Physically Based Rendering (600.657)

Intersection Acceleration

Intersection Testing

Accelerated techniques try to leverage:

- Grouping: To efficiently discard groups of primitives that are guaranteed to be missed by the ray.
- Ordering: To test nearer intersections first and allow for early termination if there is a hit.

Intersection Testing

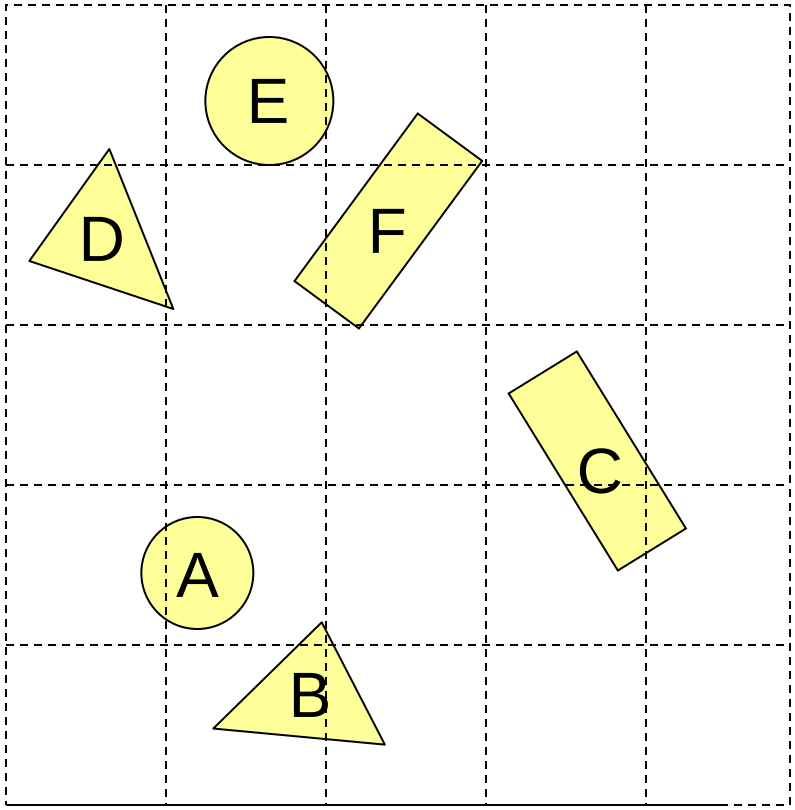
<u>Two Approaches</u>:

1. Space partitions:
   Decompose space into cells and assign primitives to the cells in which they fall.
   - A primitive may appear in multiple cells
2. Object partitions:
   Group objects into clusters
   - Cluster volumes may overlap

Uniform (Voxel) Grid Acceleration

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

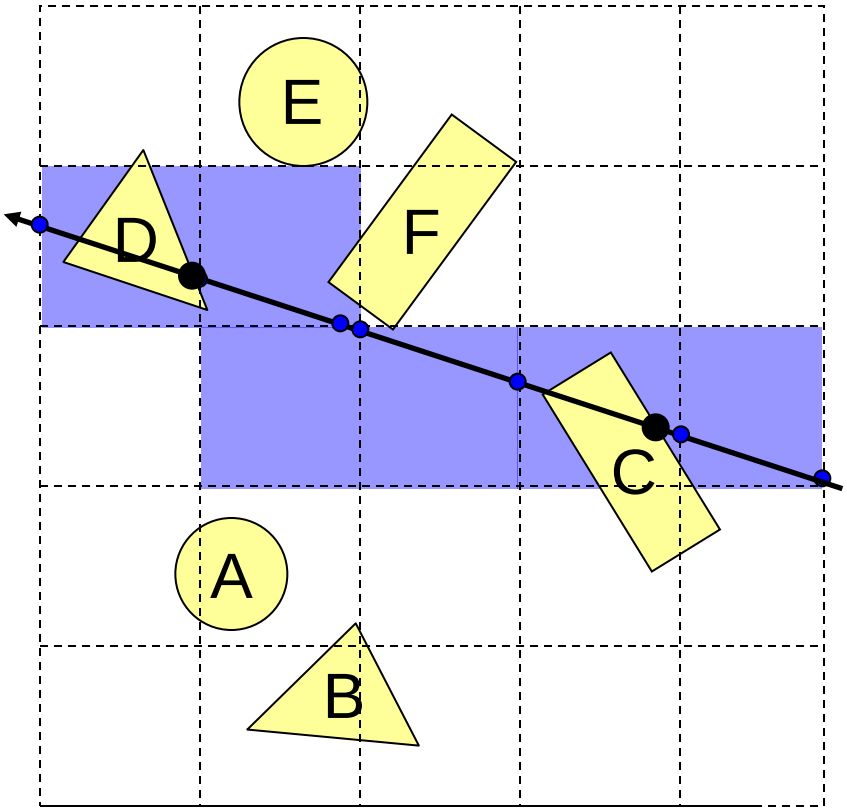
- A primitive may belong to multiple cells
- A cell may have multiple primitives



Uniform (Voxel) Grid Acceleration

- Trace rays through grid cells
  - Fast
  - Incremental

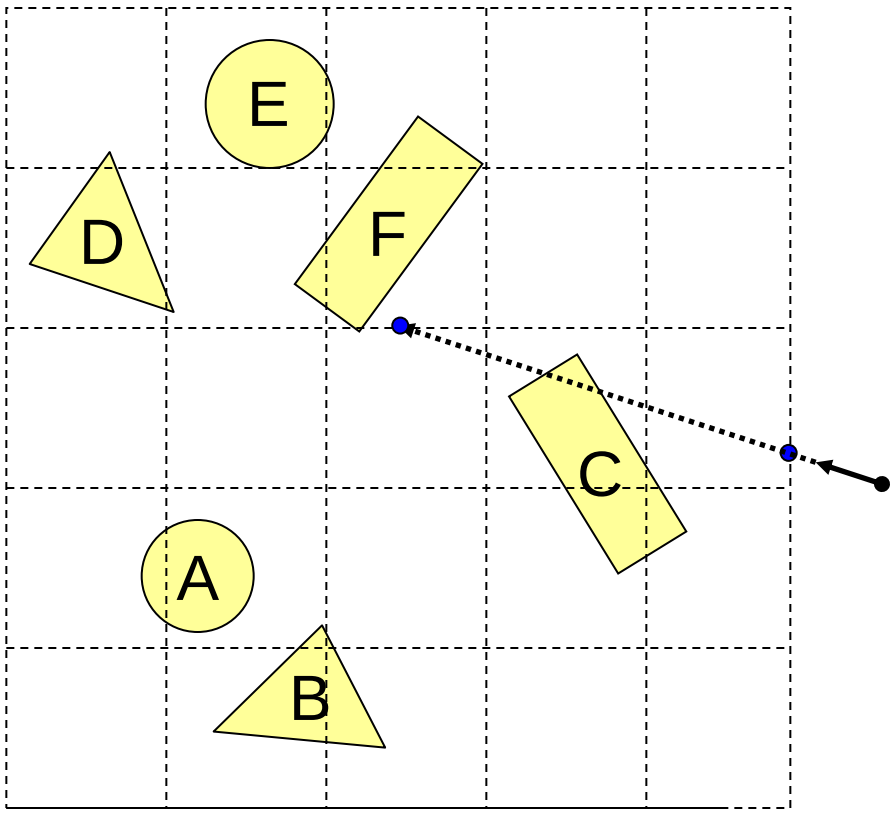
Only check primitives in intersected grid cells



Uniform (Voxel) Grid Acceleration

Traversal:

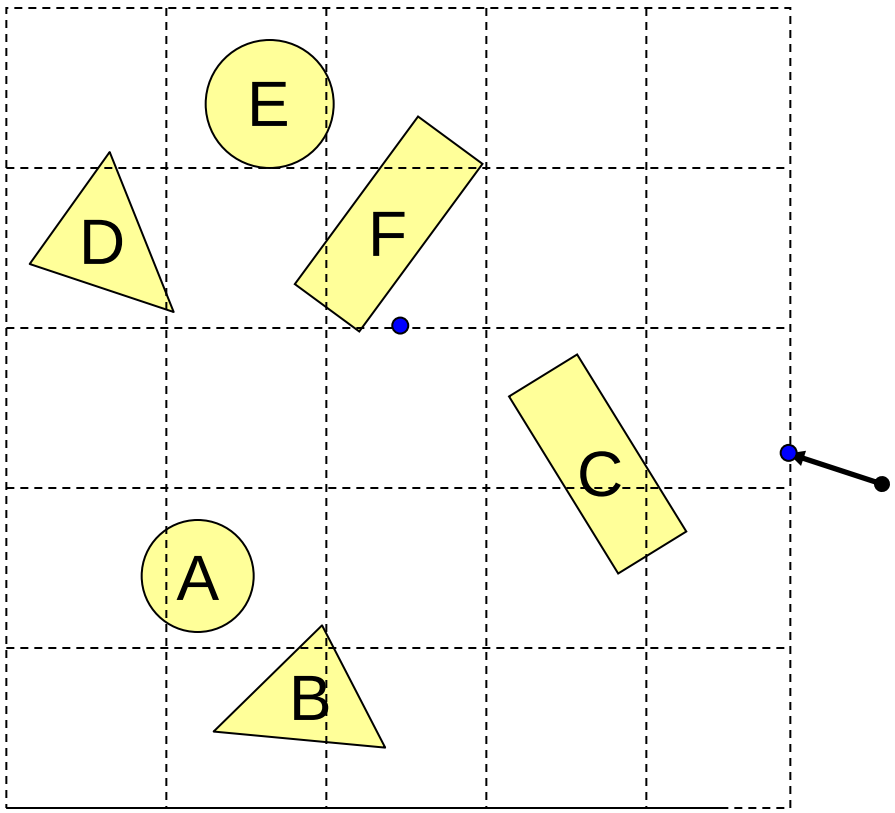
1. Find initial *x*, *y* intersections and *t* values



Uniform (Voxel) Grid Acceleration

Traversal:

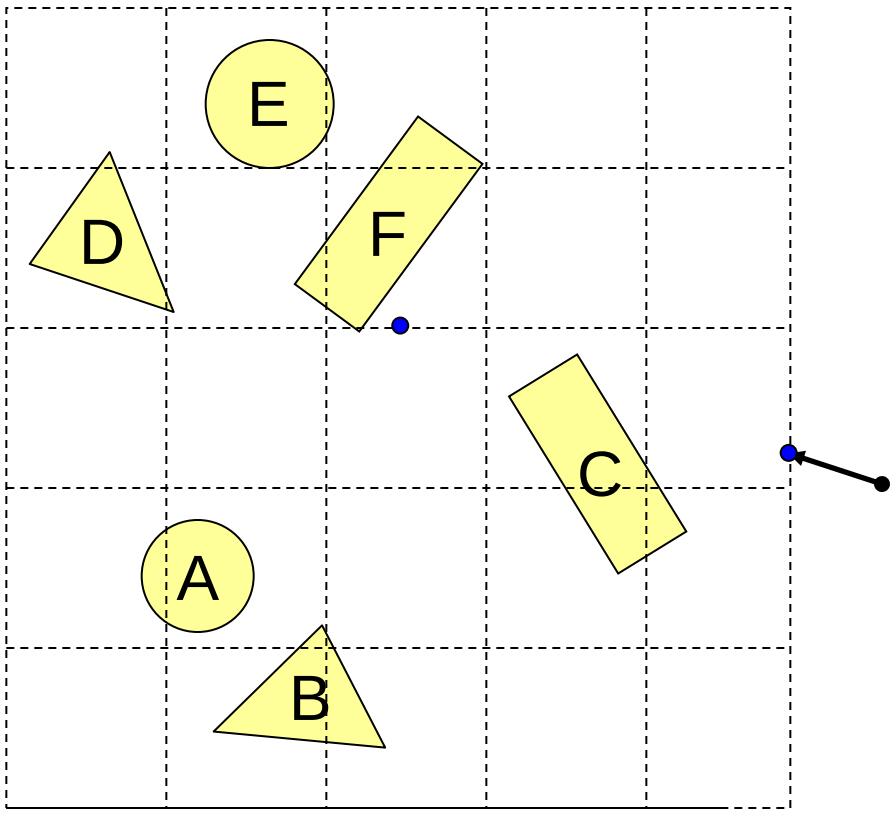
1. Find initial *x*, *y* intersections and *t* values
2. While inside:



Uniform (Voxel) Grid Acceleration

Traversal:

1. Find initial *x*, *y* intersections and *t* values
2. While inside:
   1. **Find closer hit dir.**



Uniform (Voxel) Grid Acceleration

Traversal:

1. Find initial *x*, *y* intersections and *t* values
2. While inside:
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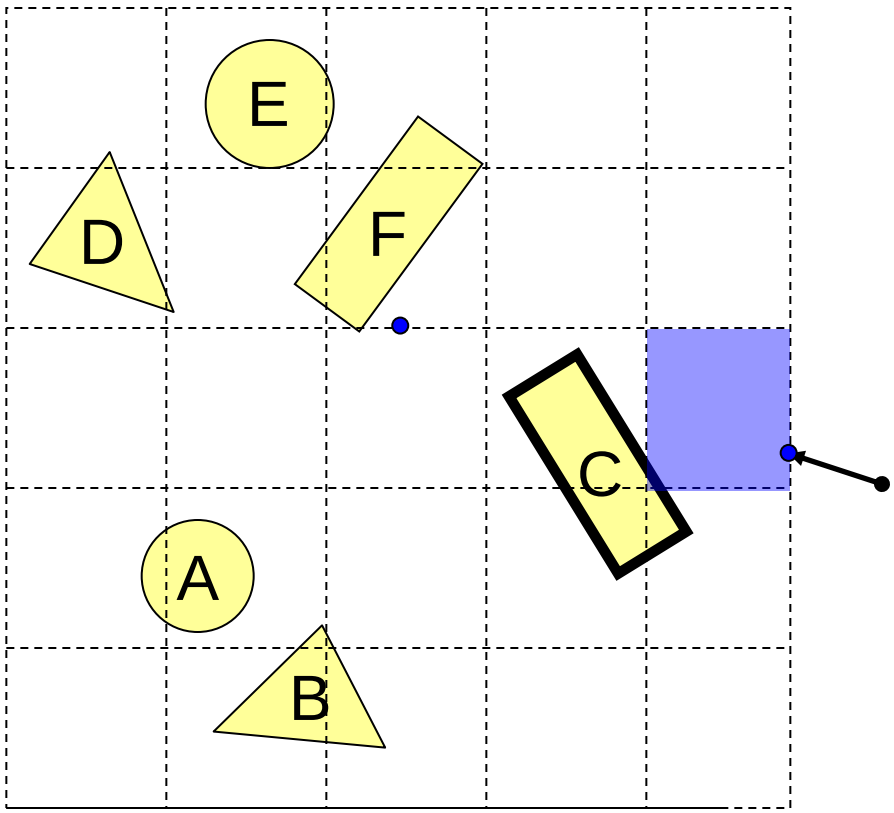
   2. **Test prims. in voxel**



Uniform (Voxel) Grid Acceleration

Traversal:

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   3. **If hit inside voxel:**
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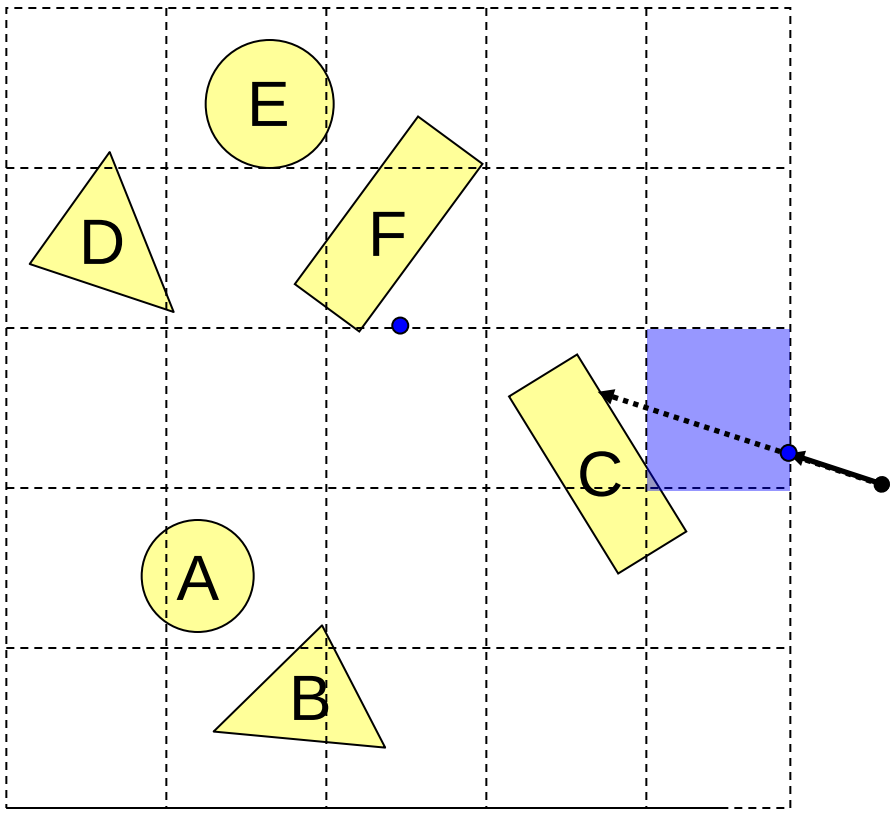

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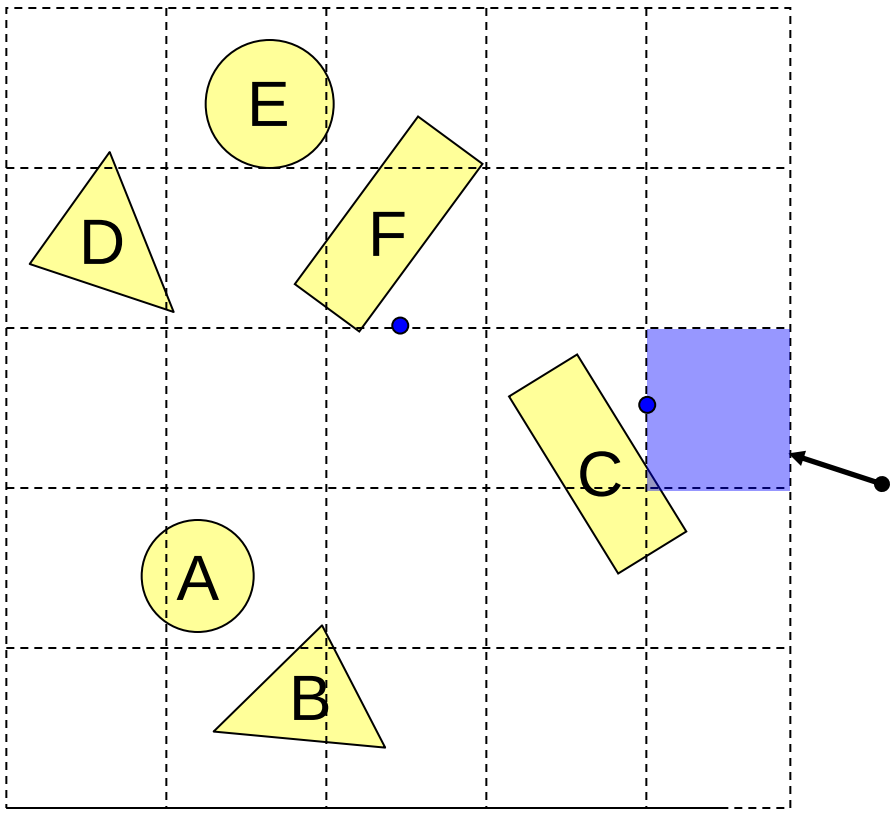
   4. **Update current *t***



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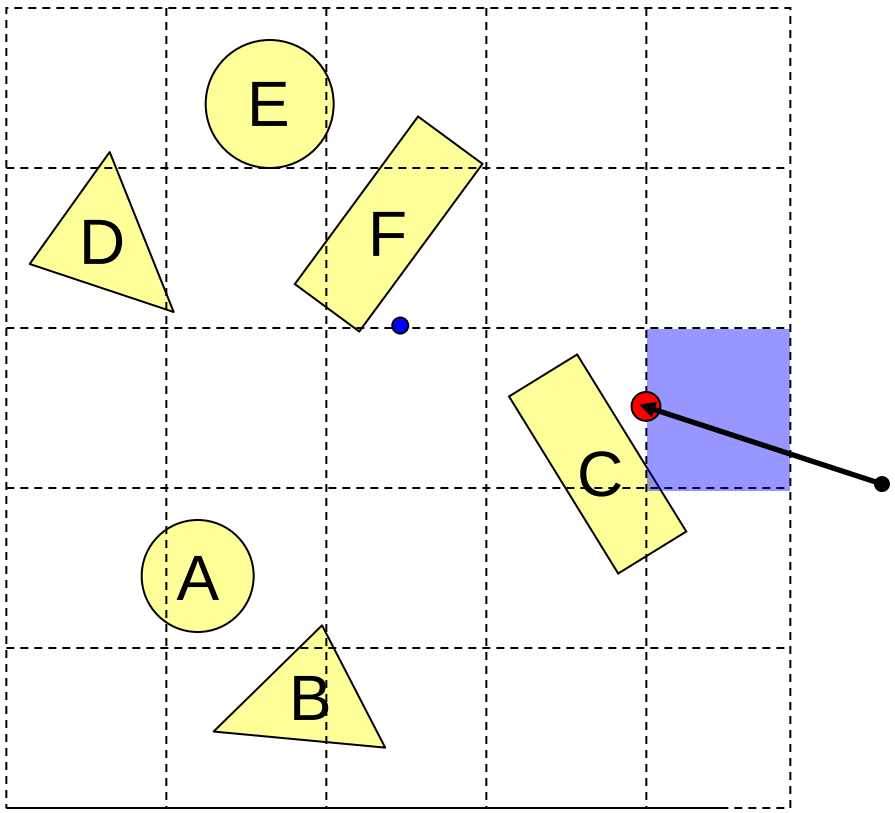

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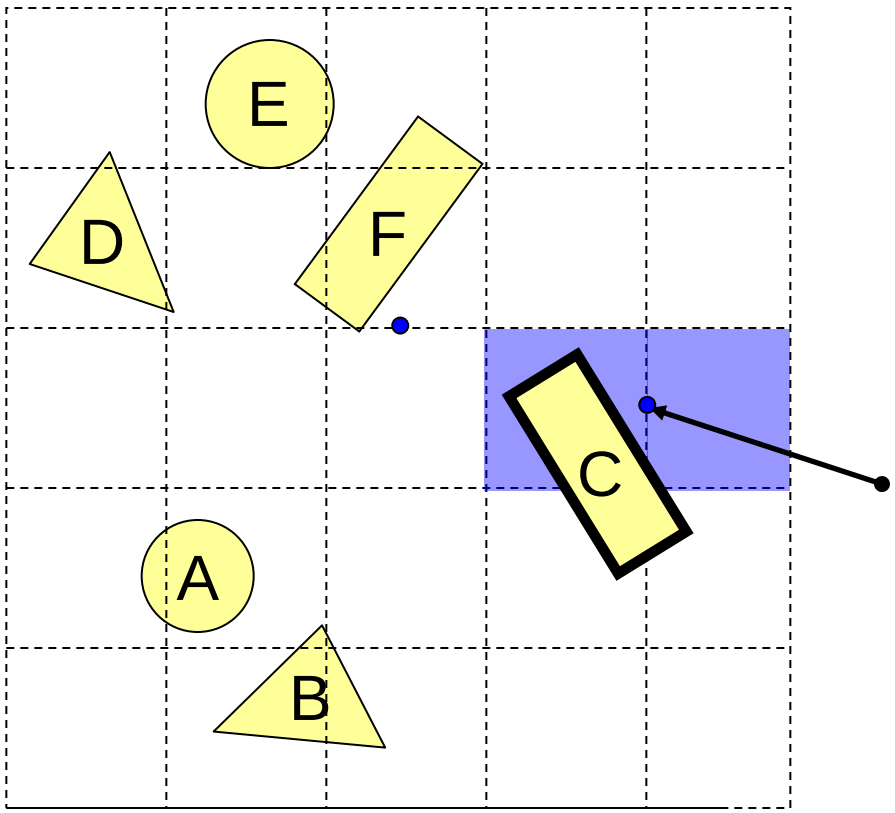

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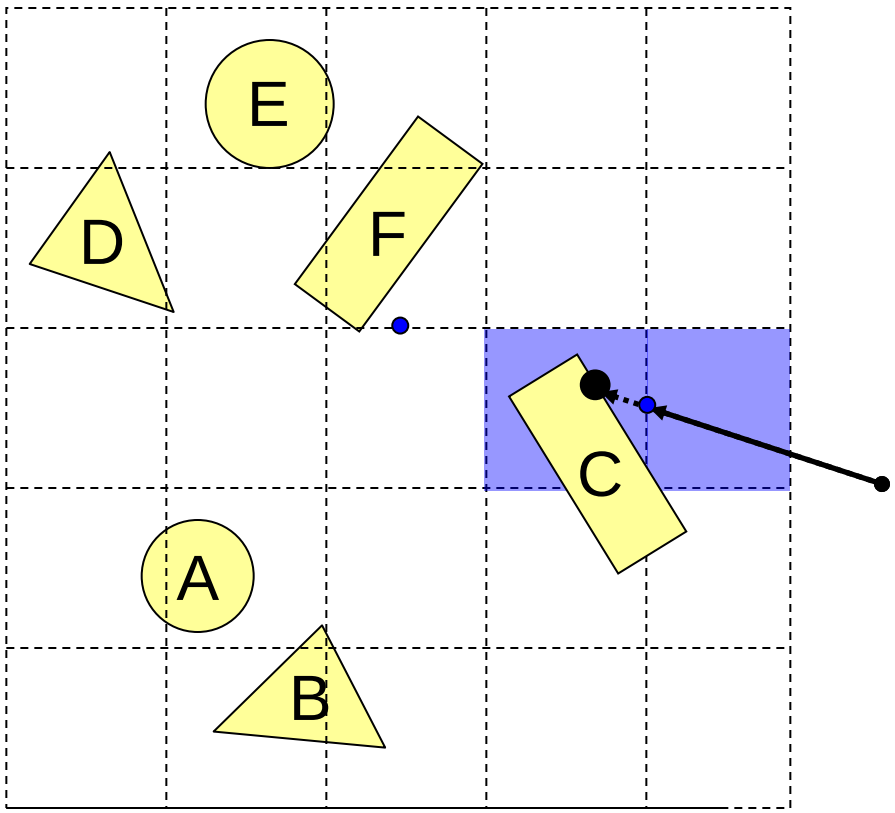

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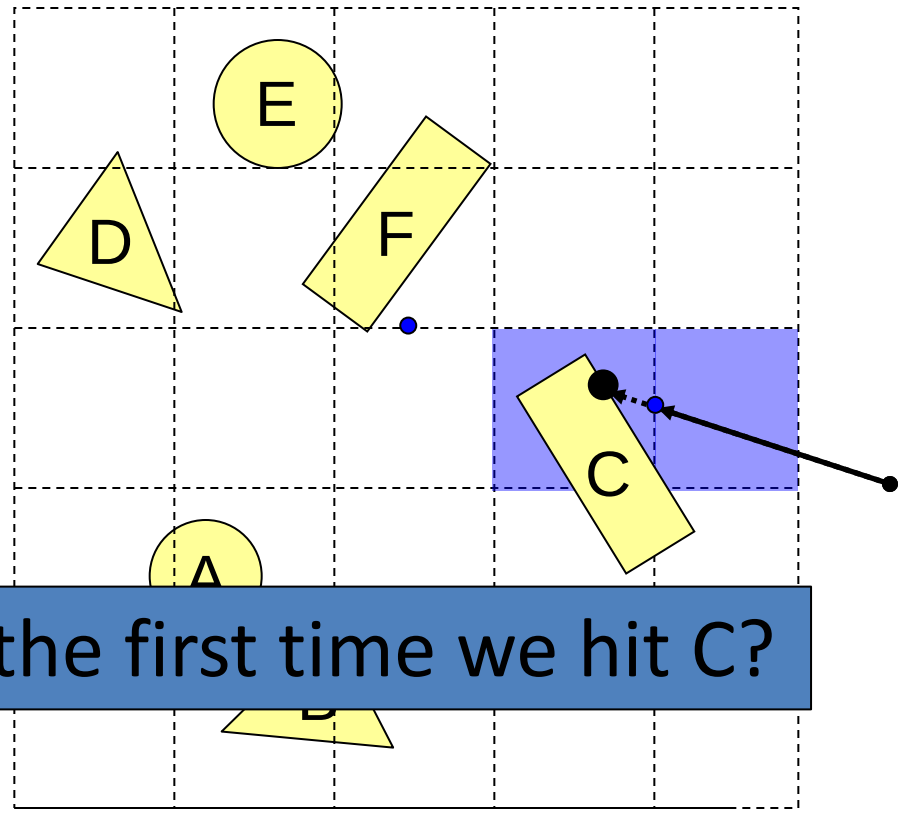

Couldn't we just stop the first time we hit C?

Uniform (Voxel) Grid Acceleration

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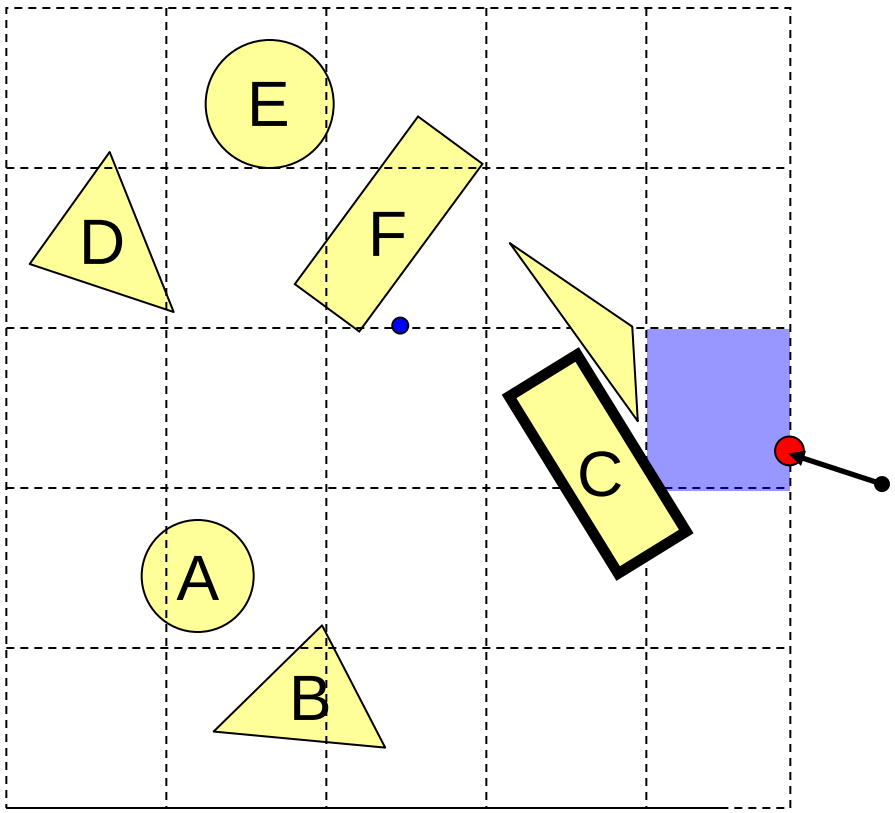

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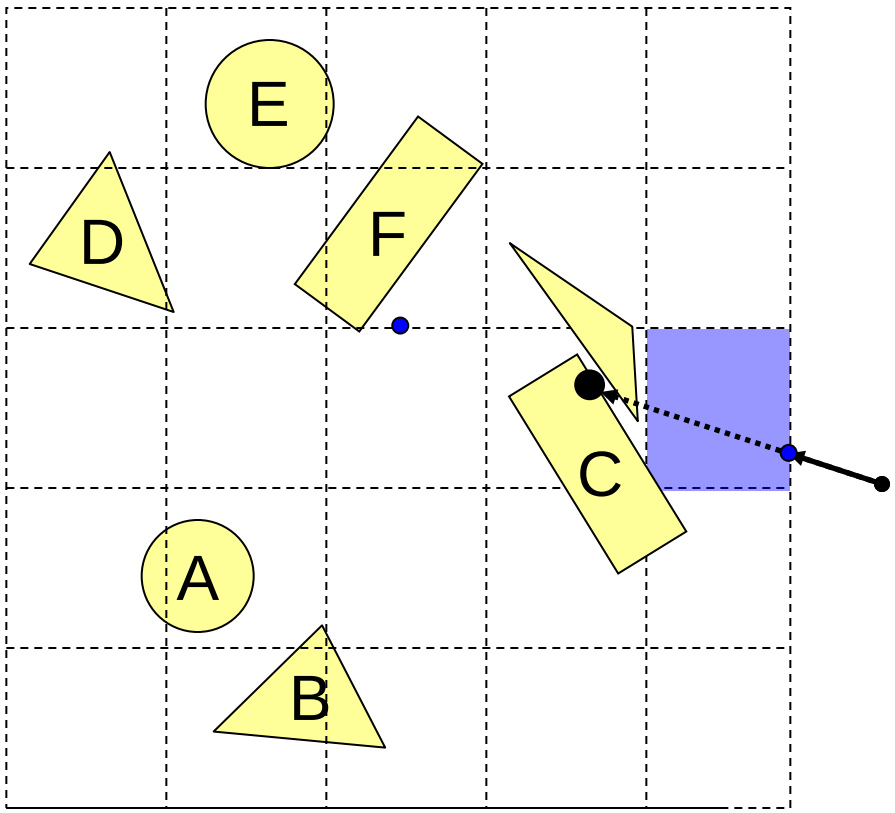

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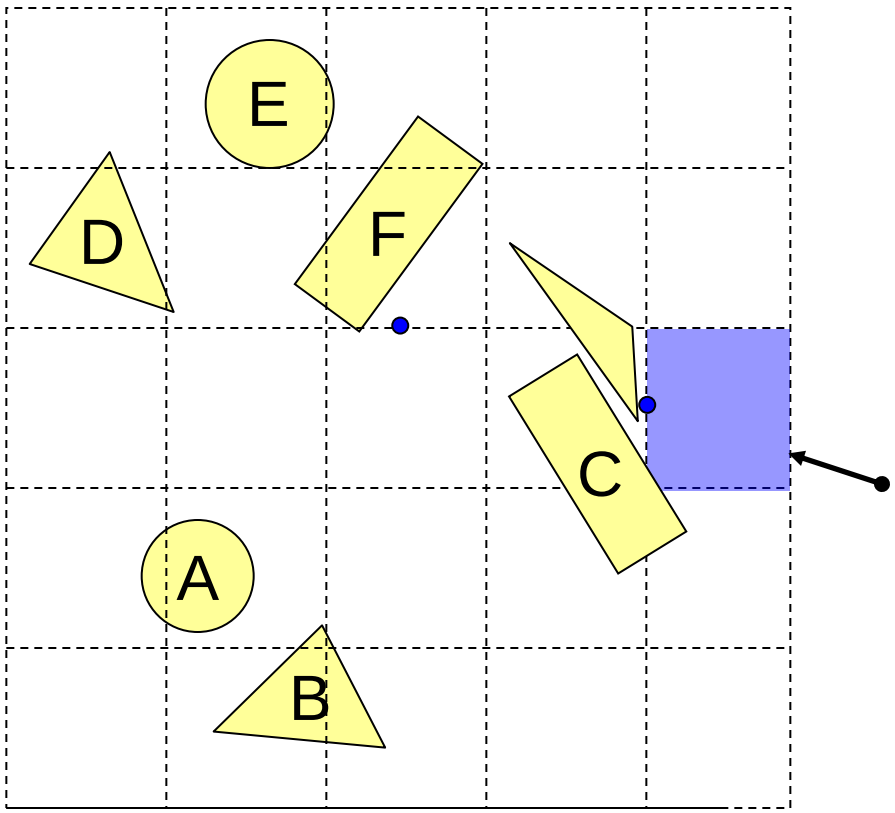

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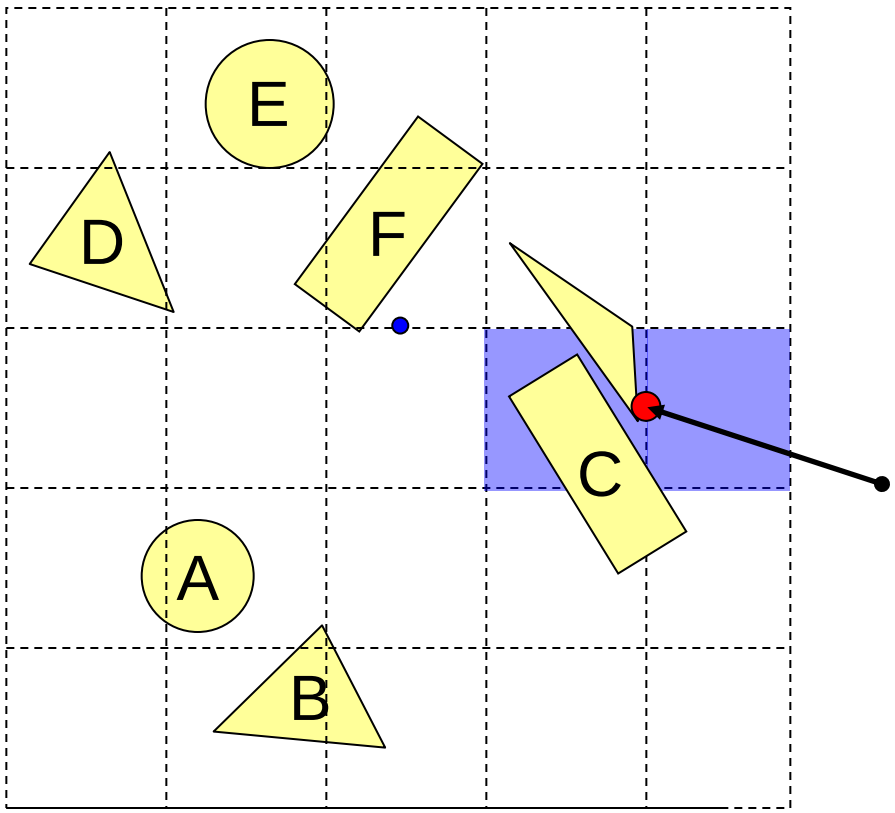

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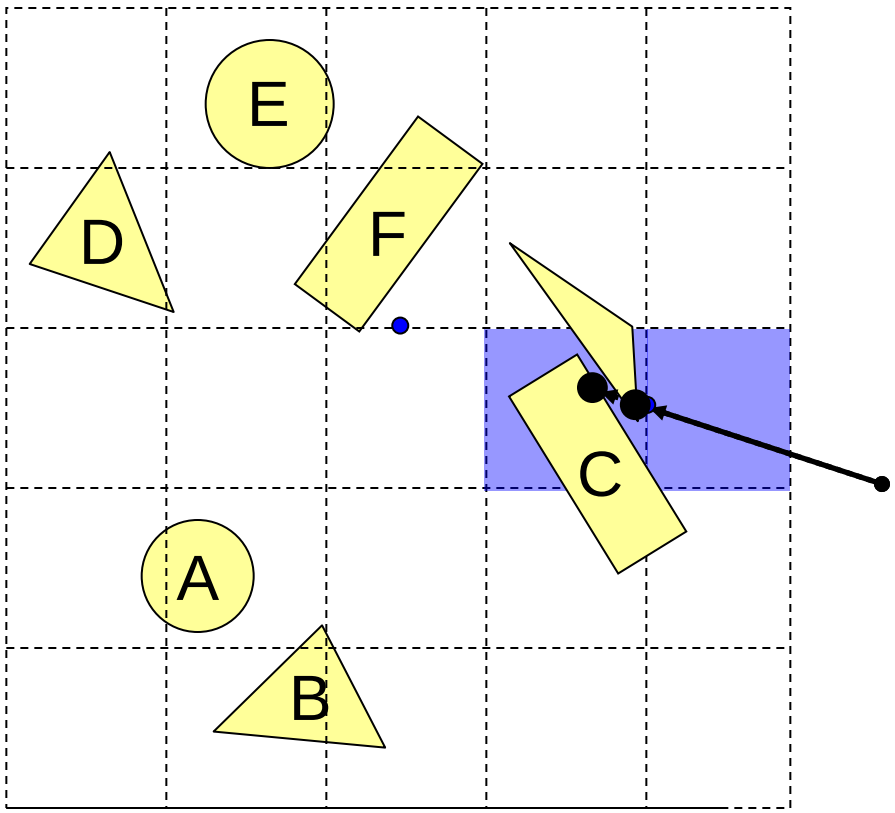
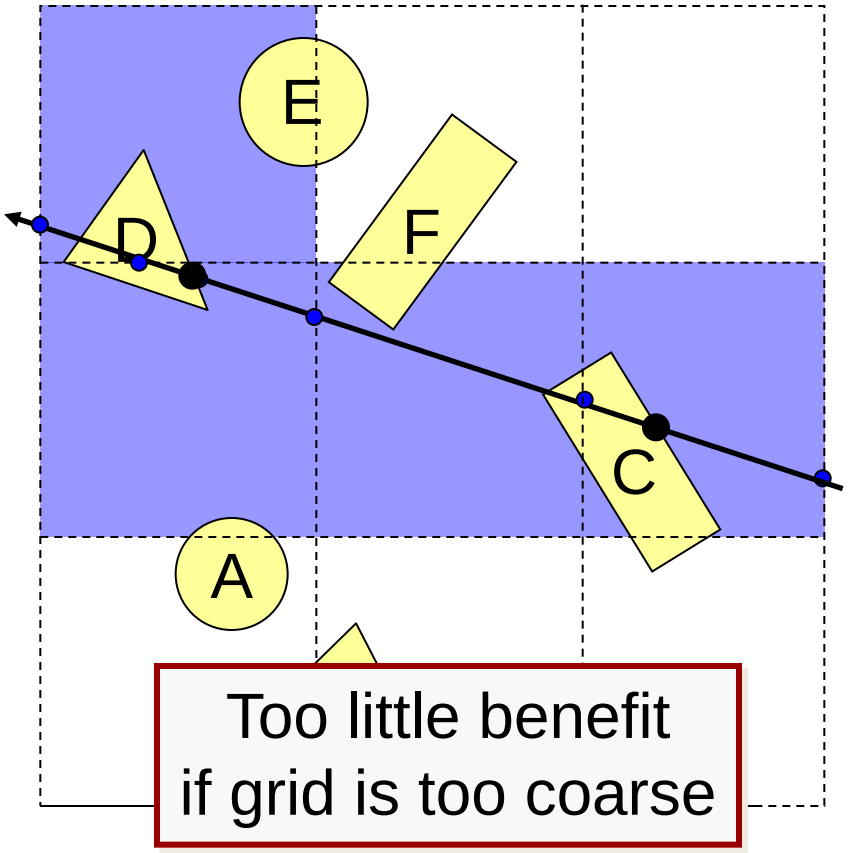
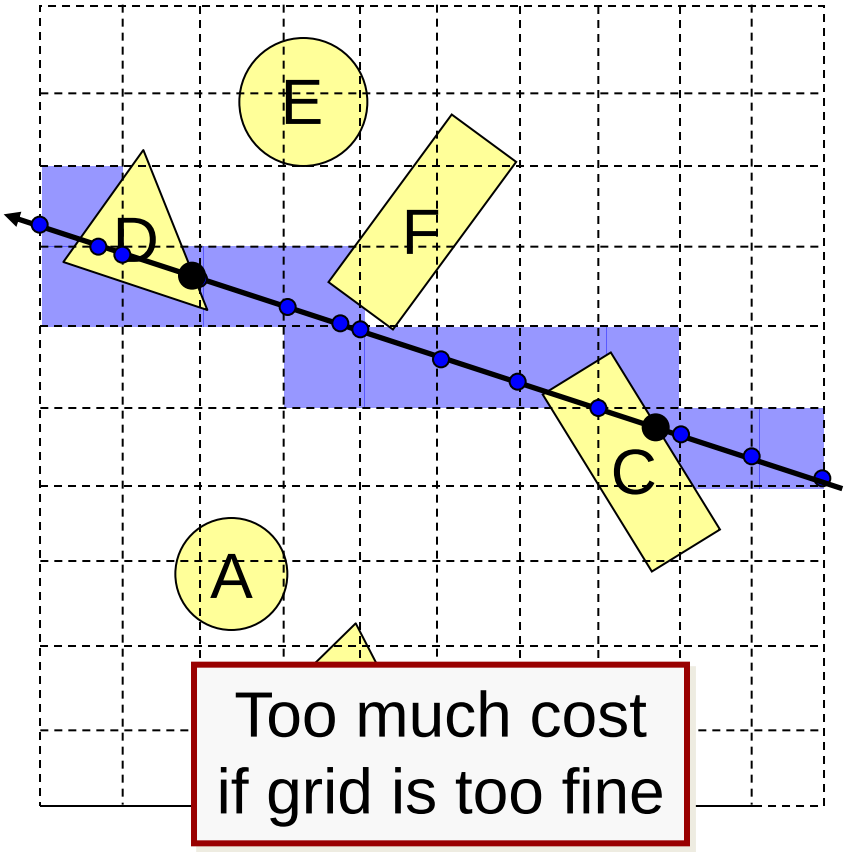


Uniform (Voxel) Grid Acceleration

- Potential problem:
  - How choose suitable grid resolution?

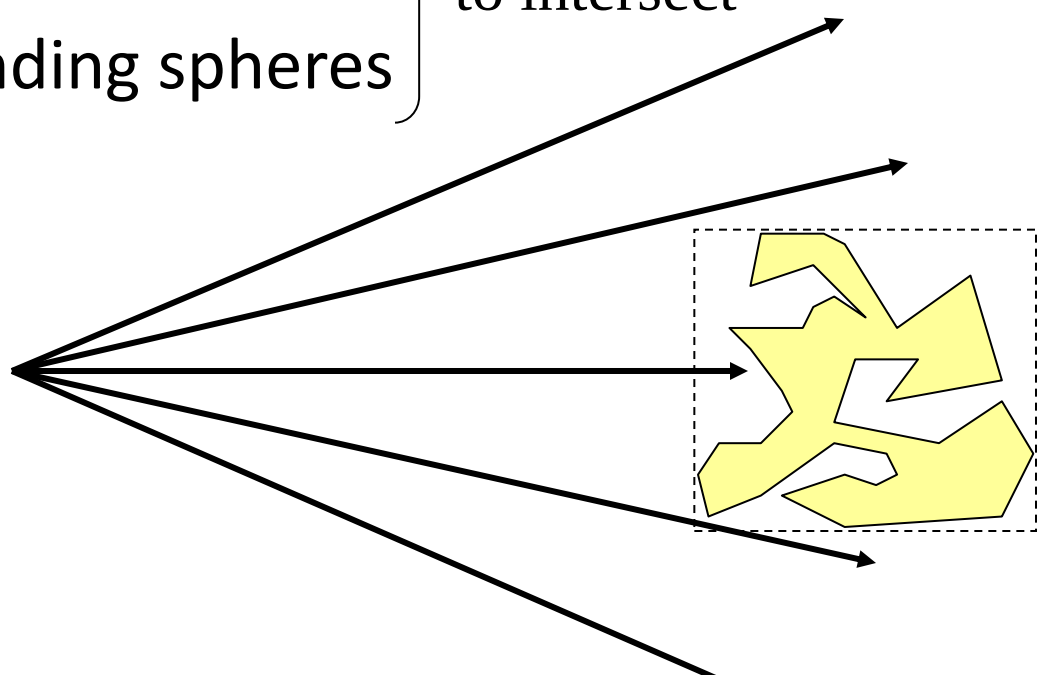




Bounding Volumes

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

Stuff that's easy to intersect



Bounding Volumes

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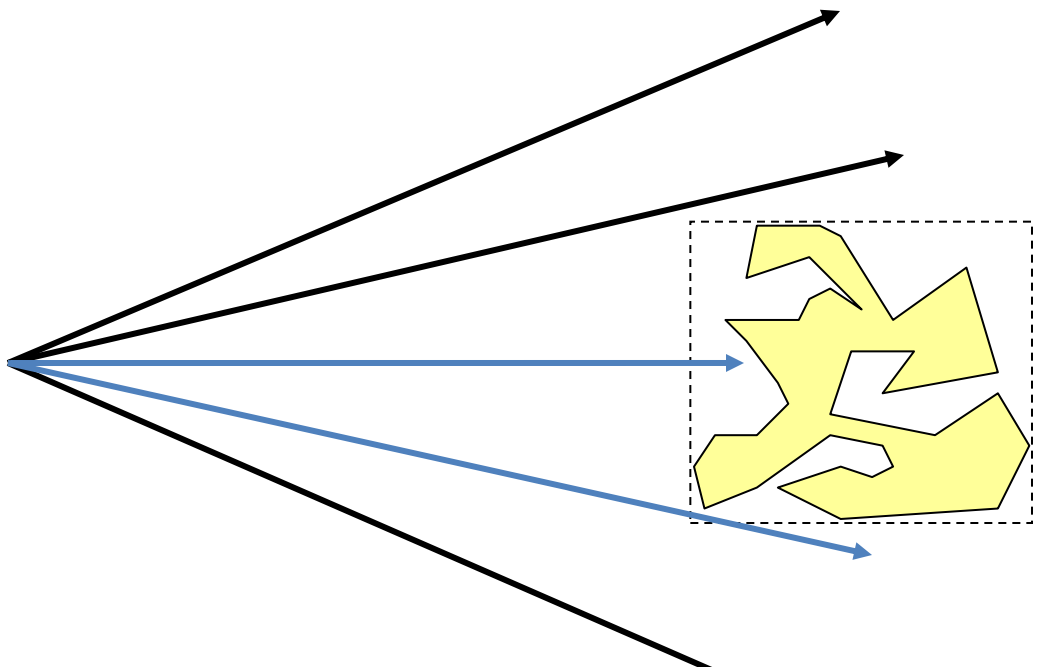
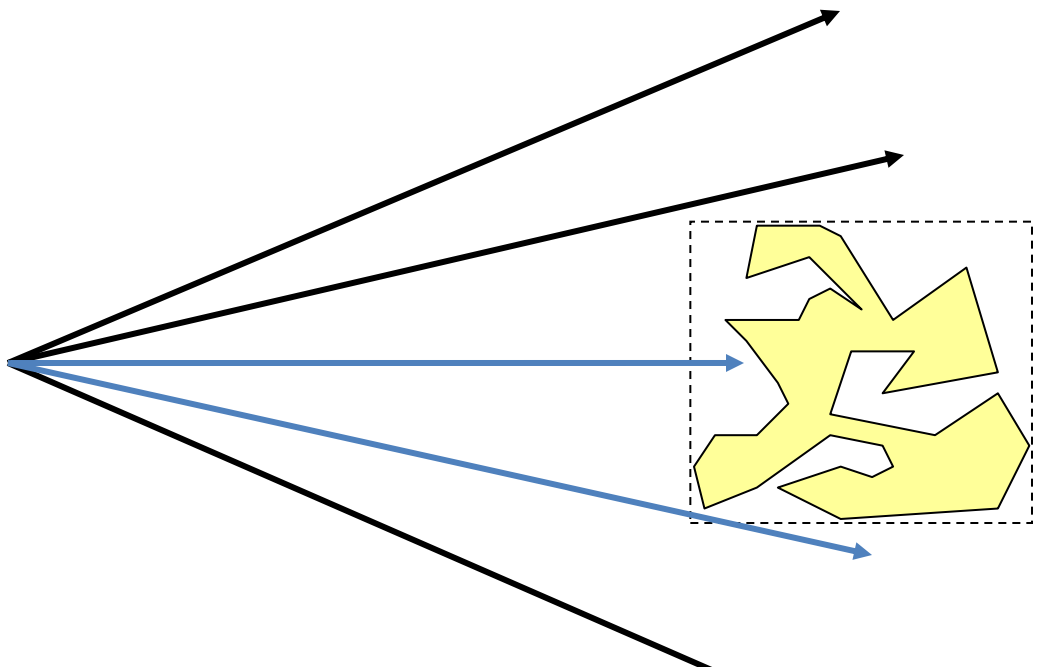


Bounding Volumes

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



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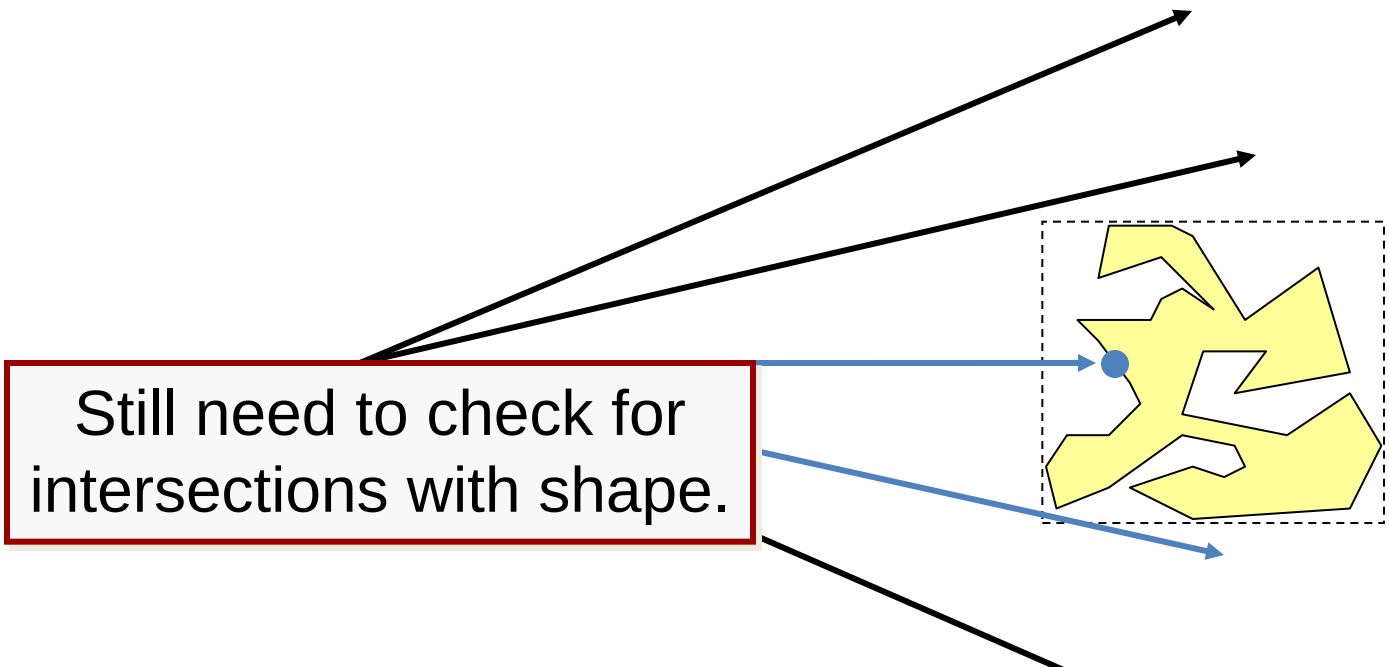
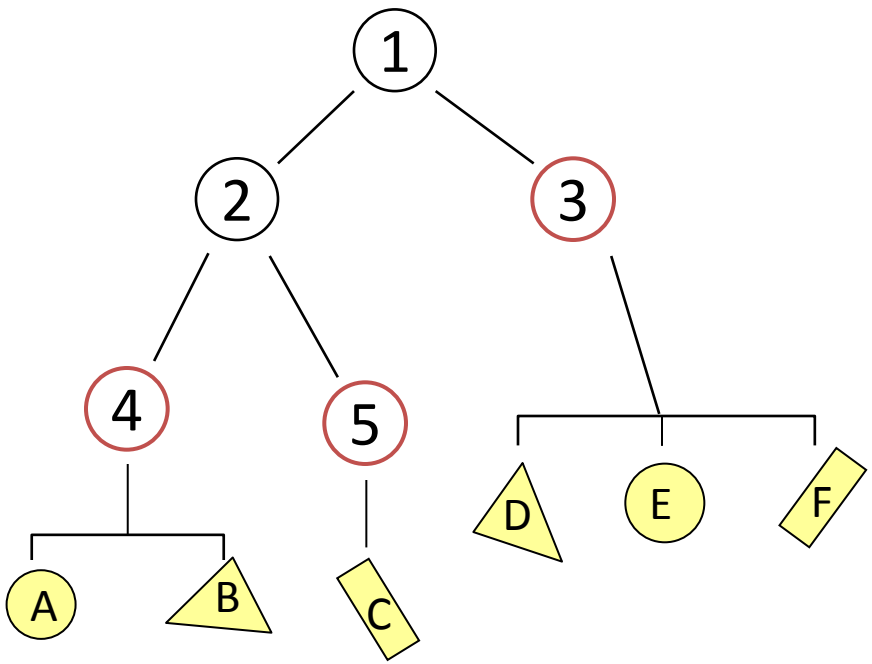
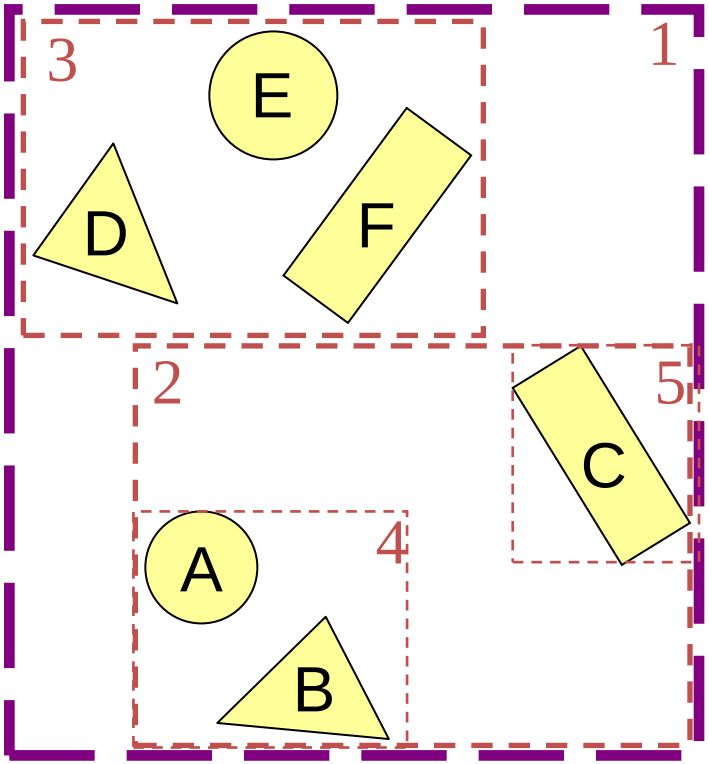


Bounding Volume Hierarchies

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





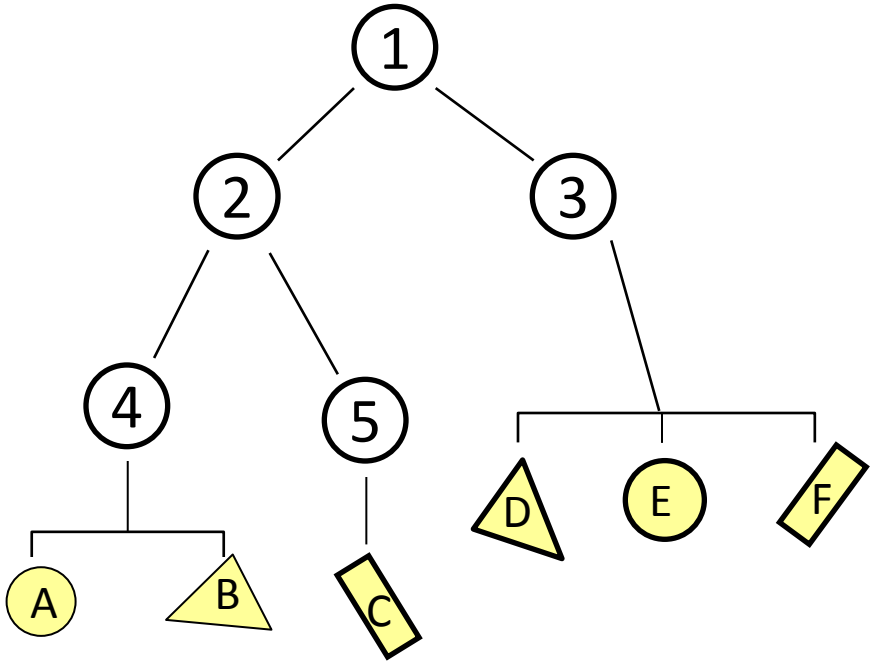
Bounding Volume Hierarchies

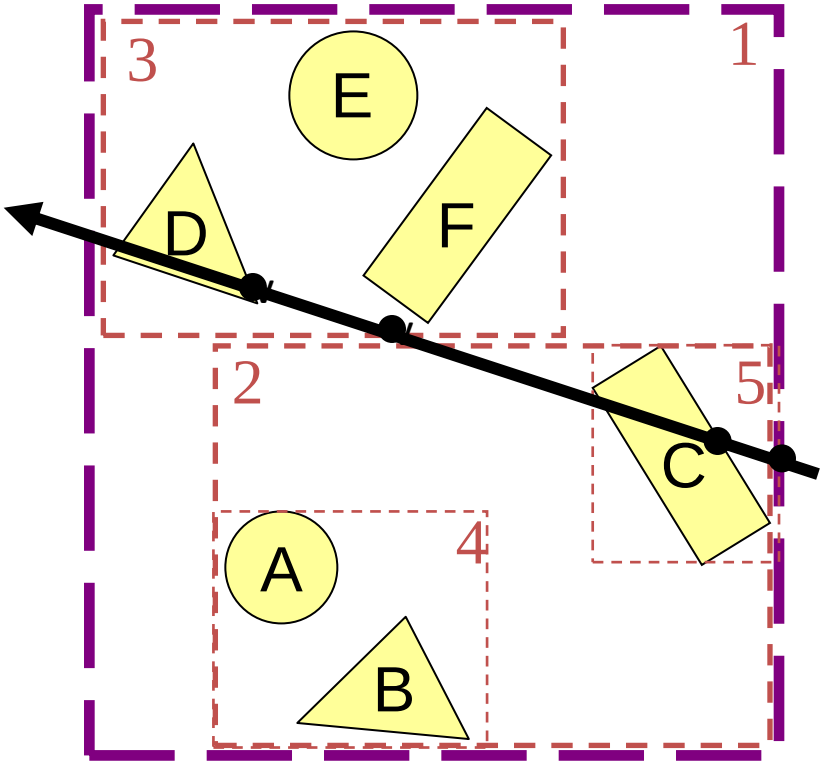
- Grouping acceleration

```
Float FindIntersection( Ray ray, Node node) {
        min_t = -1

        if( !intersect ( node.boundingVolume ) )            // Test Bounding box
                return min_t

        foreach shape {                                     // Test node's shape
                t = Intersect( shape )
                if( t>0 && (t<min_t || min_t<0) )  min_t = t
        }

        for each child {                                    // Test node's children
                t = FindIntersection(ray, child)
                if (t>0 && (t < min_t || min_t<0) )  min_t = t
        }
        return min_t;
}
```

Bounding Volume Hierarchies

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





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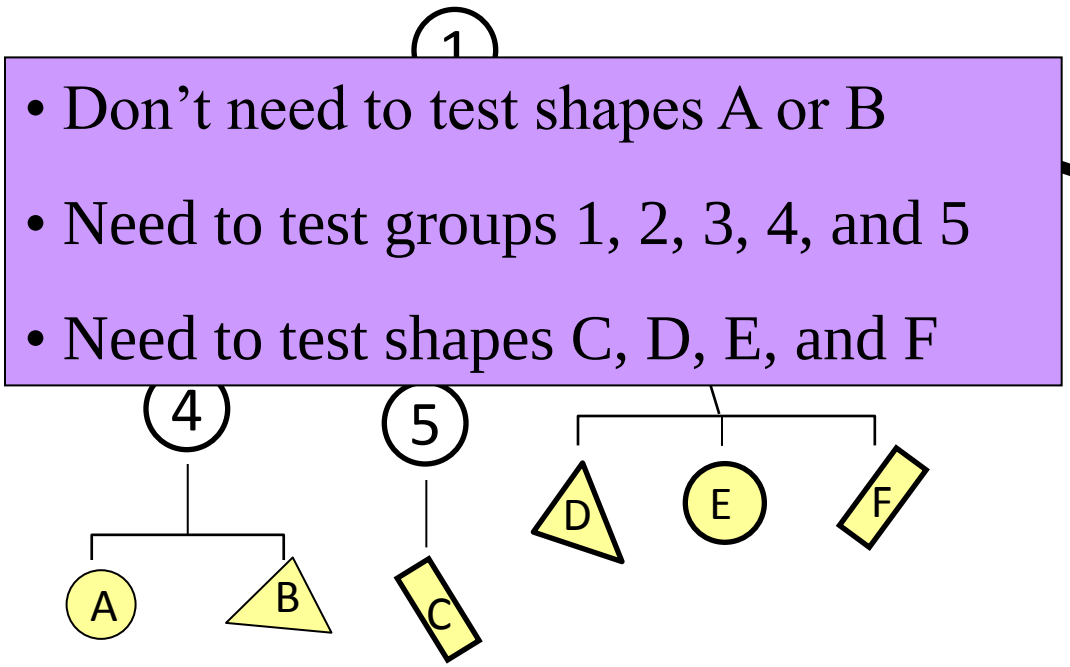
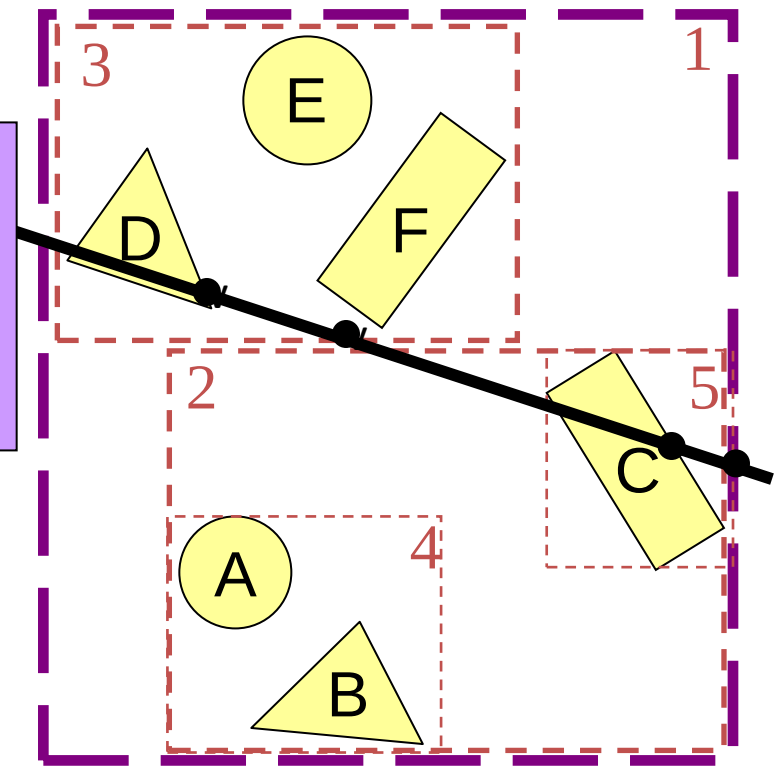


- Don't need to test shapes A or B
- Need to test groups 1, 2, 3, 4, and 5
- Need to test shapes C, D, E, and F



Bounding Volume Hierarchies

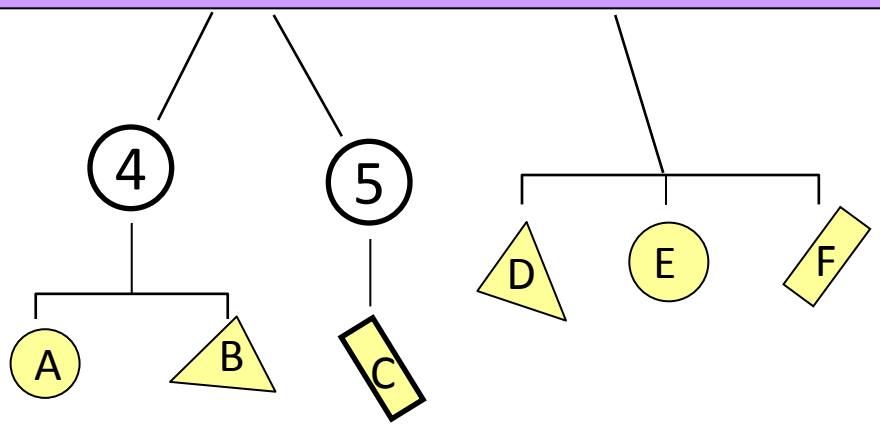
- Grouping + Ordering acceleration

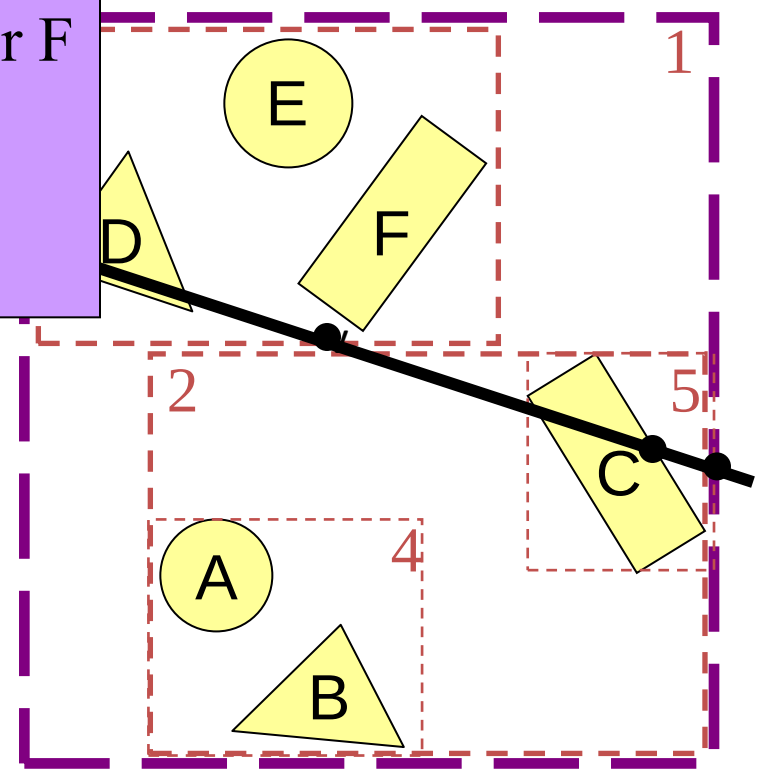
```
Float FindIntersection(Ray ray, Node node) {
        // Find intersections with the shapes of the node
        …
        // Find intersections with child node bounding volumes
        ...
        // Sort child intersections front to back
        ...

        // Process intersections (checking for early termination)
        for each intersected child  {
                if (min_t < bv_t[child]) break;
                t = FindIntersection(ray, child);
                if (t>0 && (t < min_t || min_t<0) )  min_t = t
        }
        return min_t
}
```

Bounding Volume Hierarchies

- Build (binary) hierarchy of bounding volumes
  - Bounding volume of interior node contains all

- Don't need to test shapes A, B, D, E, or F
- Need to test groups 1, 2, 3, 4, and 5
- Need to test shape C





Bounding Volume Hierarchies

- How do we build up the bounding volume hierarchy?

Bounding Volume Hierarchies

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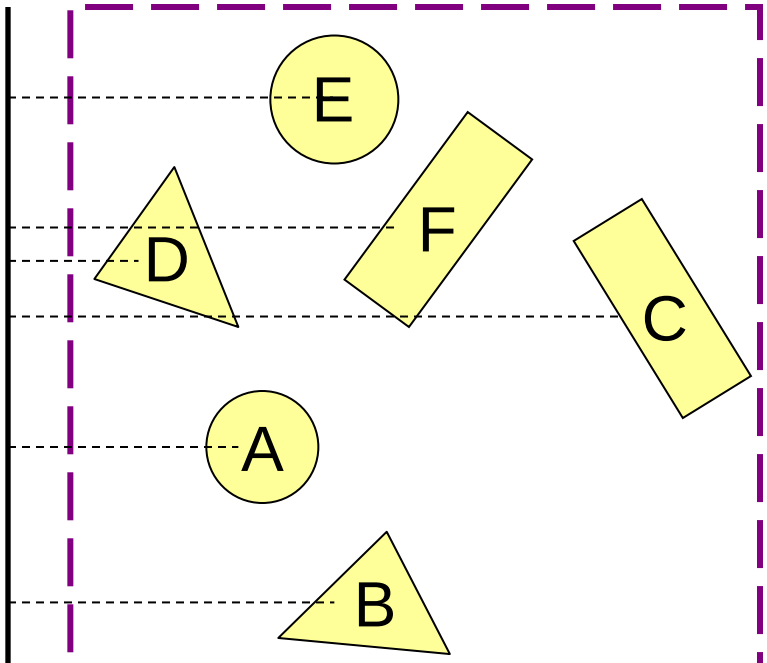
  Choose an axis:

1. Evenly split primitives based on centroids.



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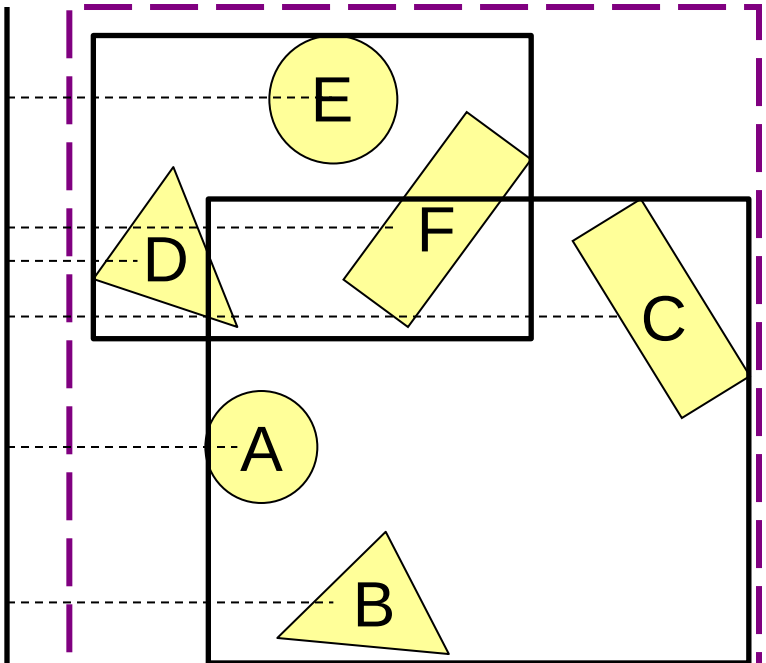
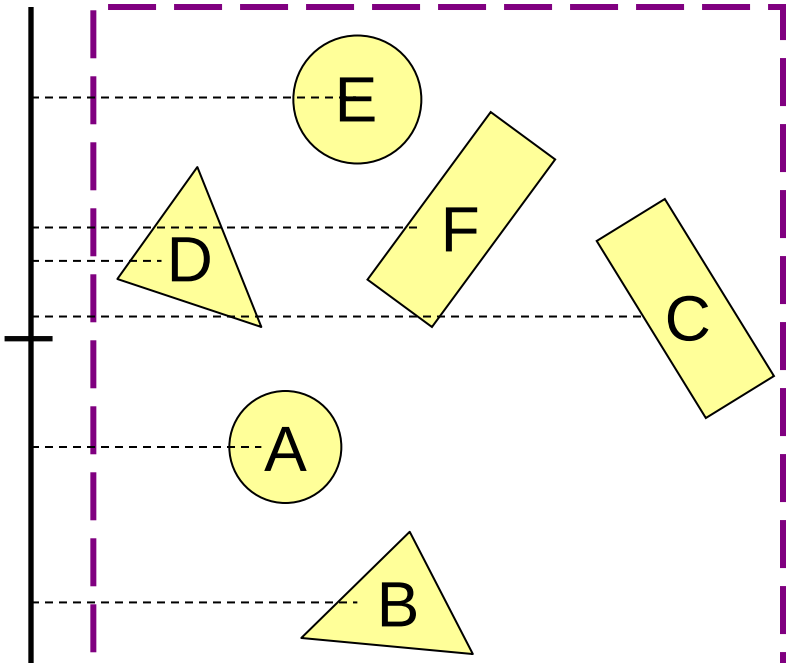


Bounding Volume Hierarchies

- How do we build up the bounding volume hierarchy?
  Choose an axis:

1. Evenly split primitives based on centroids.
2. Find the center and split left/right.



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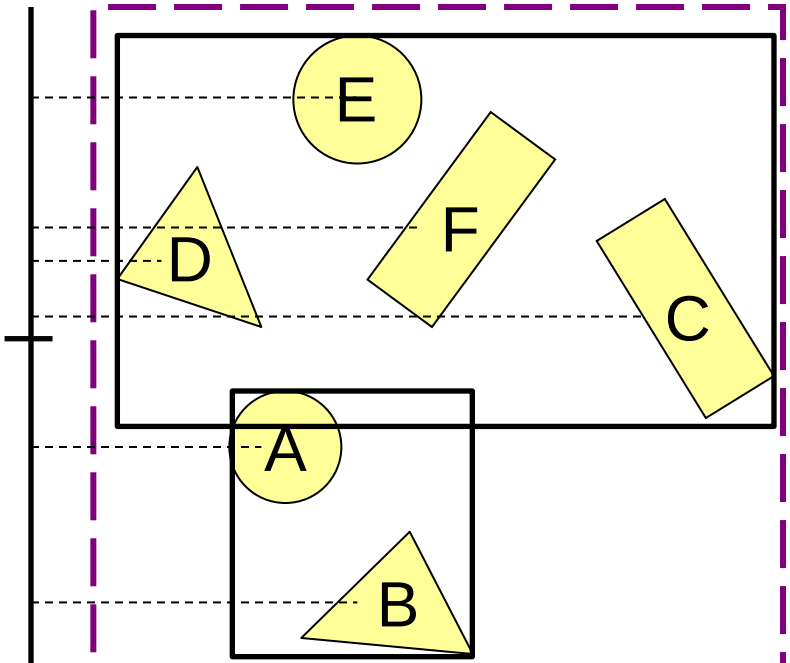


Bounding Volume Hierarchies

- How do we build up the bounding volume hierarchy?

3. Surface area heuristic:

$$\min\left(\underbrace{c_{\text{isect}} N}_{\text{Cost of leaf node}}, \underbrace{c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)}_{\text{Cost of child nodes } A/B}\right)$$

c_{isect}: Cost of testing for intersection
c_{trav}: Cost of traversing a bounding volume
N: number of primitives in bounding volume
$N_{A/B}$: number of primitives in child A/B
$p_{A/B}$: probability that a ray isect the bounding volume will isect the child volume A/B

Minimum Area Heuristic

$$\min\left(c_{\text{isect}} N, c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)\right)$$

<u>Challenge 1</u>:

How do you assign probabilities?

<u>Challenge 2</u>:

How do you choose the one out of $2^{N-1}-1$ different (non-trivial) ways to partition?

Minimum Area Heuristic

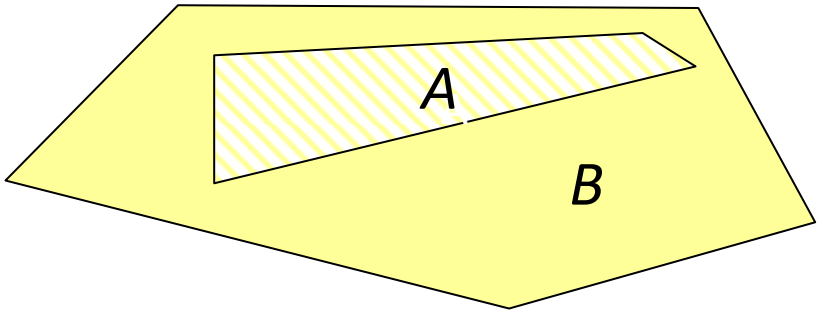
$$\min\left(c_{\text{isect}} N, c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)\right)$$

<u>Challenge 1</u>:

How do you assign probabilities?

For two convex shapes $A \subset B$, the probability that a ray entering B will also enter A is:

$$\text{Area}(\partial A) \,/\, \text{Area}(\partial B)$$



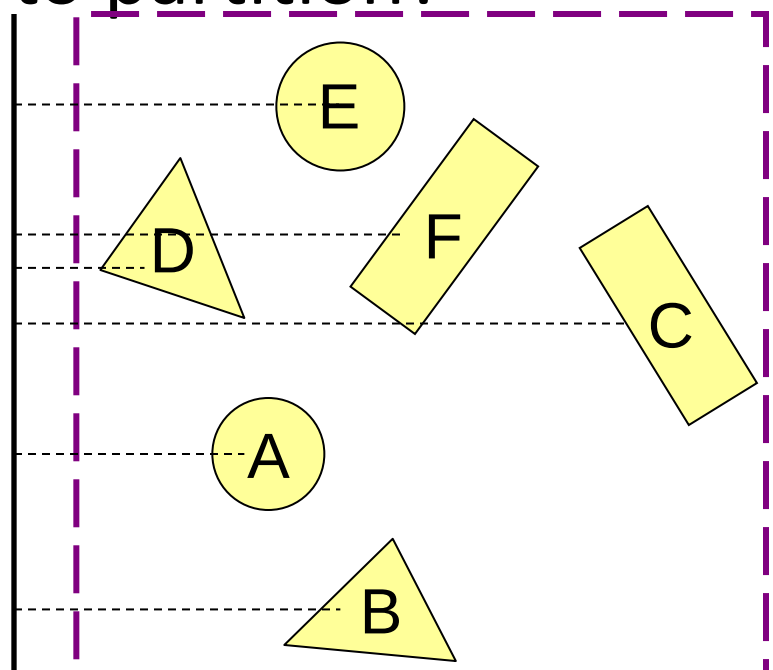
Minimum Area Heuristic

$$\min\left(c_{\text{isect}}N, c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)\right)$$

<u>Challenge 2</u>:

How do you choose the one out of 2^{N-1}-1 different (non-trivial) ways to partition?

Splitting by looking at centroids relative to a split position, there are only N-1 split positions to consider.



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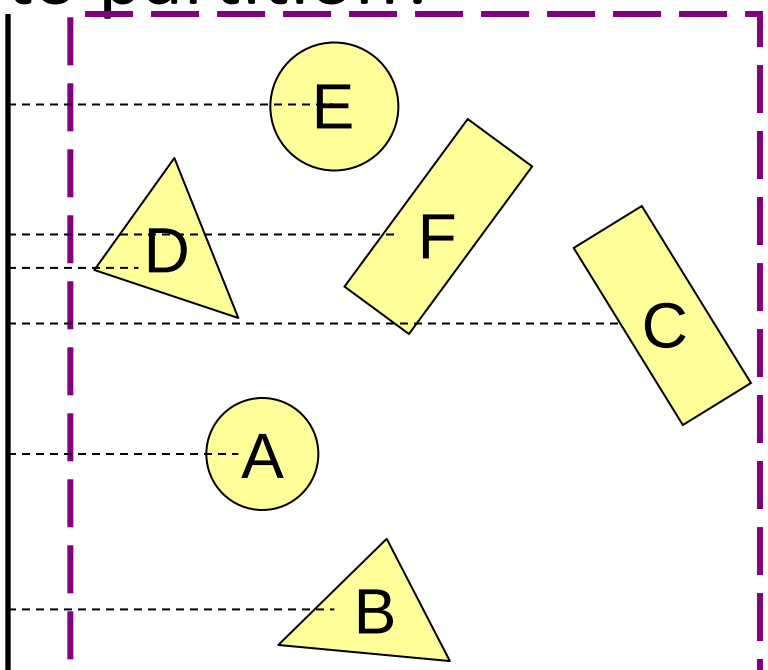

Choose the cost minimizer

Minimum Area Heuristic

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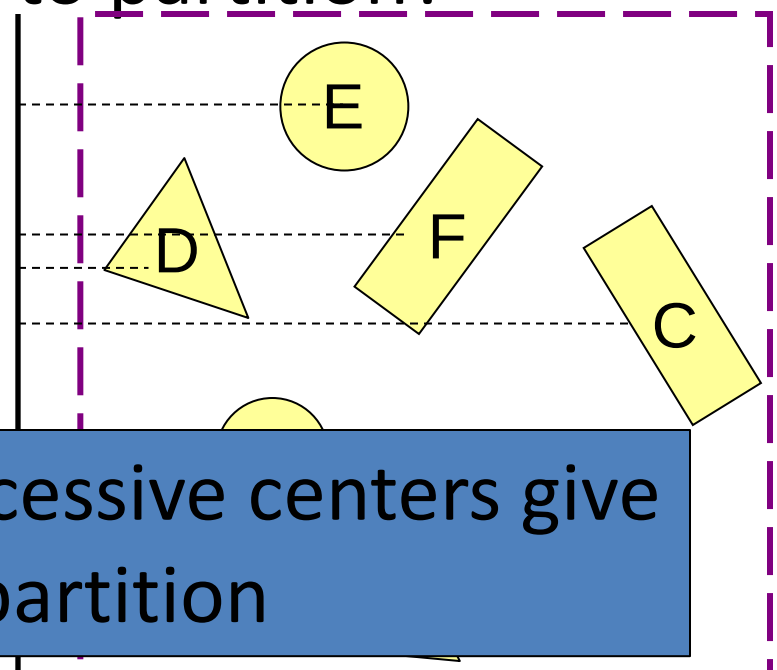
Splitting by looking at centroids relative to a split position, there are only N-1 split positions to c

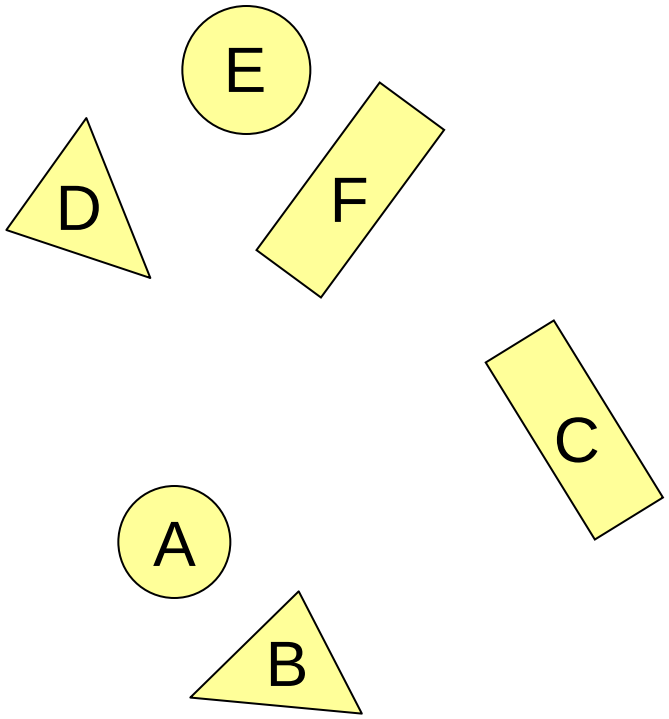
Cho



All splits between successive centers give the same partition

Kd Trees

- Split along the coordinate axes



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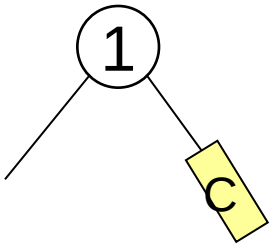

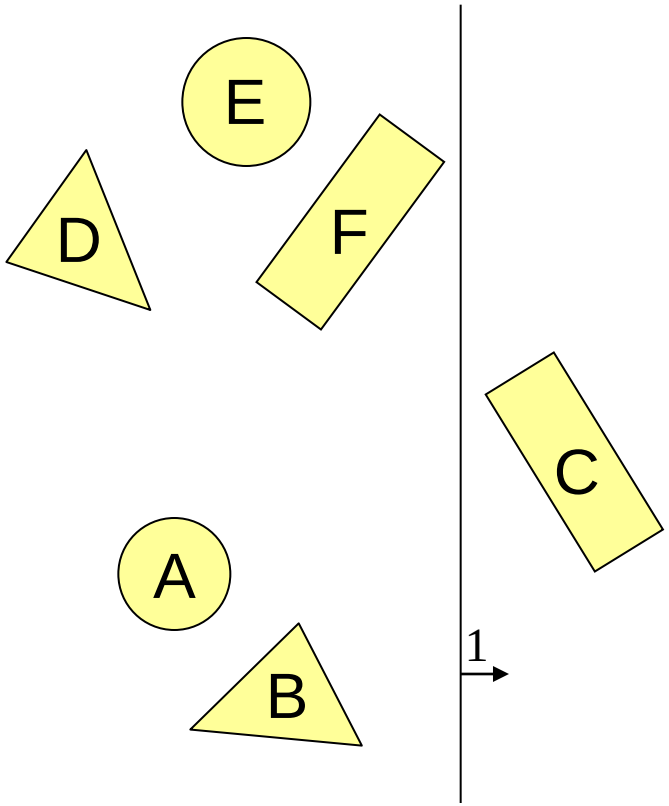

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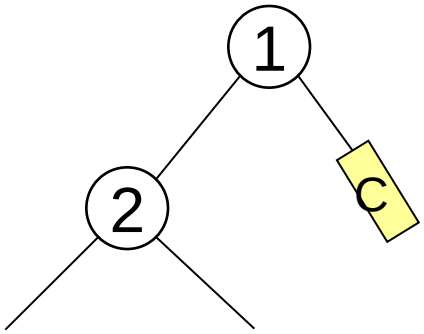

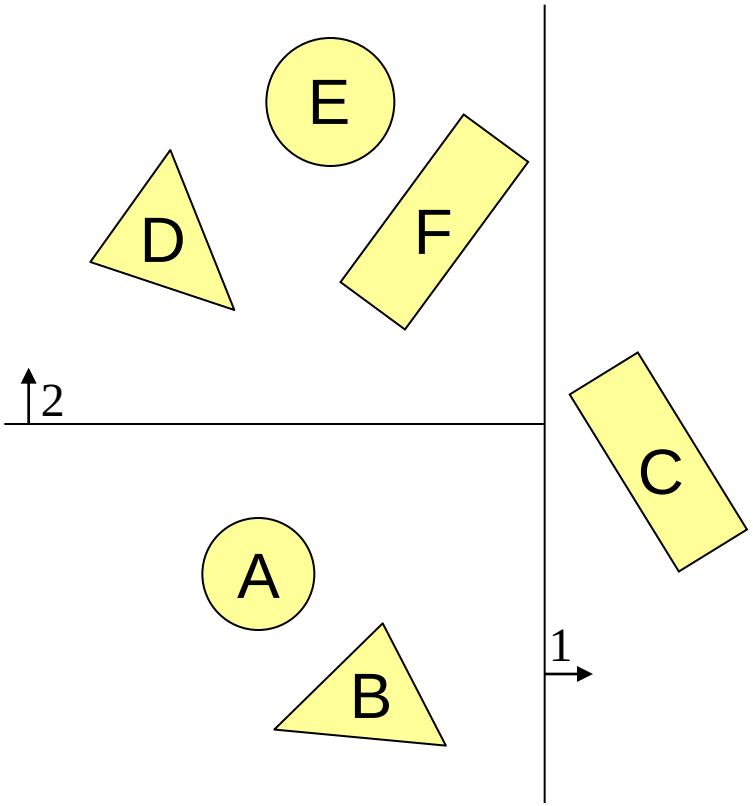

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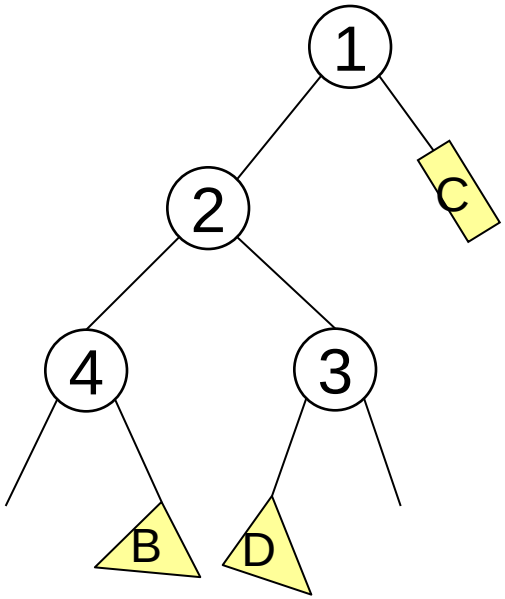

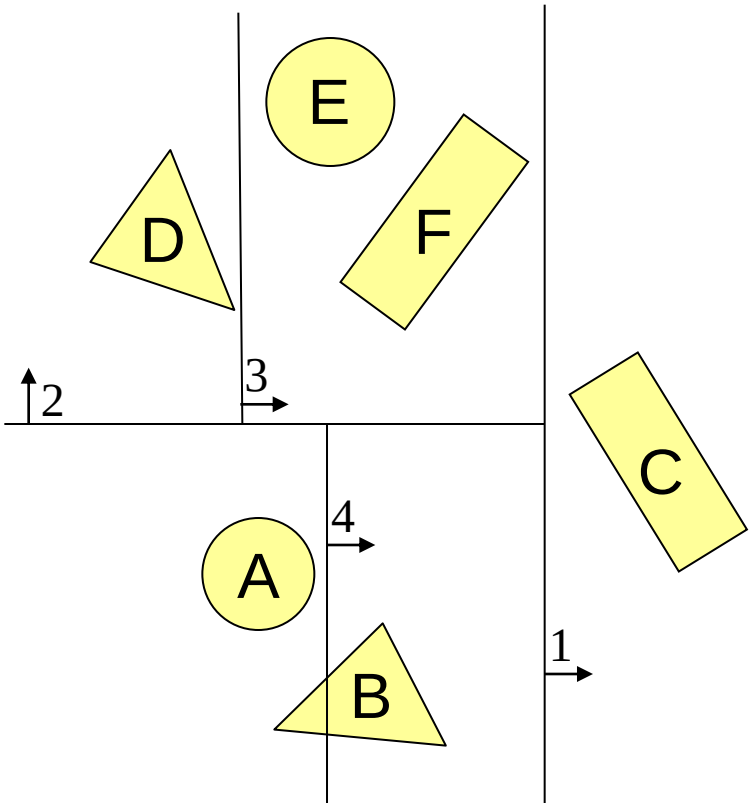

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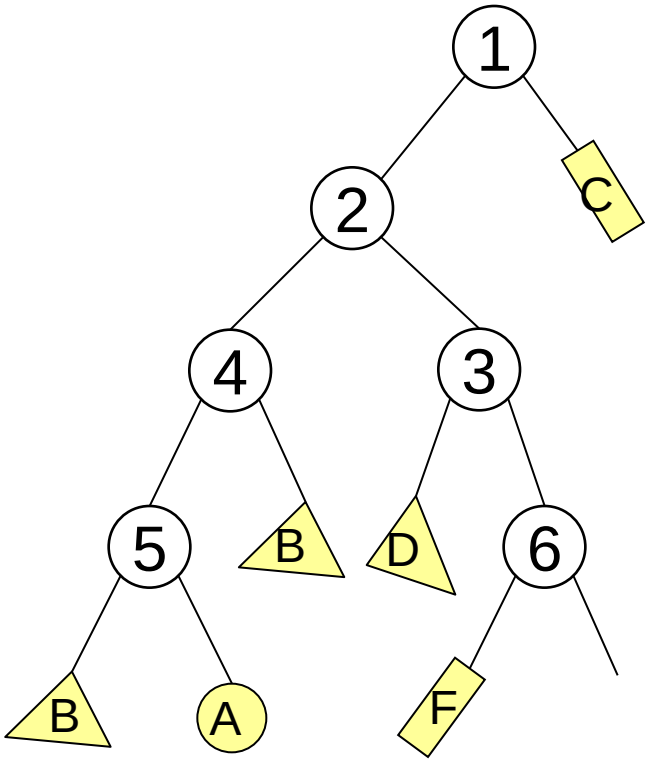

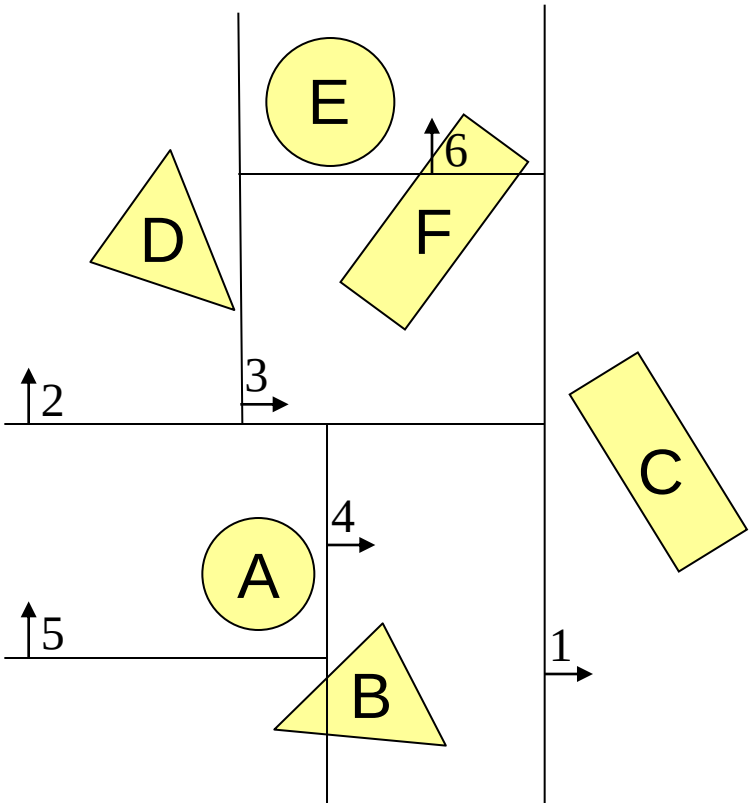

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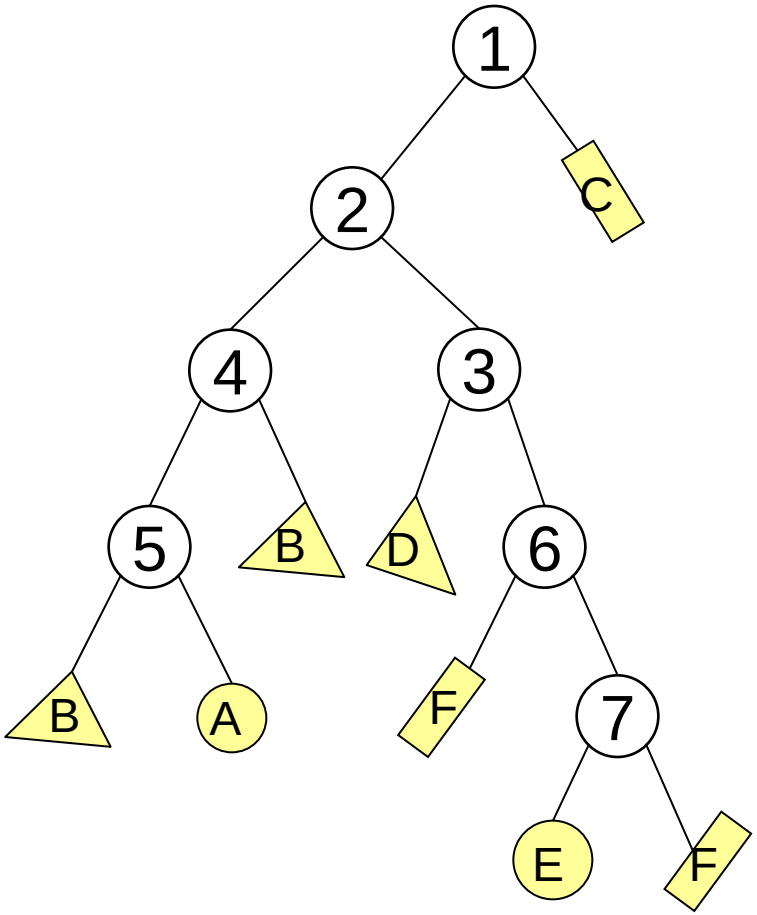

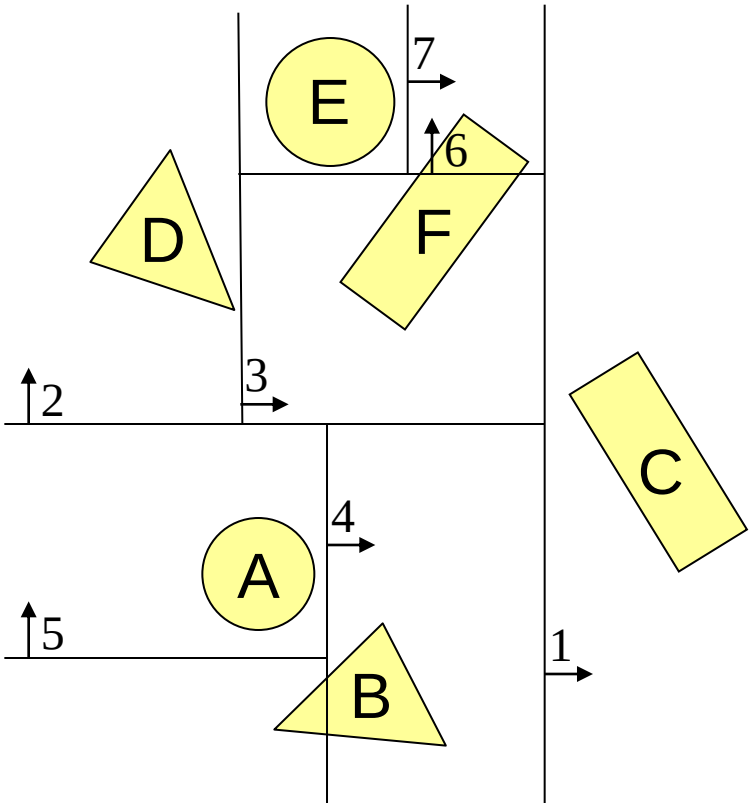

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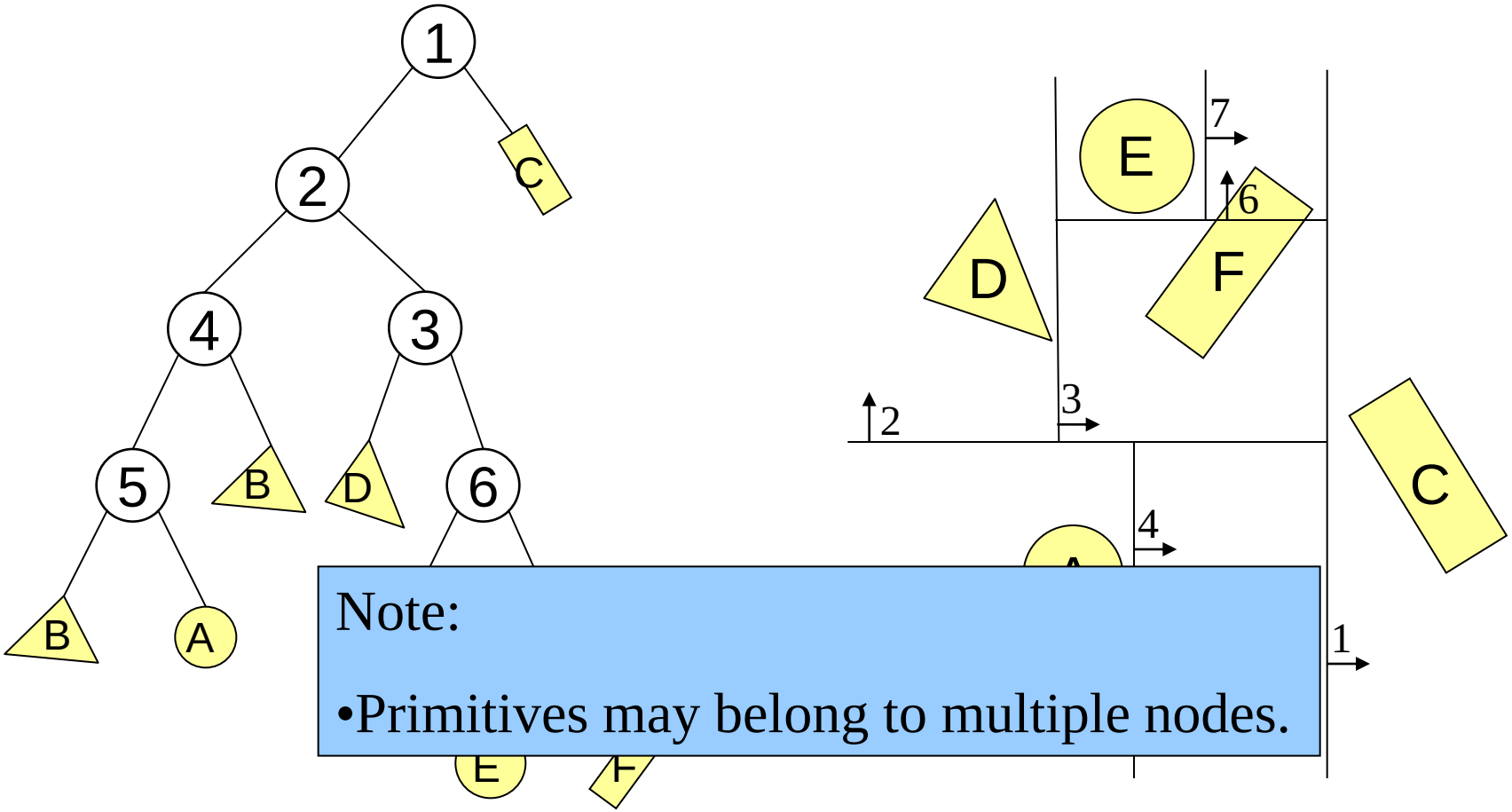


Note:

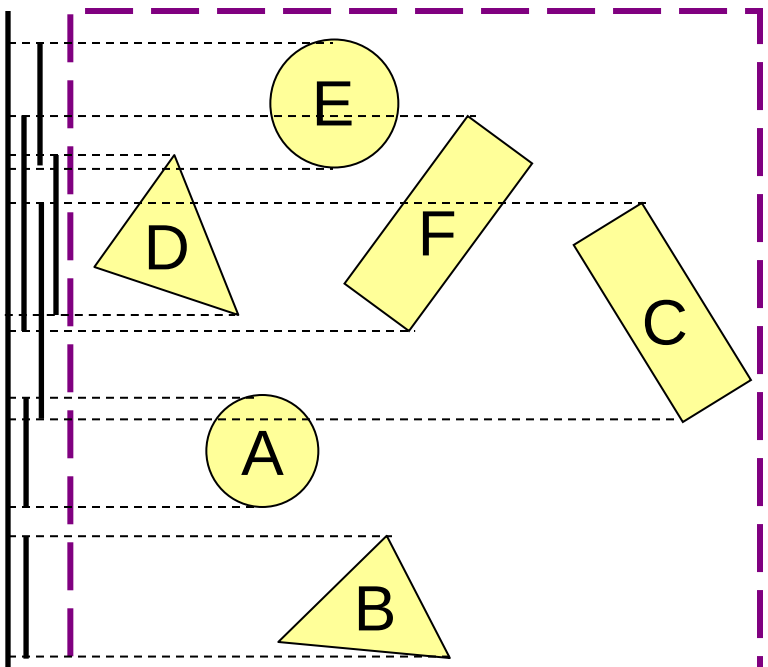
•Primitives may belong to multiple nodes.

Minimum Area Heuristic

$$\min\left(c_{\text{isect}} N, c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)\right)$$

<u>Challenge 2</u>:

How do you choose a partition location?



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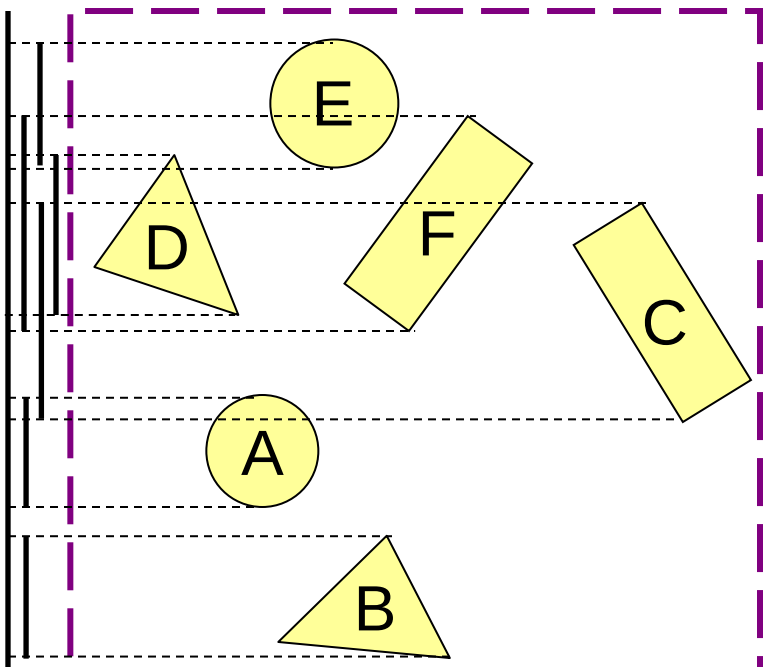
How do you choose a partition location?

Look at the end-points of the projection of the bounding boxes on the axes.



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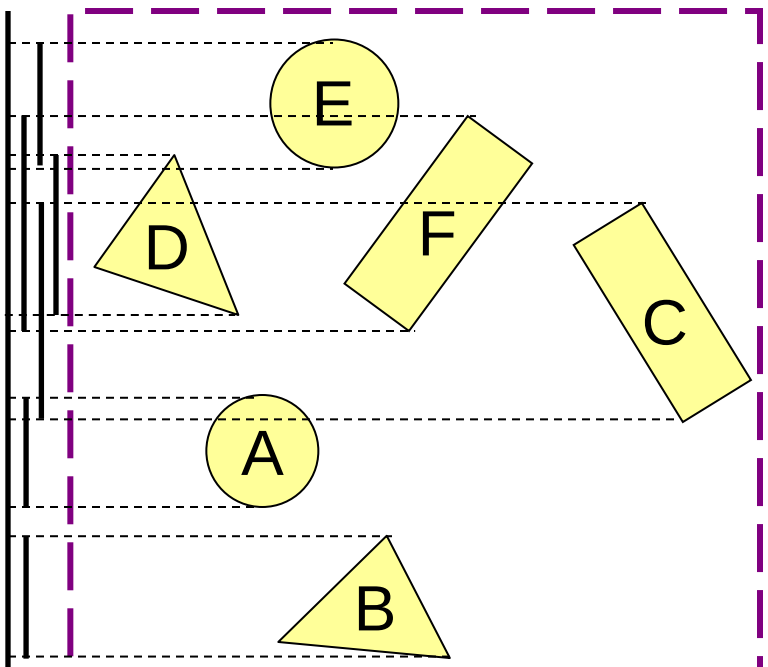
Choose the partition that minimizes the cost.



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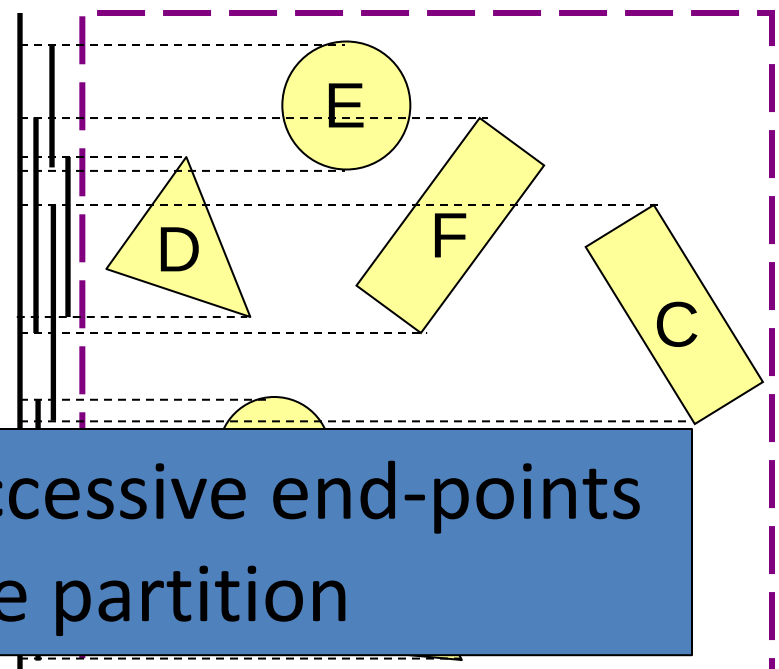

All splits between successive end-points give the same partition

Minimum Area Heuristic

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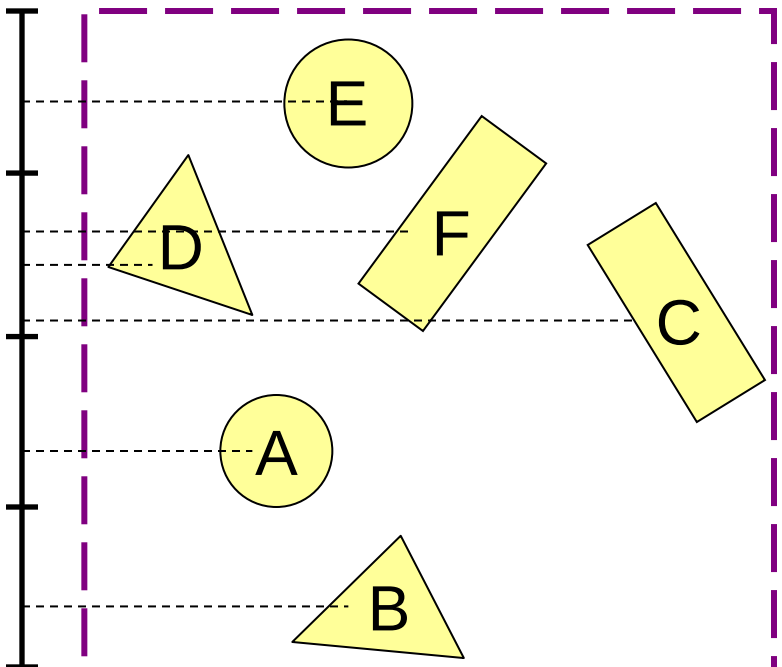
How do you choose a partition location?

For efficiency, generate *k* buckets and only consider partitioning on bucket boundaries.

Choose the partition that minimizes the cost.



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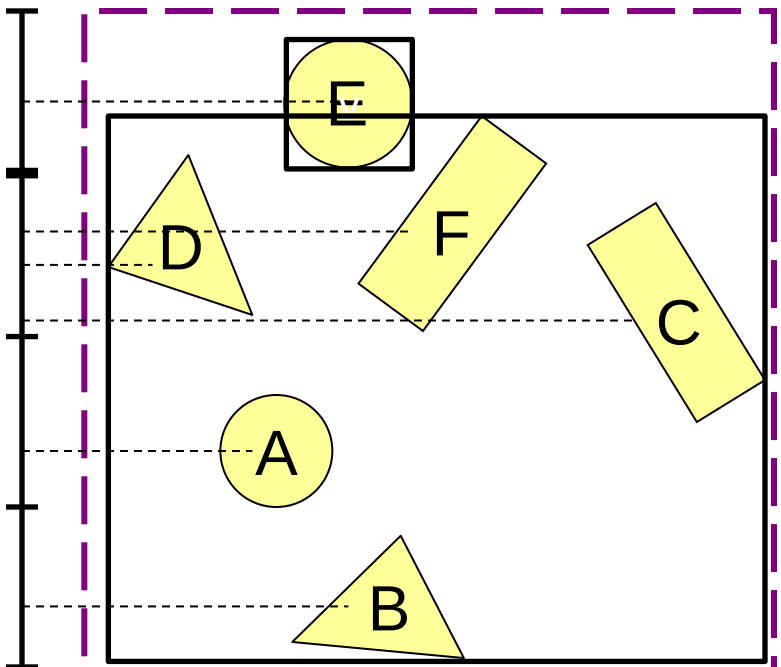

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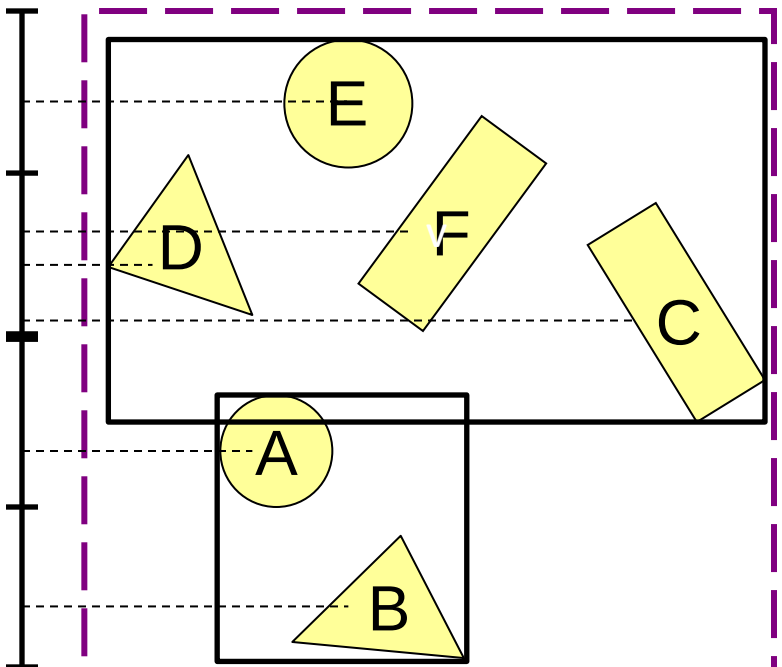

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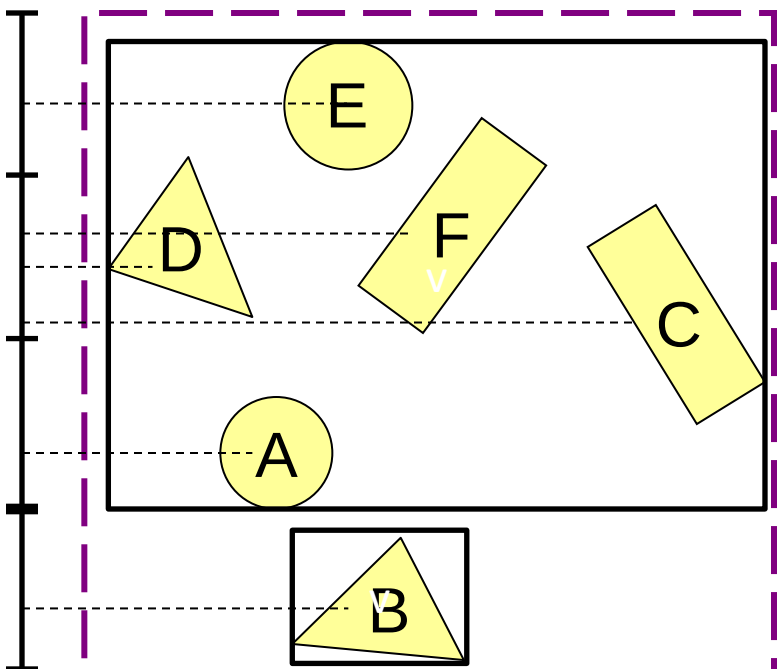

Minimum Area Heuristic

<u>Note</u>:

In contrast to bounding volumes, it may make sense to create kd-tree nodes with no primitives (to cull out large empty space):

$$\min\left(c_{\text{isect}} N, c_{\text{trav}} + c_{\text{isect}}\left(p_A N_A + p_B N_B\right)\right)$$

$$\Downarrow$$

$$\min\left(c_{\text{isect}} N, c_{\text{trav}} + c_{\text{isect}}(1-\beta)\left(p_A N_A + p_B N_B\right)\right)$$

with $0 \leq \beta \leq 1$ and $\beta = 0$ if $N_A, N_B \neq N$