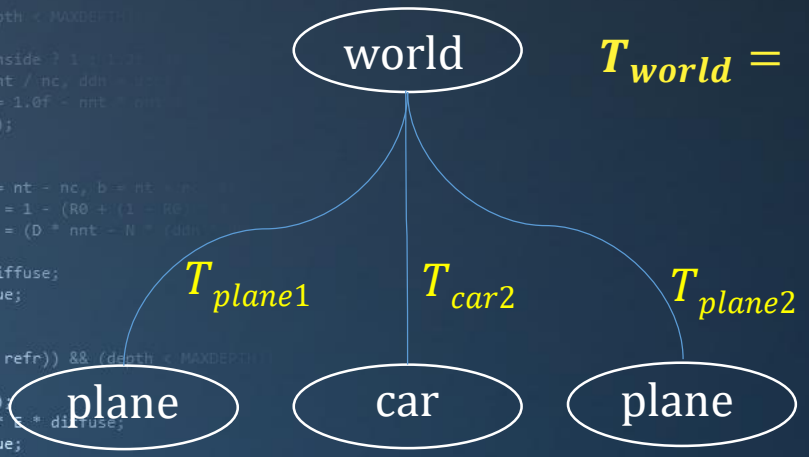
INFOGR – Computer Graphics

Jacco Bikker & Debabrata Panja - April-July 2018

Lecture 13: “Visibility”

Welcome!



$$T_{world} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{plane} = \begin{bmatrix} 1 & 0 & 0 & x_{plane} \\ 0 & 1 & 0 & y_{plane} \\ 0 & 0 & 1 & z_{plane} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

To world space:

Do nothing, or:

$T_w = identity = I$

$T_w = T_{local} * T_{w\_parent}$

To camera space:

1. $T_c = inv(T_{cam})$
2. Render ‘world’ with I, T_c
3. Render children

1. $T_c = T_{local} * T_{c\_parent}$
2. $T_w = T_{local} * T_{w\_parent}$
3. Render ‘plane’ with T_w, T_c
4. Render children

```
void SGNode::Render( mat4 Twparent, mat4 Tcparent )
{
    mat4 Tw = Tlocal * Twparent;
    mat4 Tc = Tlocal * Tcparent;
    mesh.Draw( Tw, Tc );
    for each child: Draw( Tw, Tc );
}
```

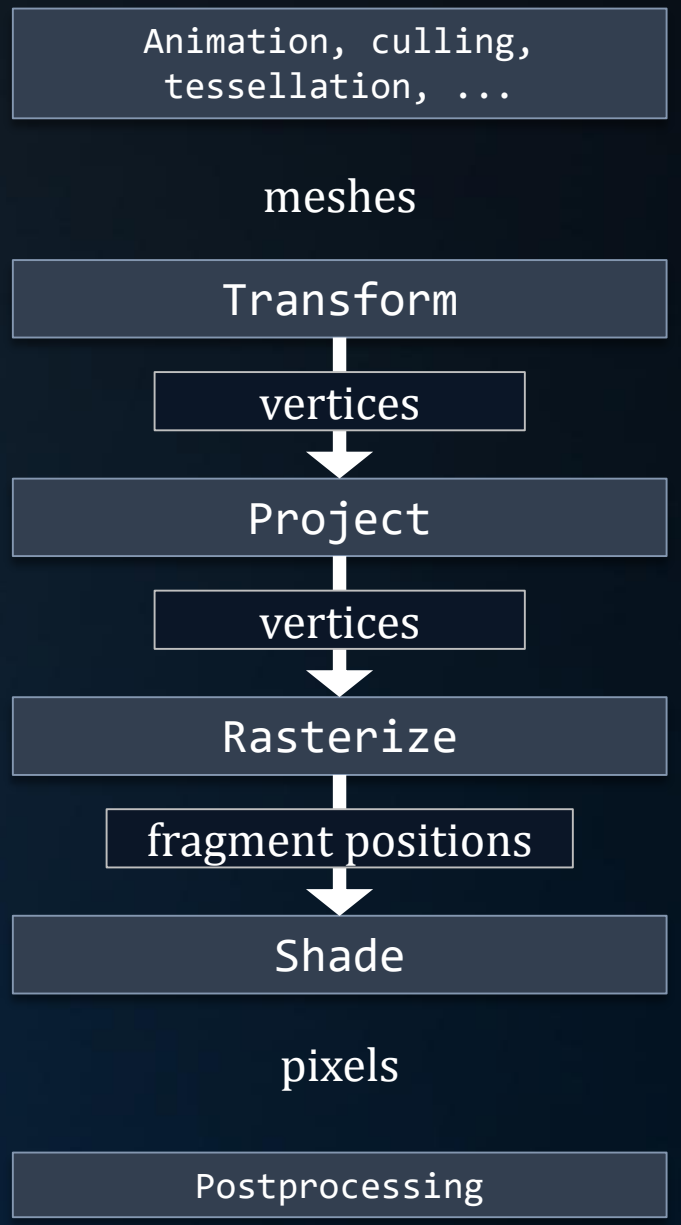
Today’s Agenda:

- Depth Sorting
- Clipping
- Visibility

Depth Sorting

Rendering – Functional overview

1. Transform:
   translating / rotating meshes
2. Project:
   calculating 2D screen positions
3. Rasterize:
   determining affected pixels
4. Shade:
   calculate color per affected pixel



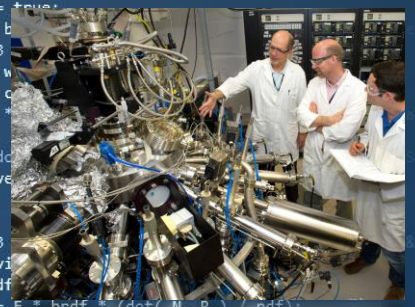
Depth Sorting

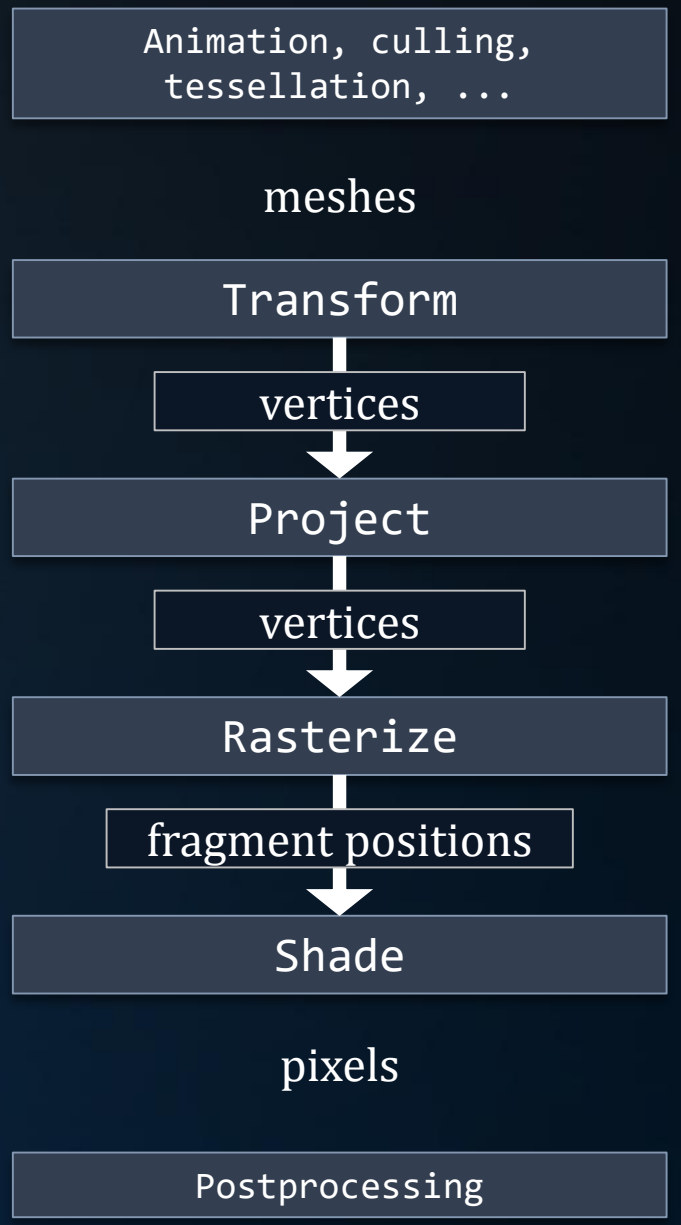
3. Rasterize:
   determining affected pixels

Questions:

- What is the screen space position of the fragment?
- Is that position actually on-screen?
- Is the fragment the nearest fragment for the affected pixel?

How do we efficiently determine *visibility* of a pixel?



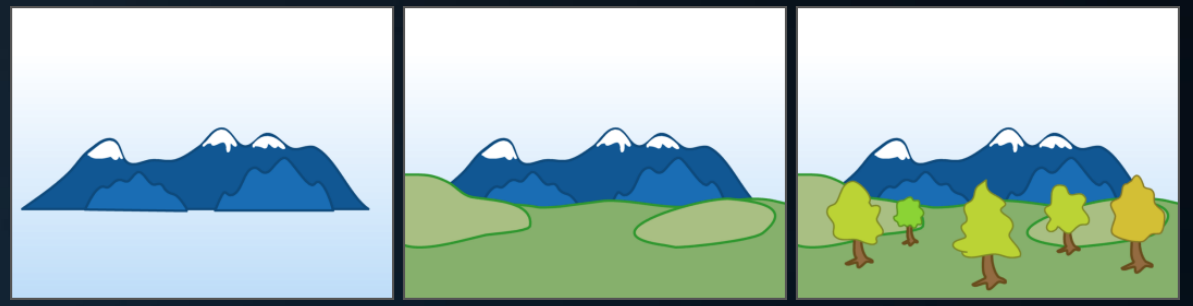



Part of the tree is off-screen
Too far away to draw
Tree requires little detail
City obscured by tree
Torso closer than ground
Tree between ground & sun

Depth Sorting

Old-skool depth sorting: Painter’s Algorithm

- Sort polygons by depth
- Based on polygon center
- Render depth-first

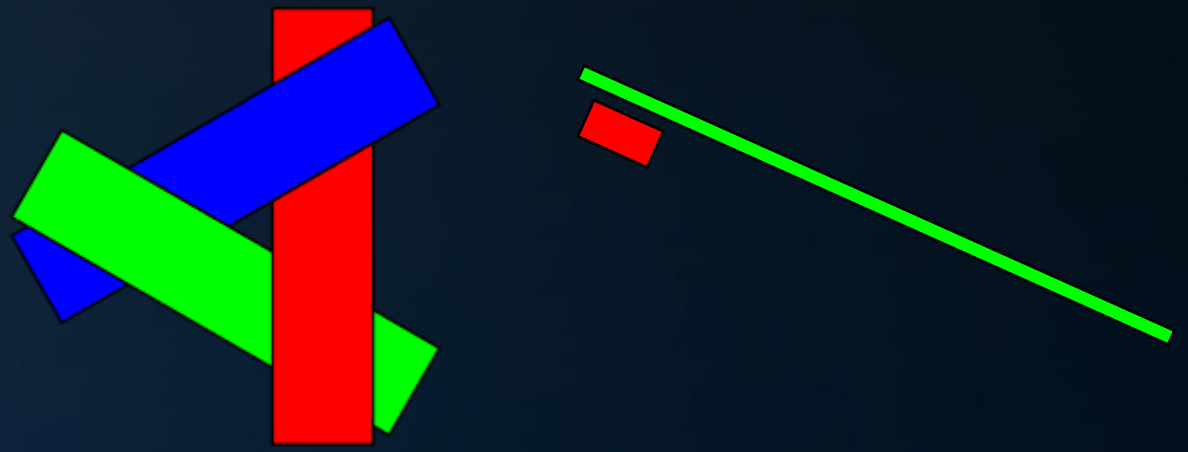


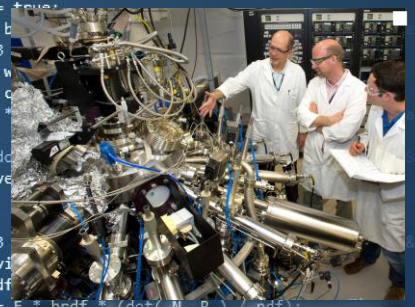
Advantage:

- Doesn’t require z-buffer

Problems:

- Cost of sorting
- Doesn’t handle all cases
- Overdraw

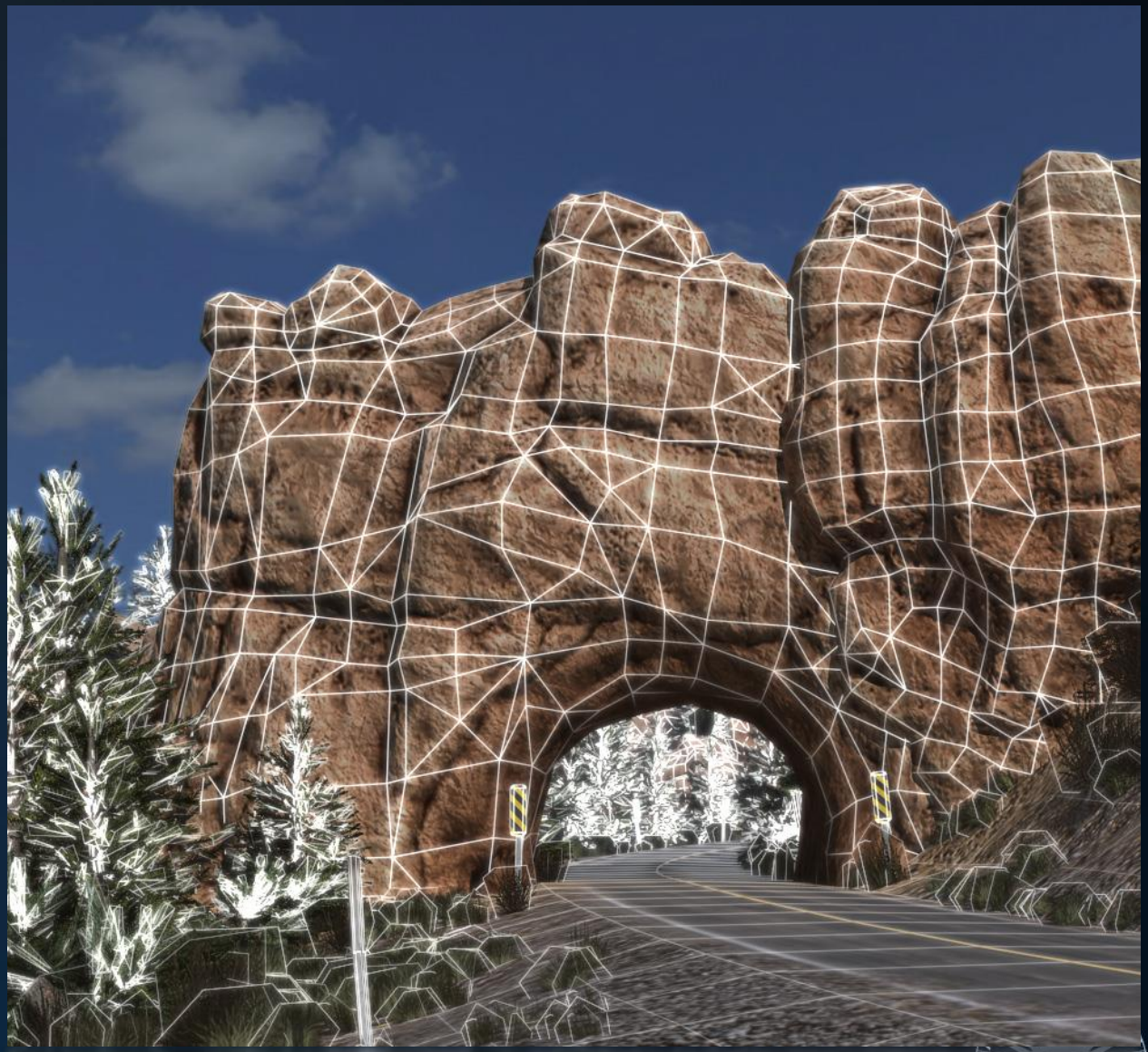




Depth Sorting

Overdraw:

Inefficiency caused by drawing multiple times to the same pixel.



Depth Sorting

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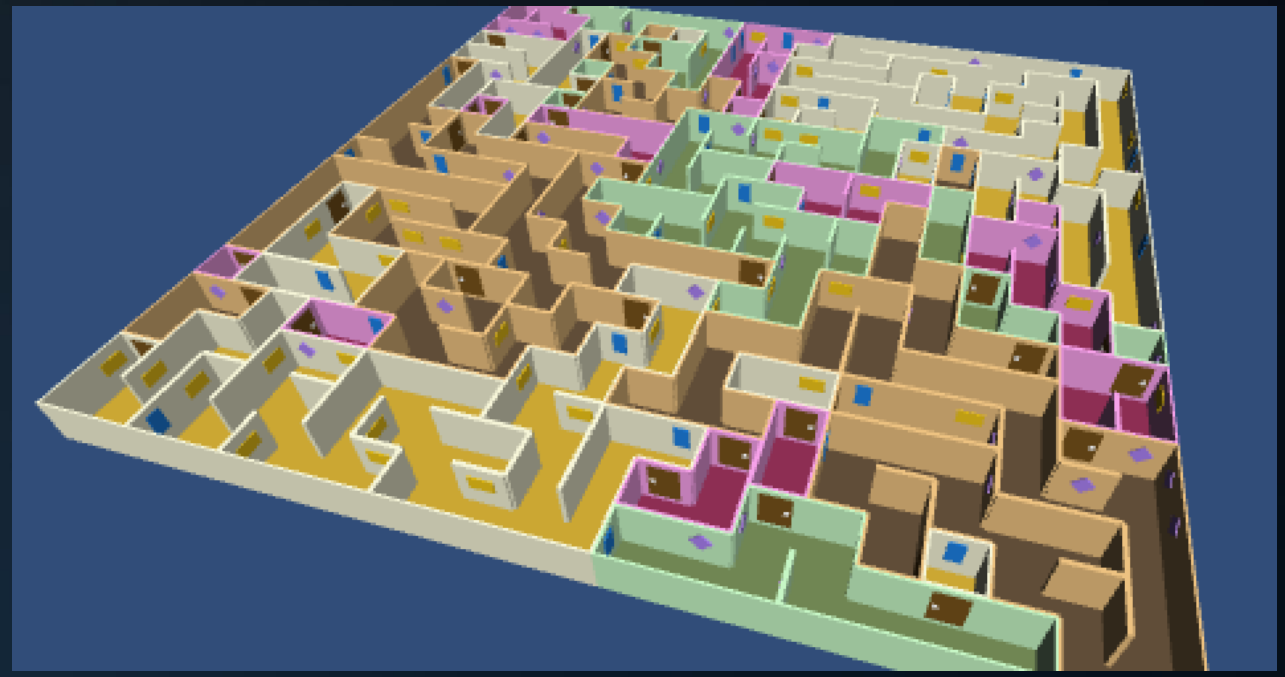

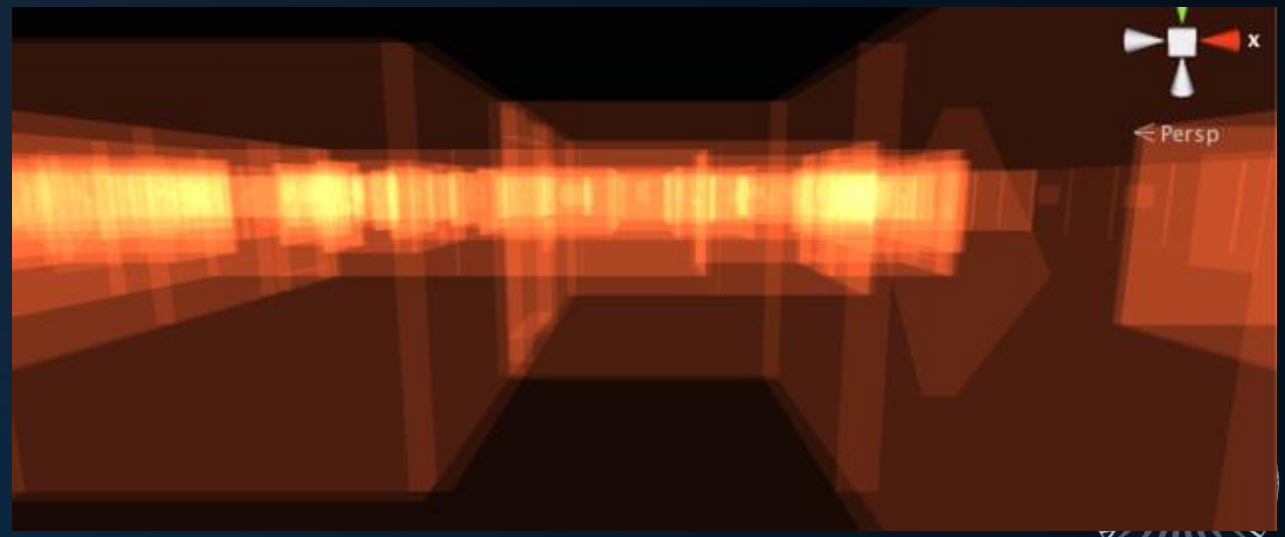

Depth Sorting

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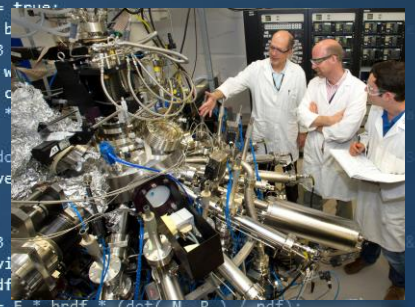

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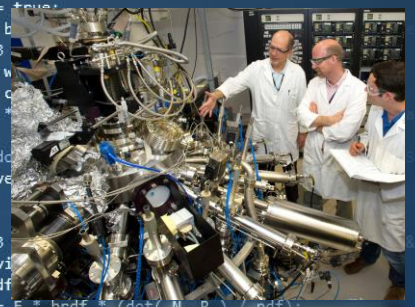
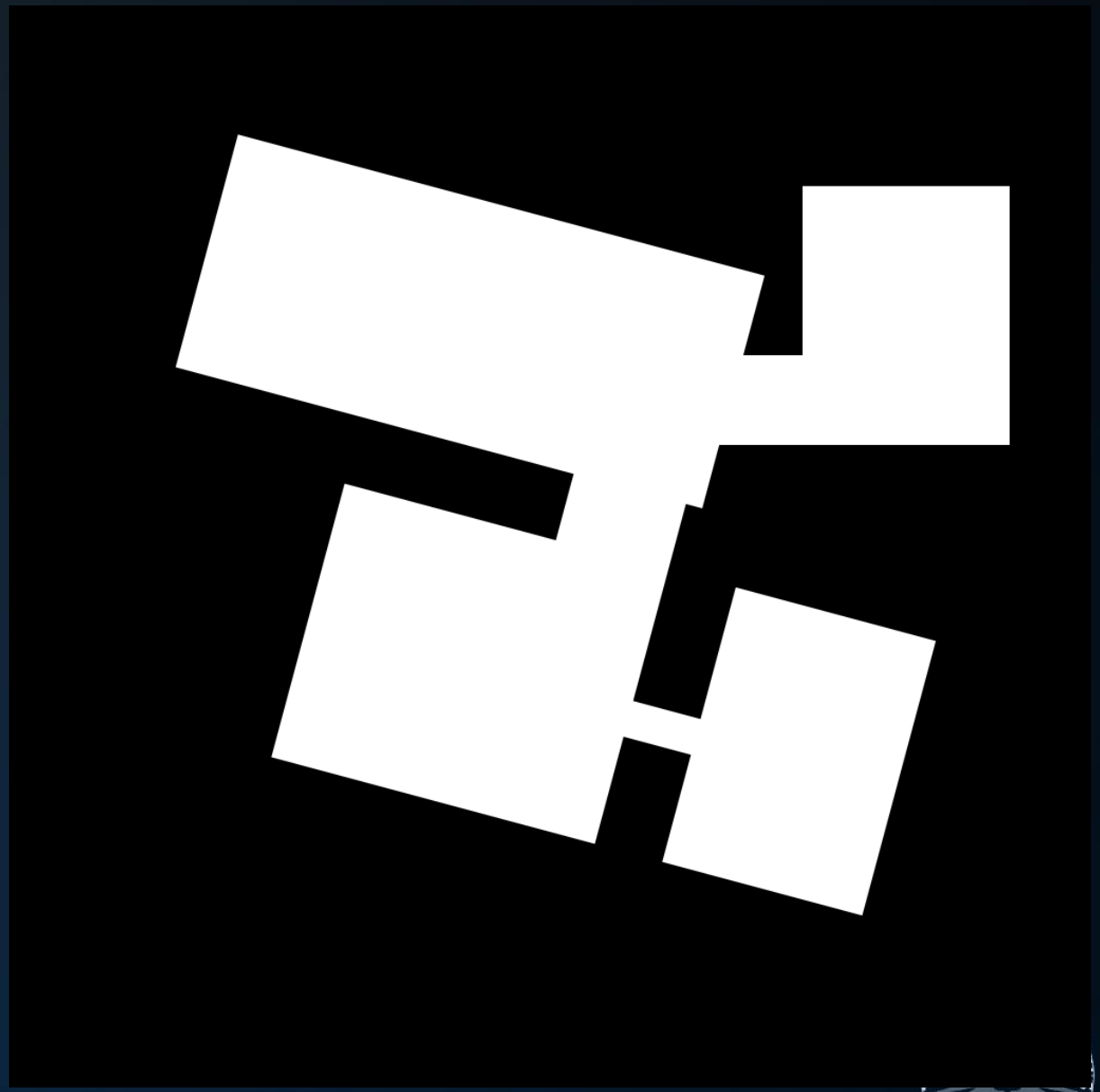


Depth Sorting

Correct order: BSP

root



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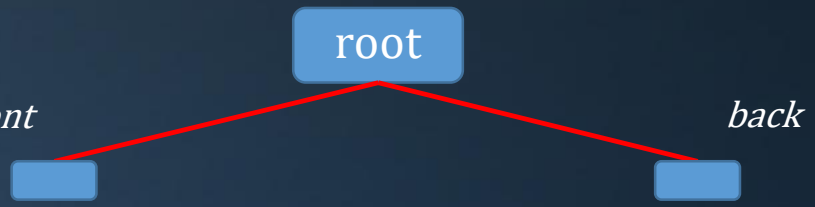

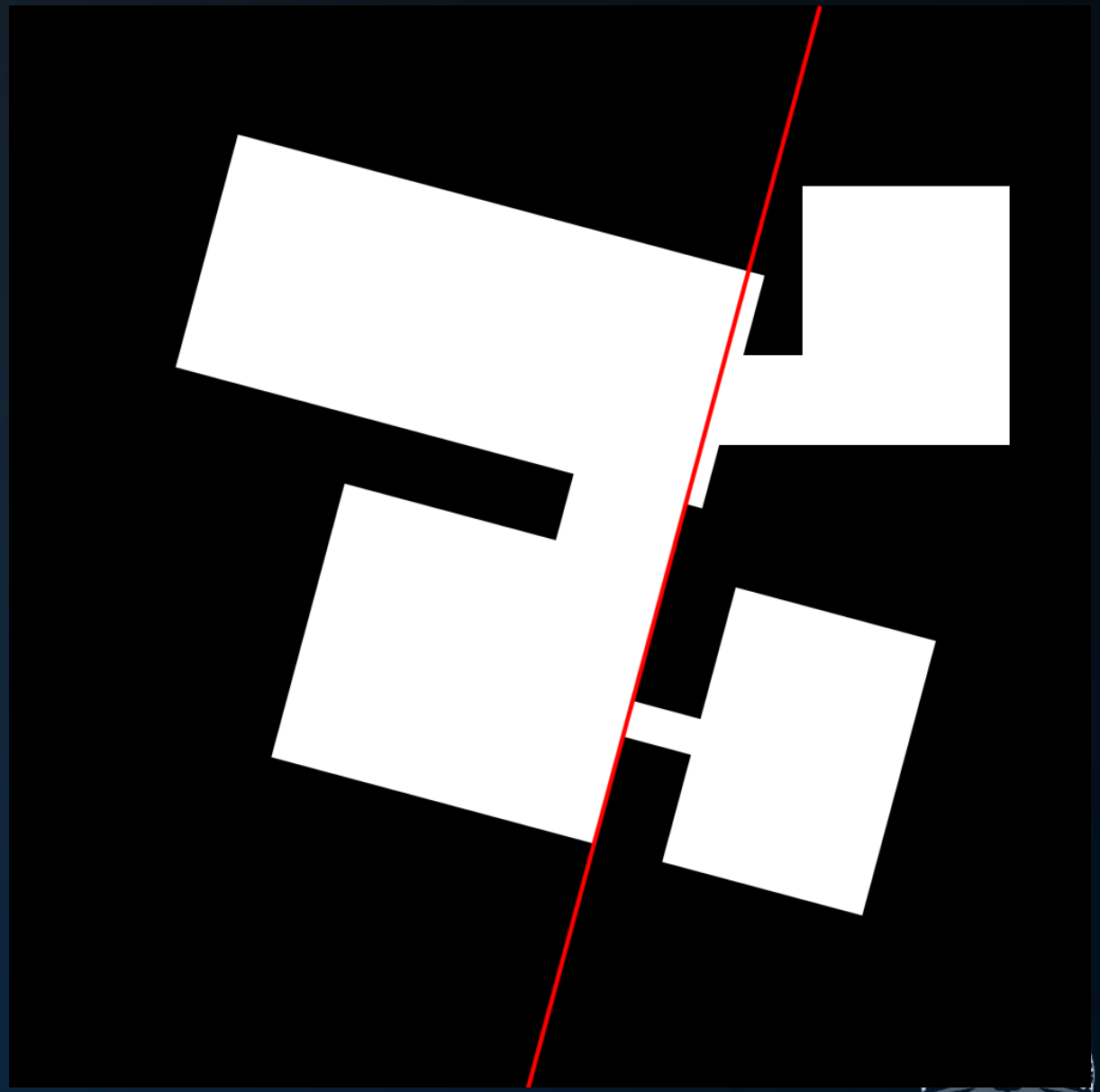

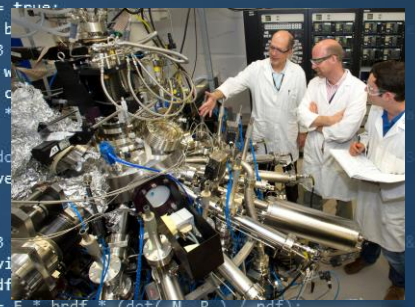

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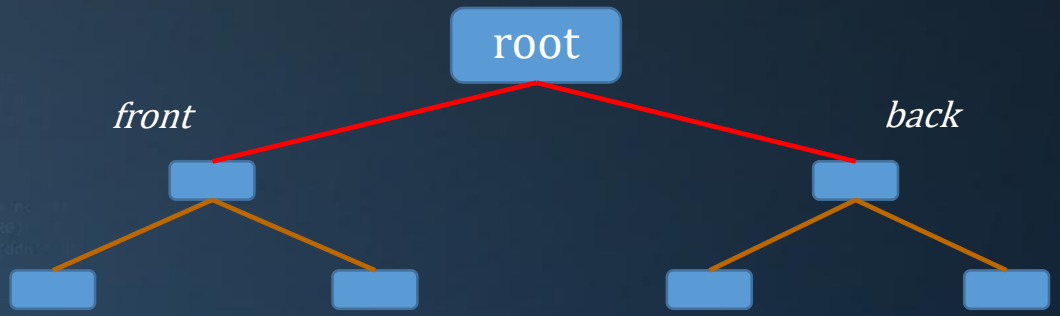

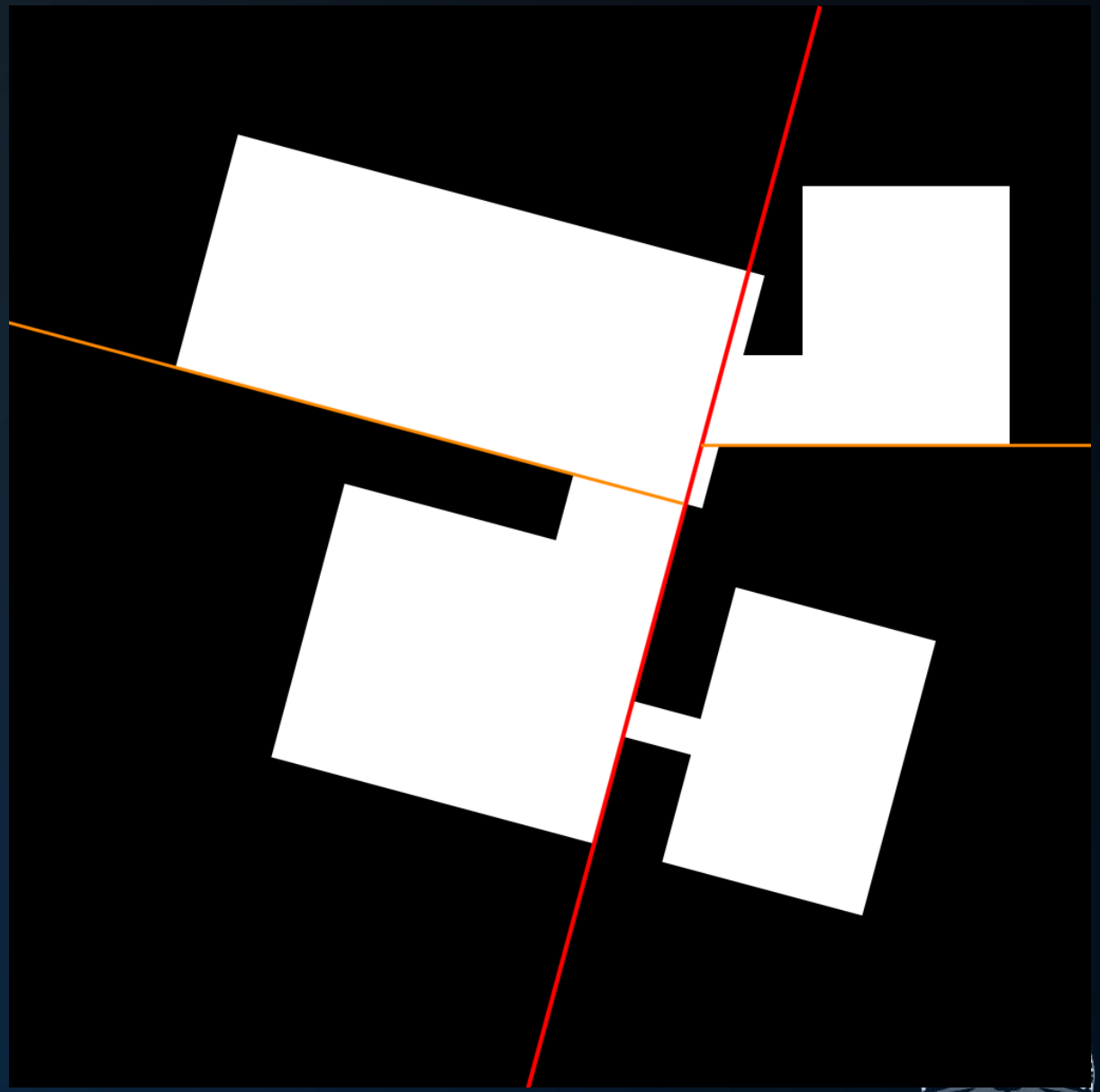

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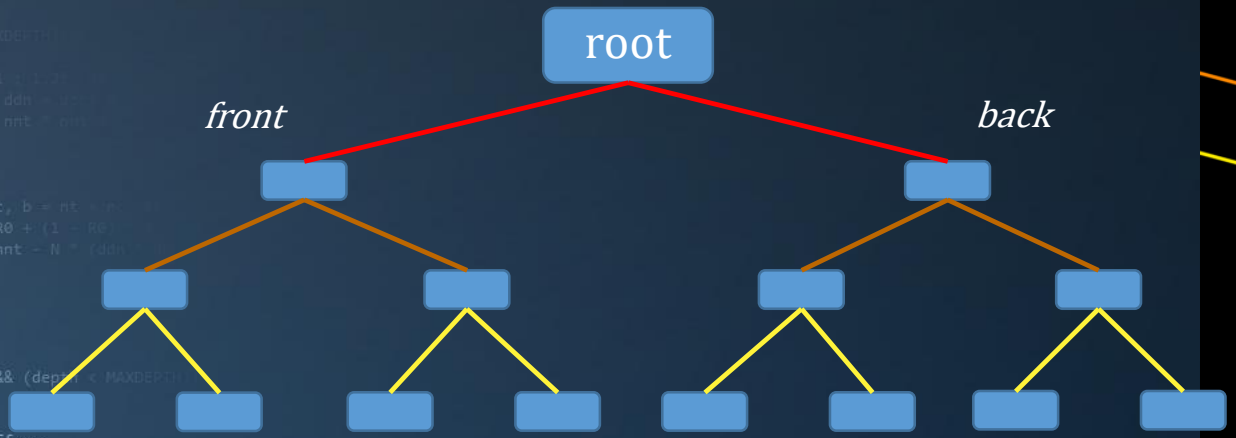

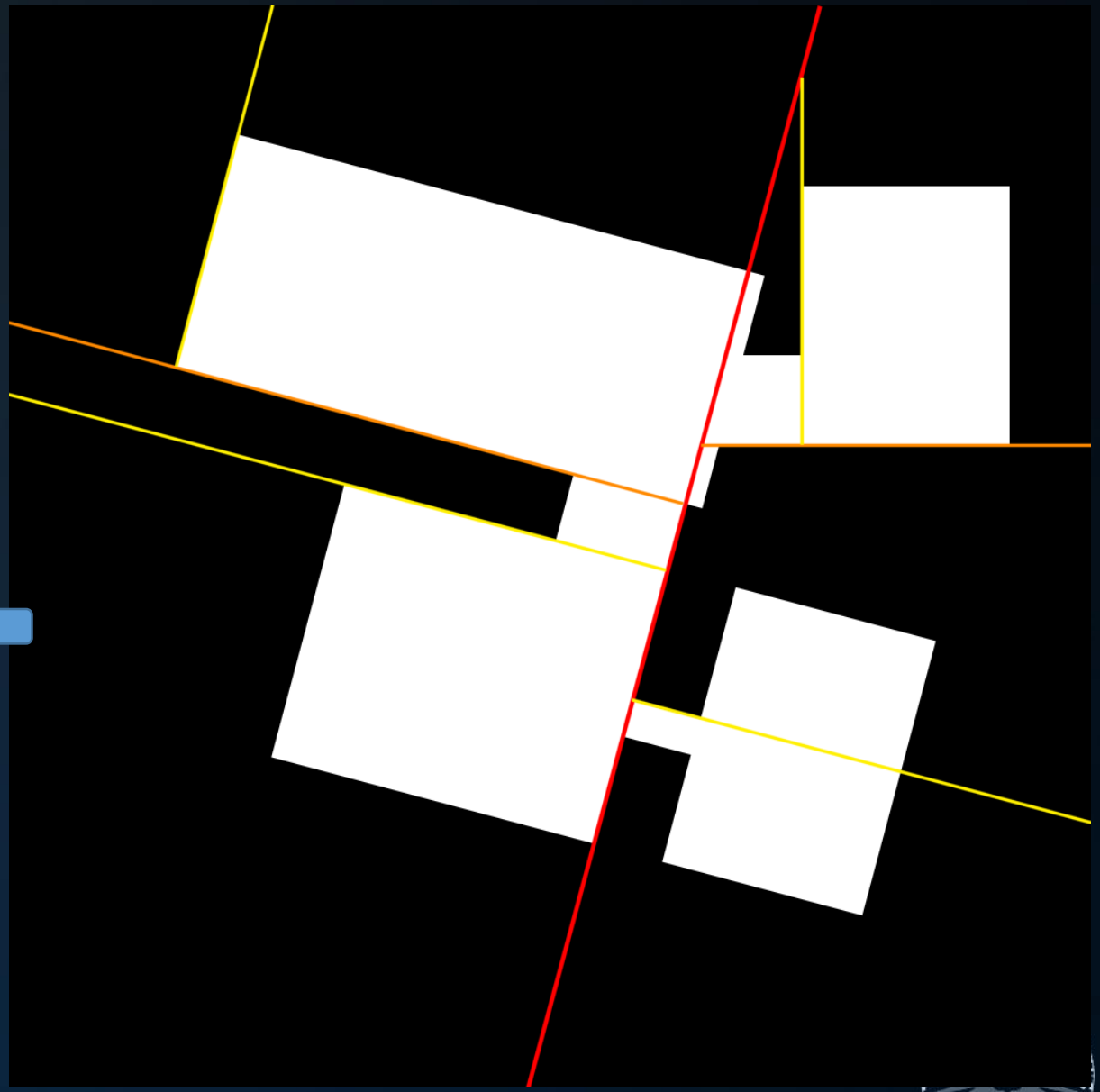

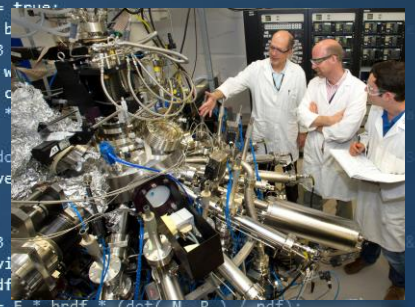

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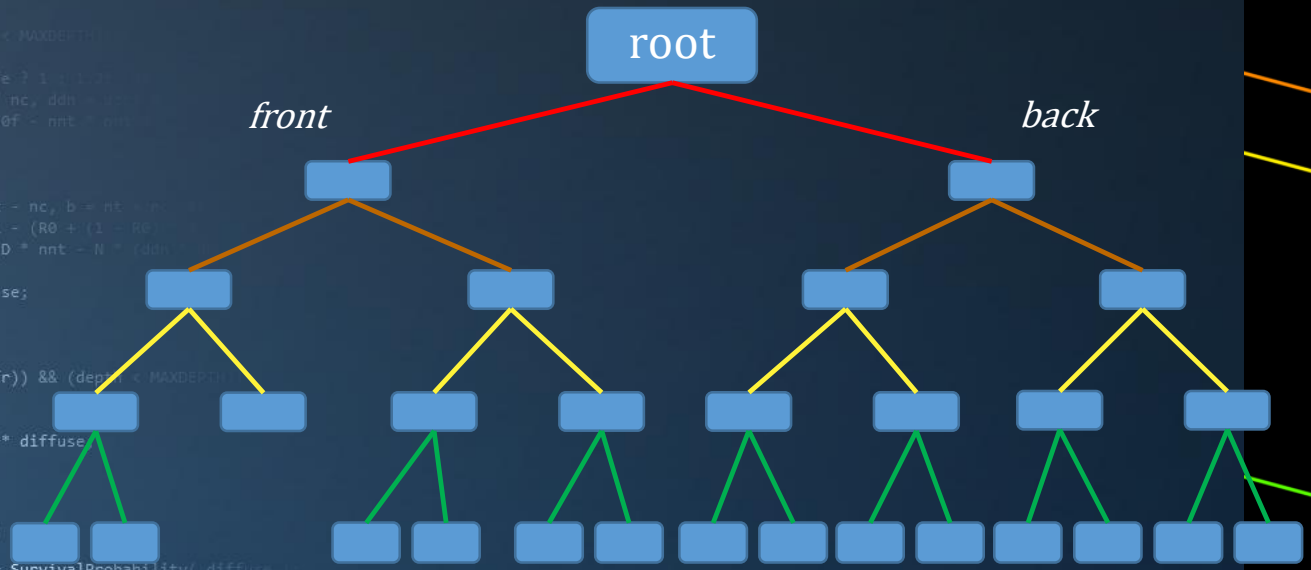

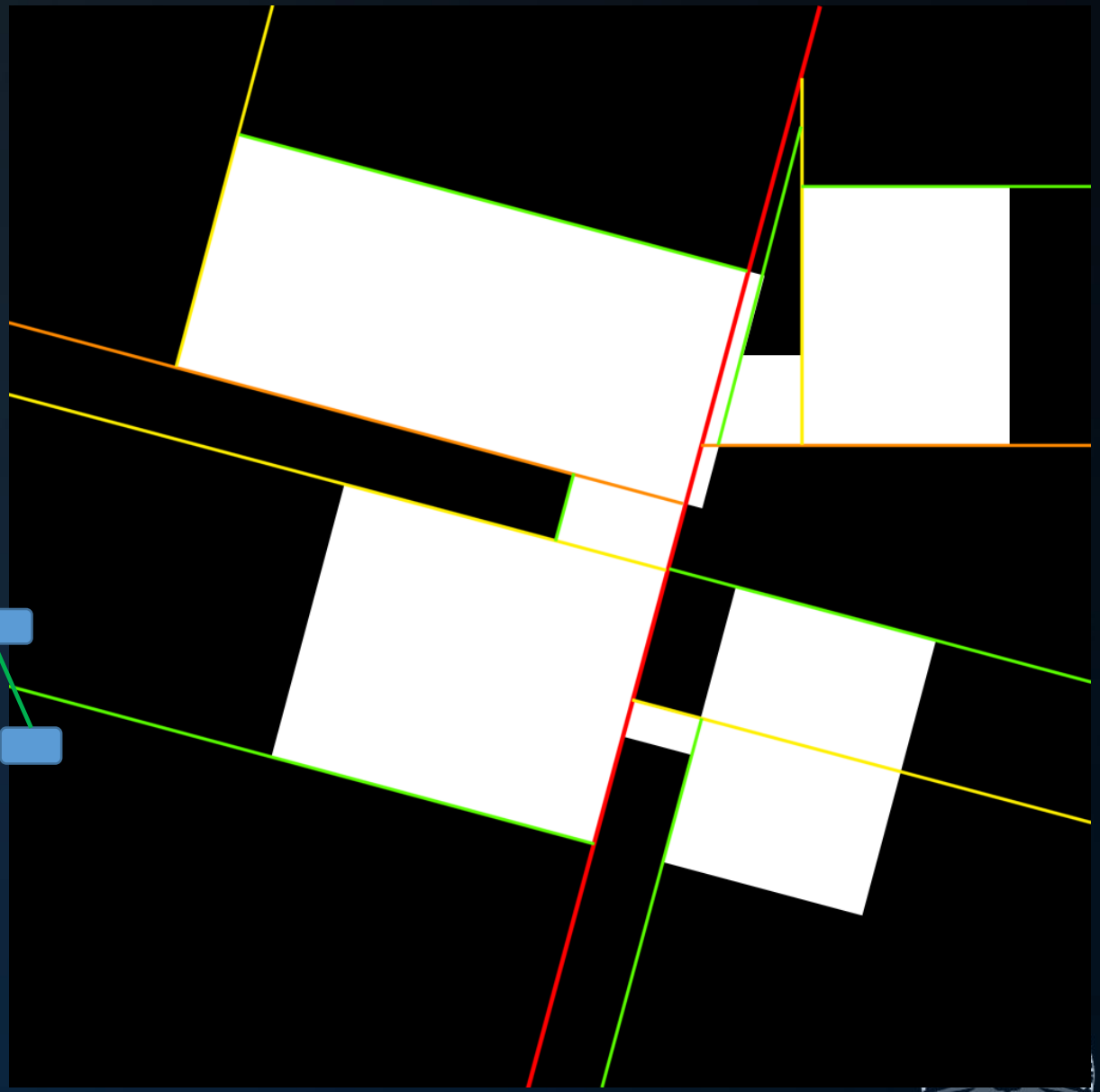

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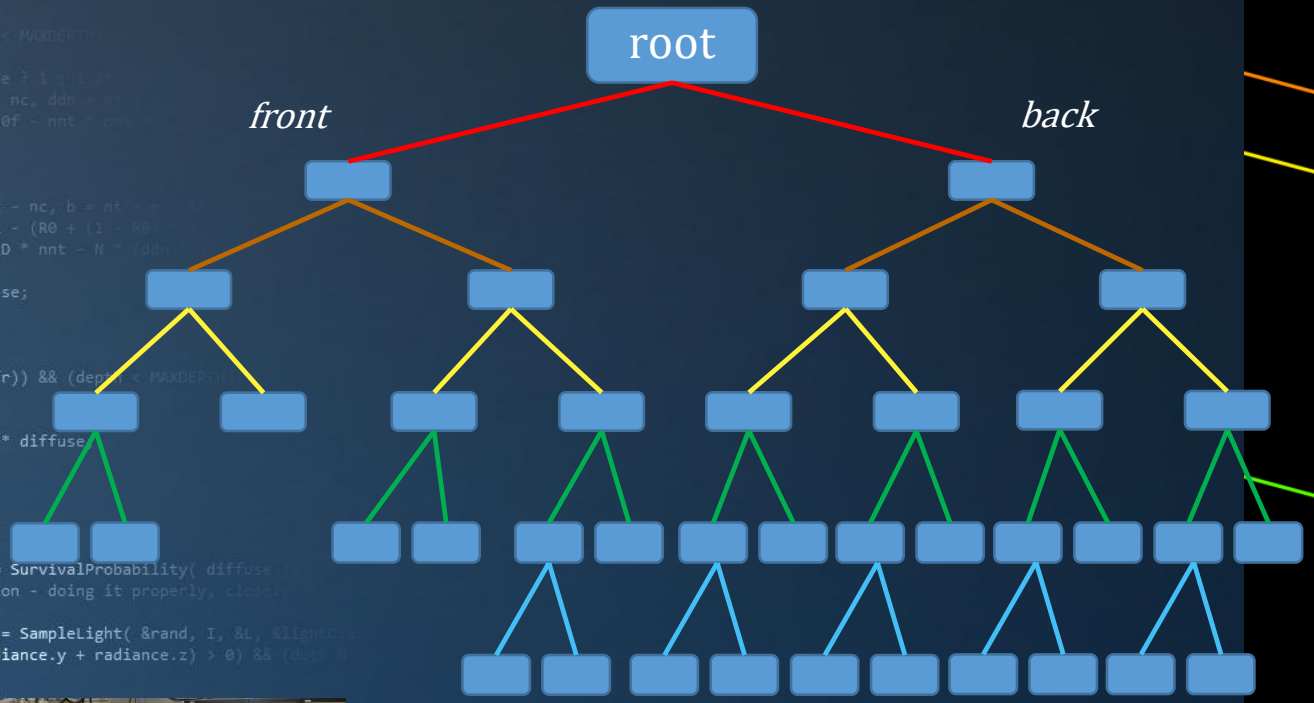

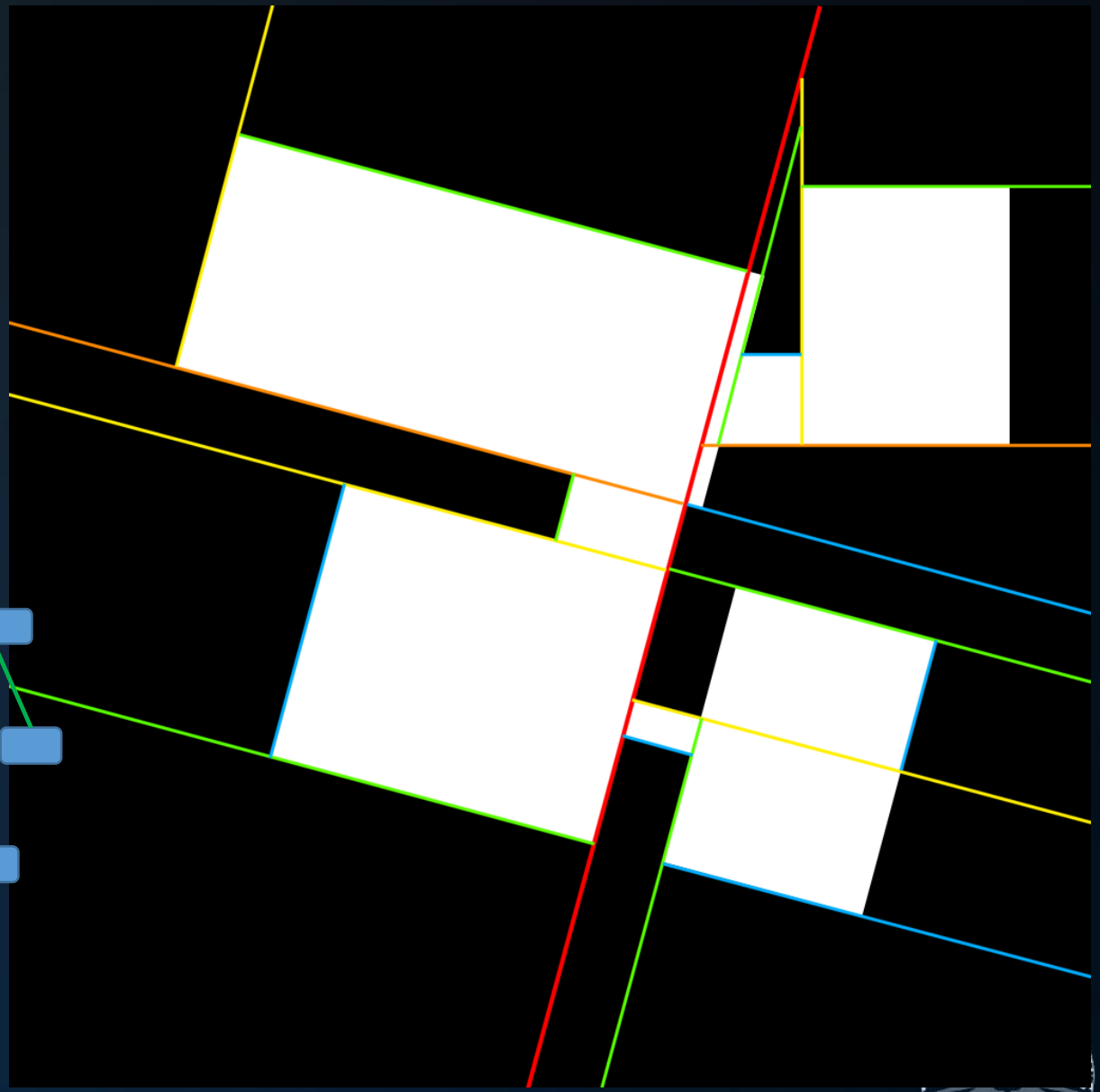

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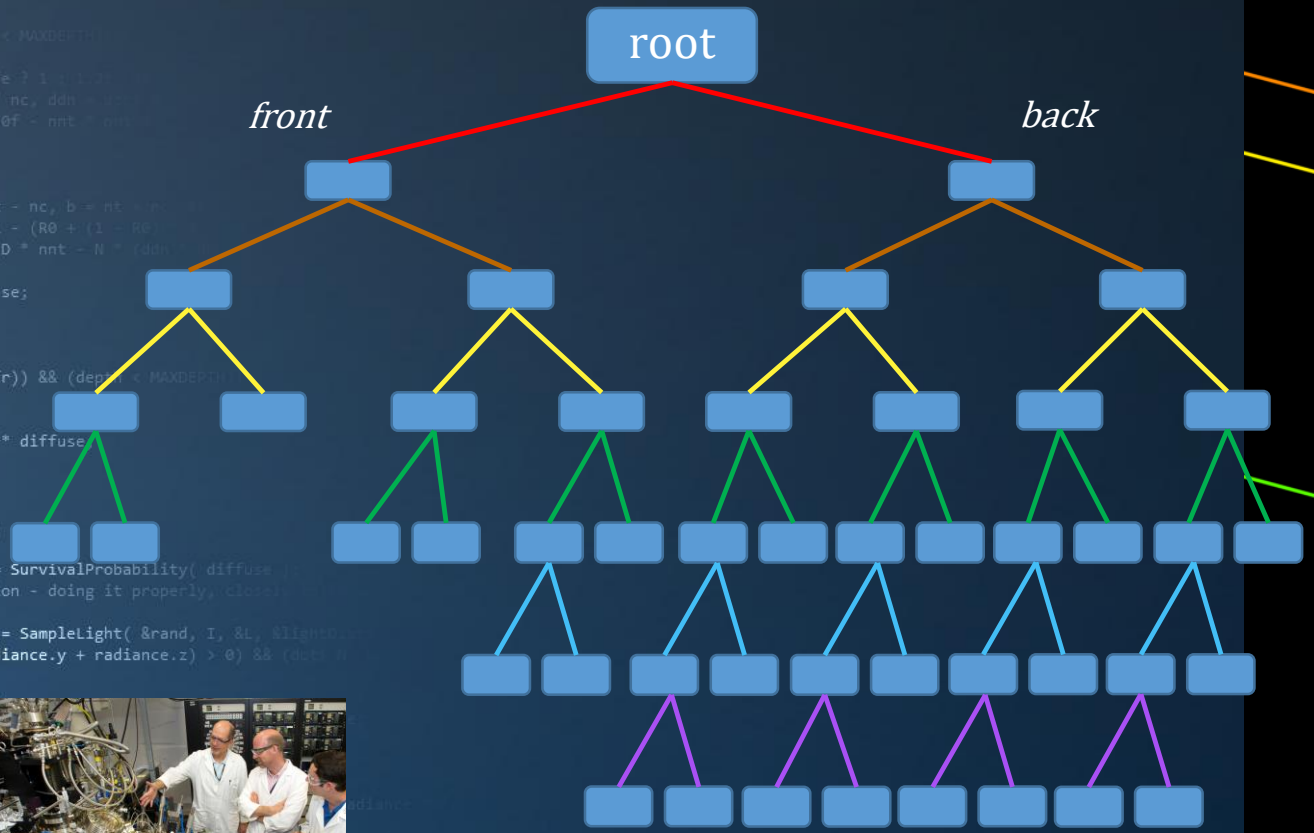
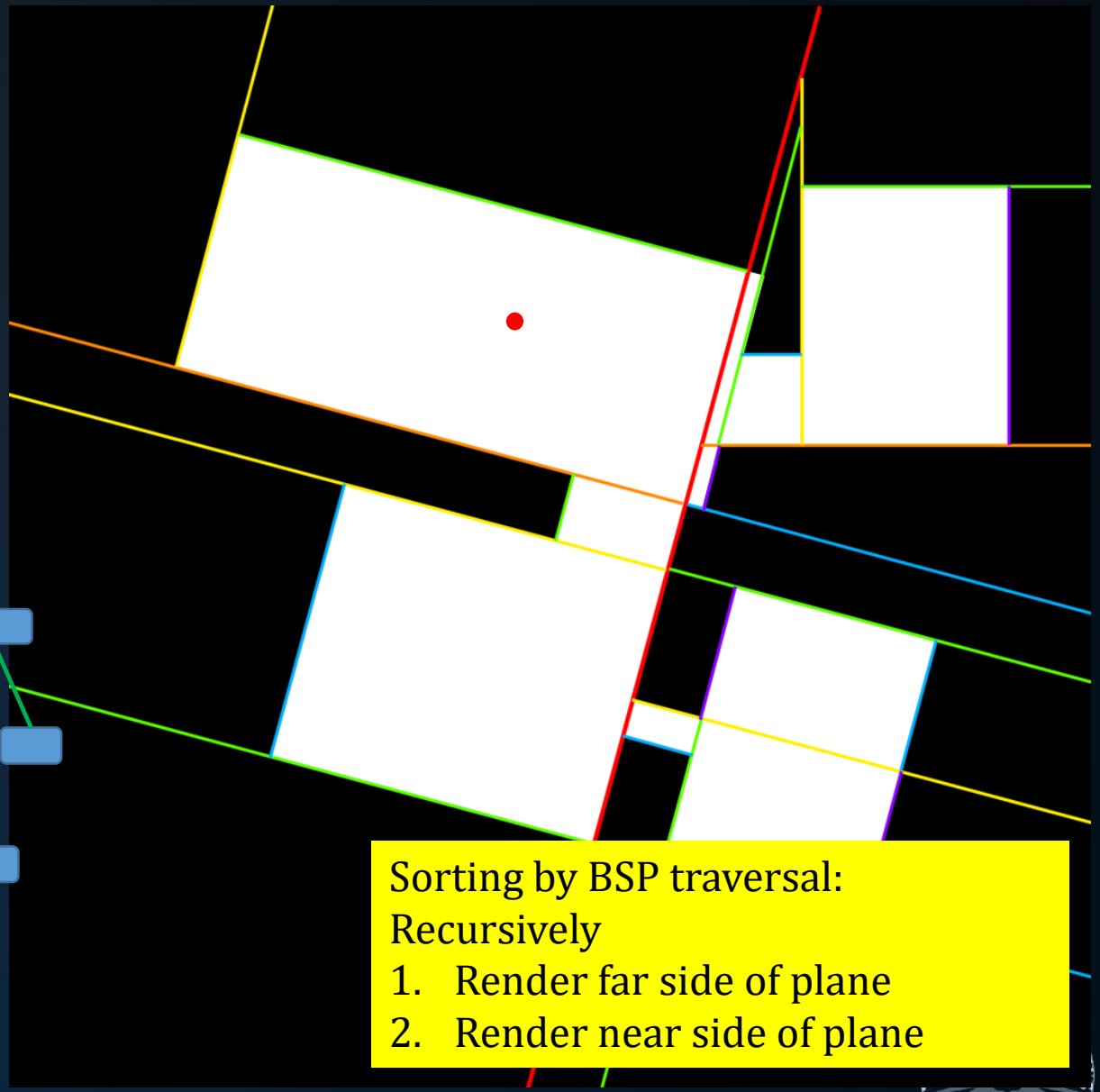




Sorting by BSP traversal:
Recursively
1. Render far side of plane
2. Render near side of plane

Depth Sorting

Draw order using a BSP:

- Guaranteed to be correct (hard cases result in polygon splits)
- No sorting required, just a tree traversal

But:

- Requires construction of BSP: not suitable for dynamic objects
- Does not eliminate overdraw

Depth Sorting

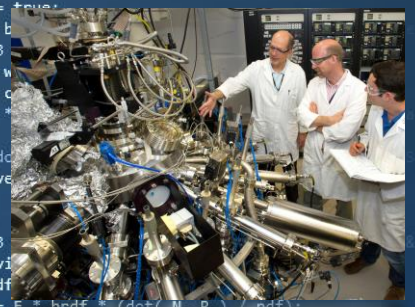
Z-buffer

A z-buffer stores, per screen pixel, a depth value.
The depth of each fragment is checked against this value:

- If the fragment is further away, it is discarded
- Otherwise, it is drawn, and the z-buffer is updated.

The z-buffer requires:

- An additional buffer
- Initialization of the buffer to z_{max}
- Interpolation of z over the triangle
- A z-buffer read and compare, and possibly a write.



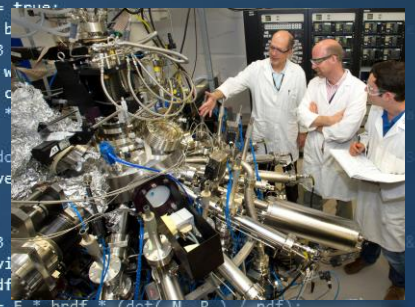
Depth Sorting

Z-buffer

What is the best representation for depth in a z-buffer?

1. Interpolated z (convenient, intuitive);
2. 1/z (or: $n + f - \frac{fn}{z}$) (more accurate nearby);
3. (int)((2^31-1)/z);
4. (uint)((2^32-1)/-z);
5. (uint)((2^32-1)/(-z + 1)).

Note: we use $z_{\text{int}} = \frac{(2^{32}-1)}{-z+1}$:
this way, any $z < 0$ will be in the range $z_{\text{adjusted}} = -z_{original} + 1 = 1..\infty$, therefore $1/z_{adjusted}$ will be in the range 0..1, and thus the integer value we will store uses the full range of $0..2^{32} - 1$.
Here, $z_{int} = 0$ represents $z_{original} = 0$, and $z_{int} = 2^{32} - 1$ represents $z_{original} = -\infty$.



Even more details:
https://developer.nvidia.com/content/depth-precision-visualized
http://outerra.blogspot.nl/2012/11/maximizing-depth-buffer-range-and.html

Depth Sorting

Z-buffer optimization

In the ideal case, the nearest fragment for a pixel is drawn first:

- This causes all subsequent fragments for the pixel to be discarded;
- This minimizes the number of writes to the frame buffer and z-buffer.

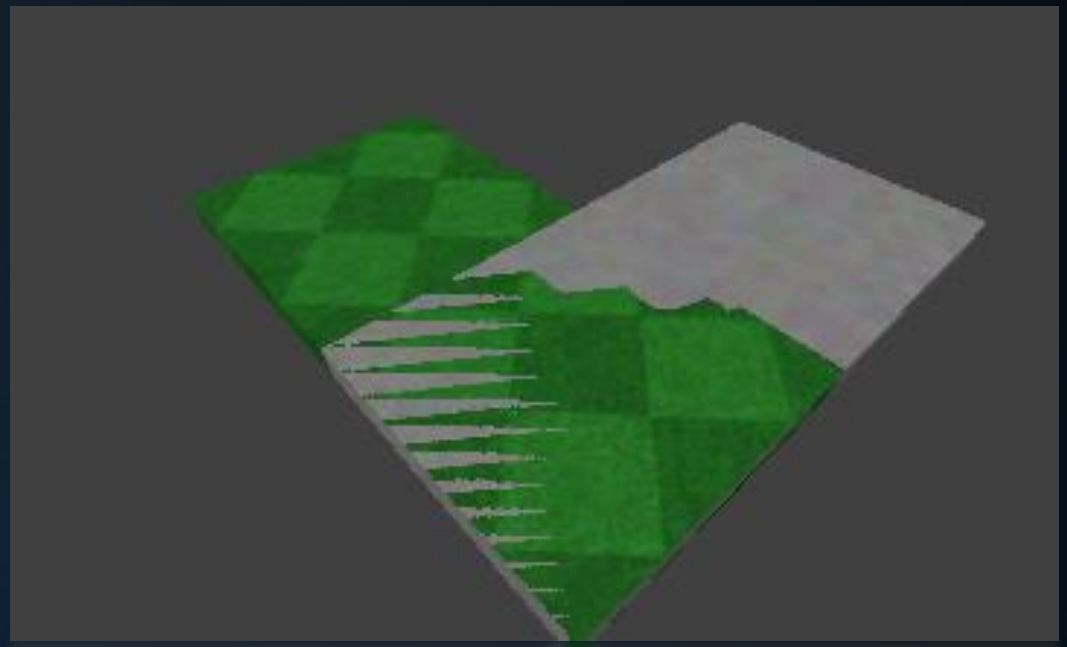
The ideal case can be approached by using Painter’s to ‘pre-sort’.

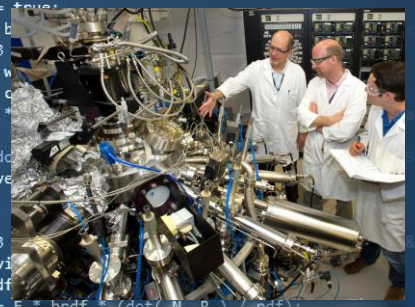
Depth Sorting

‘Z-fighting’:

Occurs when two polygons have almost identical z-values.

Floating point inaccuracies during interpolation will cause unpleasant patterns in the image.






Part of the tree is off-screen
Stuff that is too far to draw
Tree requires little detail
√ City obscured by tree
√ Torso closer than ground
Tree between ground & sun

Today’s Agenda:

- Depth Sorting
- Clipping
- Visibility

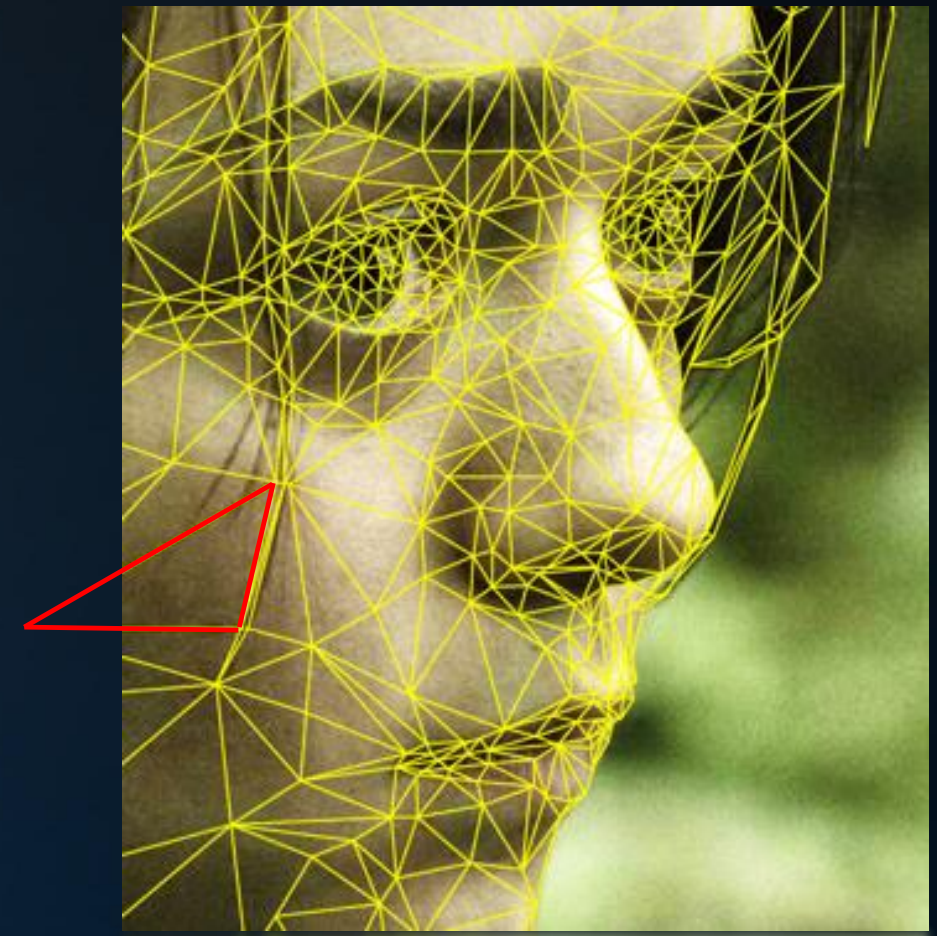
Clipping

Clipping

Many triangles are partially off-screen. This is handled by *clipping* them.

Sutherland-Hodgeman clipping:

Clip triangle against 1 plane at a time;
Emit *n-gon* (0, 3 or 4 vertices).

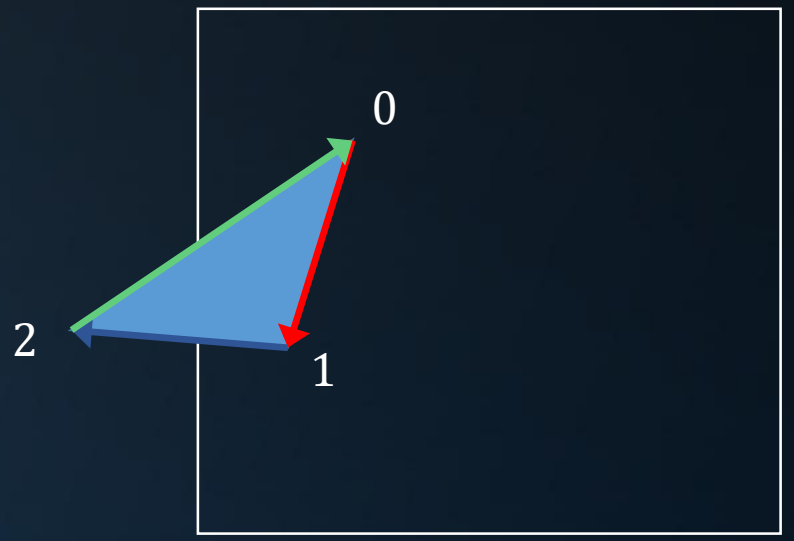


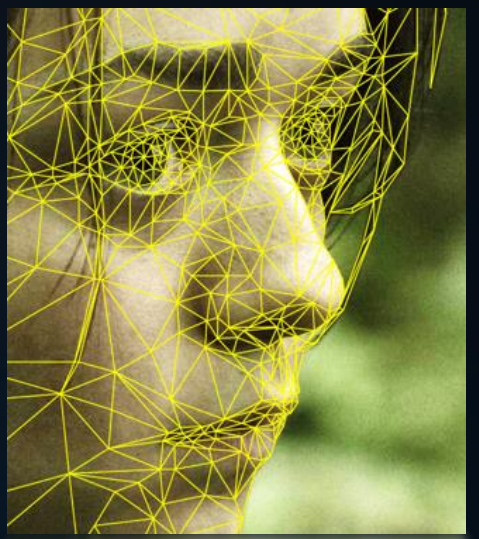
Clipping

Sutherland-Hodgeman

Input: list of vertices

Algorithm:





Per edge with vertices v_0 and v_1:

- If v_0 and v_1 are ‘in’, emit v_1
- If v_0 is ‘in’, but v_1 is ‘out’, emit C
- If v_0 is ‘out’, but v_1 is ‘in’, emit C and v_1

where C is the intersection point of the edge and the plane.

Output: list of vertices, defining a convex n-gon.

in	out
Vertex 0	Vertex 1
Vertex 1	Intersection 1
Vertex 2	Intersection 2
	Vertex 0

Clipping

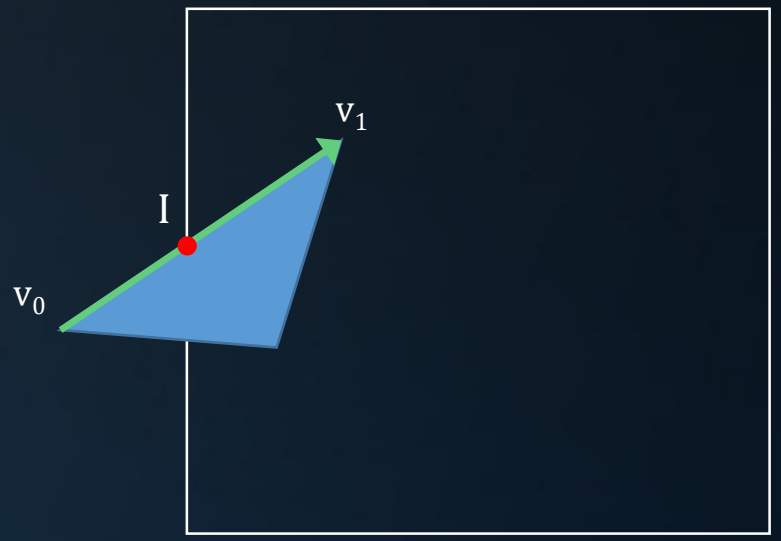
Sutherland-Hodgeman

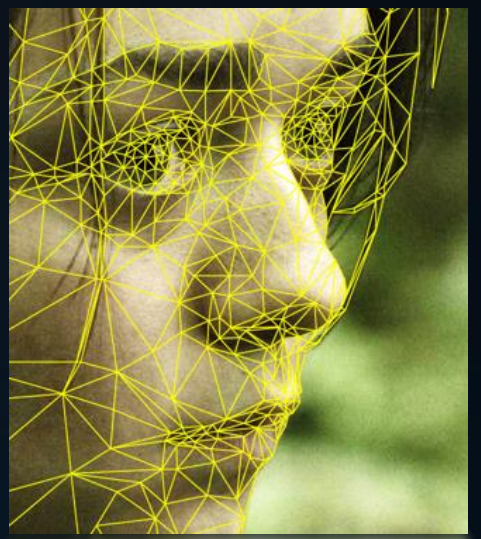
Calculating the intersections with plane $ax + by + cz + d = 0$:

$$dist_v = v \cdot \begin{pmatrix} a \\ b \\ c \end{pmatrix} + d$$

$$f = \frac{|dist_{v0}|}{|dist_{v0}| + |dist_{v1}|}$$

$$I = v_0 + f(v_1 - v_0)$$





After clipping, the input n-gon may have at most 1 extra vertex. We may have to triangulate it:

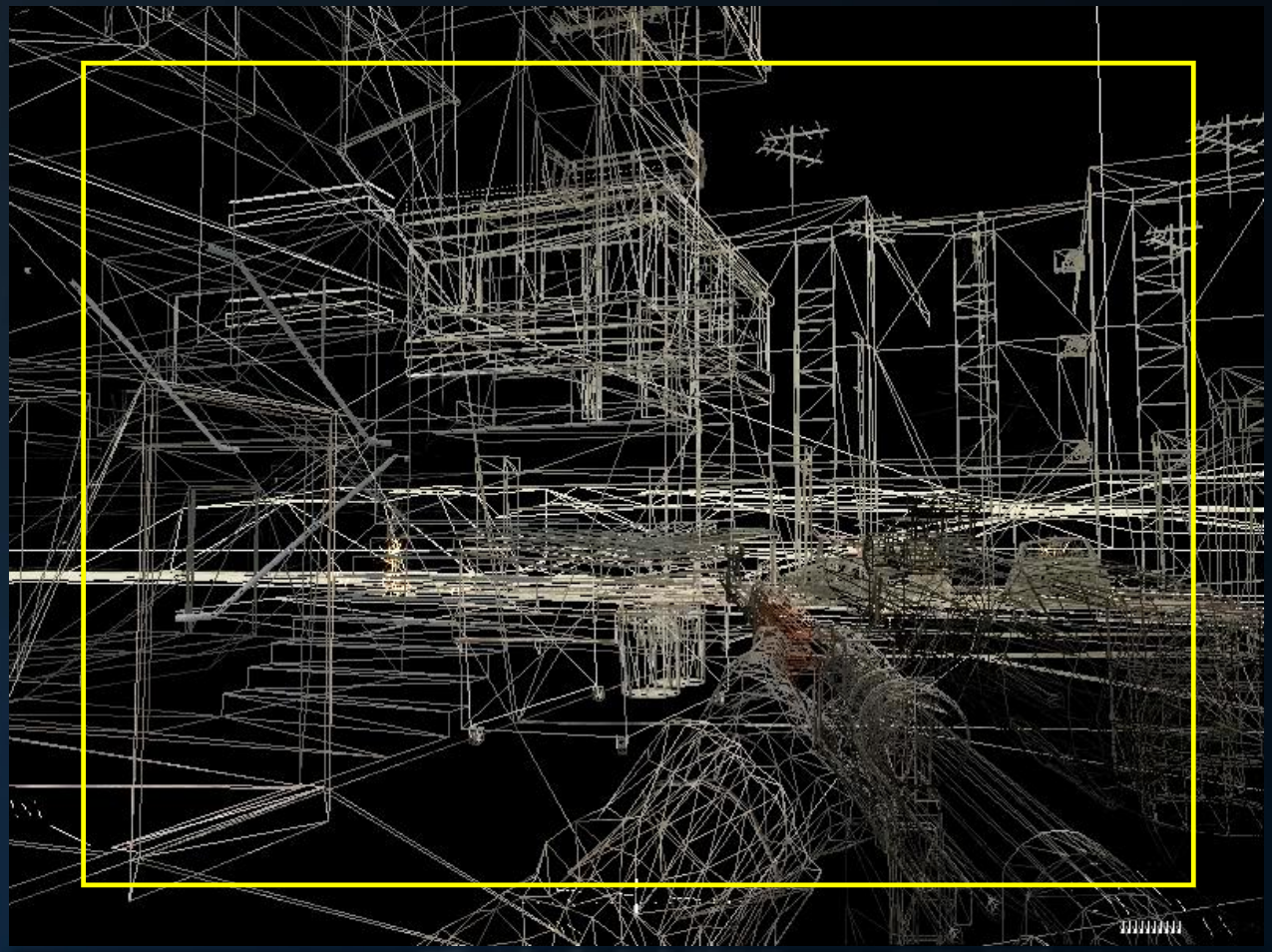
0,1,2,3,4 ➔ 0, 1, 2 + 0, 2, 3 + 0, 3, 4.

Clipping

Guard bands

To reduce the number of polygons that need clipping, some hardware uses *guard bands* : an invisible band of pixels outside the screen.

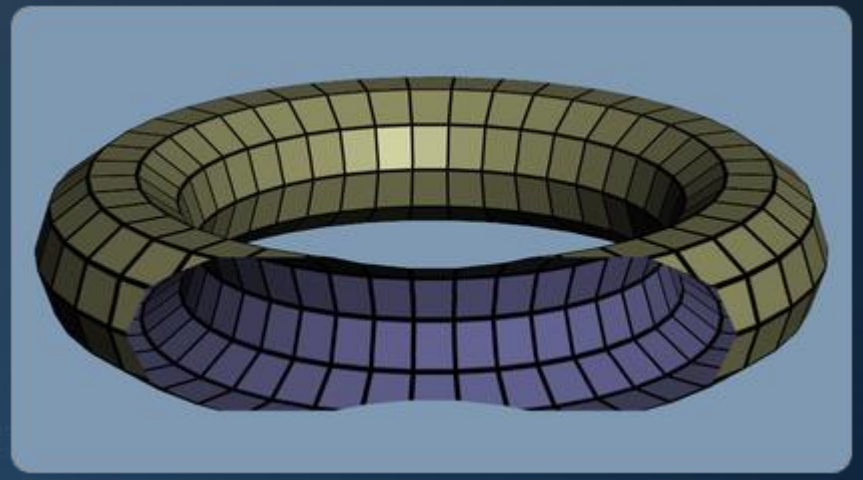
- Polygons outside the screen are discarded, even if they touch the guard band;
- Polygons partially inside, partially in the guard band are drawn without clipping;
- Polygons partially inside the screen, partially outside the guard band are clipped.

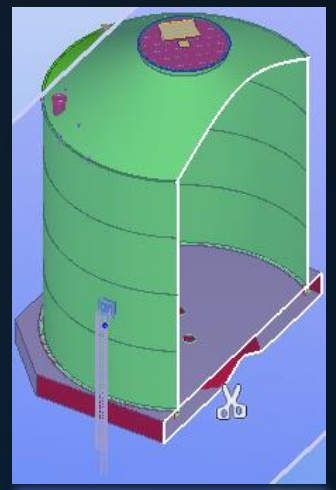


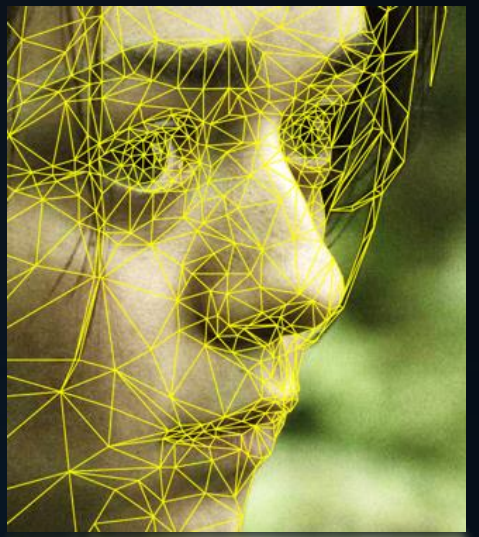
Clipping

Sutherland-Hodgeman

Clipping can be done against arbitrary planes.







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√ Part of the tree is off-screen
Stuff that is too far to draw
Tree requires little detail
√ City obscured by tree
√ Torso closer than ground
Tree between ground & sun

Visibility

Only rendering what’s visible:

“Performance should be determined by visible geometry, not overall world size.”

- Do not render geometry outside the view frustum
- Better: do not *process* geometry outside frustum
- Do not render occluded geometry
- Do not render anything more detailed than strictly necessary

Visibility

Culling

Observation:
50% of the faces of a cube are not visible.

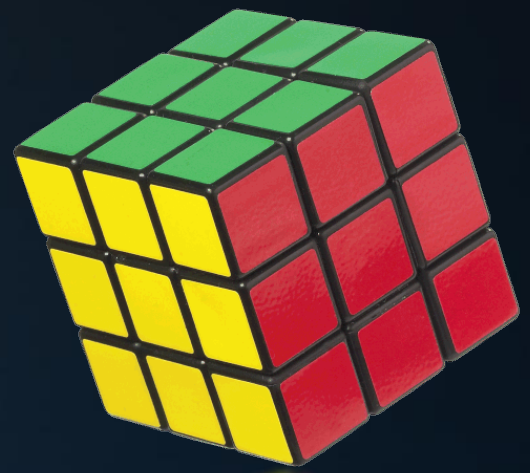
On average, this is true for all meshes.

Culling ‘backfaces’:

Triangle: $ax + by + cz + d = 0$
Camera: (x, y, z)
Visible: fill in camera position in plane equation.

$ax + by + cz + d > 0$: *visible*.

Cost: 1 dot product per triangle.



Visibility

Culling

Observation:
If the *bounding sphere* of a mesh is outside the view frustum, the mesh is not visible.

But also:
If the *bounding sphere* of a mesh intersects the view frustum, the mesh may be not visible.

View frustum culling is typically a *conservative test:* we sacrifice accuracy for efficiency.

Cost: 1 dot product per mesh.

Visibility

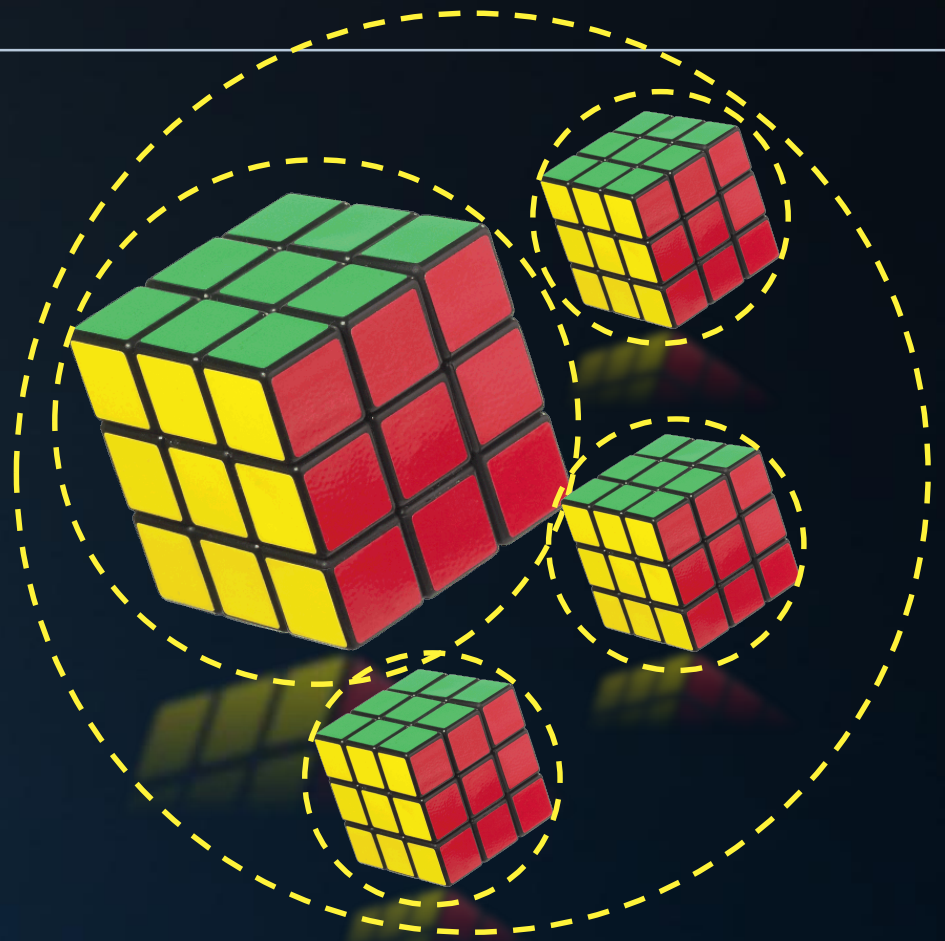
Culling

Observation:
If the *bounding sphere* over a group of bounding spheres is outside the view frustum, a group of meshes is invisible.

We can store a bounding volume hierarchy in the scene graph:

- Leaf nodes store the bounds of the meshes they represent;
- Interior nodes store the bounds over their child nodes.

Cost: 1 dot product per scene graph subtree.

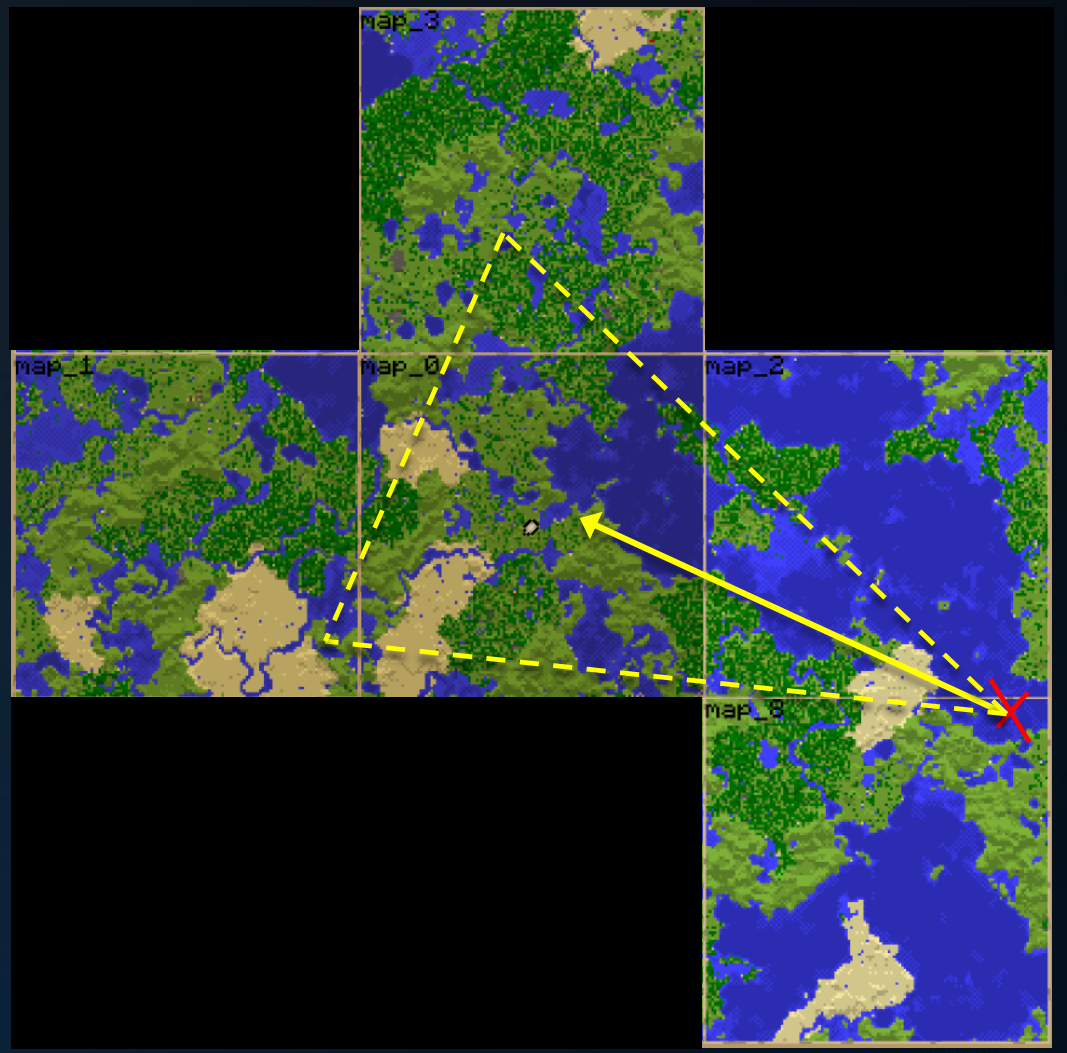


Visibility

Culling

Observation:
If a grid cell is outside the view frustum, the contents of that grid cell are not visible.

Cost: 0 for out-of-range grid cells.



Visibility

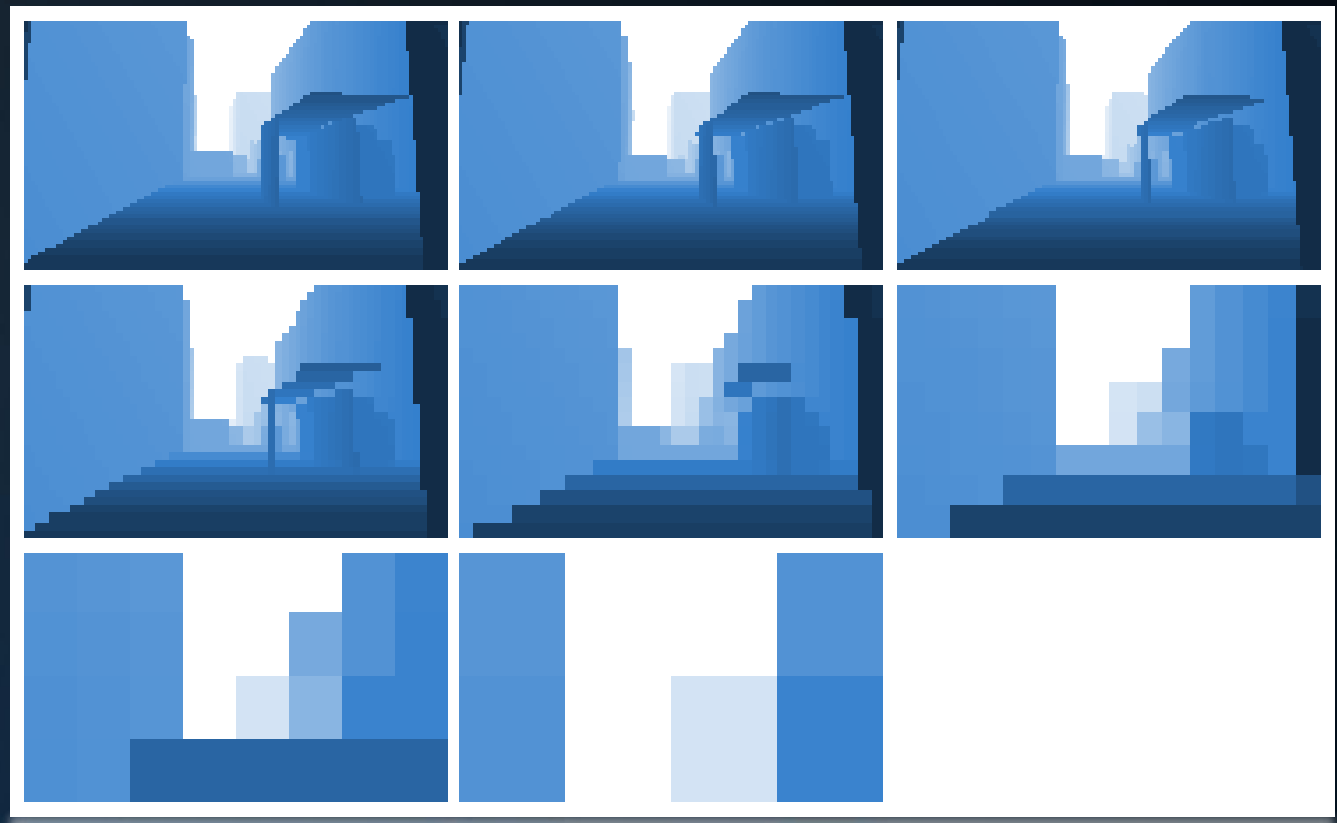
Occlusion Culling

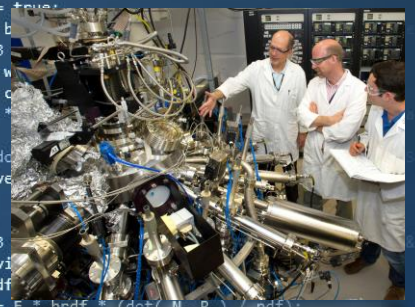
Not rendering things that are guaranteed to be behind something else.

Hierarchical z-buffer:

a set of MIP-maps of the z-buffer.

Use: with a small amount of tests, we can check the bounds of a mesh against this buffer.





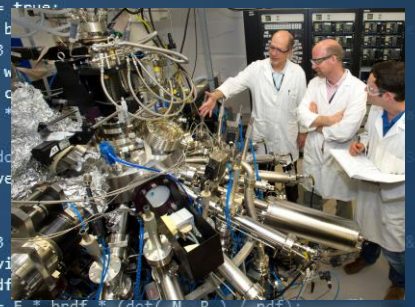
Visibility

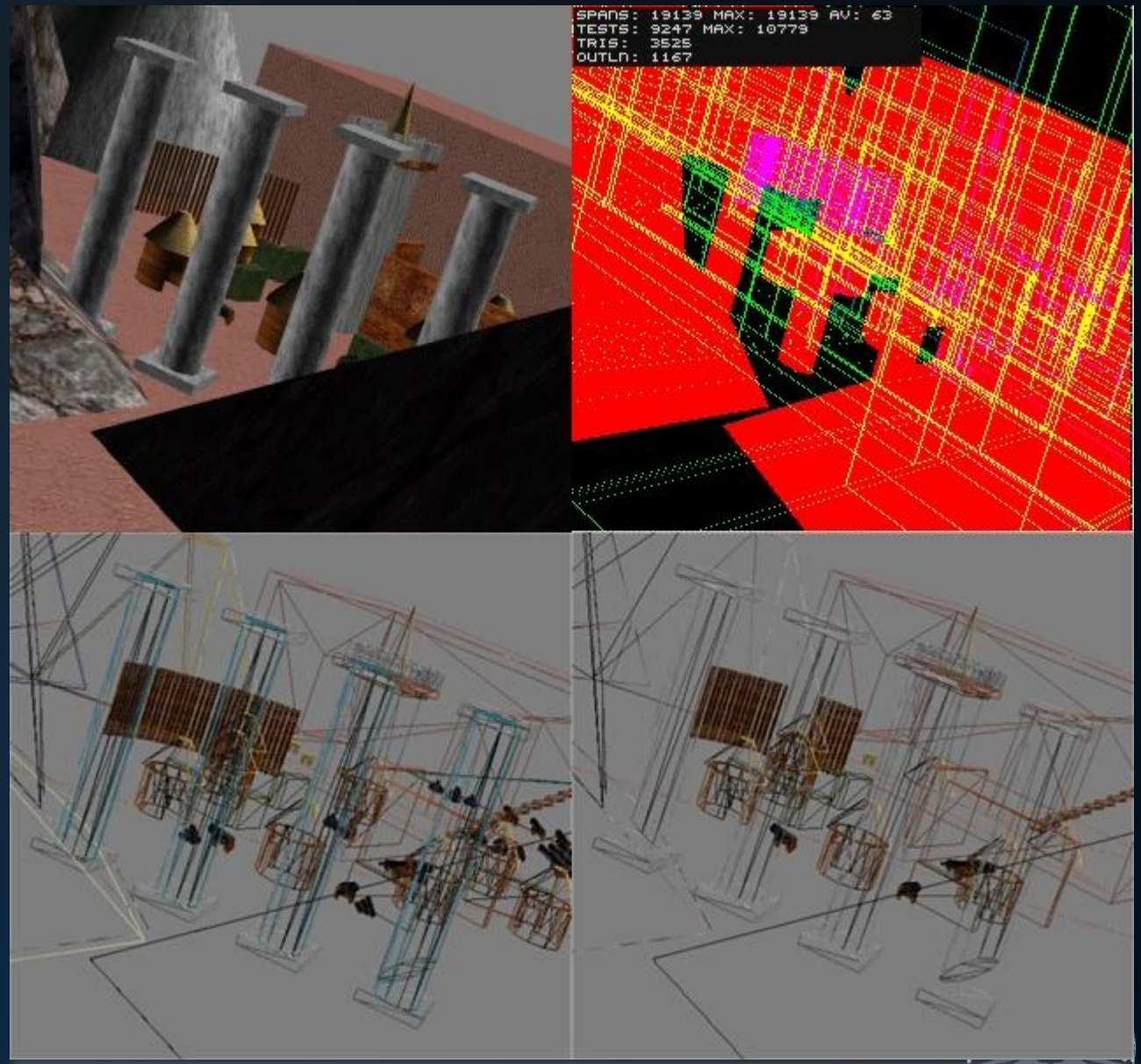
Occlusion Culling

Not rendering things that are guaranteed to be behind something else.

Coverage buffer:

A low-resolution version of (a simplified version of) the scene, rendered on the CPU, which we can use for visibility tests.





Flipcode IOTD, 2000: https://www.flipcode.com/archives/10-18-2000.shtml

Visibility

Occlusion Culling

Not rendering things that are guaranteed to be behind something else.

Coverage buffer:

A low-resolution version of (a simplified version of) the scene, rendered on the CPU, which we can use for visibility tests.

Masked Software Occlusion Culling, Intel, 2016

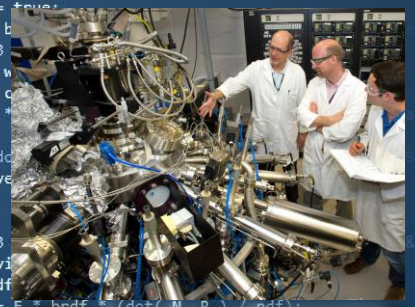
Visibility

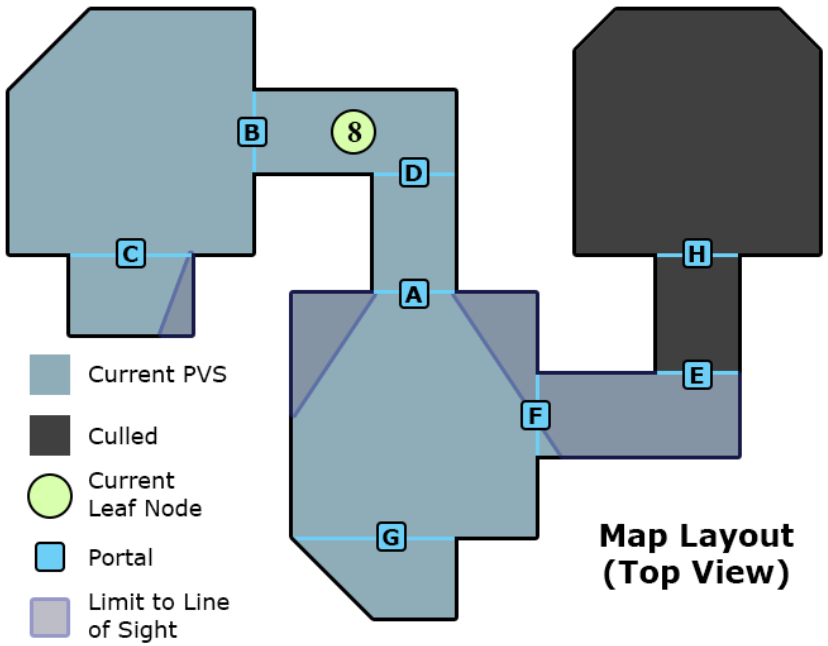
Occlusion Culling

Not rendering things that are guaranteed to be behind something else.

Potential Visibility Set:

a table that tells us which areas are mutually visible.





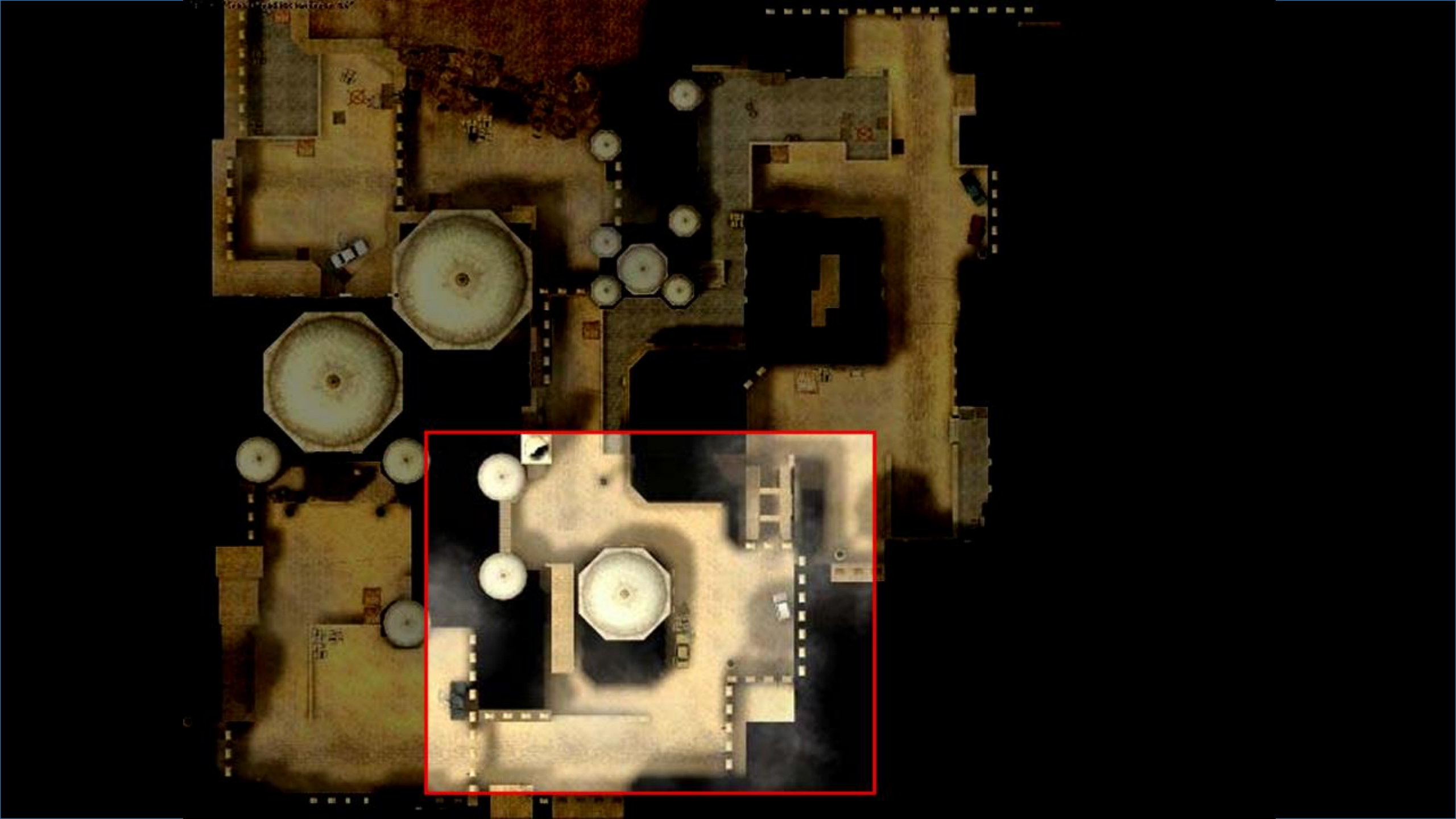
PVS-Table

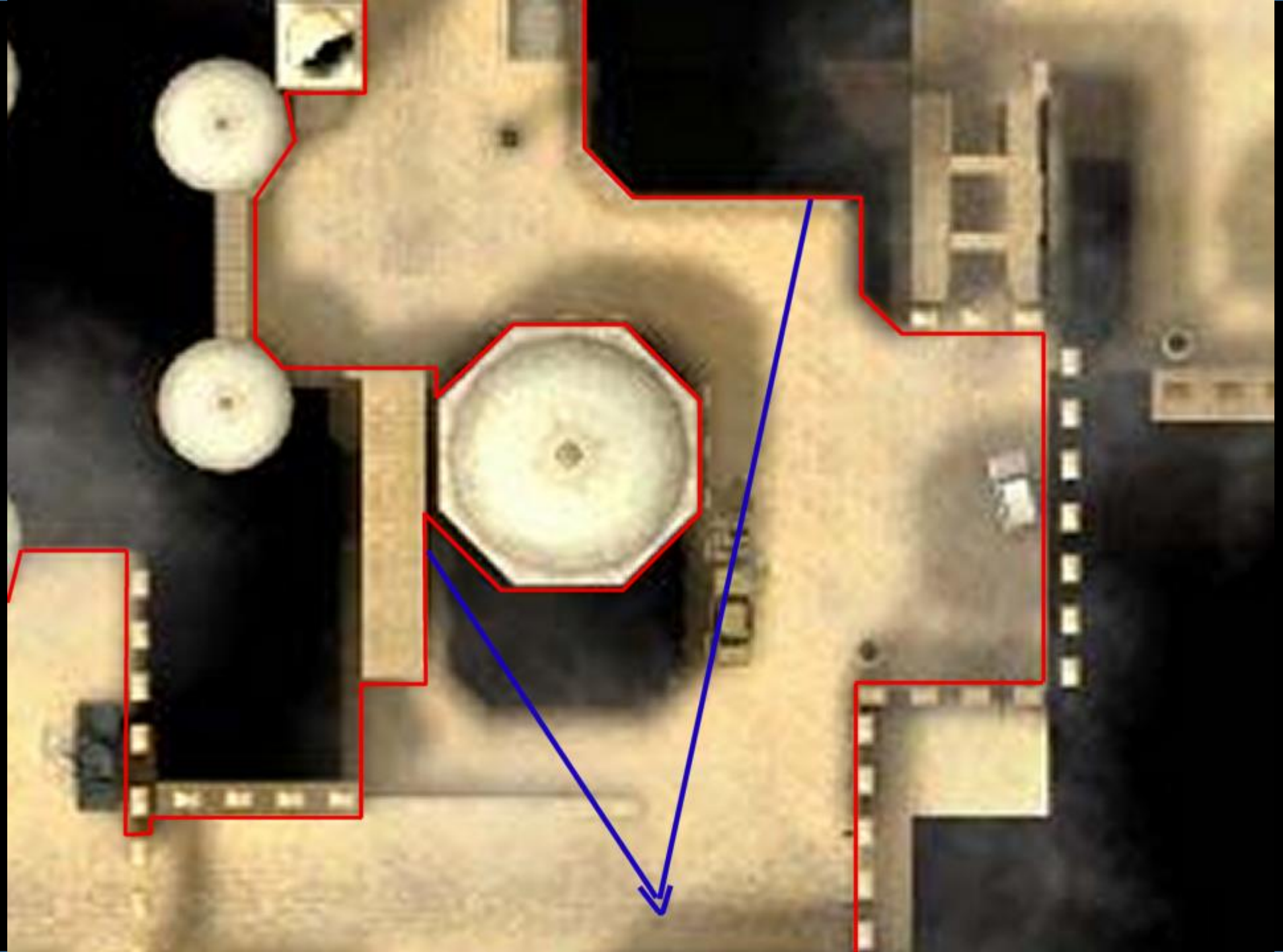
	B	C	D	E	F	G	H
A	✗	✗	✓	✗	✓	✓	✗
B		✓	✓	✗	✗	✗	✗
C			✗	✗	✗	✗	✗
D				✗	✓	✓	✗
E					✓	✓	✓
F						✓	✗
G							✗

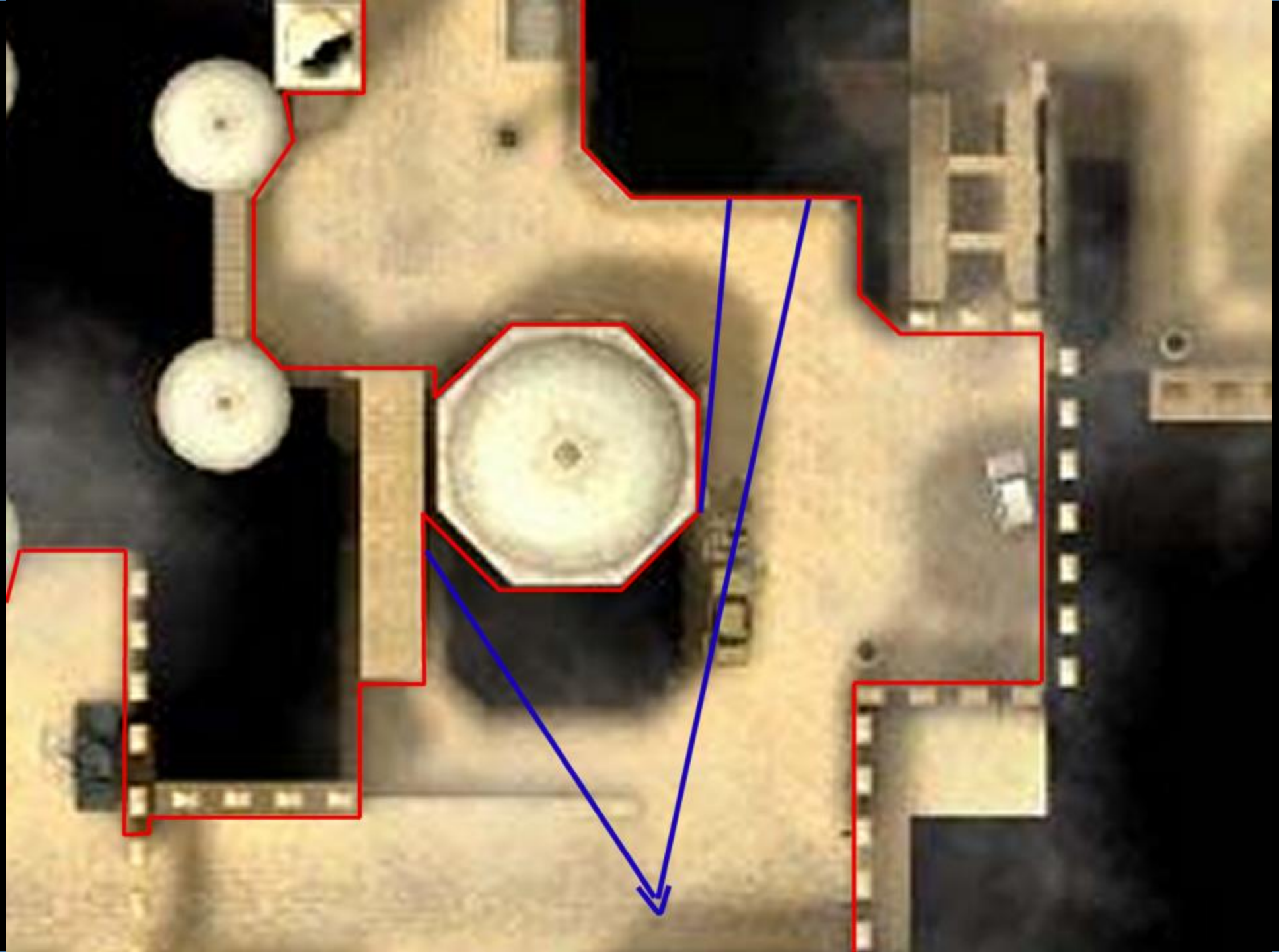
Visibility

Indoor visibility: Portals

Observation: if a window is invisible, the room it links to is invisible.





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Visibility

Visibility determination

Coarse:

- Grid-based (typically outdoor)
- Portals (typically indoor)

Finer:

- Frustum culling
- Occlusion culling

Finest:

- Backface culling
- Clipping
- Z-buffer

Today’s Agenda:

- Depth Sorting
- Clipping
- Visibility

INFOGR – Computer Graphics

Jacco Bikker & Debabrata Panja - April-July 2018

END OF lecture 13: “Visibility”

Next lecture: “Postprocessing”