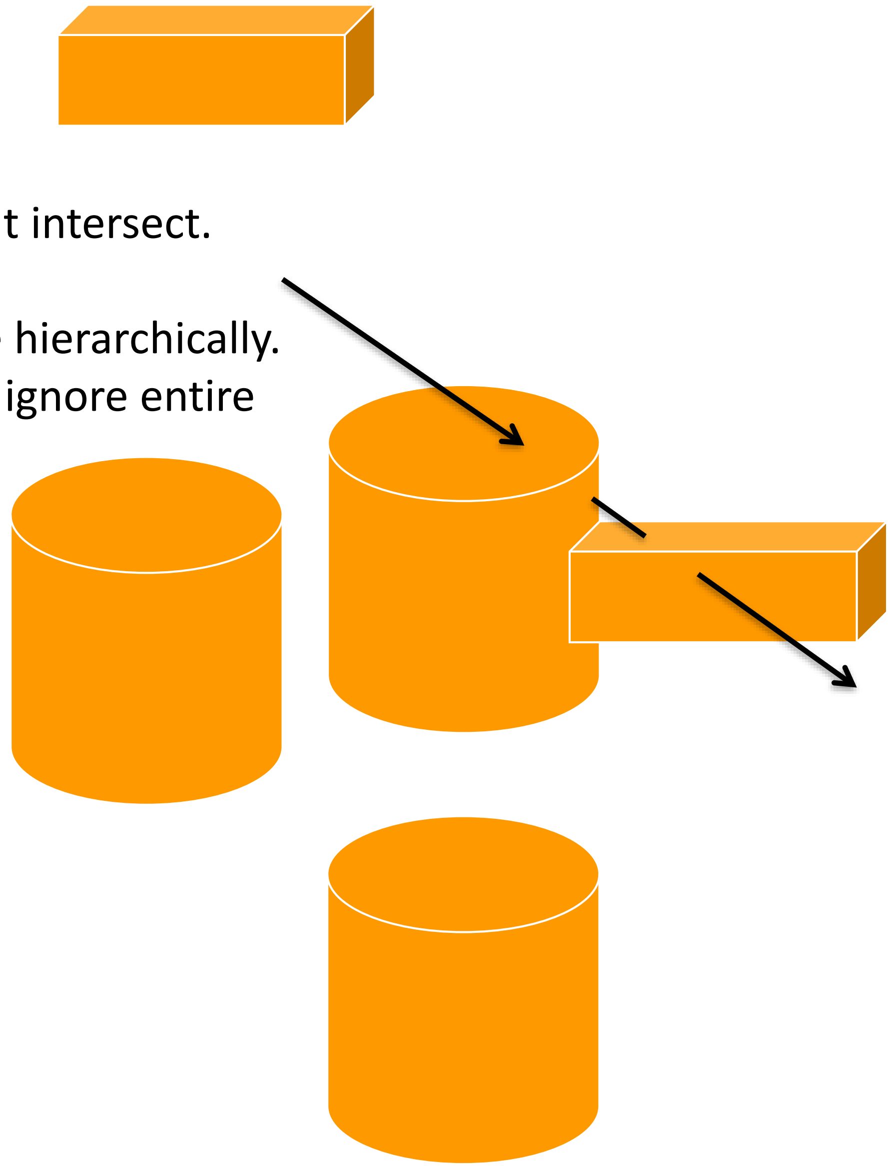


Intersecting Rays & Composite Objects

- Intersect ray with component objects
- Process the intersections ordered by depth to return intersection pairs with the object.



Ray Intersection: Efficiency Considerations



Speed-up the intersection process.

- Ignore object that clearly don't intersect.
- Use proxy geometry.
- Subdivide and structure space hierarchically.
- Project volume onto image to ignore entire

Sets of rays.

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Computing the Normal at a Hit Point

- Polygon Mesh: interpolate normals like with Phong Shading.
- Implicit surface *f(p)=0* : normal is *gradient(f)(p).*
- Explicit parametric surface *f(a,b)*: *δf(s,b)/ δs X δf(a,t)/ δt*
- Affinely transformed shape:

$$n^T \times t = n^T \times M_l^{-1} M_l \times t$$

$$n^T \times t = n^T \times M_l^{-1} M_l \times t = (M_l^{-1T} \times n)^T (M_l \times t)$$

$$n^T \times t = (M_l^{-1T} \times n)^T \times t'$$

$$n' = M_l^{-1T} \times n$$

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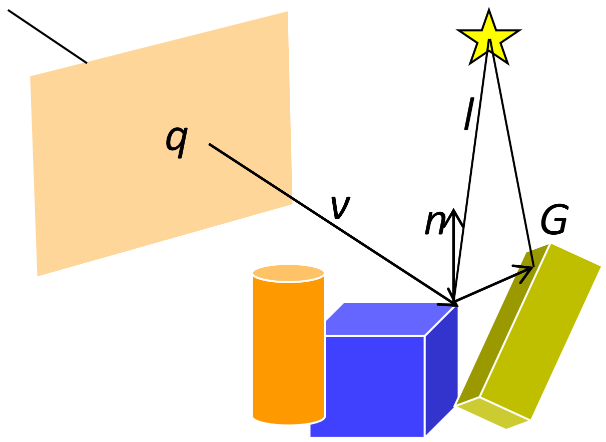
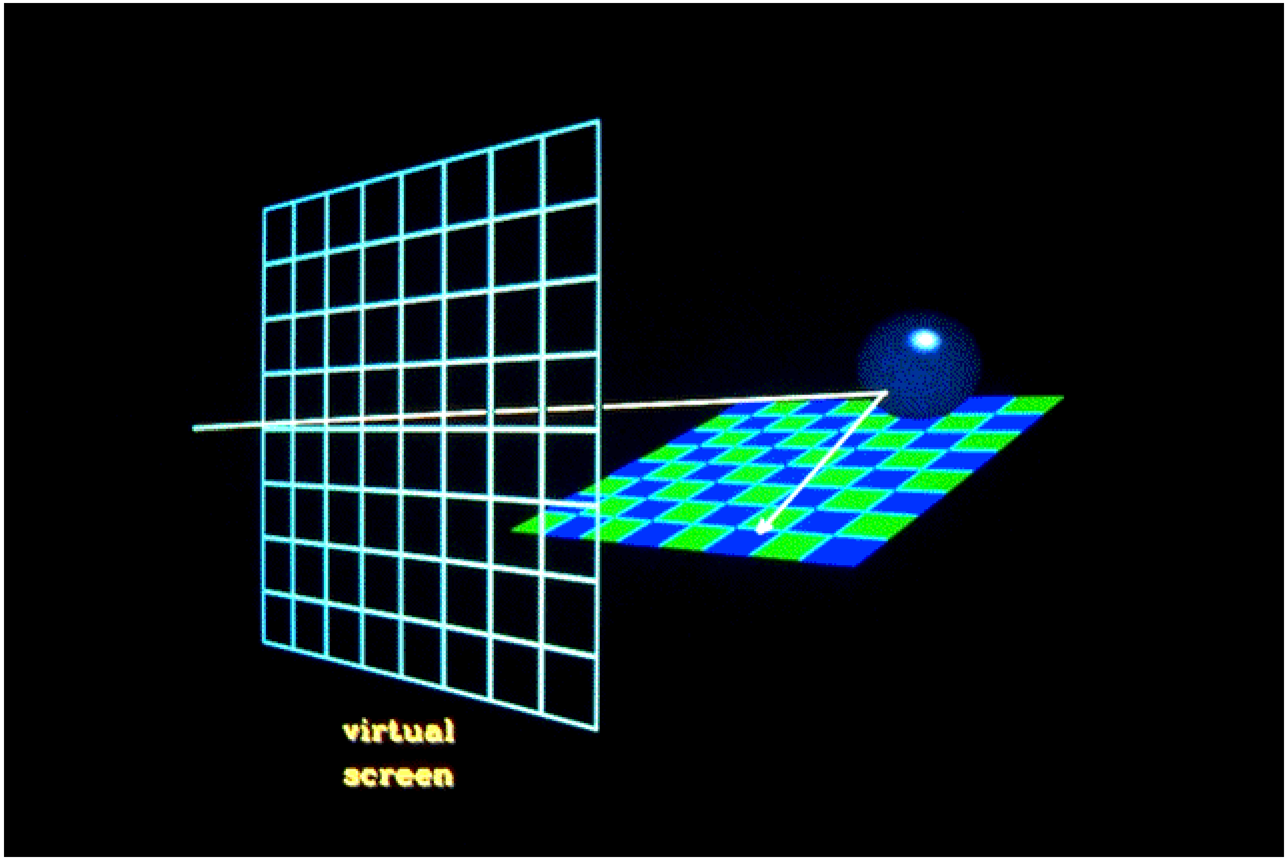
Evaluating the Shading Model

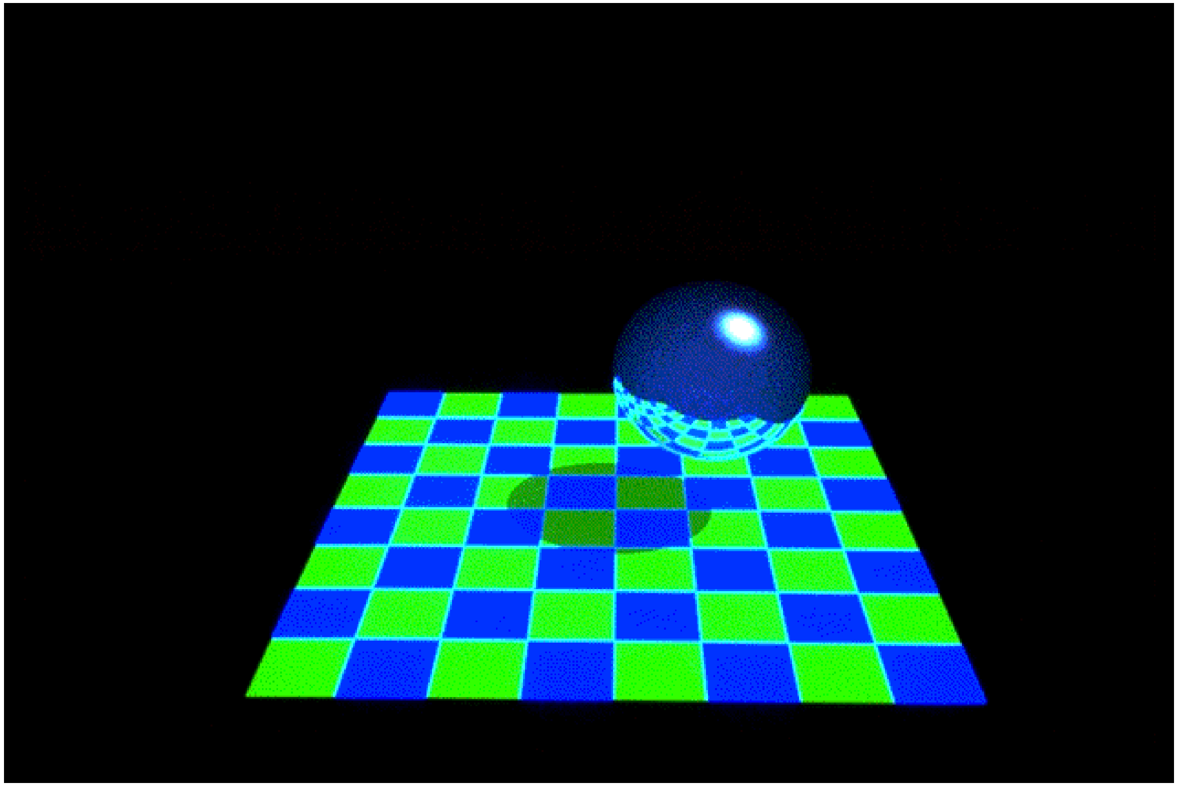
$I(q)$	$=$	$L(n,v,l)$	$+$	$G(p)k_s$
Intensity at q	=	phong local illum.	+	global specular illum.



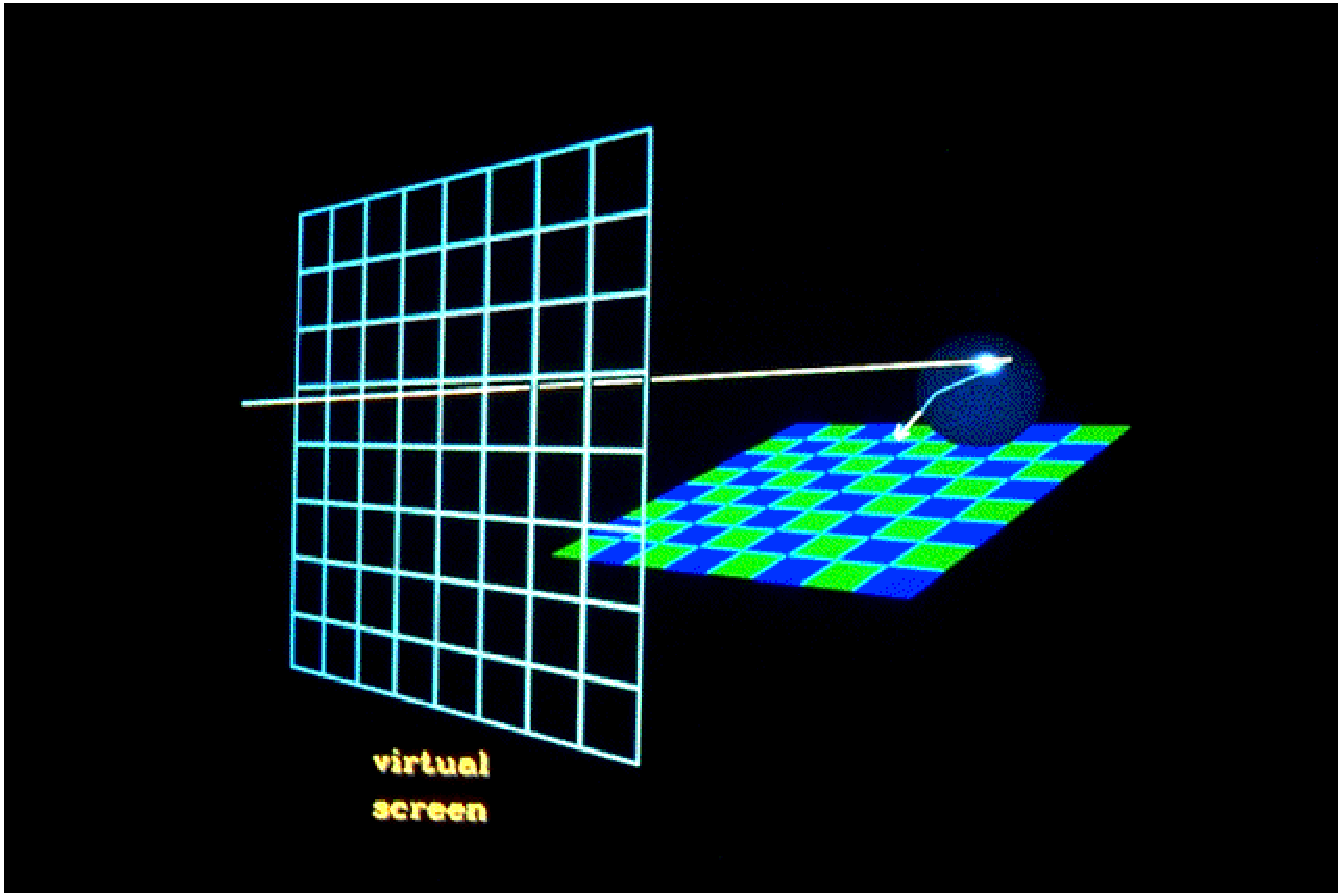
Reflected ray is sent out from intersection point



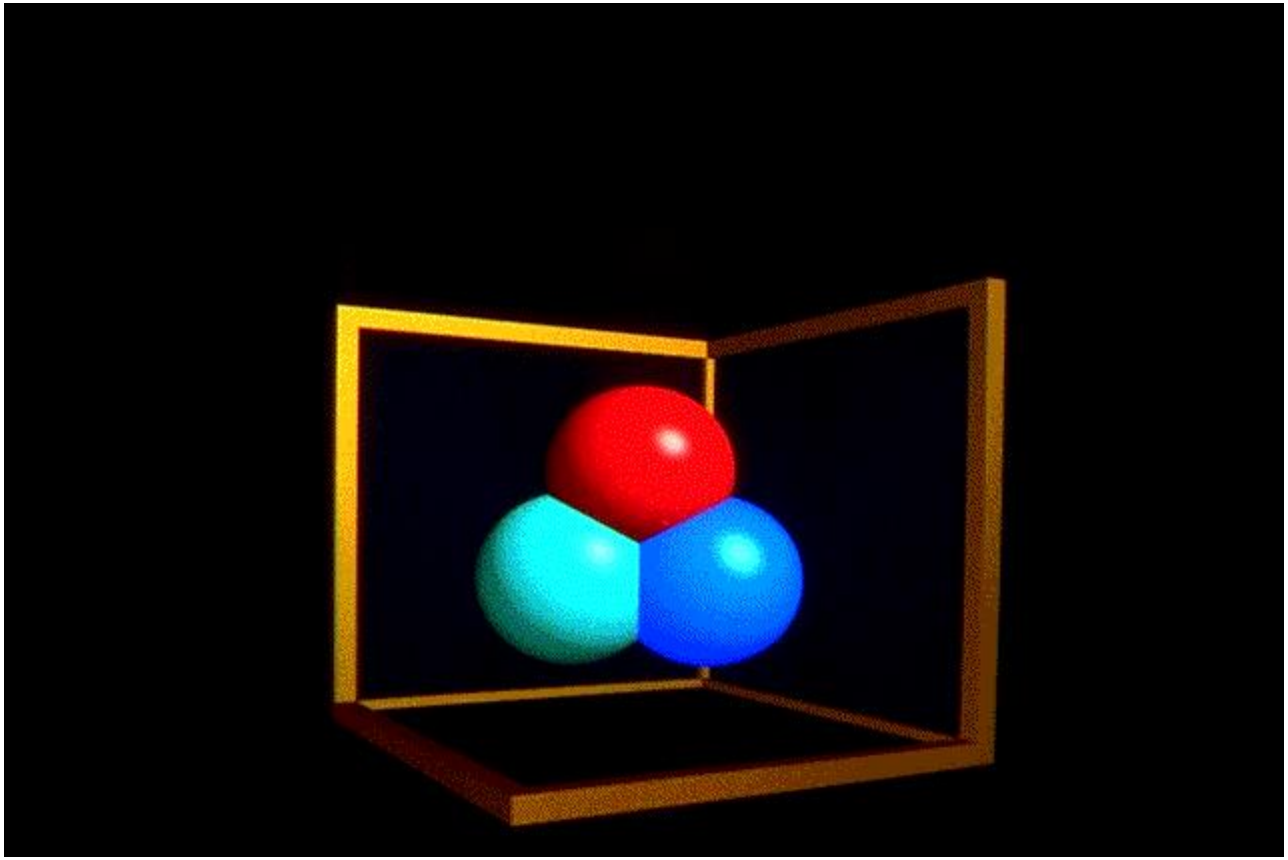
Reflected ray has hit object



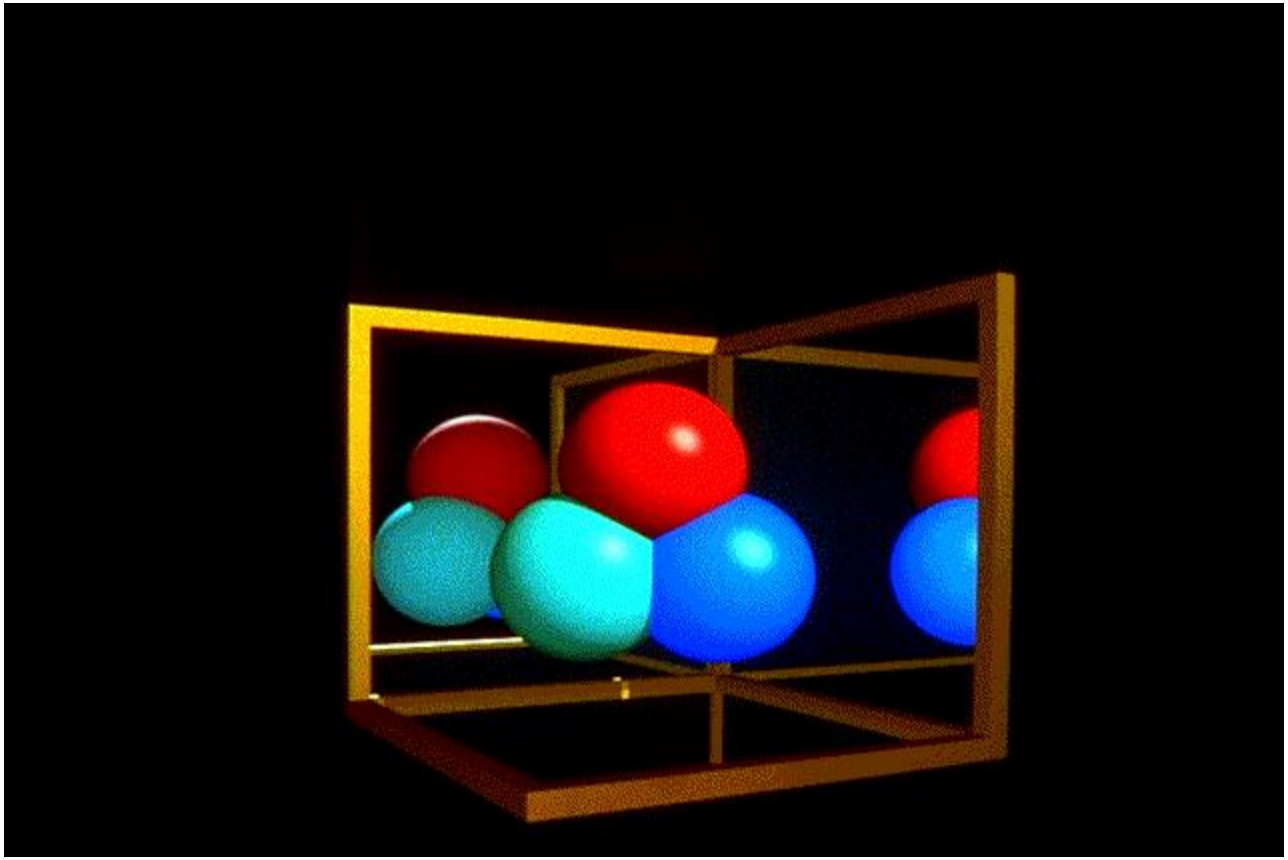
Transmitted ray generated for transparent objects



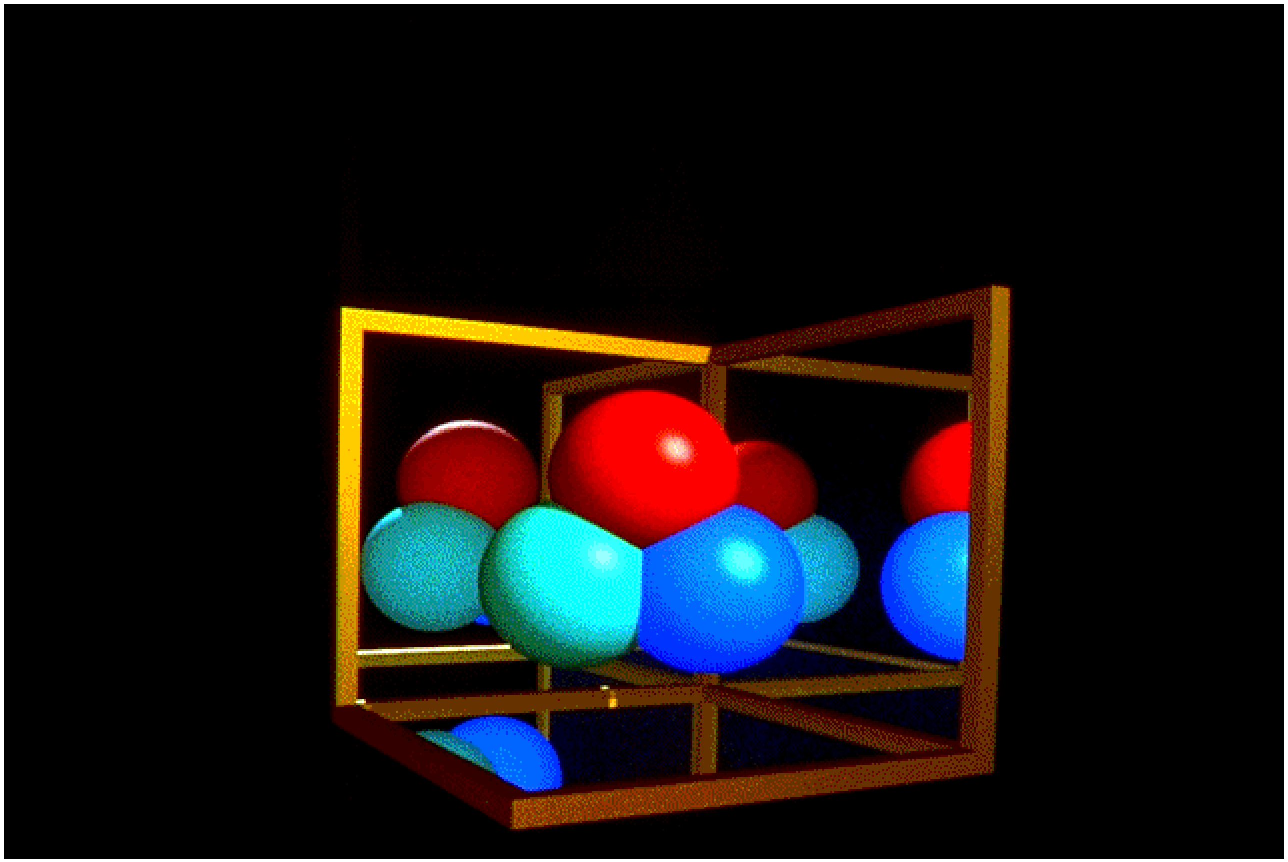
No reflection



Single reflection



Double reflection



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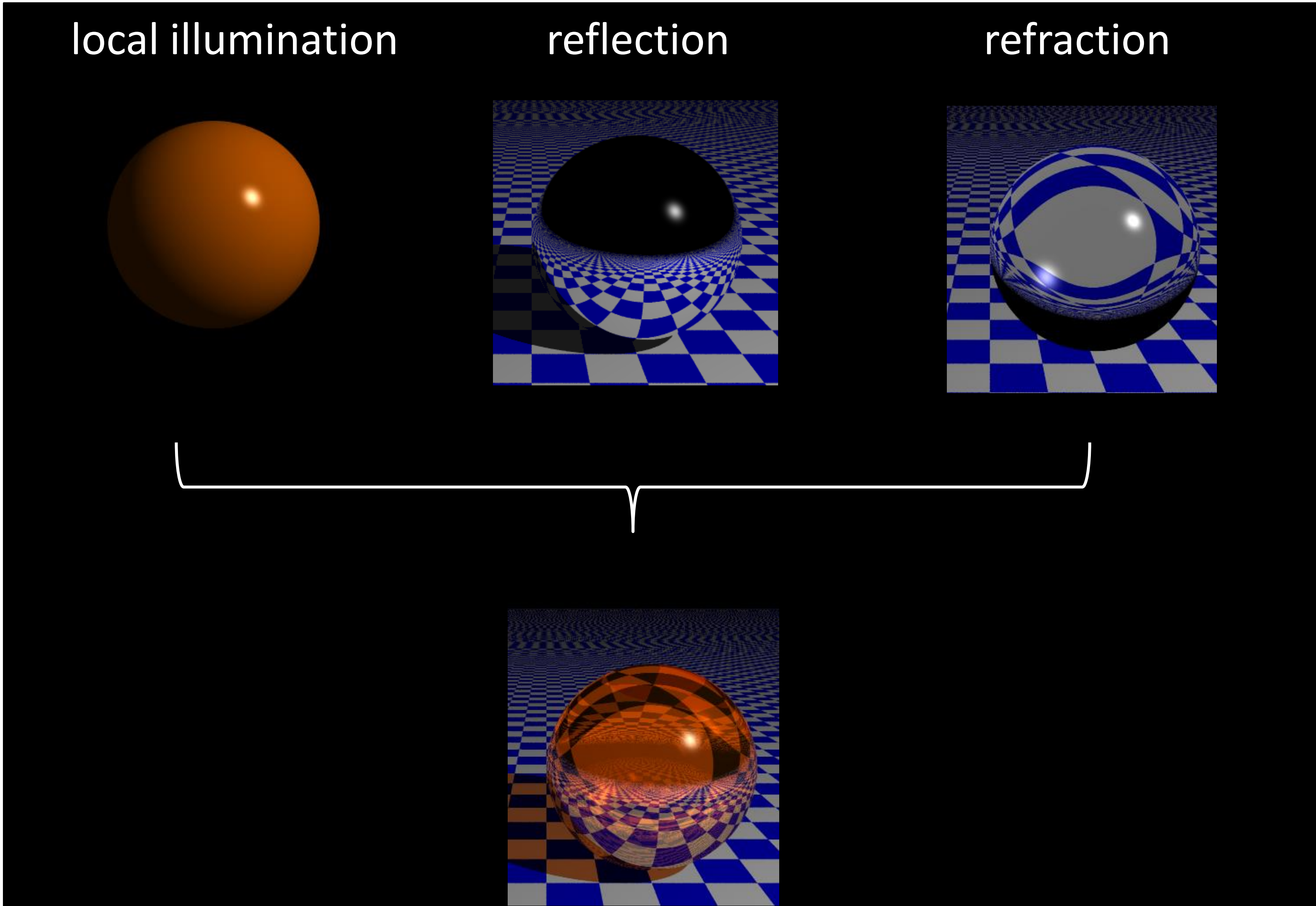
Ray Tracing with Refraction

For transparent objects spawn an additional ray along the refracted direction and recursively return the light contributed due to refraction.


local illumination
reflection
refraction

Ray Tracing Deficiencies

- Ignores light transport mechanisms involving diffuse surfaces.

- Intersection computation time can be long and recursive algorithm can lead to exponential complexity.

Ray Tracing Efficiency Improvements

Bounding volumes

Spatial subdivision

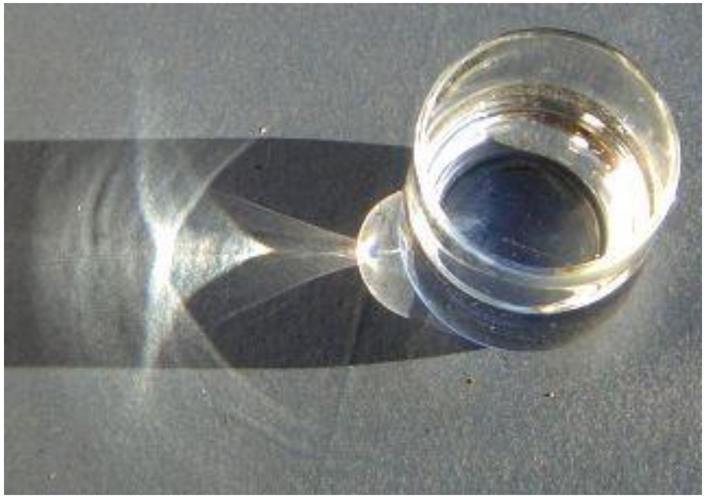
- Octrees
- BSP

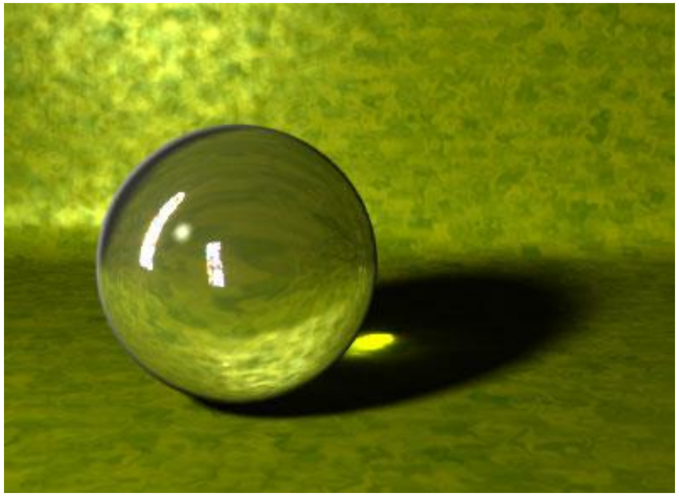
Ray Tracing Improvements: Caustics

Ray Tracing Improvements: Image Quality

Backwards ray tracing

- Trace from the light to the surfaces and then from the eye to the surfaces
- “shower” scene with light and then collect it
- “Where does light go?” vs “Where does light come from?”
- Good for caustics
- Transport E – S – S – S - D – S – S – S - L





Ray Tracing Improvements: Image Quality

Cone tracing

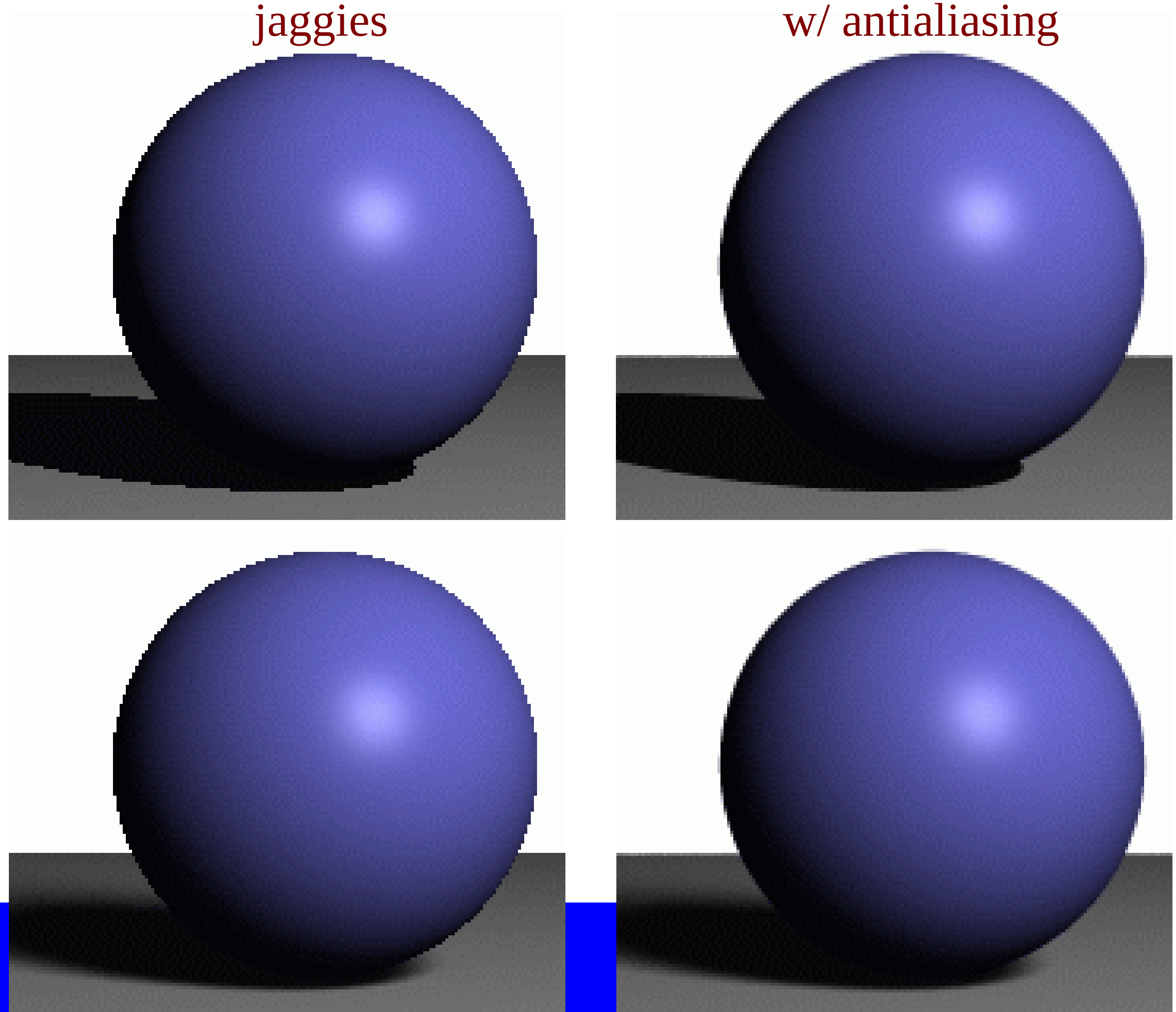
- Models some dispersion effects

Distributed Ray Tracing

- Super sample each ray
- Blurred reflections, refractions
- Soft shadows
- Depth of field
- Motion blur

Stochastic Ray Tracing

Antialiasing – Supersampling



Radiosity

- Diffuse interaction within a closed environment
- Theoretically sound
- View independent
- No specular interactions
- Color bleeding visual effects
- Transport E – D – D – D - L