קורס גרפיקה ממוחשבת

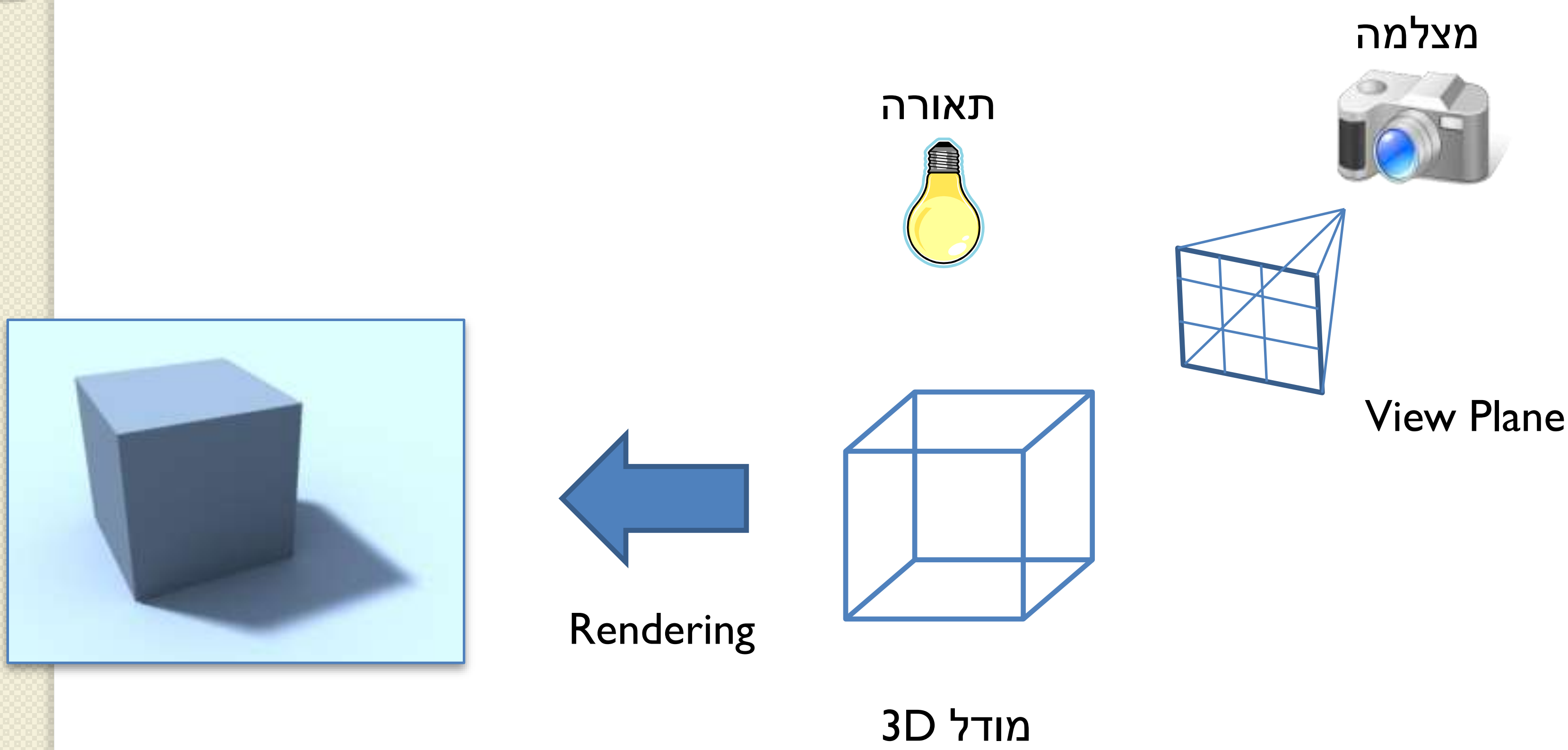
2008 סמסטר ב'

Rendering

חלק מהשקפים מעובדים משקפים של פרדו דוראנד, טומס פנקהאוסר ודניאל כהן-אור

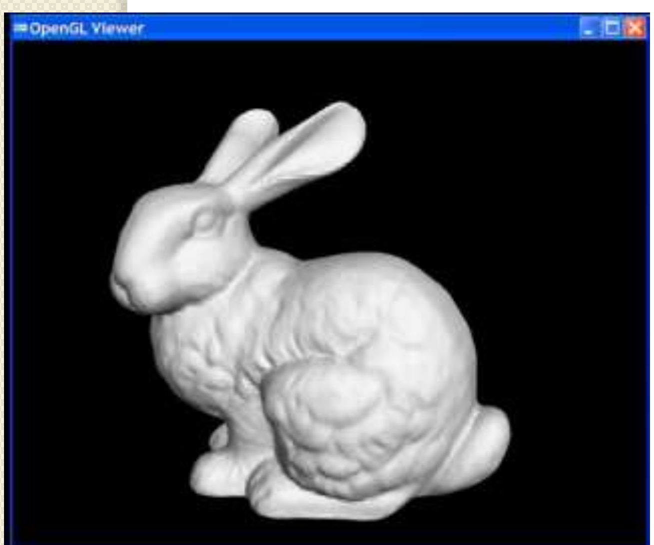
What is 3D rendering?

- Construct an image from a 3D model



Rendering Scenarios

- אינטראקטיבי
  - מייצרים תמונות בשבריר שנייה (לפחות 10 בשנייה) כאשר המשתמש שולט בפרמטרים של הרינדור
    - יש צורך להשיג את האיכות הגבוהה ביותר בהתחשב בזמן הנתון (הקצב הנדרש)
    - שימושי לויזואליזציות, משחקים וכו'



Rendering Scenarios

- אצווה (batch)
  - כל תמונה מיוצרת ברמת פירוט גבוהה ככל האפשר עבור סט ספציפי של פרמטרים
    - לוקח כמה זמן שצריך
    - שימושי לפוטוריאליזם, סרטים וכו'

Jensen

3D Rendering Issues

- What does a 3D rendering system have to do?
  - Camera
  - Visible surface determination
  - Lights
  - Reflectance
  - Shadows
  - Indirect Illumination
  - Sampling
  - Etc.

Camera Models

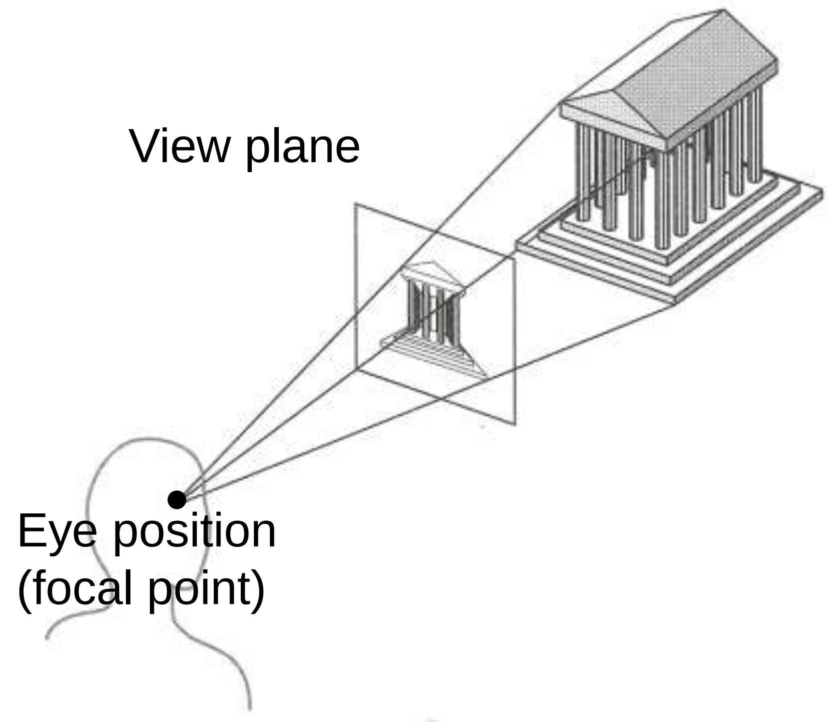
- The most common model is pin-hole camera
  - All captured light rays arrive along paths toward focal point without lens distortion (everything is in focus)
  - Sensor response proportional to radiance

Other models consider …

Depth of field

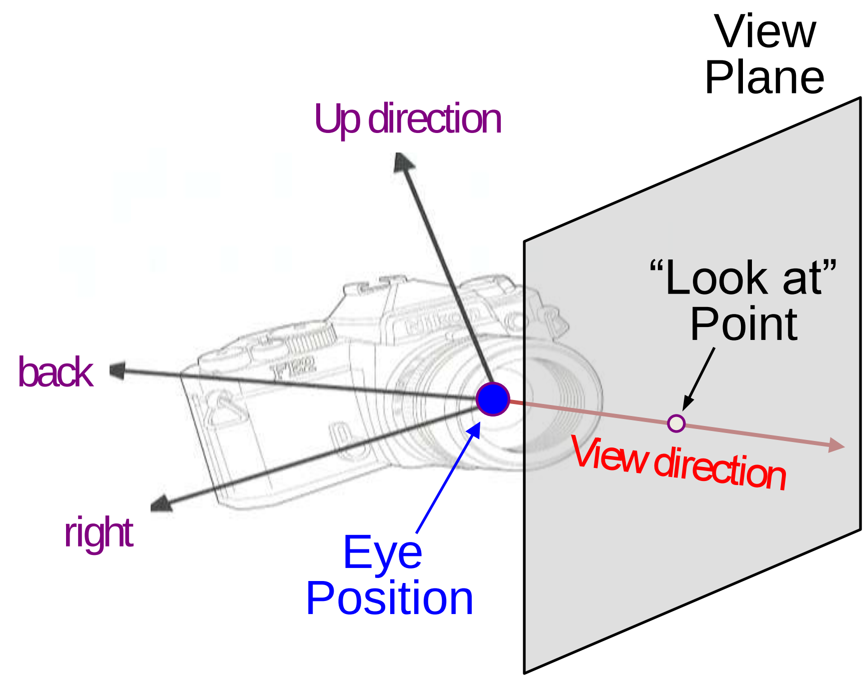
Motion blur

Lens distortion

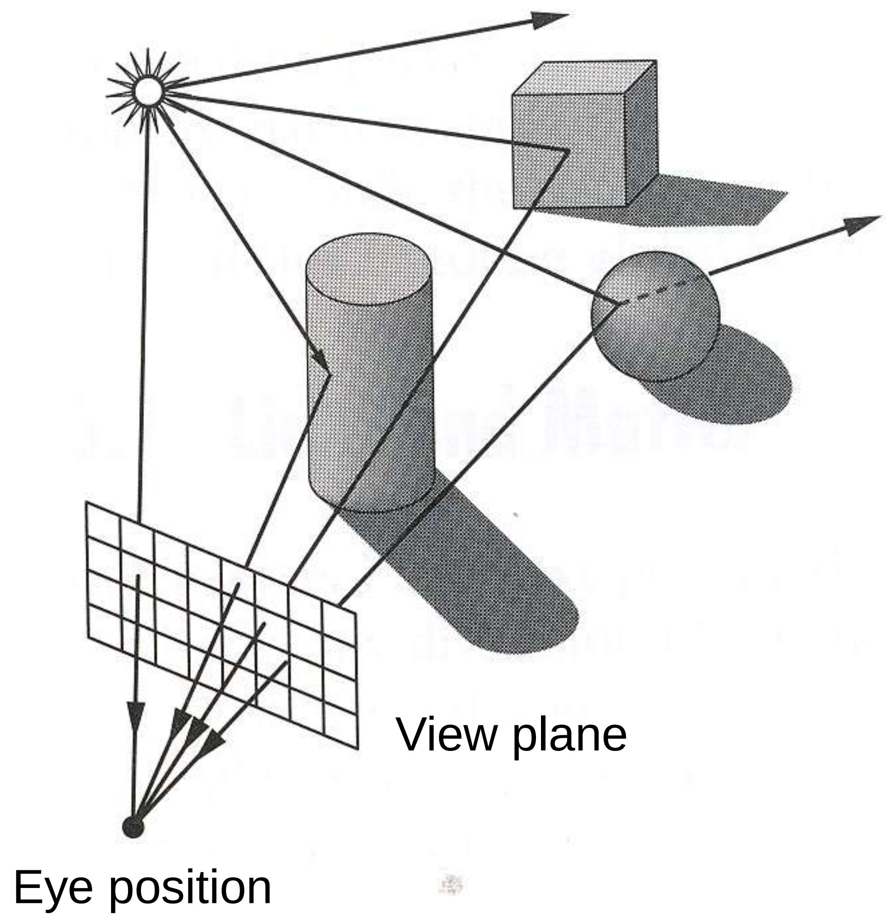


Camera Parameters

- Position
  - Eye position (px, py, pz)
- Orientation
  - View direction (dx, dy, dz)
  - Up direction (ux, uy, uz)
- Aperature
  - Field of view (xfov, yfov)
- Film plane
  - “Look at” point
  - View plane normal



View Plane



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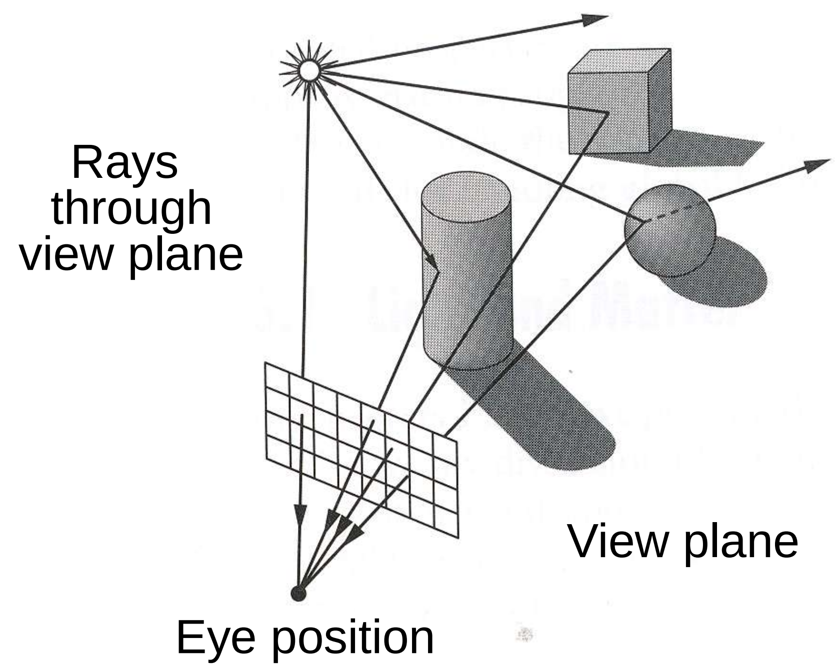
Visible Surface Determination

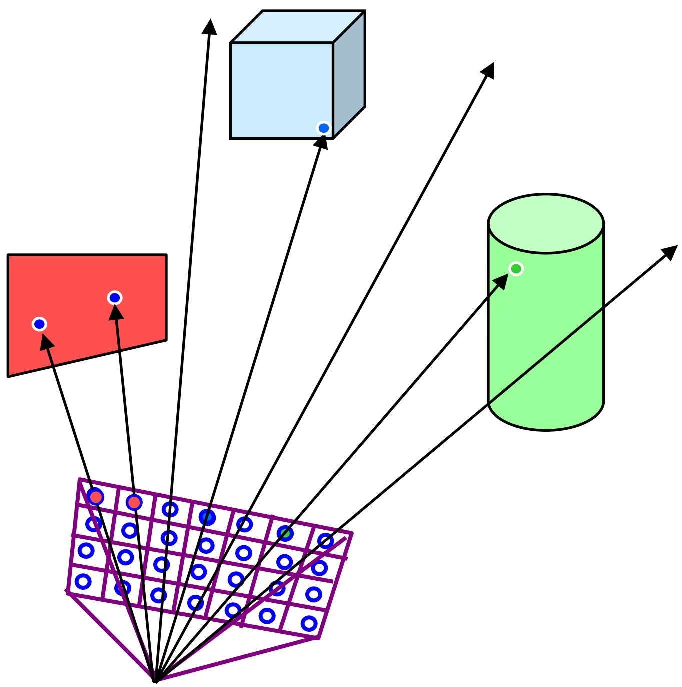
- The color of each pixel on the view plane depends on the radiance emanating from visible surfaces

Simplest method is ray casting



Ray Casting

- For each sample …
  - Construct ray from eye position through view plane
  - Find first surface intersected by ray through pixel
  - Compute color of sample based on surface radiance



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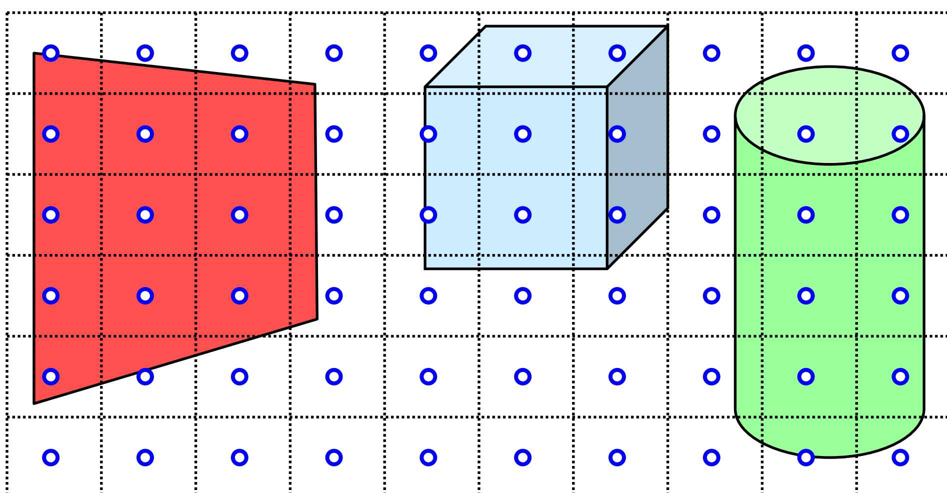

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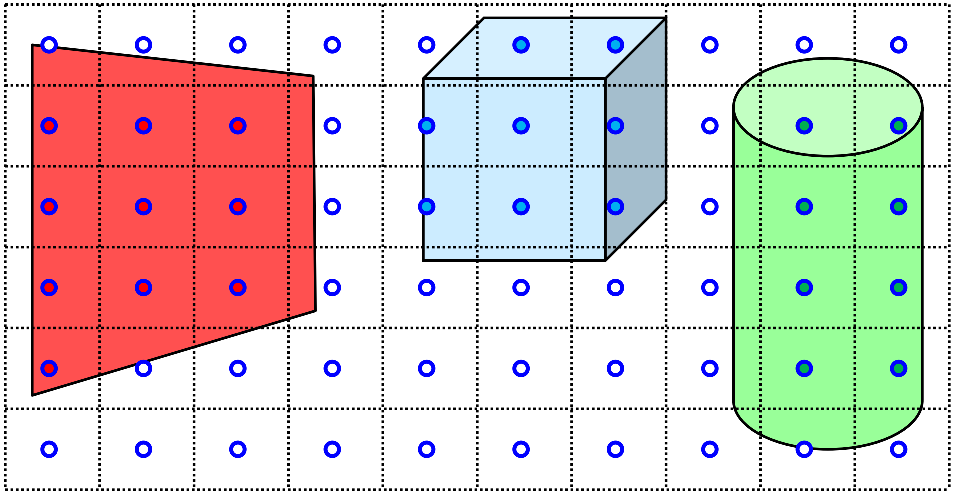

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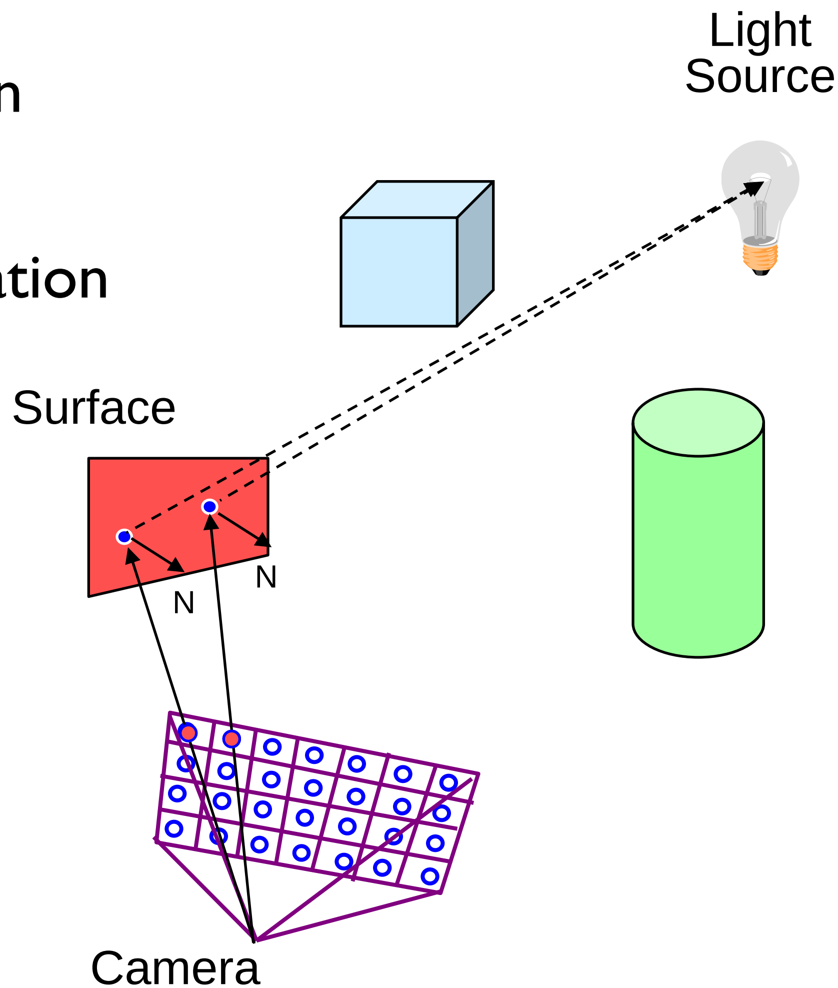
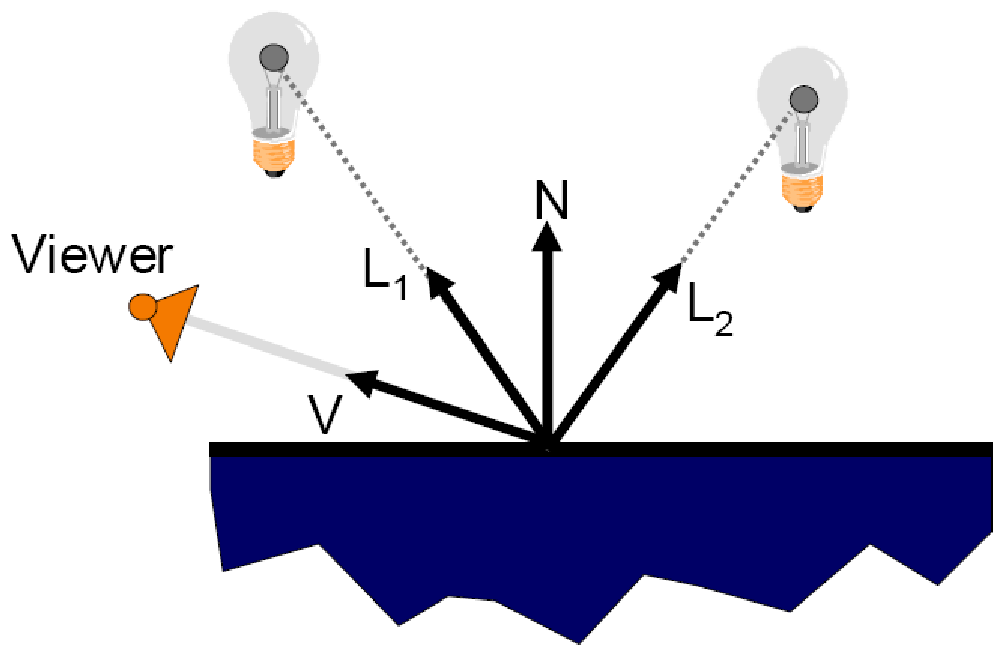
Lighting Simulation

- Lighting parameters
  - Light source emission
  - Surface reflectance
  - Atmospheric attenuation
  - Camera response

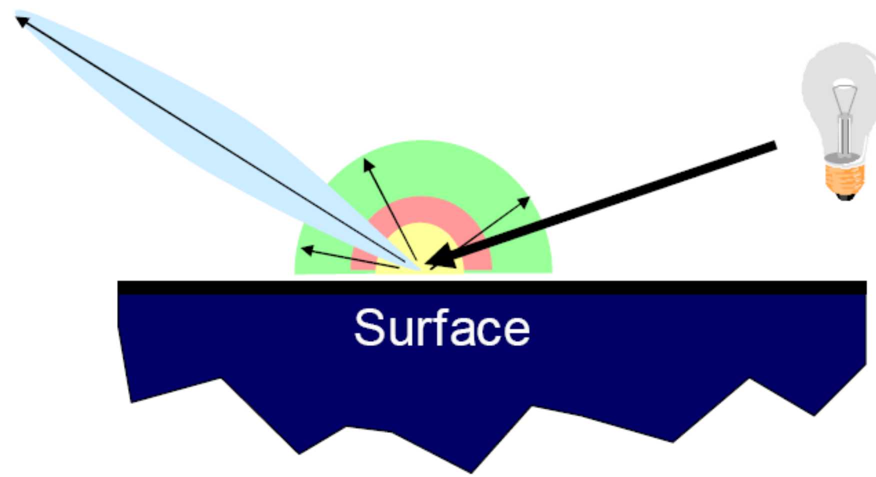


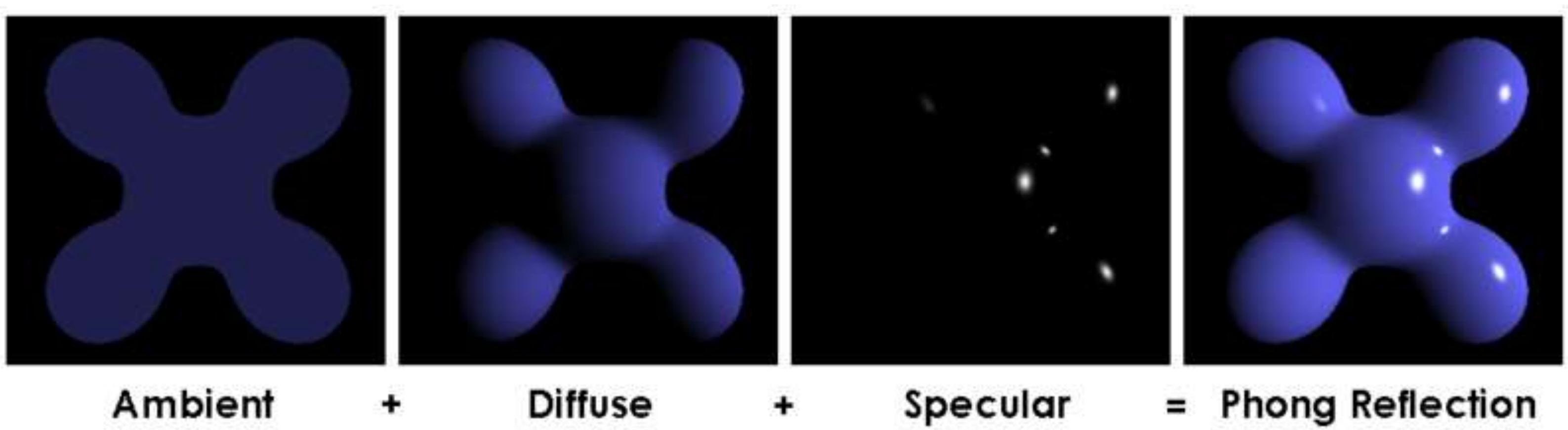
Lighting Simulation



OpenGL Reflectance Model

- Simple analytic model
  - Diffuse reflection+
  - Specular reflection+
  - Emission+
  - “ambient”





3D Rendering Issues

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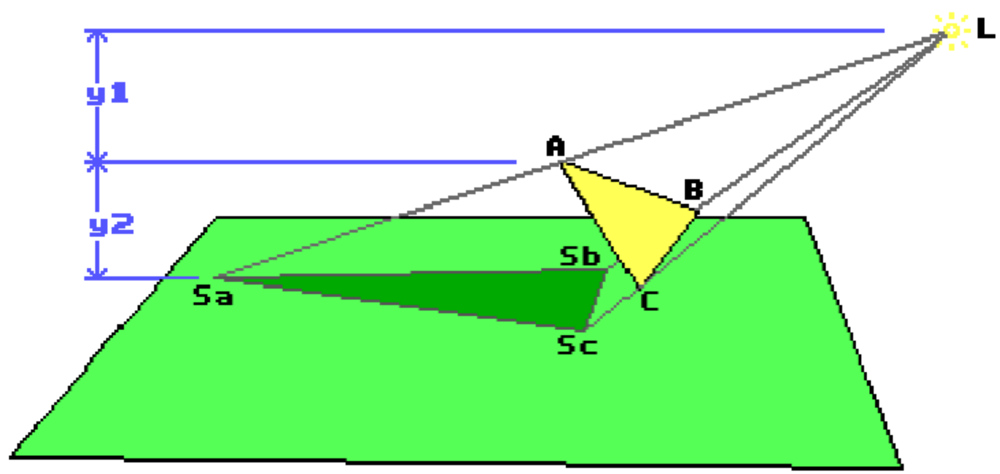
Shadows

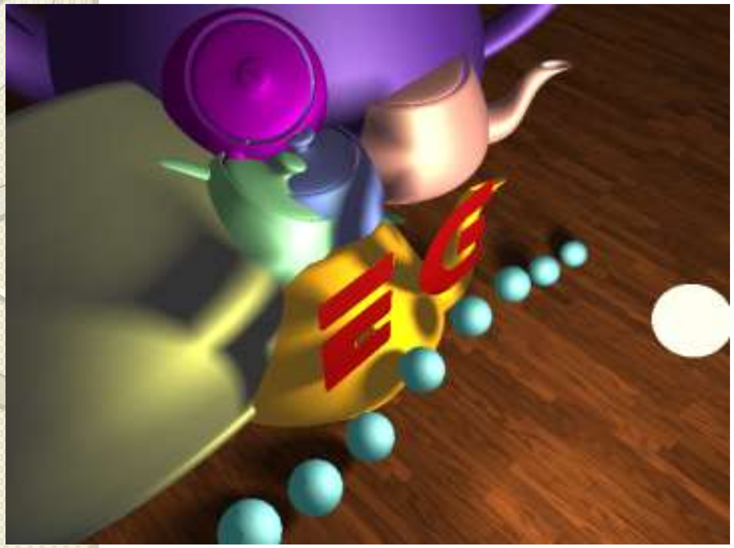
- Occlusions from light sources

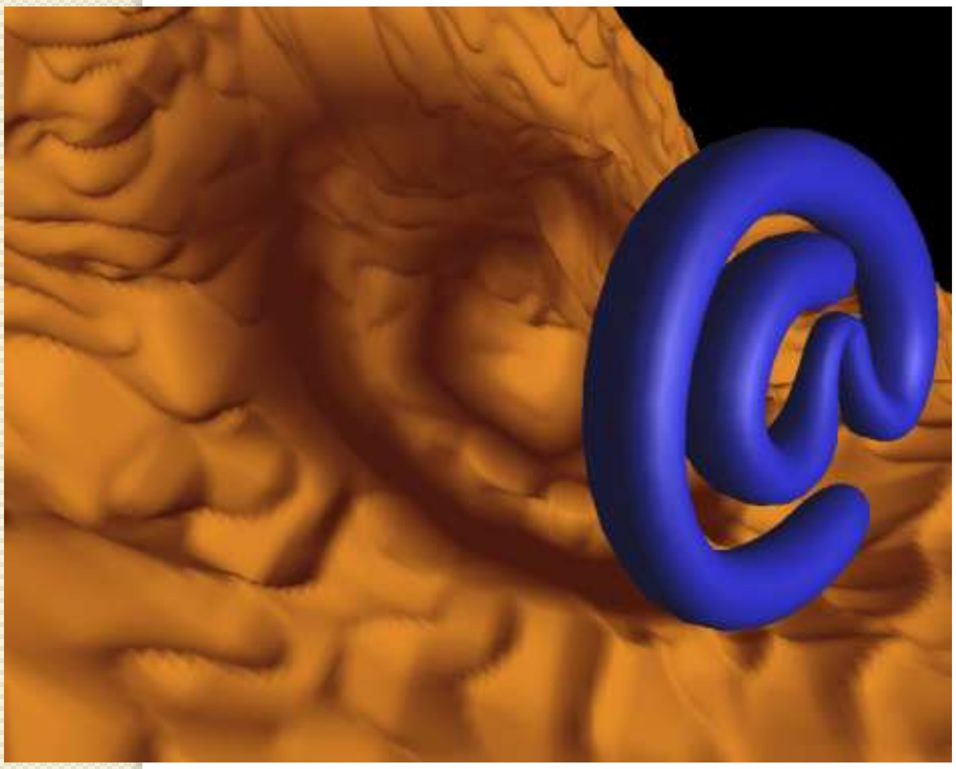


Shadows

- Occlusions from light sources
  - Soft shadows with area light source

Shadows





3D Rendering Issues

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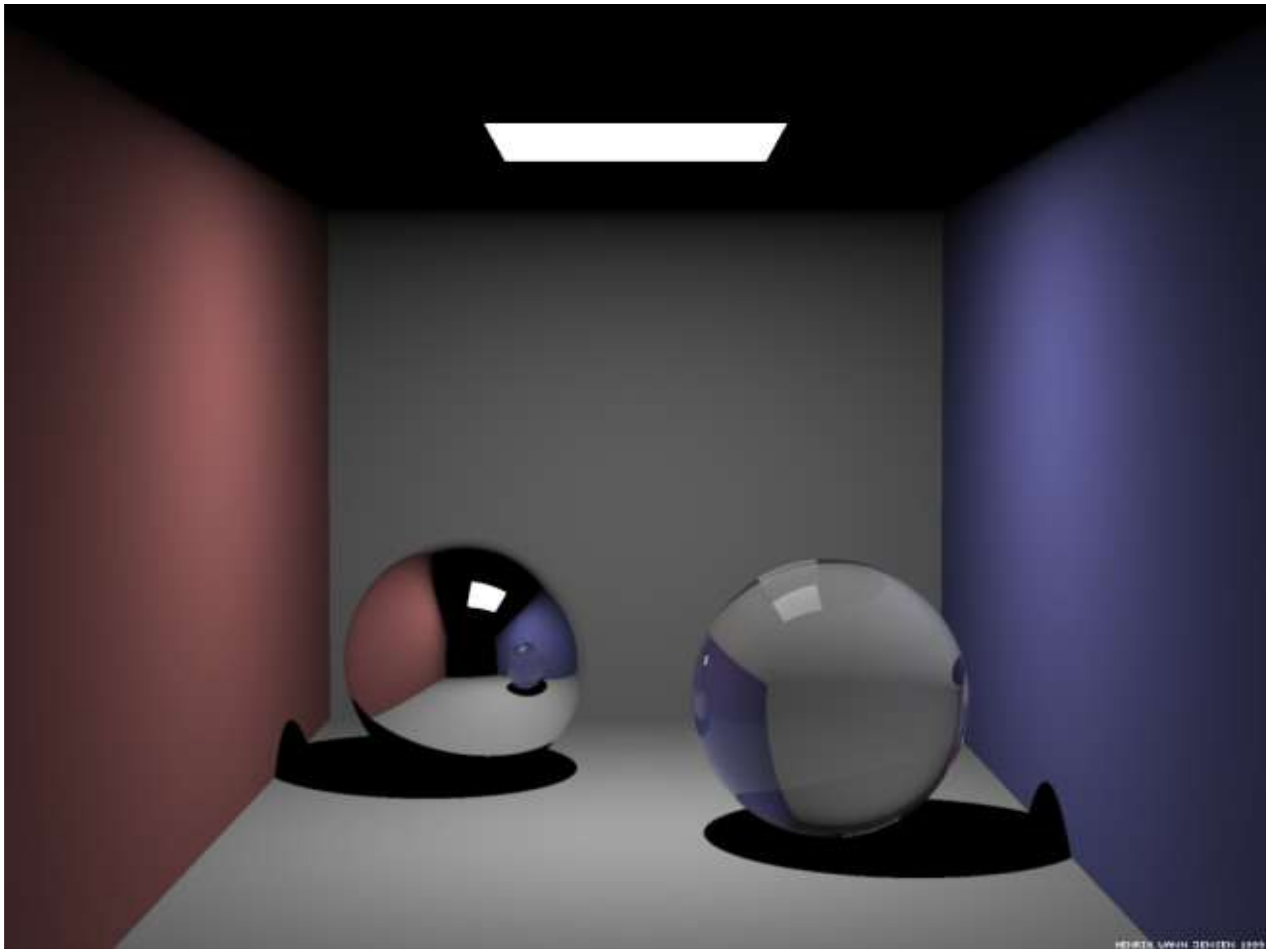
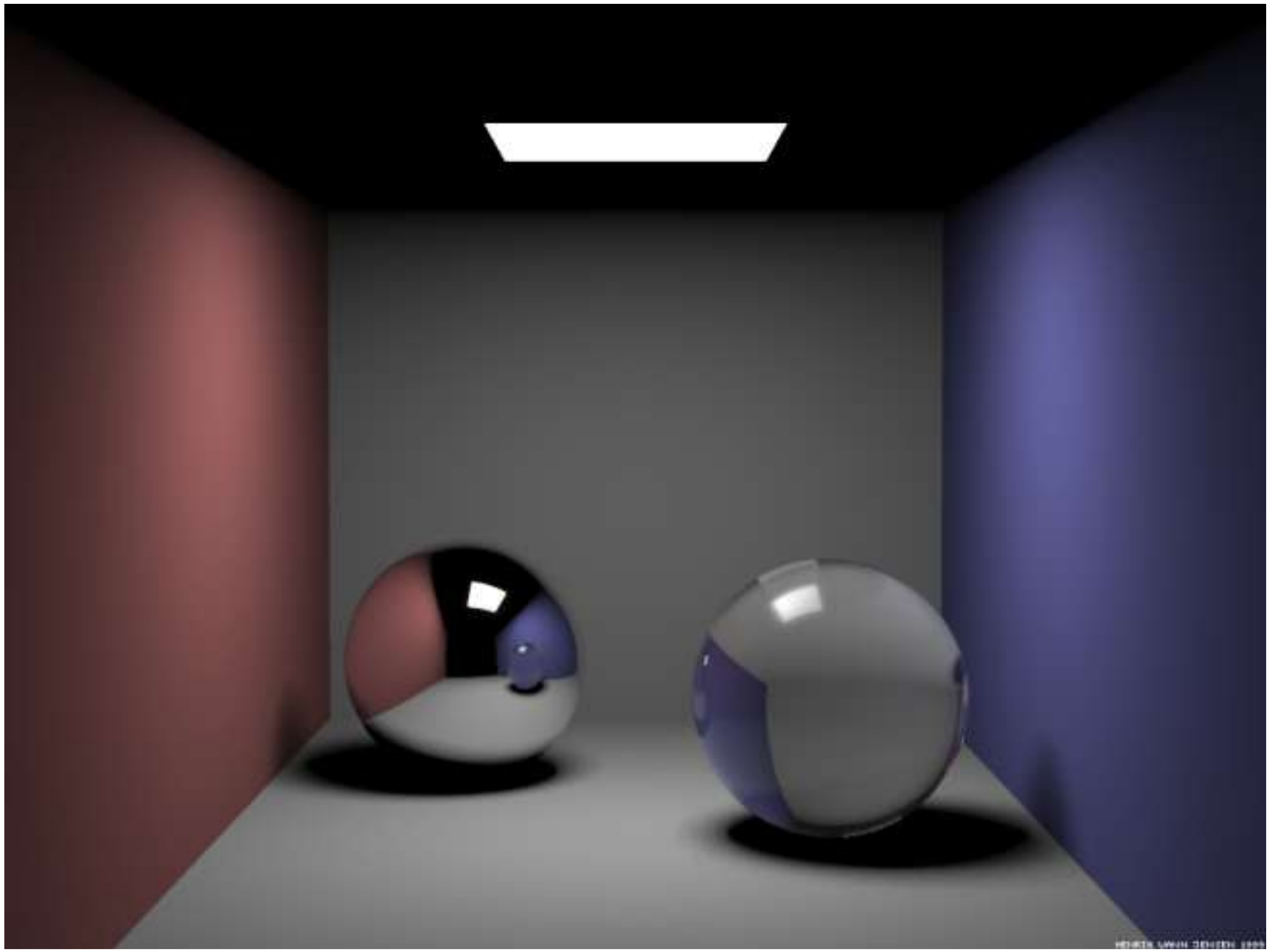
Path Types

Direct diffuse + indirect specular and transmission



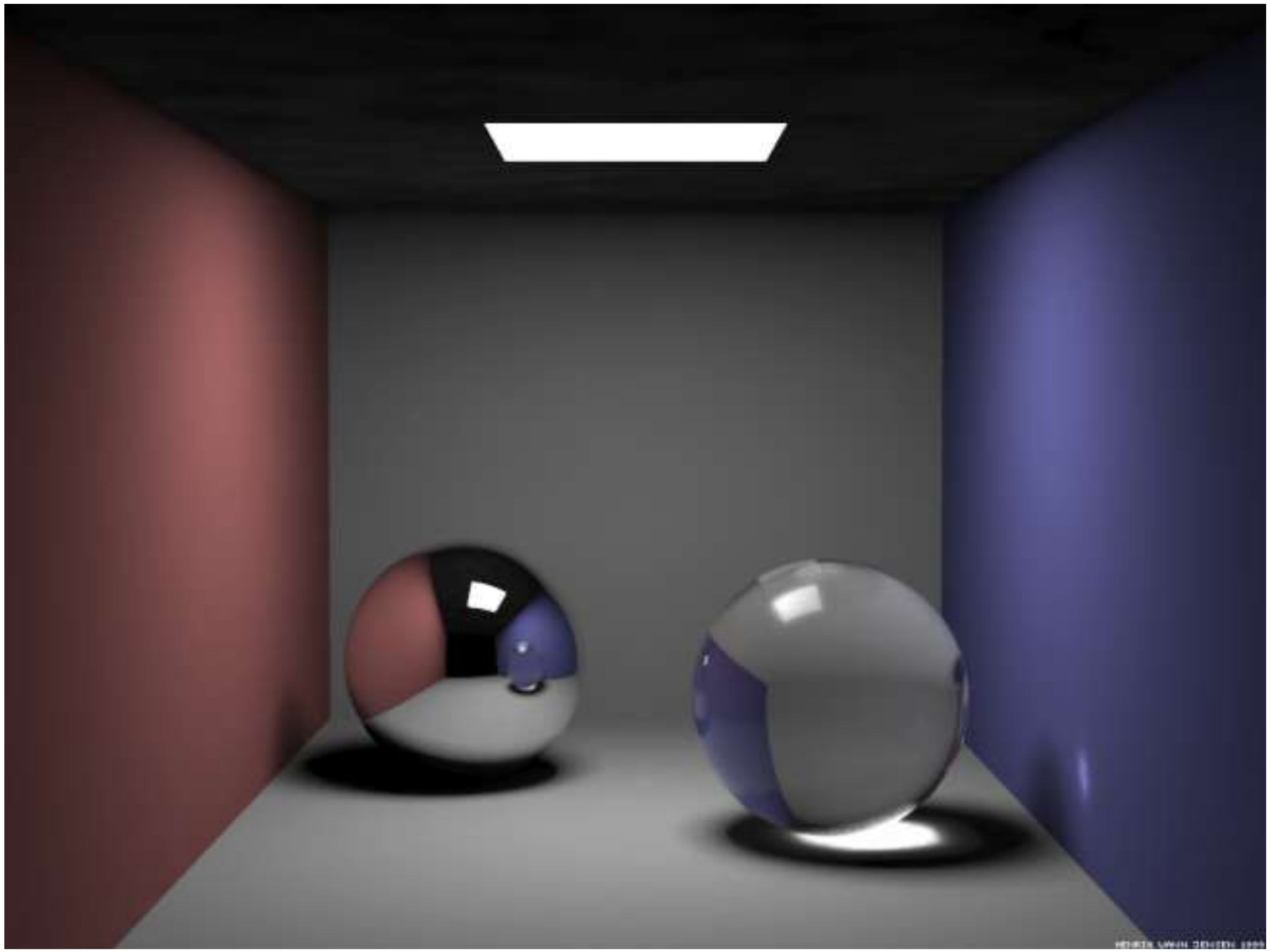
Path Types

+ Soft Shadows



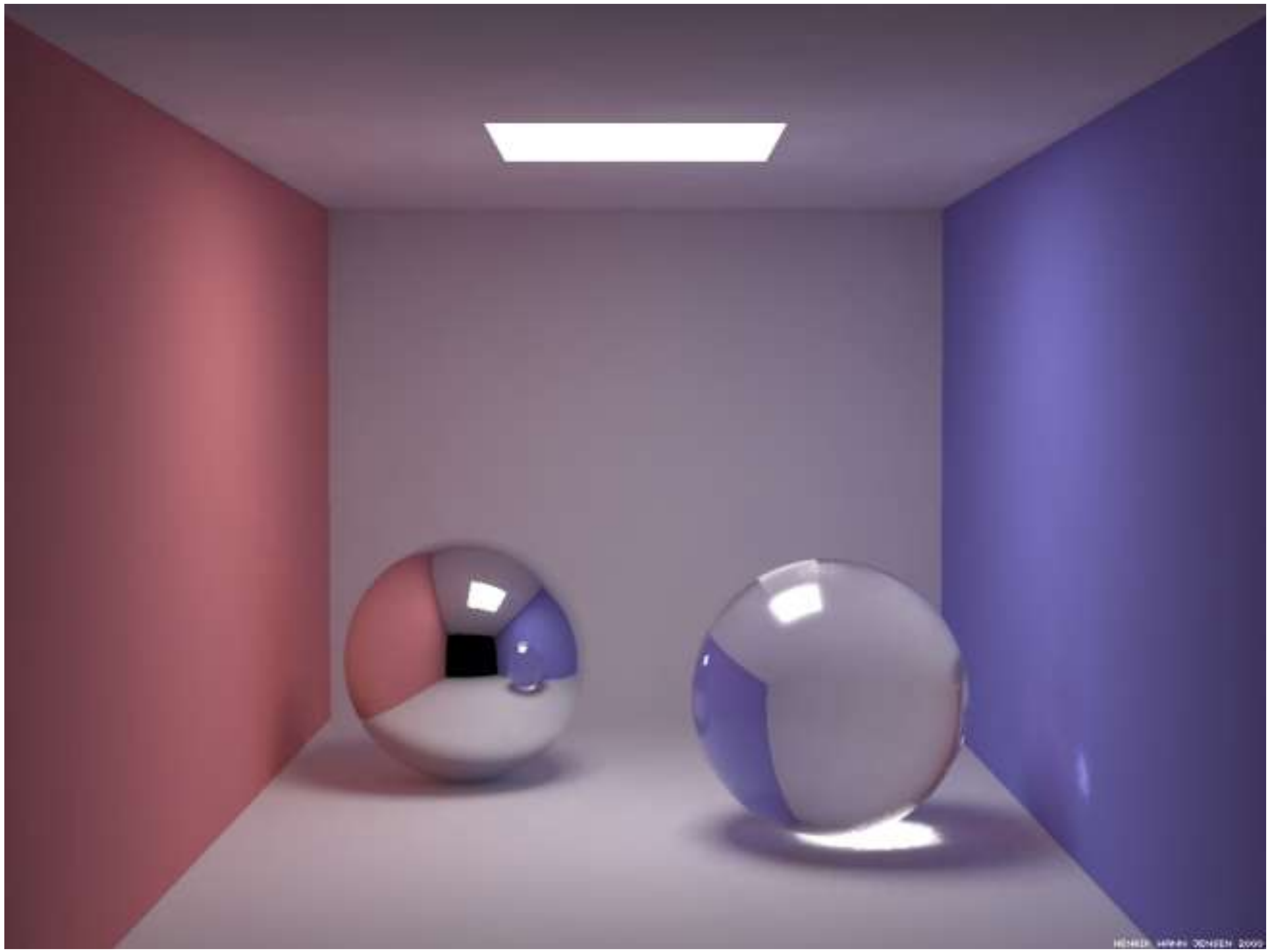
Path Types

+ caustics



Path Types

+ indirect diffuse illumination



3D Rendering Issues

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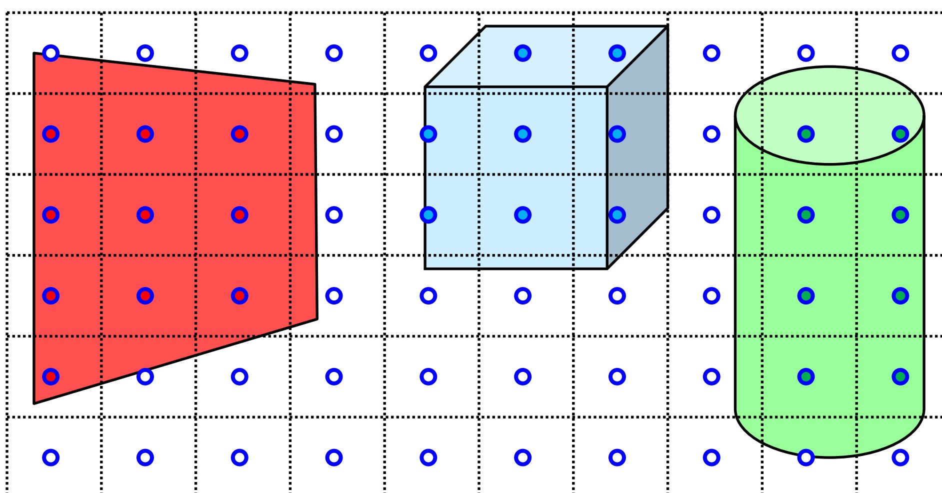
  - Etc.

- Scene can be sampled with any ray
  - Rendering is a problem in sampling and reconstruction

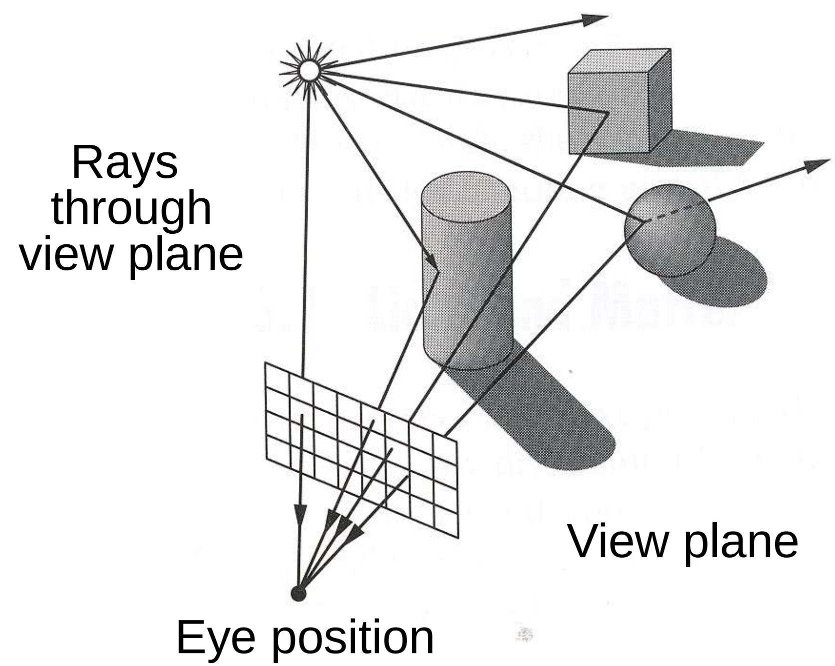


RAY CASTING

3D Rendering

- The color of each pixel on the view plane depends on the radiance emanating from visible surfaces

Simplest method is ray casting



Ray Casting

- For each sample …
  - Construct ray from eye position through view plane
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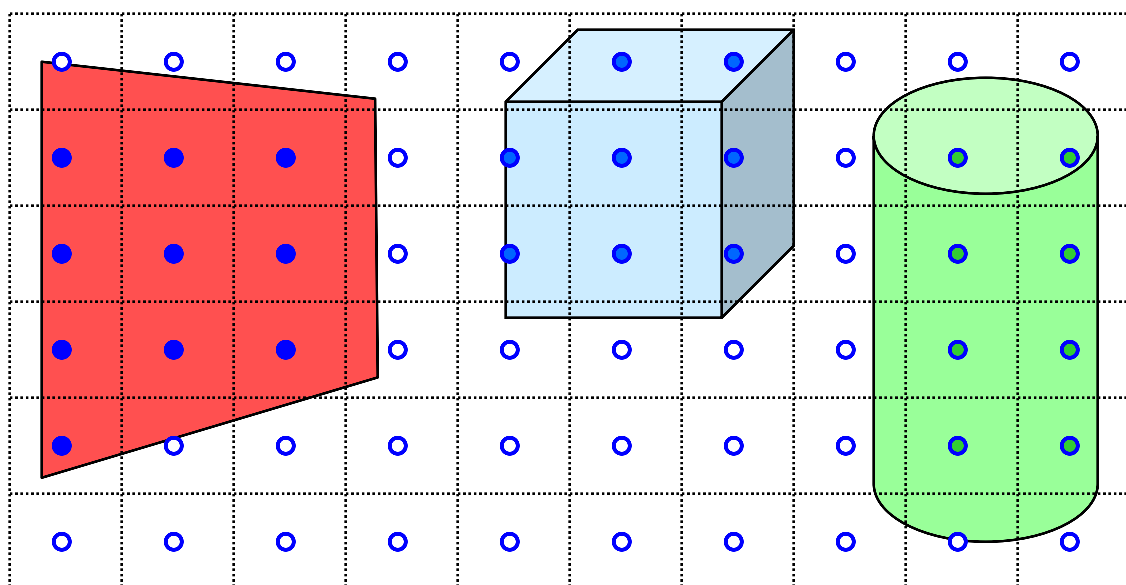

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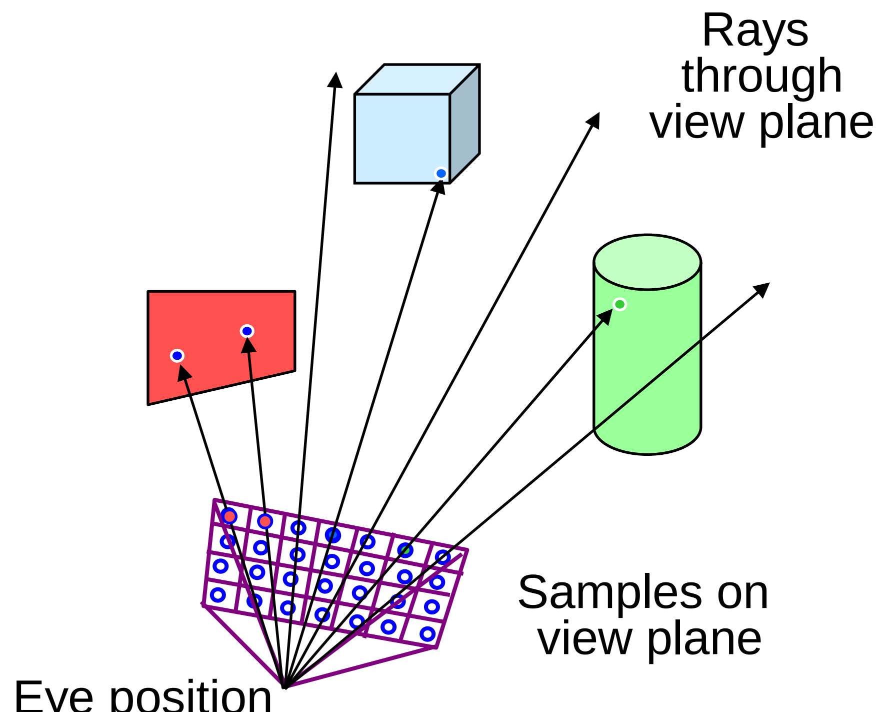

Ray Casting

- Simple implementation:

```
Image RayCast(Camera camera, Scene scene, int width, int height)
{
    Image image = new Image(width, height);
    for (int i = 0; i < width; i++) {
        for (int j = 0; j < height; j++) {
            Ray ray = ConstructRayThroughPixel(camera, i, j);
            Intersection hit = FindIntersection(ray, scene);
            image[i][j] = GetColor(hit);
        }
    }
    return image;
}
```

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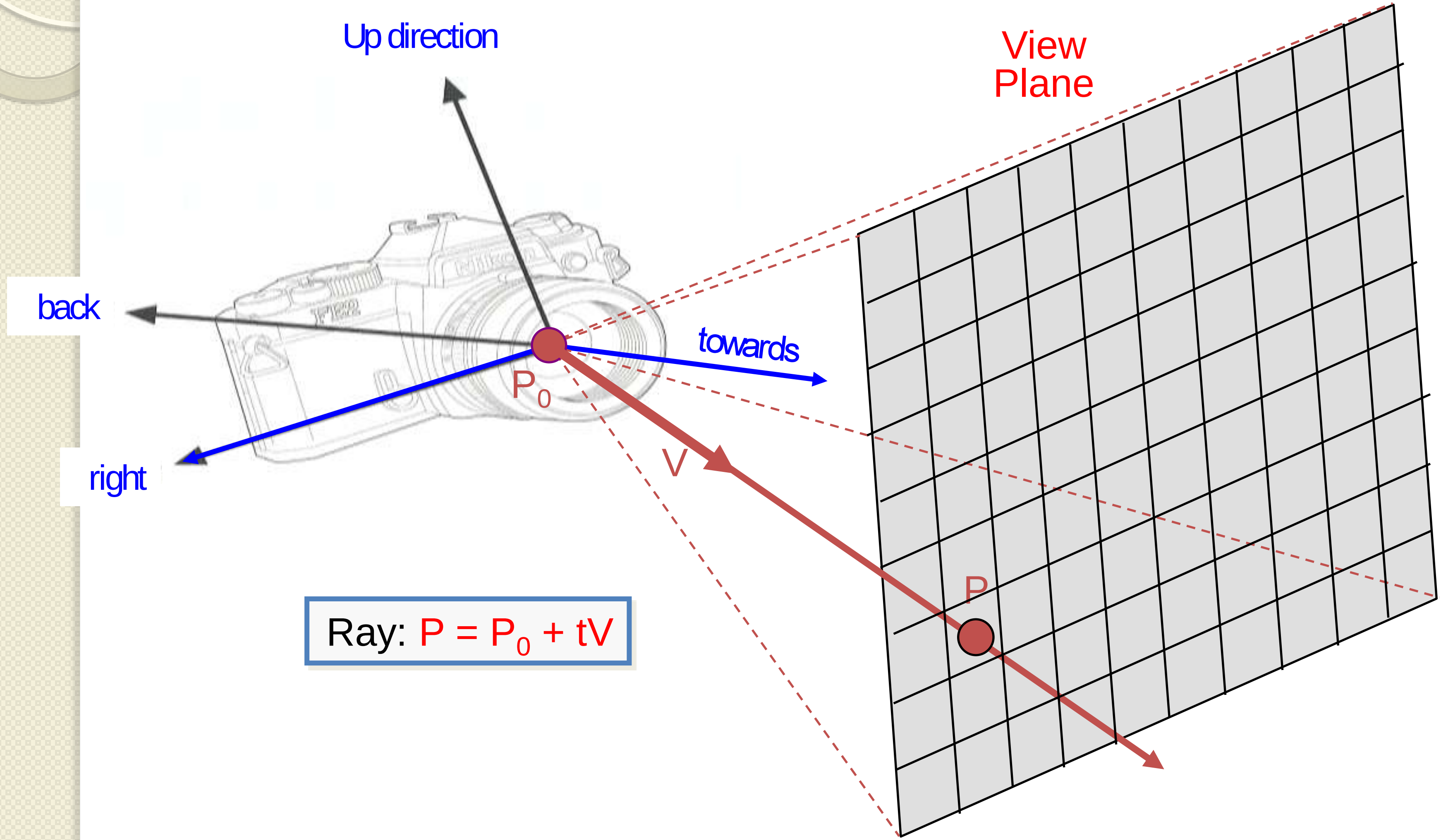
Constructing Ray Through a Pixel



Ray: $P = P_0 + tV$

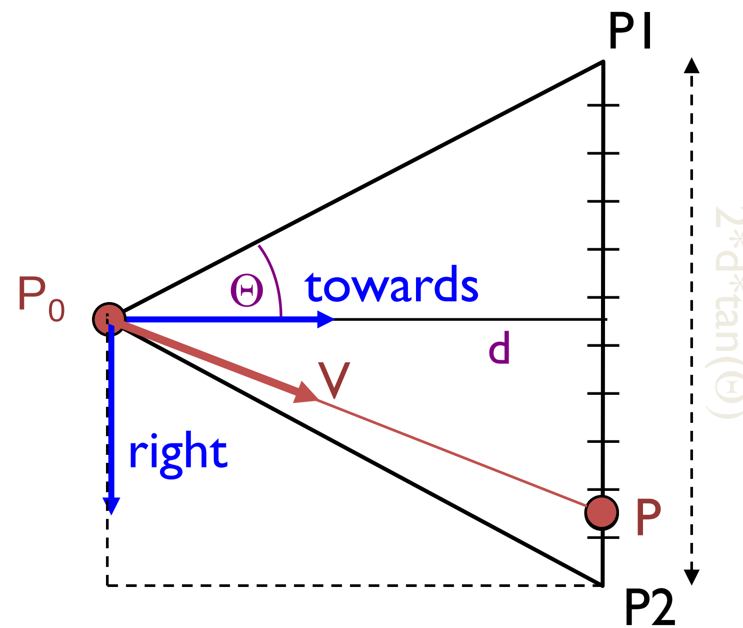
Constructing Ray Through a Pixel

- 2D Example

Θ = frustum half-angle
d = distance to view plane

right = towards x up

$P1 = P_0 + d*towards - d*\tan(\Theta)*right$
$P2 = P_0 + d*towards + d*\tan(\Theta)*right$



$P = P1 + (i/width + 0.5) * 2*d*\tan(\Theta)*right$
$V = (P - P_0) / ||P - P_0||$

Ray: $P = P_0 + tV$

Ray Casting

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			Intersection hit = FindIntersection(ray, scene);
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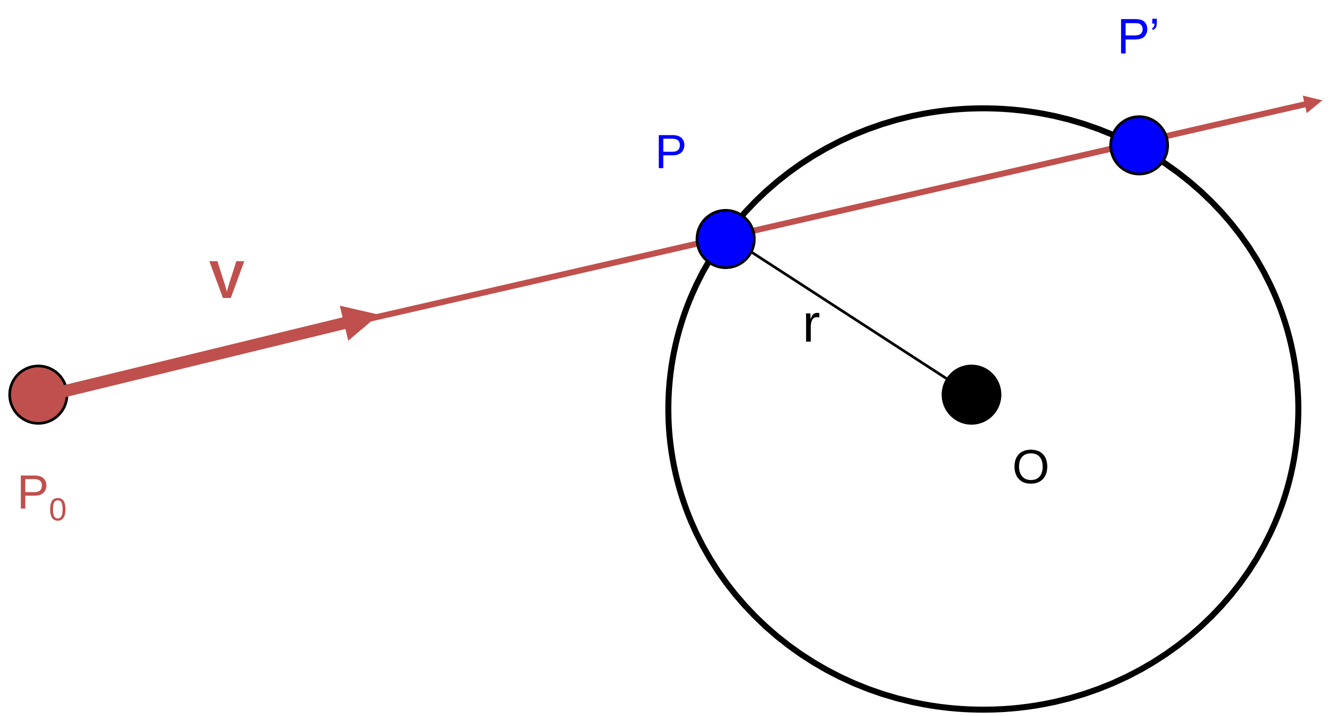
		}
	}
	return image;
}
```

Ray-Scene Intersection

- Intersections with geometric primitives
  - Sphere
  - Triangle
  - Groups of primitives (scene)
- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform grids
    - Octrees
    - BSP trees

Ray-Sphere Intersection

Ray: $P = P_0 + tV$
Sphere: $|P - O|^2 - r^2 = 0$



Ray-Sphere Intersection I

Ray: $P = P_0 + tV$
Sphere: $|P - O|^2 - r^2 = 0$

Algebraic Method

Substituting for P, we get:

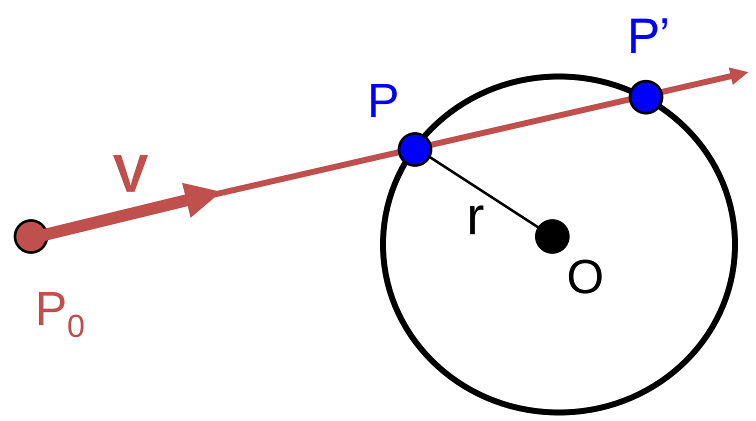
$$|\mathbf{P_0 + tV} - O|^2 - r^2 = 0$$

Solve quadratic equation:

$$at^2 + bt + c = 0$$

where:

$$a = 1$$
$$b = 2\, V \bullet (P_0 - O)$$
$$c = |P_0 - O|^2 - r^2 = 0$$



$P = P_0 + tV$

Ray-Sphere Intersection II

Ray: $P = P_0 + tV$
Sphere: $|P - O|^2 - r^2 = 0$

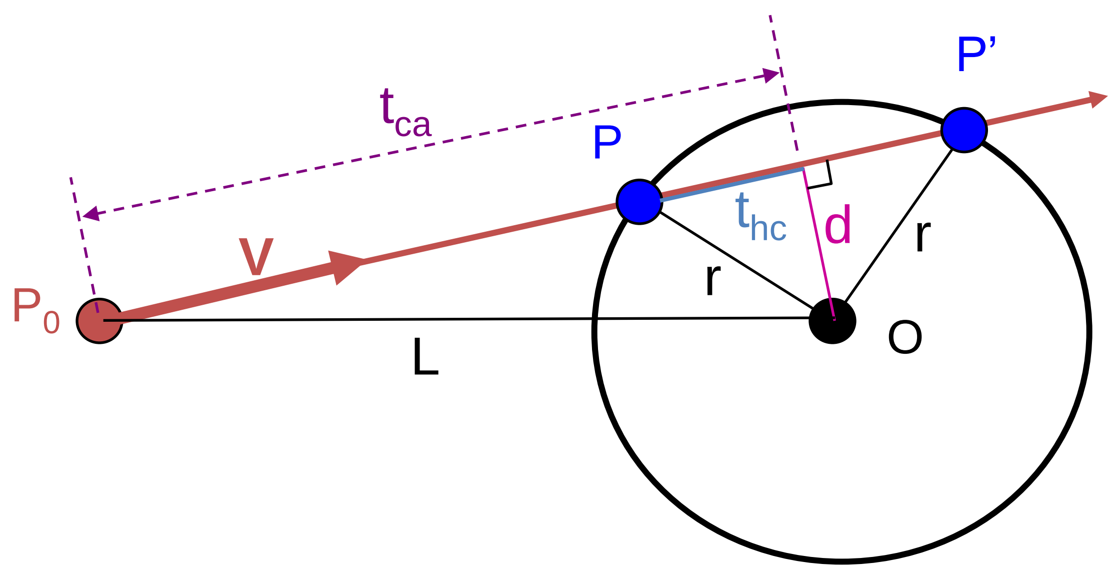
Geometric Method

$L = O - P_0$

$t_{ca} = L \bullet V$
if ($t_{ca} < 0$) return 0

$d^2 = L \bullet L - t_{ca}^2$
if ($d^2 > r^2$) return 0

$t_{hc} = \text{sqrt}(r^2 - d^2)$
$t = t_{ca} - t_{hc}$ and $t_{ca} + t_{hc}$

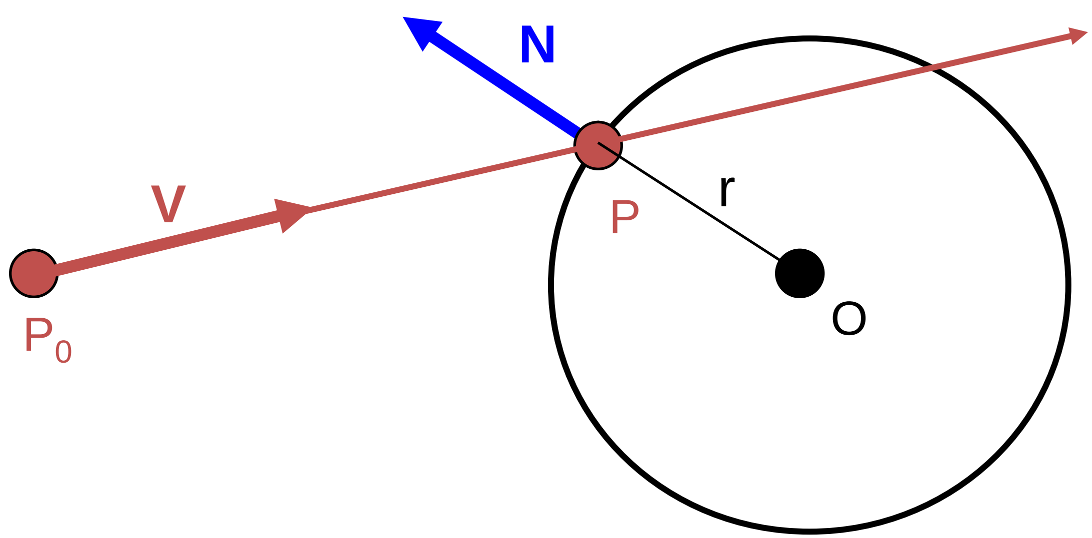


$P = P_0 + tV$

Ray-Sphere Intersection

- Need normal vector at intersection for lighting calculations

$$N = (P - O) / ||P - O||$$

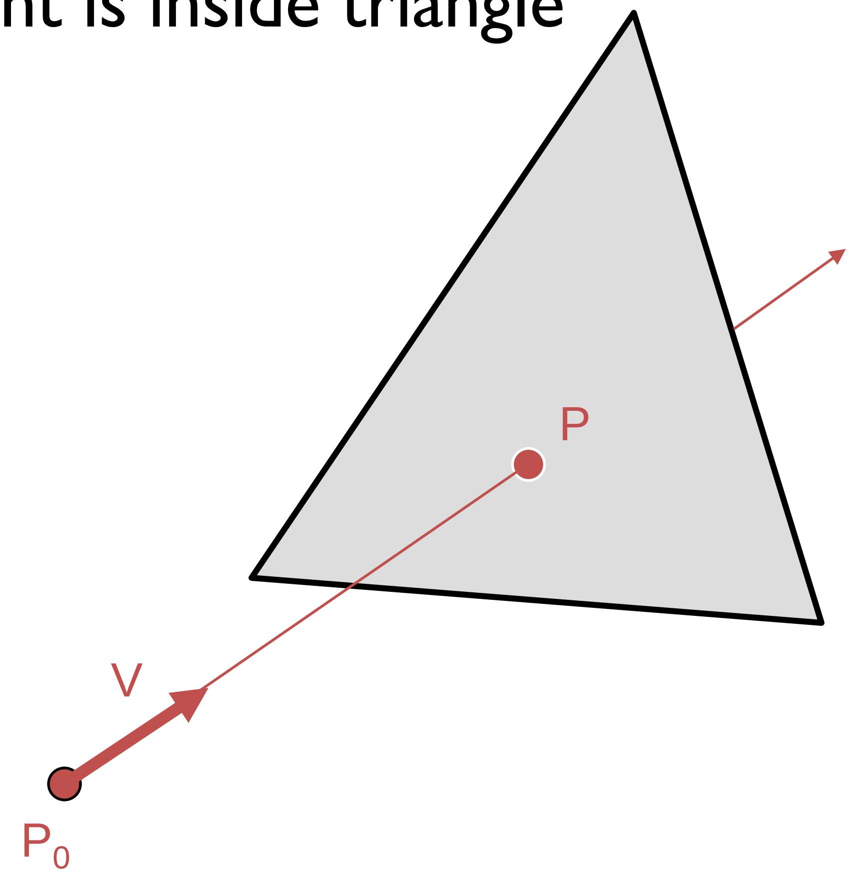


Ray-Scene Intersection

- Intersections with geometric primitives
  - Sphere
  - » **Triangle**
  - Groups of primitives (scene)
- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform grids
    - Octrees
    - BSP trees

Ray-Triangle Intersection

- First, intersect ray with plane
- Then, check if point is inside triangle



Algebraic Method

Ray-Plane Intersection

Ray: $P = P_0 + tV$

Plane: $N(P-P_0)=0 \rightarrow P \cdot N + c = 0$

Substituting for P, we get:

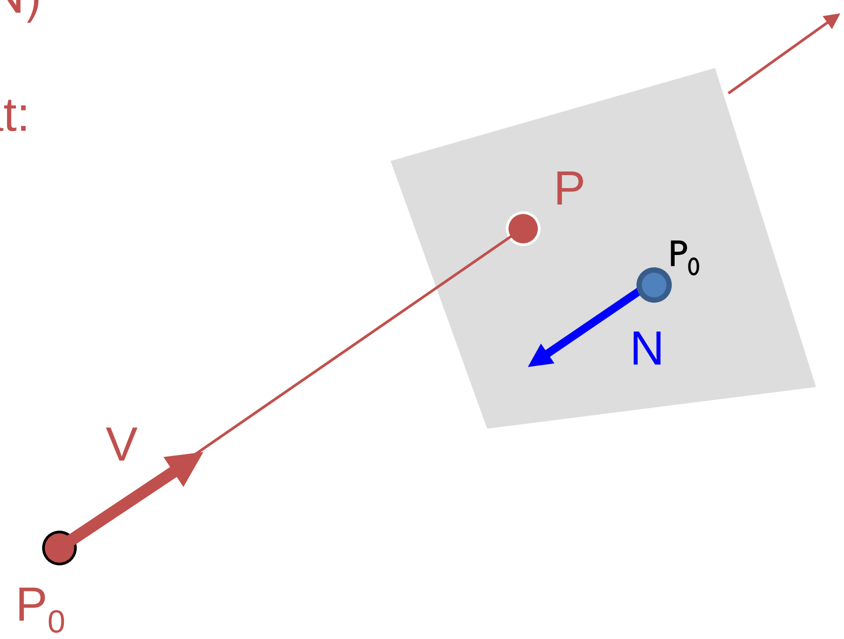
$$(\mathbf{P_0 + tV}) \cdot N + c = 0$$

Solution:

$$t = -(P_0 \cdot N + c) / (V \cdot N)$$

And the intersection at:

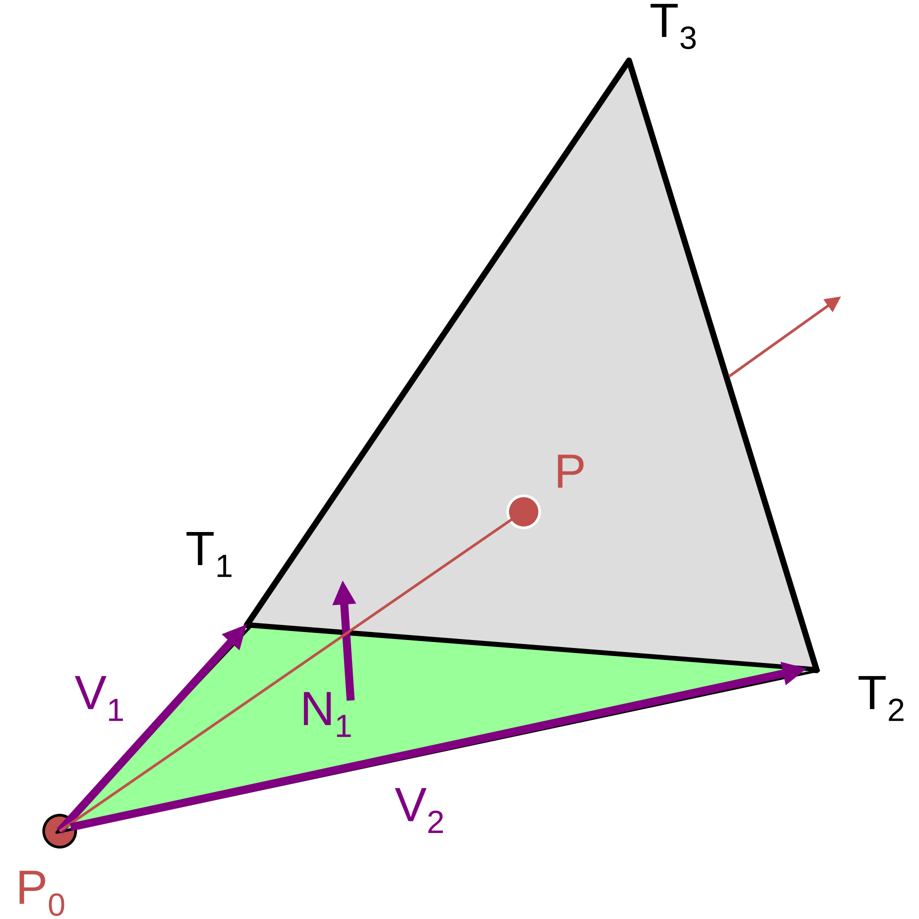
$P = P_0 + tV$



Ray-Triangle Intersection I

- Check if point is inside triangle algebraically

For each side of triangle
  $V_1 = T_1 - P$
  $V_2 = T_2 - P$
  $N_1 = V_2 \times V_1$
  Normalize N_1
  if $(P - P_0) \bullet N_1 < 0$
    return FALSE;
end



Ray-Triangle Intersection II

- Check if point is inside triangle parametrically

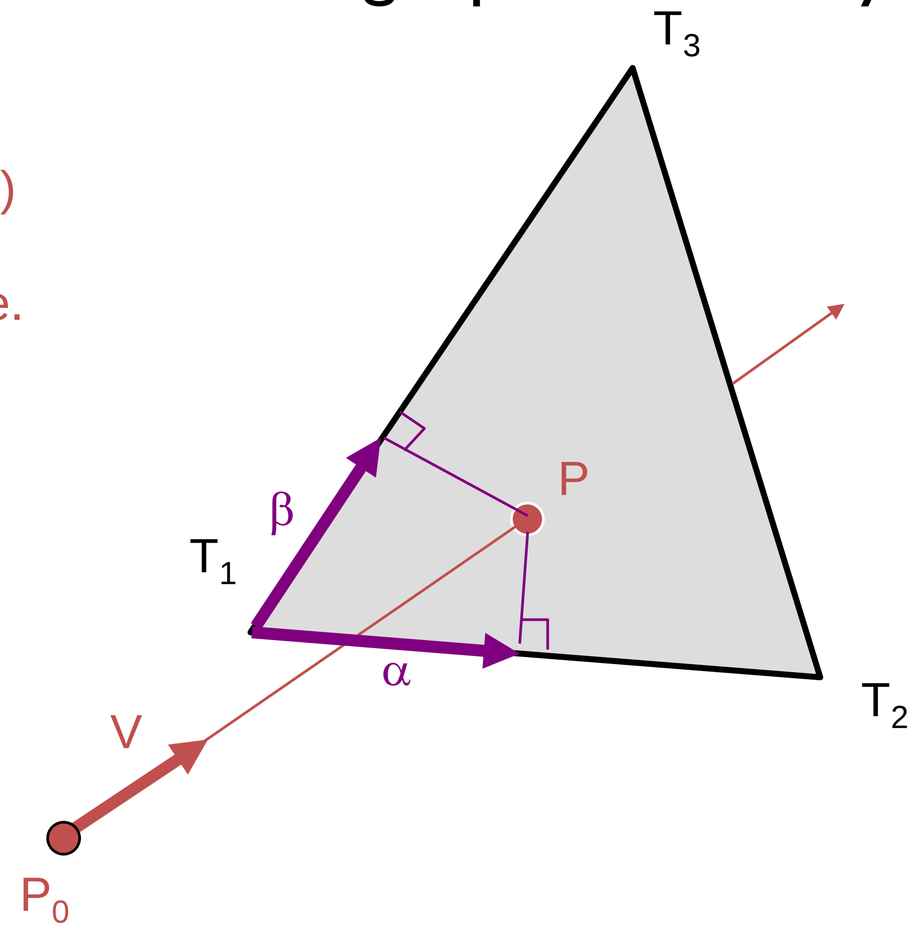
Compute α, β:

$$P = \alpha\,(T_2 - T_1) + \beta\,(T_3 - T_1)$$

Check if point inside triangle.

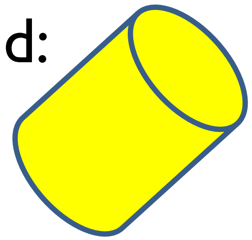
$$0 \le \alpha \le 1 \text{ and } 0 \le \beta \le 1$$

$$\alpha + \beta \le 1$$

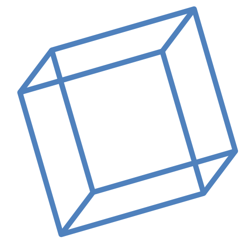


Other Ray-Primitive Intersections

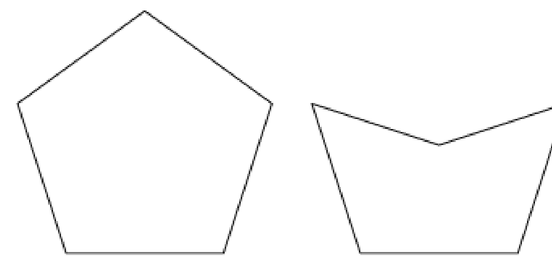
- Cone, cylinder, ellipsoid:
  - Similar to sphere



- Box
  - Intersect 3 front-facing planes, return closest



- Convex polygon
  - Same as triangle (check point-in-polygon algebraically)
- Concave polygon
  - Same plane intersection
  - More complex point-in-polygon test



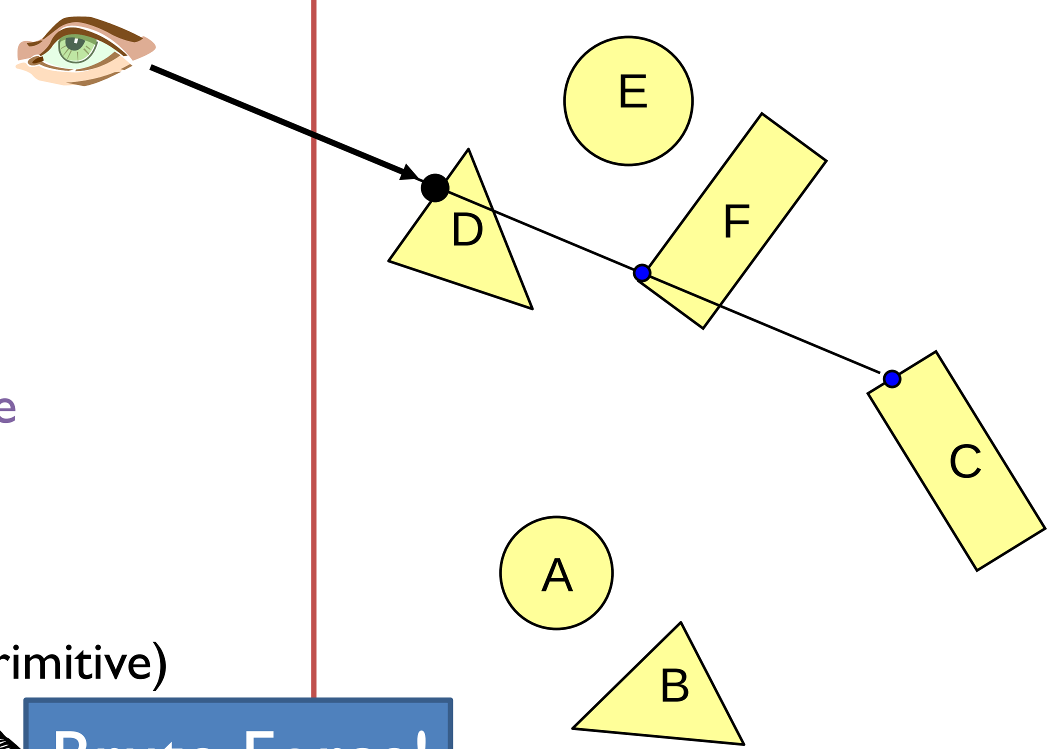
convex polygon *concave polygon*

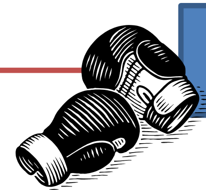
Algorithms for 3D object intersection: http://www.realtimerendering.com/int/

Ray-Scene Intersection

- Find intersection with front-most primitive in group

```
Intersection FindIntersection(Ray ray, Scene scene)
{
    min_t = infinity
    min_primitive = NULL
    For each primitive in scene {
        t = Intersect(ray, primitive);
        if (t < min_t) then
            min_primitive = primitive
            min_t = t
        }
    }
    return Intersection(min_t, min_primitive)
}
```





Brute Force!

Ray-Scene Intersection

- Intersections with geometric primitives
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  - Triangle
  - Groups of primitives (scene)
- » Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
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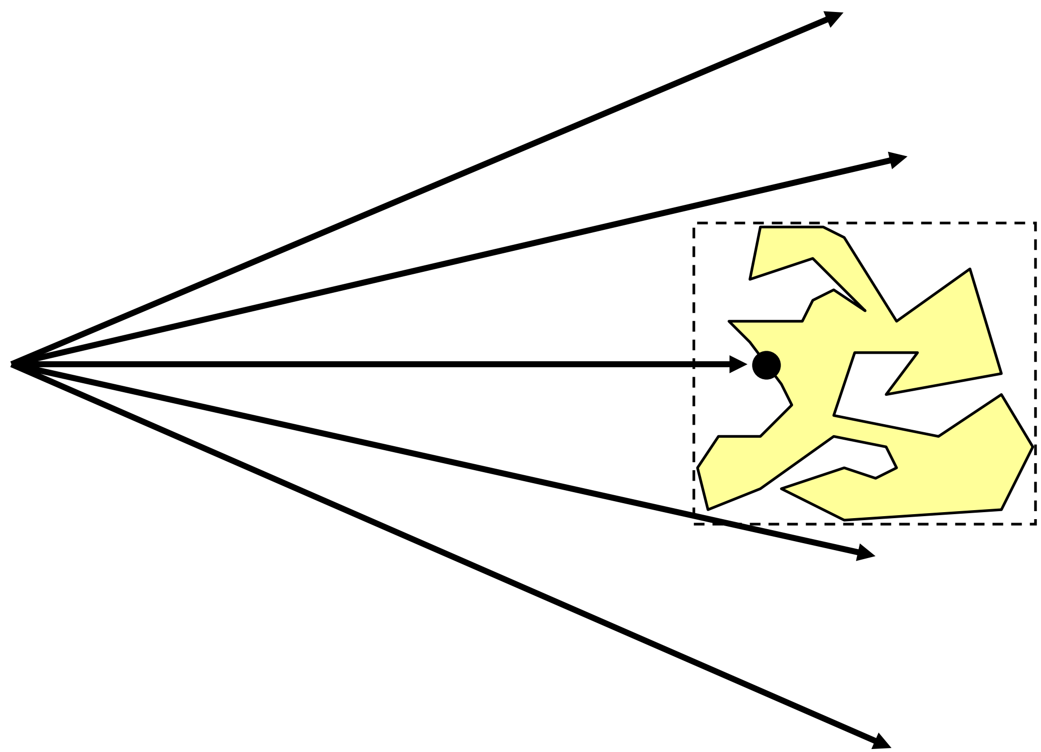
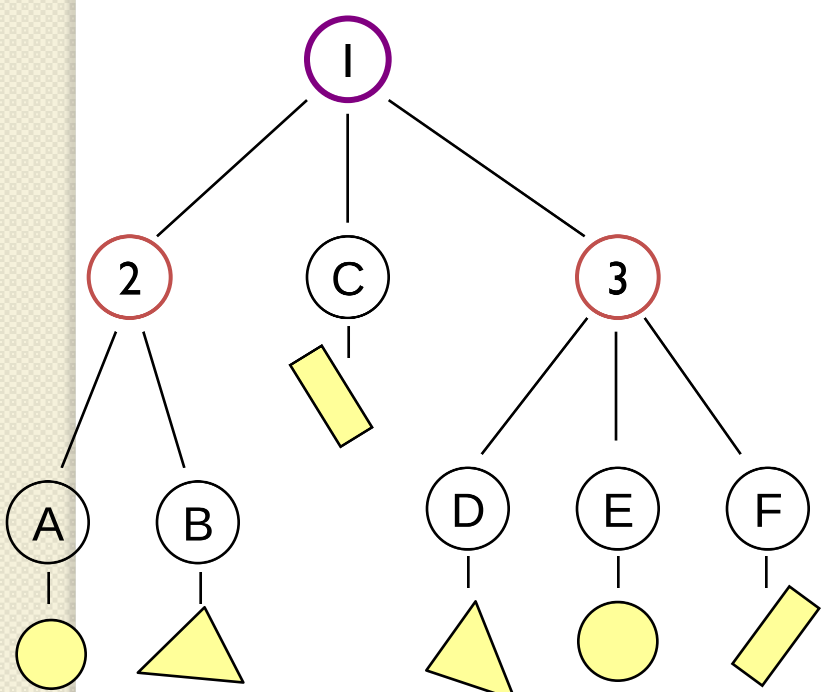
Bounding Volumes

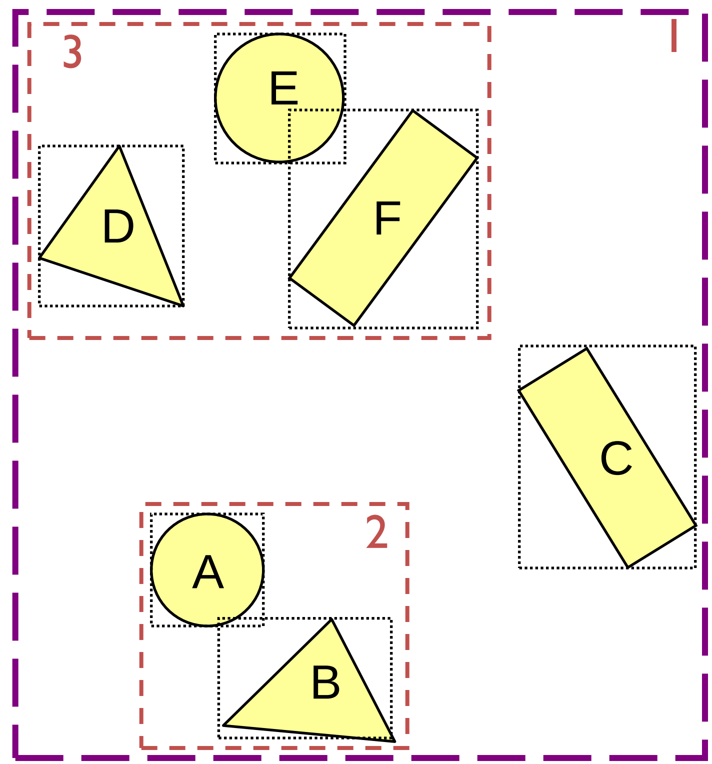
- Check for intersection with simple shape first
  - If ray doesn't intersect bounding volume, then it doesn't intersect its contents



Bounding Volume Hierarchies I

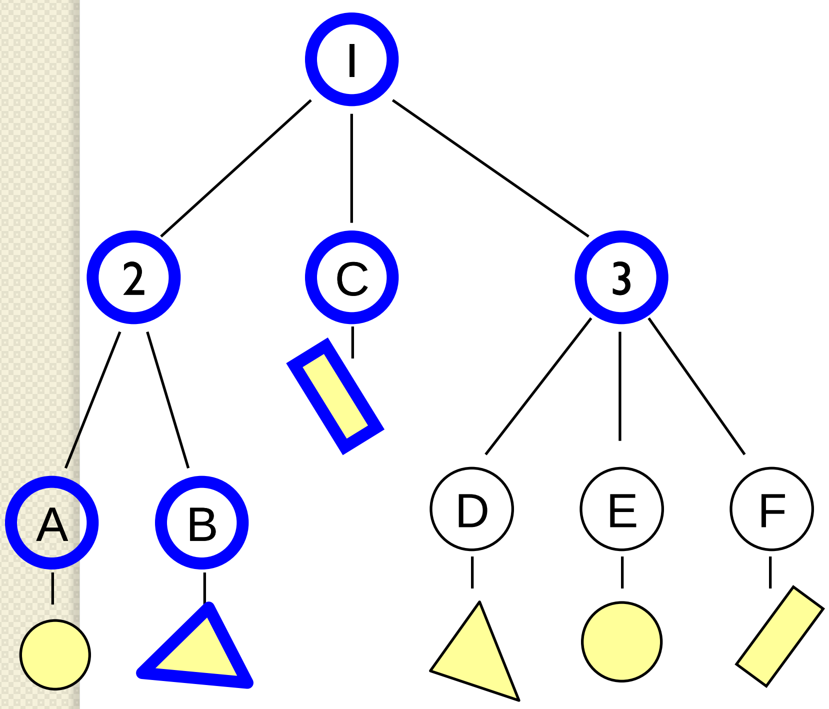
- Build hierarchy of bounding volumes
    - Bounding volume of interior node contains all children

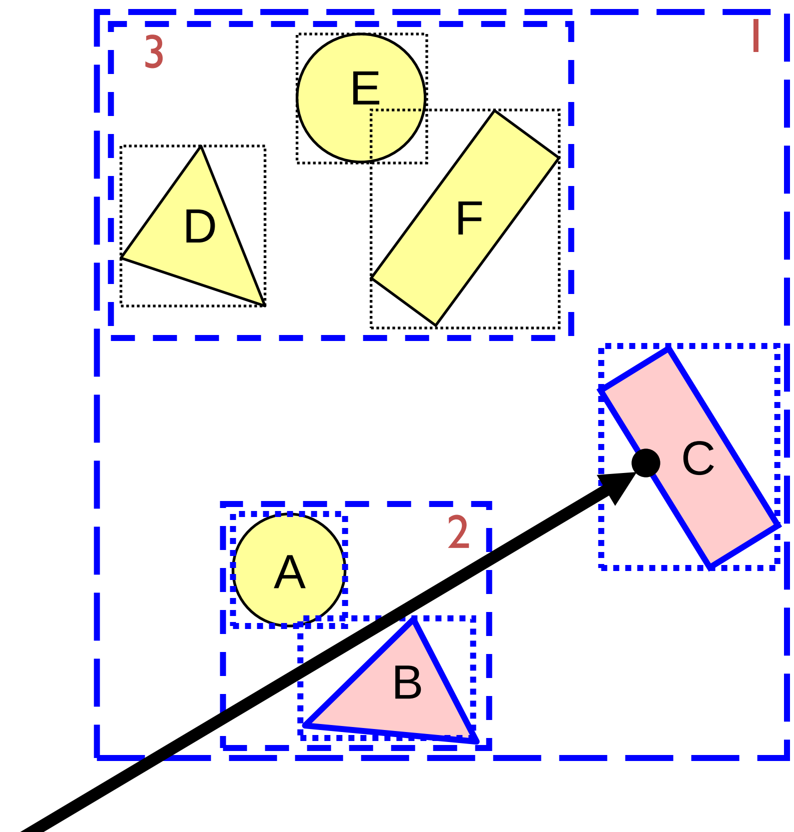




Bounding Volume Hierarchies

- Use hierarchy to accelerate ray intersections
  - Intersect node contents only if hit bounding volume





Bounding Volume Hierarchies III

- Sort hits & detect early termination

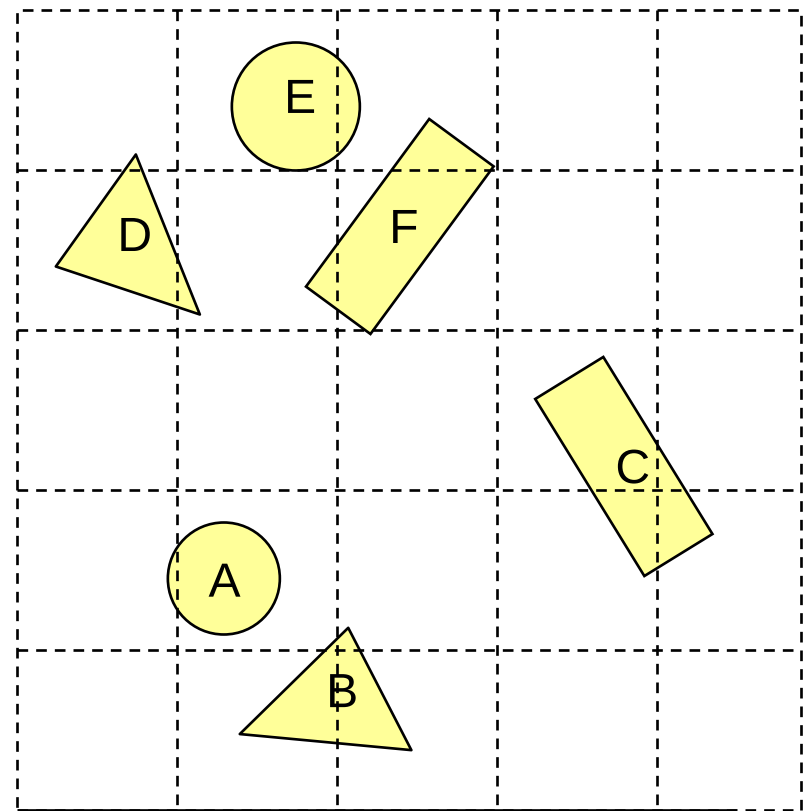
```
FindIntersection(Ray ray, Node node)
{
    // Find intersections with child node bounding volumes
    ...
    // Sort intersections front to back
    ...
    // Process intersections (checking for early termination)
    min_t = infinity;
    for each intersected child i {
        if (min_t < bv_t[i]) break;
        shape_t = FindIntersection(ray, child);
        if (shape_t < min_t) { min_t = shape_t;}
    }
    return min_t;
}
```

Ray-Scene Intersection

- Intersections with geometric primitives
  - Sphere
  - Triangle
  - Groups of primitives (scene)
- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform grids
    - Octrees
    - BSP trees

Uniform Grid

- Construct uniform grid over scene
  - Index primitives according to overlaps with grid cells

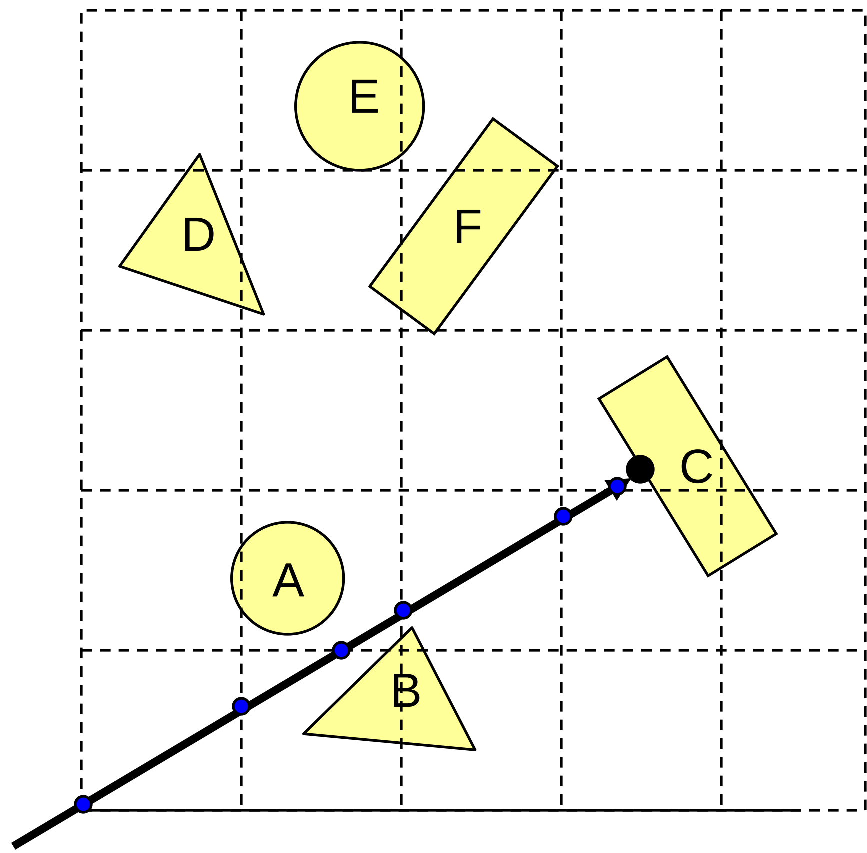


Uniform Grid

- Trace rays through grid cells
  - Fast
  - Incremental

Only check primitives in intersected grid cells

Given an entry point into a cell and a vector, its easy to calculate exit point

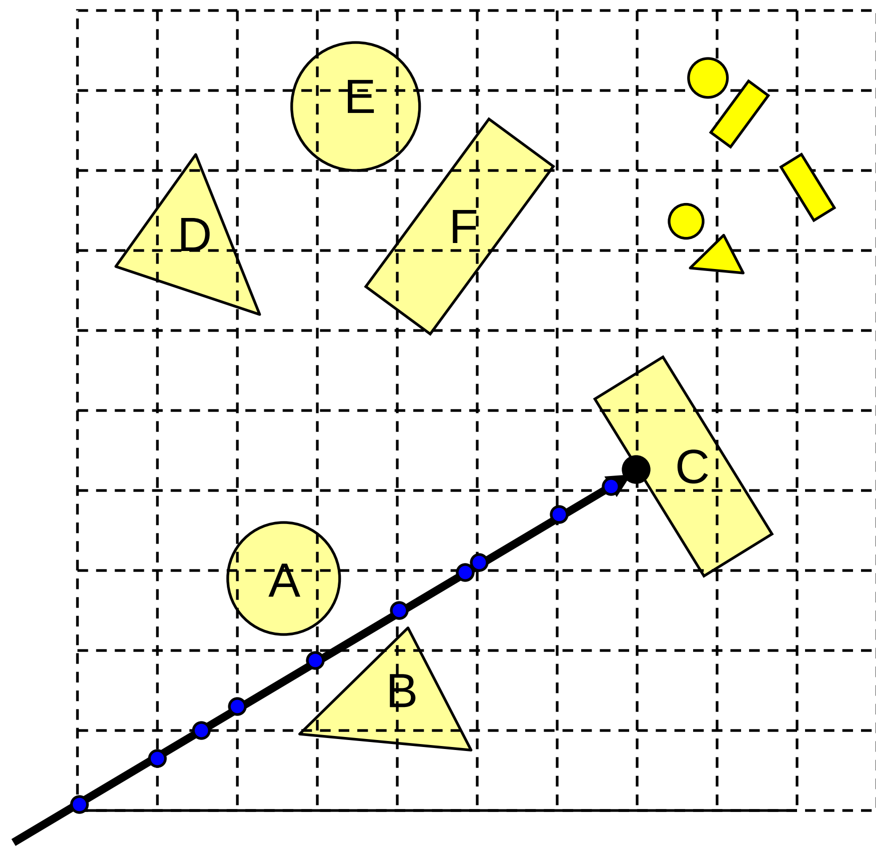


Uniform Grid

- Potential problem:
  - How choose suitable grid resolution?

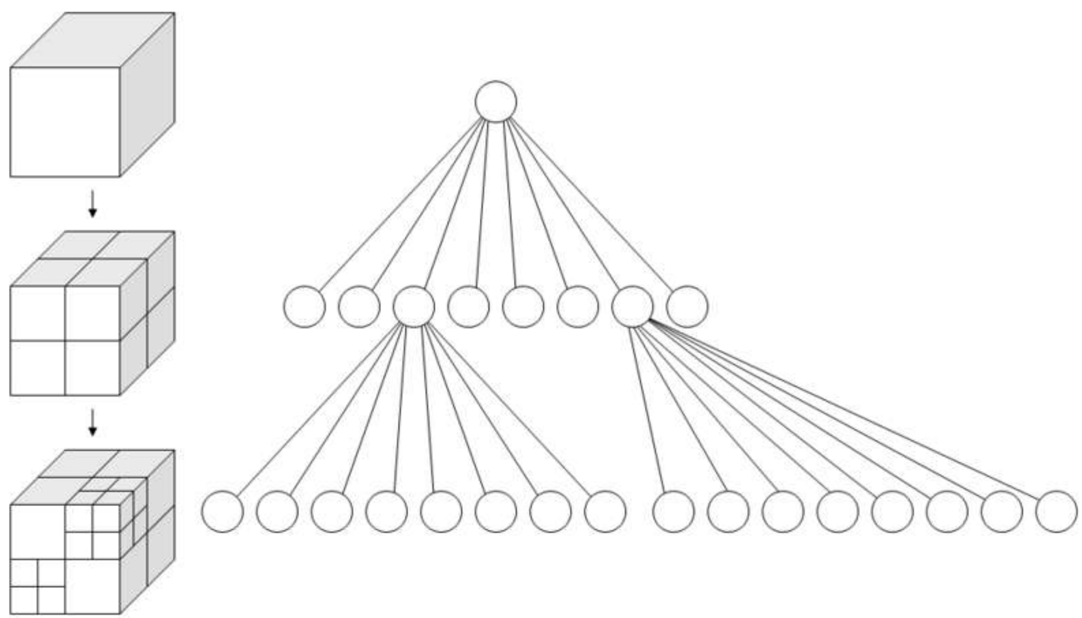
Too little benefit
if grid is too coarse

Too much cost
if grid is too fine



Octree

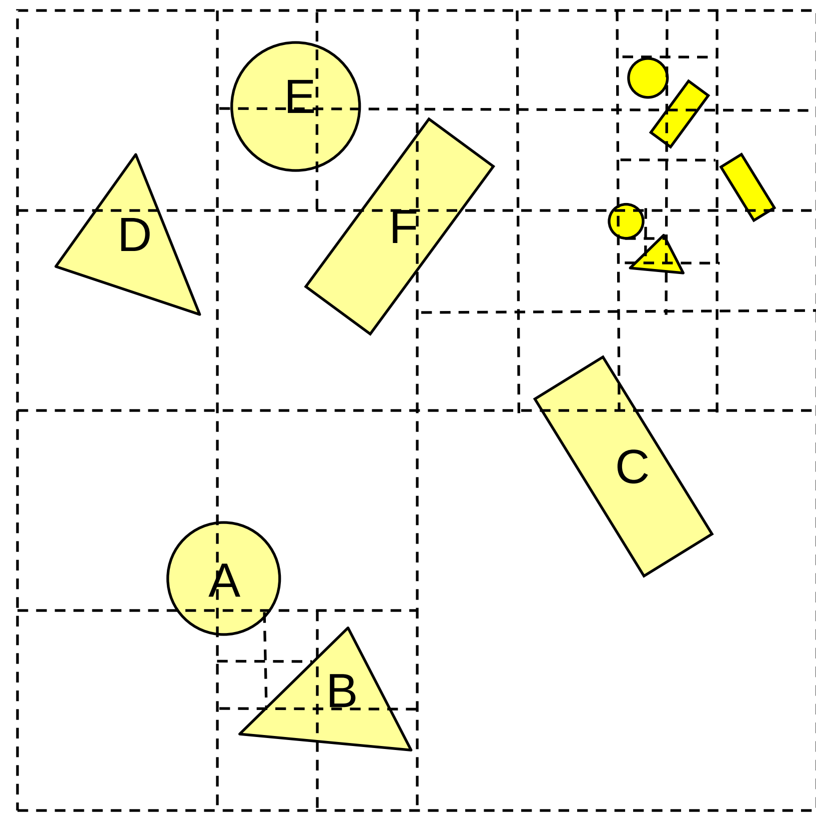
- A tree data structure used to partition three dimensional space
- 3D analog of *Quadtrees (2D)*



Octree

- Construct adaptive grid over scene
  - Recursively subdivide box-shaped cells into 8 octants
  - Index primitives by overlaps with cells

Generally fewer cells

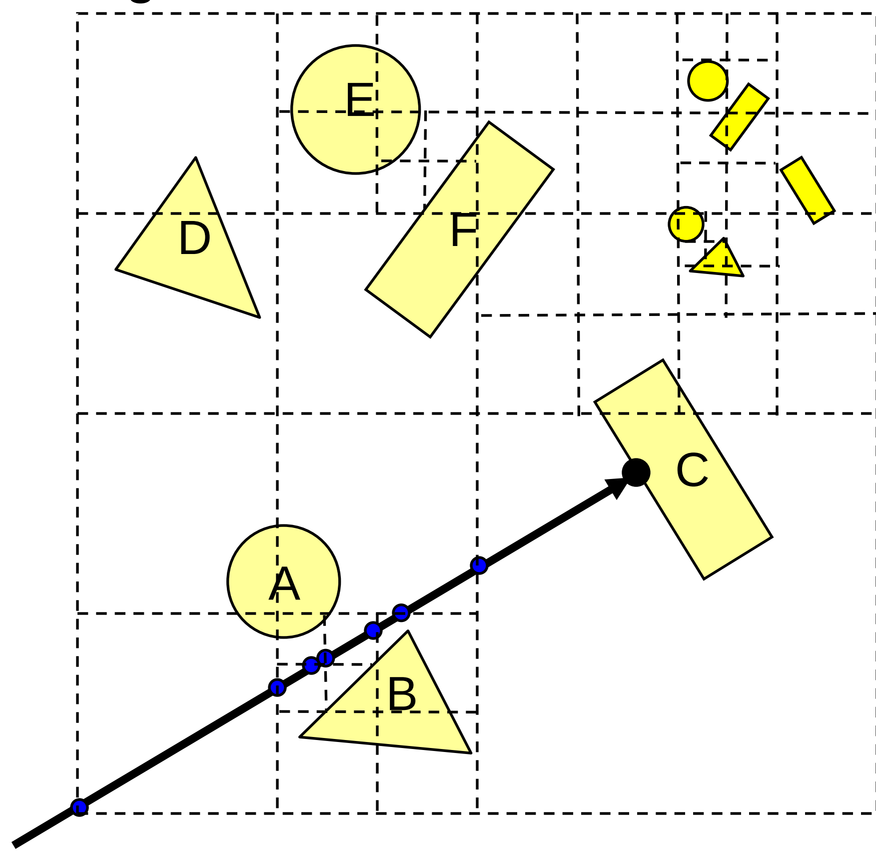


Quadtree

Octree

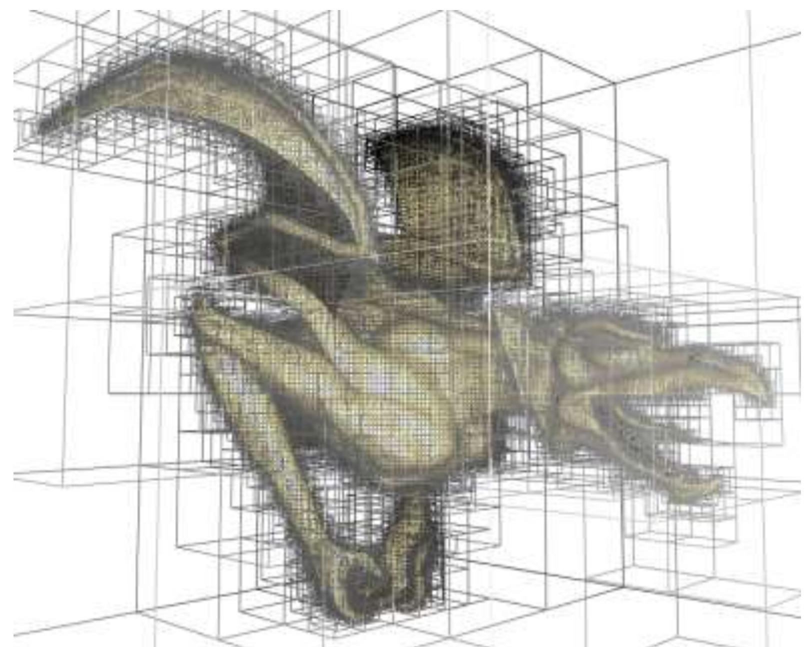
- Trace rays through neighbor cells
  - Fewer cells
  - More complex neighbor finding

Trade-off fewer cells for more expensive traversal



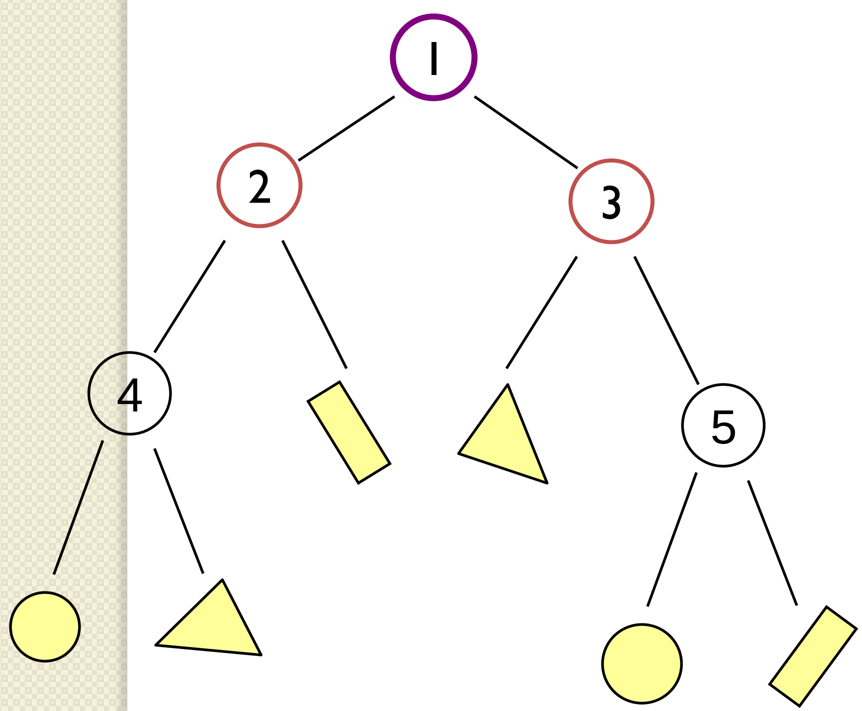
Octree

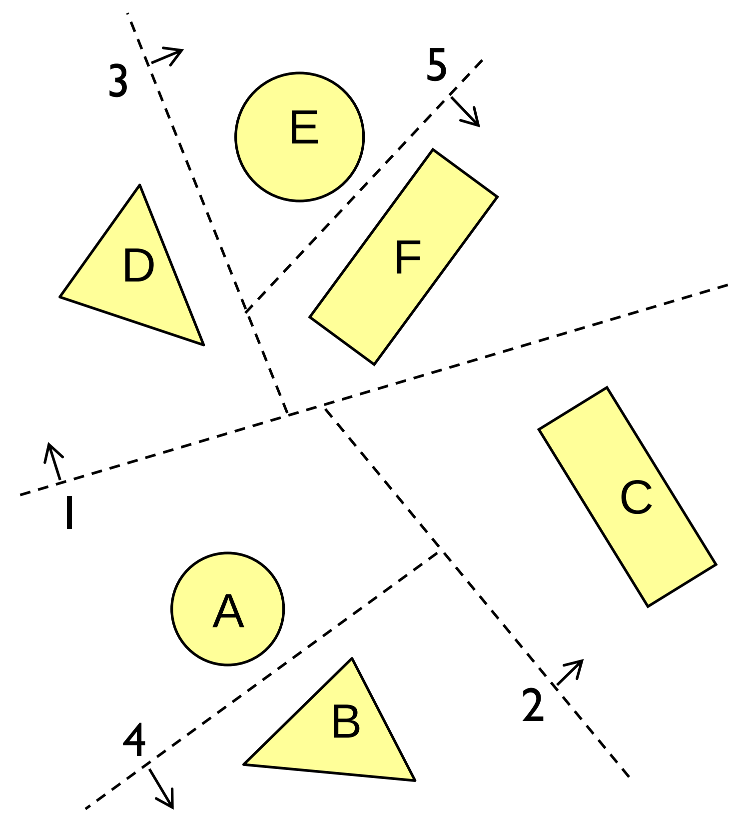
- Very useful in computer graphics, used for
  - Intersections
  - Collisions
  - Color quantization
  - Surface reconstruction (meshing)
  - …



Binary Space Partition (BSP) Tree

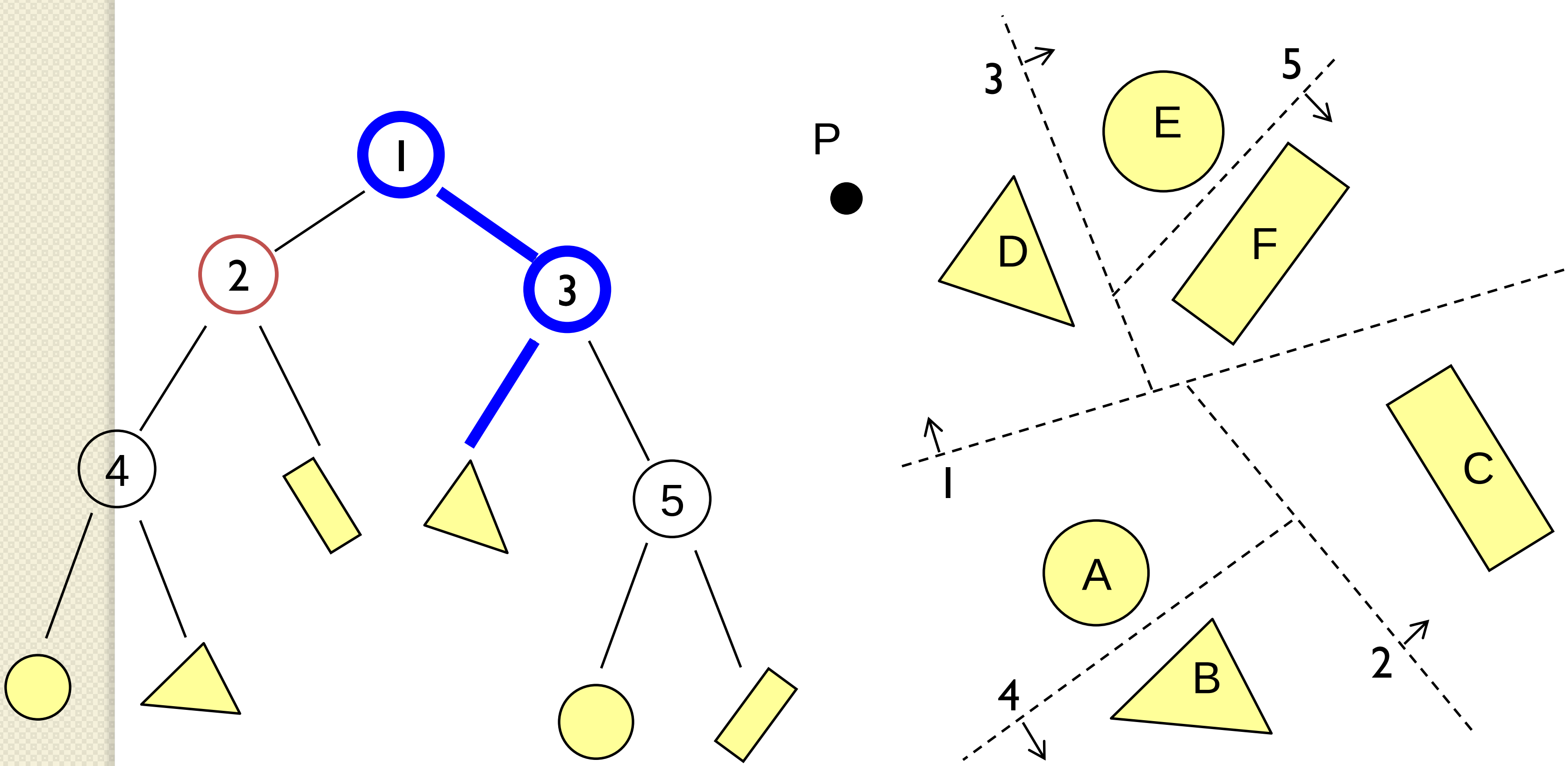
- Recursively partition space by planes
  - Every cell is a convex polyhedron





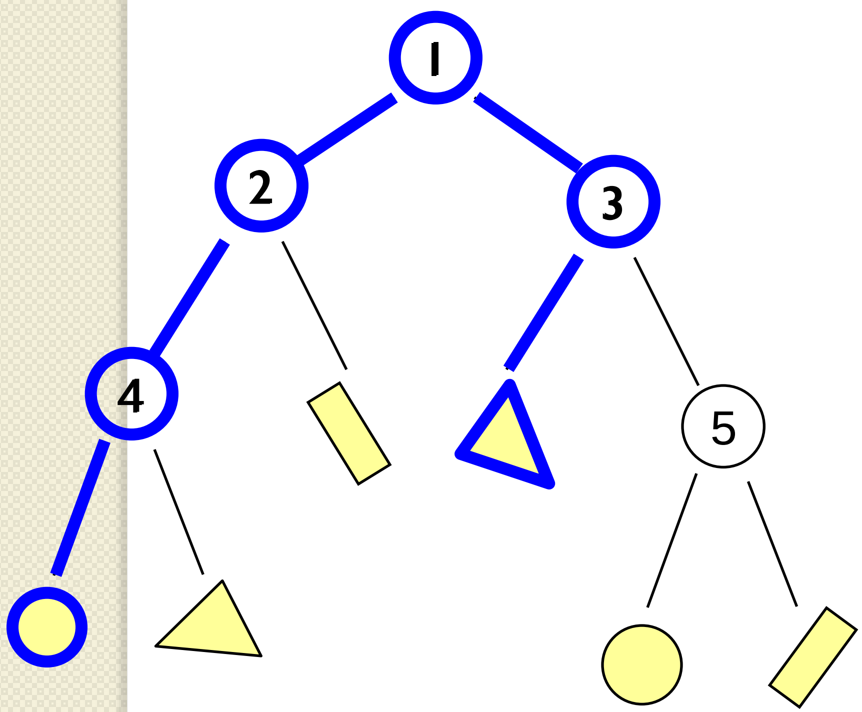
Binary Space Partition (BSP) Tree

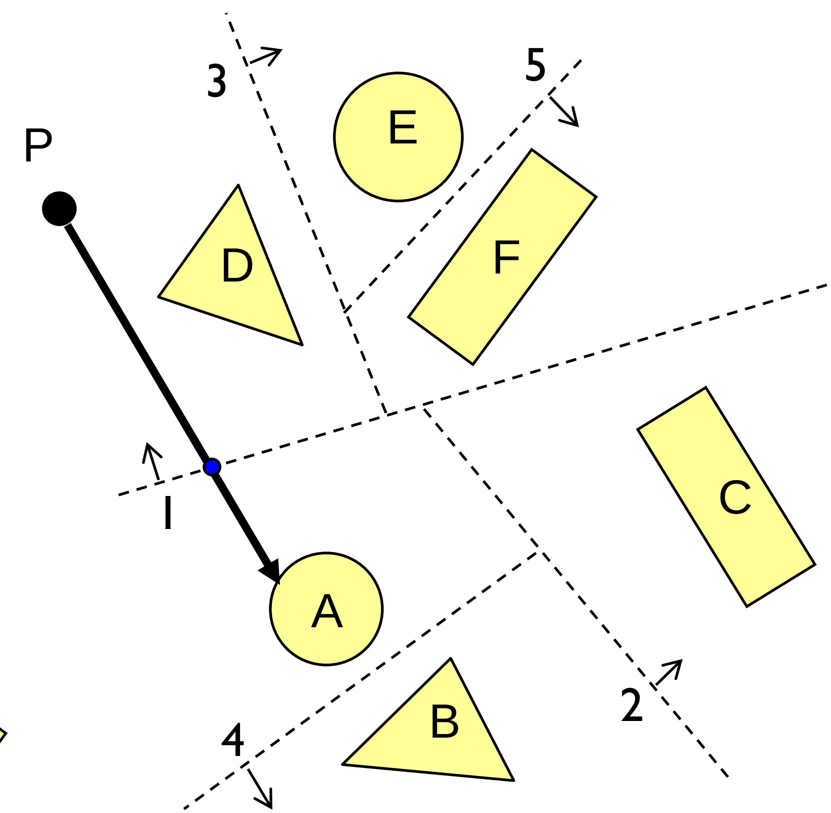
- Simple recursive algorithms
  - Example: point finding



Binary Space Partition (BSP) Tree

- Trace rays by recursion on tree
  - BSP construction enables simple front-to-back traversal



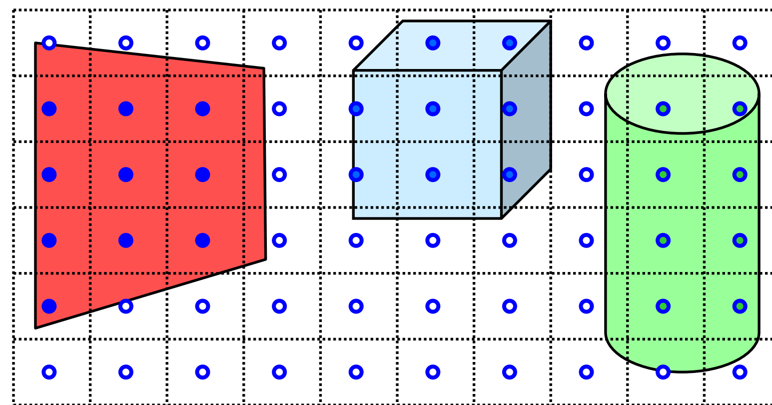


Binary Space Partition (BSP) Tree

```
RayTreeIntersect(Ray ray, Node node, double min, double max)
{
    if (Node is a leaf)
        return intersection of closest primitive in cell, or NULL if none
    else
        dist = distance of the ray point to split plane of node
        near_child = child of node that contains the origin of Ray
        far_child = other child of node
        if the interval to look is on near side
            return RayTreeIntersect(ray, near_child, min, max)
        else if the interval to look is on far side
            return RayTreeIntersect(ray, far_child, min, max)
        else if the interval to look is on both side
            if (RayTreeIntersect(ray, near_child, min, dist)) return …;
            else return RayTreeIntersect(ray, far_child, dist, max)
}
```

Other Accelerations

- Screen space coherence
  - Check last hit first
  - Beam tracing
  - Pencil tracing
  - Cone tracing
- Memory coherence
  - Large scenes
- Parallelism
  - Ray casting is “embarassingly parallelizable”
- etc.



Summary

- Writing a simple ray casting renderer is easy
  - Generate rays
  - Intersection tests
  - Lighting calculations
- What next?
  - Illumination