Accelerating Ray-Scene Intersection Calculations

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CS 4810: Graphics

Acknowledgment: slides by Jason Lawrence, Misha Kazhdan, Allison Klein, Tom Funkhouser, Adam Finkelstein and David Dobkin

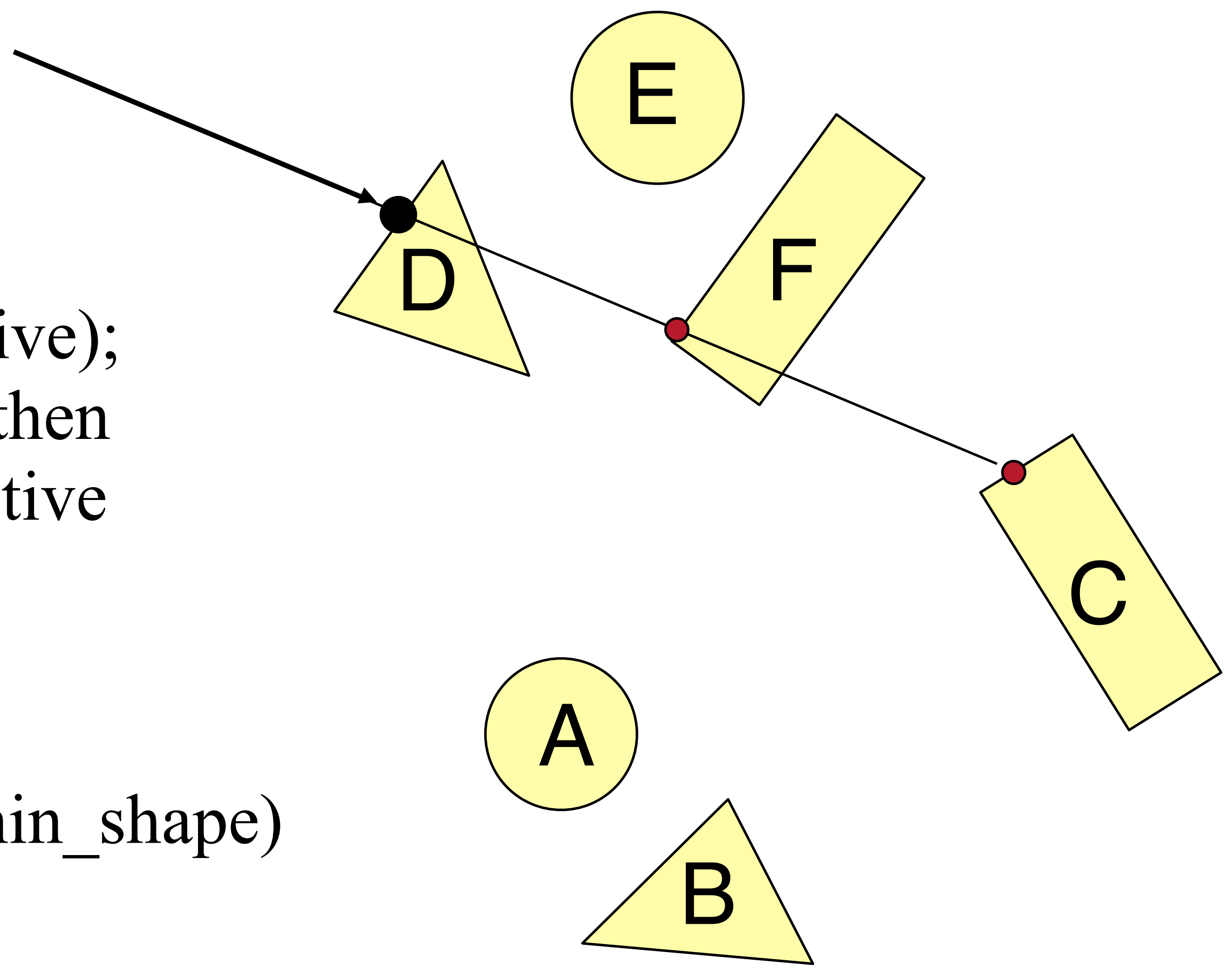
Overview

- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform grids
    - Octrees
    - BSP trees

Goal

- Find intersection with front-most primitive in group

```
Intersection FindIntersection(Ray ray, Scene scene)
{
    min_t = ∞
    min_shape = NULL
    For each primitive in scene
    {
        t = Intersect(ray, primitive);
        if (t > 0 and t < min_t) then
            min_shape = primitive
            min_t = t
        }
    }
    return Intersection(min_t, min_shape)
}
```



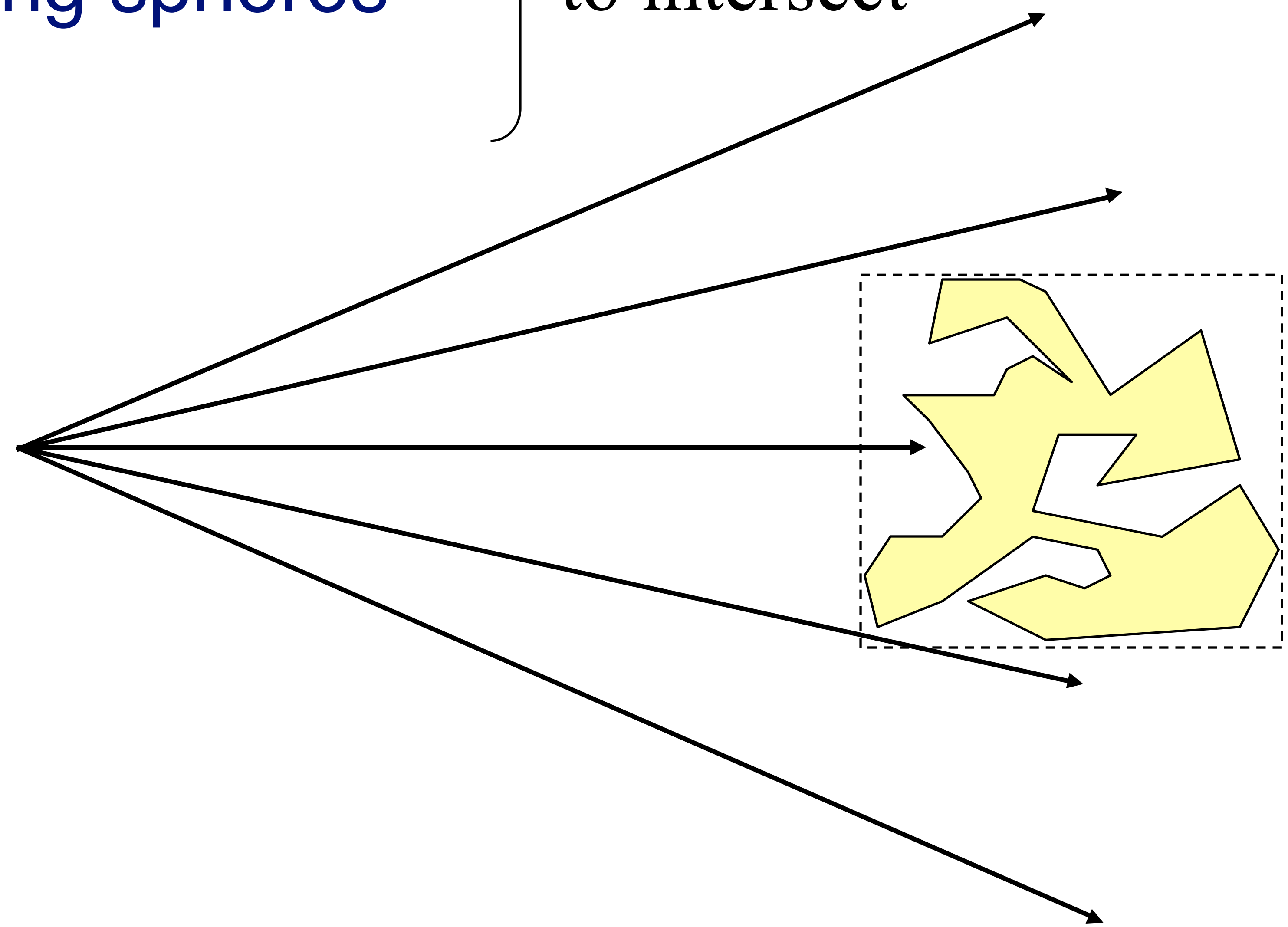
Acceleration Techniques

- A direct approach tests for an intersection of every ray with every primitive in the scene.
- Acceleration techniques:
  - **o** Grouping:
    Group primitives together and test if the ray intersects the group. If it doesn't, don't test individual primitives.
  - **o** Ordering:
    Test primitives/groups based on their distance along the ray. If you find a close hit, don't test distant primitives/groups.

Bounding Volumes

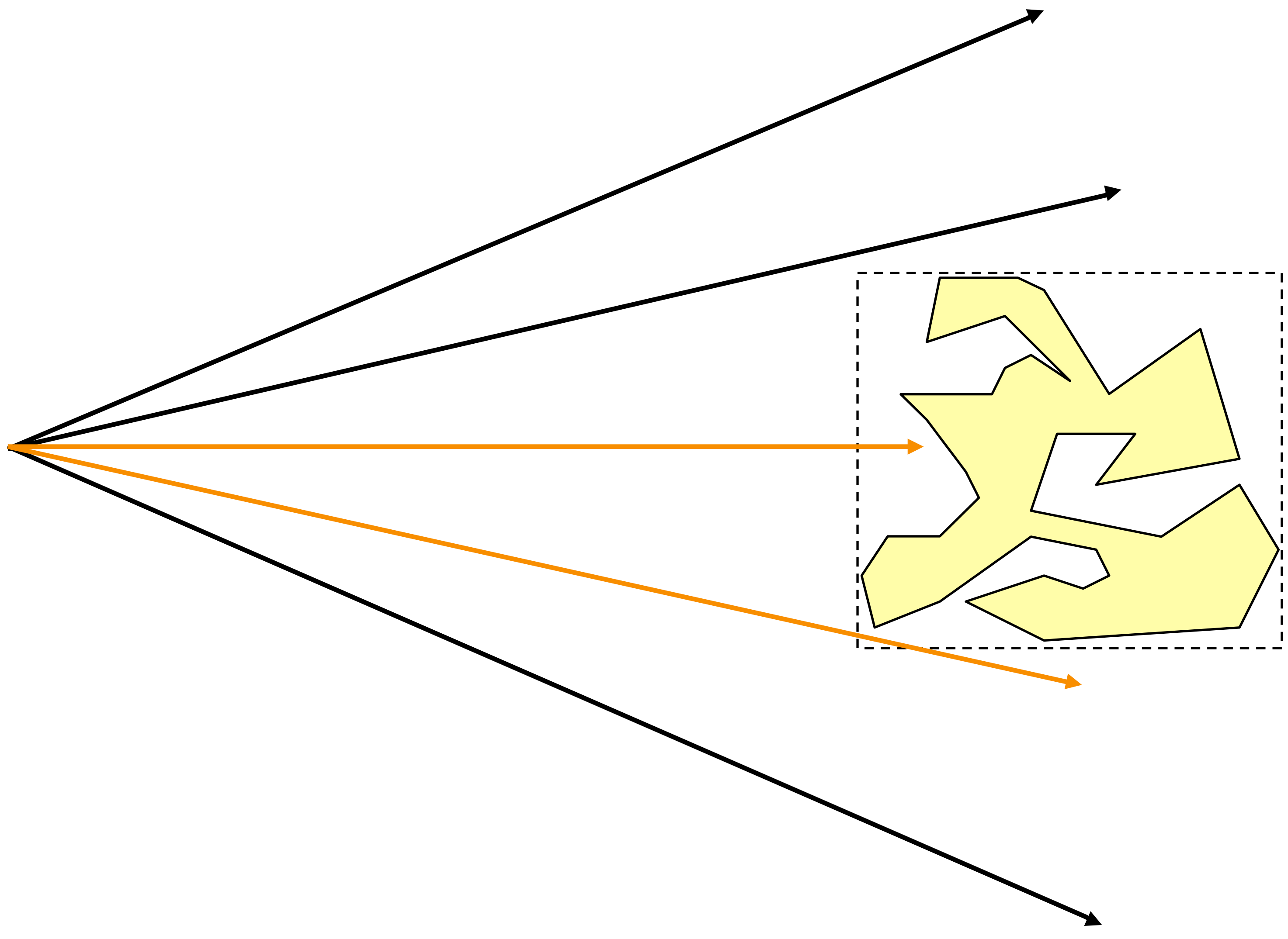
- Check for intersection with the bounding volume:
  - Bounding cubes
  - Bounding boxes
  - Bounding spheres
  - Etc.

Stuff that's easy to intersect



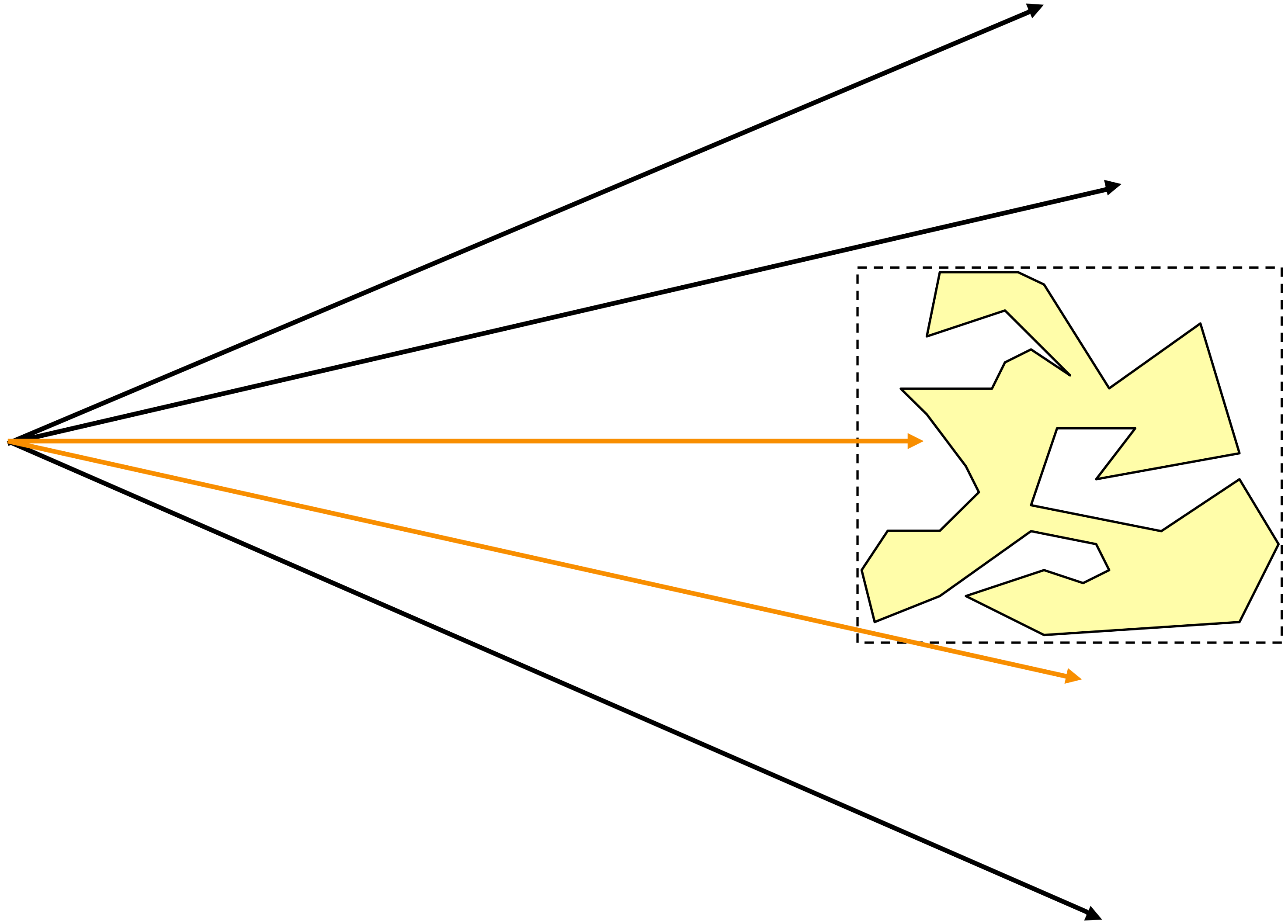
Bounding Volumes

- Check for intersection with the bounding volume



Bounding Volumes

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



Bounding Volumes

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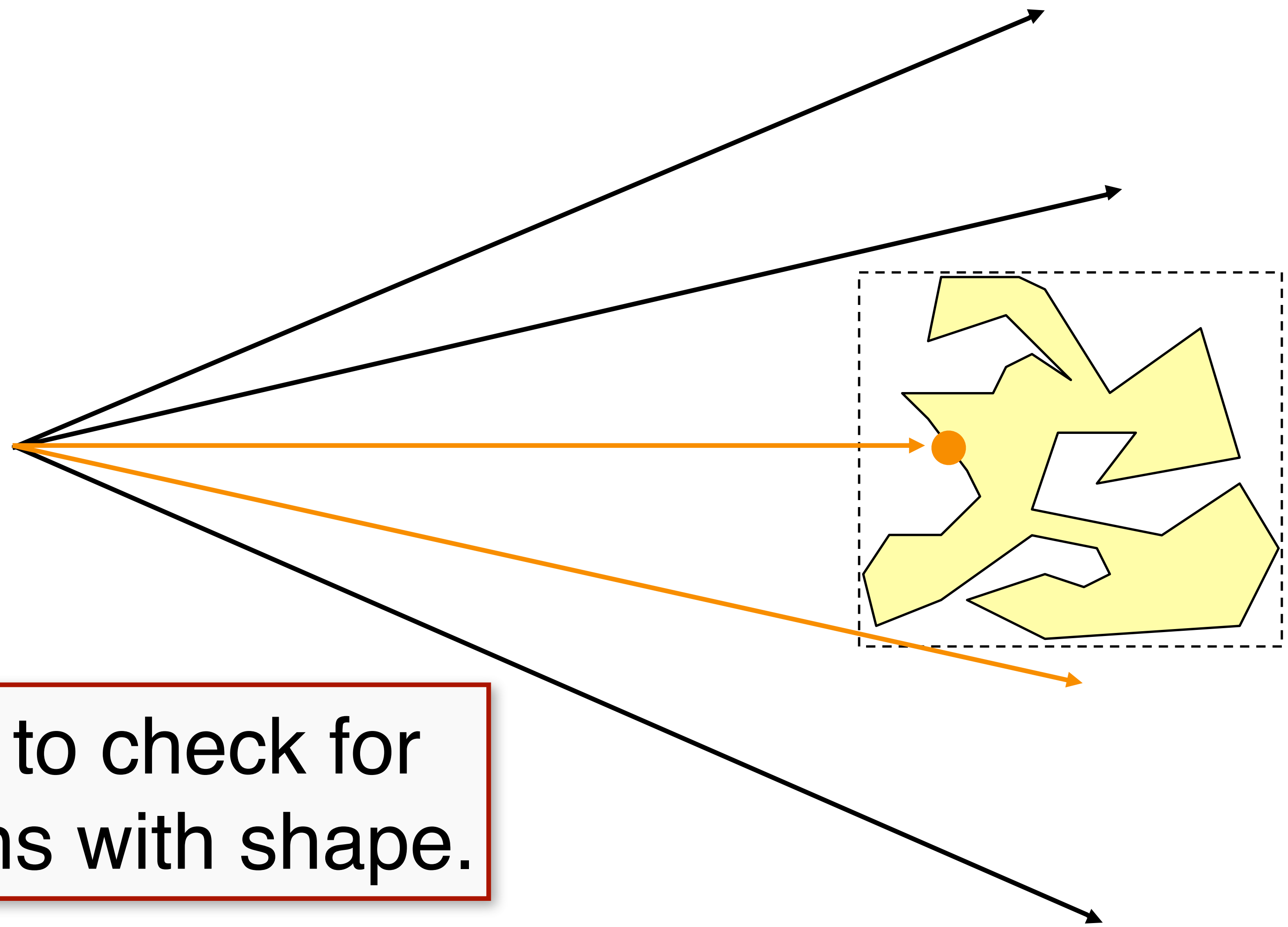
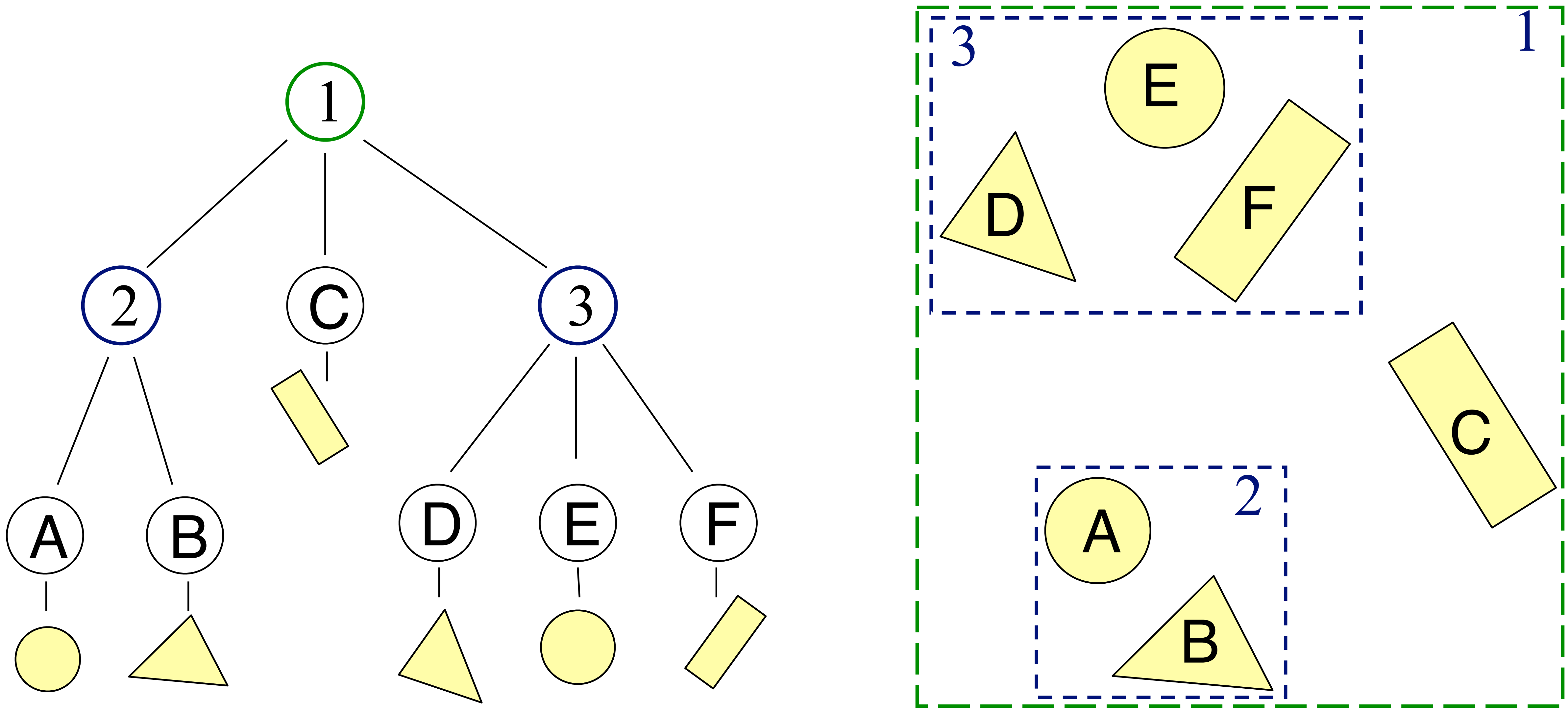


Still need to check for intersections with shape.

Bounding Volume Hierarchies

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



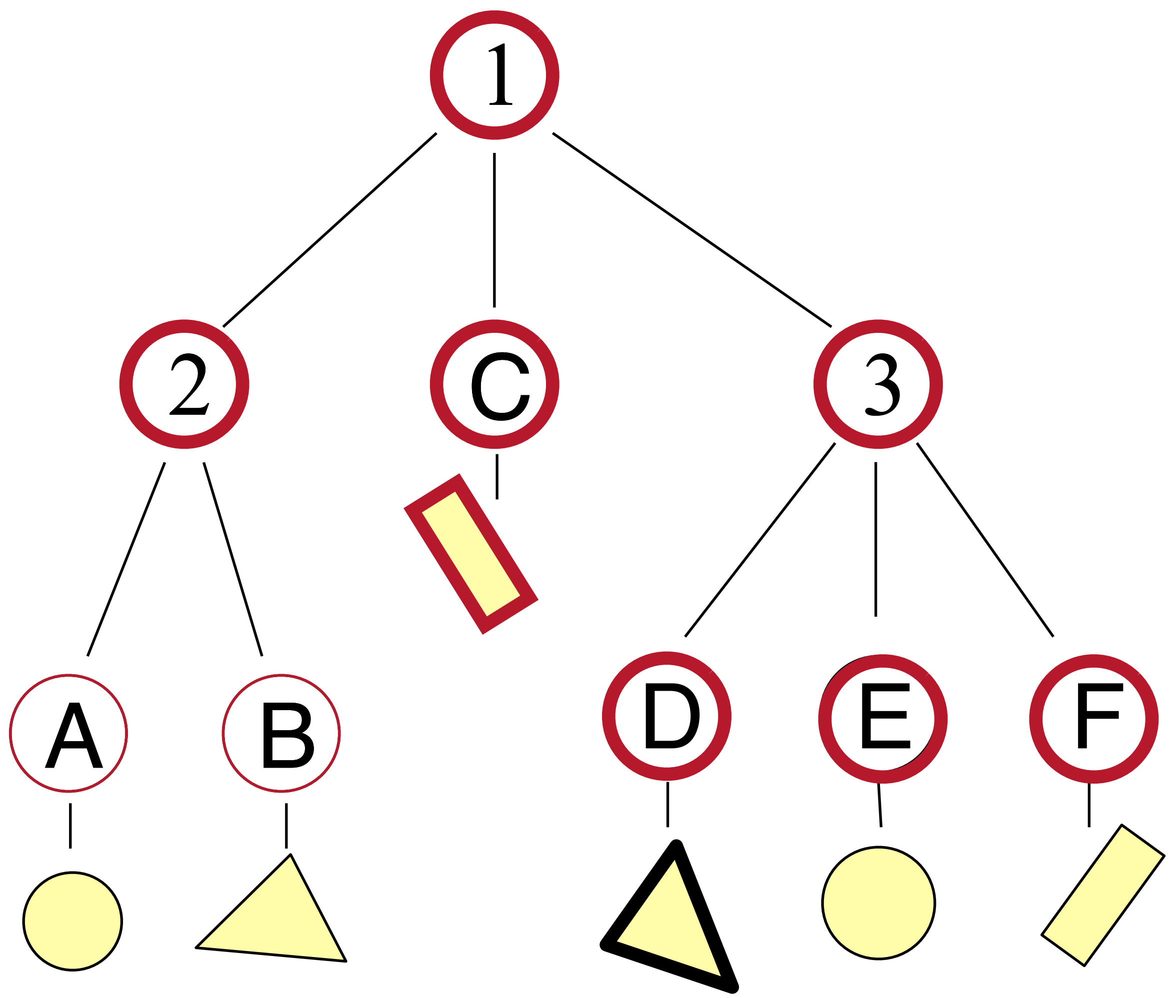
Bounding Volume Hierarchies

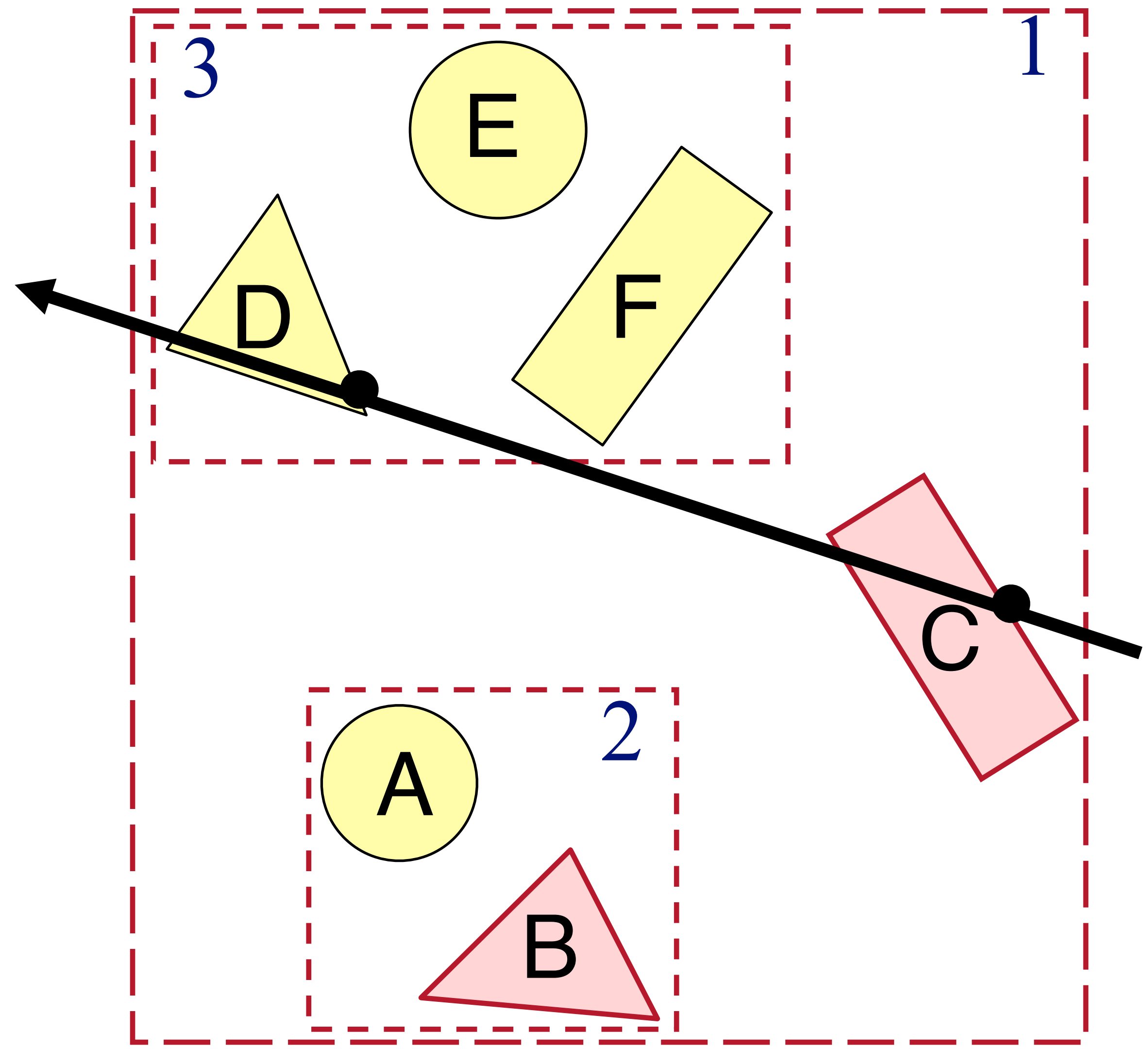
- Grouping acceleration

```
FindIntersection(Ray ray, Node node) {
        min_t = ∞
        min_shape = NULL

        // Test if you intersect the bounding volume
        if( !intersect ( node.boundingVolume ) ) {
                return (min_t,min_shape);
        }

        // Test the children
        for each child {
                (t, shape) = FindIntersection(ray, child)
                if (t < min_t) {min_shape=shape}
        }
        return (min_t, min_shape);
}
```

Bounding Volume Hierarchies

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

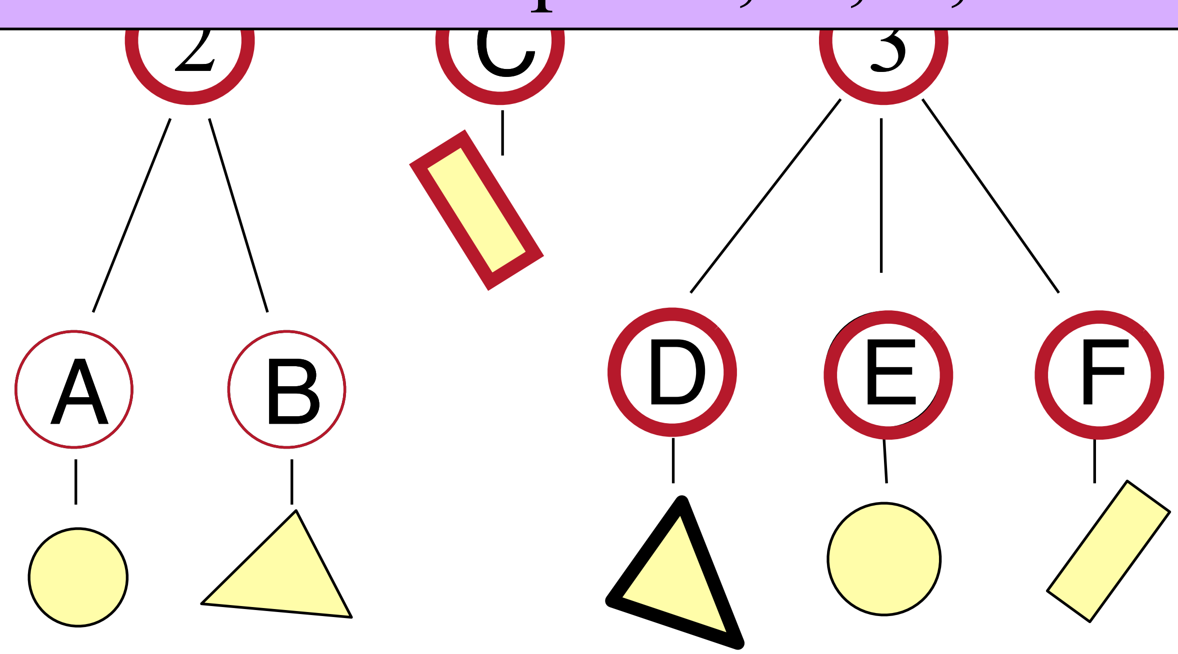


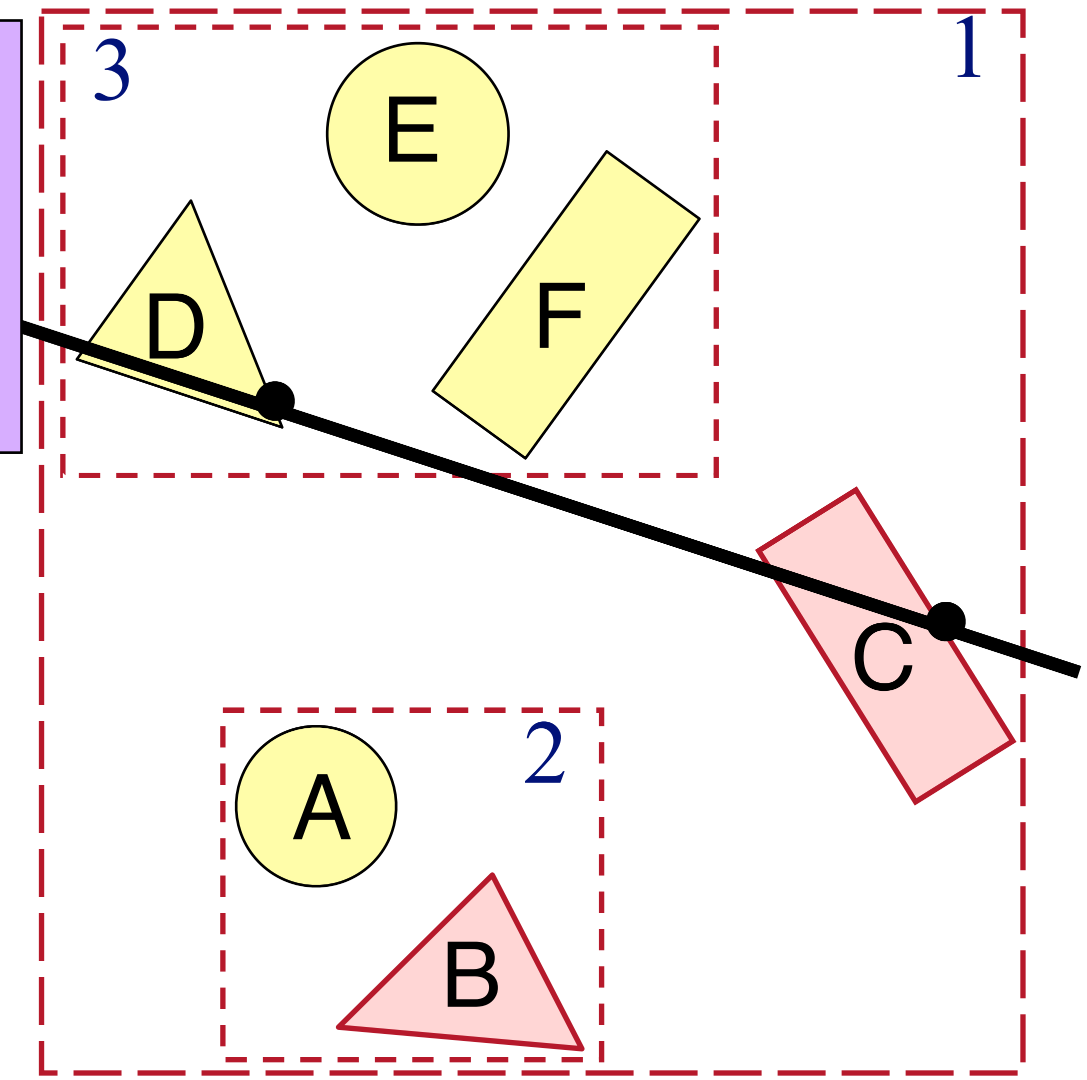


Bounding Volume Hierarchies

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

- Don't need to test shapes A or B
- Need to test groups 1, 2, and 3
- Need to test shapes C, D, E, and F





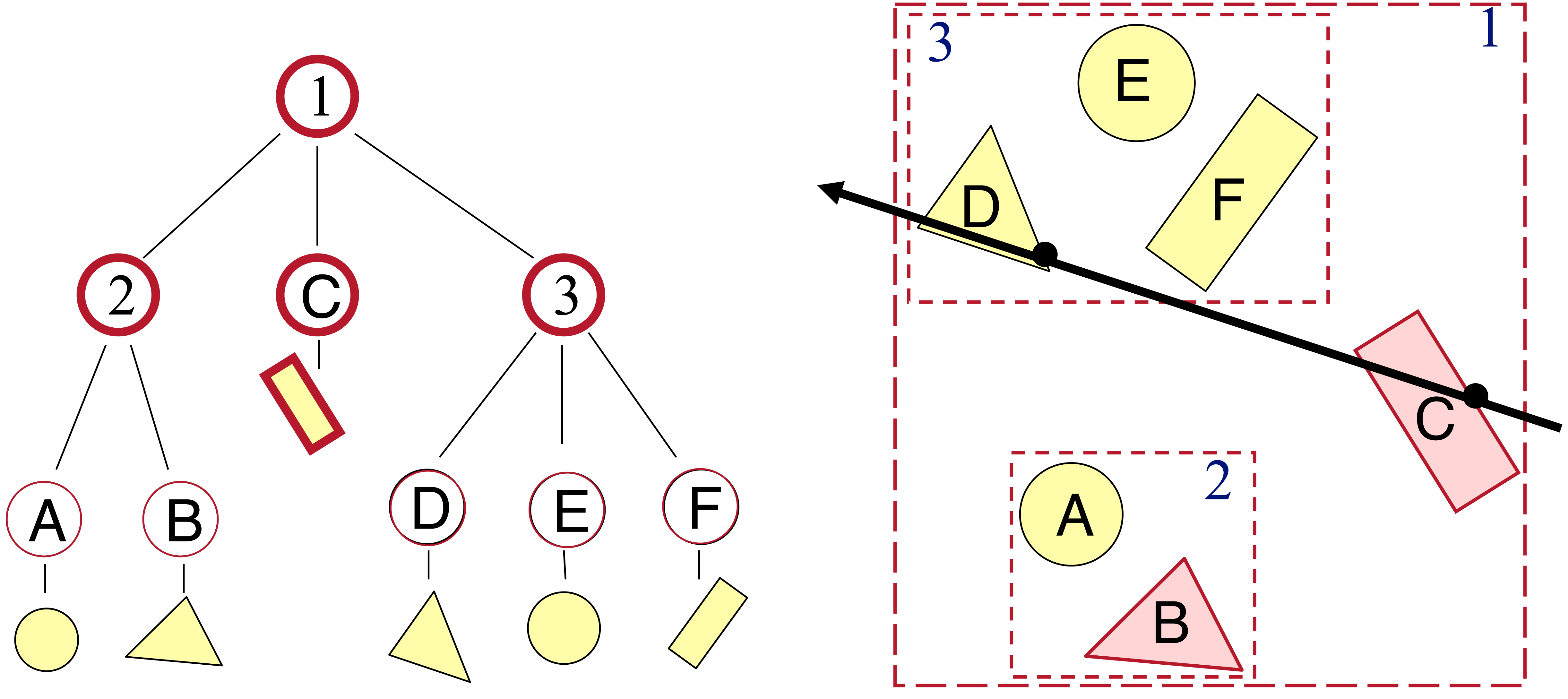
Bounding Volume Hierarchies

- Grouping + Ordering acceleration

```
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 = ∞
        min_shape = NULL
        for each intersected child  {
                if (min_t < bv_t[child]) break;
                (t, shape) = FindIntersection(ray, child);
                if (t < min_t) {
                        min_t = t
                        min_shape = shape
                }
        }
        return (min_t, min_shape);
}
```

Bounding Volume Hierarchies

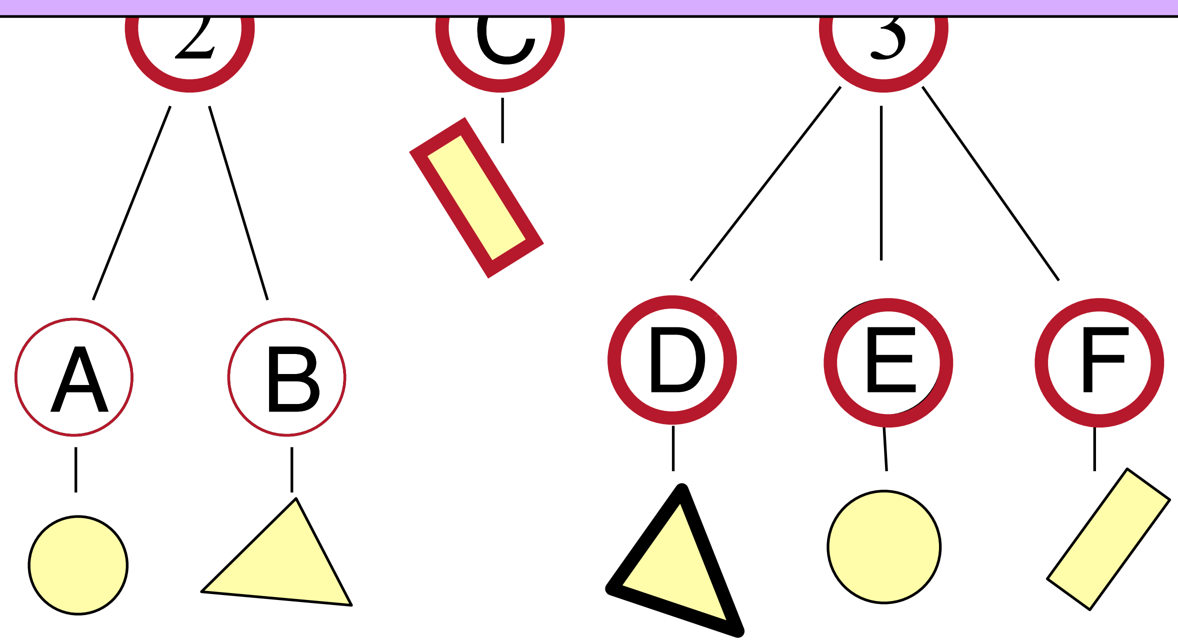
- Use hierarchy to accelerate ray intersections
  - Intersect nodes only if you haven't hit anything closer

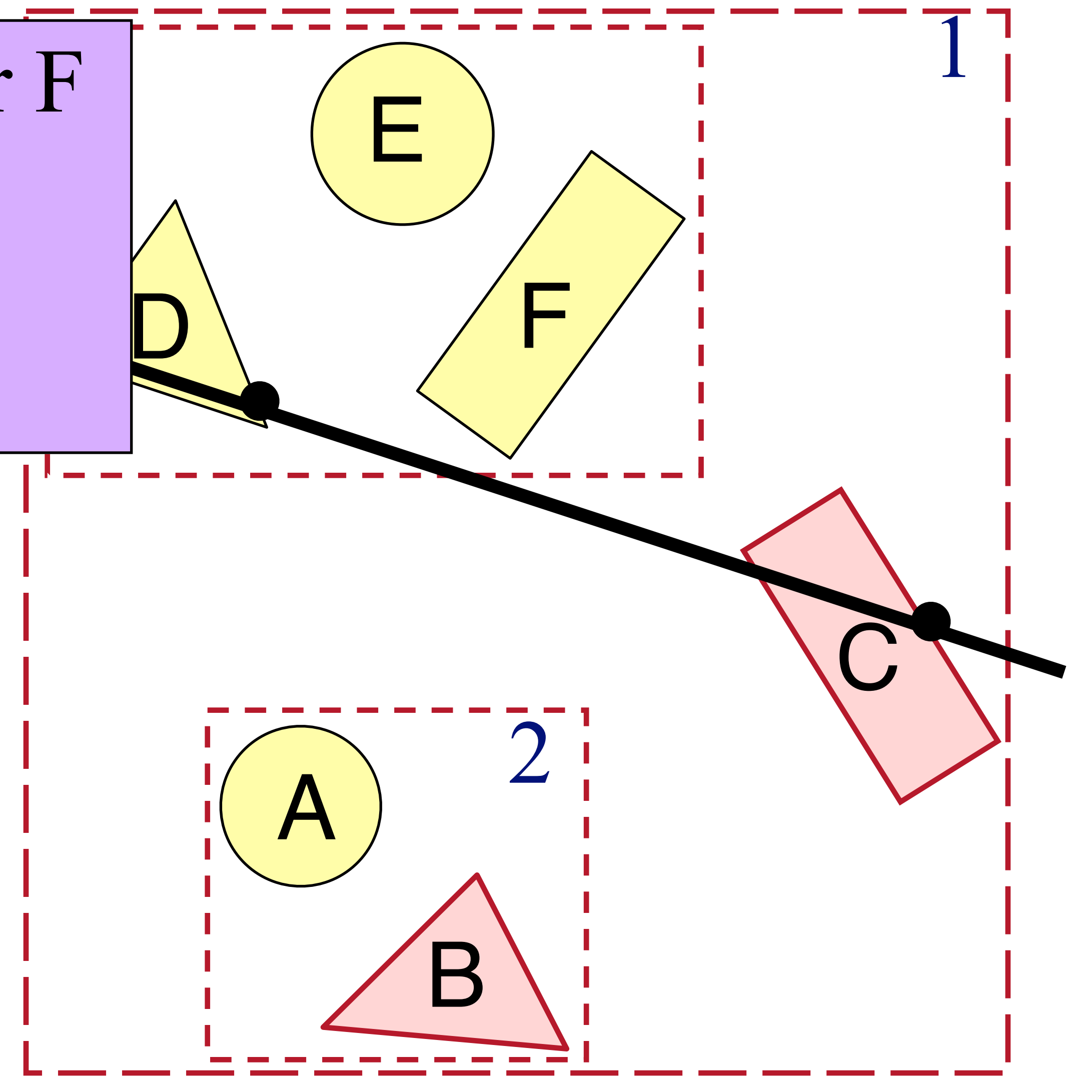


Bounding Volume Hierarchies

- Use hierarchy to accelerate ray intersections
  - Intersect nodes only if you haven't hit anything closer

- Don't need to test shapes A, B, D, E, or F
- Need to test groups 1, 2, and 3
- Need to test shape C





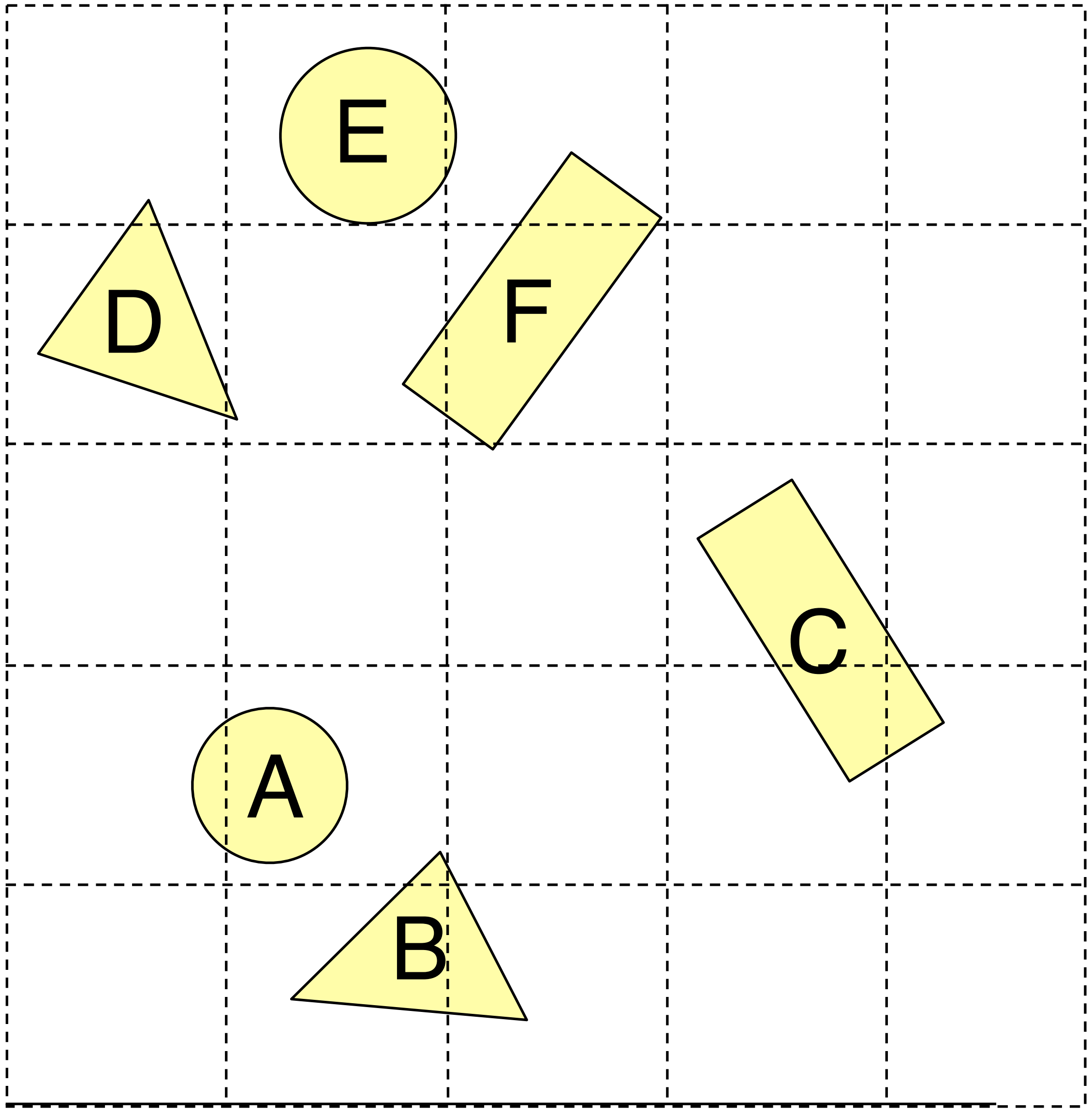
Overview

- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform grids
    - Octrees
    - BSP trees

Uniform (Voxel) Grid

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

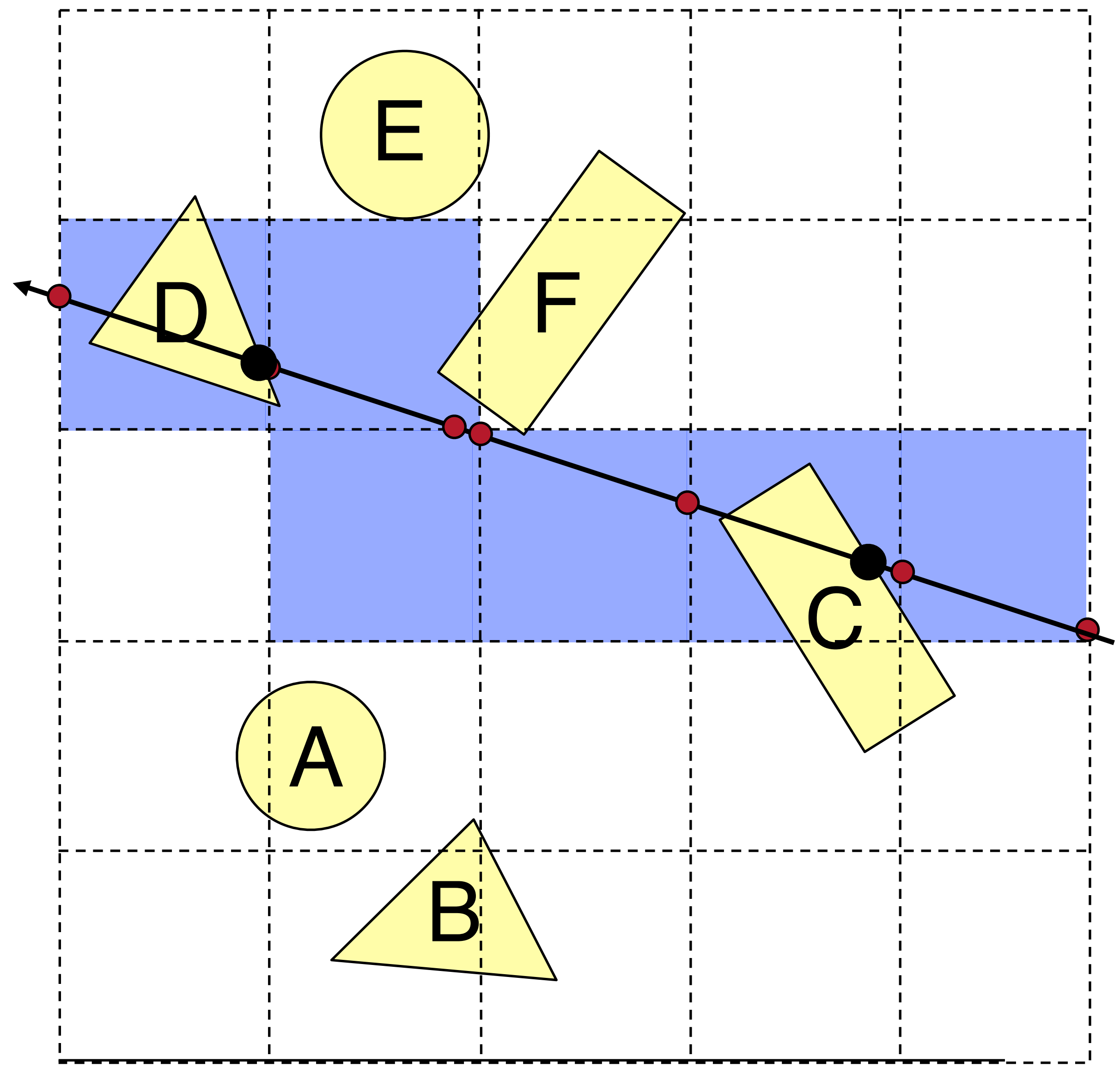
- A primitive may belong to multiple cells
- A cell may have multiple primitives



Uniform (Voxel) Grid

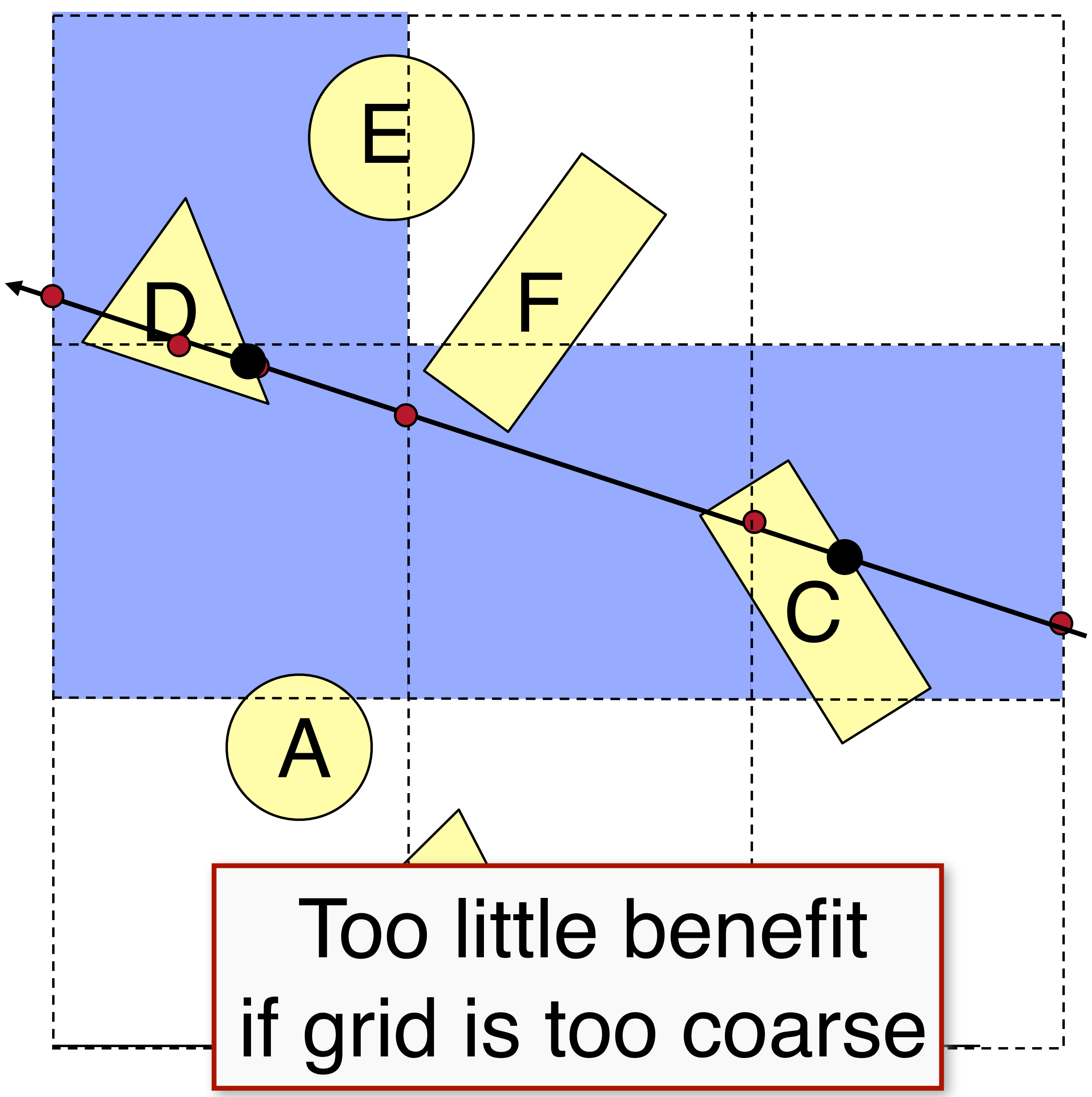
- Trace rays through grid cells
  - Fast
  - Incremental

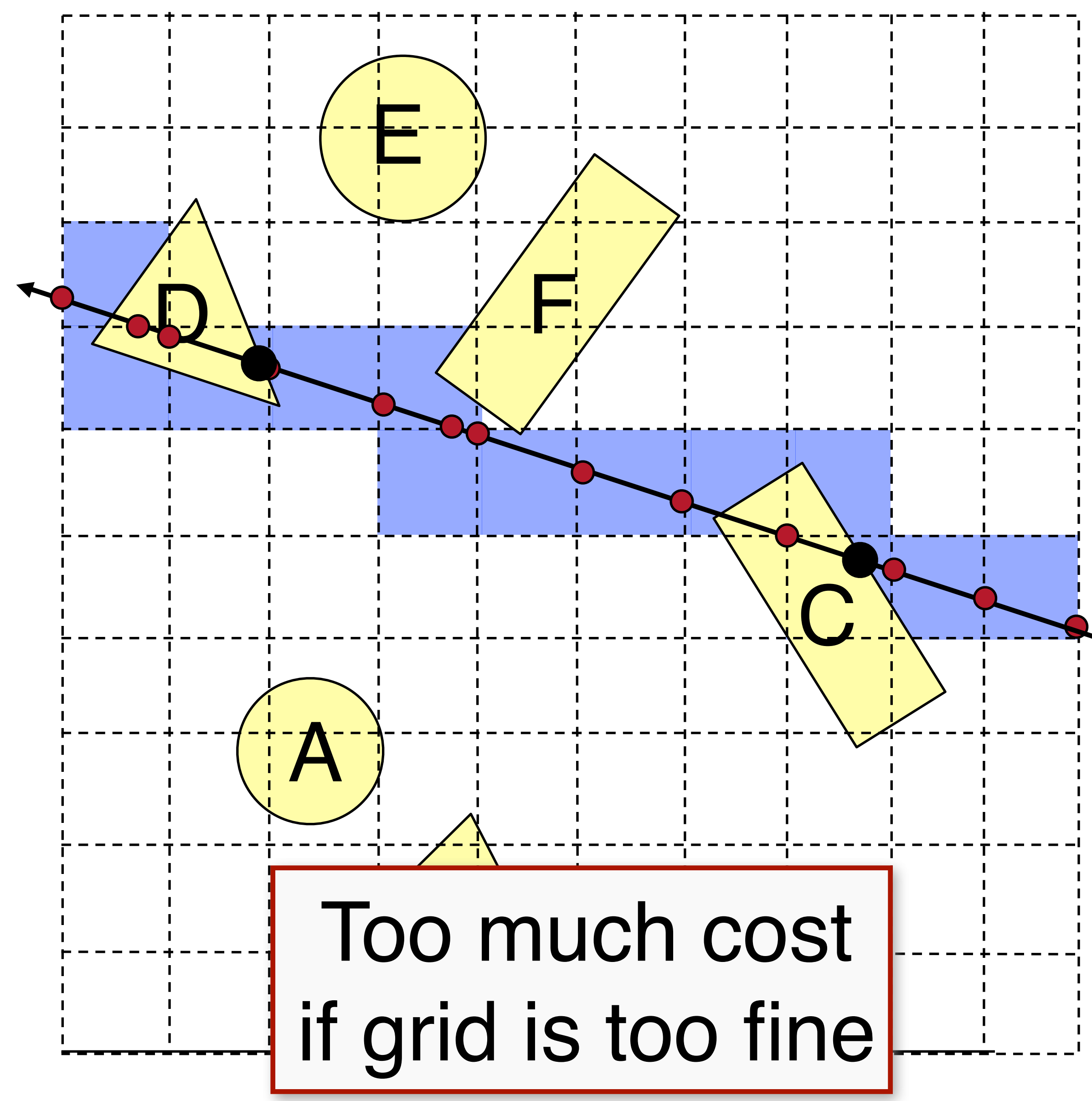
Only check primitives in intersected grid cells



Uniform (Voxel) Grid

- Potential problem:
  - How choose suitable grid resolution?





"Teapot in a Stadium" Problem

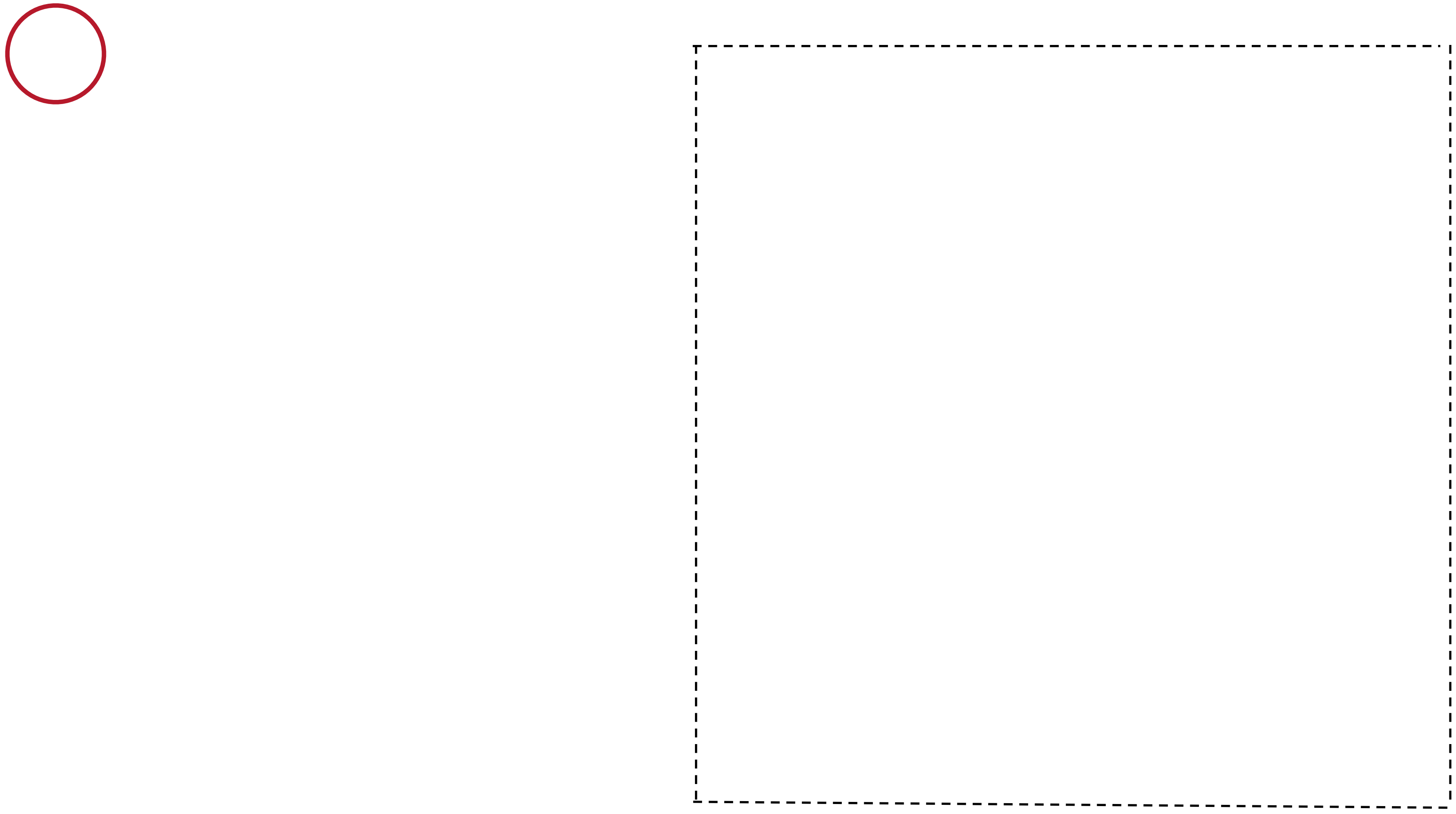
Could have much complicated geometry (e.g. a teapot) inside a single cell of the voxel grid.
Why is this problematic?

Ray-Scene Intersection

- » Acceleration techniques
  - o Bounding volume hierarchies
  - o Spatial partitions
    - » Uniform grids
    - » Octrees
    - » BSP trees

Octrees

- We can think of a voxel grid as a tree.
  - The root node is the entire region
  - Each node has eight children obtained by subdividing the parent into eight equal regions



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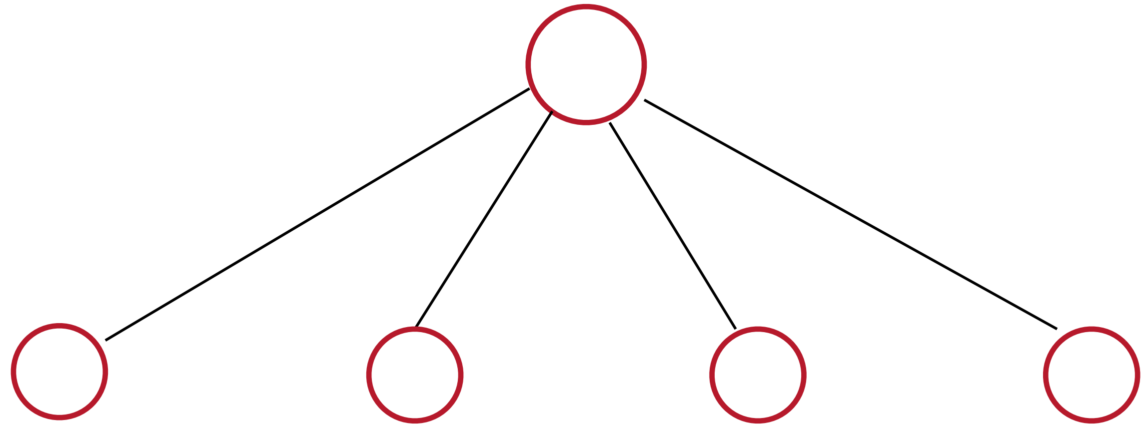

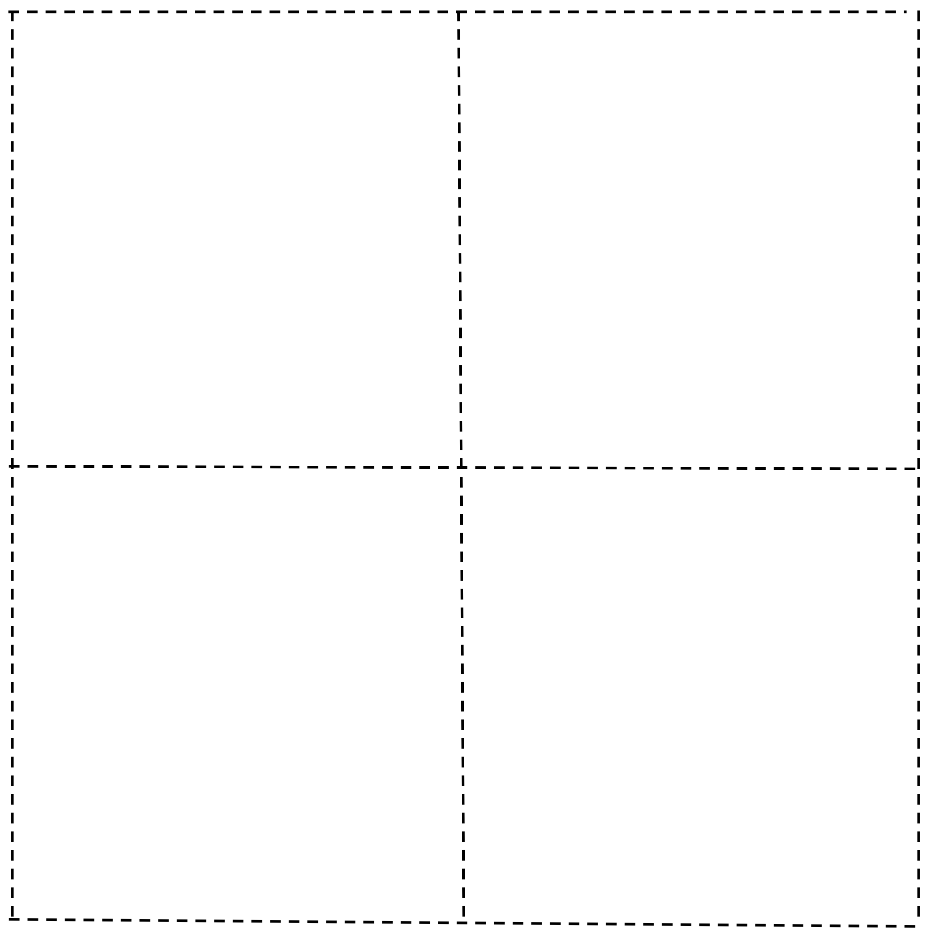

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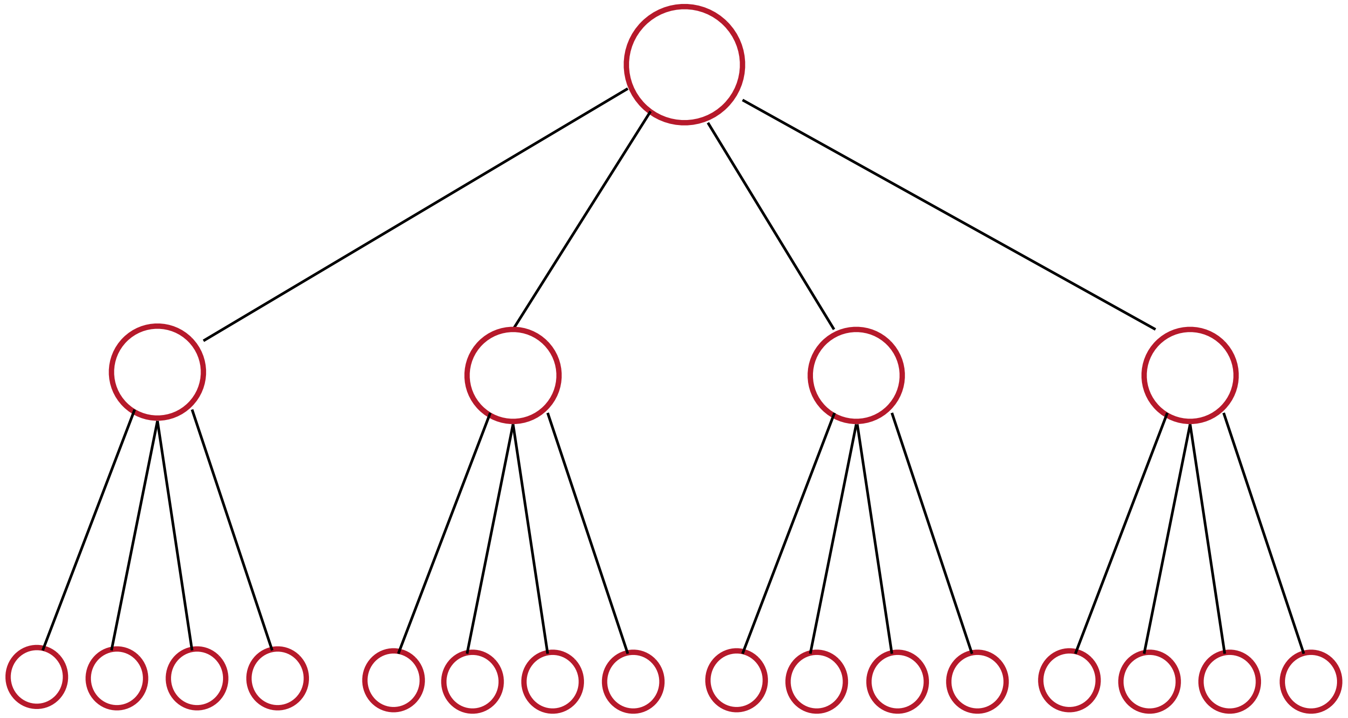

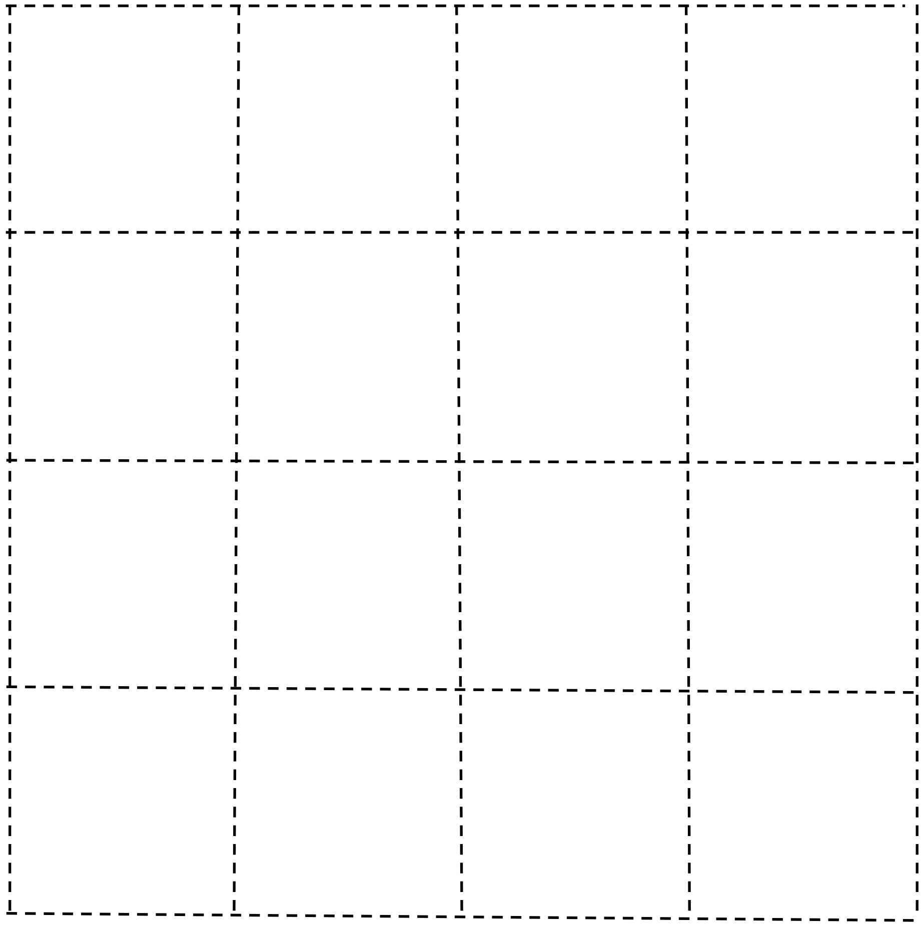

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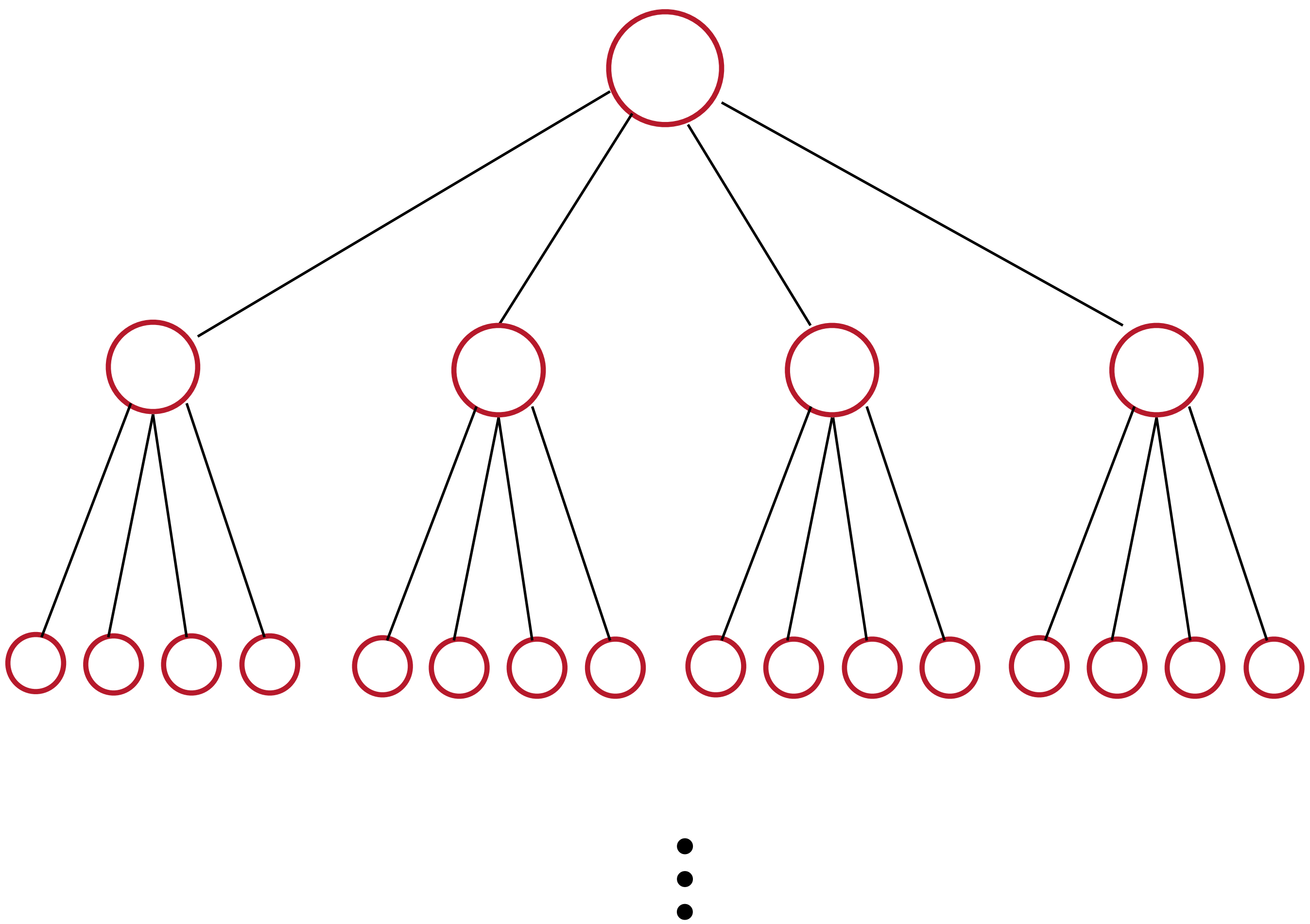
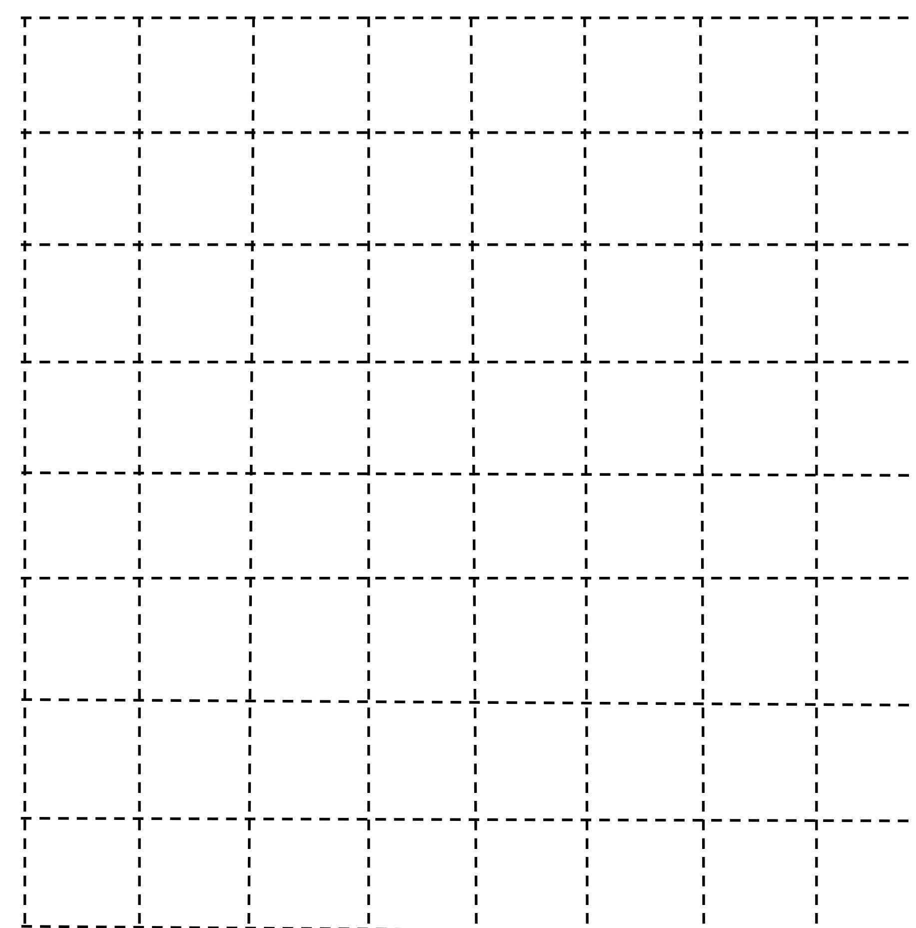
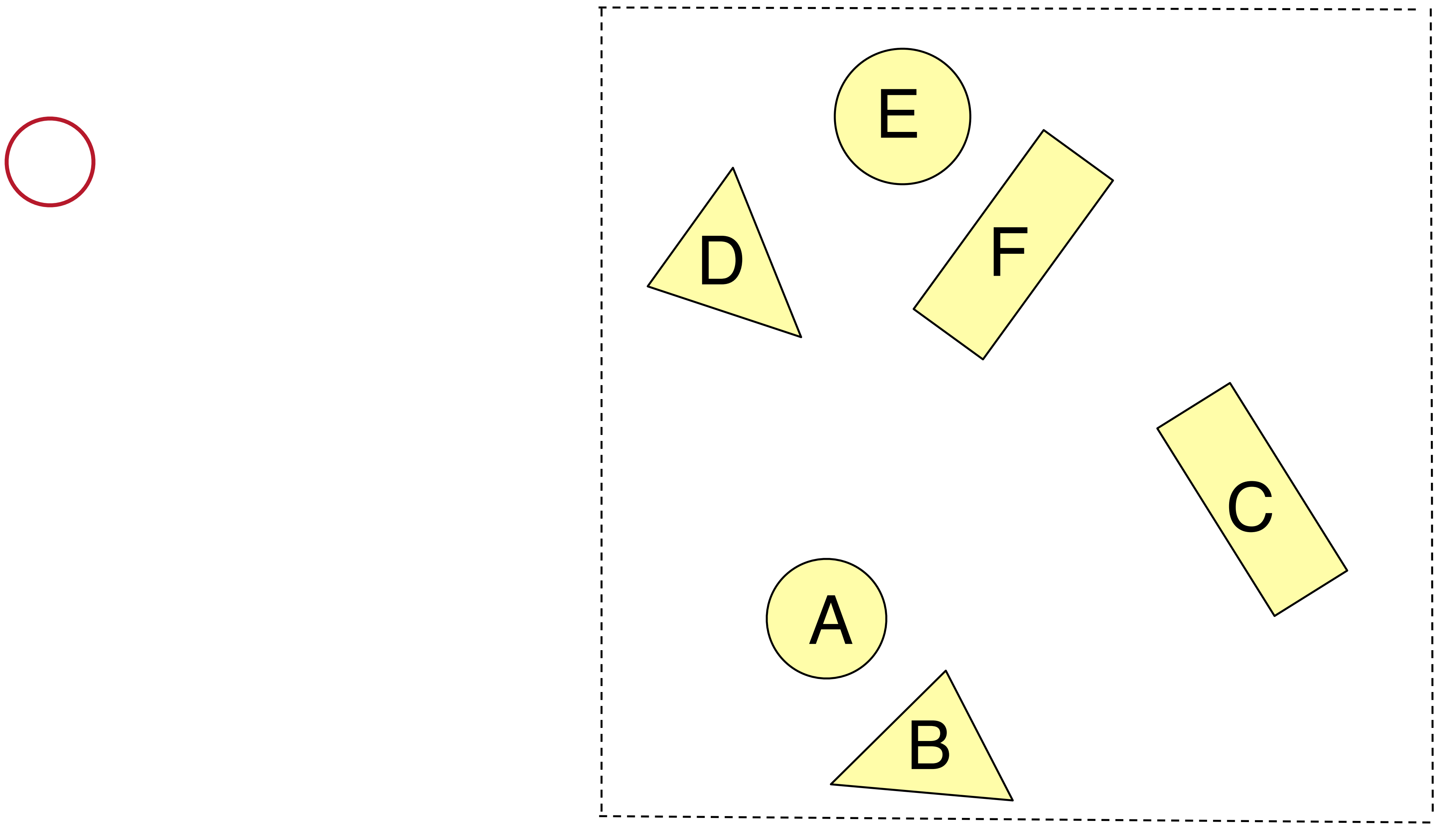




Octrees

- In an octree, we only subdivide regions that contain more than one shape.



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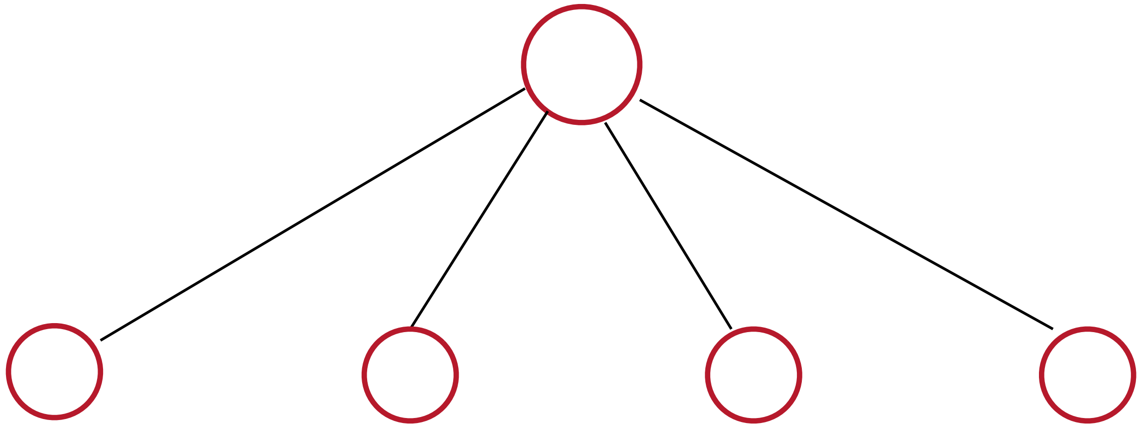

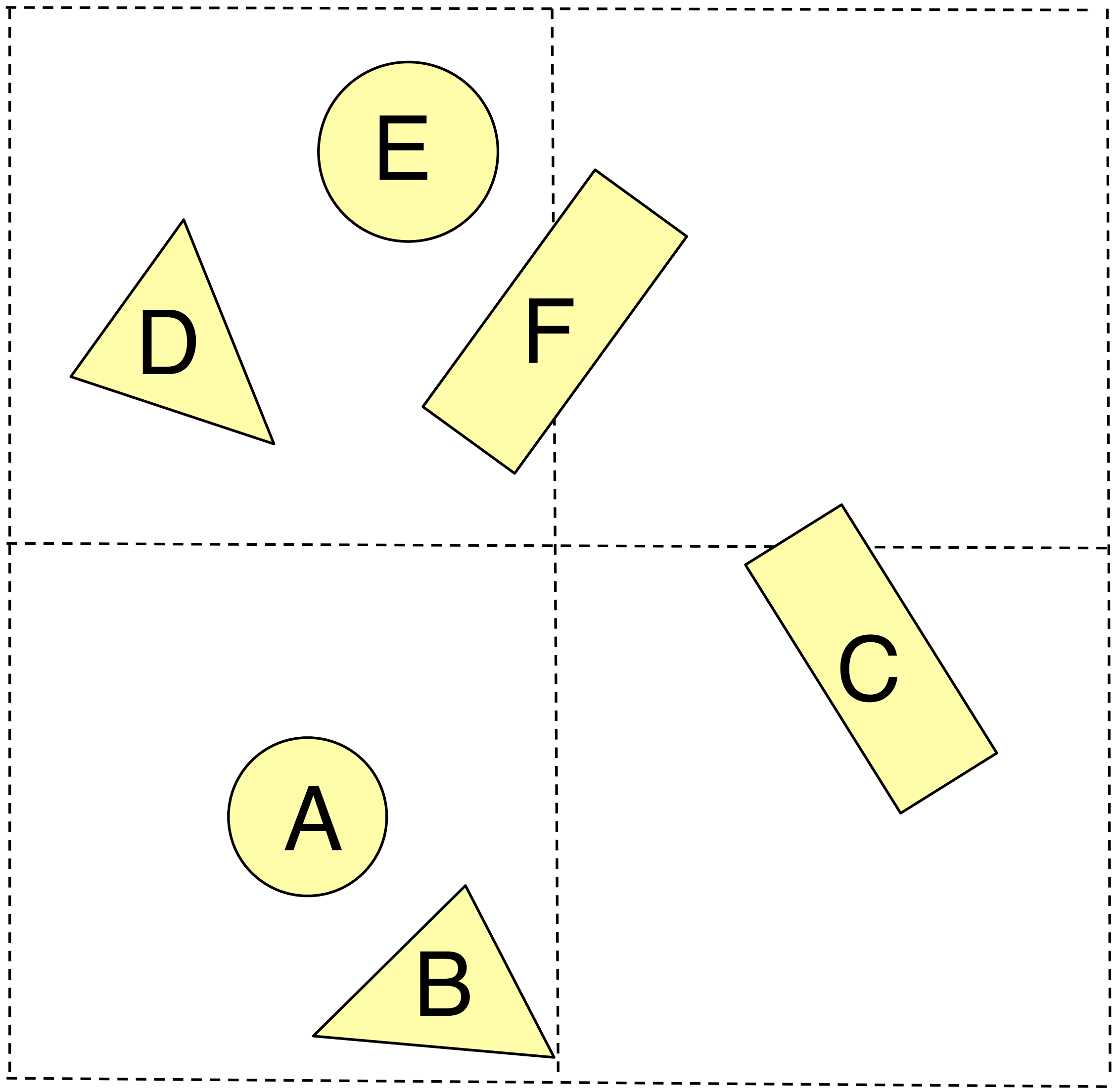

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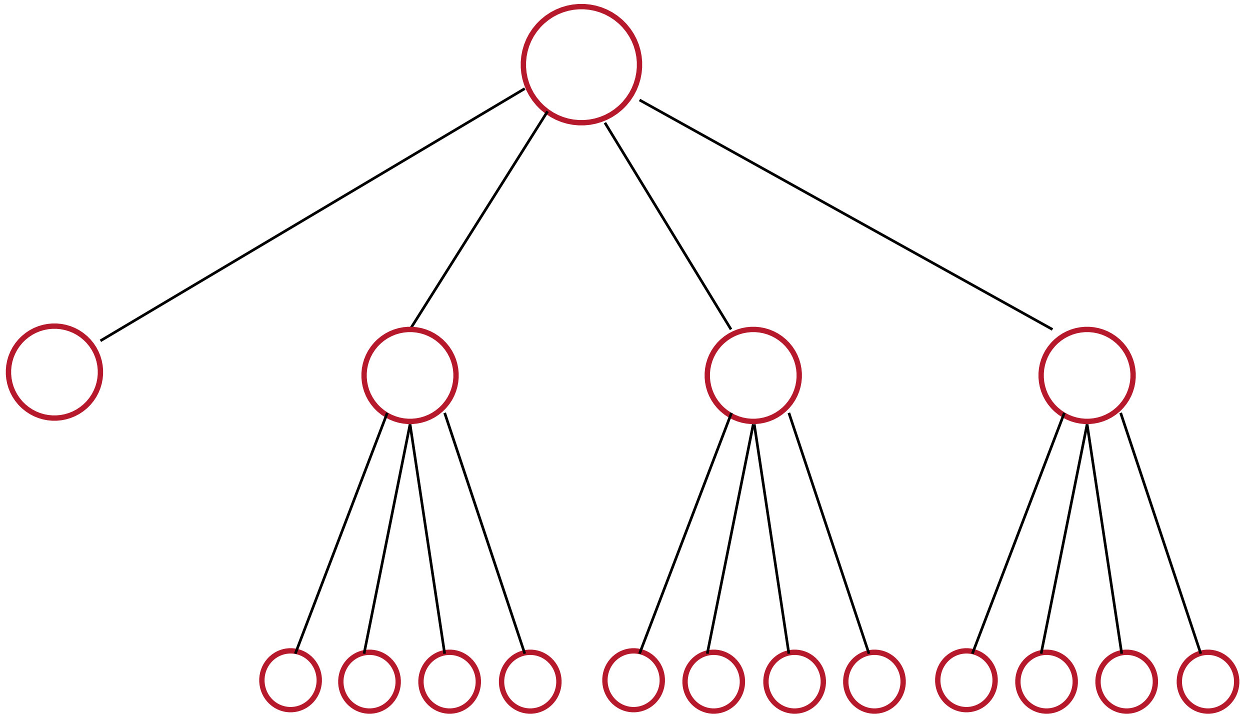

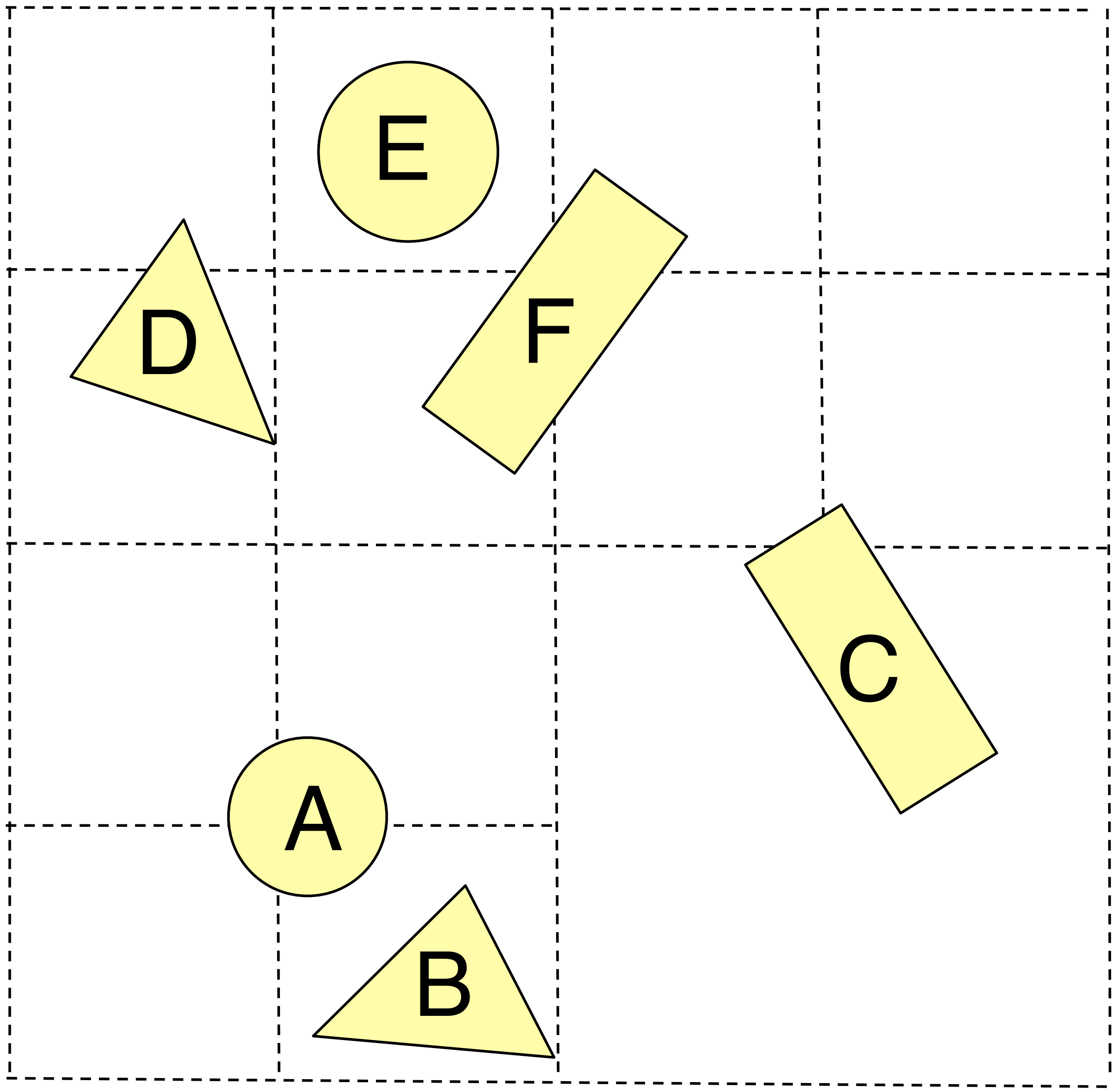

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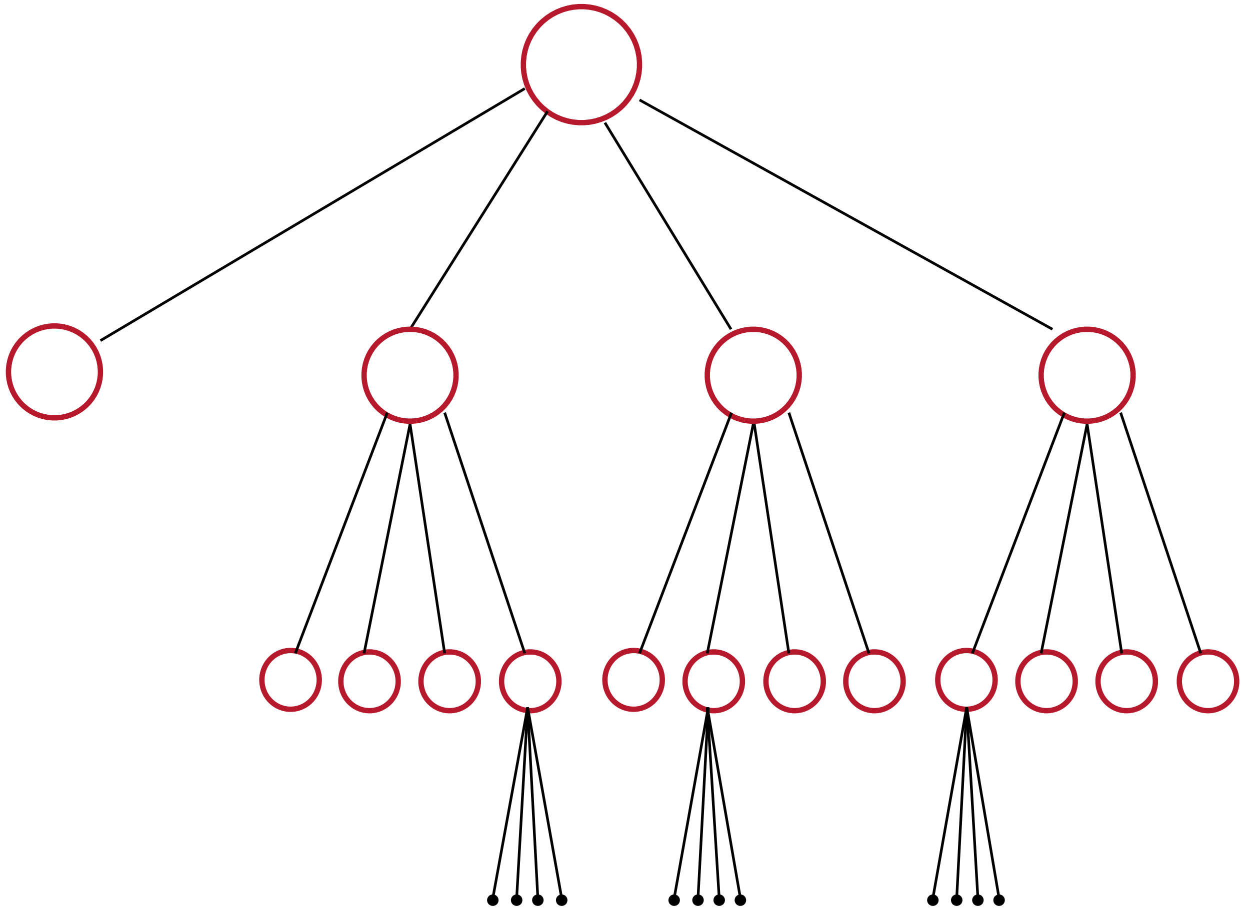

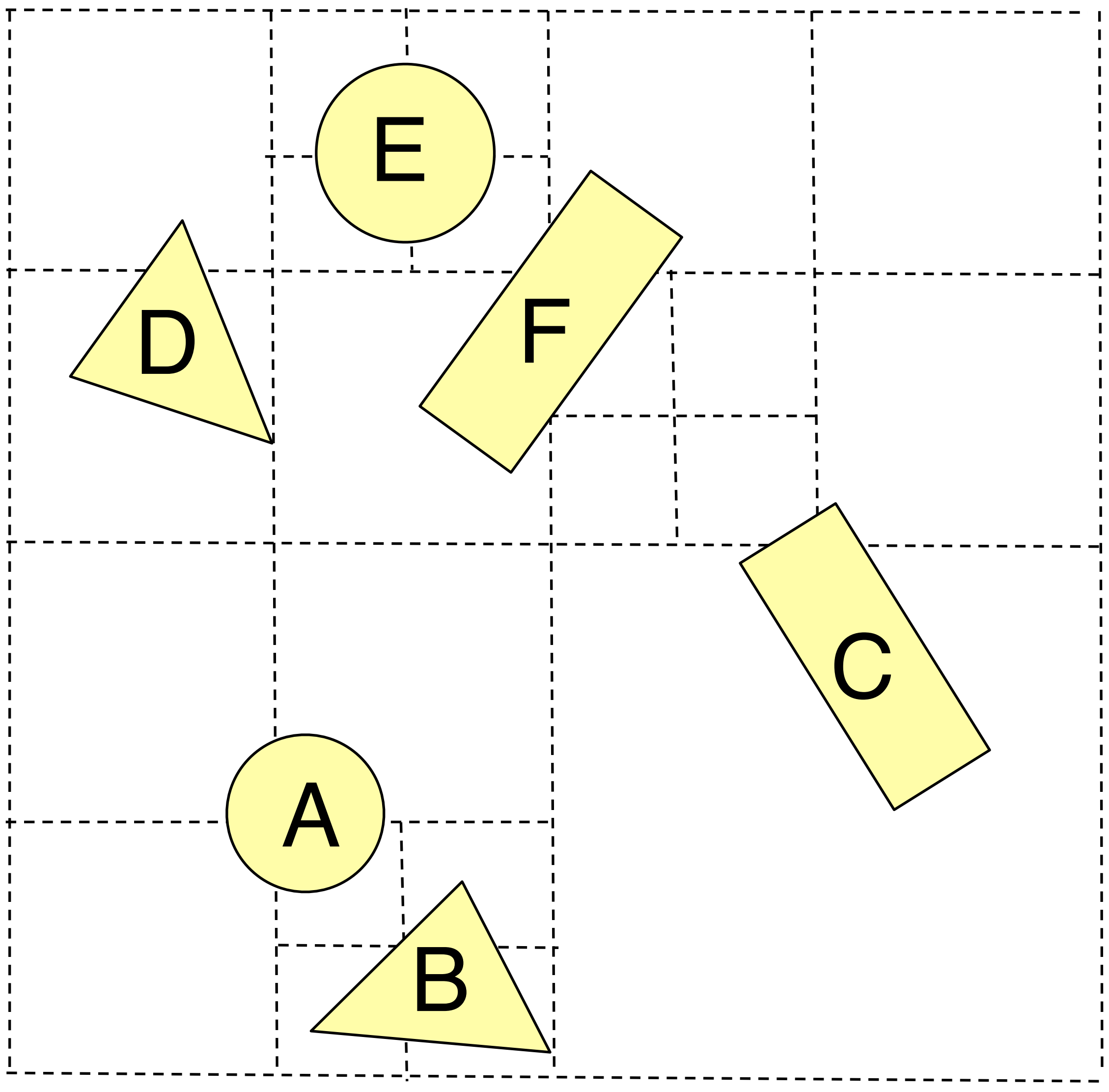

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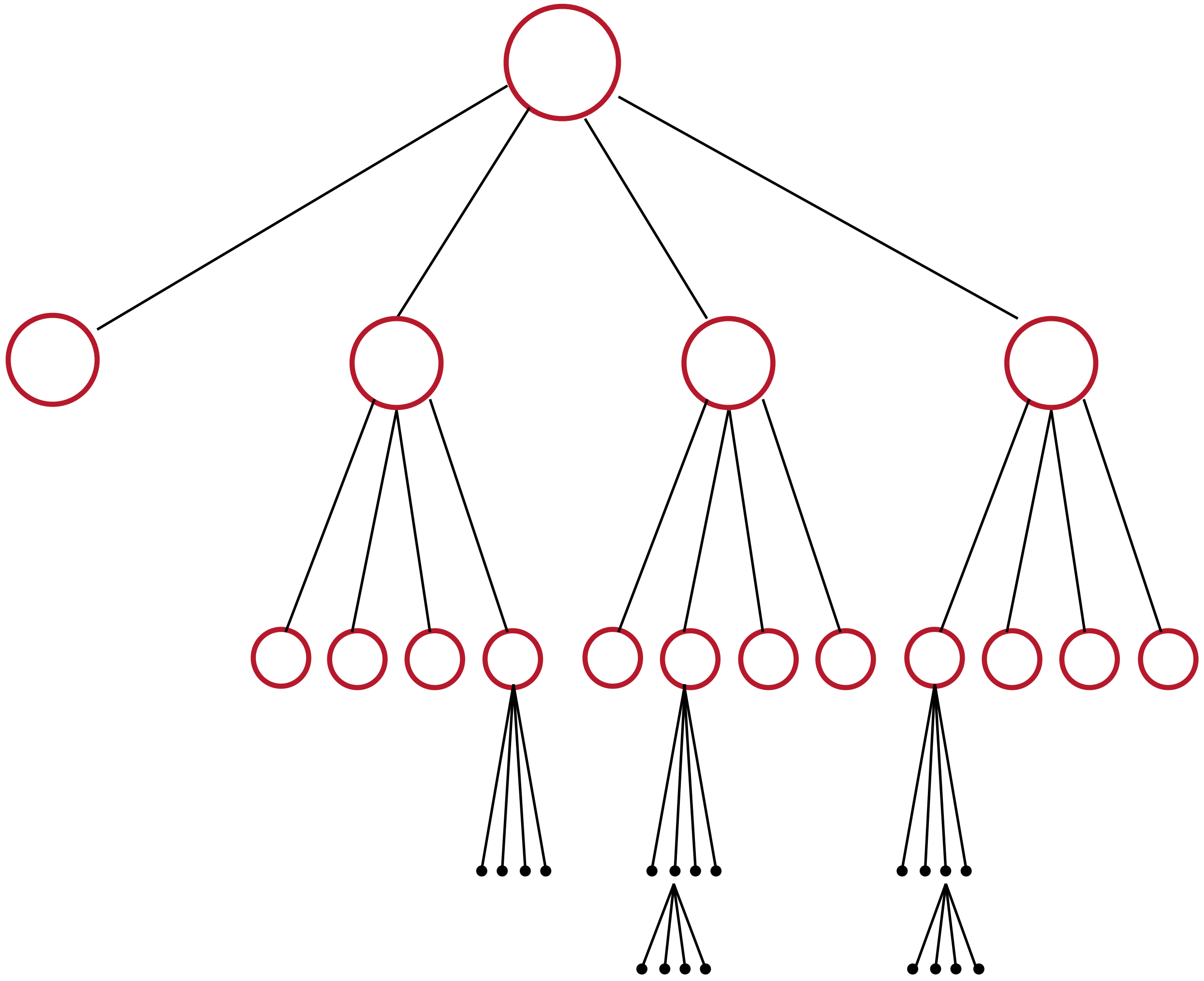
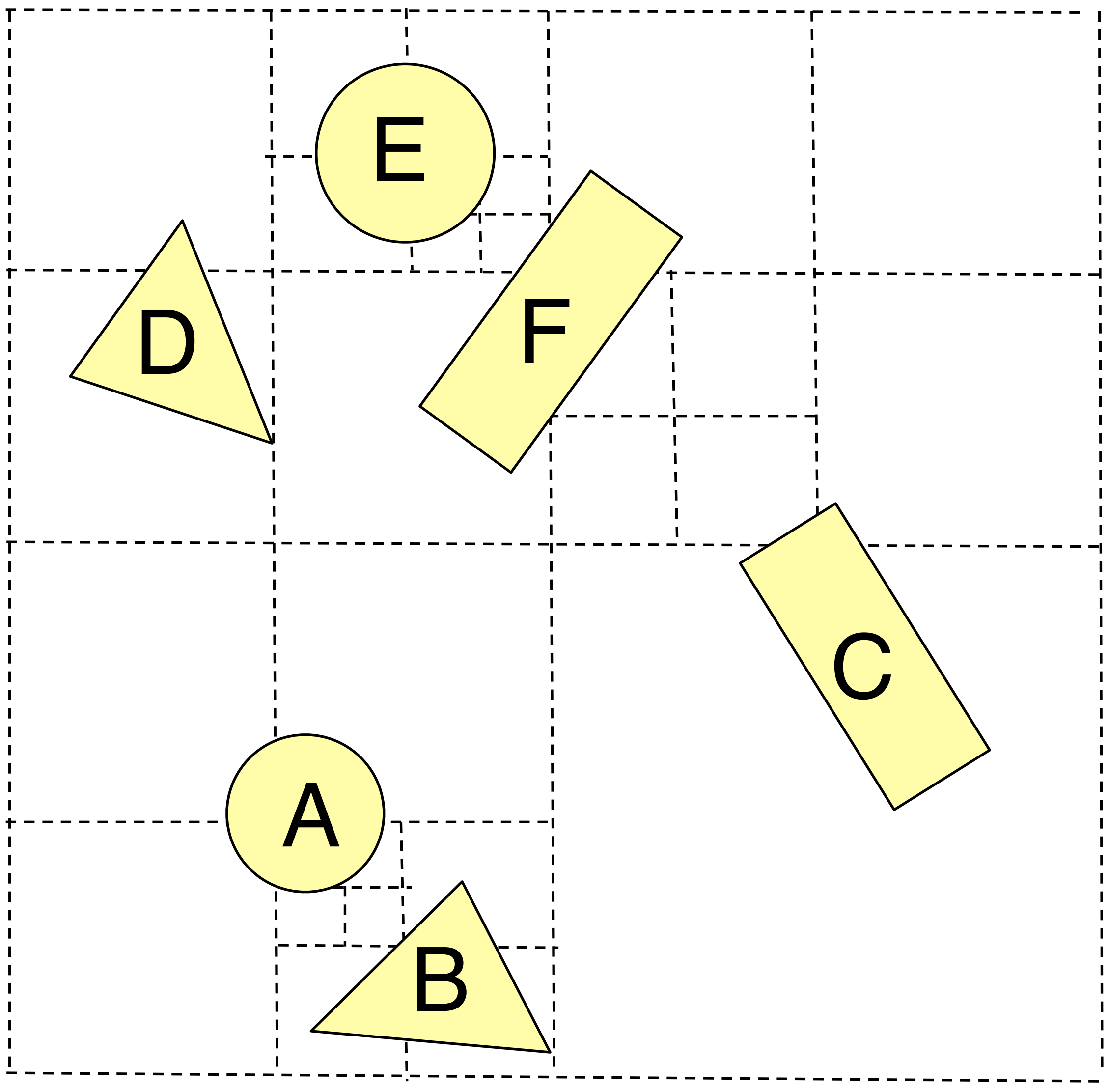
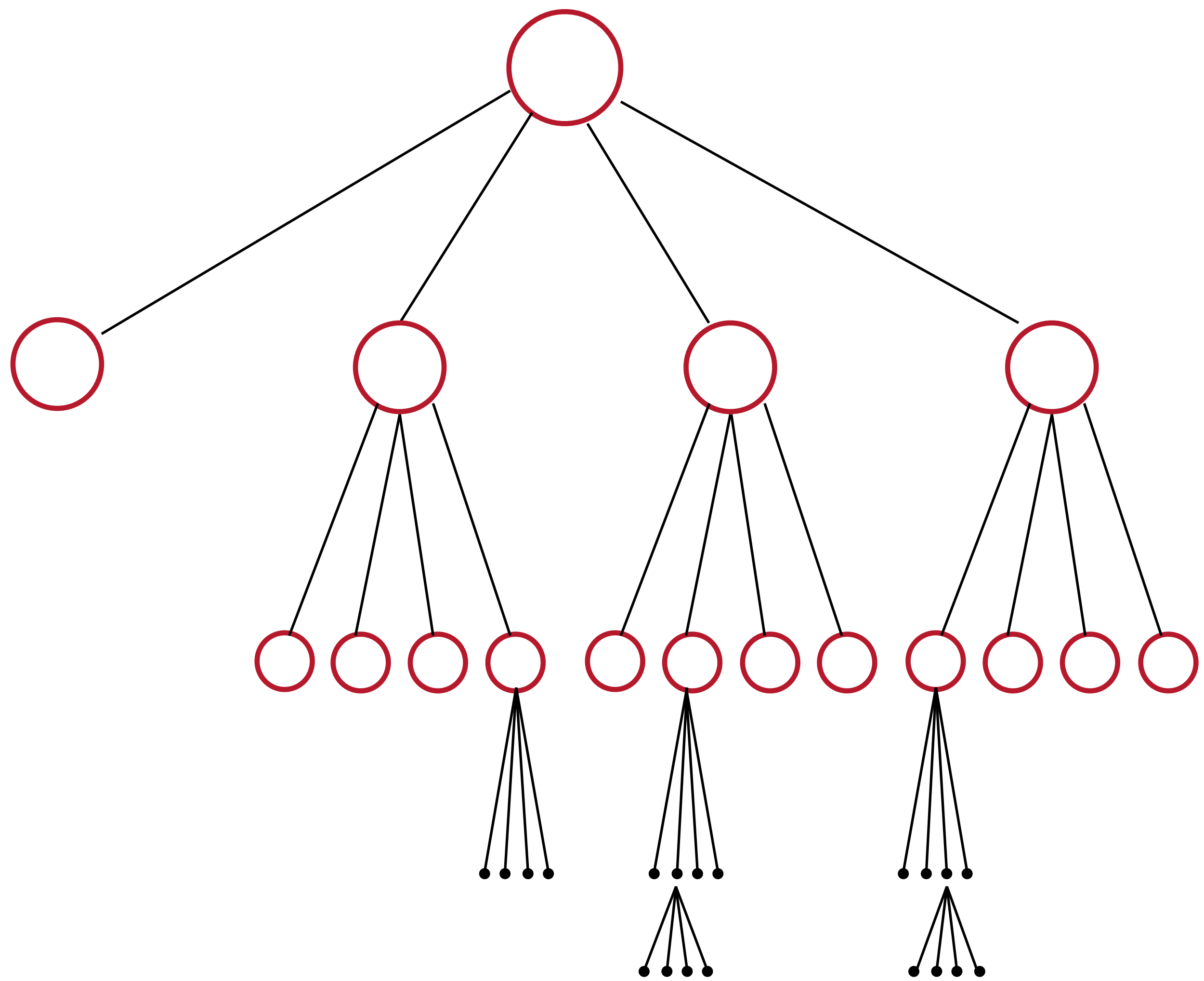
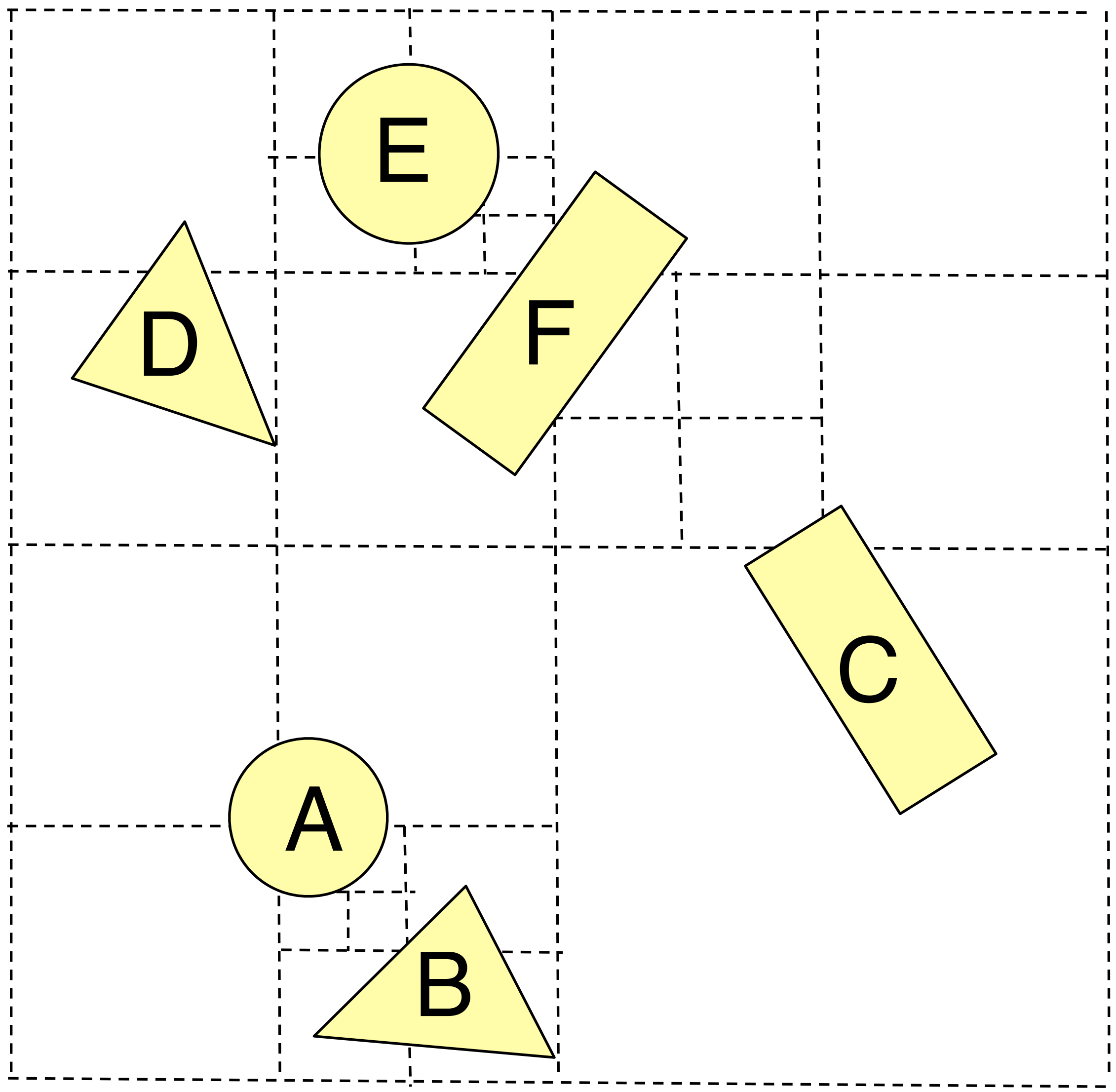




Octrees

- In an octree, we only subdivide regions that contain more than one shape.
- Adaptively determines grid resolution.



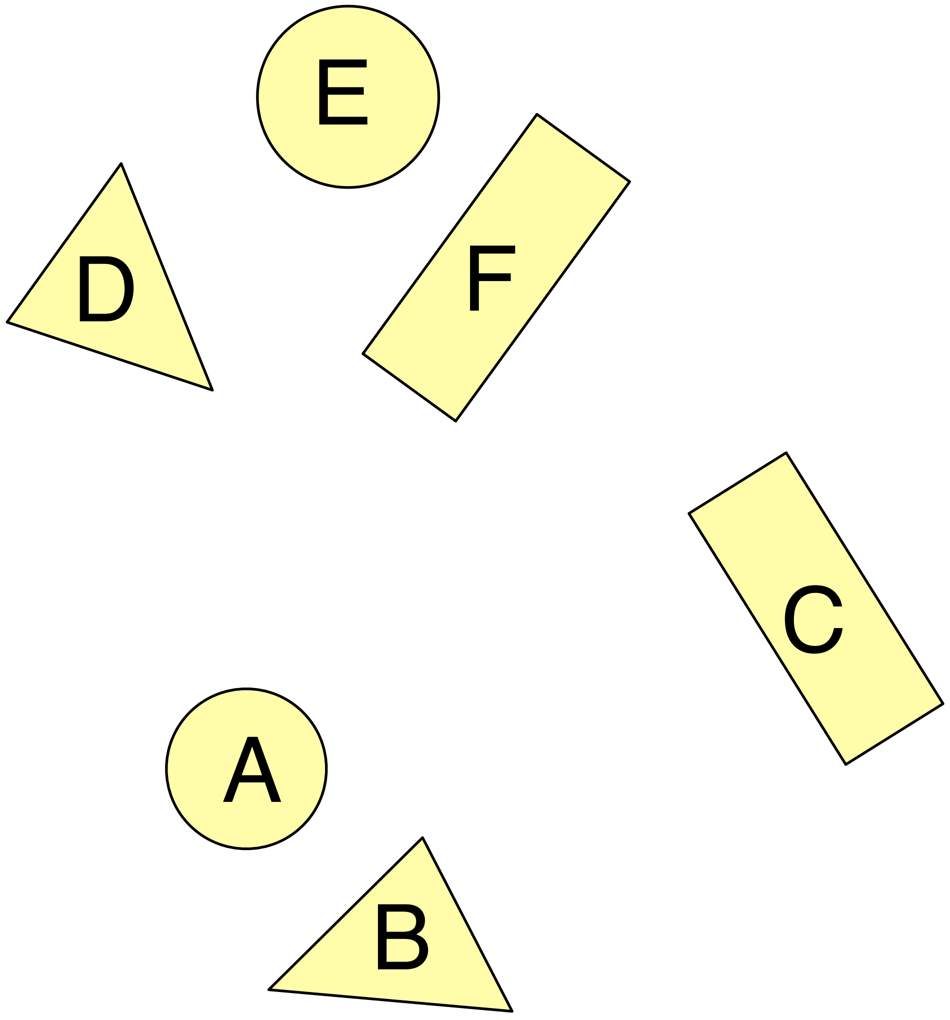


Ray-Scene Intersection

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

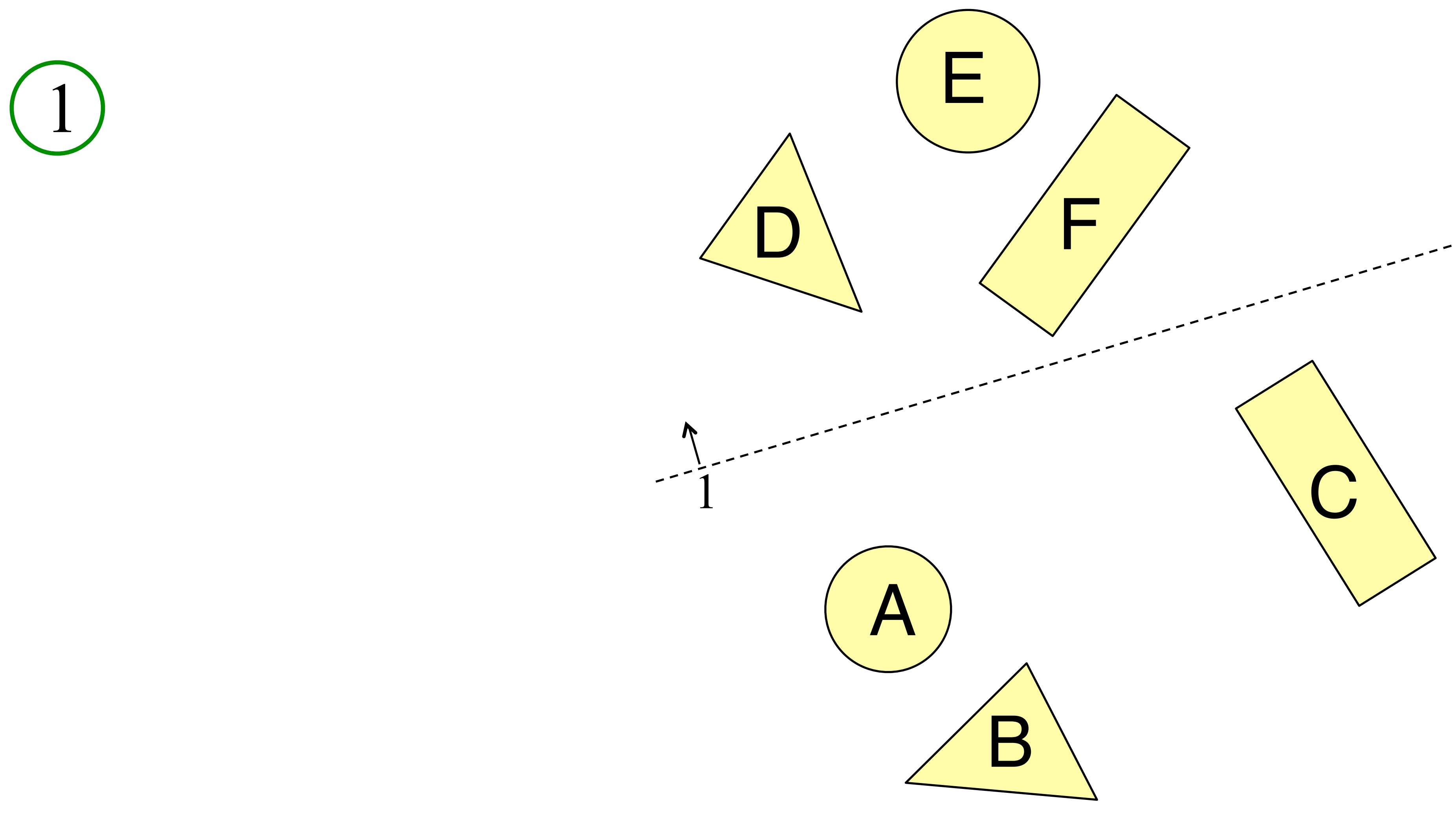
Binary Space Partition (BSP) Tree

- Recursively partition space by planes



Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.



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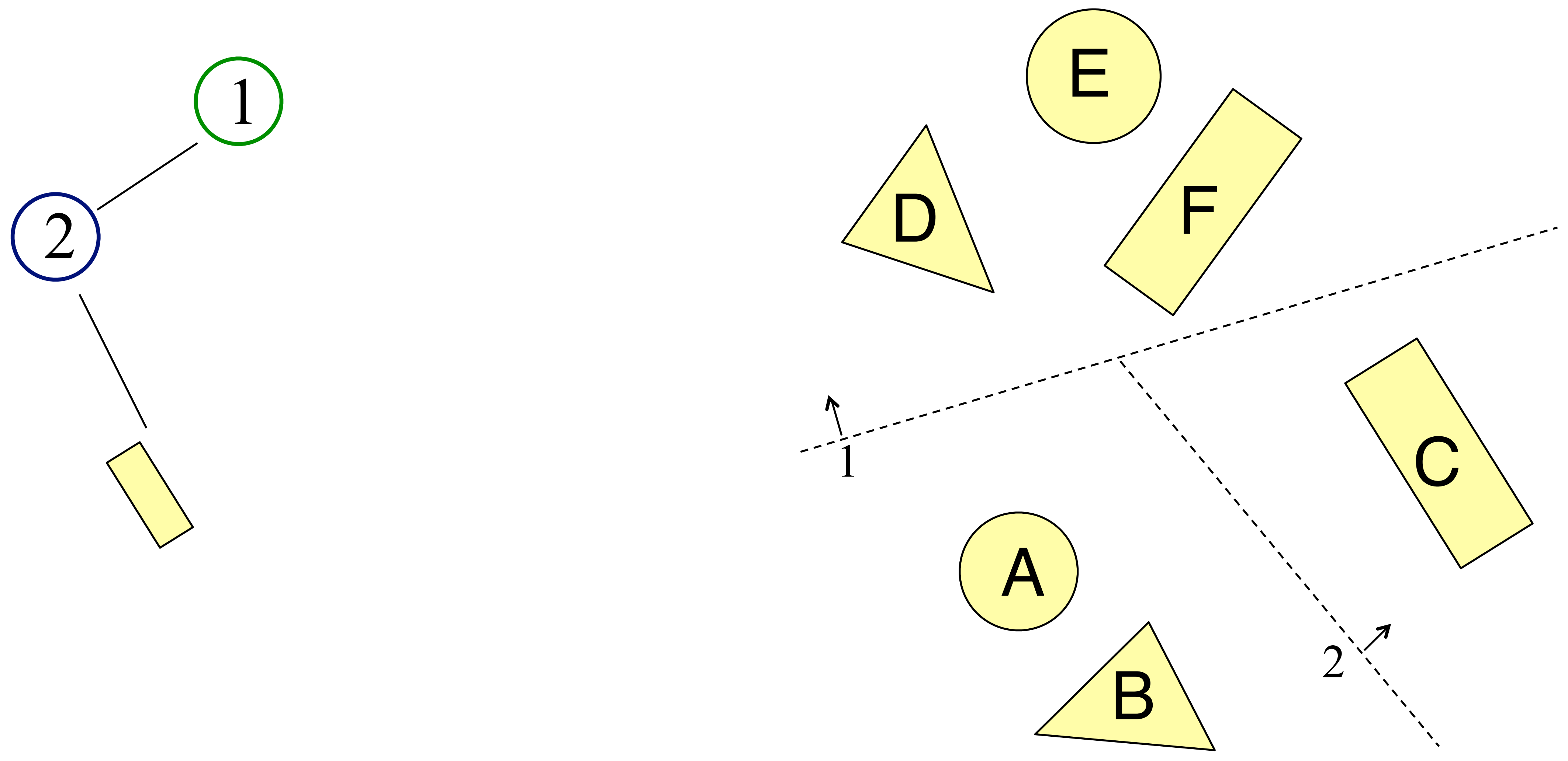

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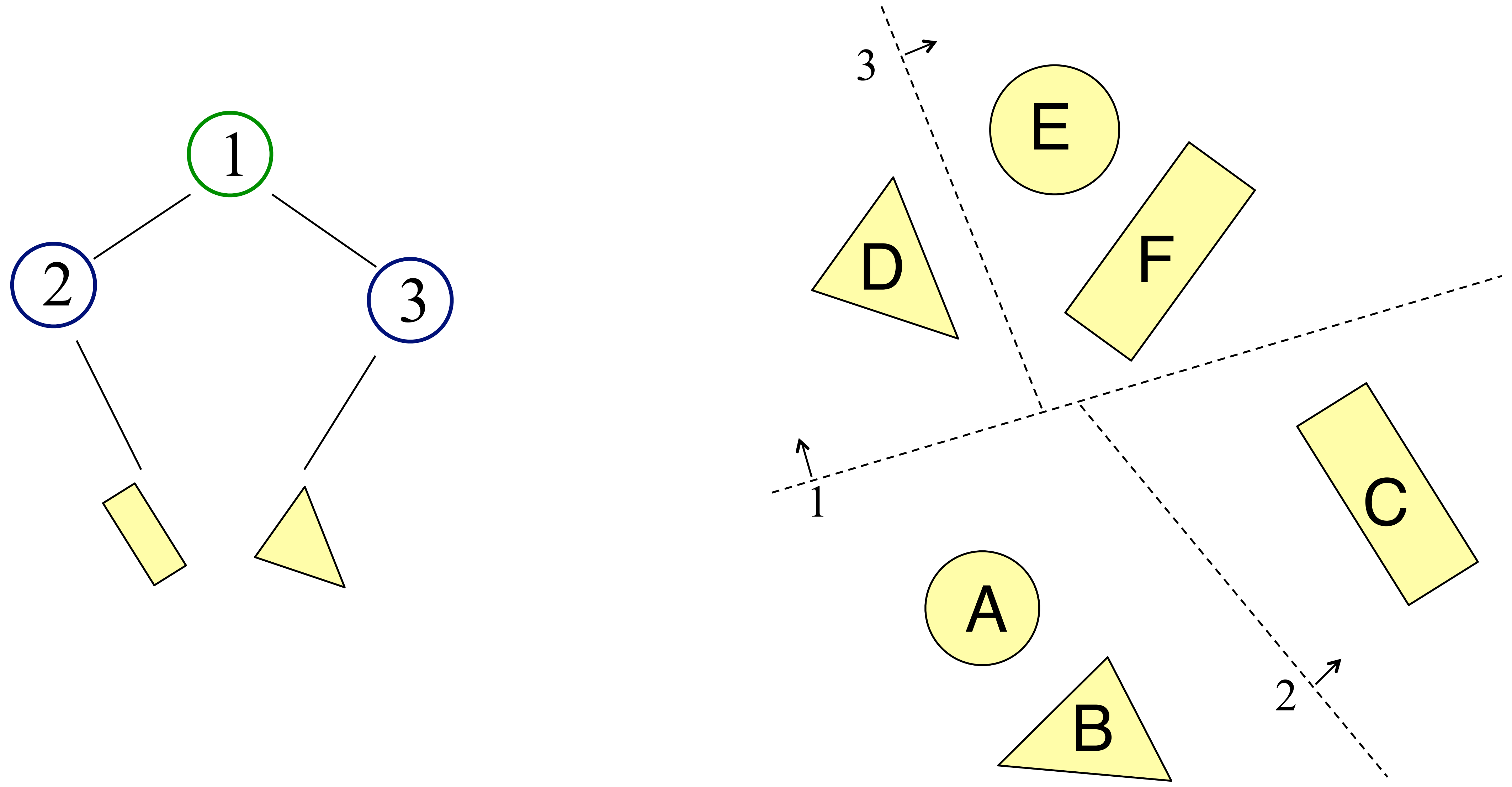

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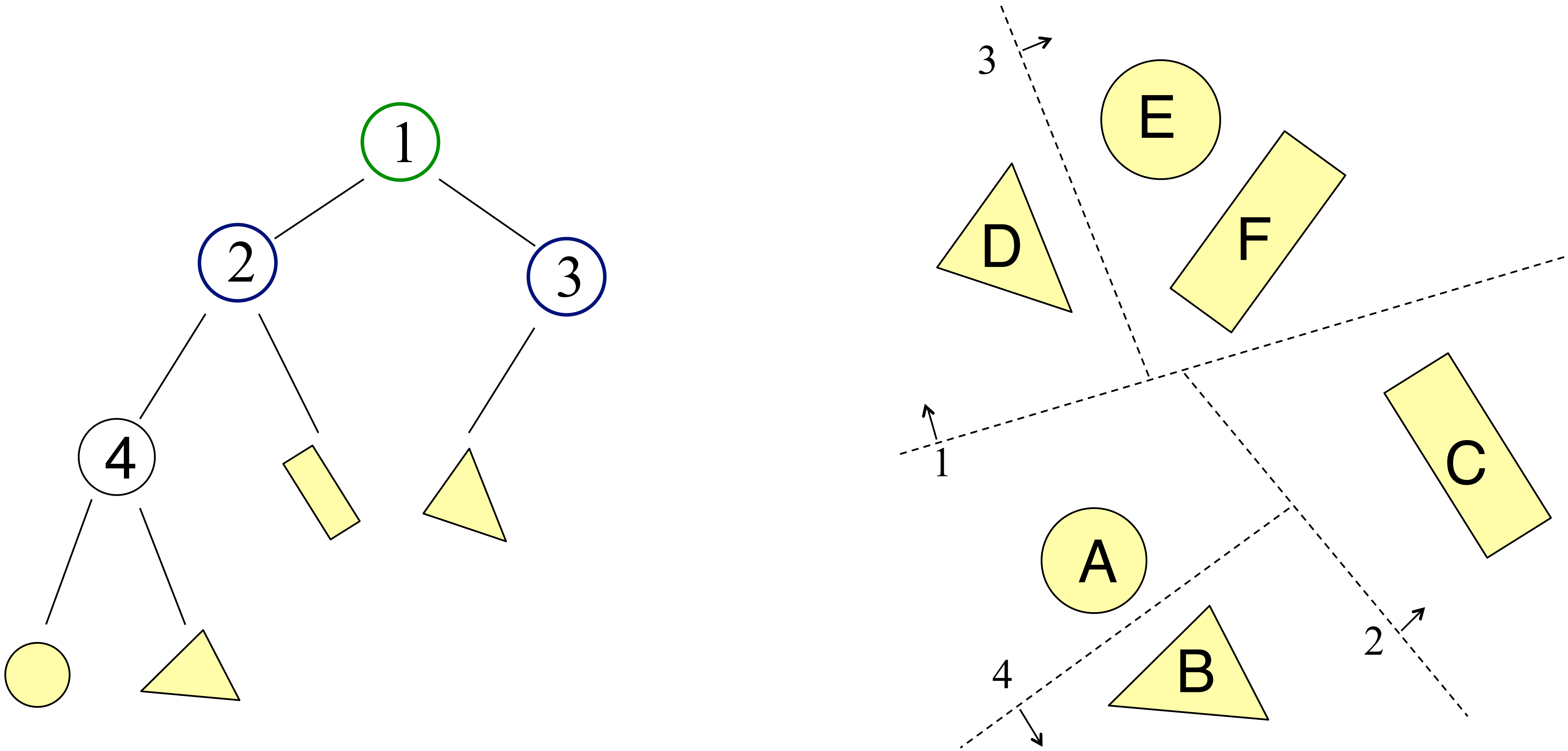

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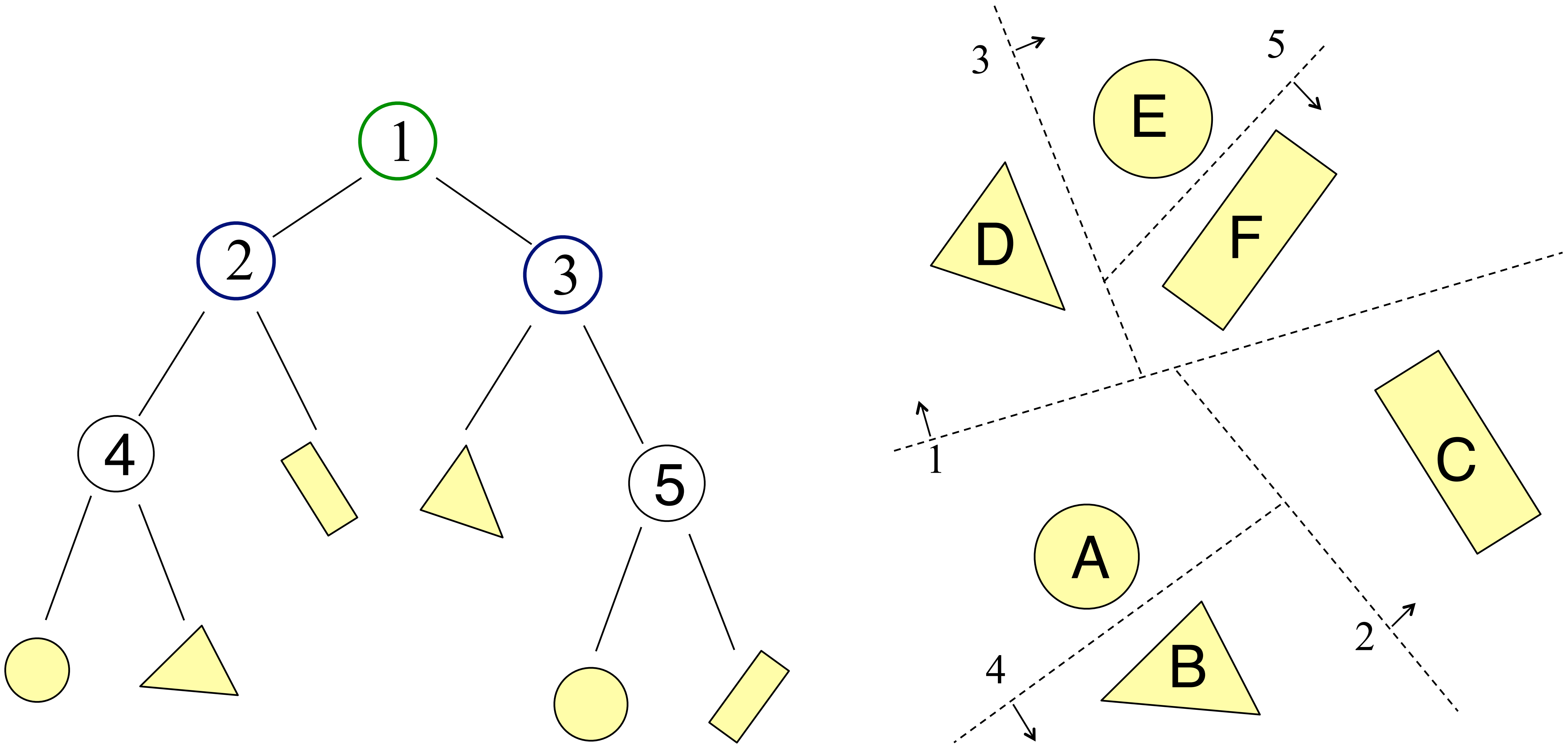
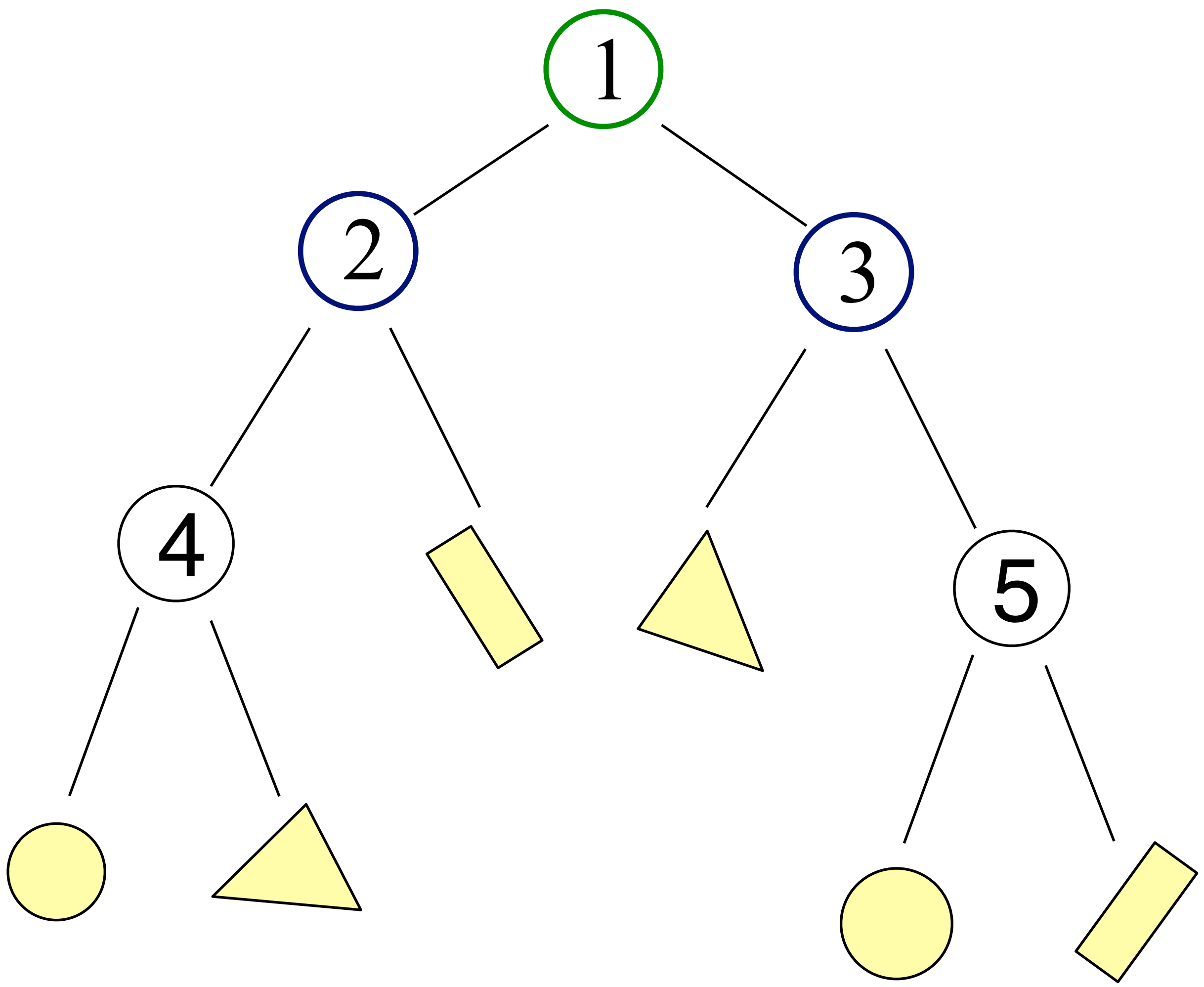
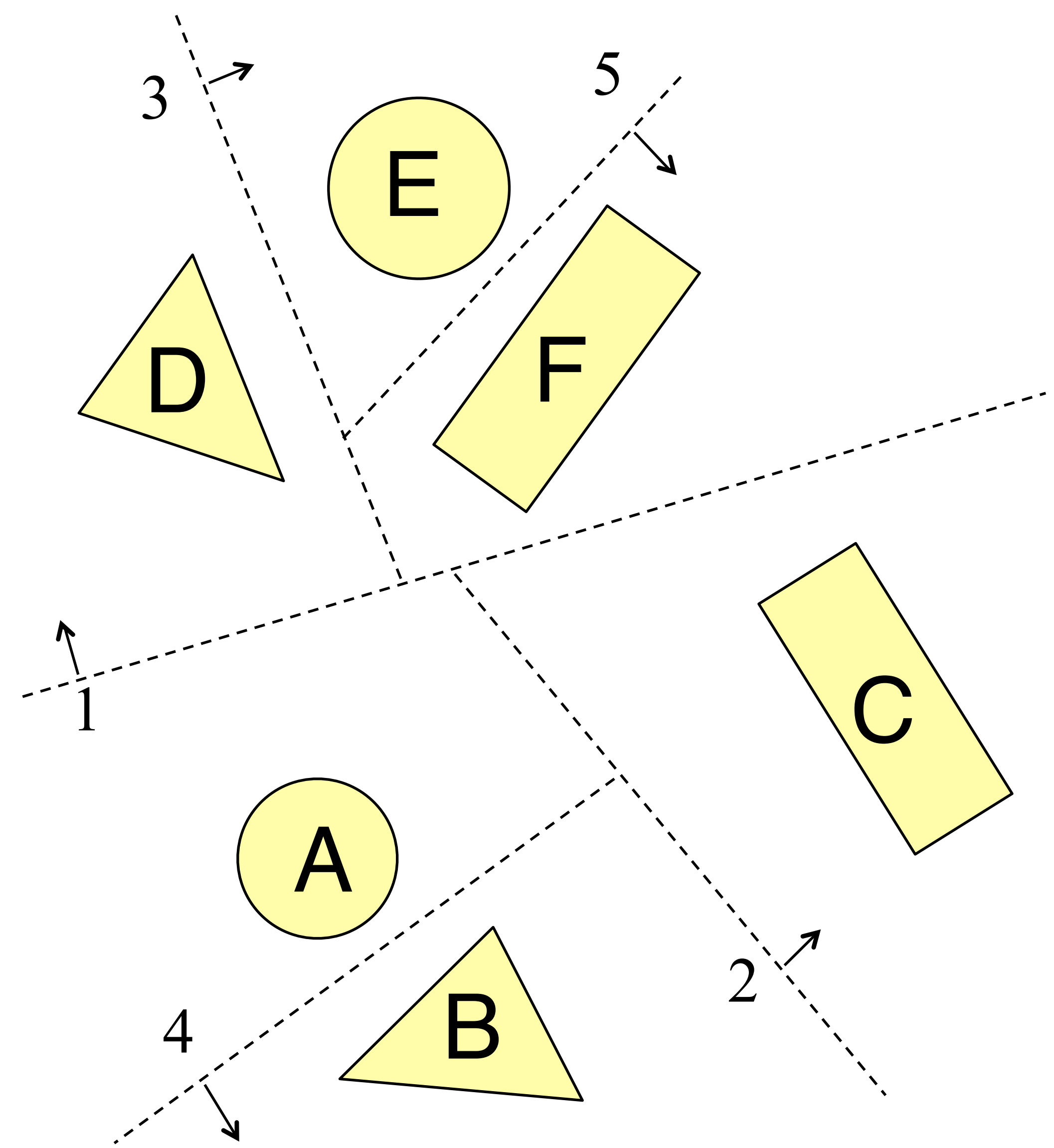


Binary Space Partition (BSP) Tree

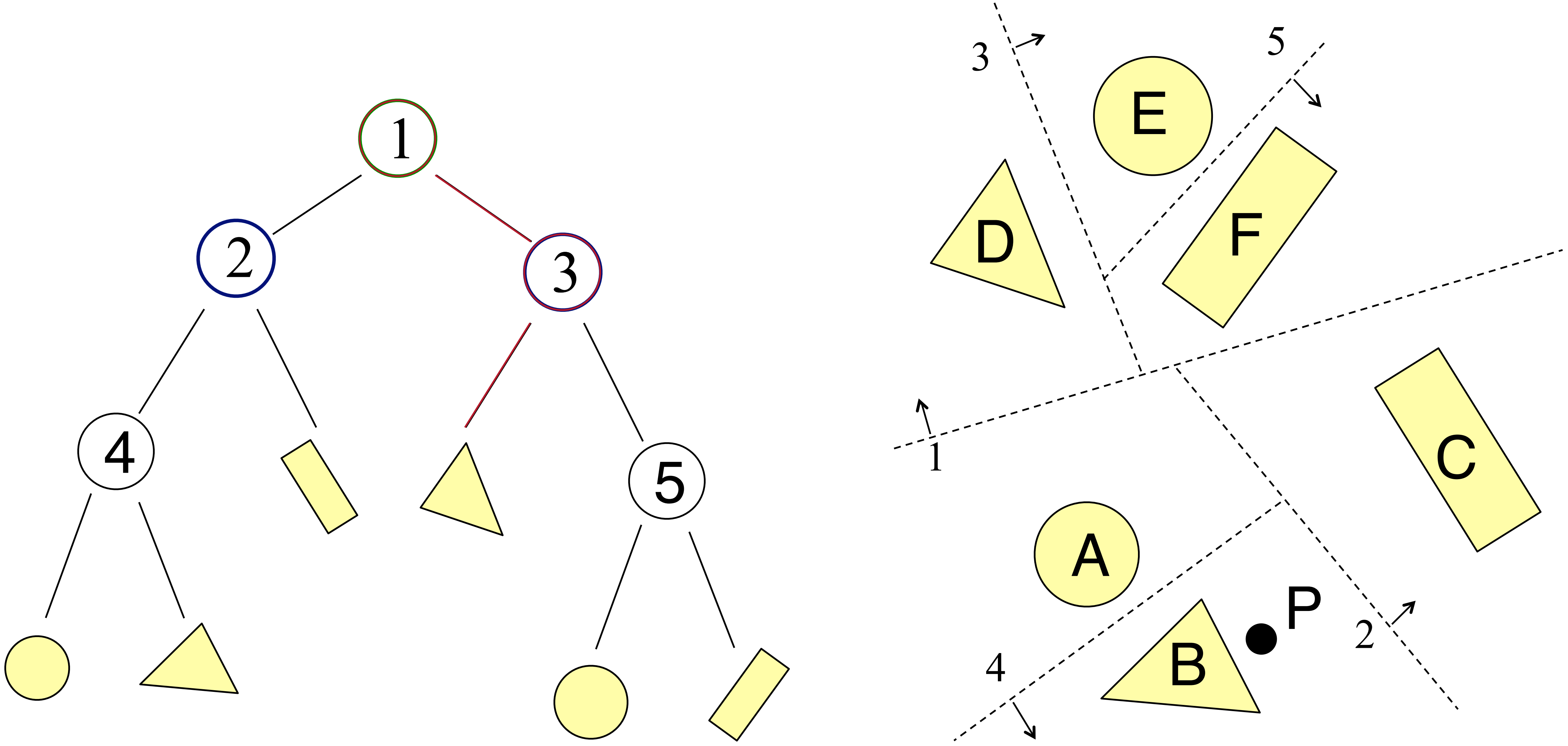
- Recursively partition space by planes
  - Every cell is a convex polyhedron





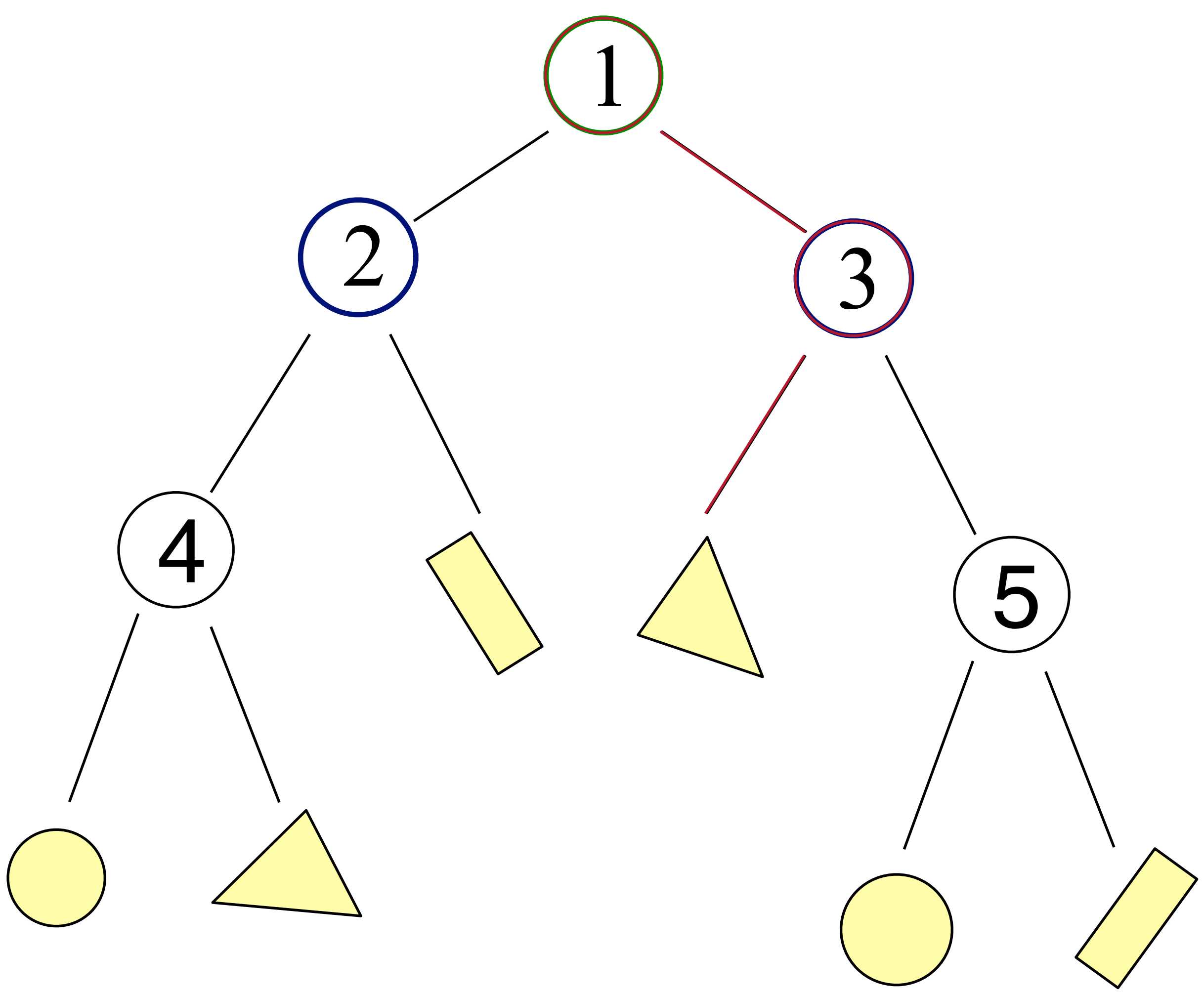
Binary Space Partition (BSP) Tree

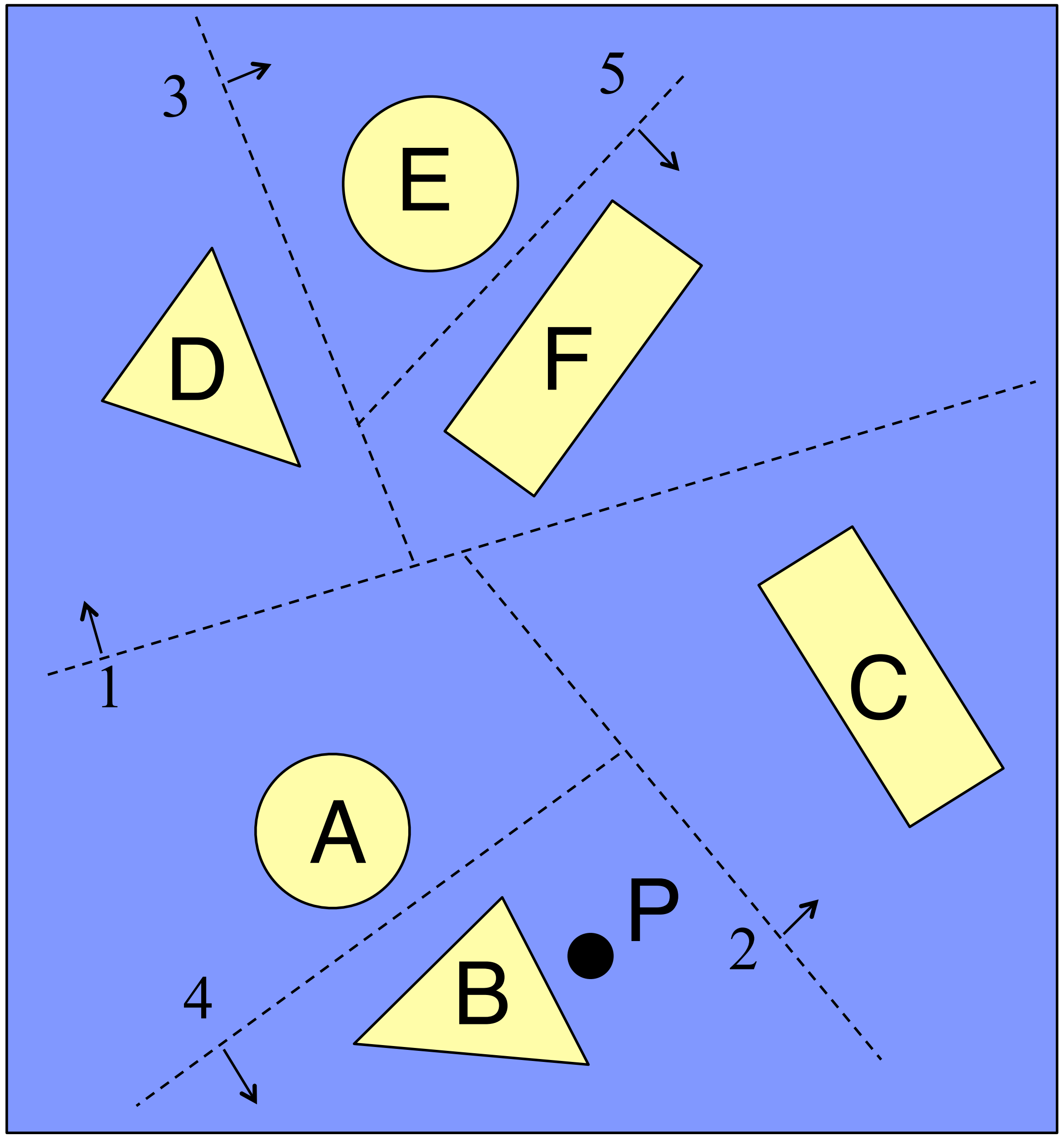
- Example: Point Intersection



Binary Space Partition (BSP) Tree

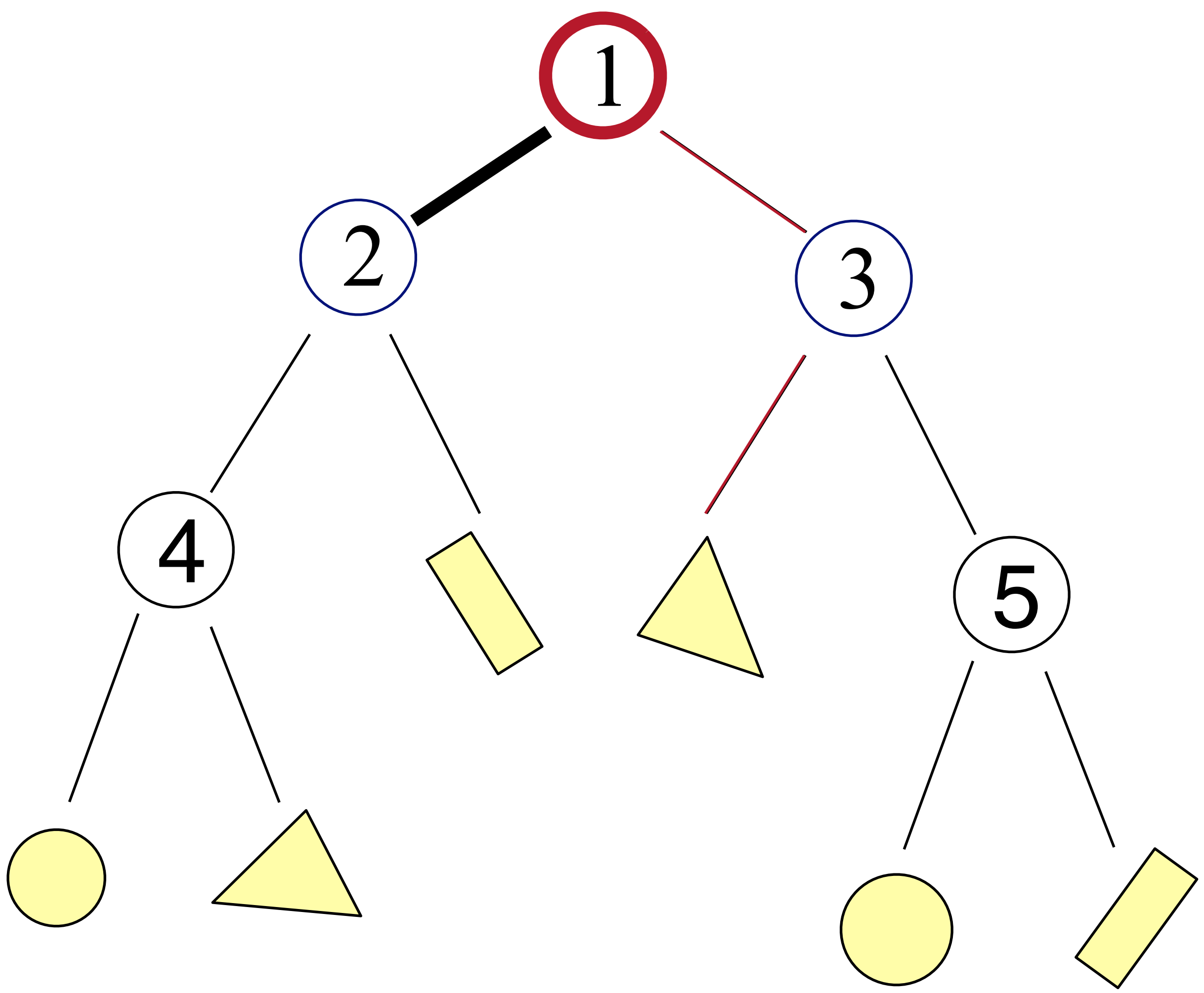
- Example: Point Intersection
  - Recursively test what side we are on

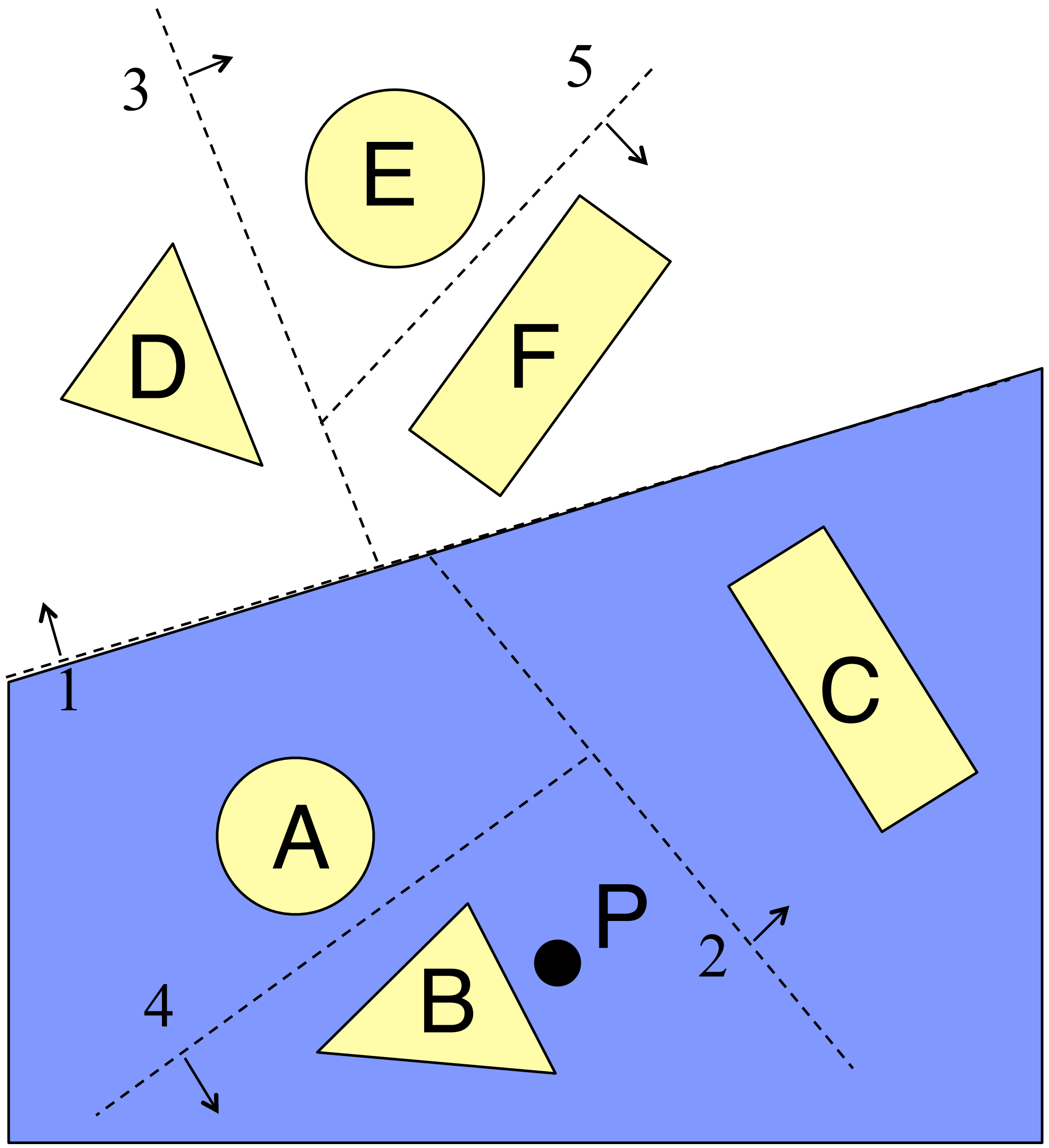




Binary Space Partition (BSP) Tree

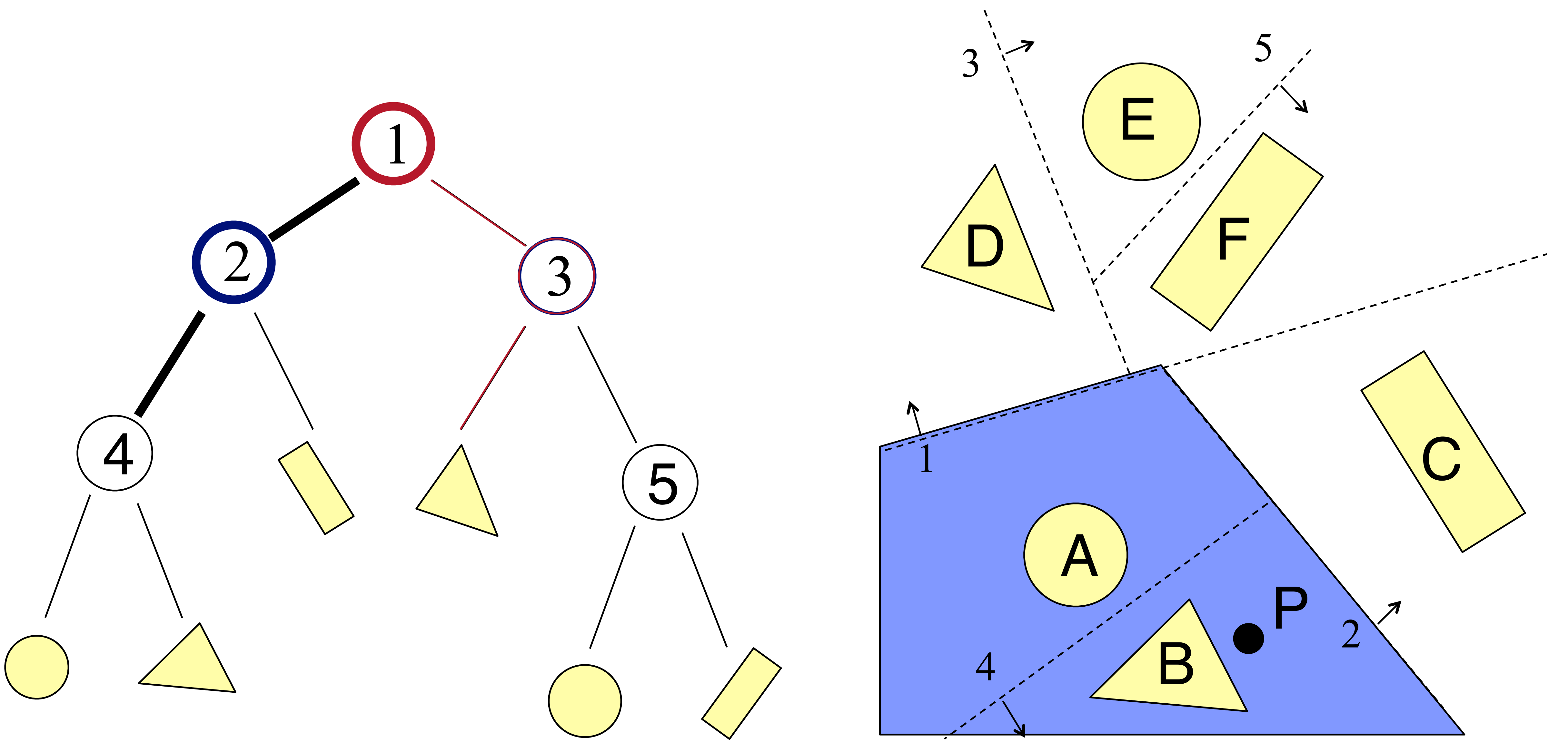
- Example: Point Intersection
  - Recursively test what side we are on
    - »Left of 1 (root) → 2





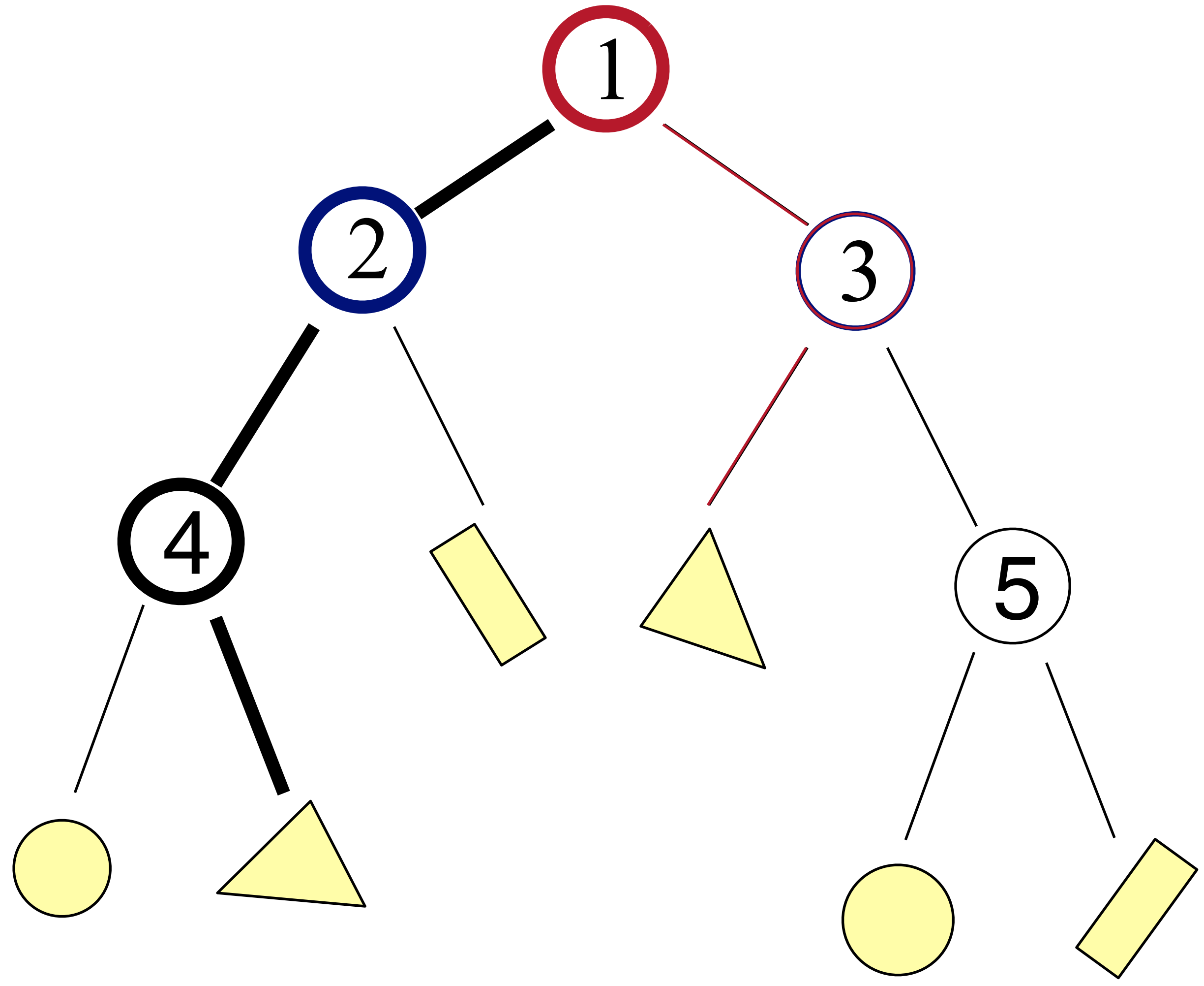
Binary Space Partition (BSP) Tree

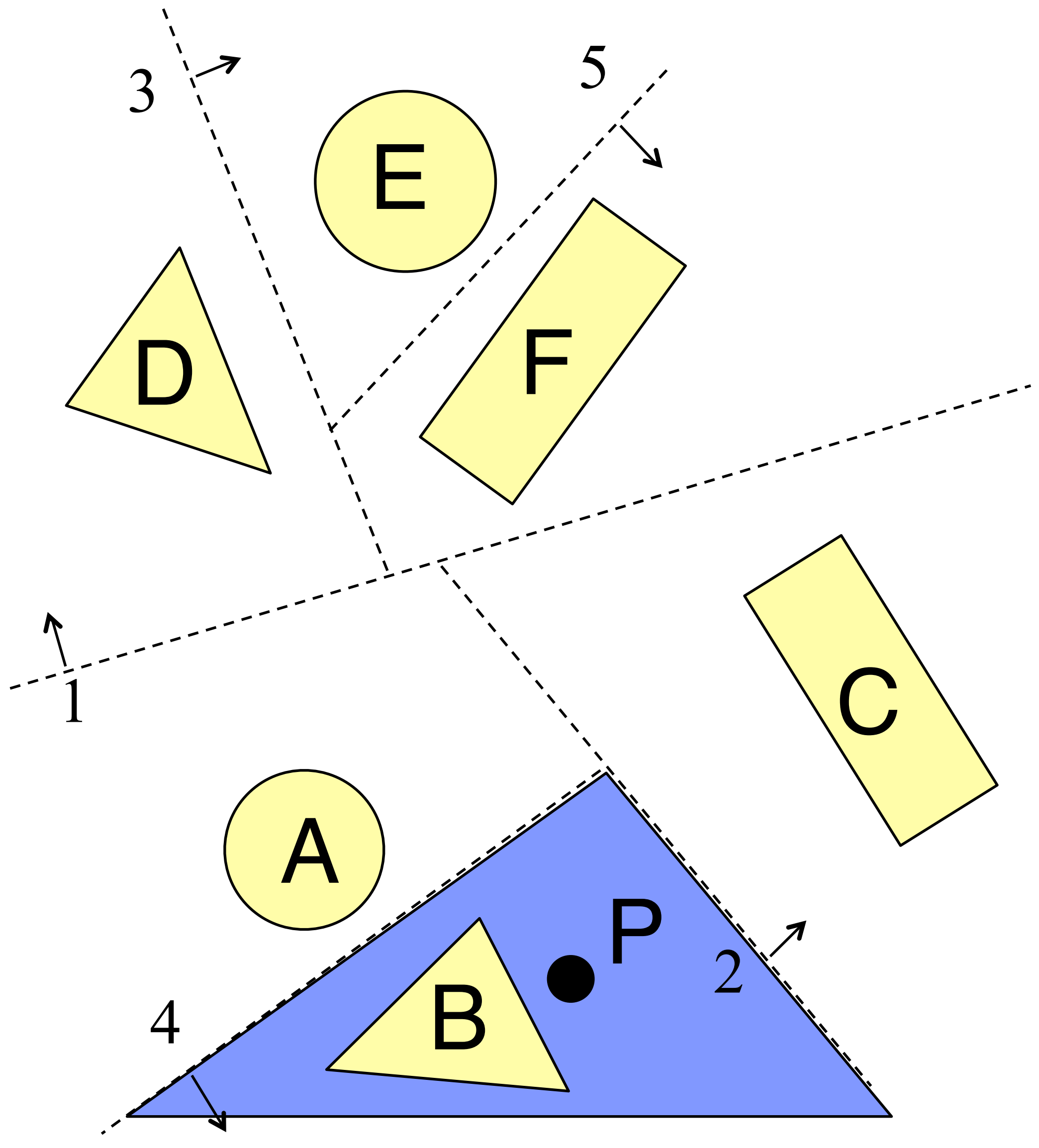
- Example: Point Intersection
  - oRecursively test what side we are on
    - »Left of 2 → 4



Binary Space Partition (BSP) Tree

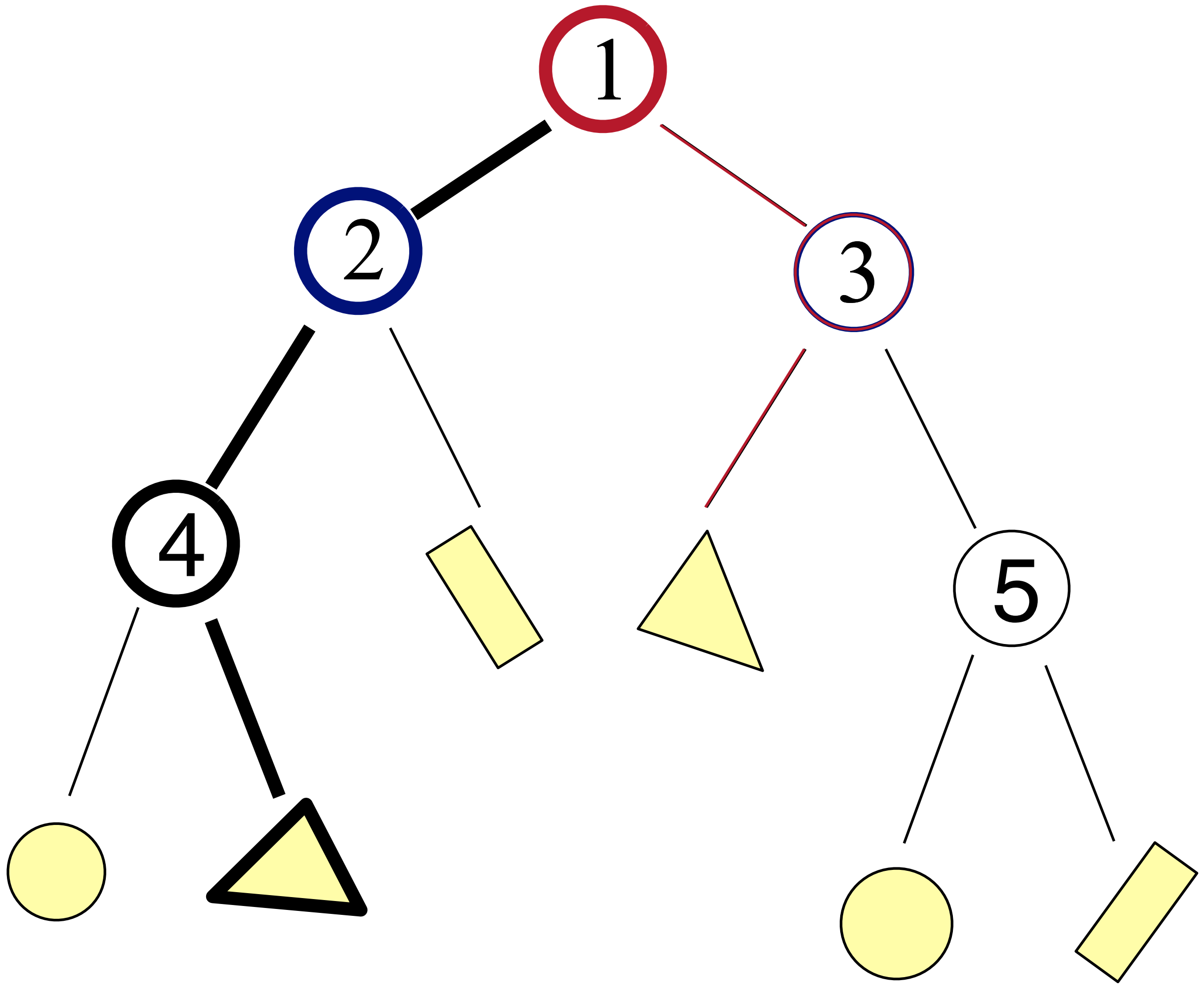
- Example: Point Intersection
  - **o**Recursively test what side we are on
    - »Right of 4 → Test B

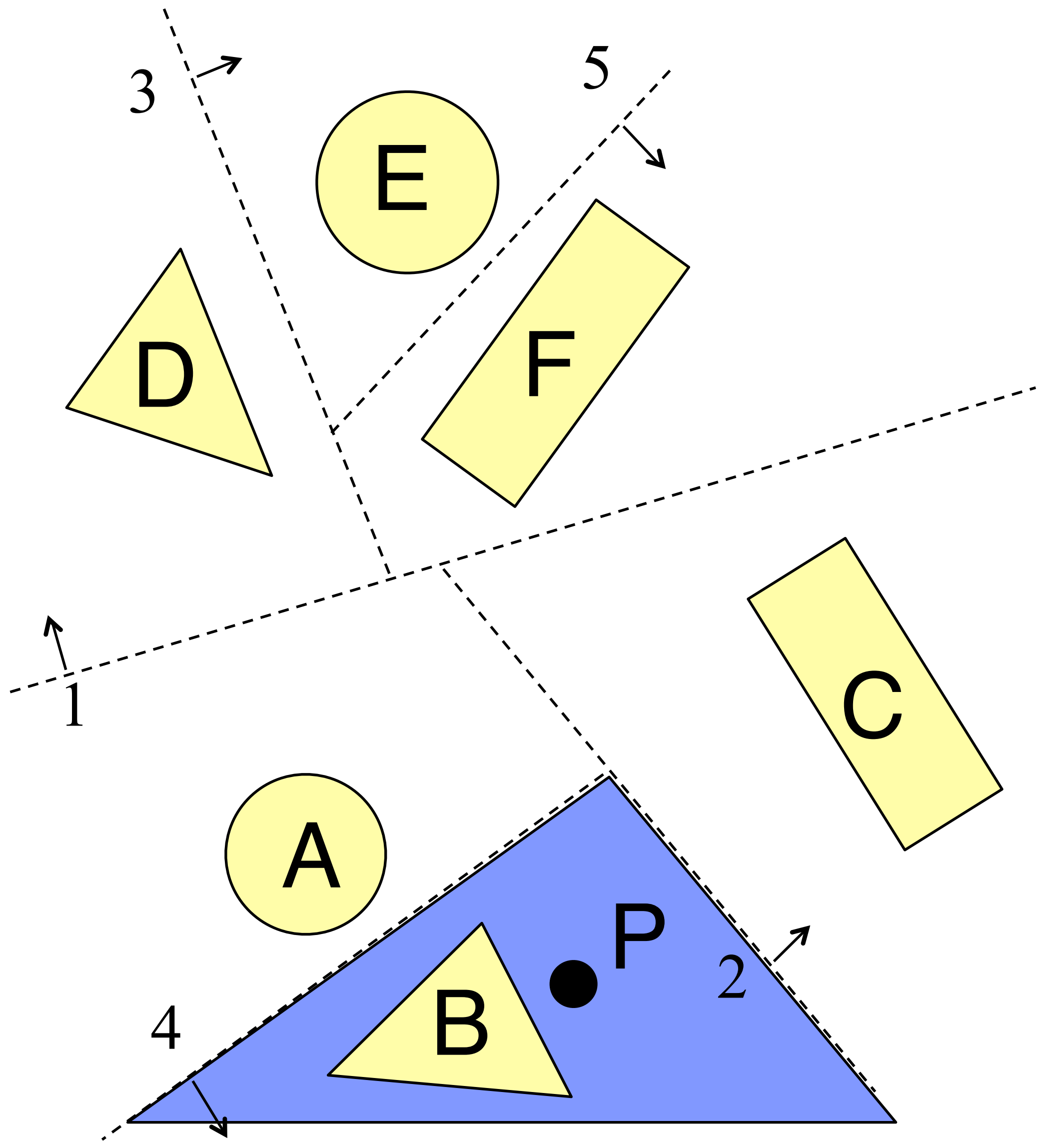




Binary Space Partition (BSP) Tree

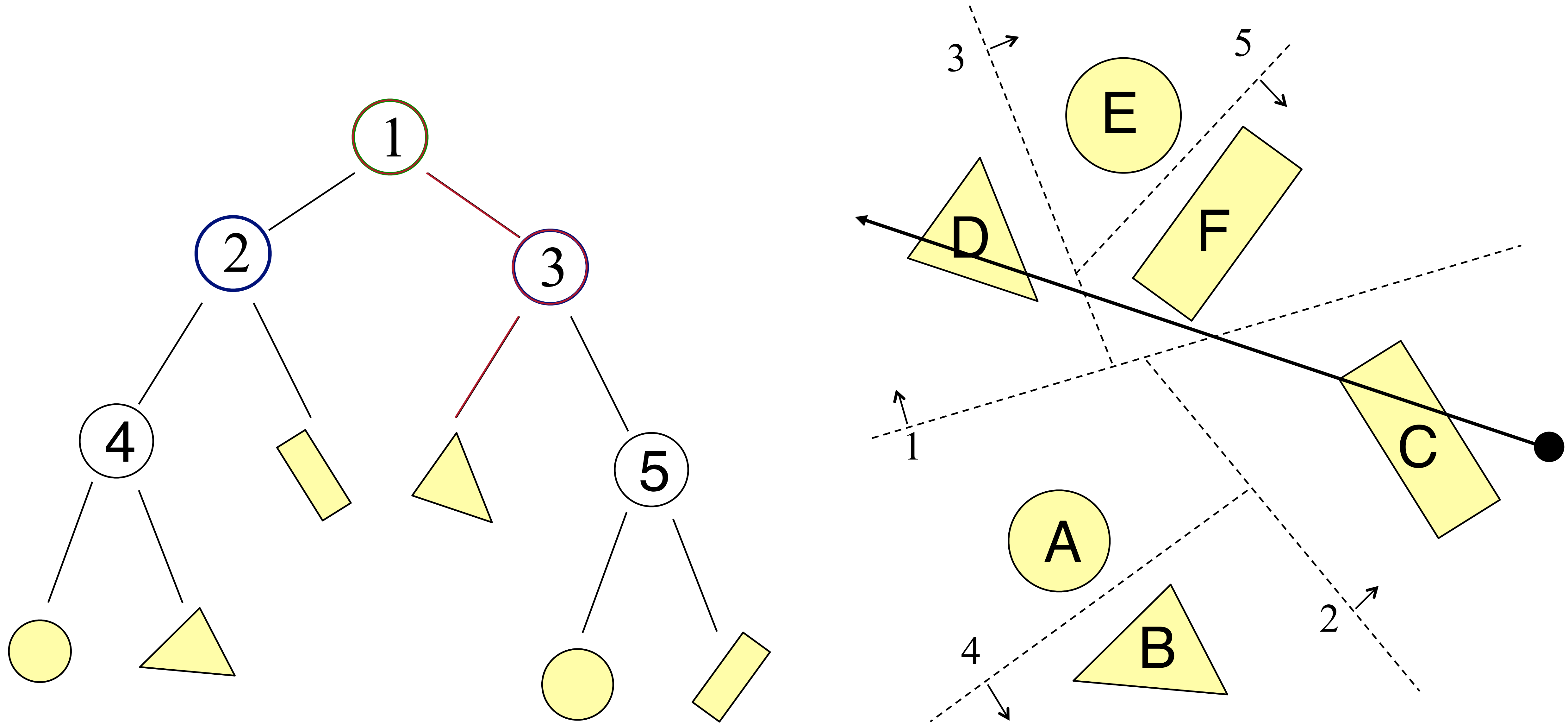
- Example: Point Intersection
  - Recursively test what side we are on
    - »Missed B. No intersection!





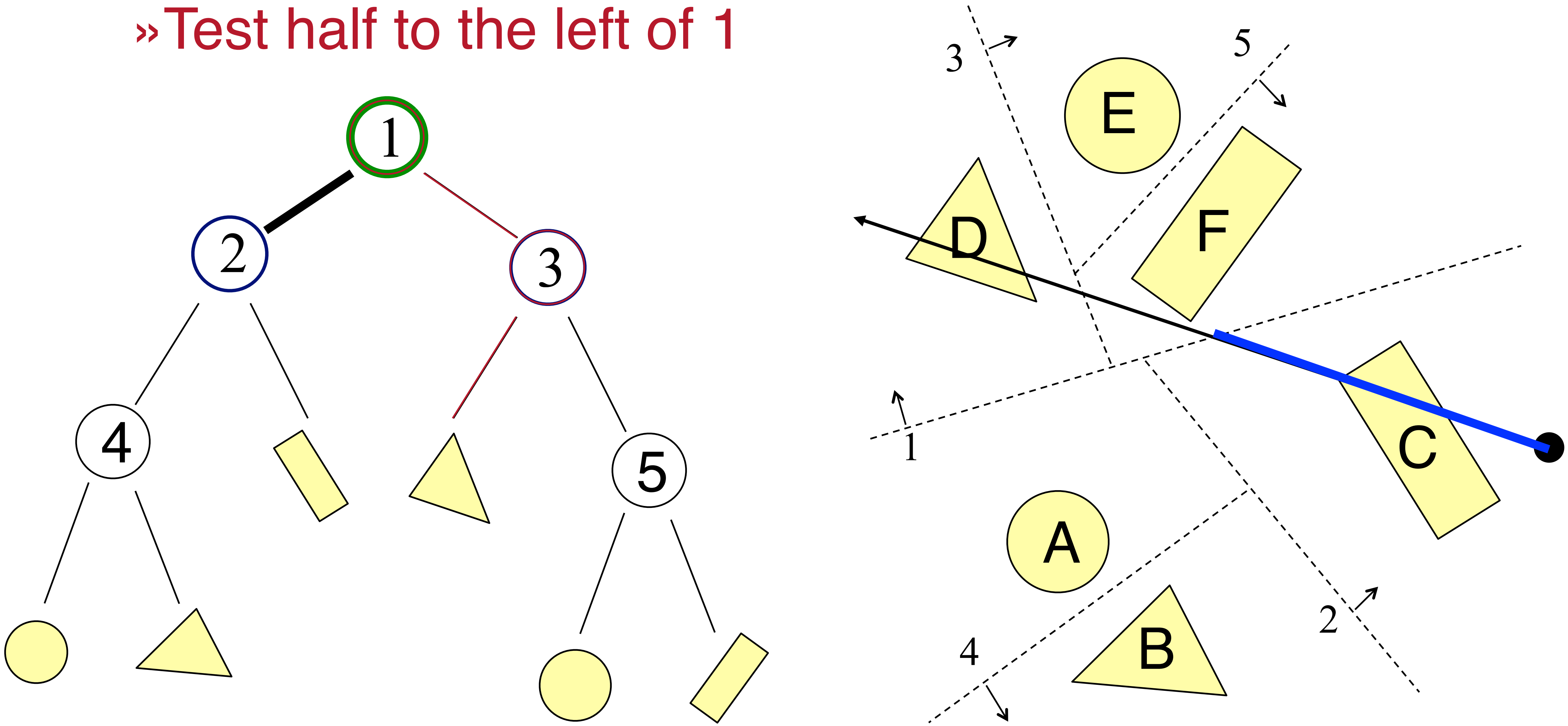
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 1
  - ???



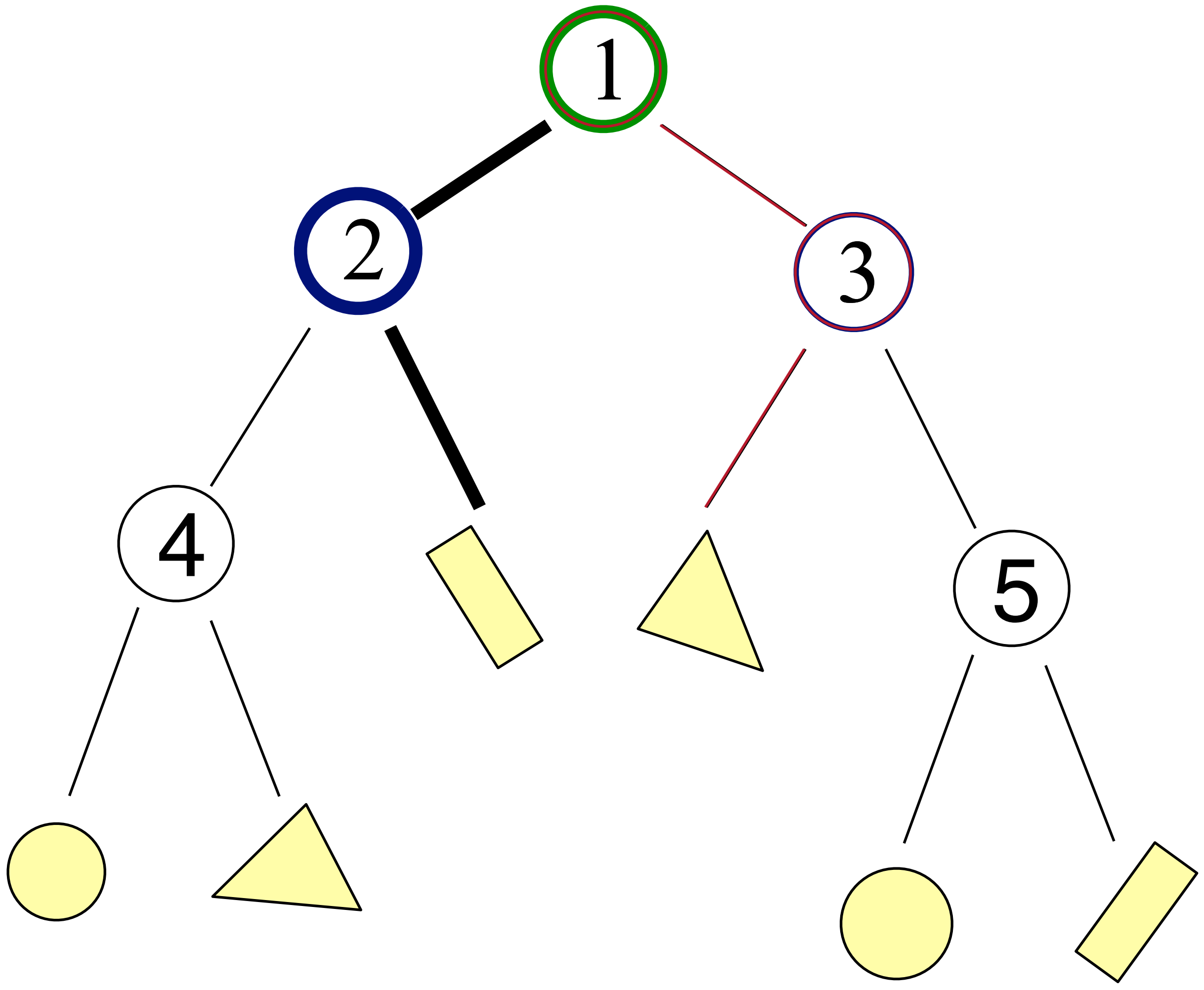
Binary Space Partition (BSP) Tree

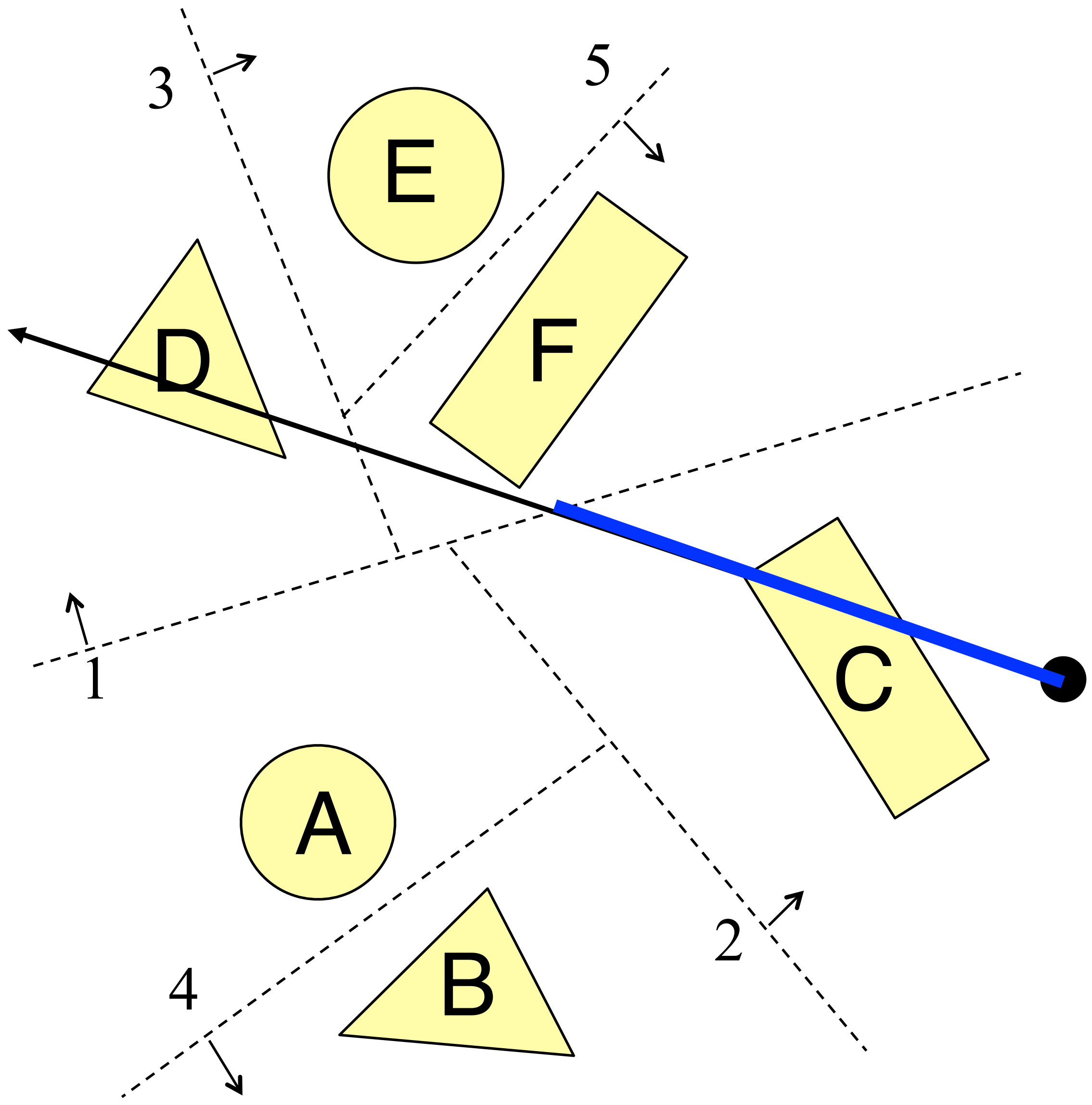
- Example: Ray Intersection 1
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - » Test half to the left of 1



Binary Space Partition (BSP) Tree

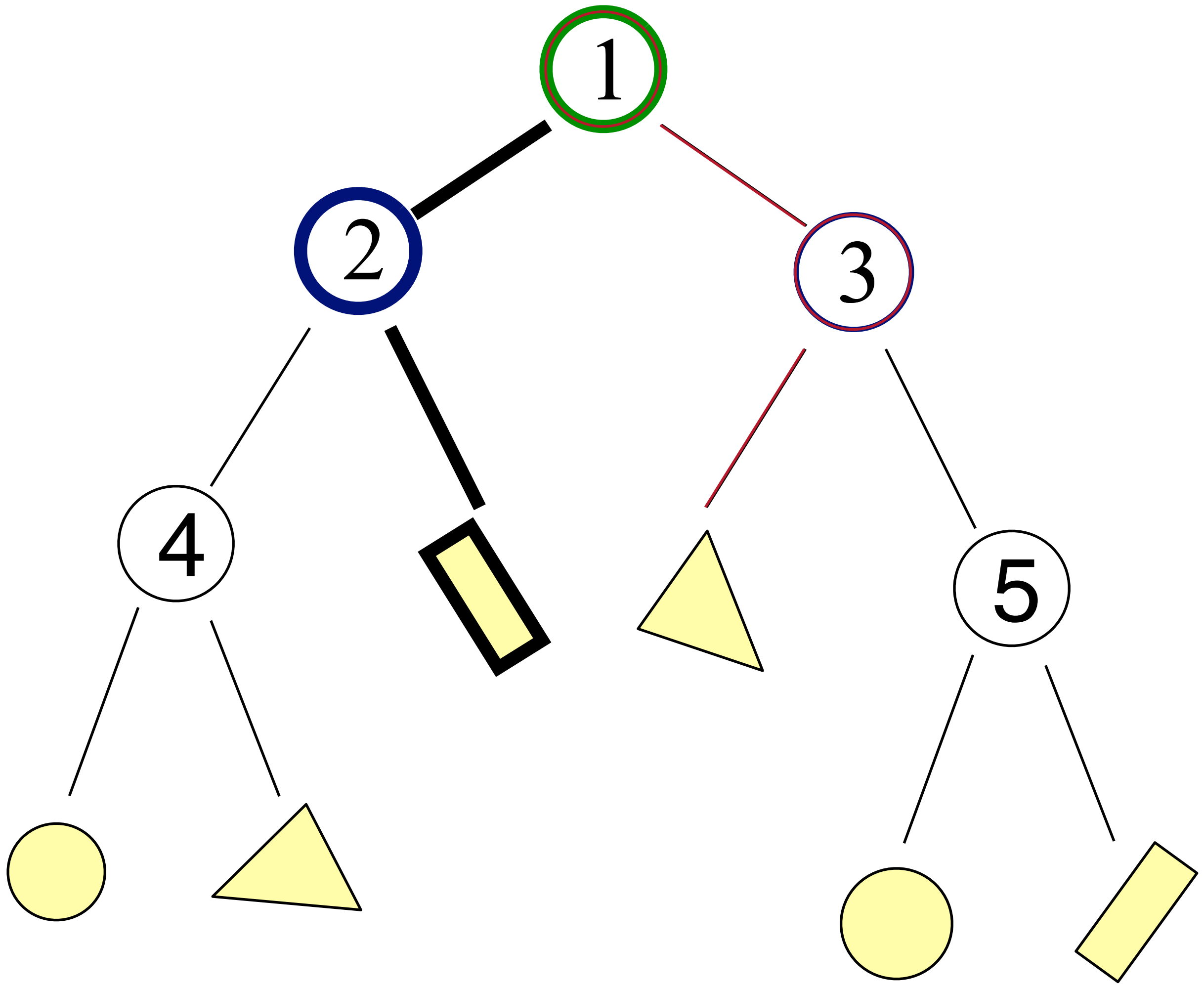
- Example: Ray Intersection 1
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - »Test half to the right of 2

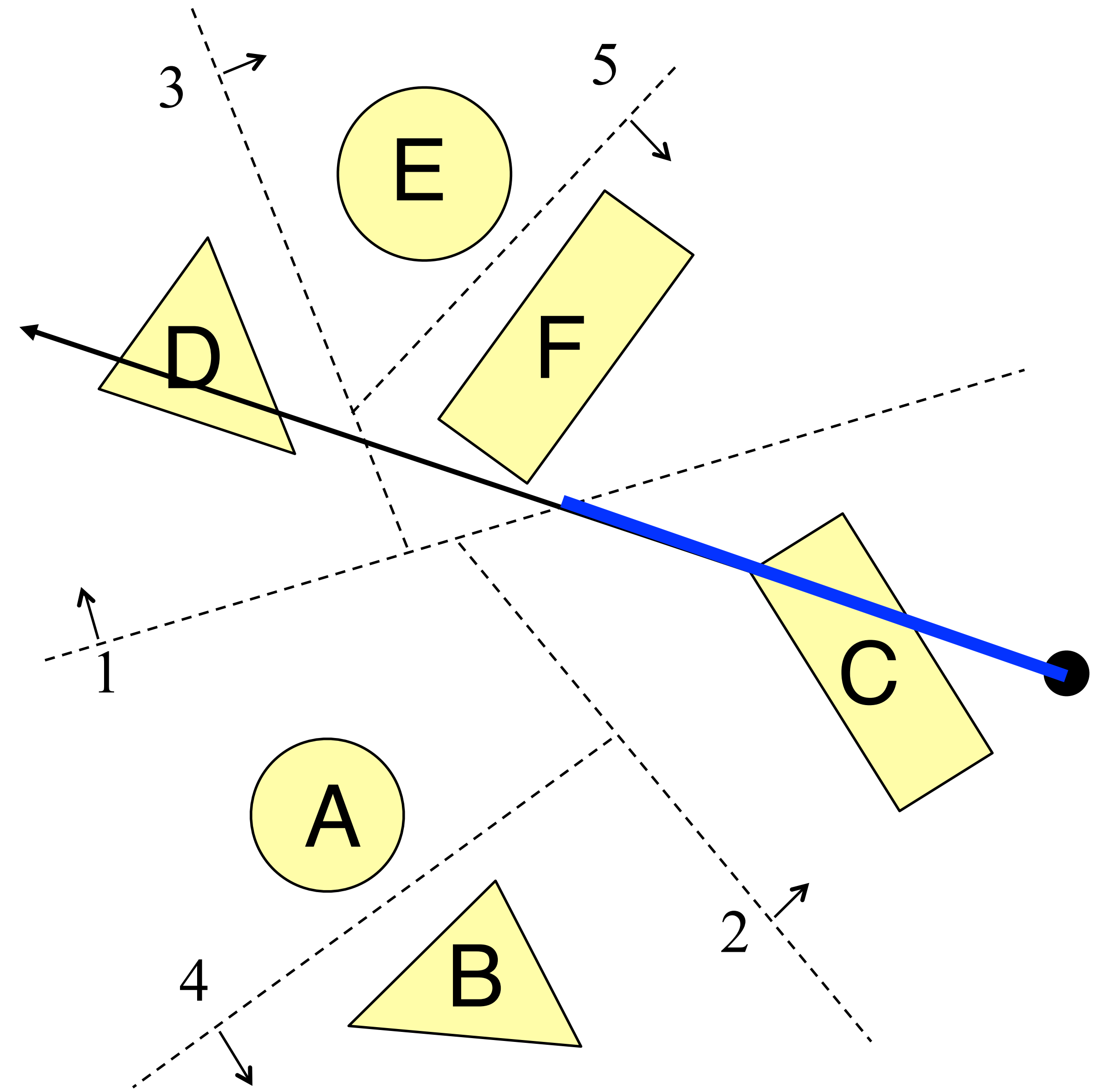




Binary Space Partition (BSP) Tree

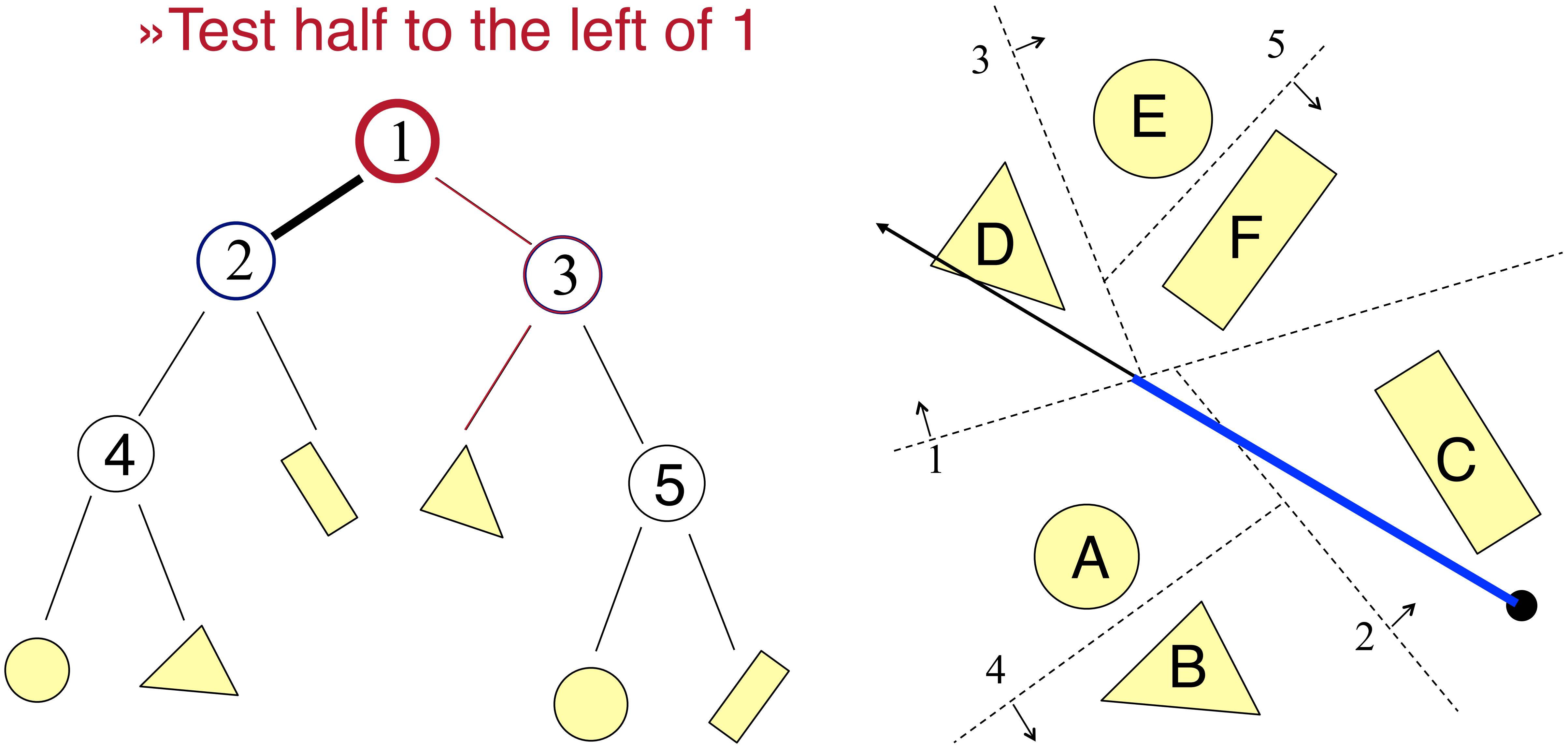
- Example: Ray Intersection 1
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - » Intersection with C. Done!





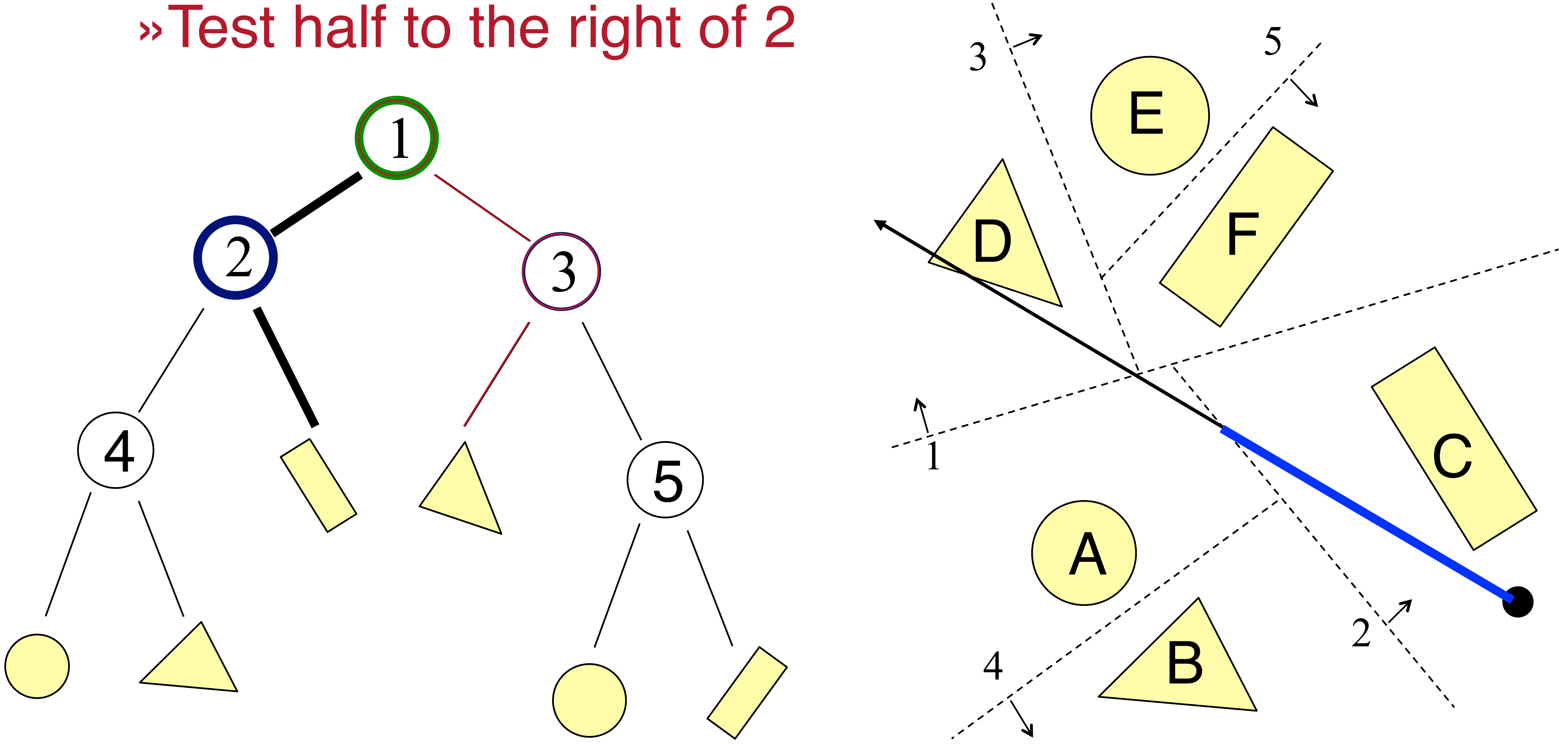
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - » Test half to the left of 1



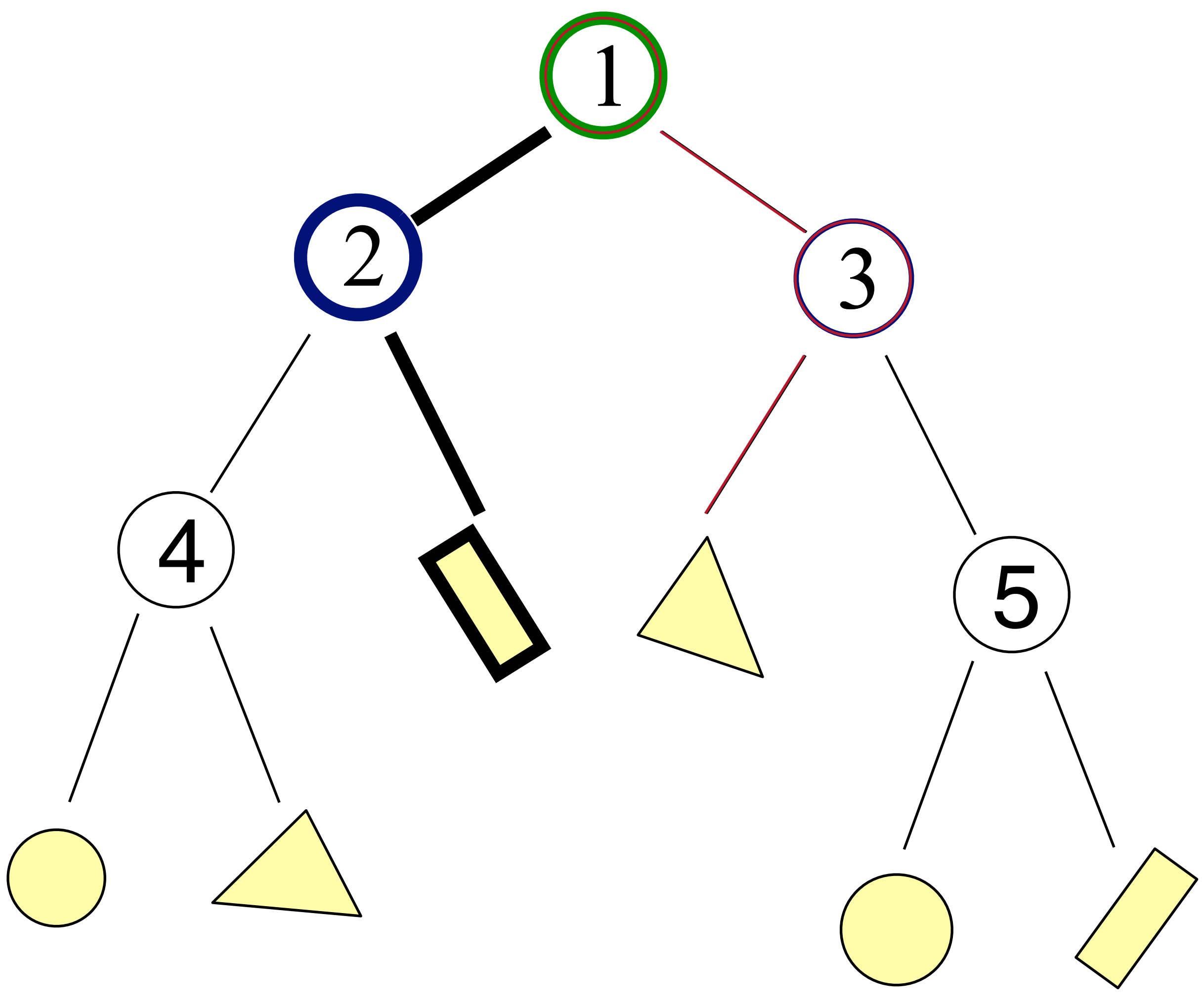
Binary Space Partition (BSP) Tree

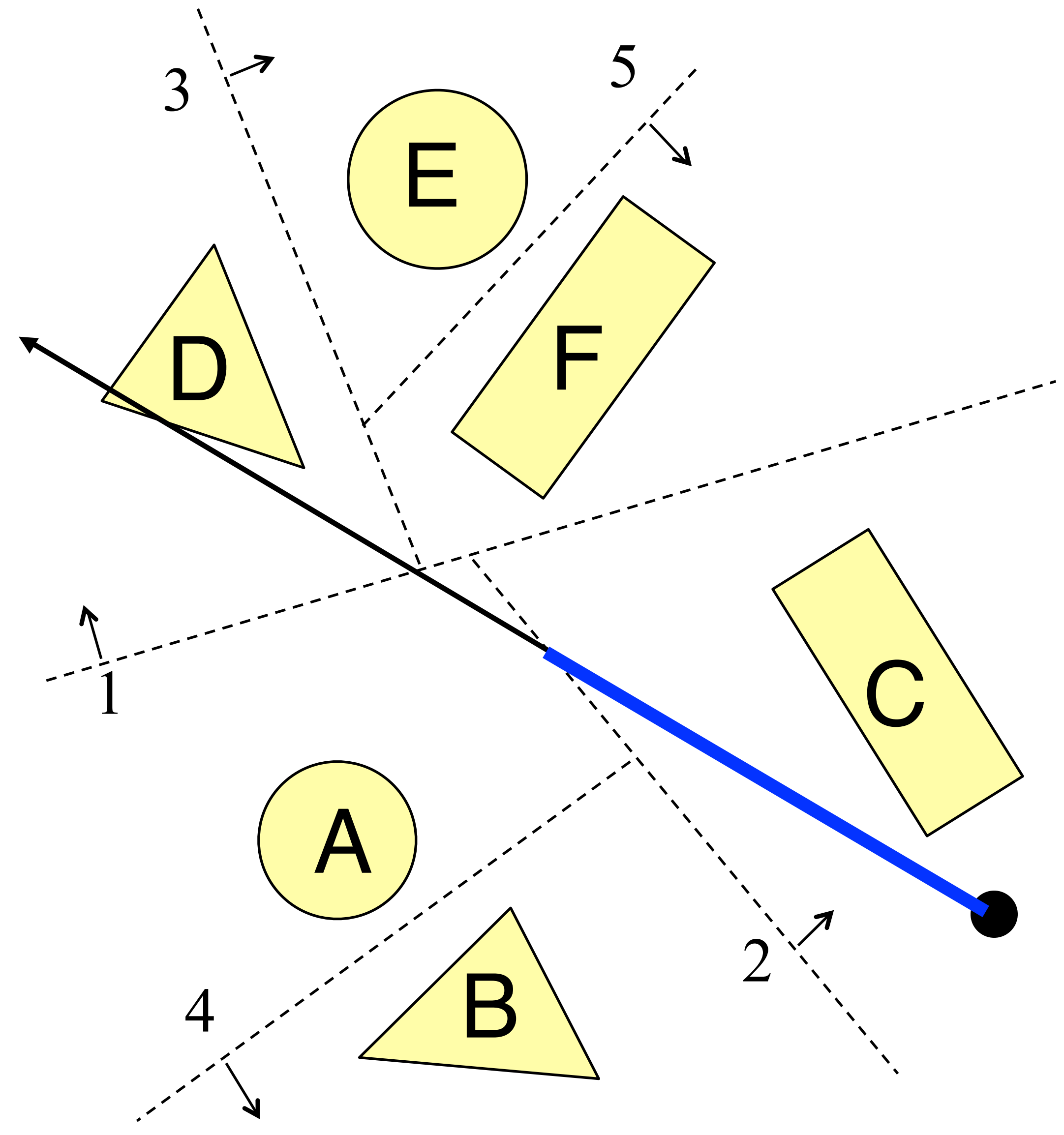
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Test half to the right of 2



Binary Space Partition (BSP) Tree

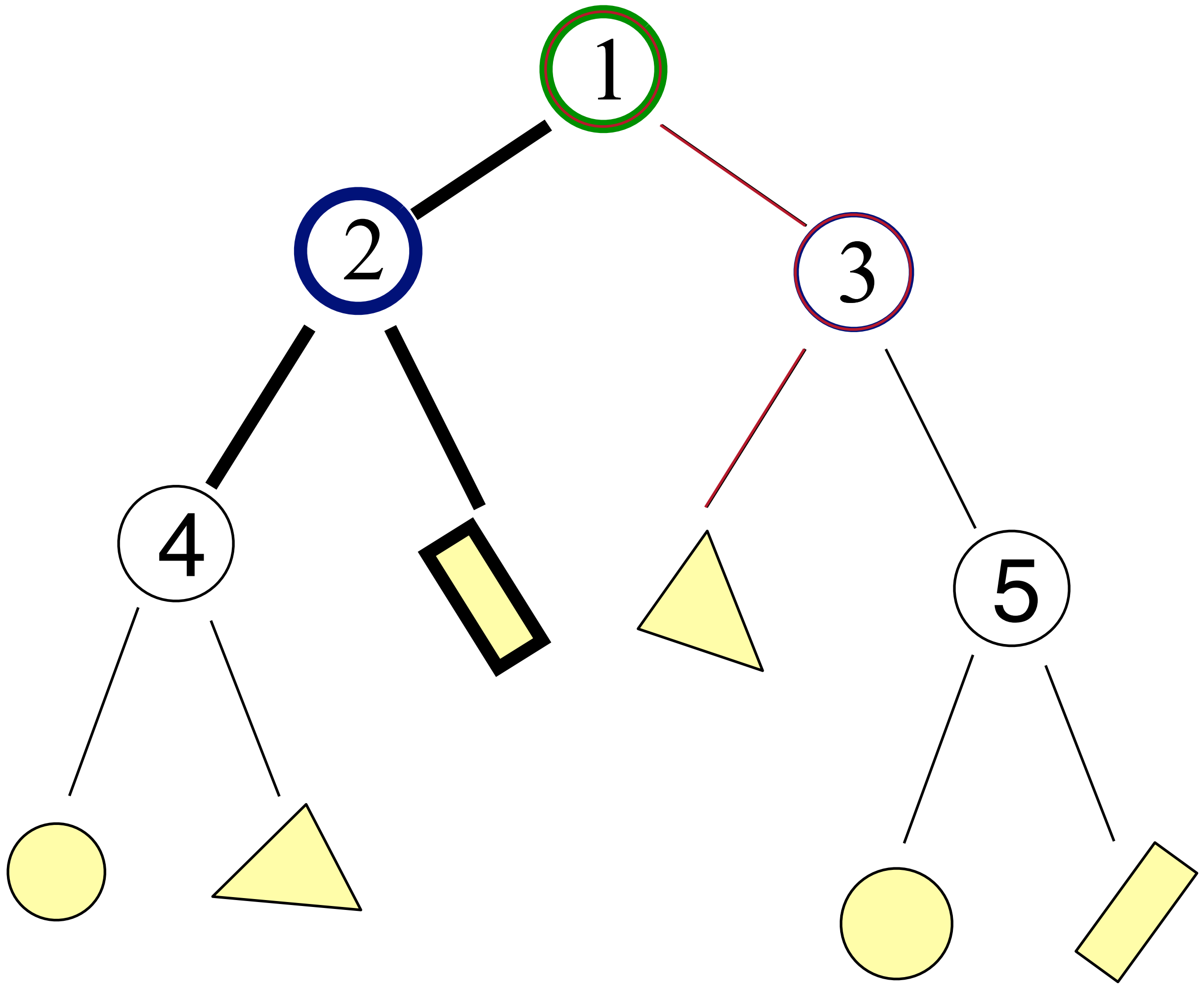
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - »Missed C. Recurse!

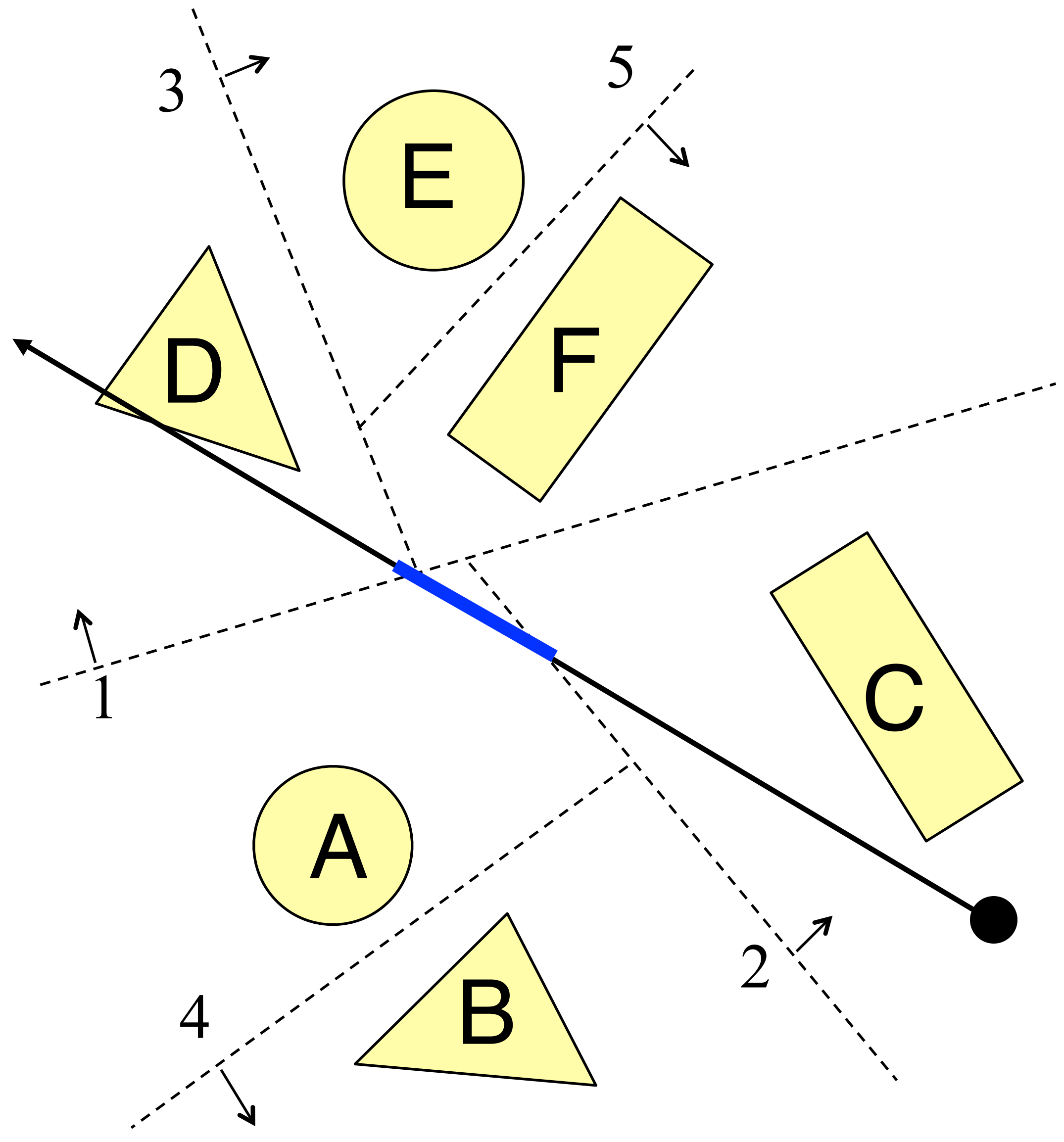




Binary Space Partition (BSP) Tree

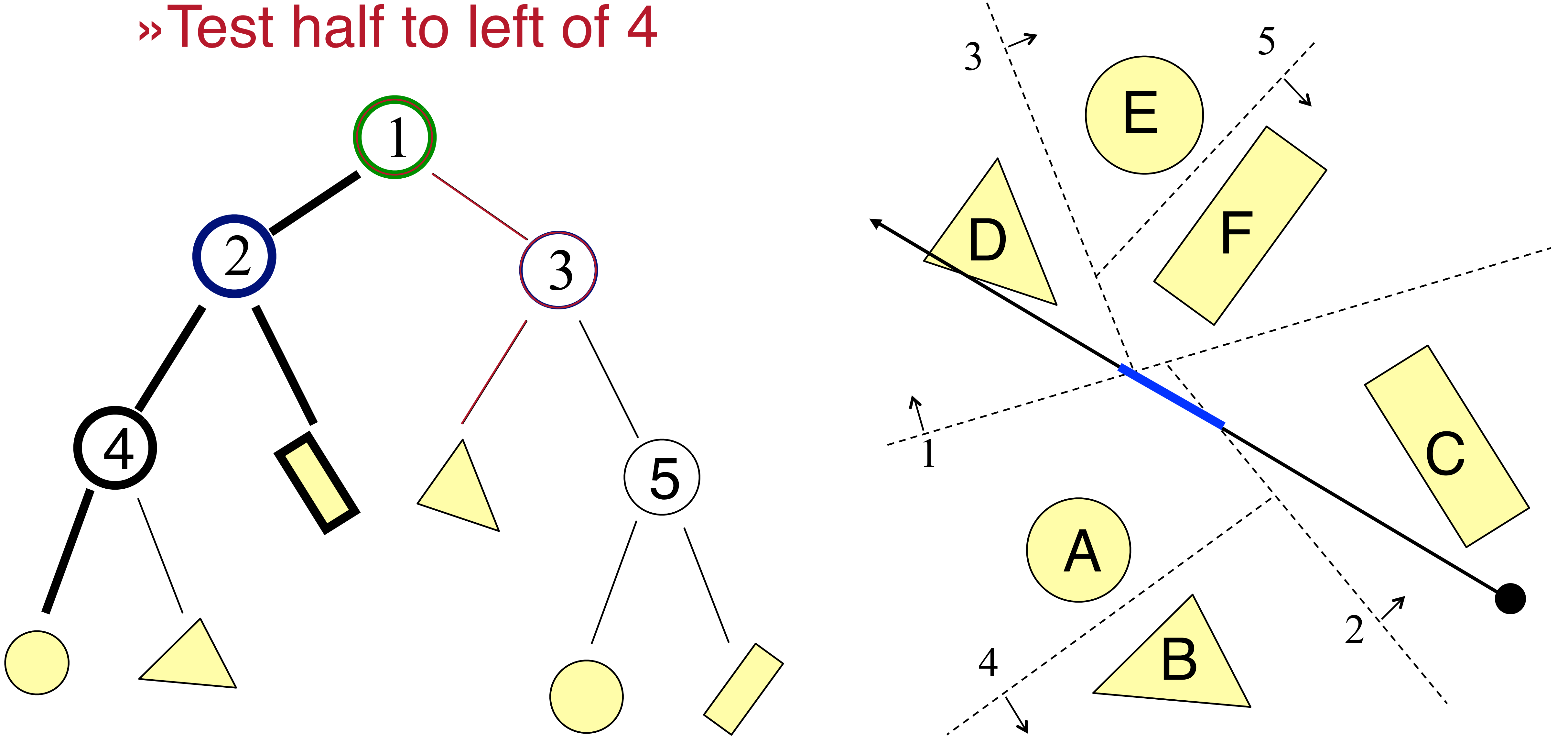
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Test half to left of 2





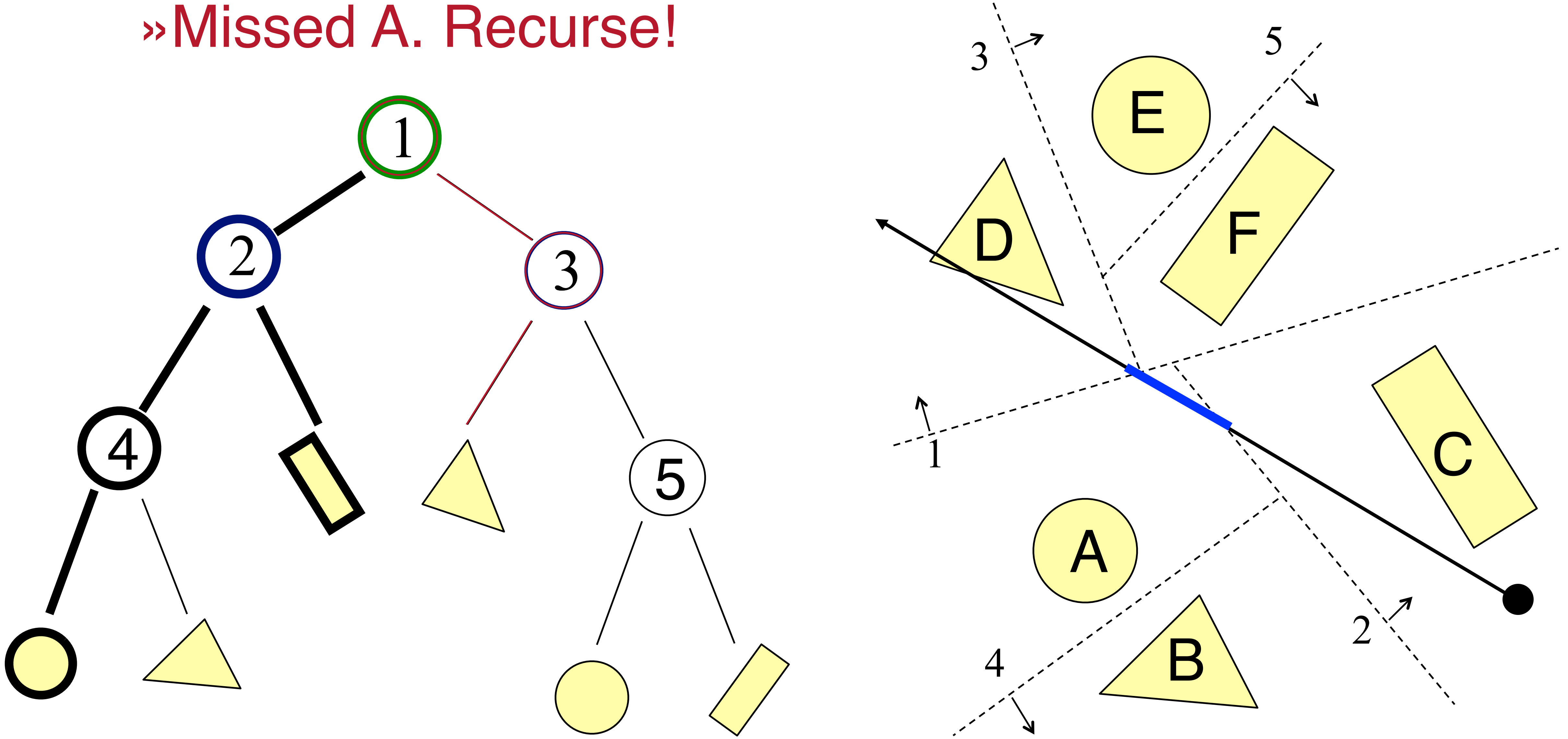
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - »Test half to left of 4



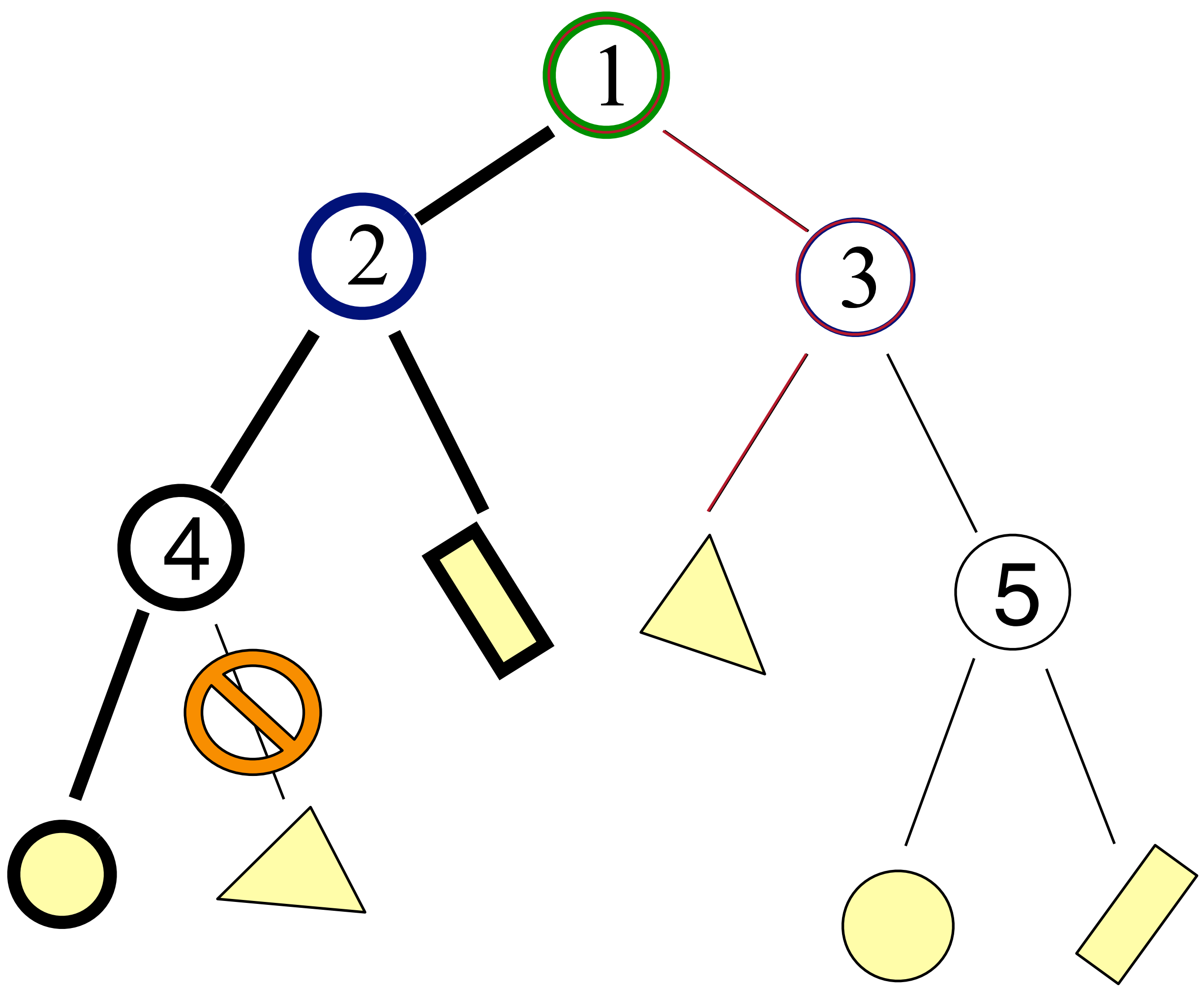
Binary Space Partition (BSP) Tree

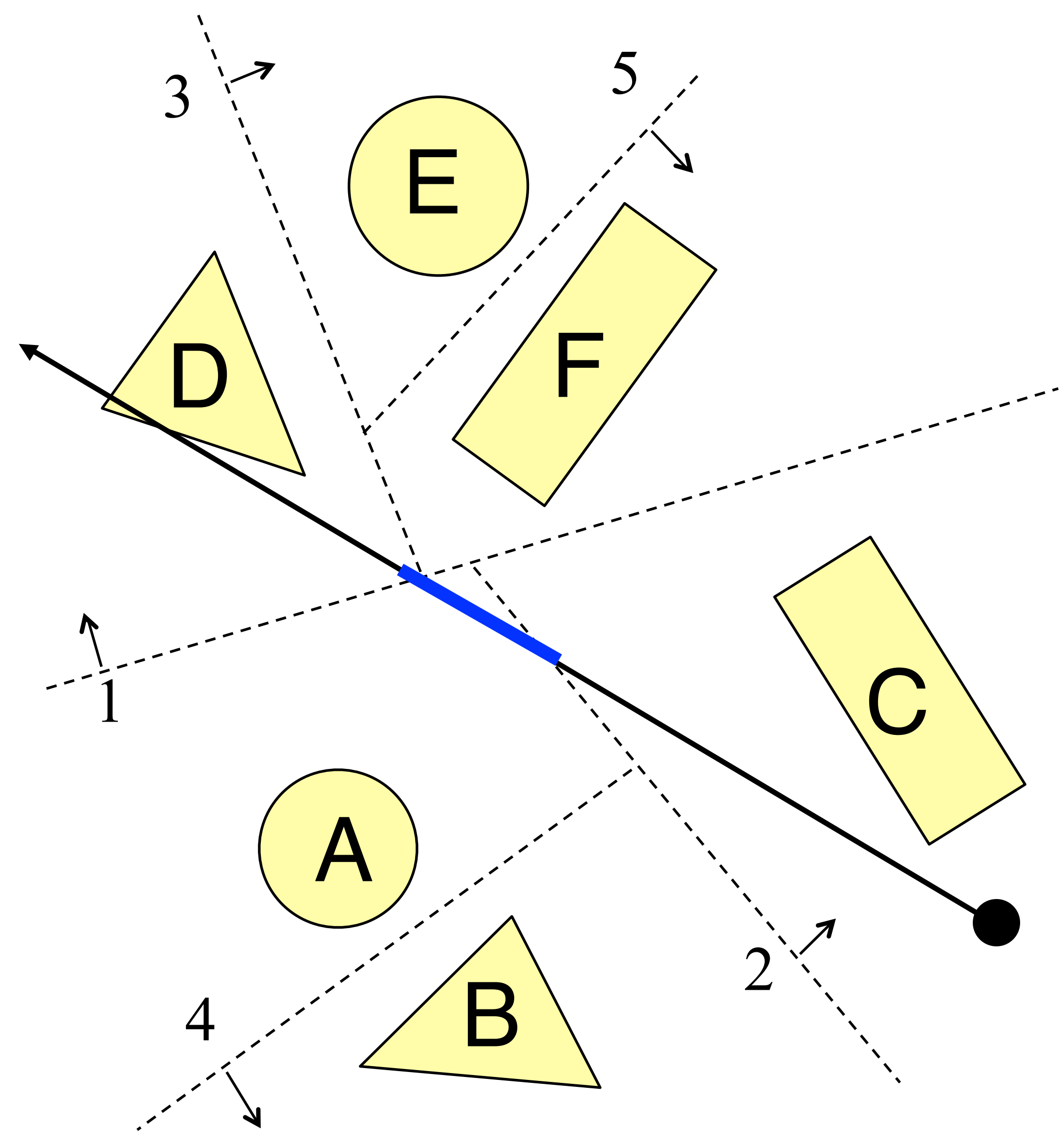
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Missed A. Recurse!



Binary Space Partition (BSP) Tree

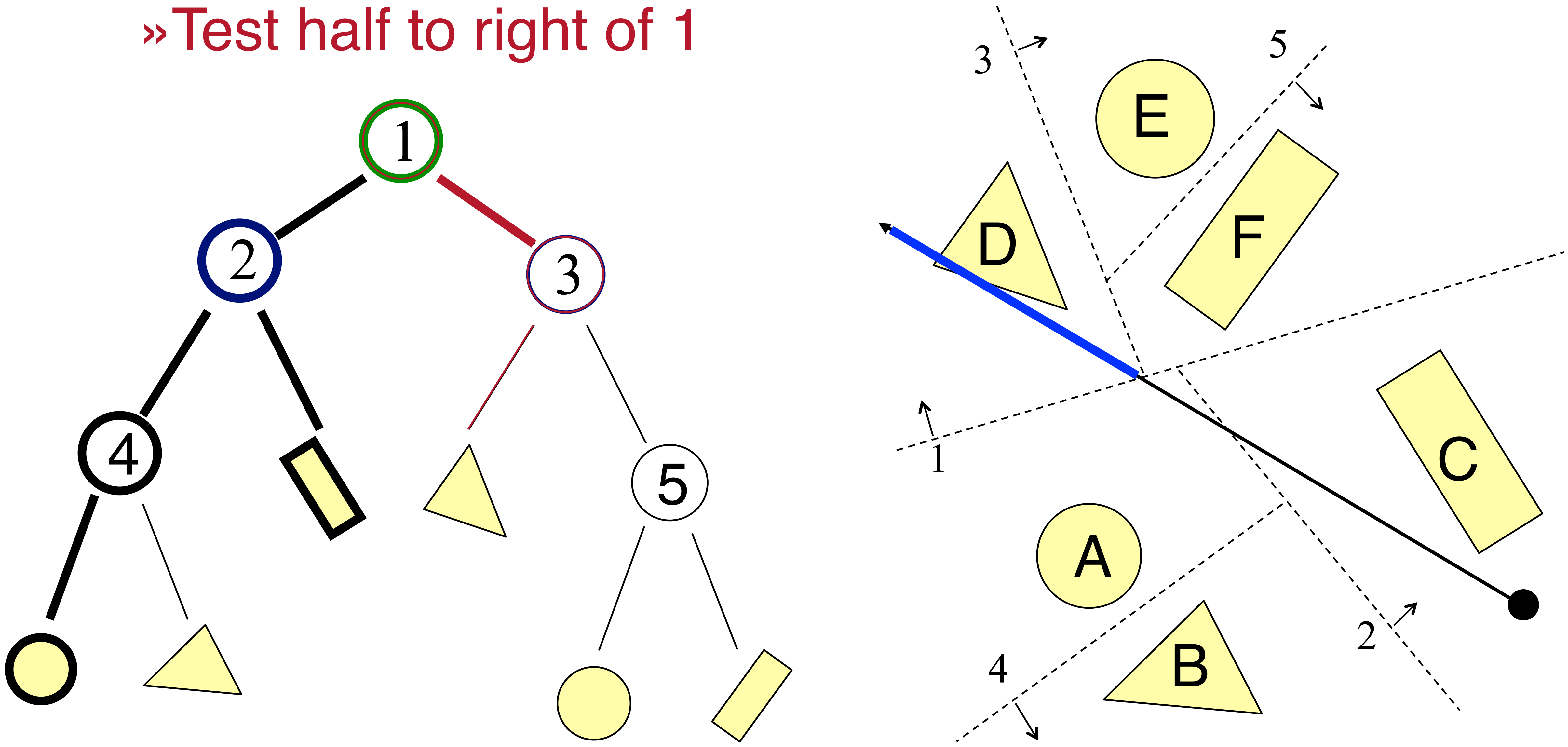
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - »No half to right of 4.





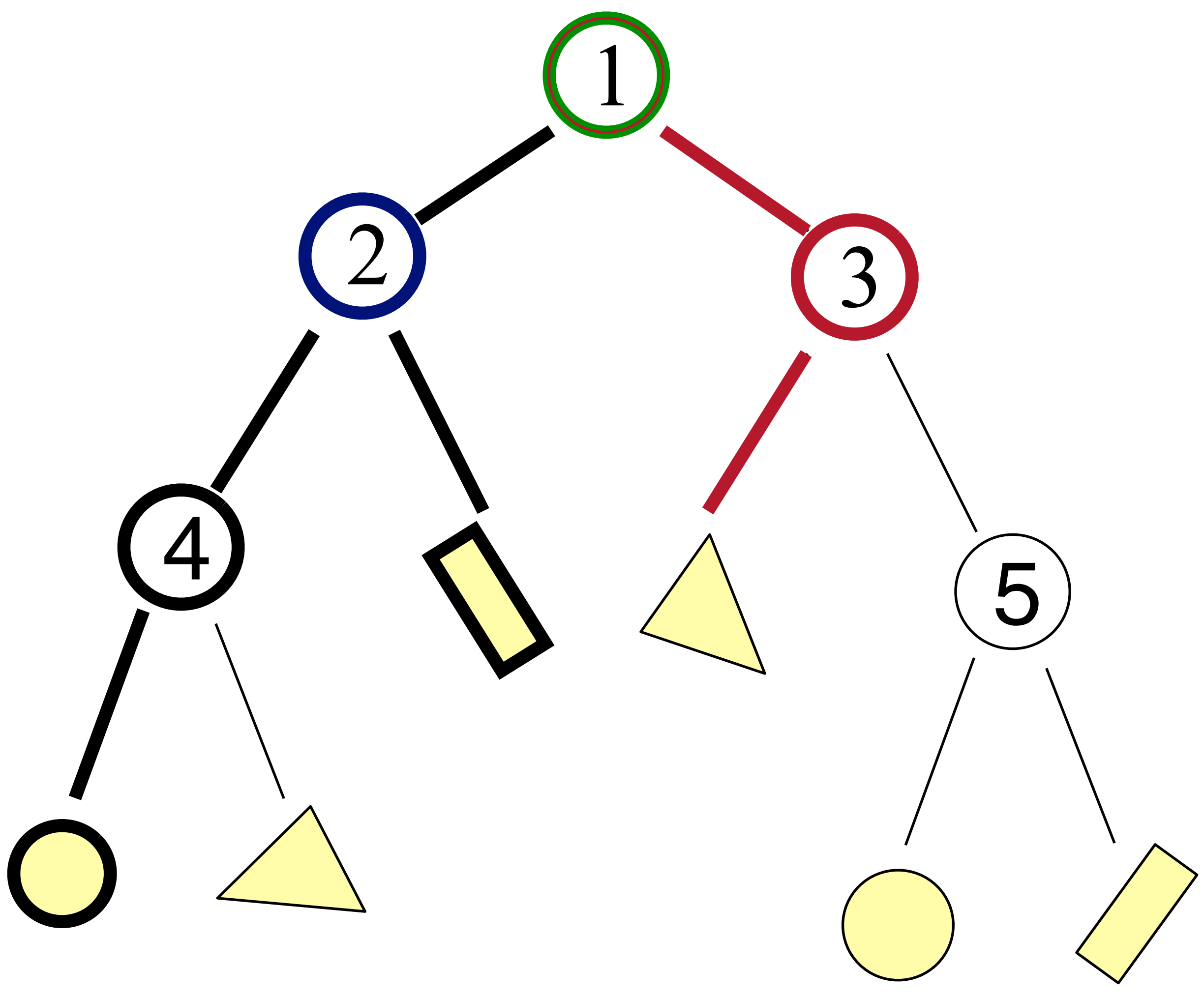
Binary Space Partition (BSP) Tree

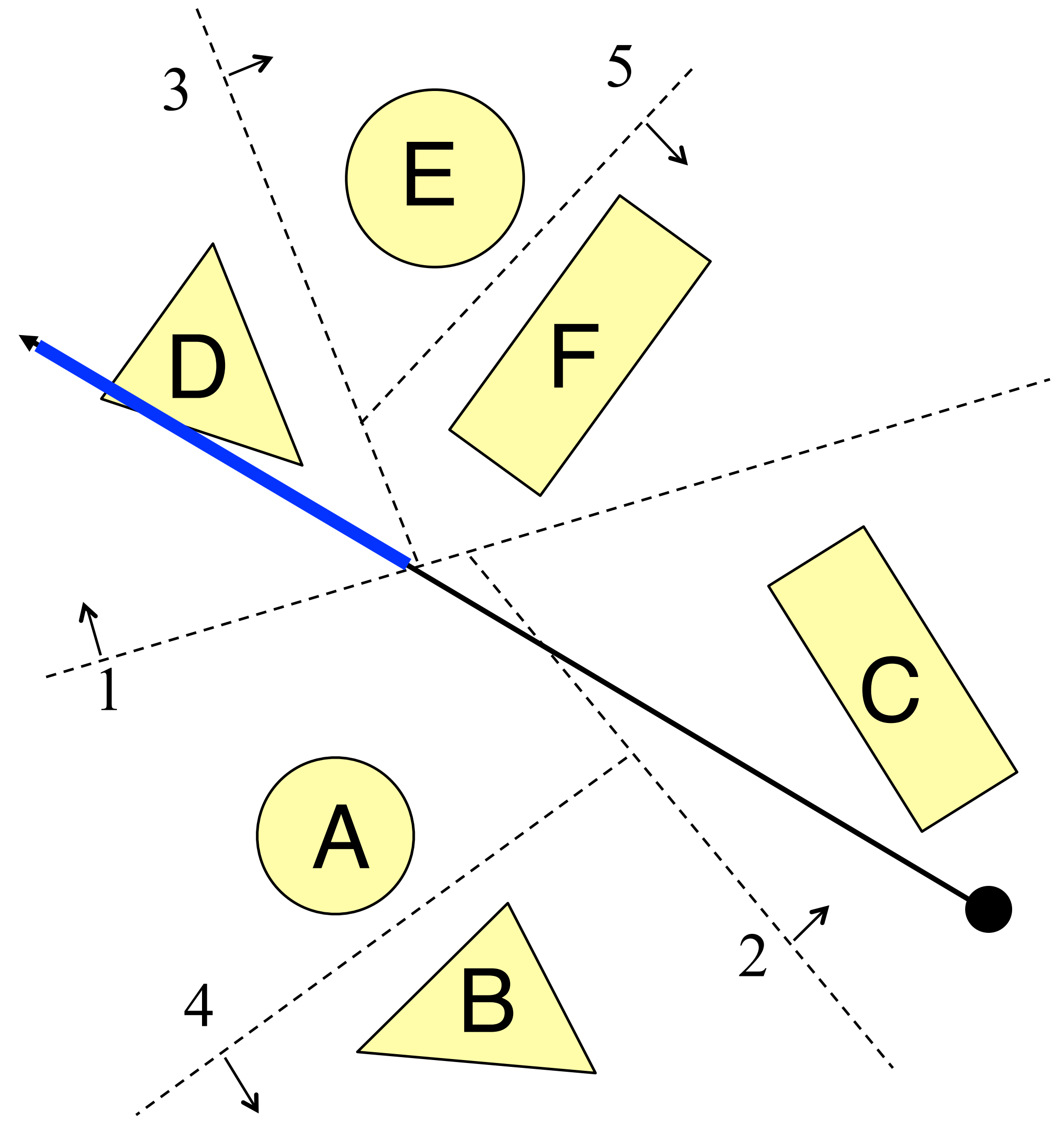
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Test half to right of 1



Binary Space Partition (BSP) Tree

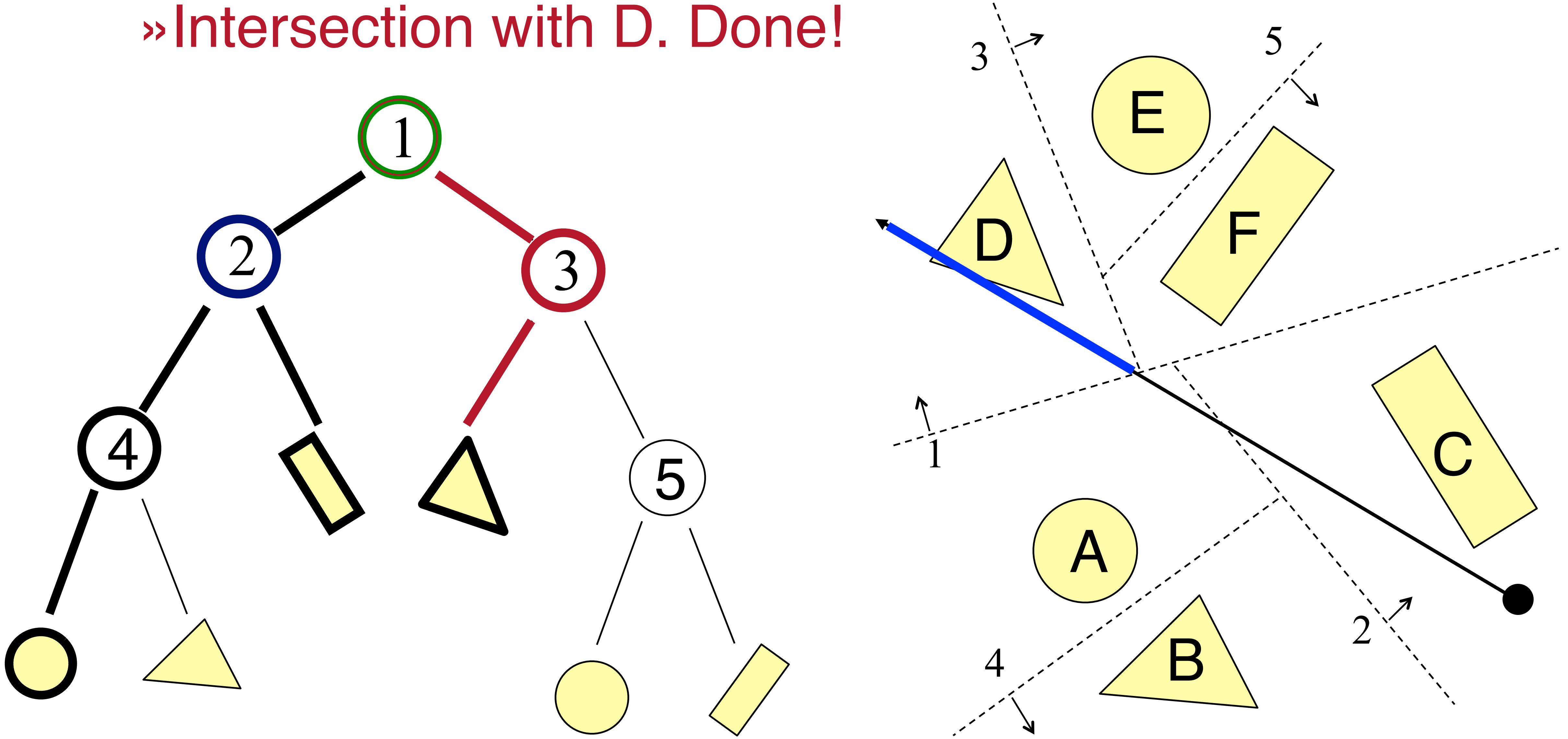
- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - » Test half to left of 3





Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - »Intersection with D. Done!



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
        // Find splitting point
        dist = distance along the ray point to split plane of node

        // Find near and far children
        near_child = child of node that contains the origin of Ray
        far_child = other child of node

    // Recurse down near child first
        if the interval to look is on near side {
            isect = RayTreeIntersect(ray, near_child, min, max)
            if( isect ) return isect    // If there's a hit, we are done
        }

        // If there's no hit, test the far child
        if the interval to look is on far side
            return RayTreeIntersect(ray, far_child, min, max)
}
```

Acceleration

- Intersection acceleration techniques are important
  - Bounding volume hierarchies
  - Spatial partitions
- General concepts
  - Sort objects spatially
  - Make trivial rejections quick

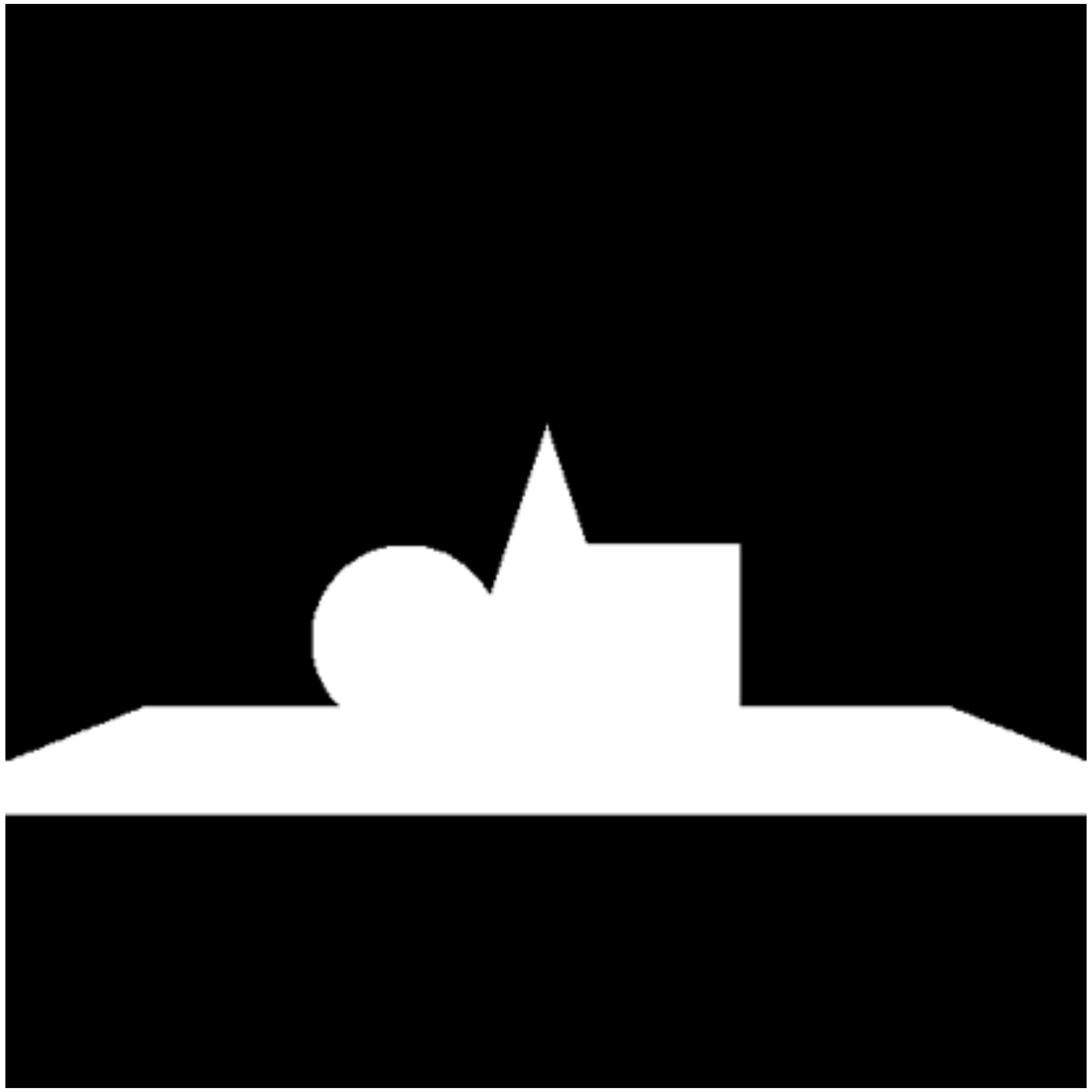
Expected time is sub-linear in number of primitives

Summary

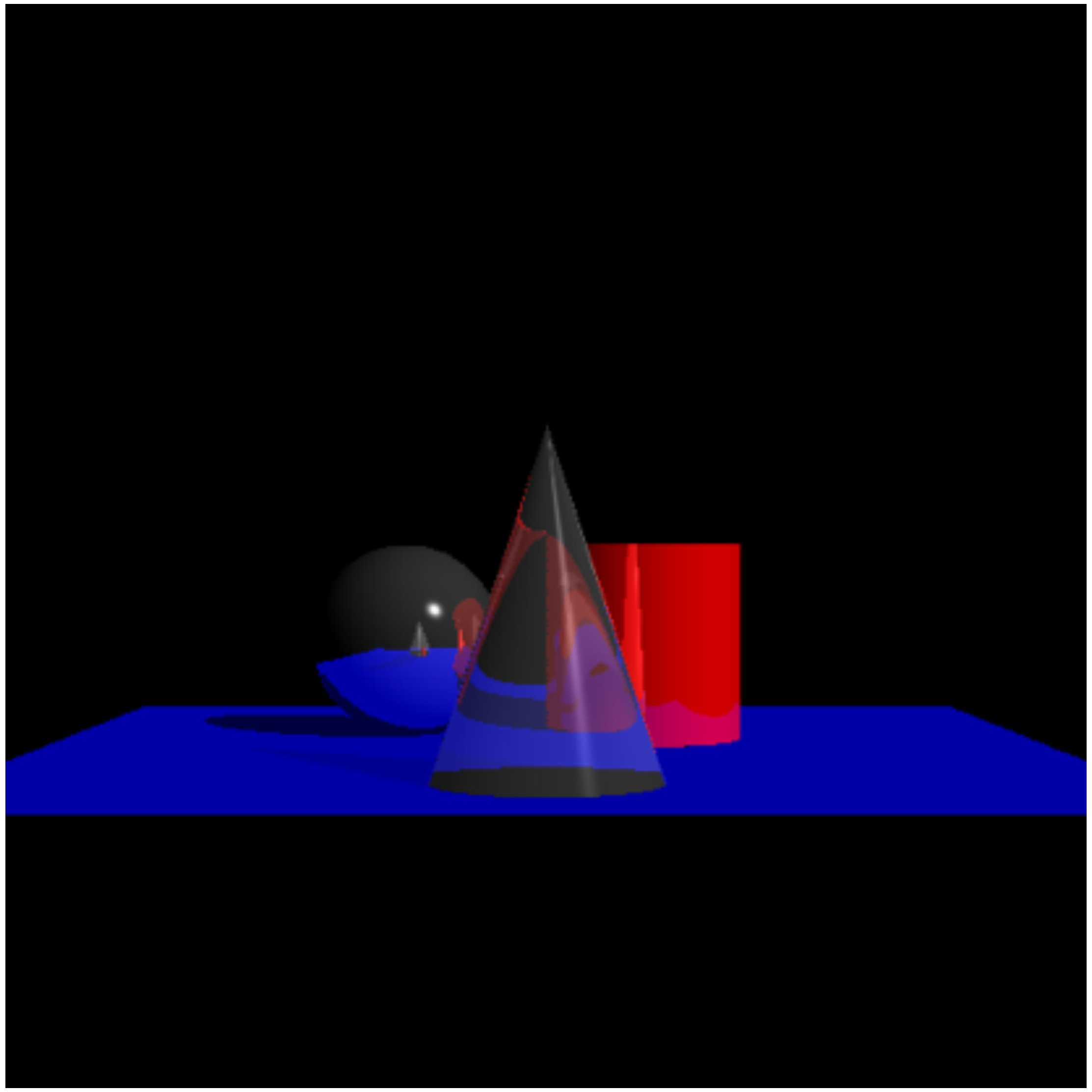
- Writing a simple ray casting renderer is easy
  - Generate rays
  - Intersection tests
  - Lighting calculations

```
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;
}
```

Next Time is Illumination!



Without Illumination



With Illumination