# Computer Graphics

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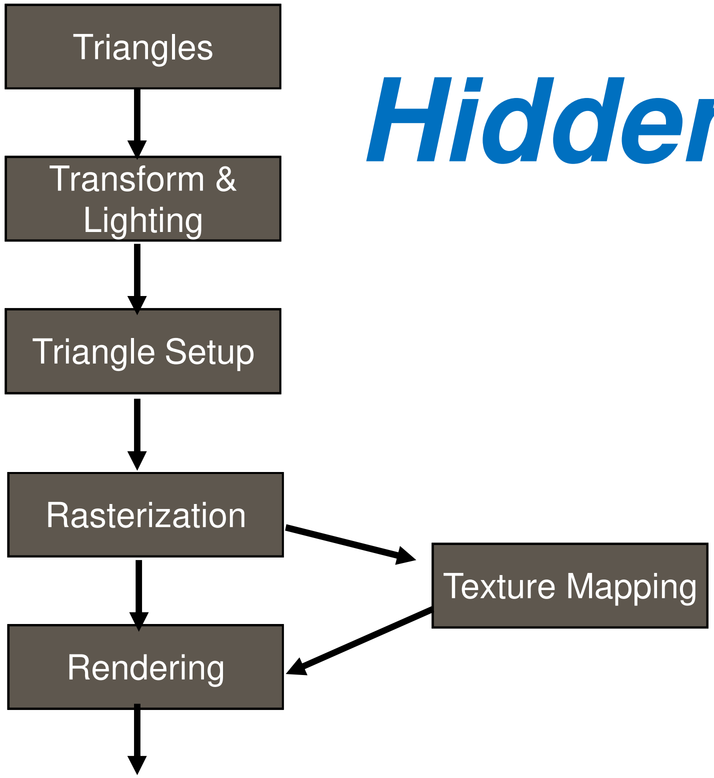
ICL/ITRI

# *Wrap up from last week*

- Color Model
- Lighting Equation
  - Illumination Model
    - Ambient
    - Diffuse
    - Specular

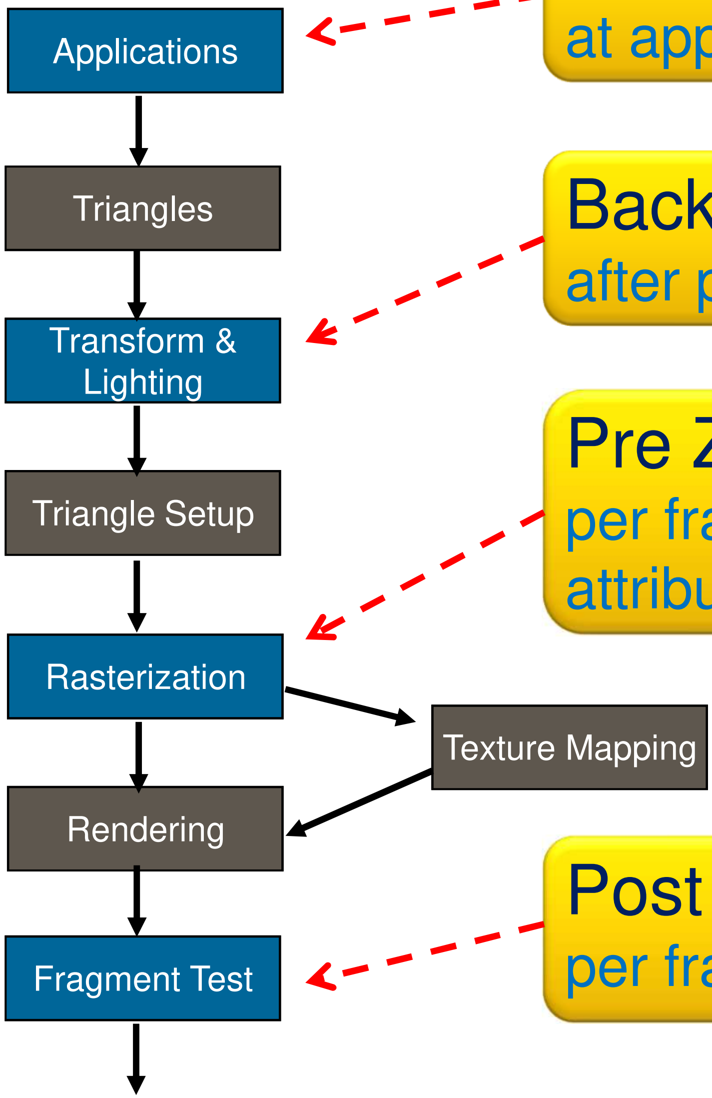
# Part I:
# Conventional 3D Graphics Pipeline




## Hidden Surface Removal (HSR)

***Remove hidden pixels / primitives***

# HSR at Different Stages




Conventional 3D Graphics Pipeline

**BSP Tree, Portal Culling**
at application

**Back-face culling**
after perspective normalization transform

**Pre Z-test (Z-buffering)**
per fragment (pixel) depth test before other attributes being rasterized

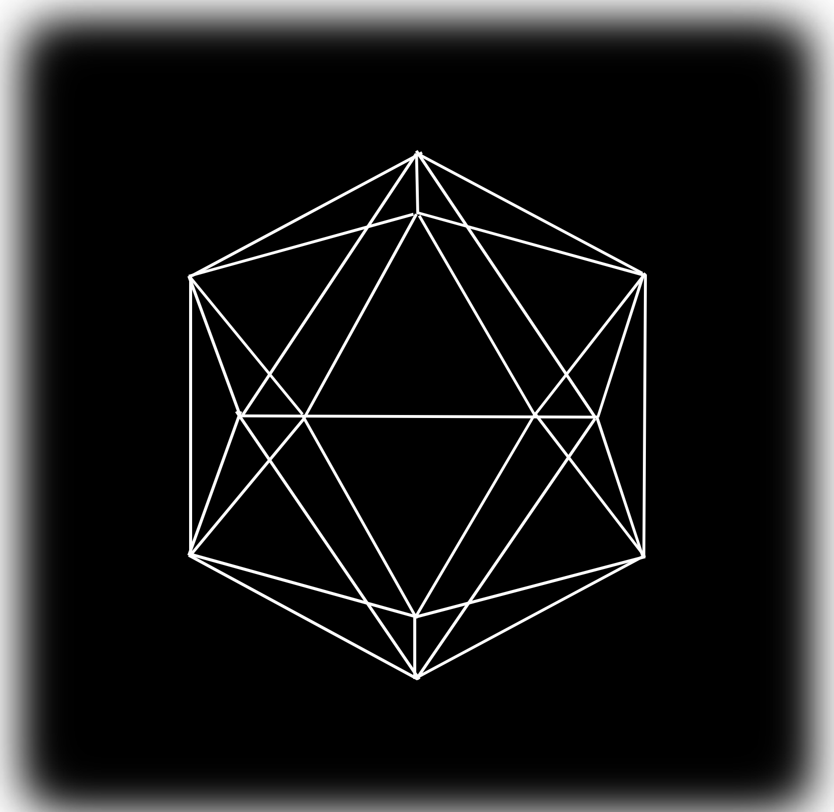
**Post Z-test (Z-buffering)**
per fragment (pixel) depth test after rendering

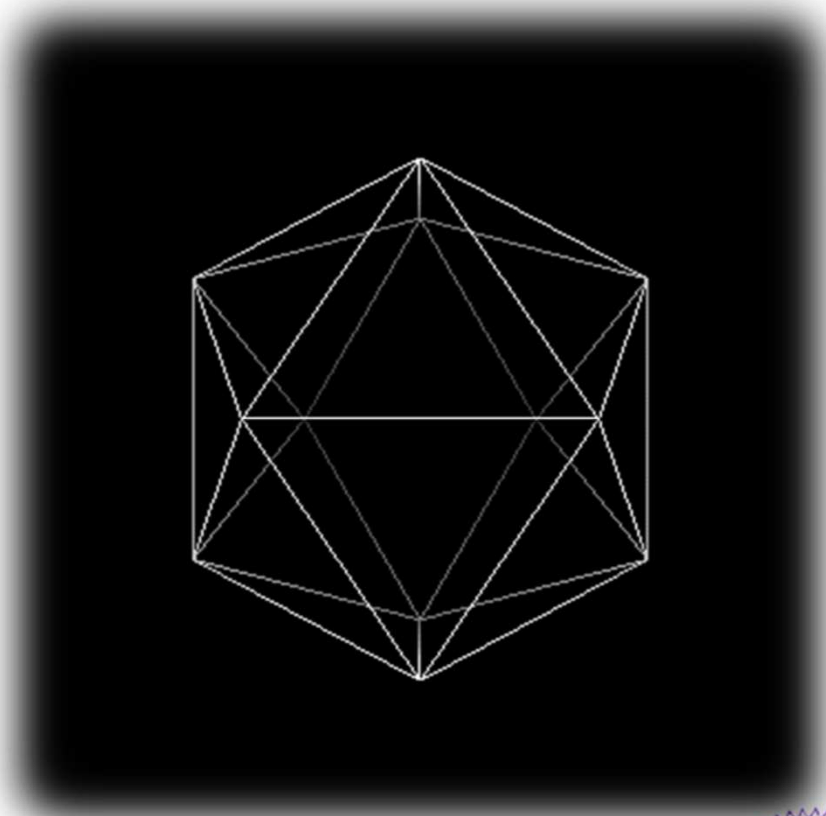
# Objectives of HSR

- Remove objects, surfaces, or pixels that are not visible
  - Clipping remove objects/surfaces that are outside the view volume
  - HSR applies on spatial relationship, especially the hidden relationship, between objects with respect to the viewing direction
- Improve performance by reducing the computation of invisible surfaces / pixels
- Perception of spatial occlusion

# Depth Cue

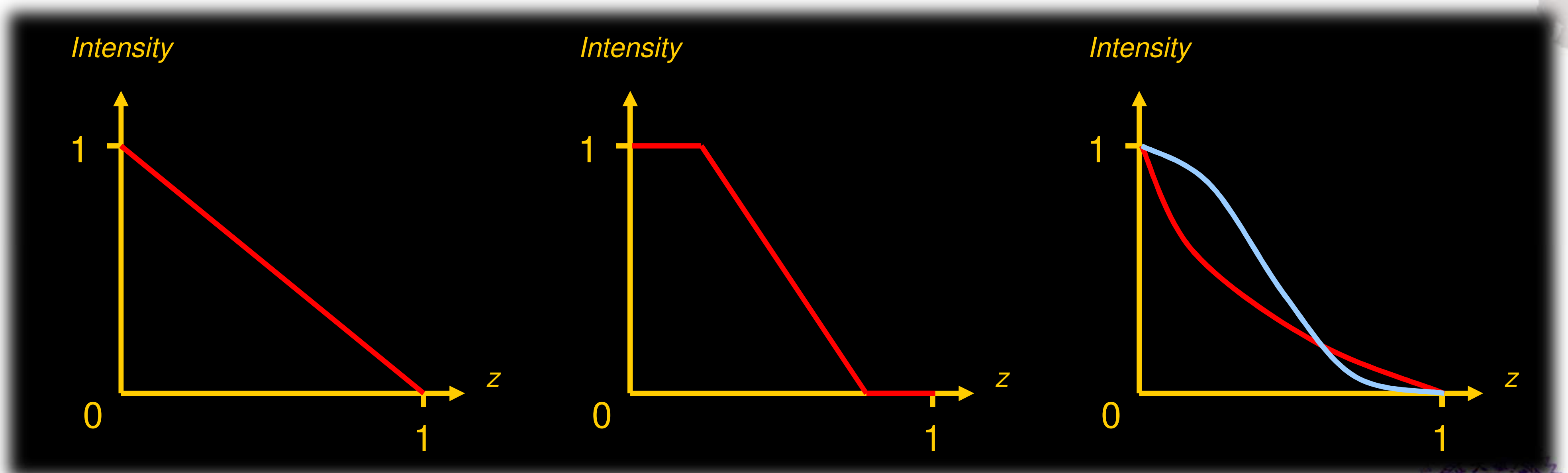
- **Wireframe Display**





# Depth Cue

- **Implementation**
  - **e.g., $Intensity = f(z) = 1/z,\ 0 \le z \le 1$**
  - **Map the intensity values within the range of [0, 255]**

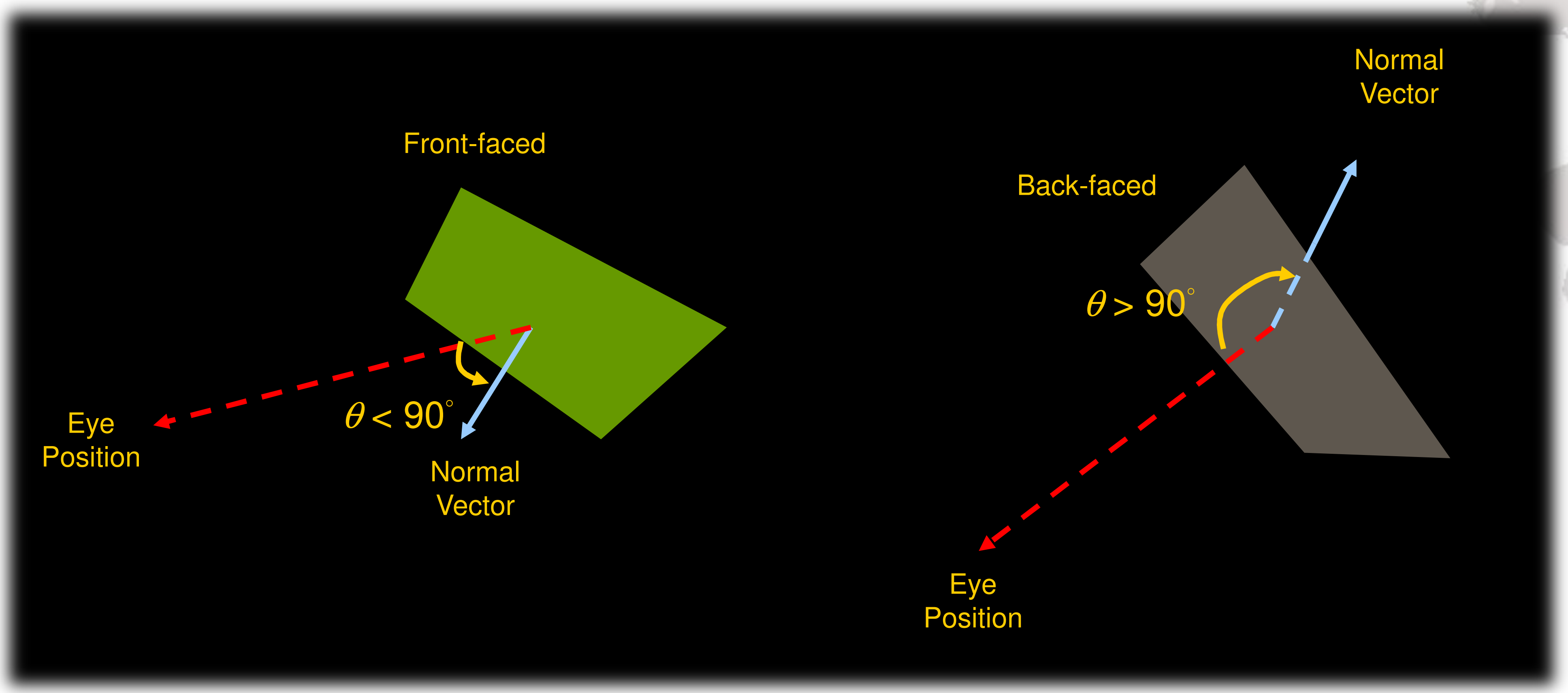


# HSR at Primitive Stage

***Back-face Culling***

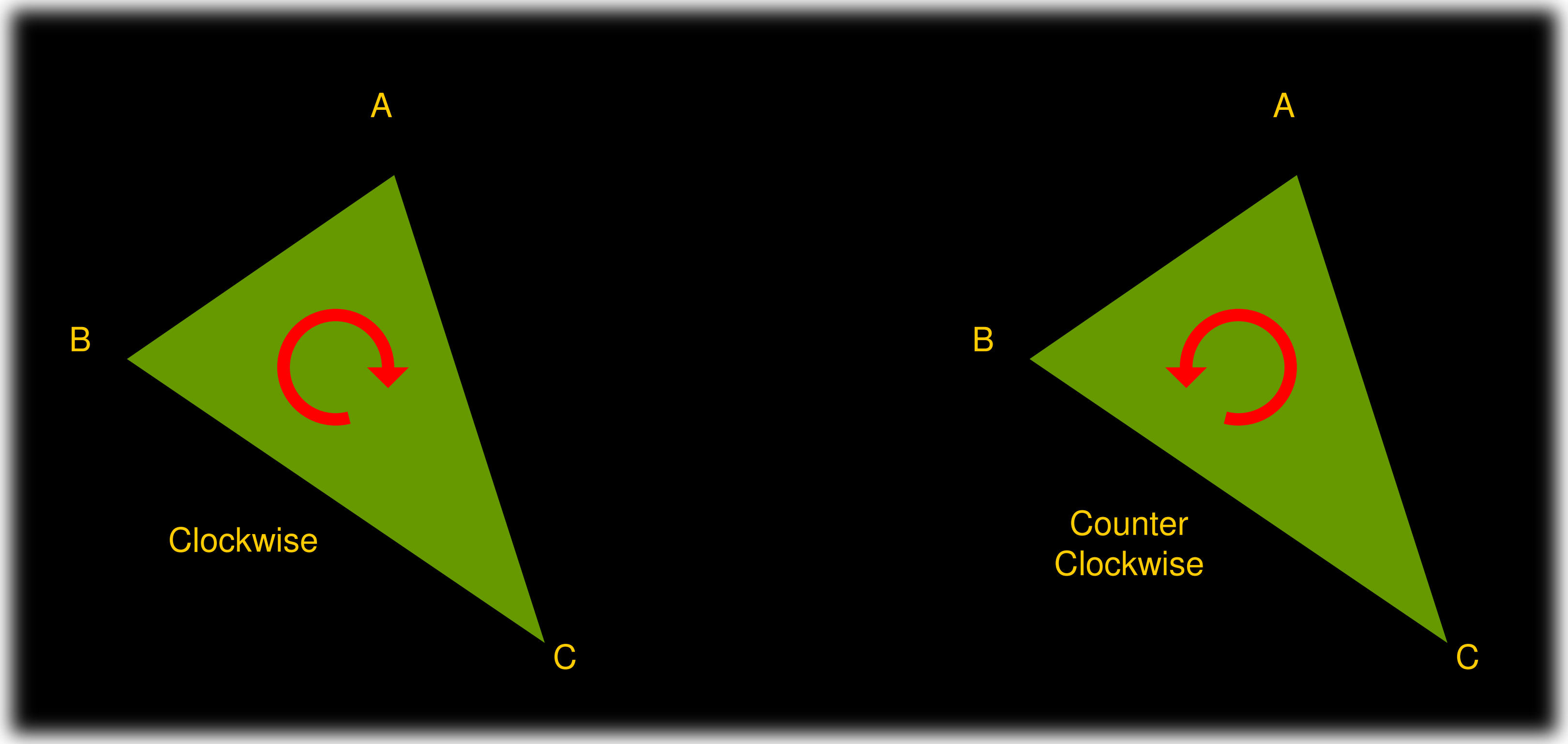
# Back-Face Culling

- **Back-face determination**



# Back-Face Culling

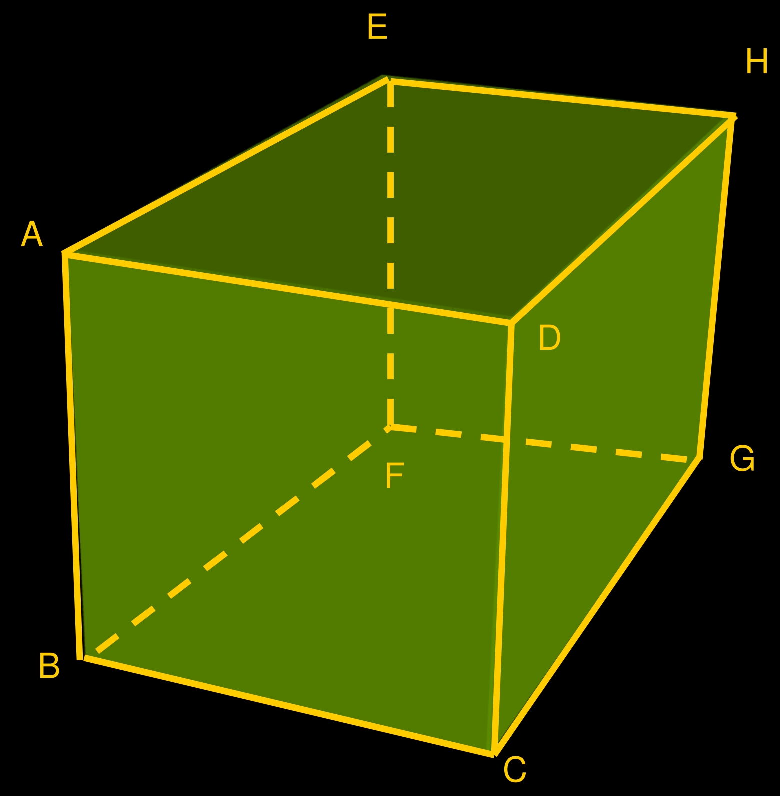
- Define clockwise or counter clockwise for front-faced polygon



# Back-Face Culling

- **Assume the counter clockwise polygon is the front-faced polygon**

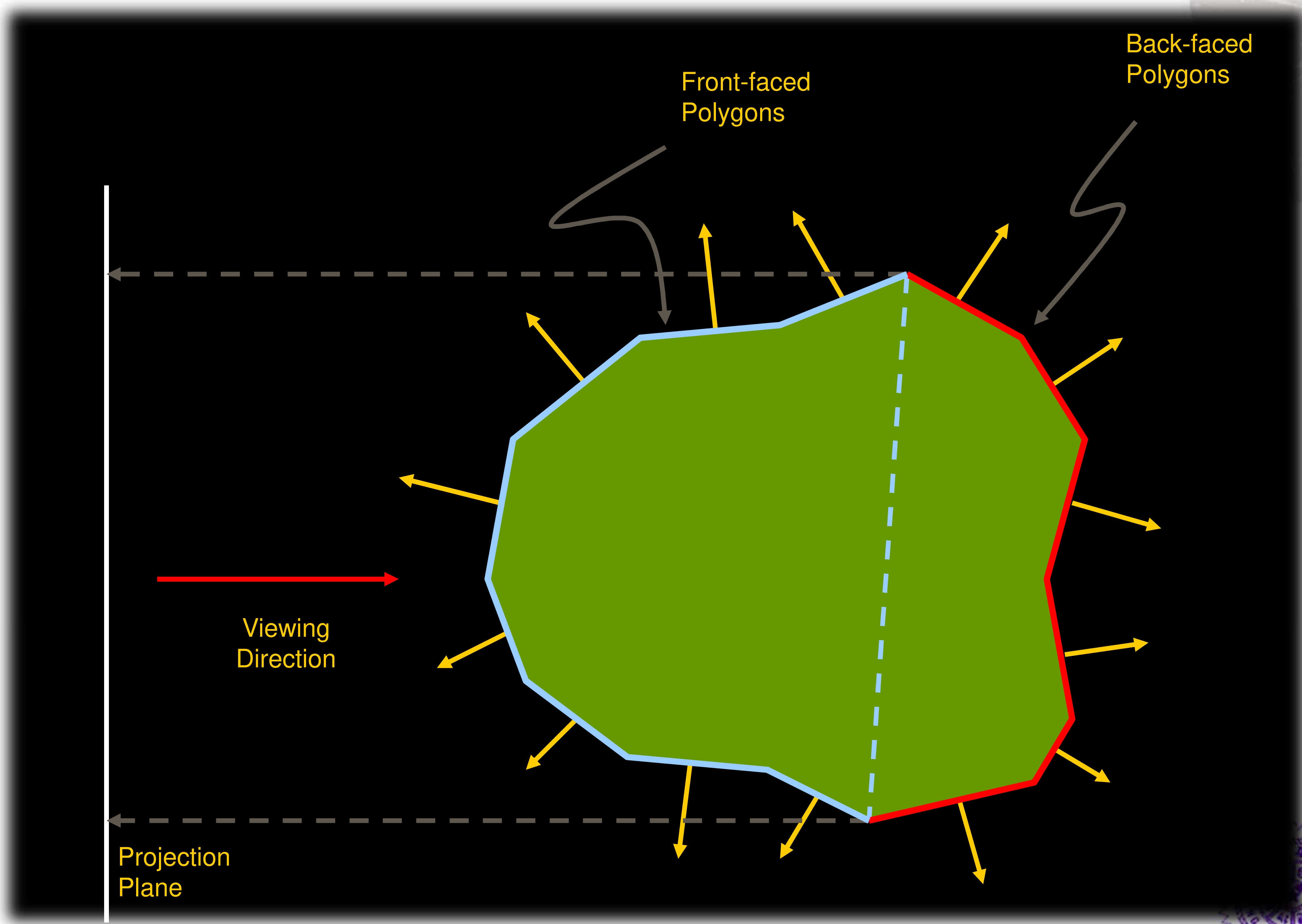
| | |
|---|---|
| Polygon(A, B, C, D) | Front-faced |
| Polygon(D, C, G, H) | Front-faced |
| Polygon(H, G, F, E) | Back-faced |
| Polygon(E, F, B, A) | Back-faced |
| Polygon(A, D, H, E) | Front-faced |
| Polygon(F, G, C, B) | Back-faced |



# Back-Face Culling

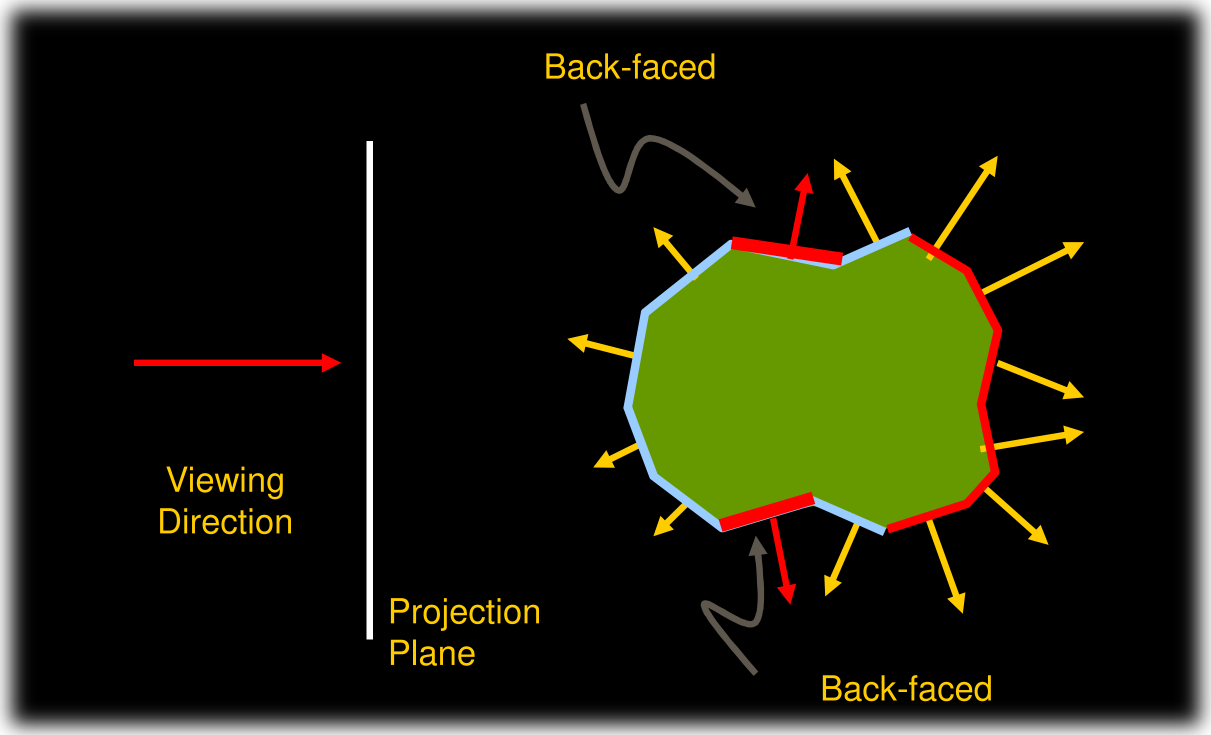
- Apply cross product to determine the normal vector of a polygon
- A dot product of the eye vector and the normal vector determines the facing attribute (assuming counter-clockwise is the vertex order of a front-faced polygon)
  - $N \cdot E > 0$ implies front-facing
  - $N \cdot E < 0$ implies back-facing
- ps. if clockwise is defined to be the front-faced then $N = -N$ before applying dot product

# Back-Face Culling



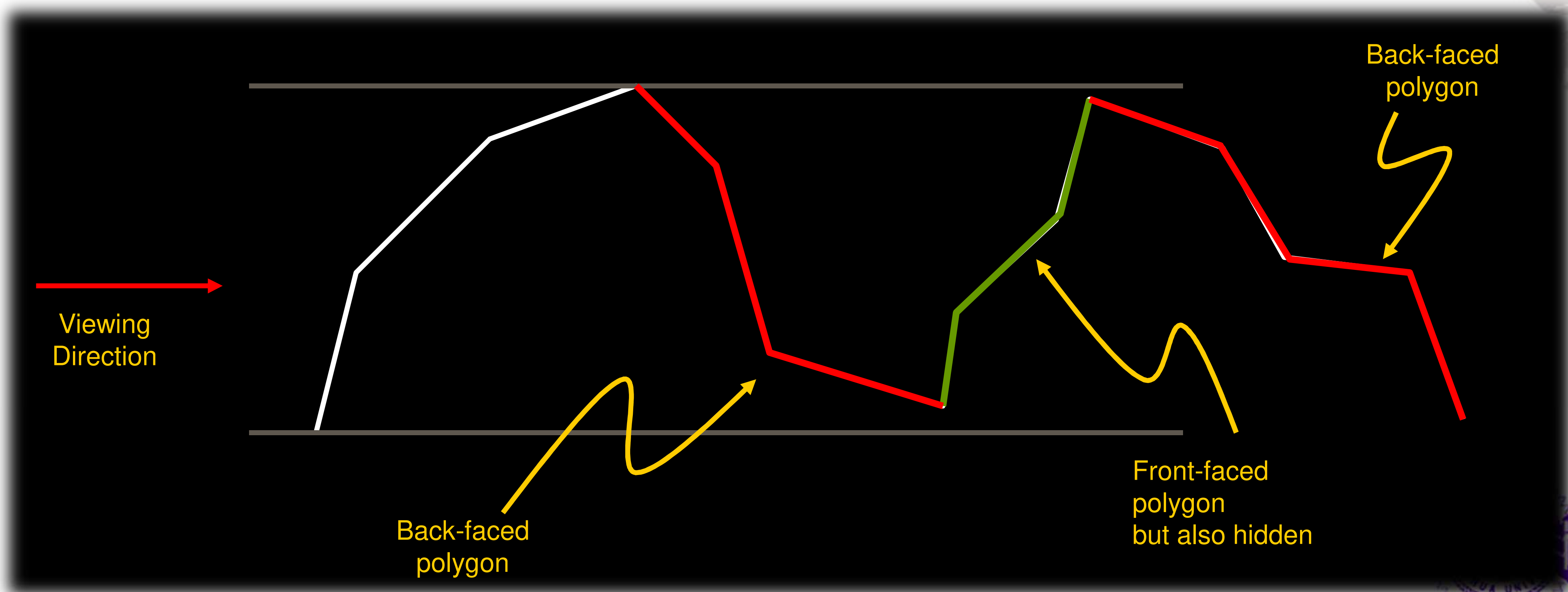
# Back-Face Culling

- Why consider parallel projection only?
  - After perspective normalization, the polygon normals will toward the right directions to distinguish front-faced or back-faced polygons



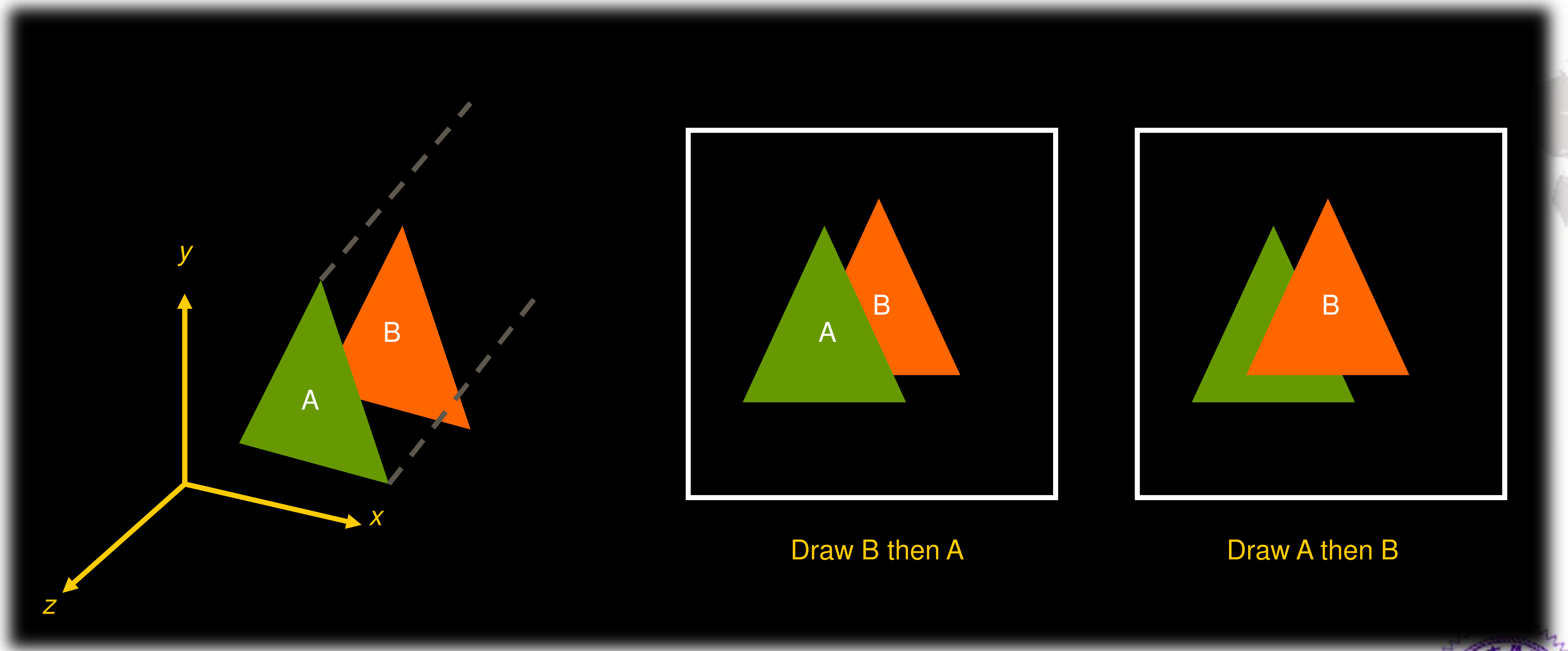
# Back-Face Culling

- **Despite the back-face culling is simple and fast to remove hidden surfaces at primitive stage, but it cannot guarantee to remove all surfaces being hidden.**



# Display Order

- **The display order might derive in different results if using only back-face culling**



# HSR at Fragment (Pixel) Stage

*Z-buffer Algorithm*

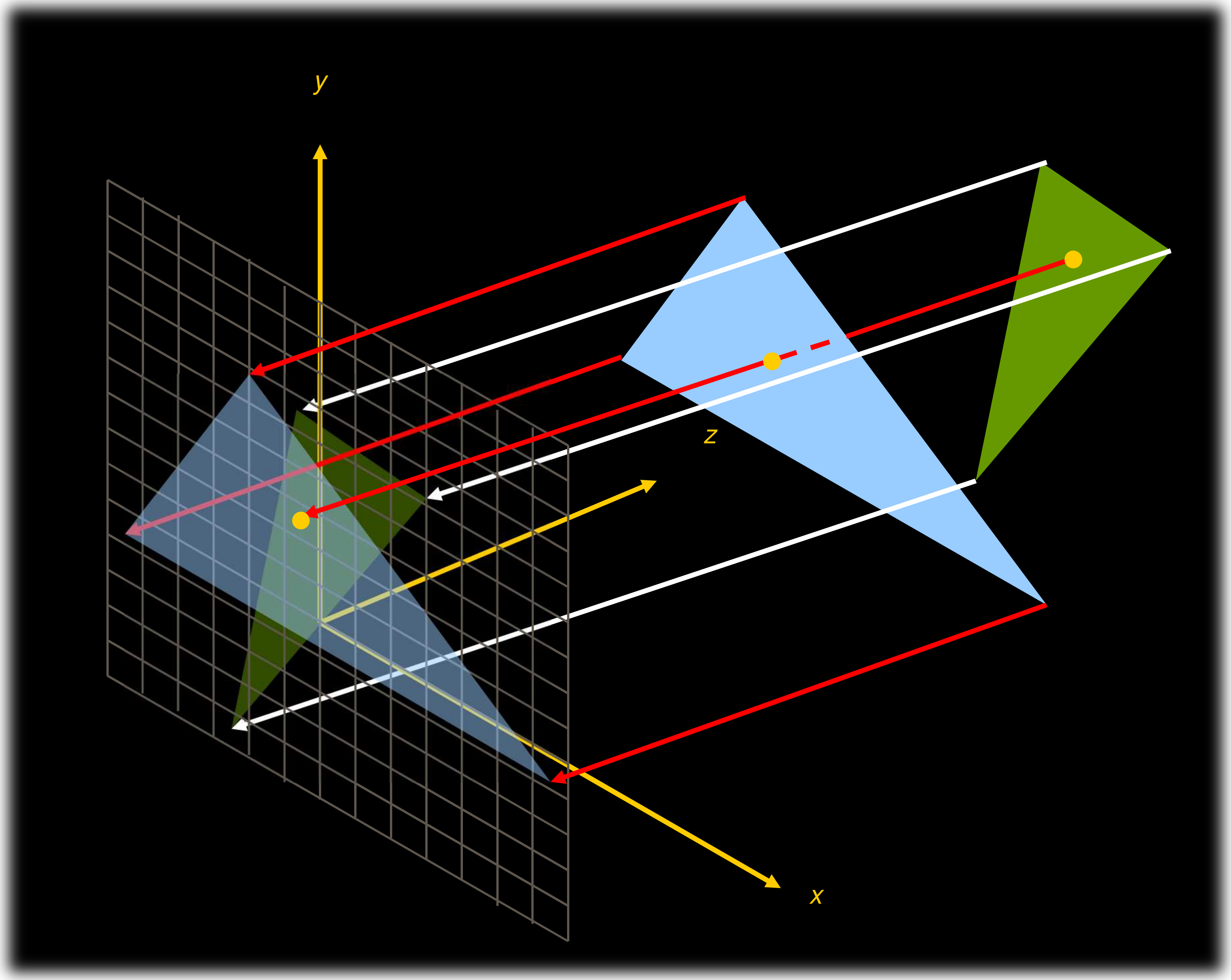
# Z-Buffer Algorithm

- Eliminate the limitation of display order
- Require a memory space, equal to the size of display buffer, to store the depth / Z values
- Comparison is required to determine which pixel is closer to the viewer

# *Z-Buffer Algorithm*

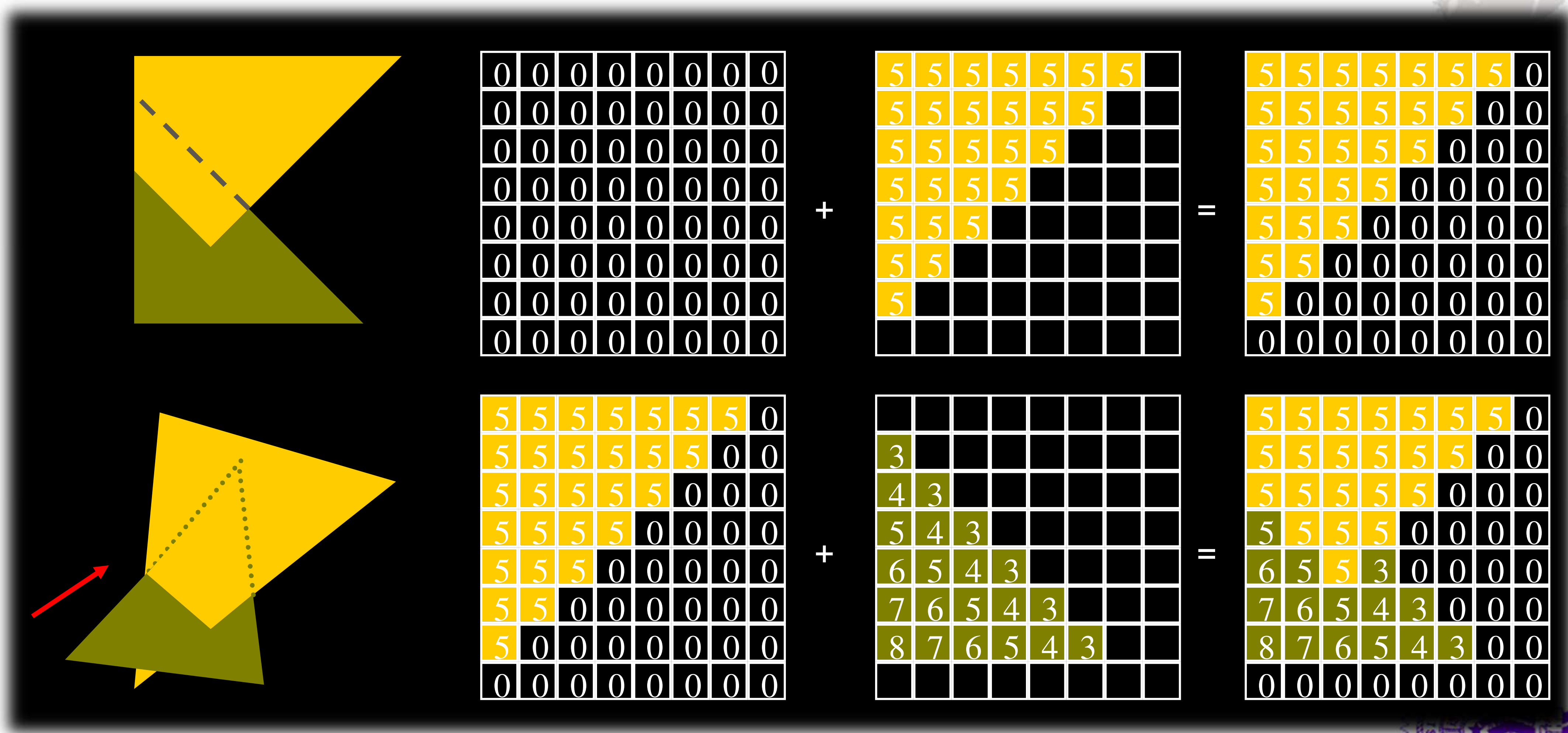
- Basic concept
  - Store the depth value of the closest object at each pixel found so far
- Render each polygon, pixel by pixel
- Compare the depth of each pixel of a polygon with the depth of the corresponding depth value in Z-buffer
- If the comparison pass, then render the color to color buffer and replace the depth value by current pixel depth

# Z-Buffer Algorithm



# Z-Buffer Algorithm

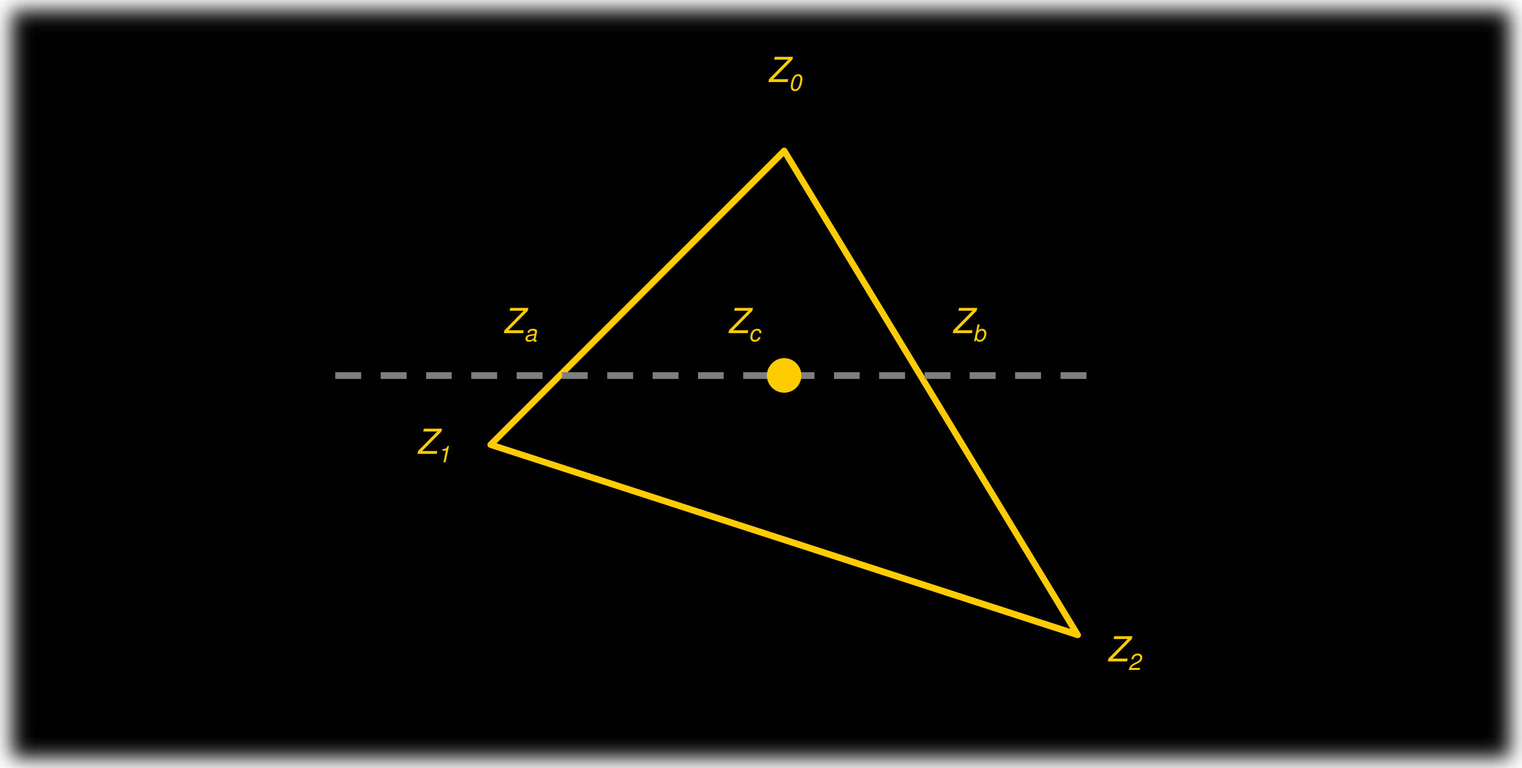
## Example: (larger z value is closer to viewer)



# Choose of Depth Values

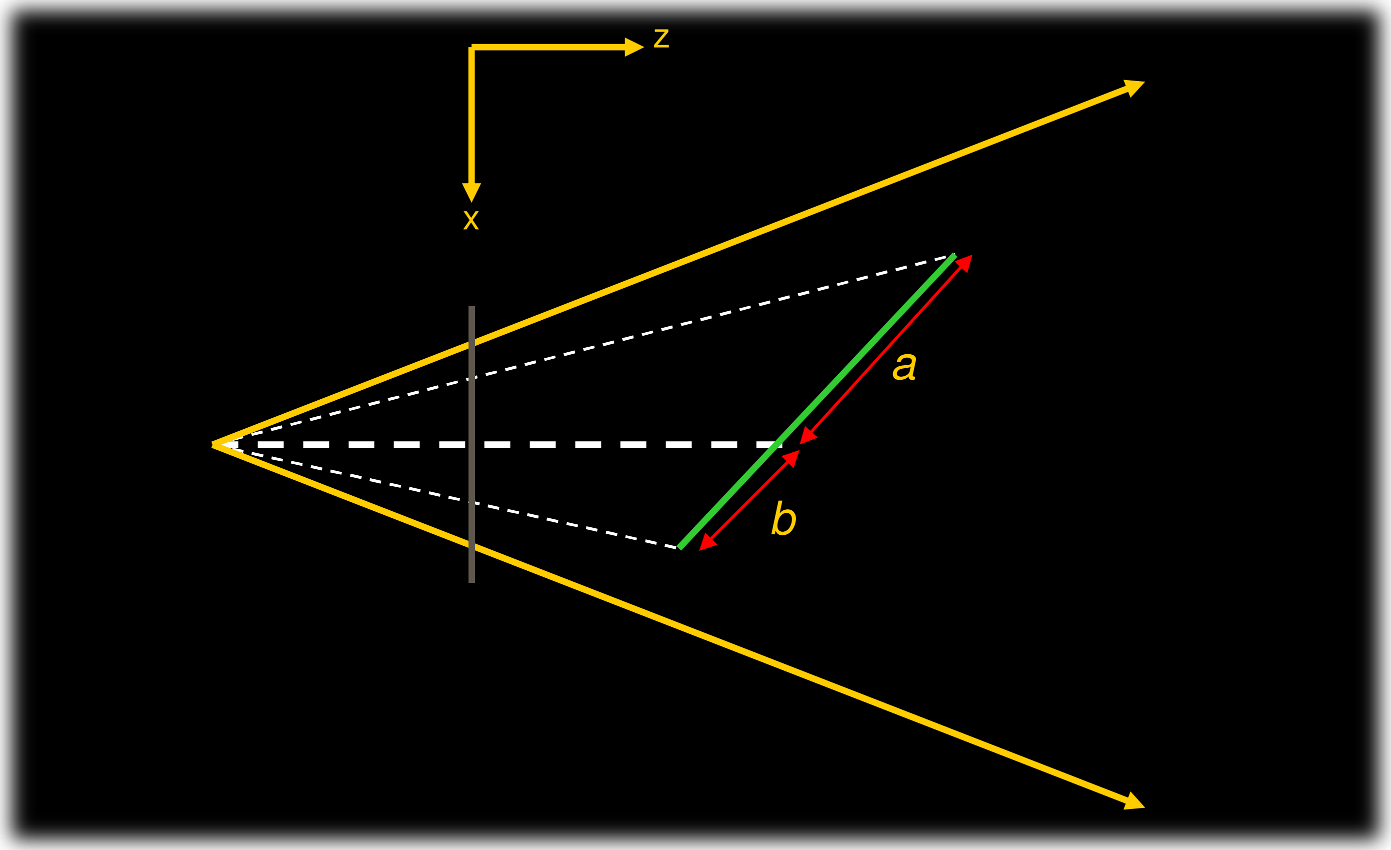
- When Interpolation Z in screen space, which Z values should be used?

  World space Z or clip space Z?



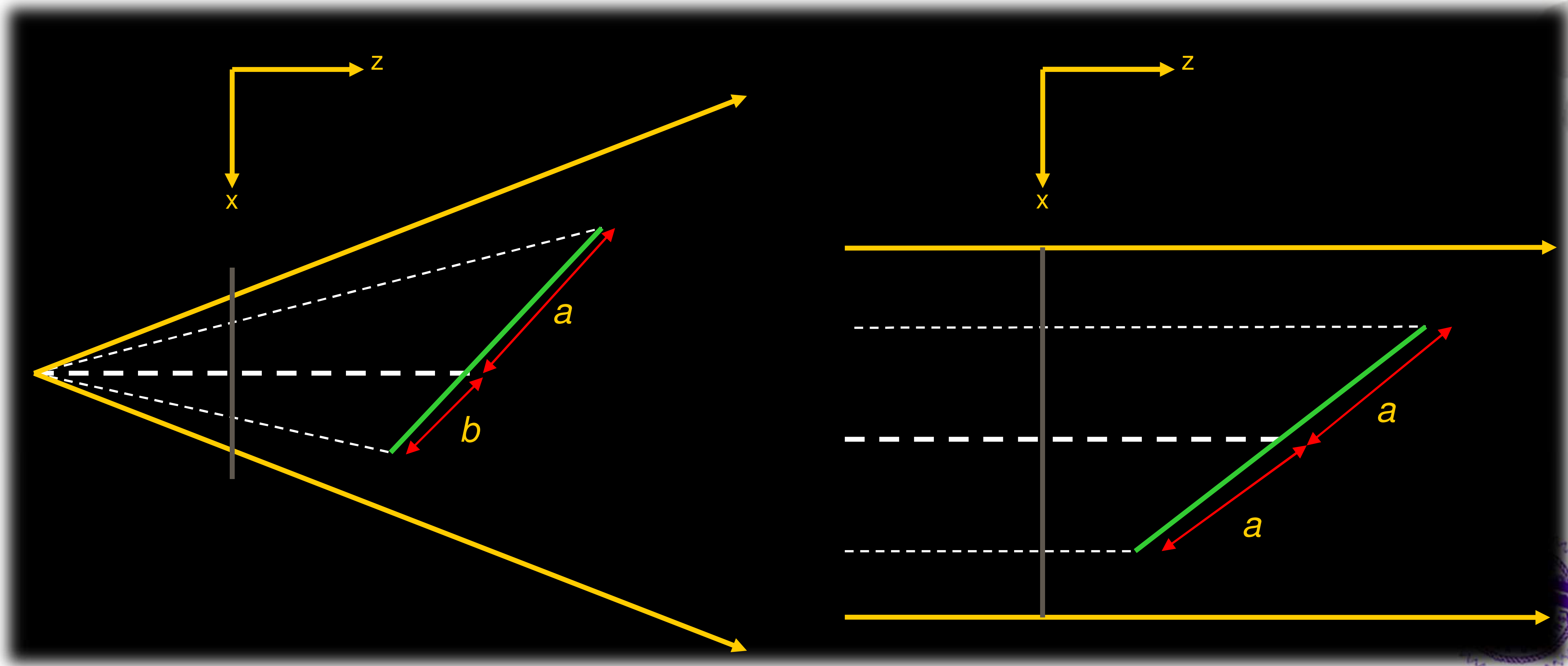
# Choose of Depth Values

- Linear interpolation for depth in screen space does not hold for depth interpolation in world space under perspective view



# Choose of Depth Values

- After perspective transform and normalized into clip space, the depth value can be used to interpolate linearly

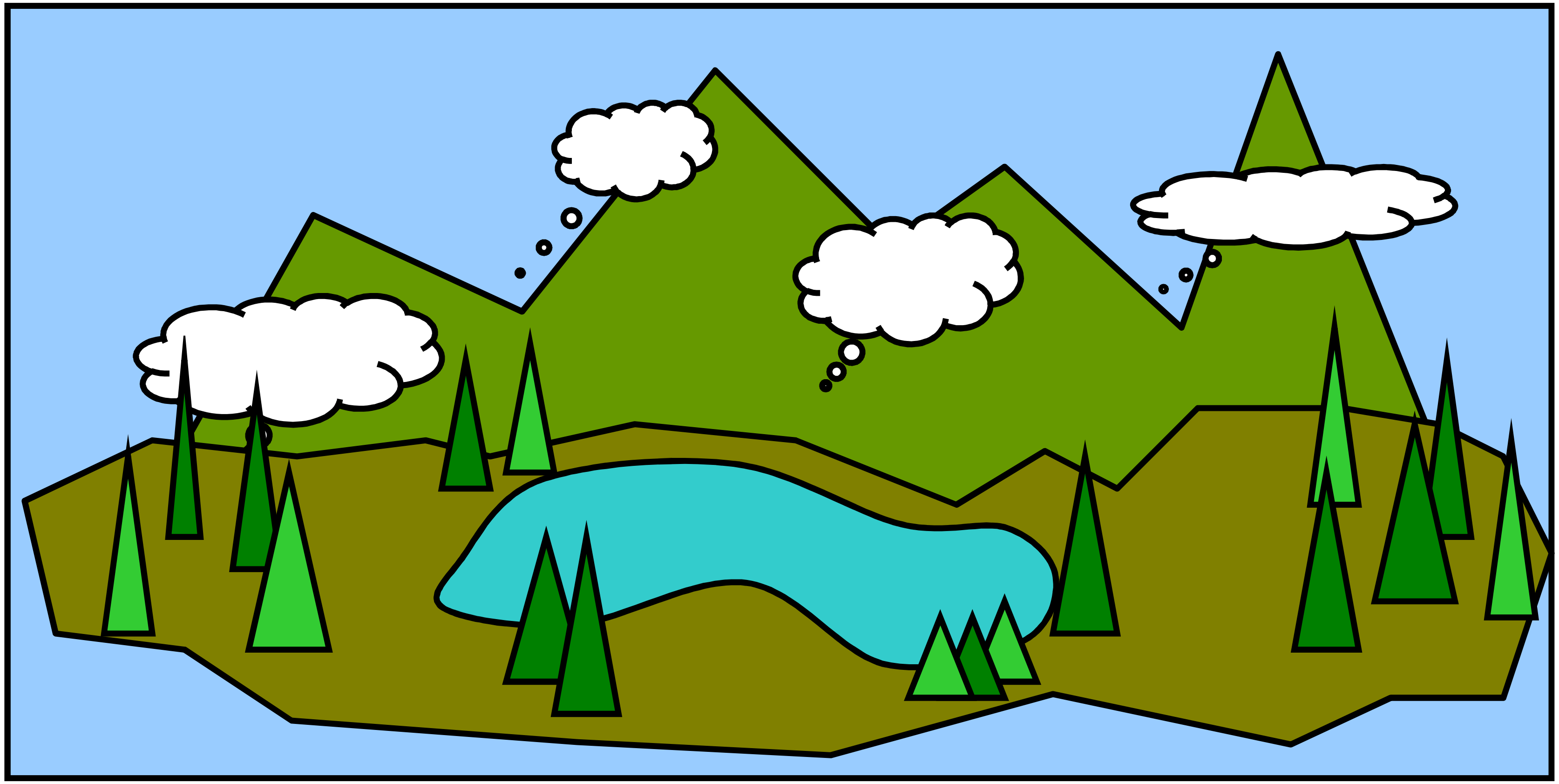


# HSR at Application Stage

**Painter's Algorithm**
**Binary Space Partition (BSP) Tree**
**Portal Culling**

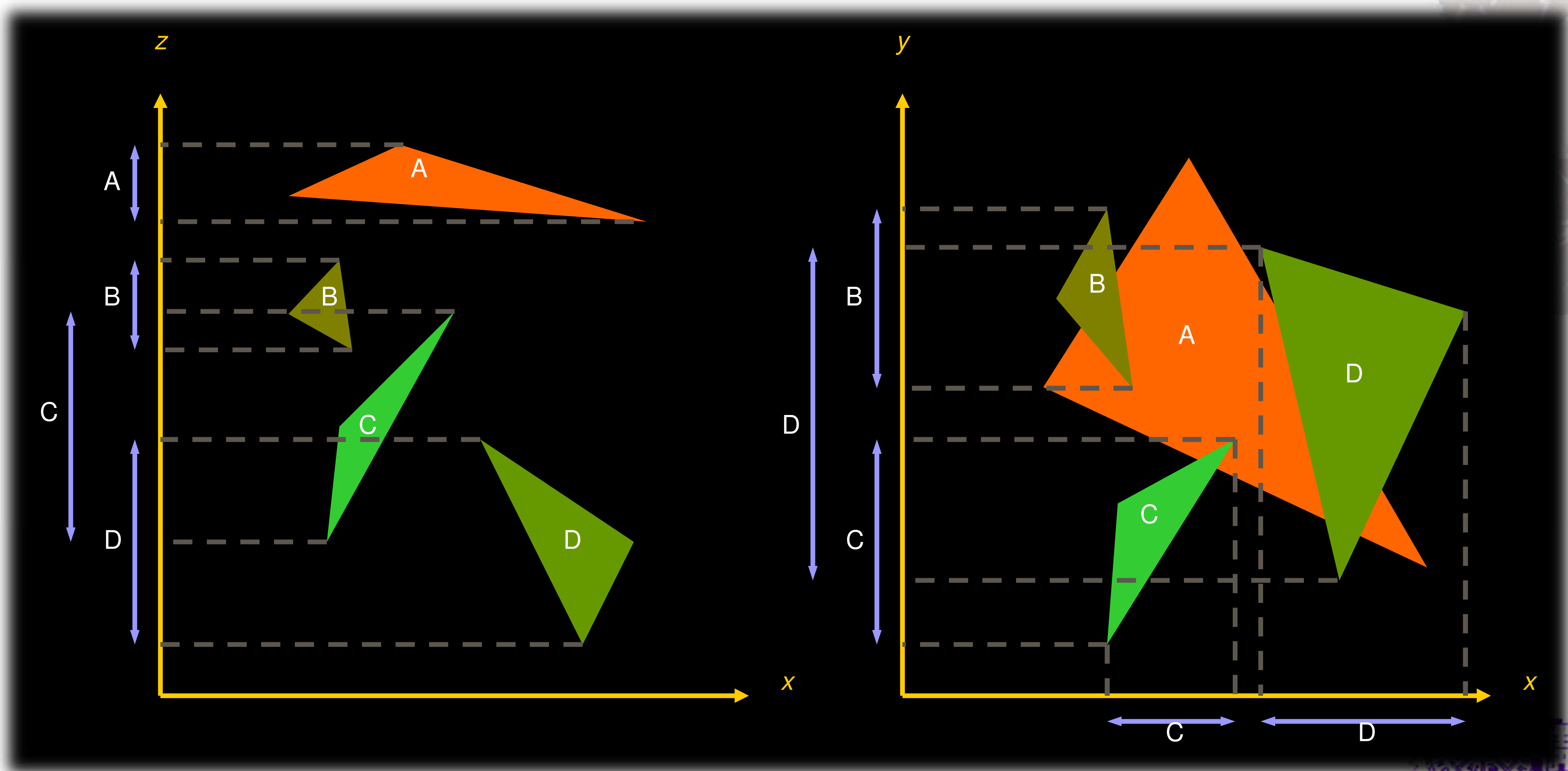
# Painter's Algorithm

- Back-to-Front Rendering



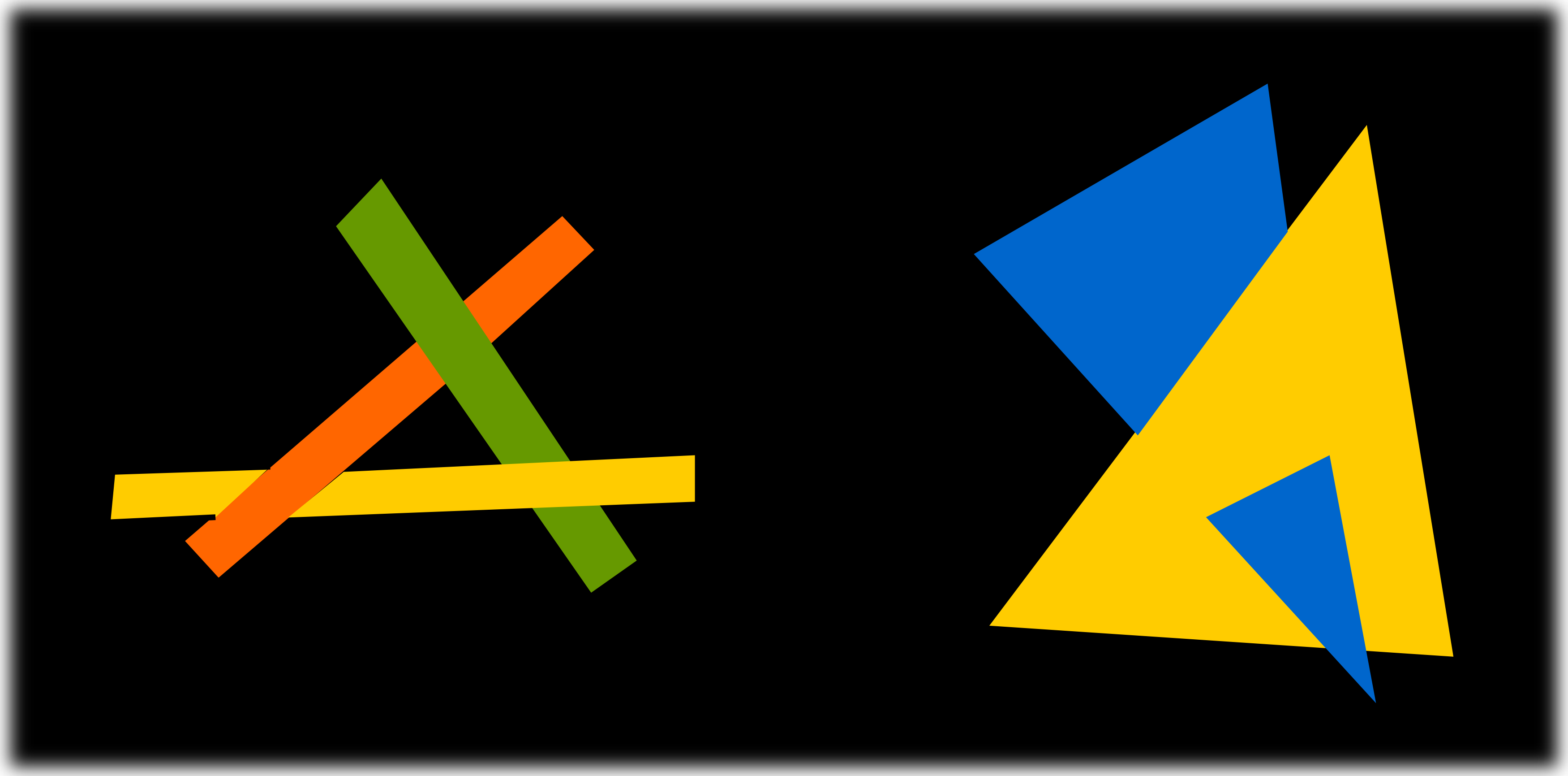
# Depth Sort

- Sort the polygons in depth order



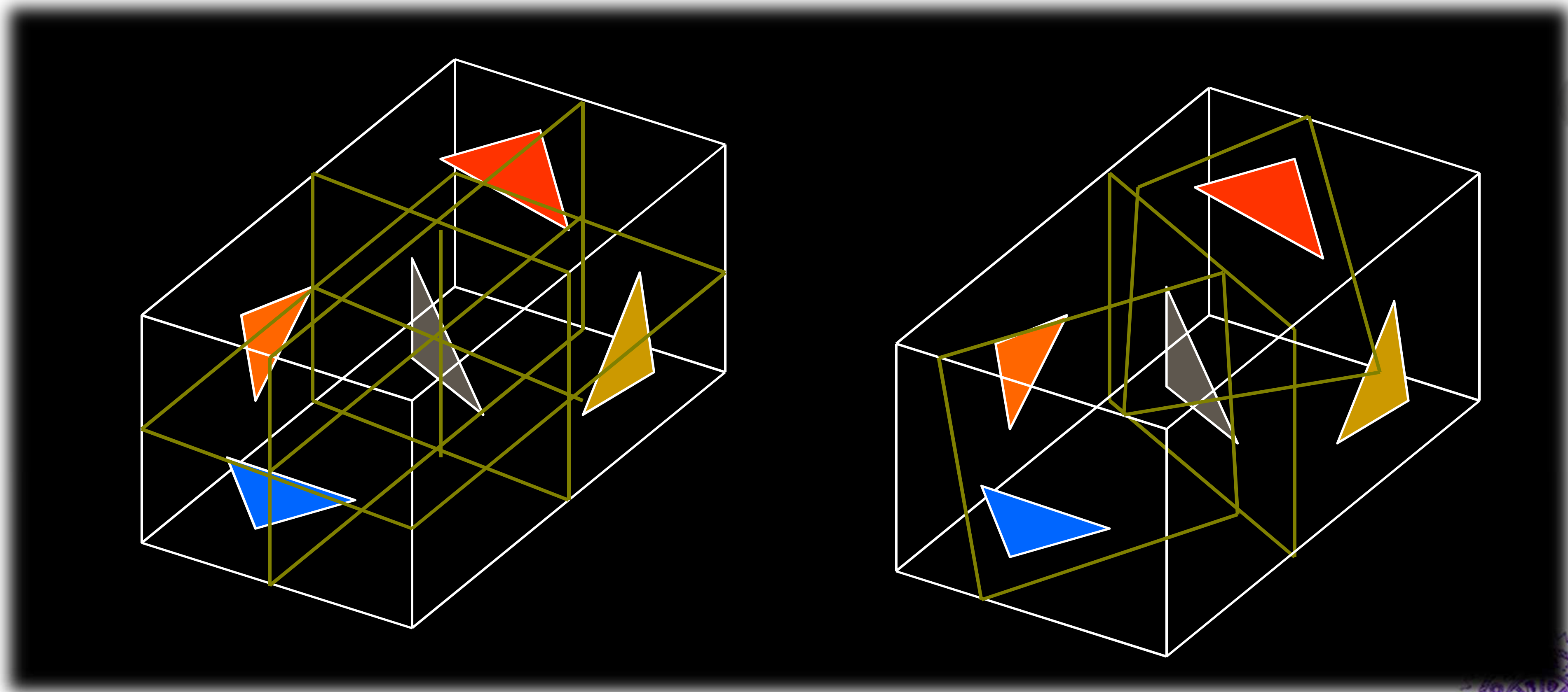
# Difficult Cases

- **Might need further subdivision to make it easy to identify the hidden surface**



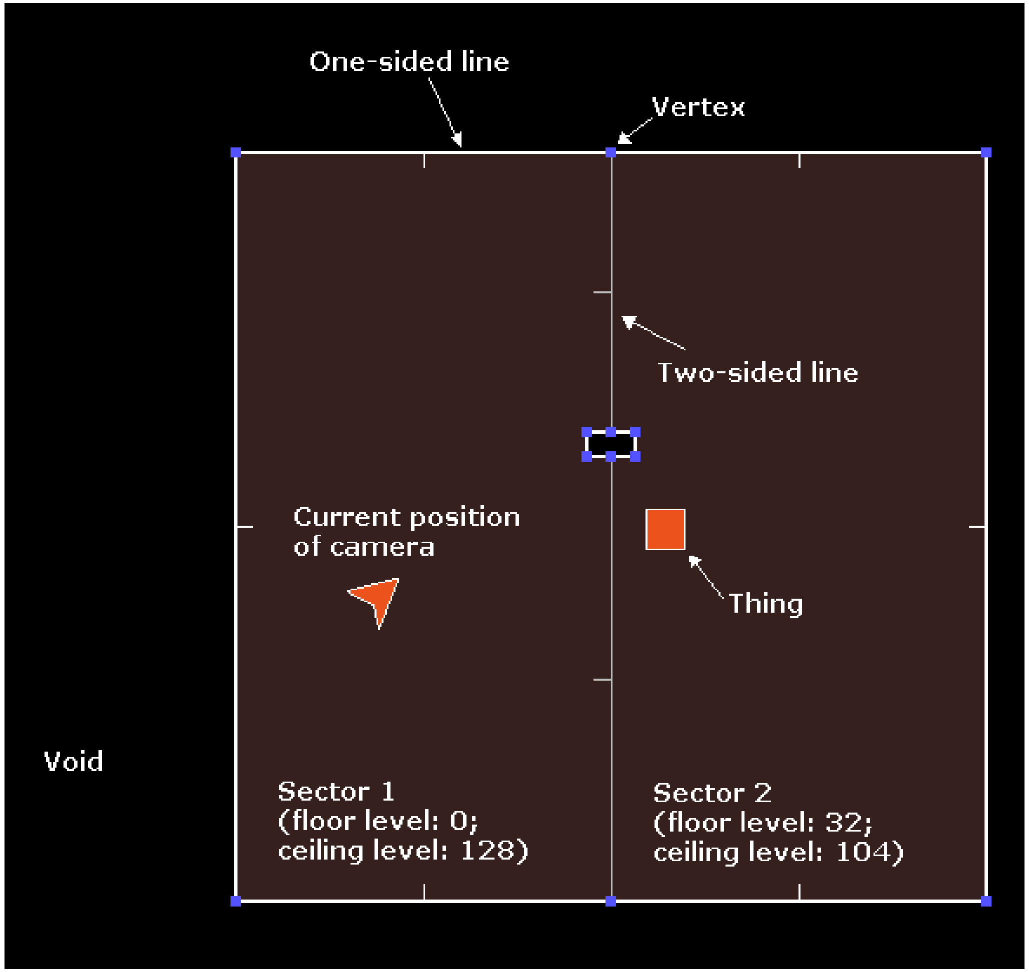
# Binary Space Partition Tree

- Axis Aligned Partition vs. Arbitrary Plane Partition



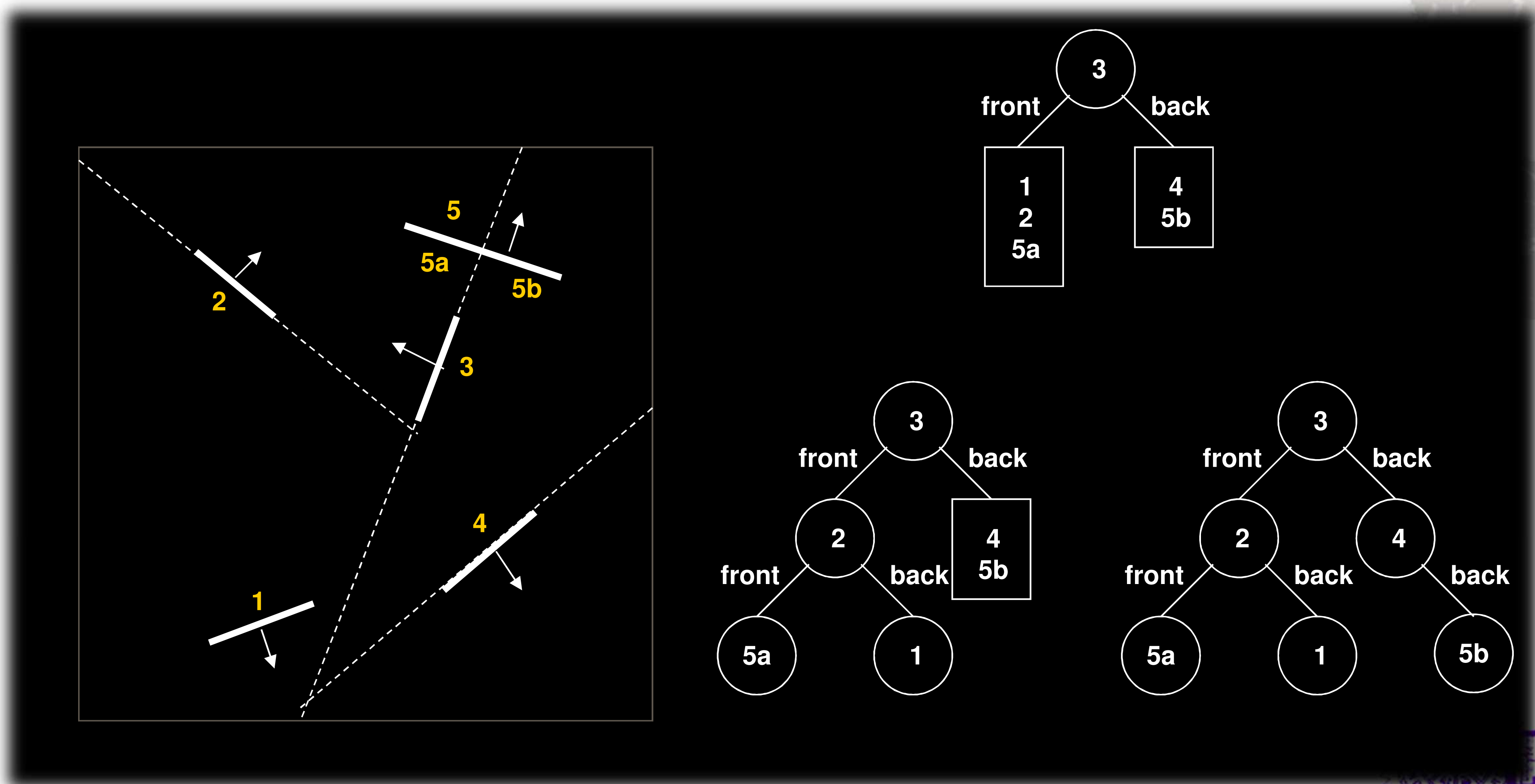
# Games using BSP Tree

- Doom-like or Quake-like Games



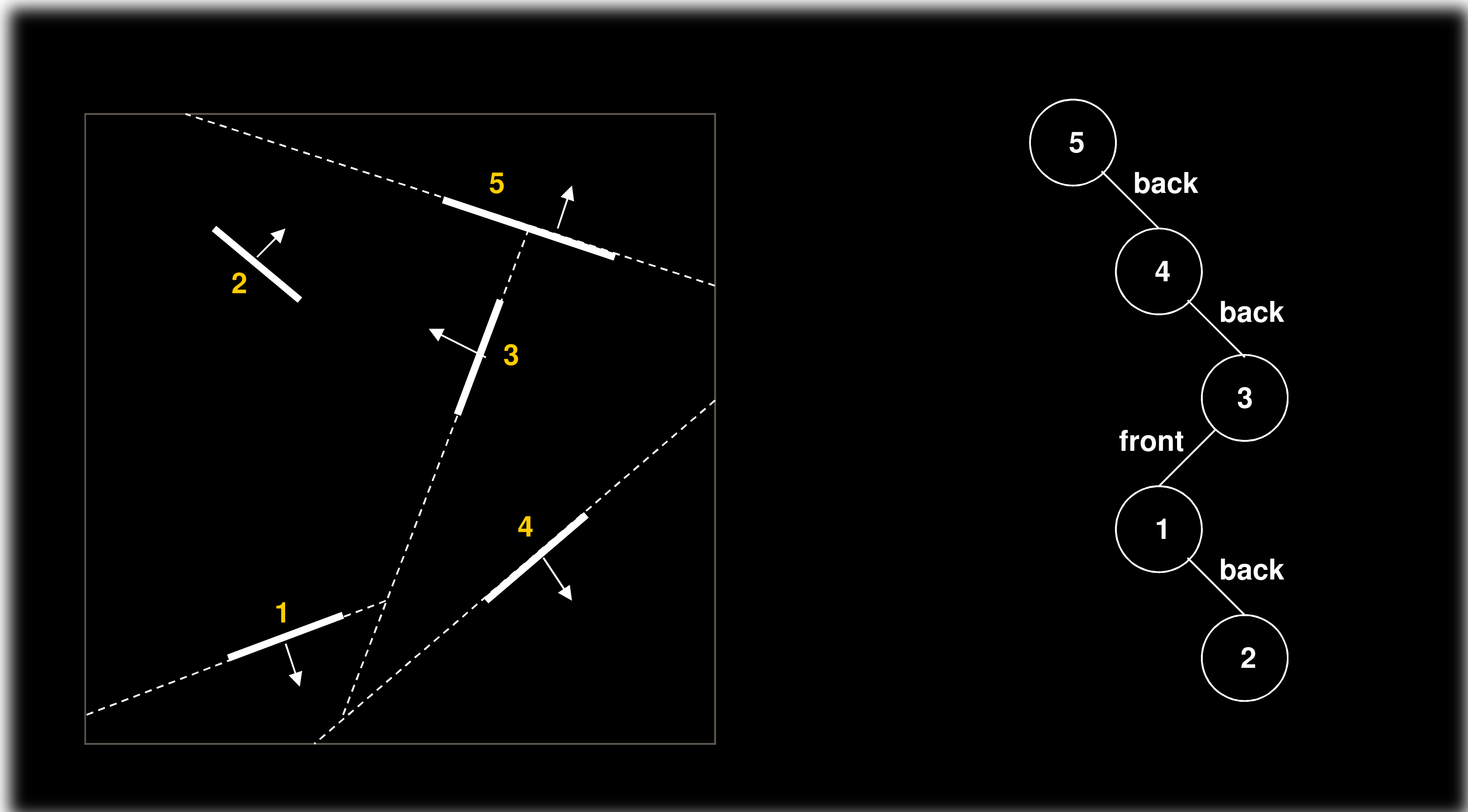

# Building a BSP Tree

- Balanced Tree



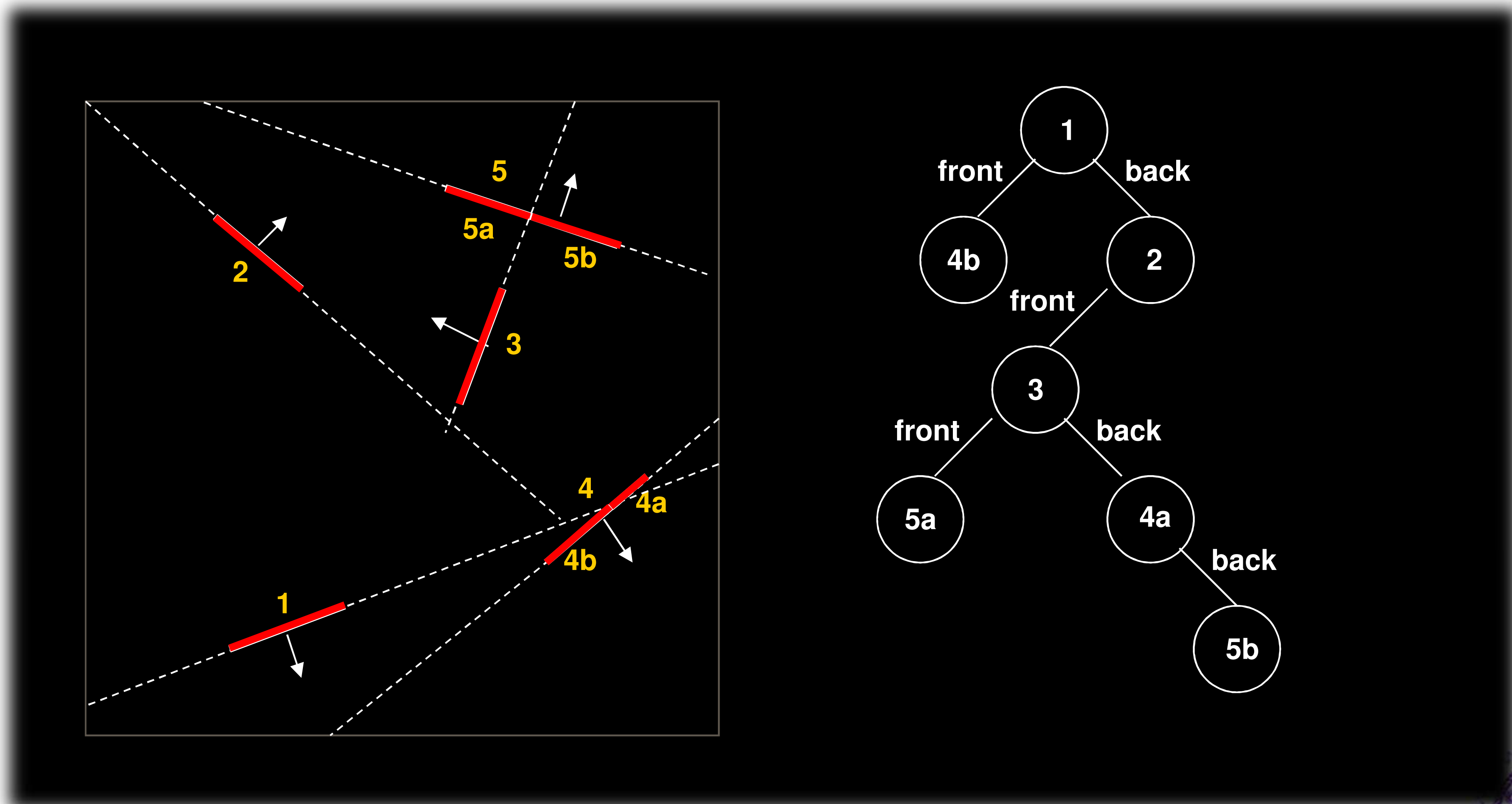
# Building a BSP Tree

- Minimize Splitting



# Building a BSP Tree

- Dynamic BSP Tree Construction



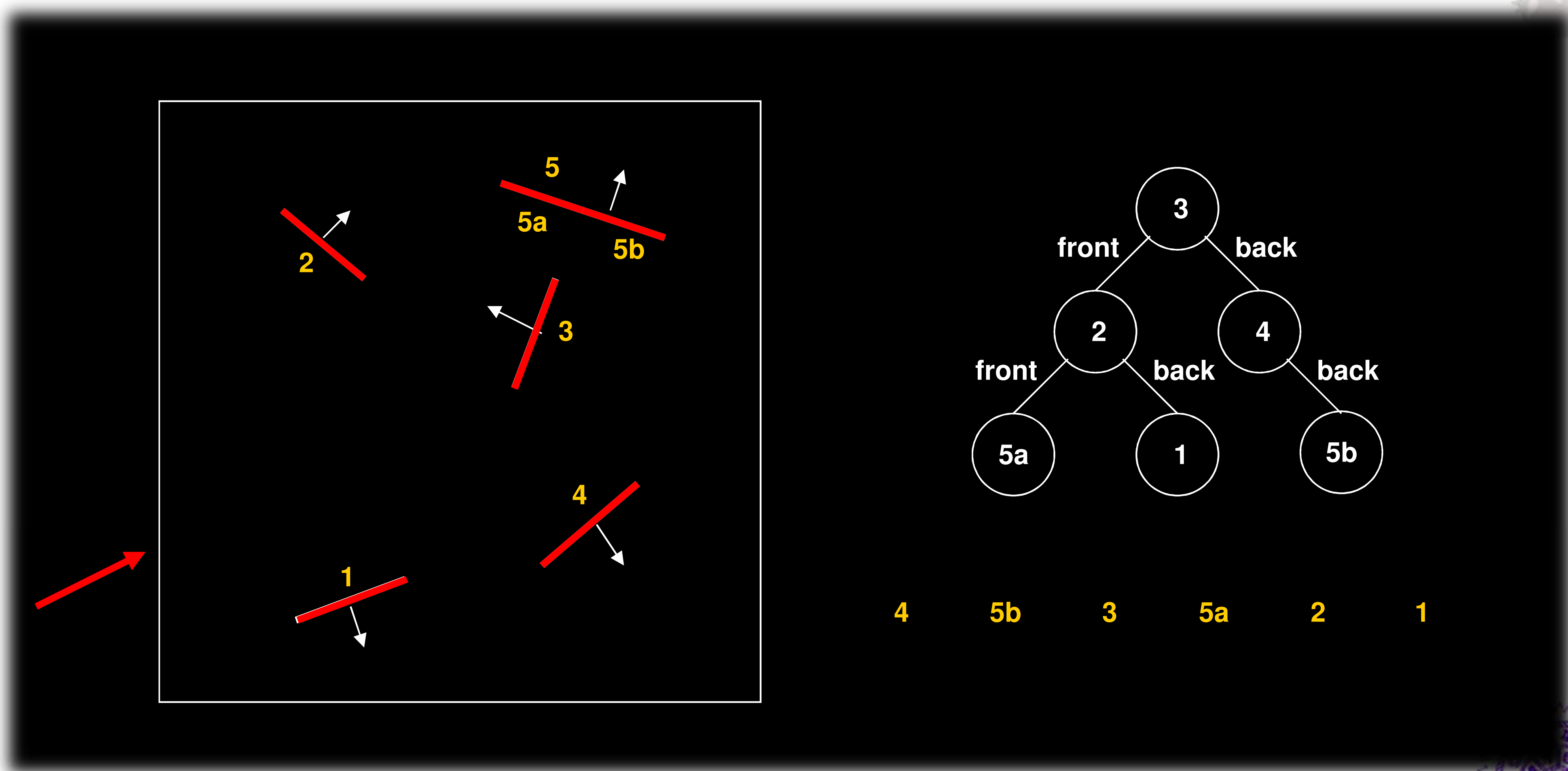
# Back-to-Front Display

- **BSP Tree Traversal for Back-to-Front Display**

```
BSP_Back_to_Front(Node)
{
    if (Node == Leaf node)
        Draw(Node)
    else
        if (Viewpoint is in front of the Node)
        {
            BSP_Back_to_Front(Back(Node))
            Draw(Node)
            BSP_Back_to_Front(Front(Node))
        }
        else if (Viewpoint is in back of the Node)
        {
            BSP_Back_to_Front(Front(Node))
            Draw(Node)
            BSP_Back_to_Front(Back(Node))
        }
}
```

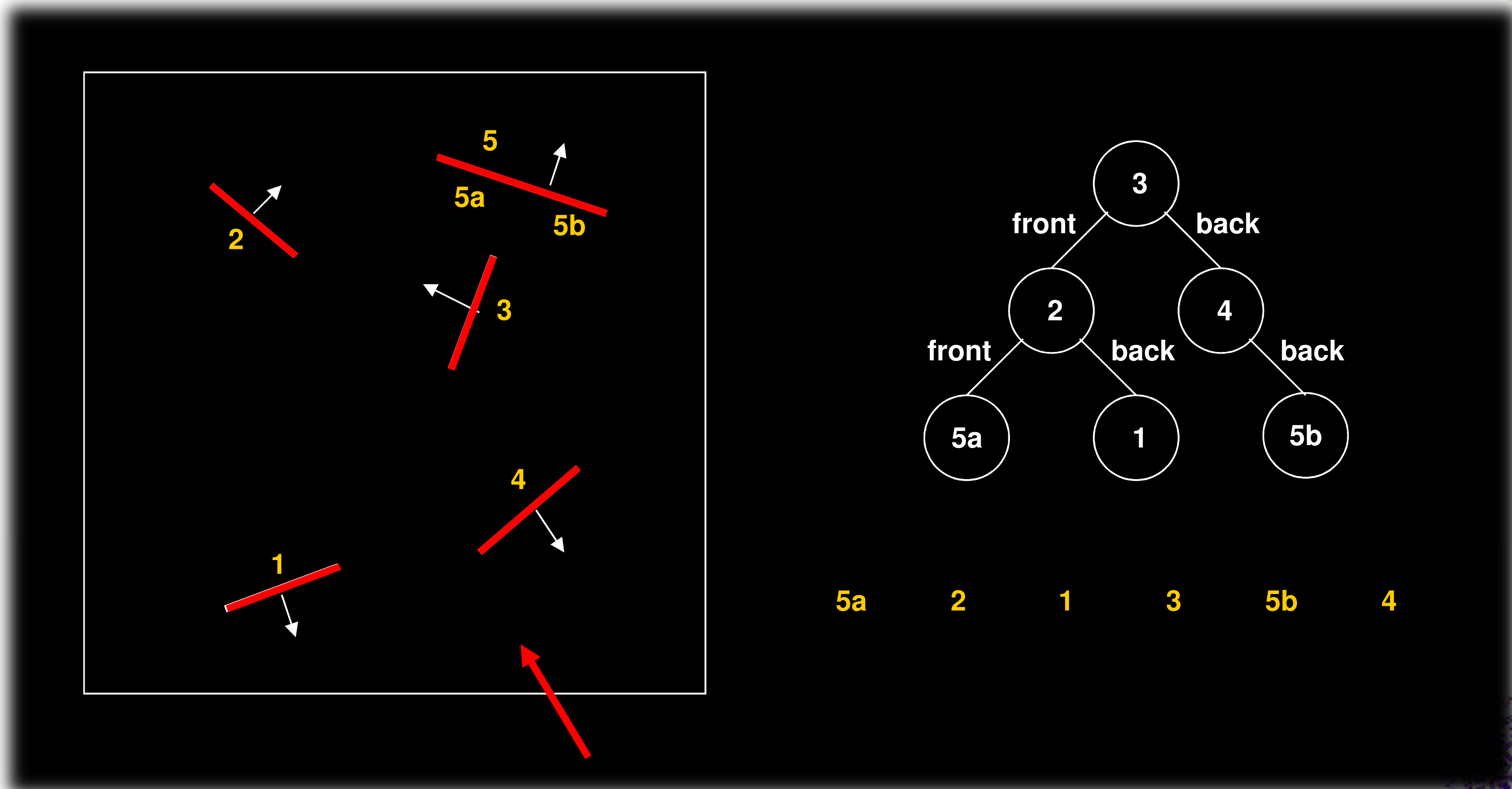
# Back-to-Front Display

- **Painter's Algorithm Approach**



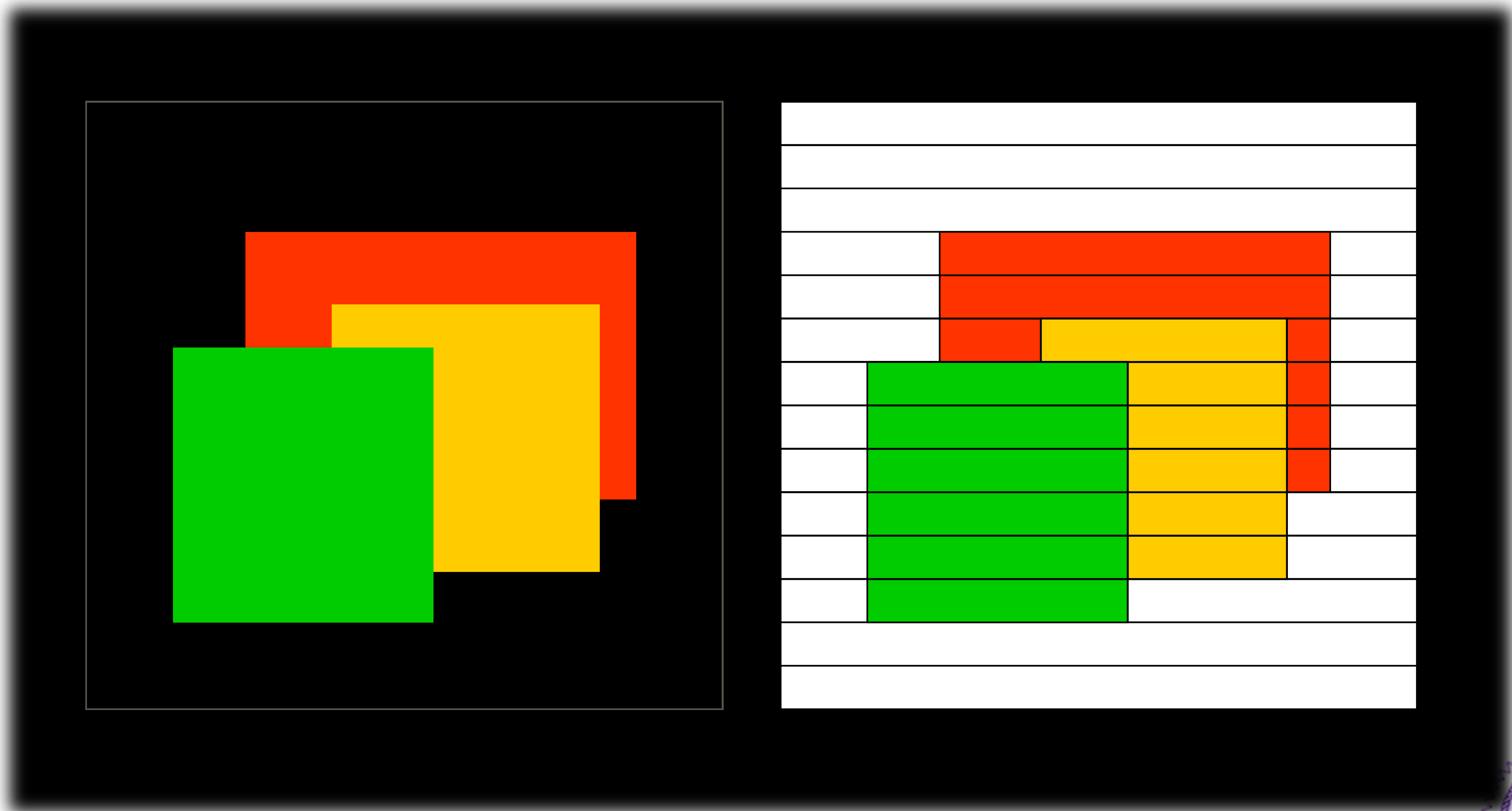
# Back-to-Front Display

- Painter's Algorithm Approach



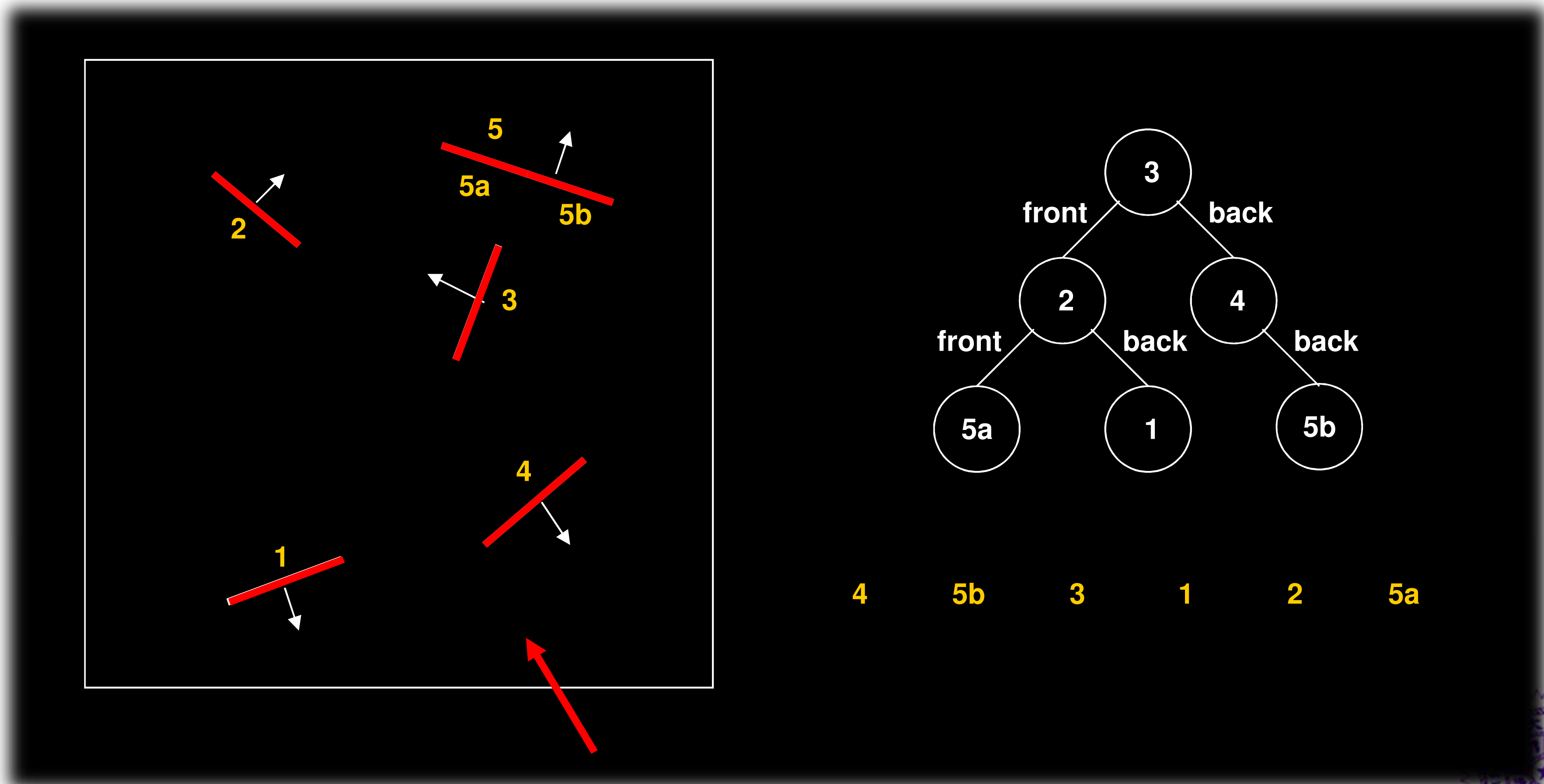
# *Front-to-Back Display*

- Scanline Approach



# Front-to-Back Display

- Scanline Approach

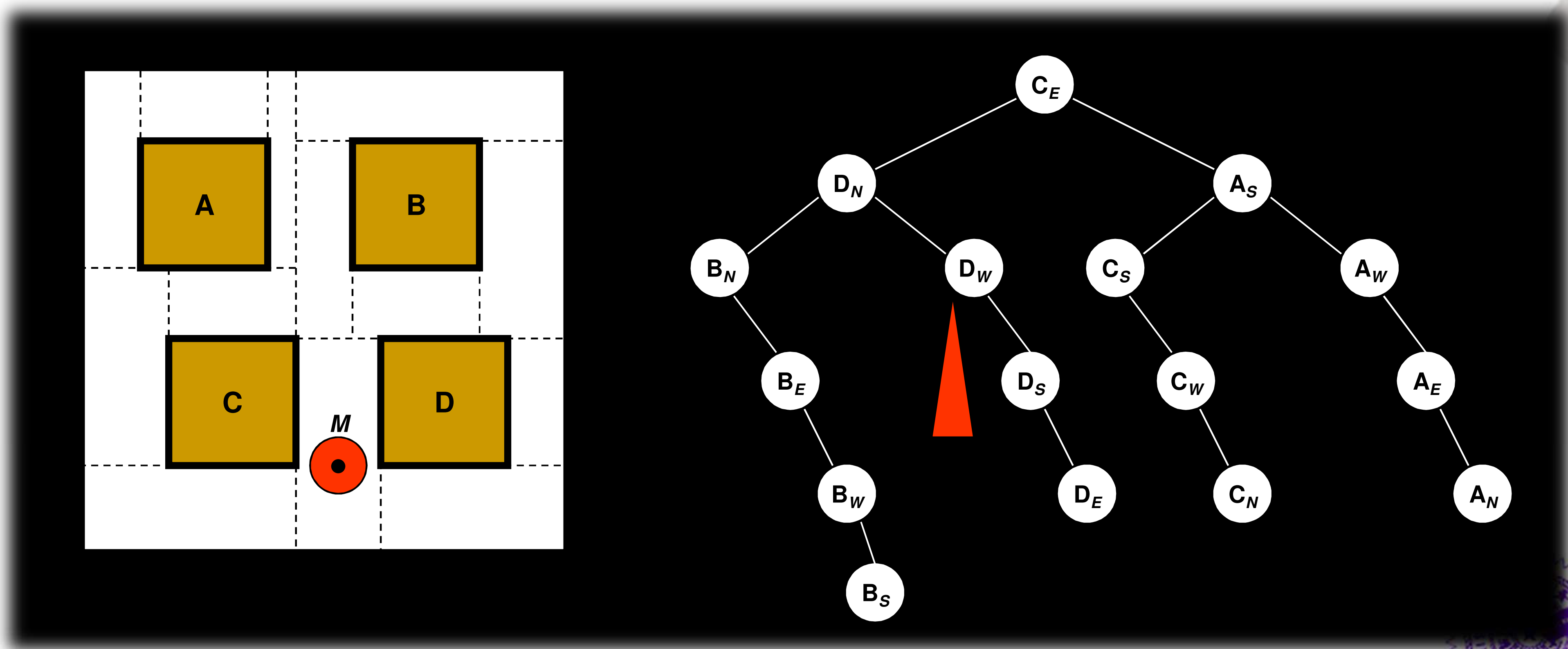


# HSR with a BSP Tree

- Back-to-Front Traversal
  - Painter's Algorithm
    - Advantage: No Z buffer is required
    - Disadvantage: Some pixels are over-drawn
- Front-to-Back Traversal
  - Scanline Algorithm
    - Advantage: Only visible pixels are drawn
    - Disadvantage: Need to maintain a dynamic scene data structure to represent pixel masks

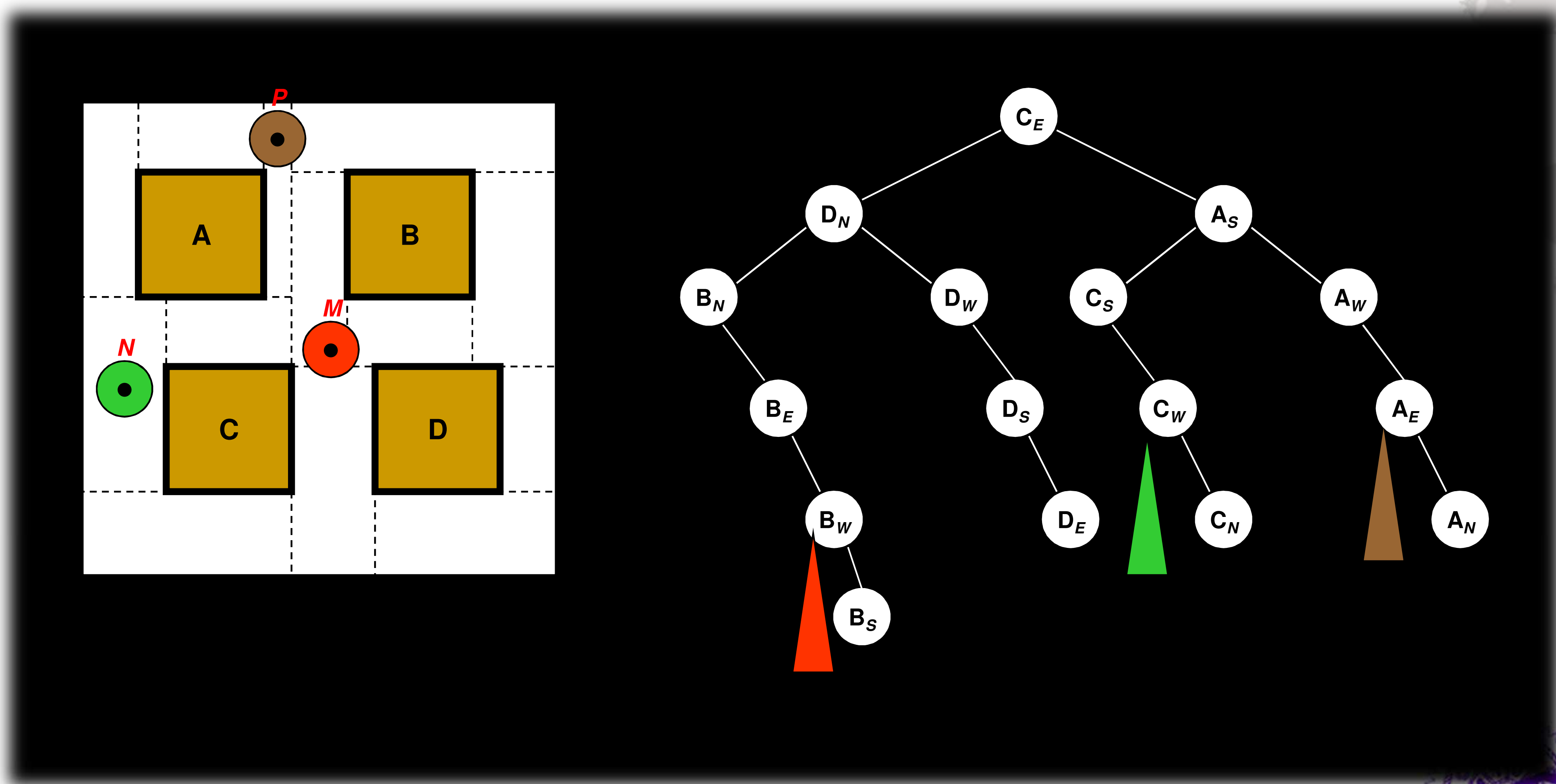
# Dynamic Scene with a BSP Tree

- Start with a BSP tree containing all the static objects in the scene
- Insert the dynamic objects into the BSP tree



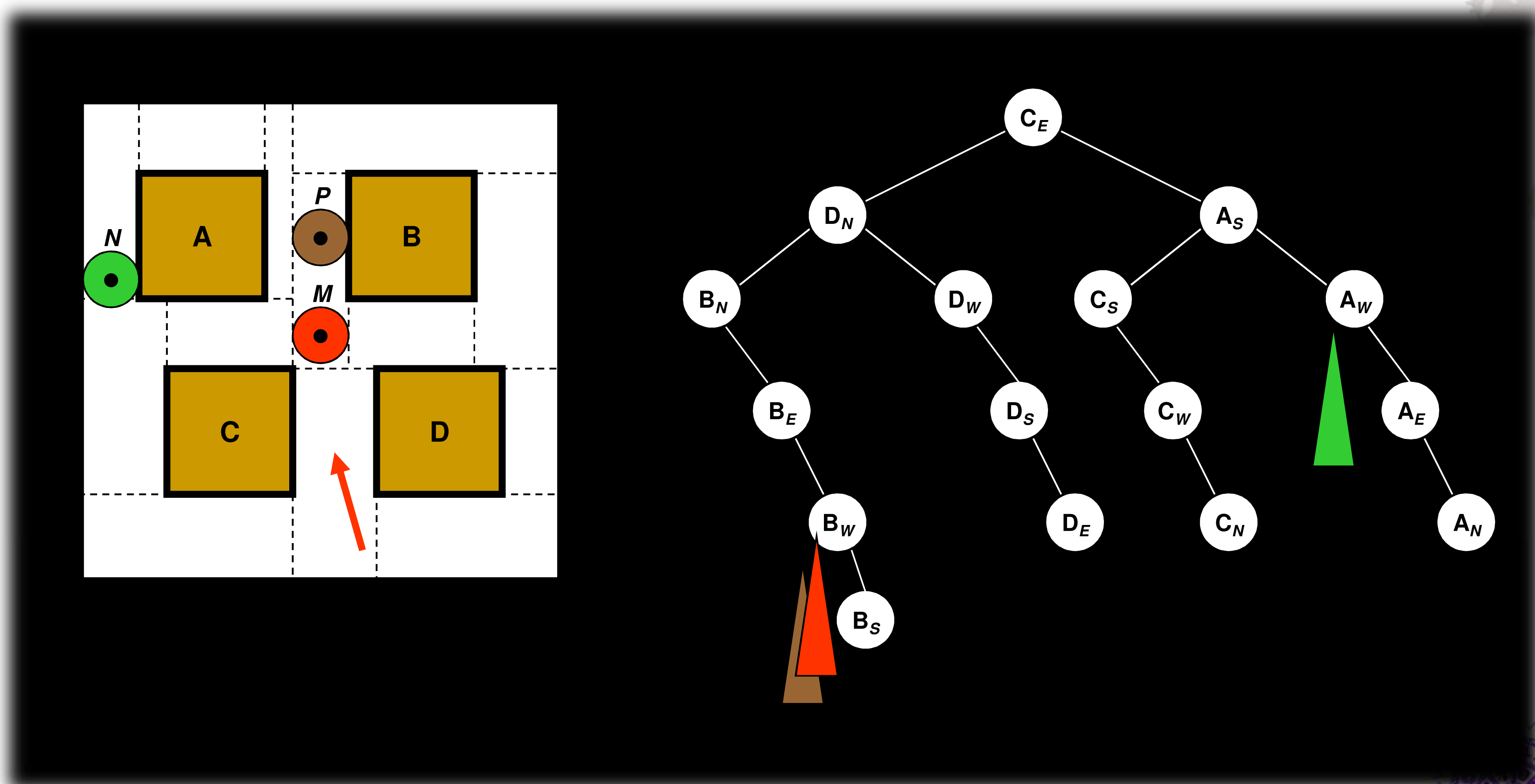
# Dynamic Scene with a BSP Tree

- Doom/Quake Like Game

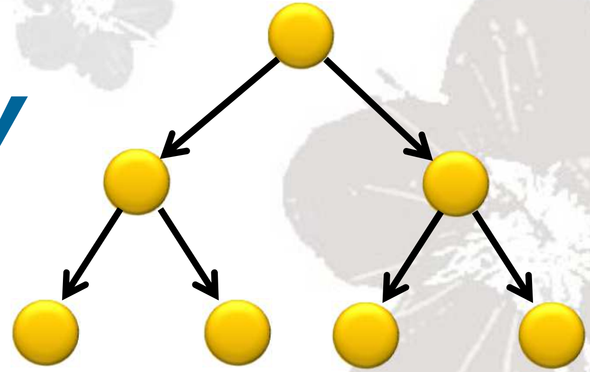


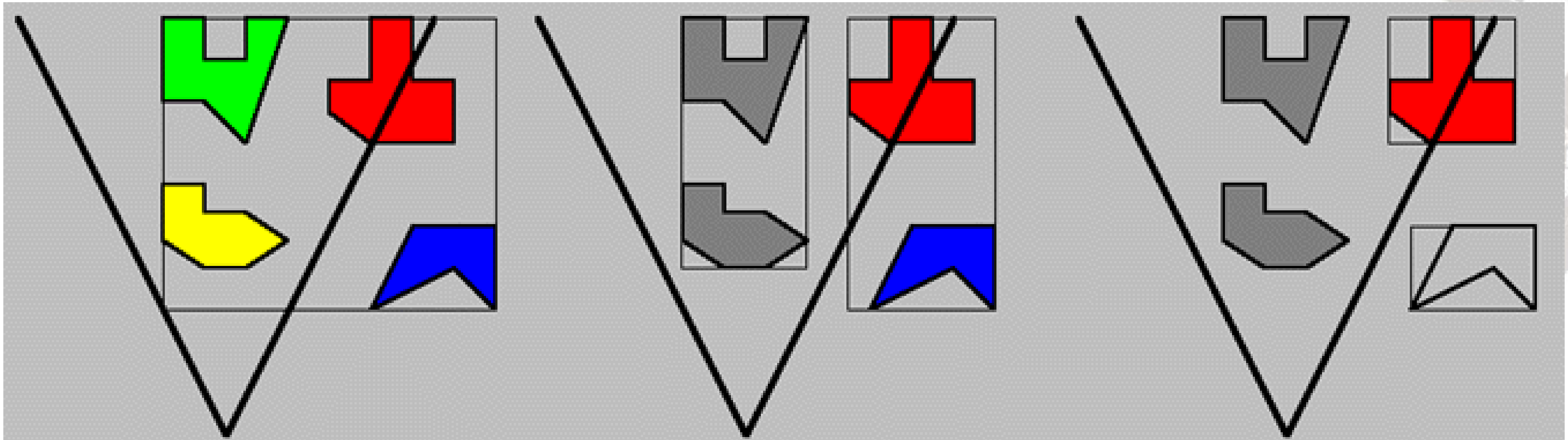
# Dynamic Scene with a BSP Tree

- Doom/Quake Like Game



# Bounding Volume Hierarchy

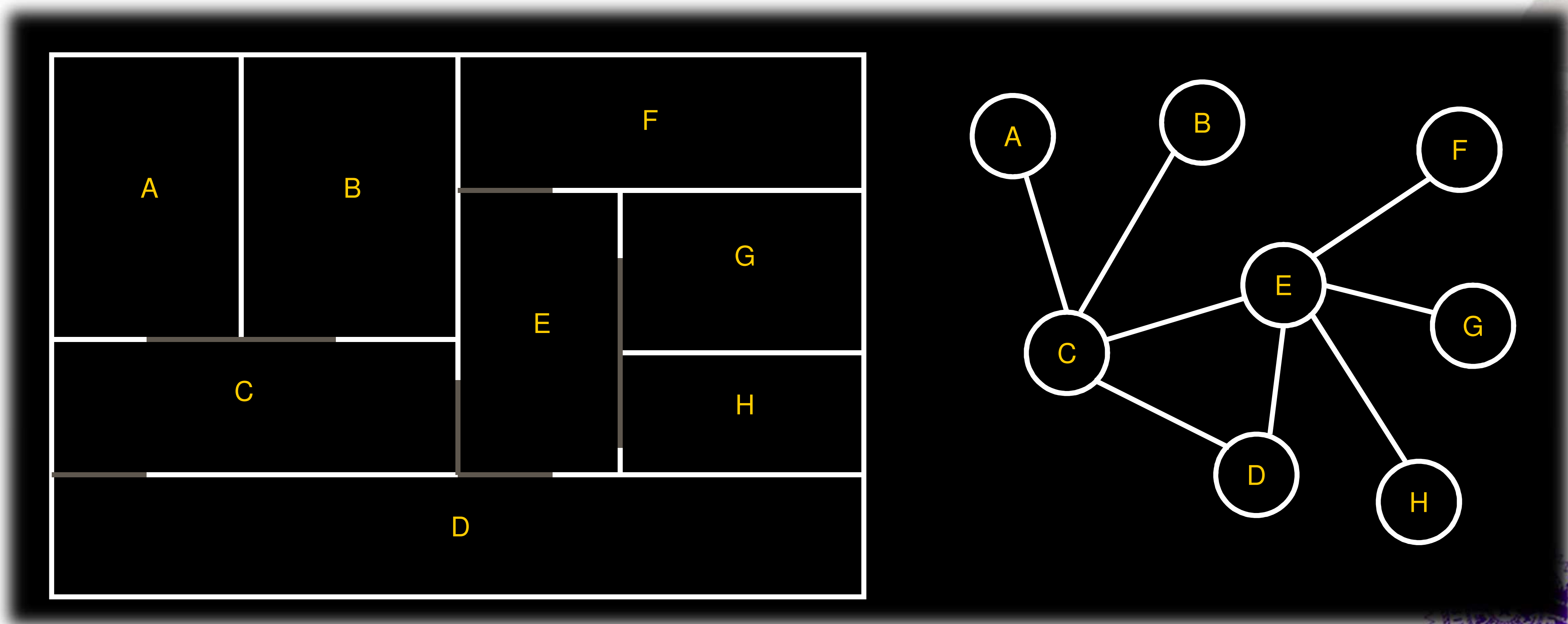




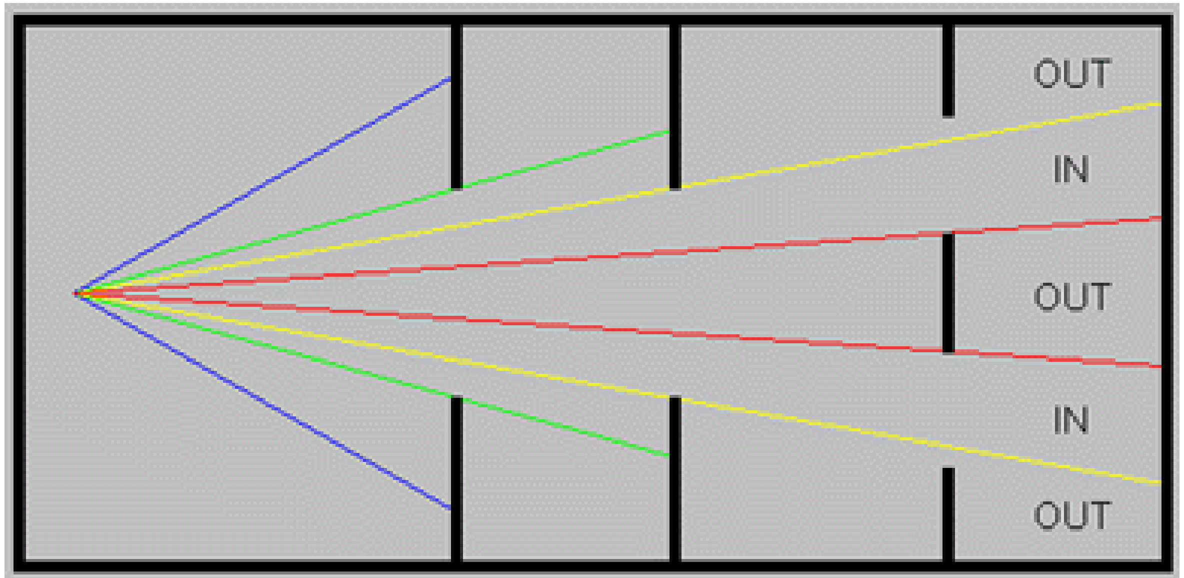
Here we show the progression of overlap tests on a simple three-level bounding-volume hierarchy. The left figure shows the top-level bounding box that encloses the entire scene; it partially overlaps so we must check its children. In the middle figure, the two child boxes are shown; the left box is completely inside so all of the objects it contains are trivially accepted (shown in gray). The right box must be traversed; the process repeats recursively. In the right figure, the lower bounding box is completely outside so its object are trivially rejected (hollowed); the upper box is partially overlapping and does not contain any child boxes, so the individual polygons must be tested for overlap (this step is sometimes omitted and the entire object is just sent to the low-level graphics pipeline).

# Portal Culling

- An adjacency graph is built to represent the connections of cells. The connections are established through portals

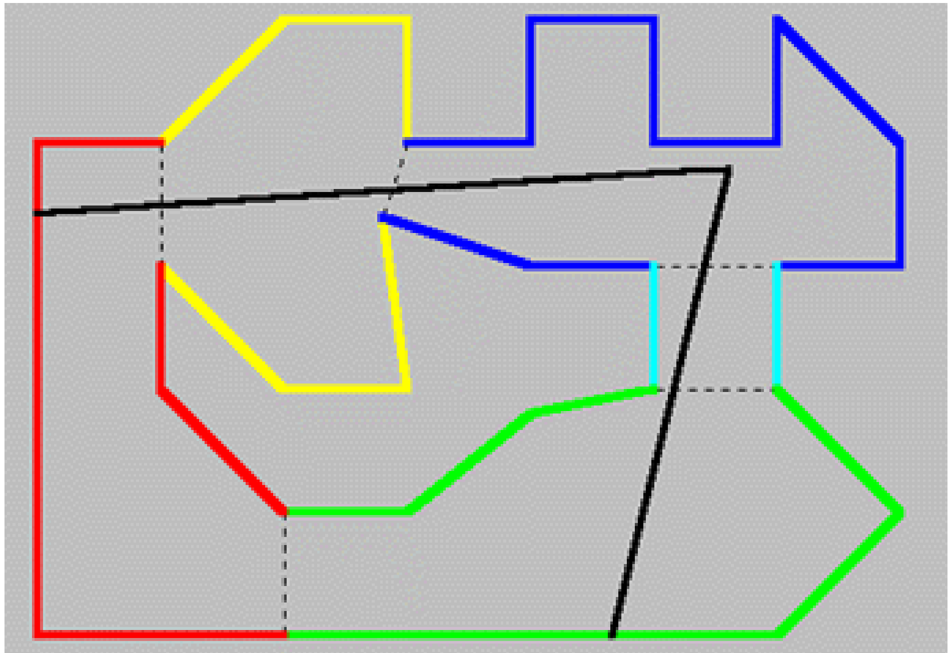


# Portal Culling

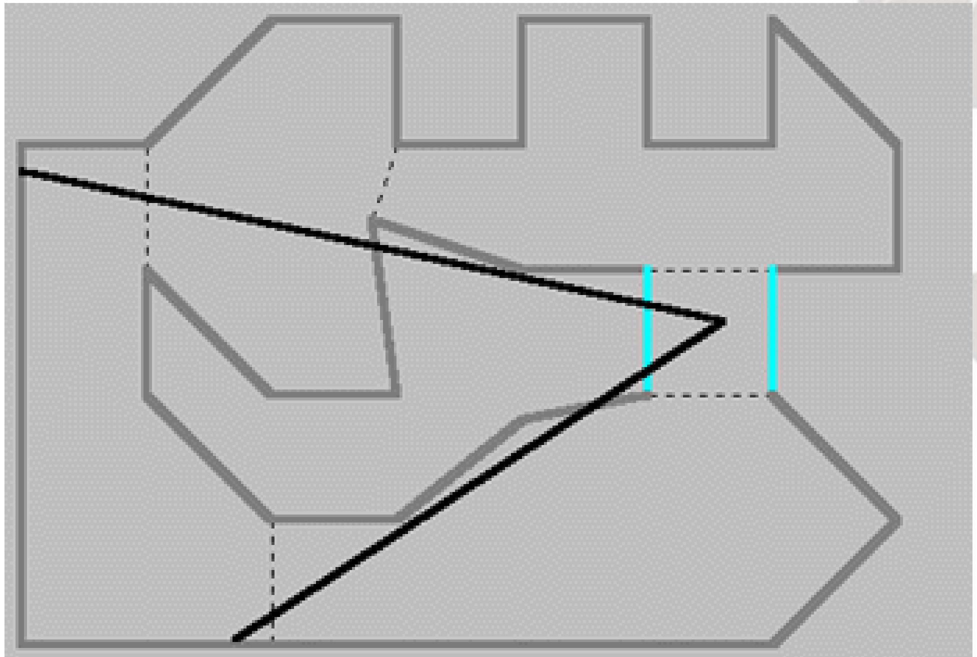



This figures illustrates the recursive nature of cells and portals. Each visible cell has at least one frustum entering it (trivial case is the first cell that contains the viewer). Objects belonging to each cell can be culled against the entering frusta. The viewer's field-of-view is indicated in blue; green lines show the frustum formed through the first portal; yellow lines indicate the second portal frustum; this final frustum is split by the last portal wall into two smaller frusta indicated with the red and yellow lines.

# Portal Culling

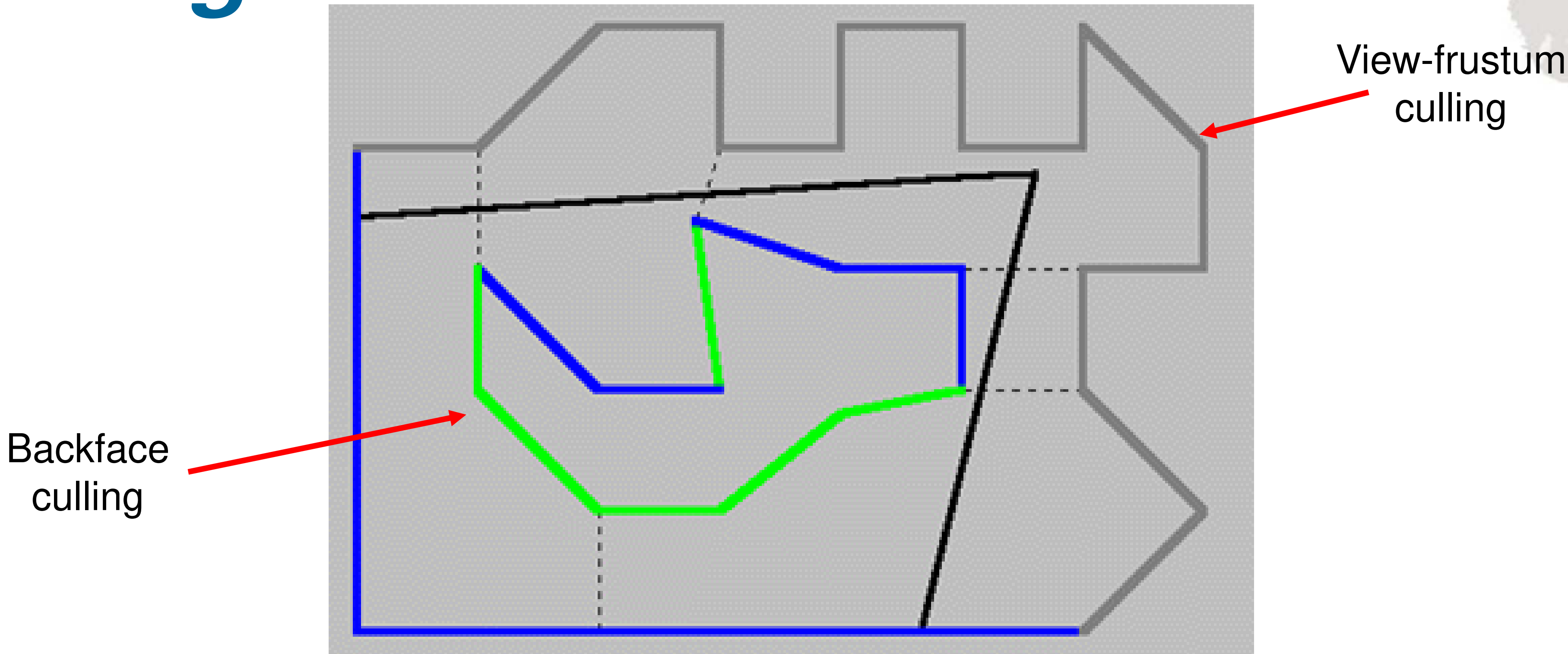


Here the world is divided into sets of polygons grouped by rooms or cells (different colors) that are separated by doorways or portals (dashed lines). Only cells visible through sequences of portals are drawn. Here there is no advantage since all cells can be seen through the portals; however, if this was used with view-frustum and backface culling we could still reduce the load.



When the viewpoint moves into a cell where long sequences of portals are no longer visible, large portions of the world are culled at a significant fraction of the cost of using other techniques (only two portal overlap tests were required). Clearly, hybrid techniques can cull even more.

# *View-Frustum Culling with Backface Culling*



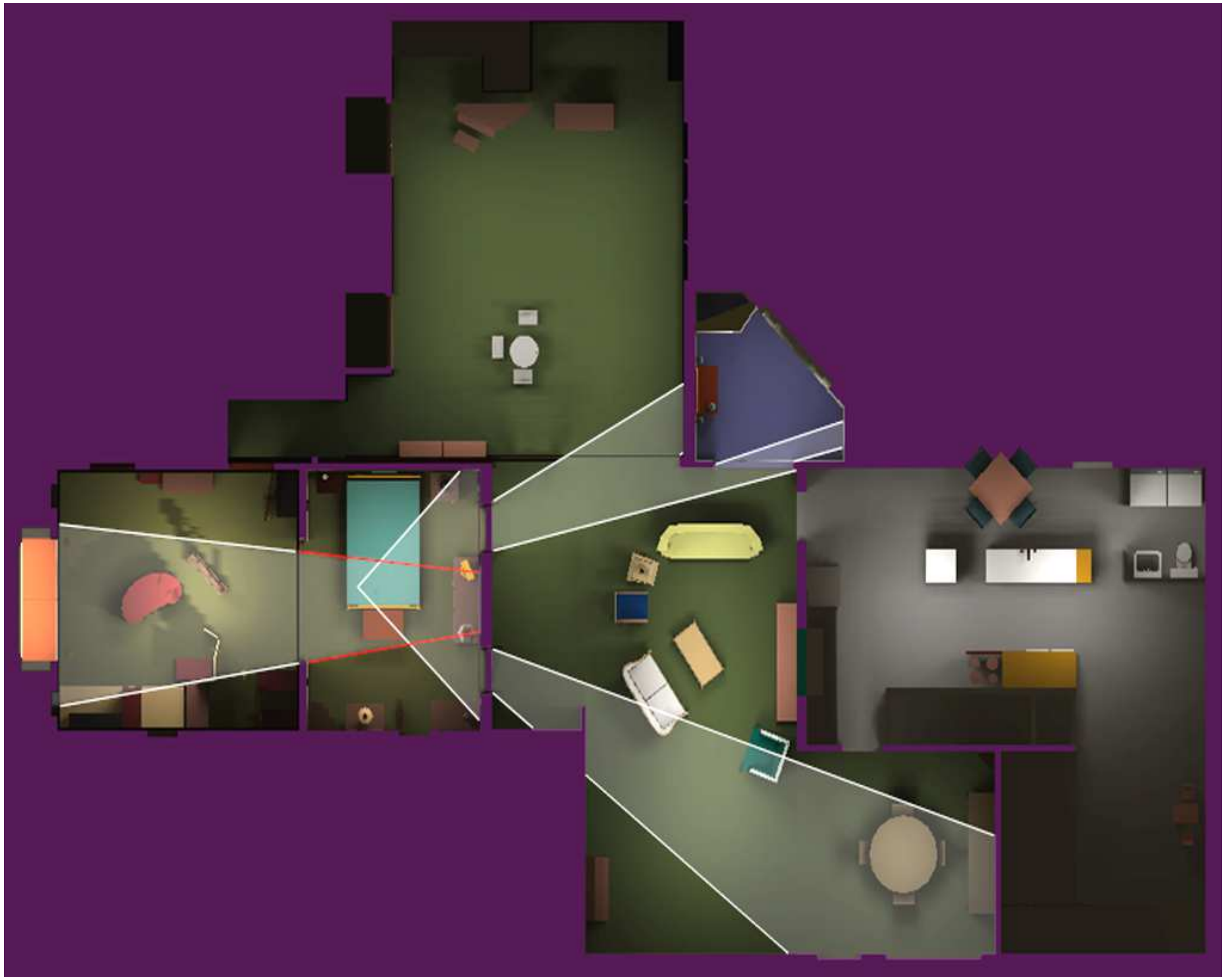

With backface culling in addition to view-frustum culling, polygons facing away from the viewer are also culled (green). Since the blue polygons are opaque, the resulting image is unaffected.

# Portal Culling Example

- Luebke and Georges, I3D 95

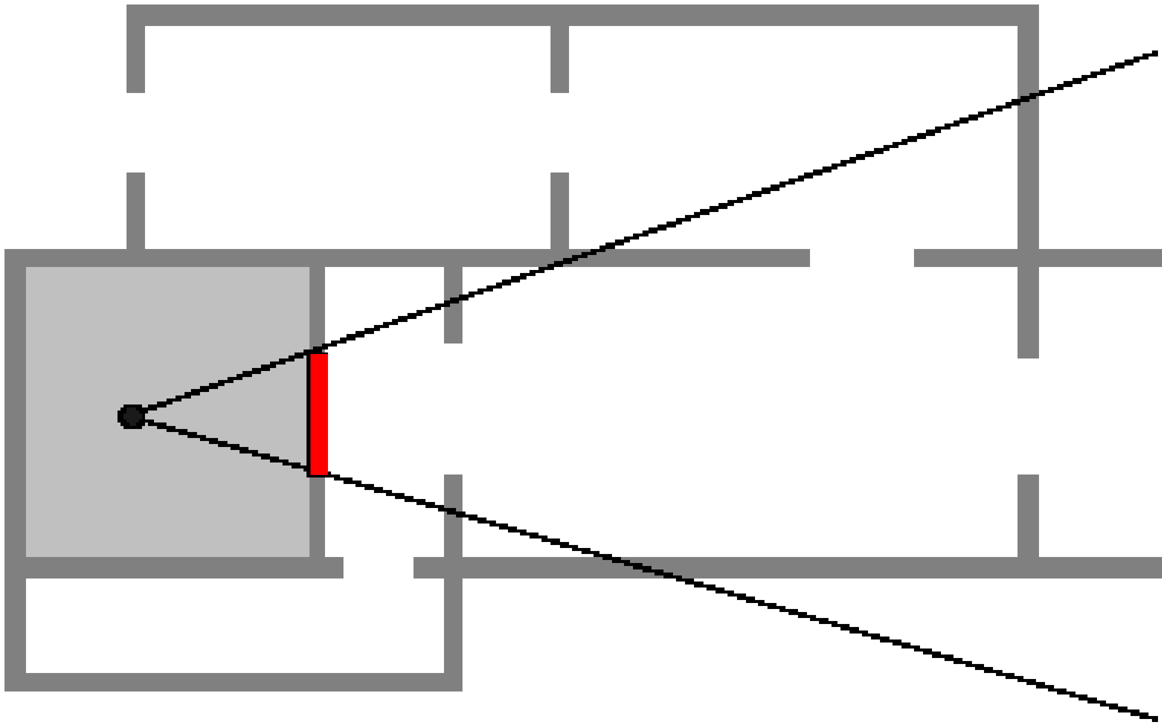
# Portal Culling Example

- Top view



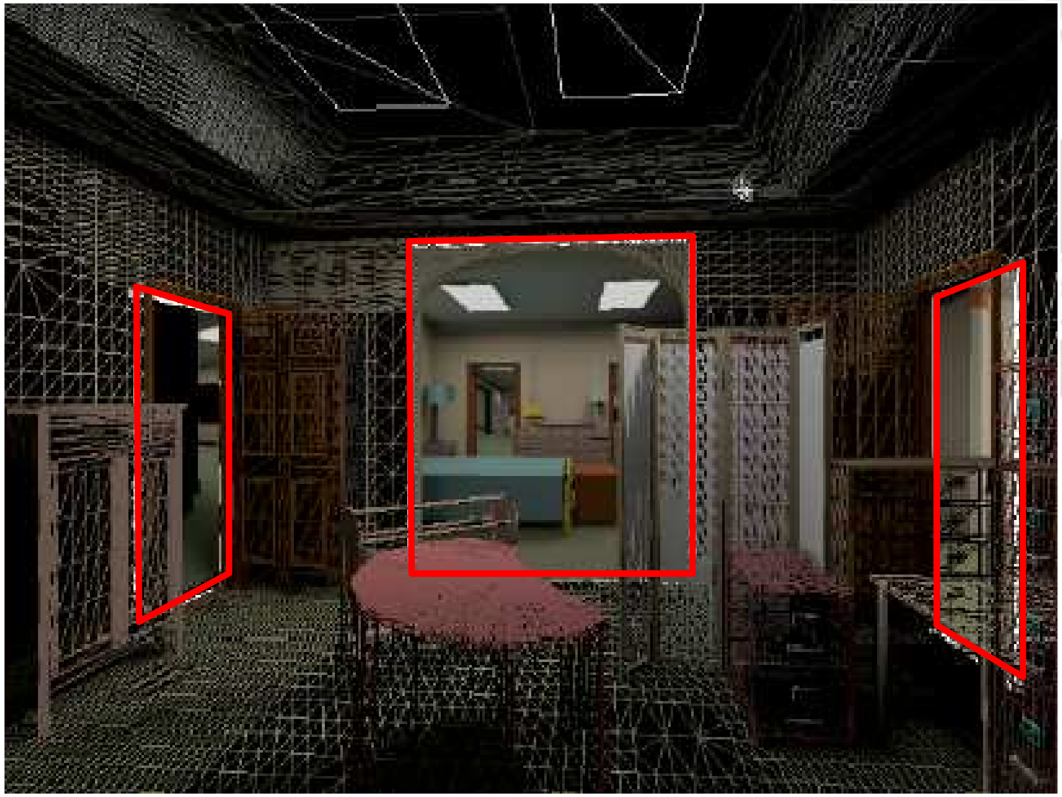
# Portal Texture

- Pre-compute portal textures to reduce rendering time during walkthrough



Aliaga and Lastra,
*IEEE Visualization '97*

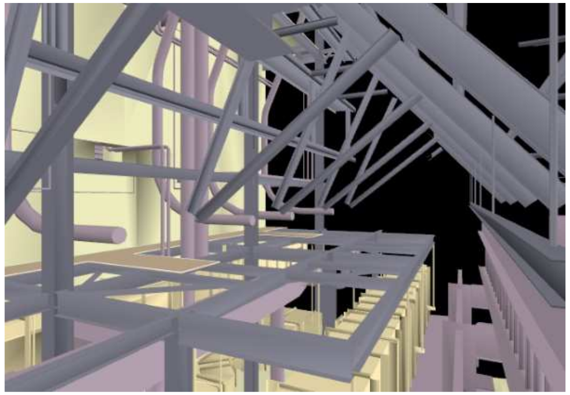
# Portal Texture



Aliaga and Lastra,
*IEEE Visualization '97*

# Portal Texture Example

Geometry



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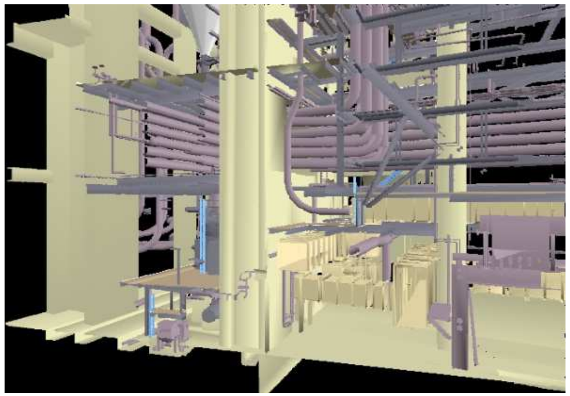
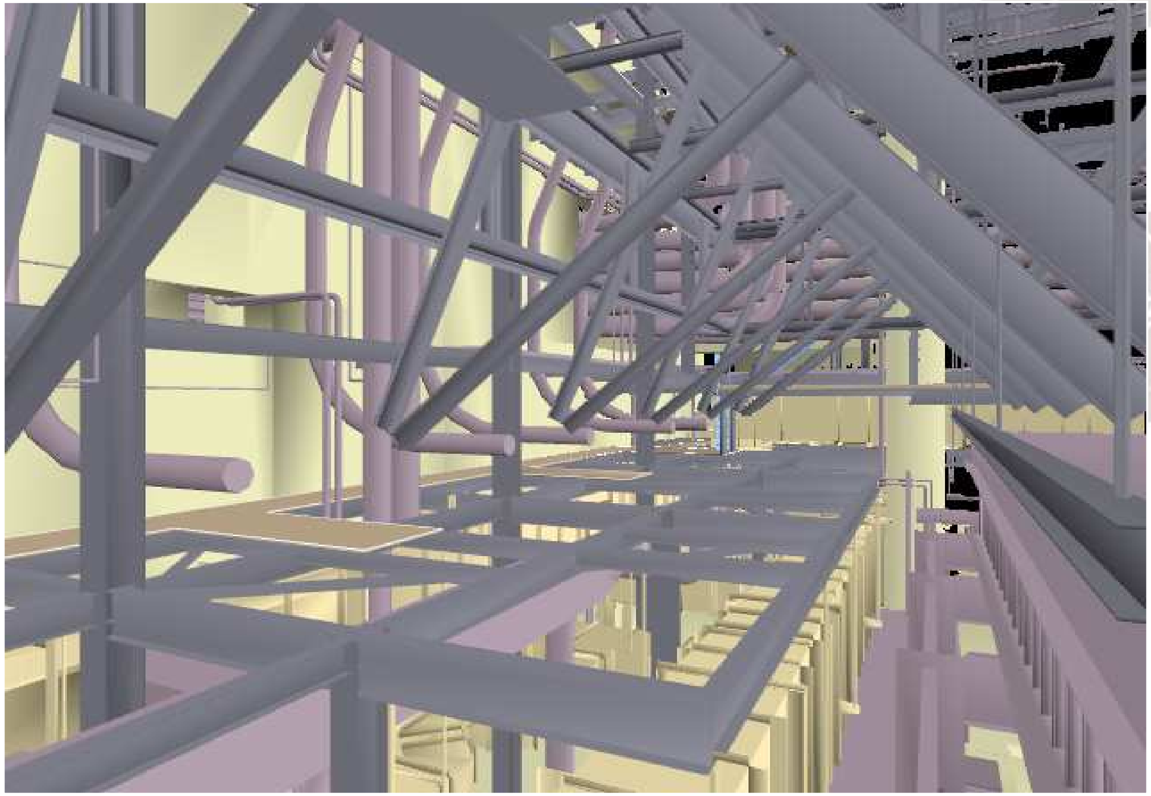


Image



Final Scene

# Q&A