# INFOGR – Computer Graphics

J. Bikker - April-July 2015 - Lecture 7: “Visibility”

# Welcome!

# …

Perpendicular

Vectors perpendicular to $\binom{x}{y}$: $\binom{-y}{x}$, $\binom{y}{-x}$

Calculating a vector perpendicular to $\begin{pmatrix}x\\y\\z\end{pmatrix}$: $\xcancel{\begin{pmatrix}-y\\x\\z\end{pmatrix}}$ $\begin{pmatrix}-y\\x\\0\end{pmatrix}$

**additional rules apply*

Verify:

$$\begin{pmatrix}x\\y\\z\end{pmatrix} \cdot \begin{pmatrix}-y\\x\\0\end{pmatrix} = x * -y + y * x + z * 0 = 0\,.$$

# Today’s Agenda:

- Depth Sorting
- Clipping
- Visibility
- The Midterm Exam

# Depth Sorting

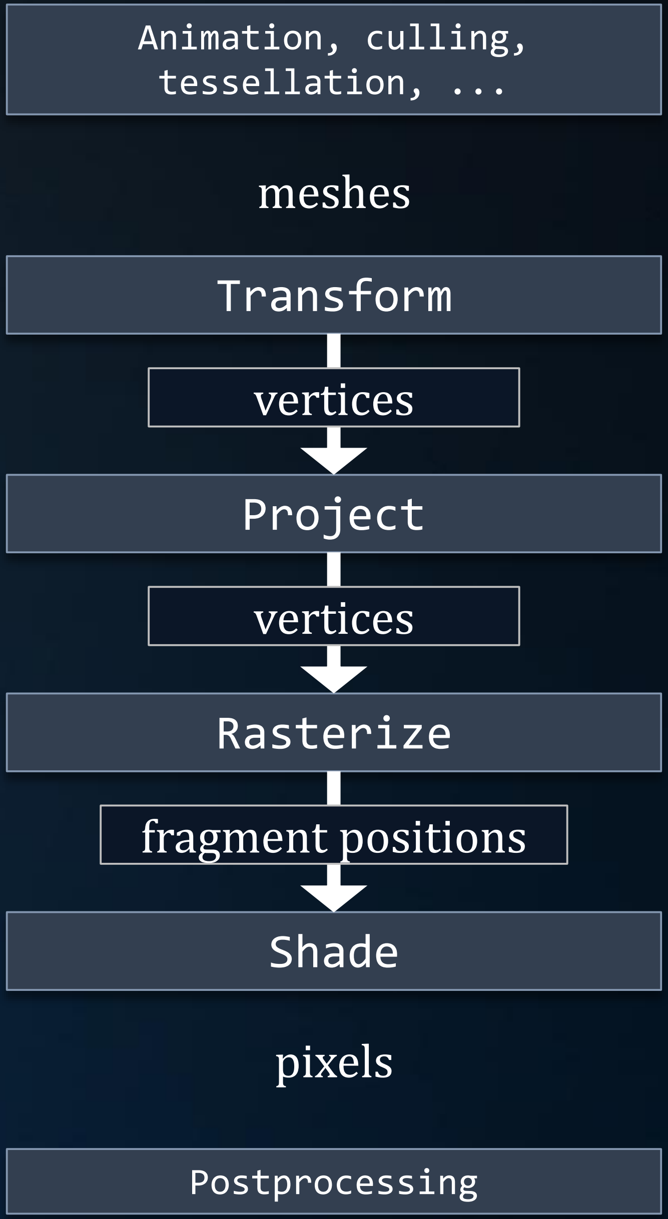
Rendering – Functional overview

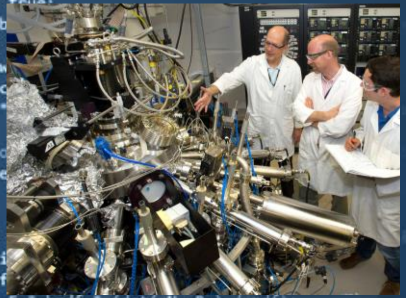
1. Transform:
   translating / rotating meshes

2. Project:
   calculating 2D screen positions

3. Rasterize:
   determining affected pixels

4. Shade:
   calculate color per affected pixel





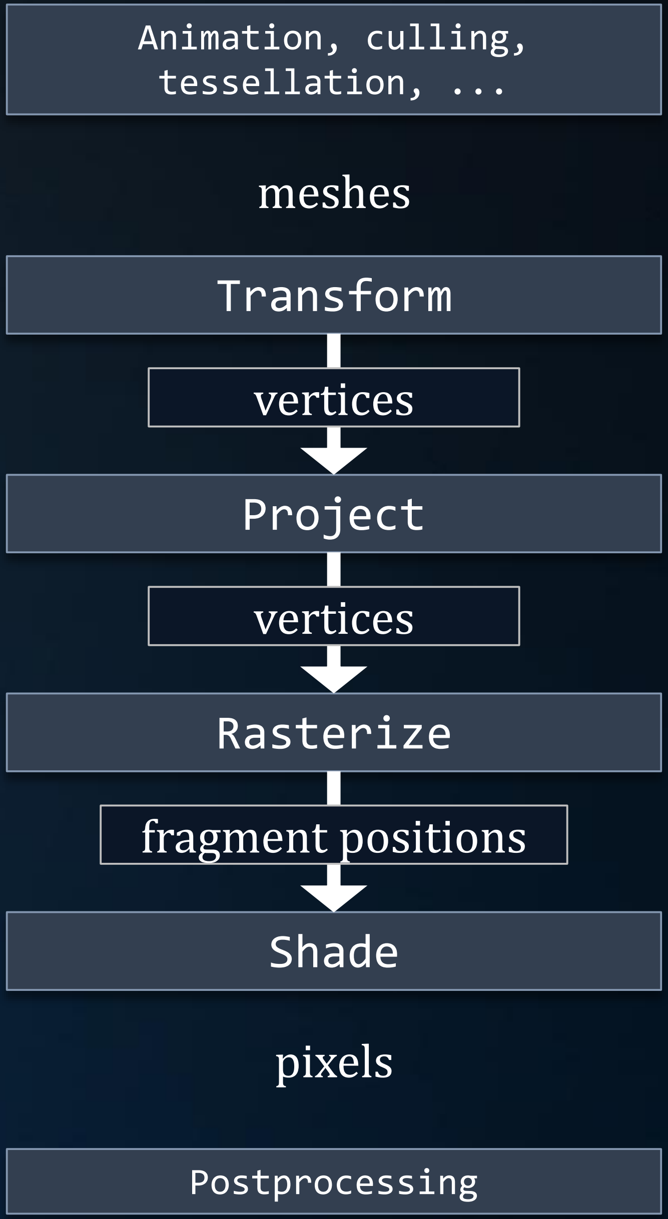
# Depth Sorting

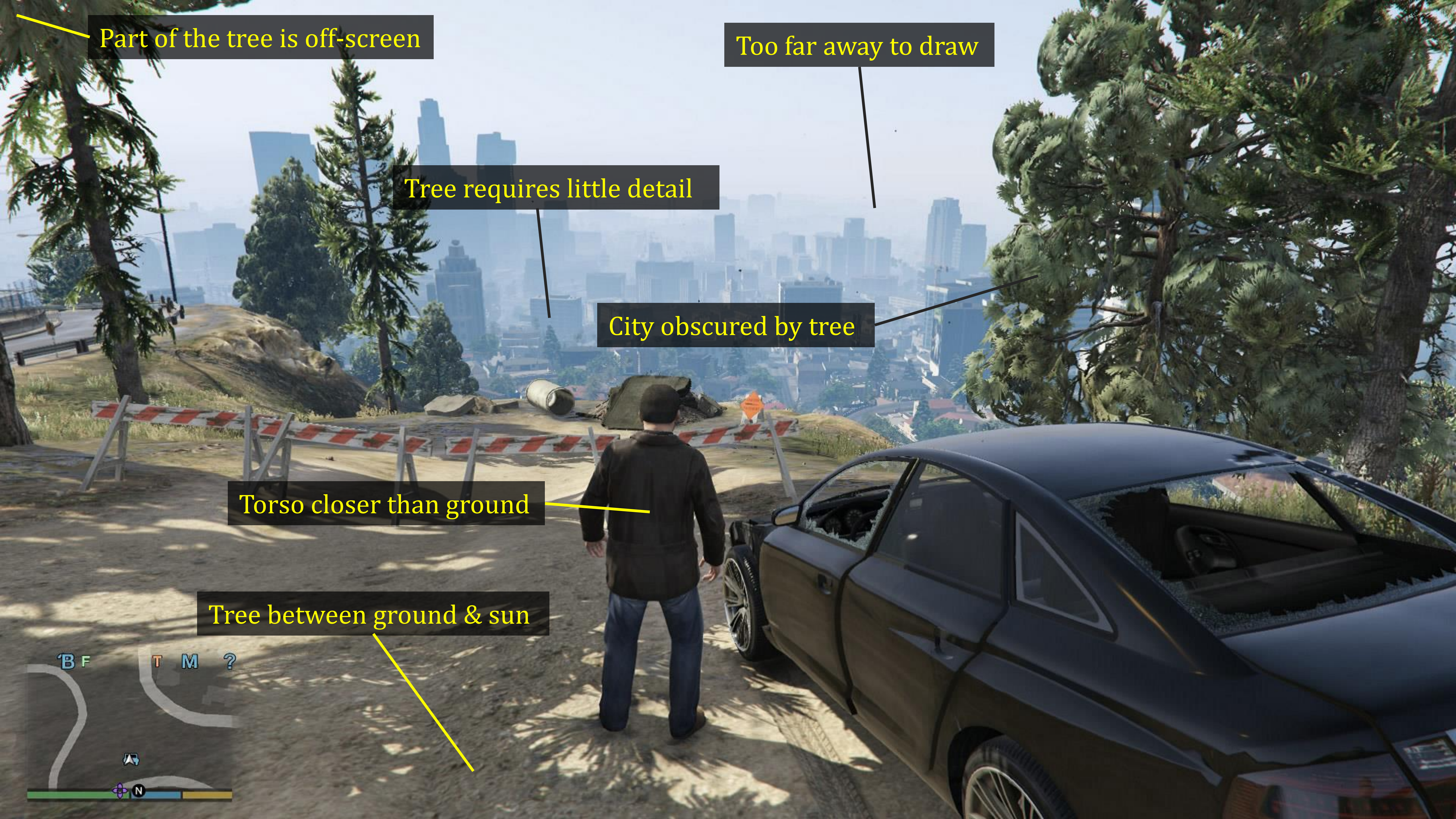
3. Rasterize:
   *determining affected pixels*

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

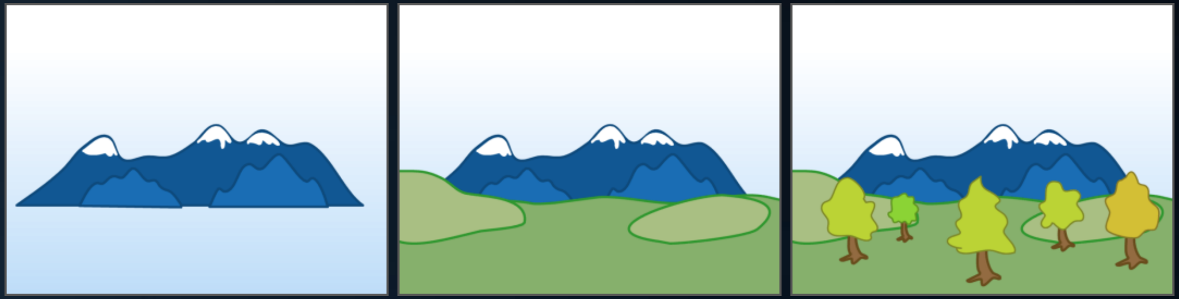
Torso closer than ground

Tree between ground & sun

# Depth Sorting

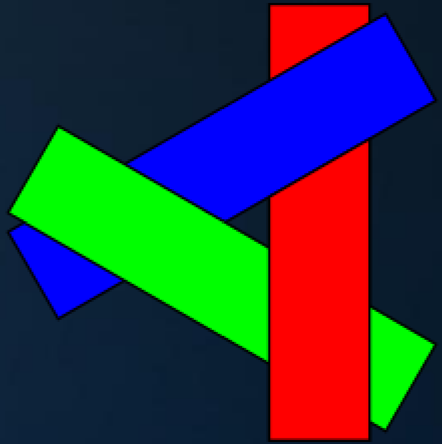
Old-skool depth sorting: Painter’s Algorithm

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



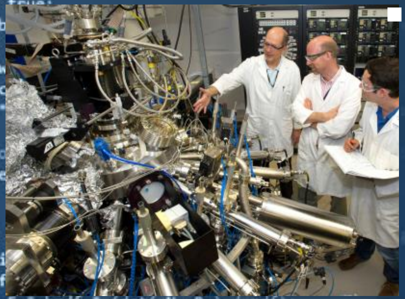
Advantage:

- Doesn’t require z-buffer



Problems:

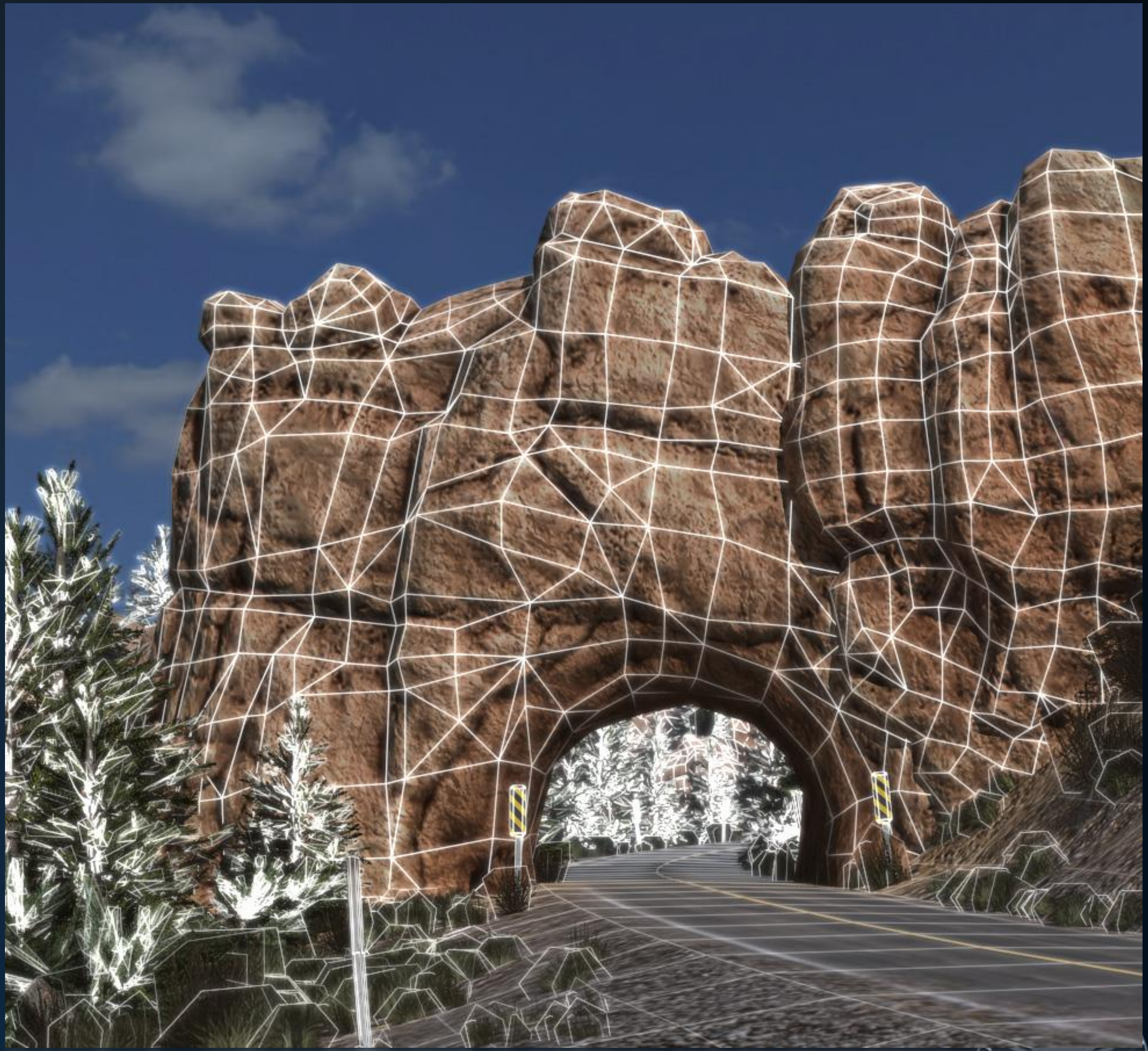
- Cost of sorting
- Doesn’t handle all cases
- Overdraw

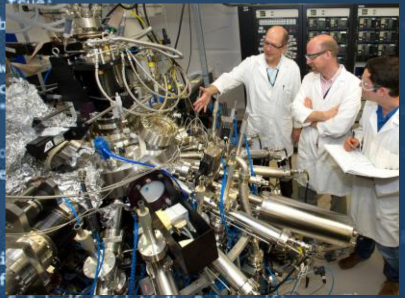


# Depth Sorting

Overdraw:

Inefficiency caused by drawing multiple times to the same pixel.

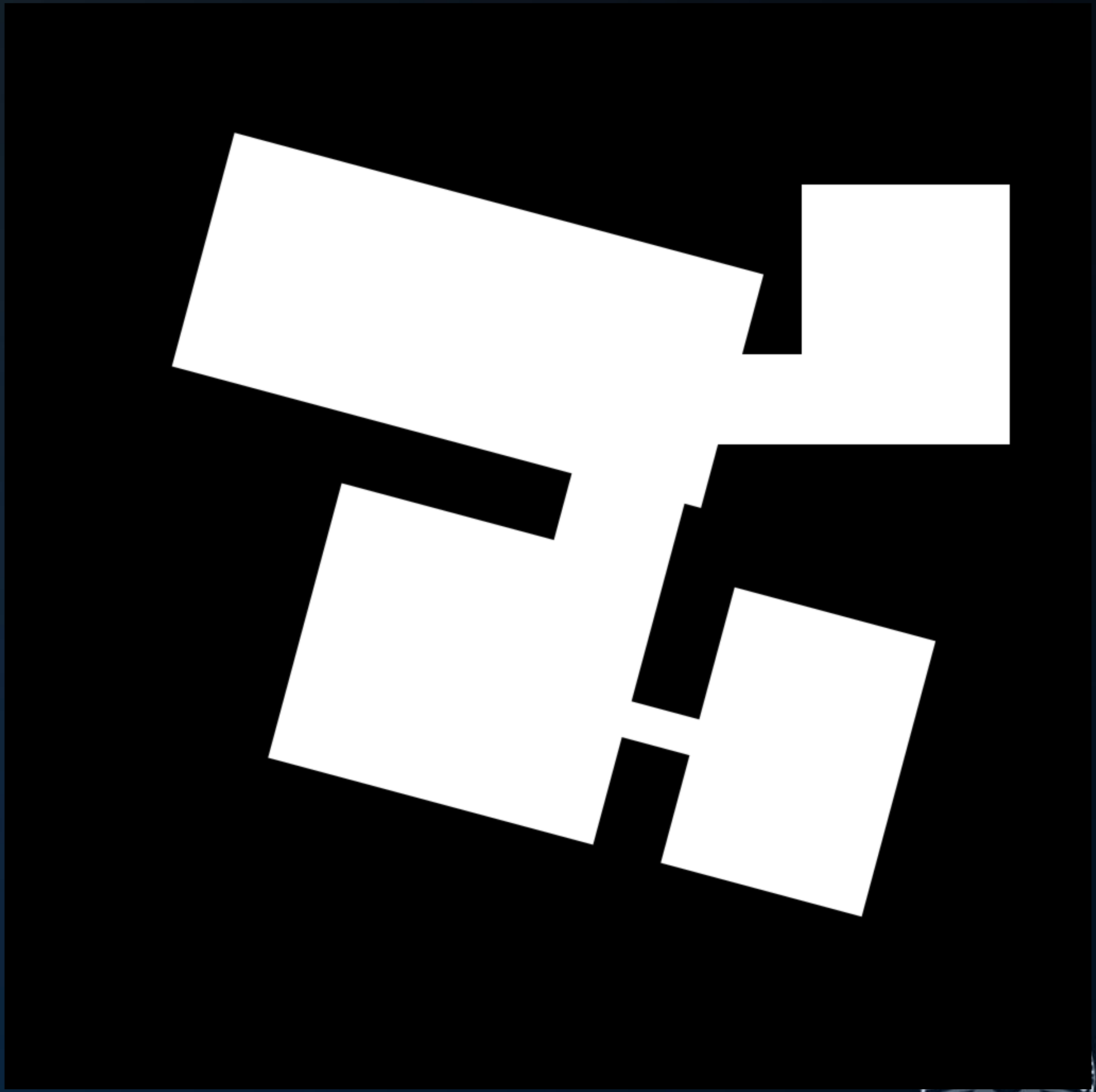




# Depth Sorting

Correct order: BSP

root



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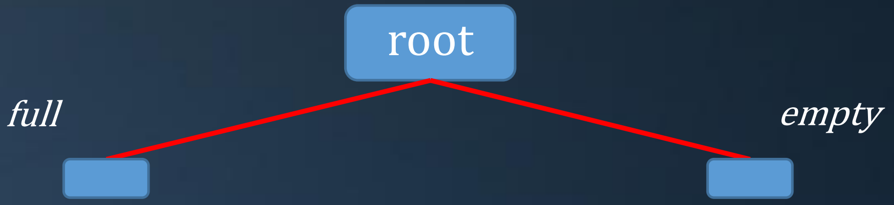

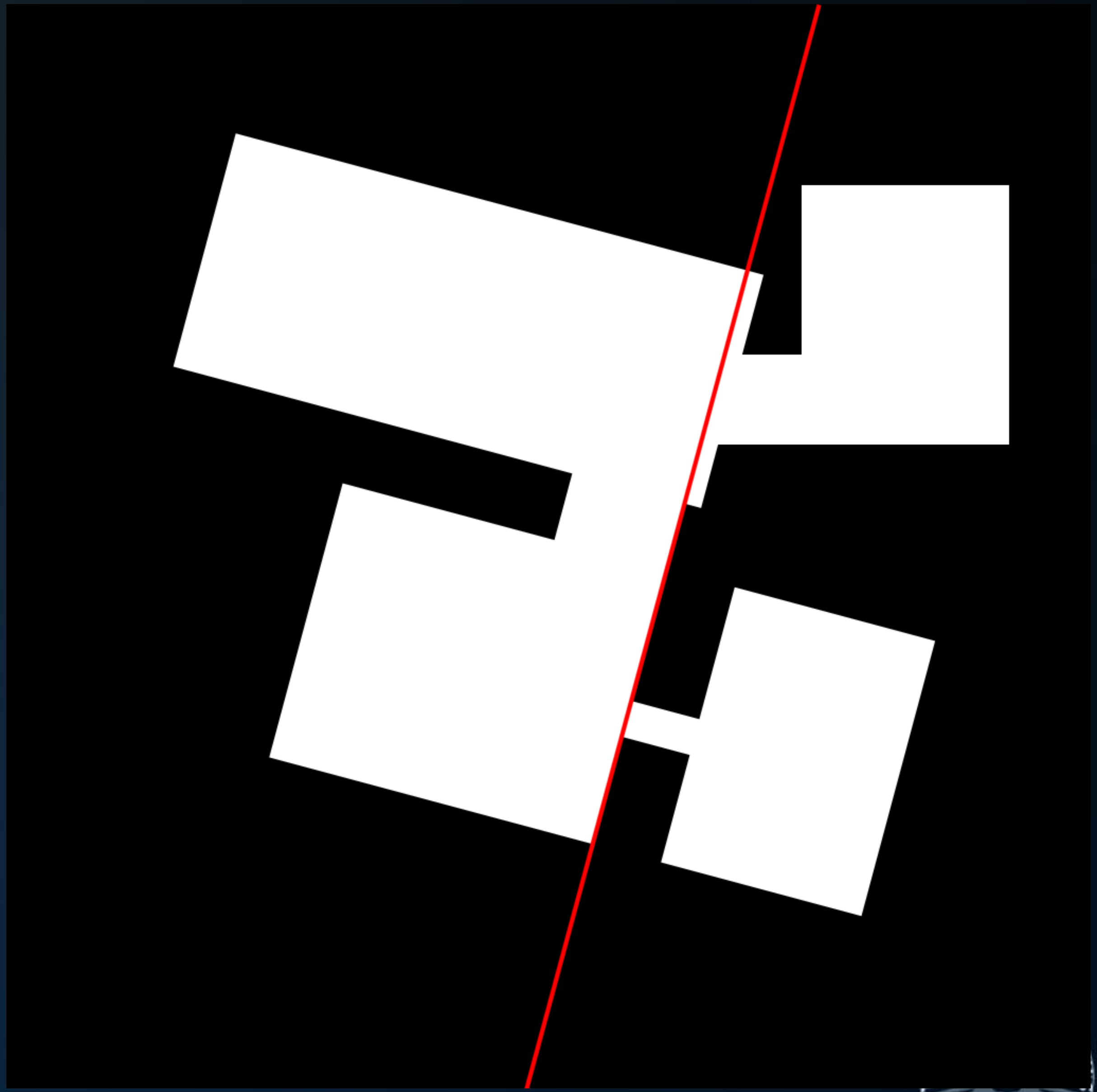

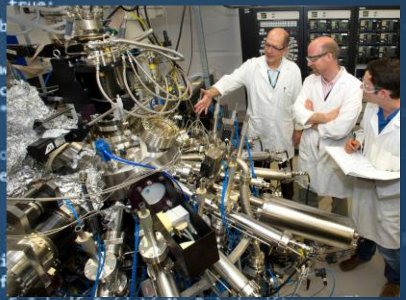

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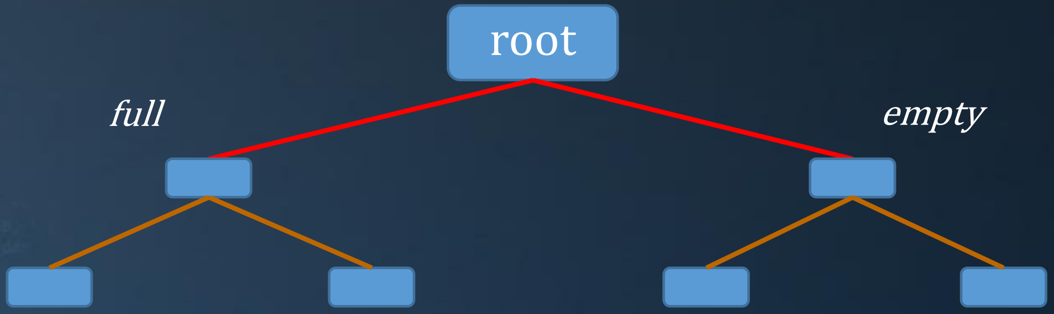

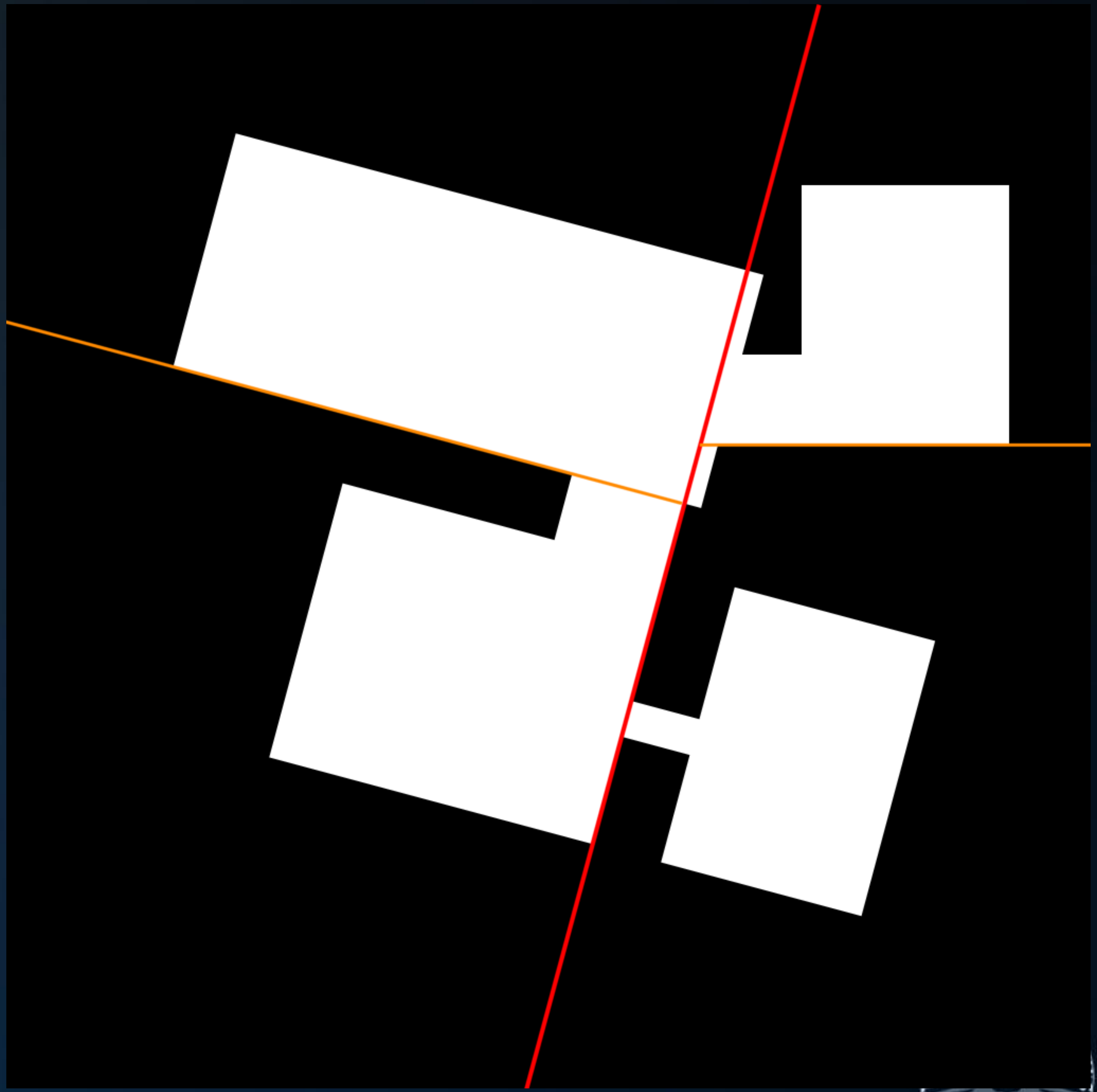

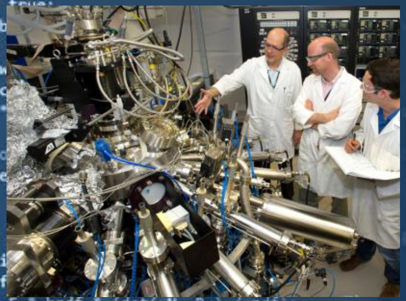

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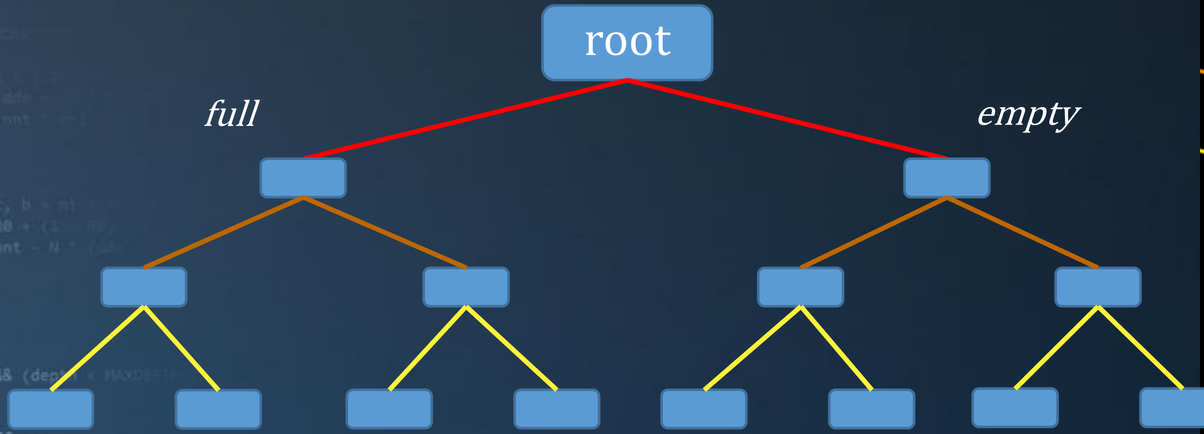

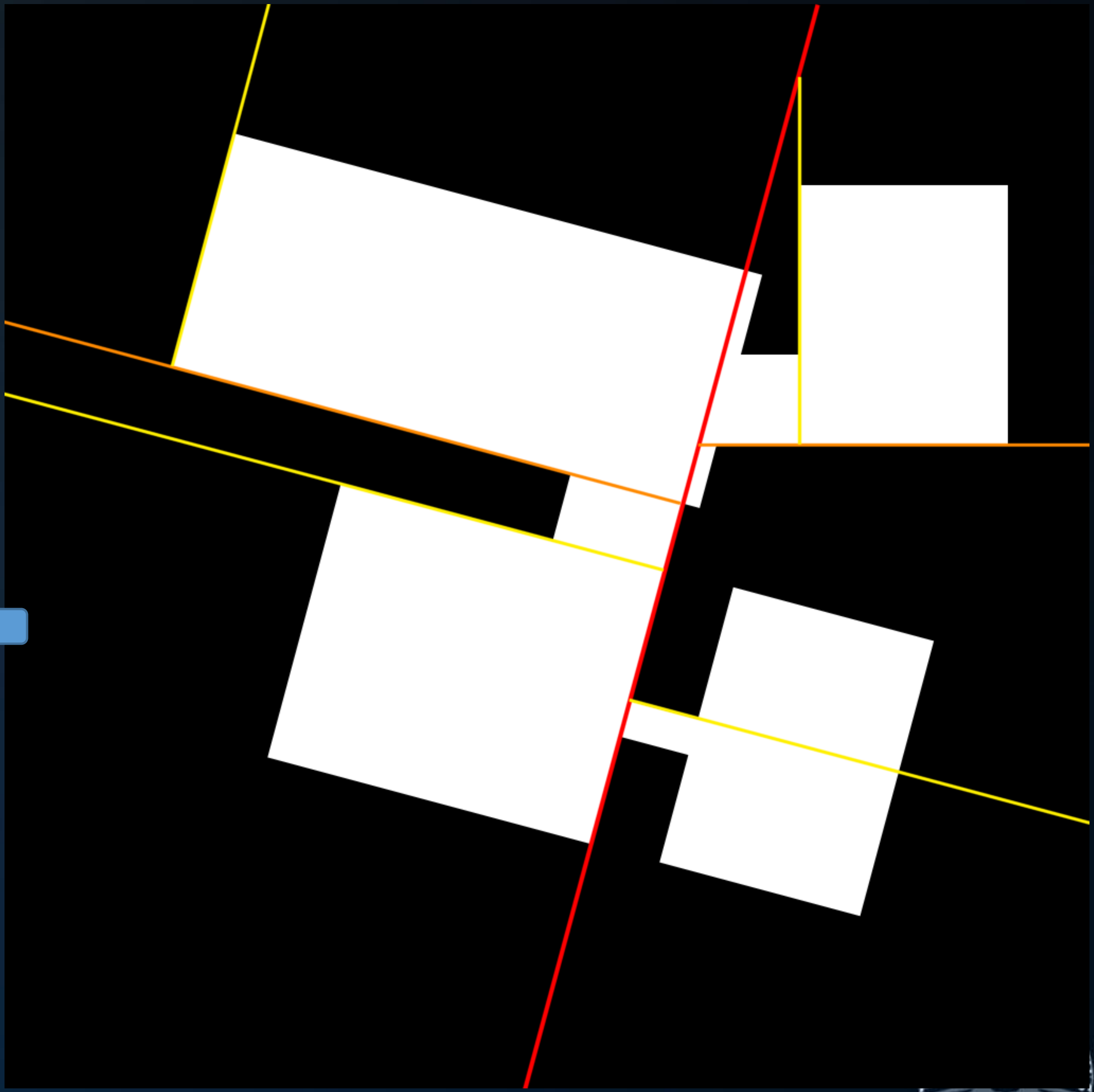

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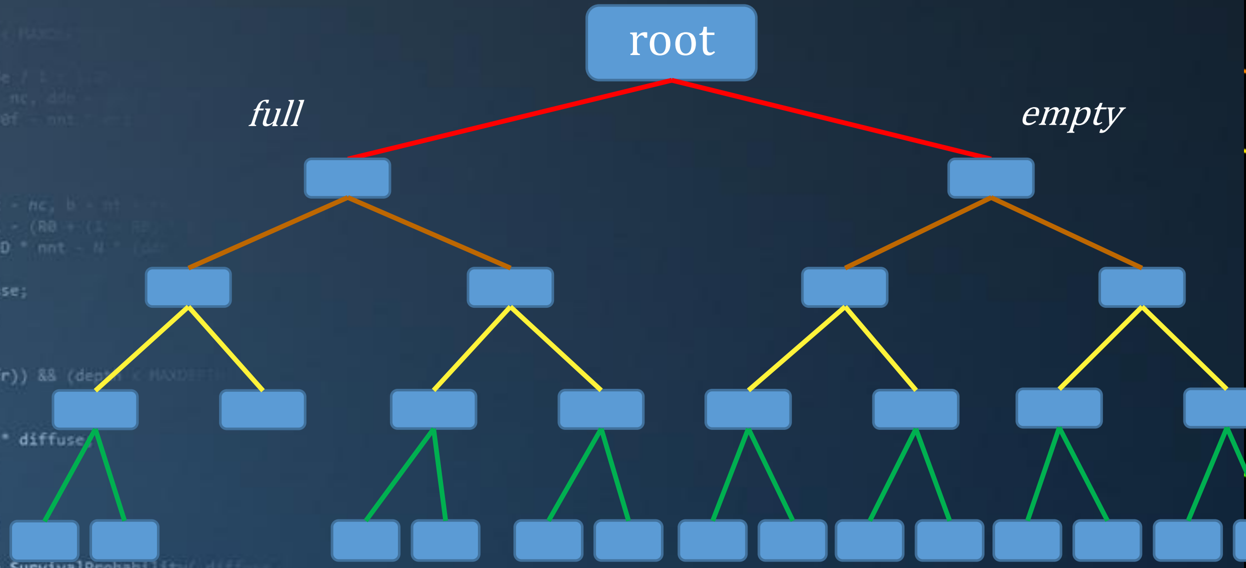

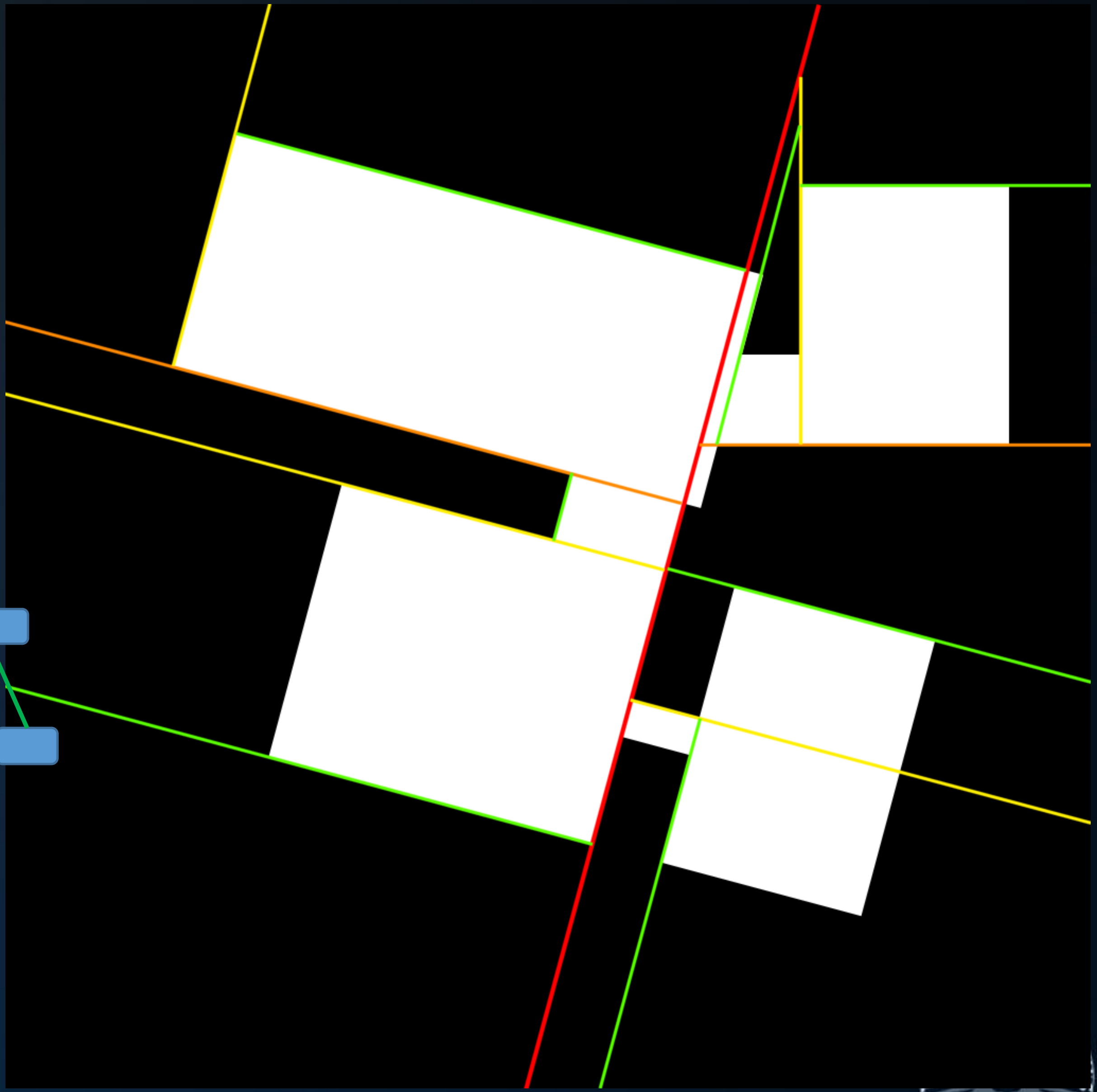

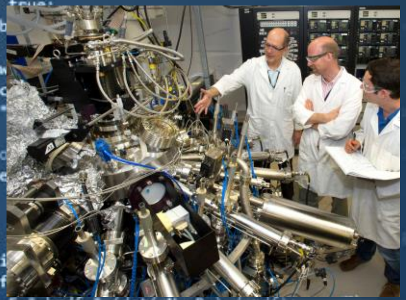

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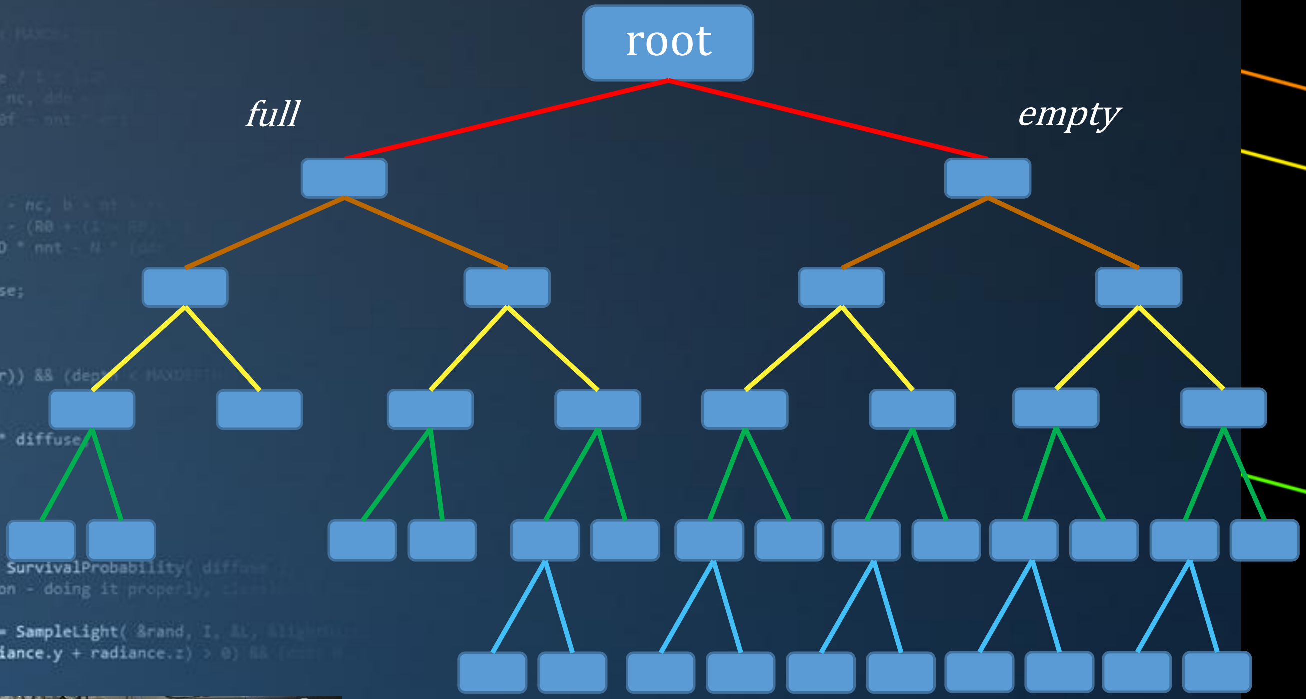

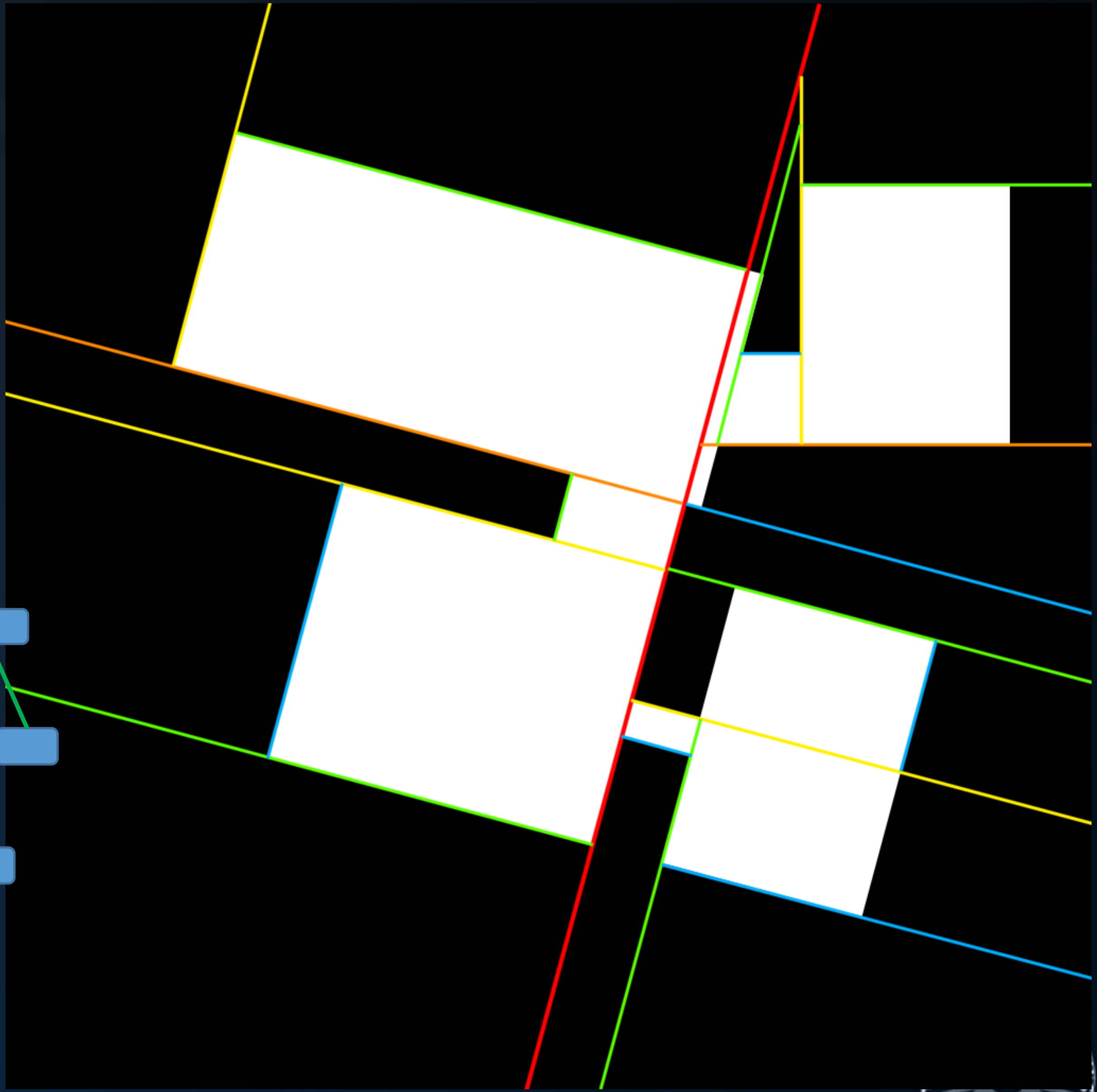

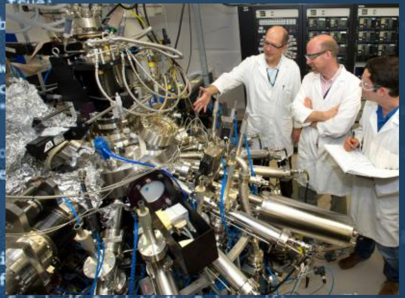

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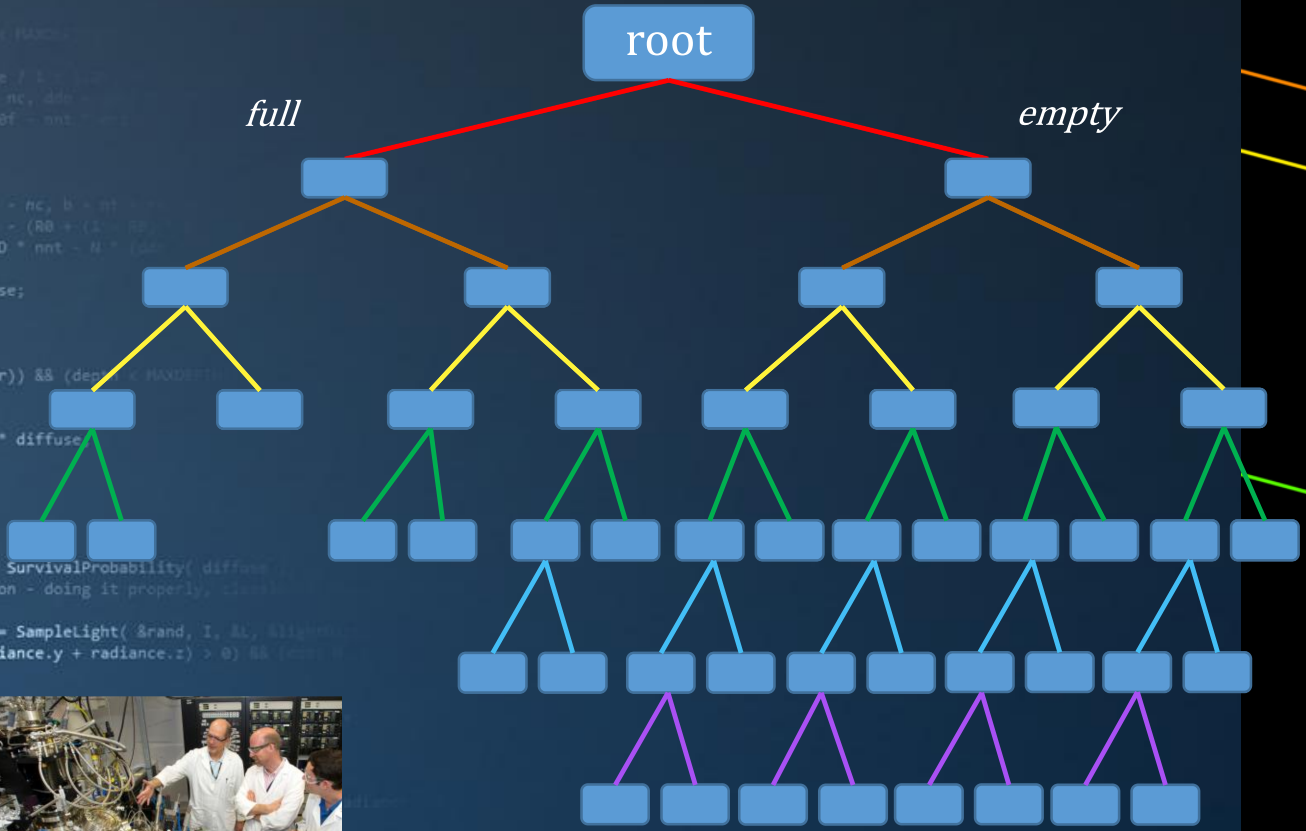
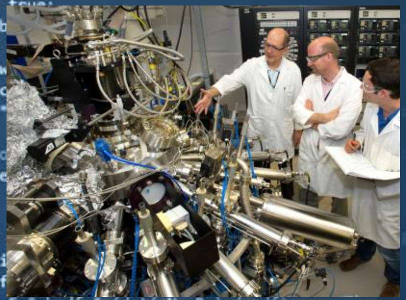
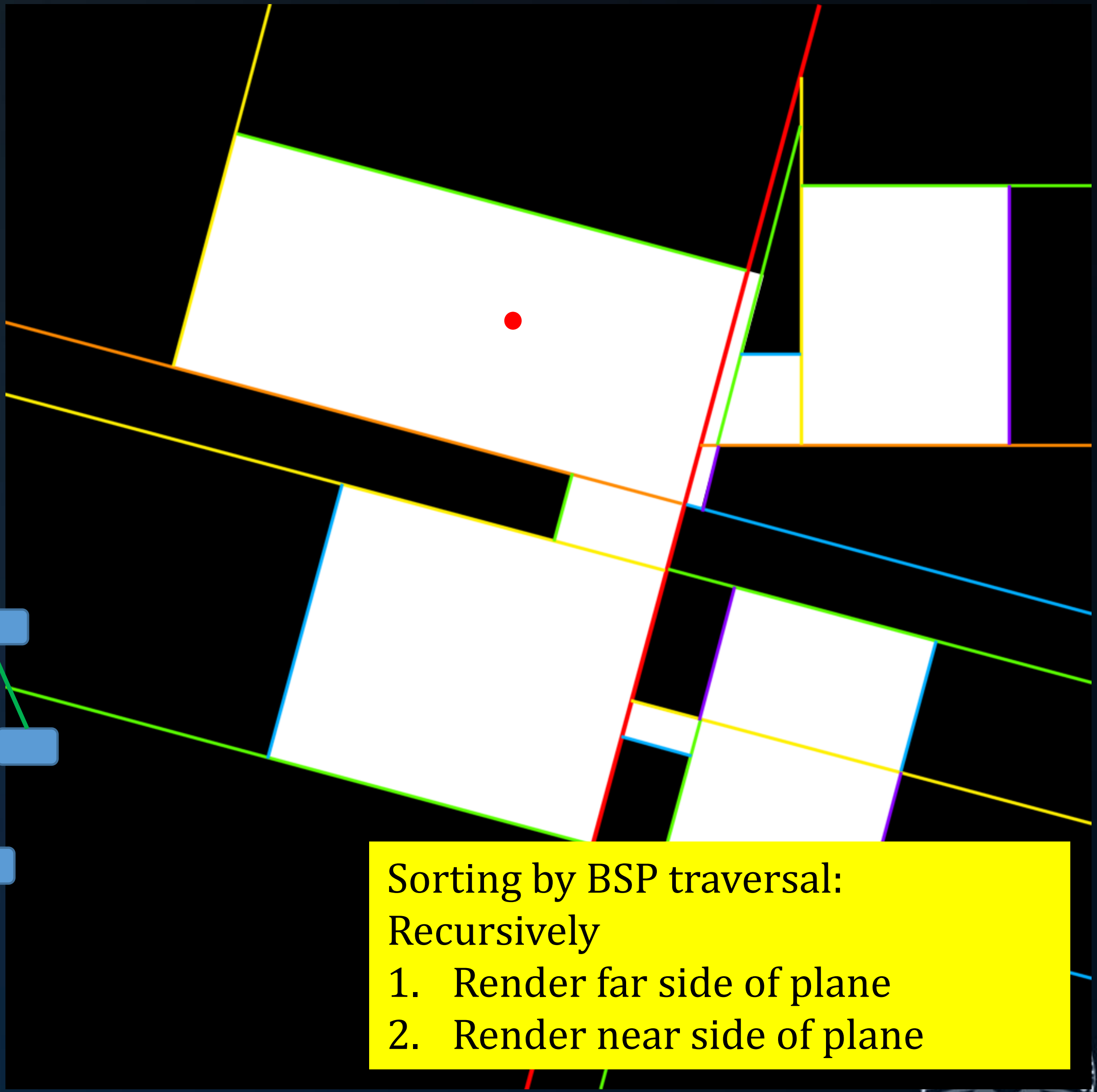






Sorting by BSP traversal:
Recursively
1. Render far side of plane
2. Render near side of plane

# 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:

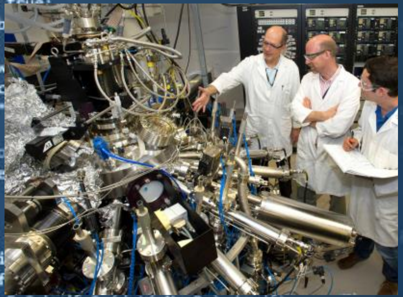
- An additional buffer
- Initialization of the buffer to $z_{max}$
- Interpolation of $z$ over the triangle
- A z-buffer read and compare, and possibly a write.

# 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)).



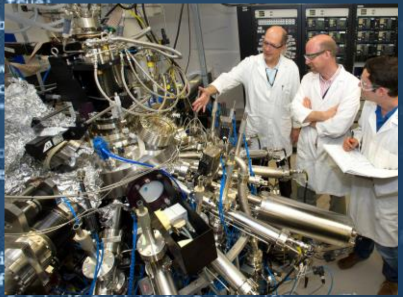
# Depth Sorting

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’.

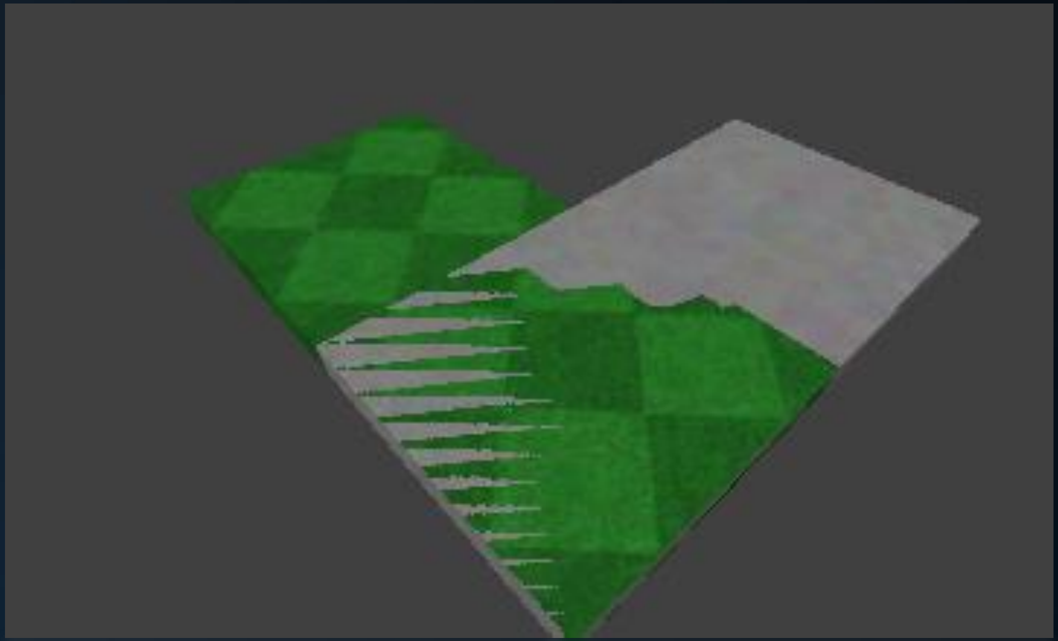


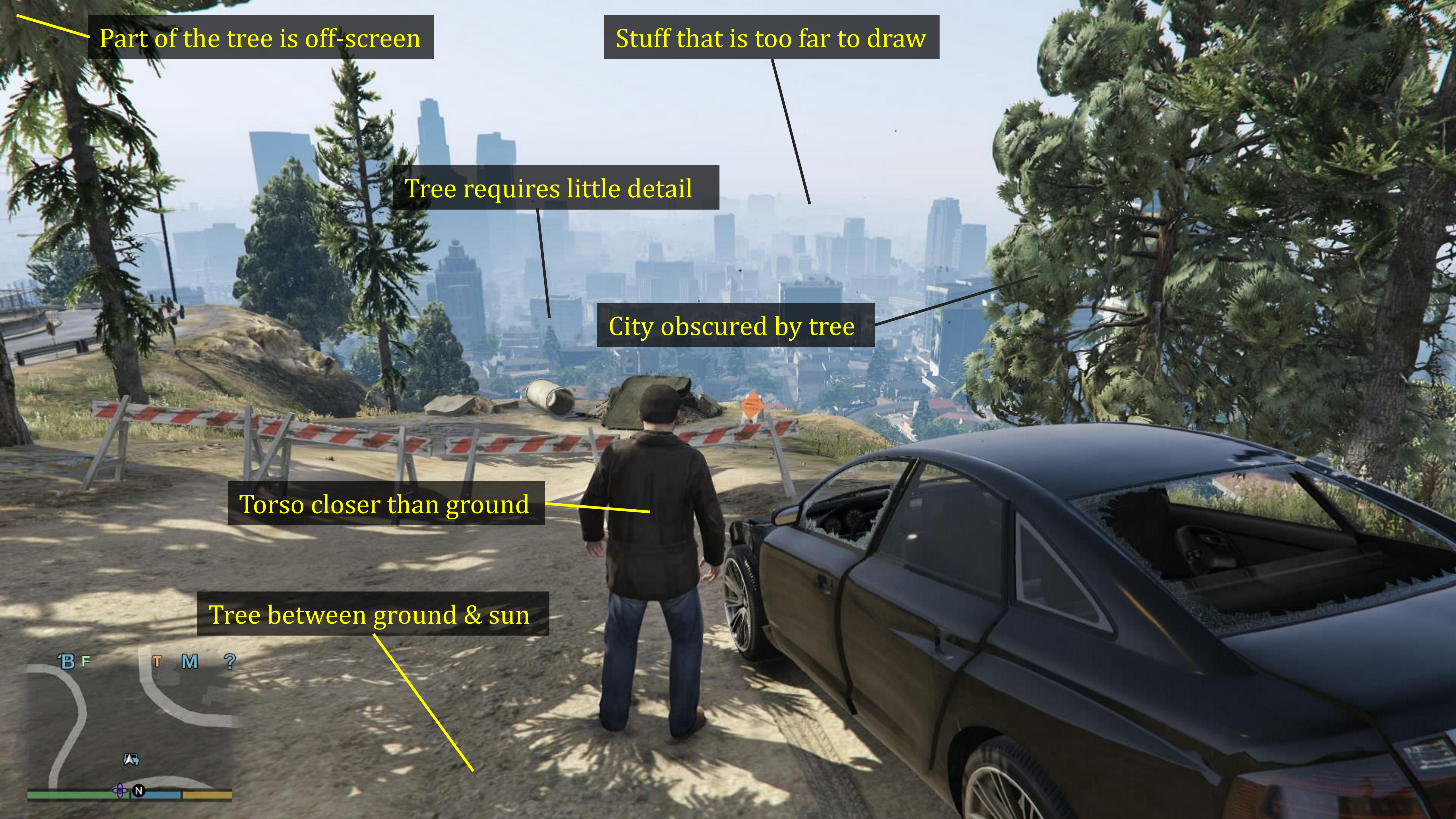
# Depth Sorting

‘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

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# Today’s Agenda:

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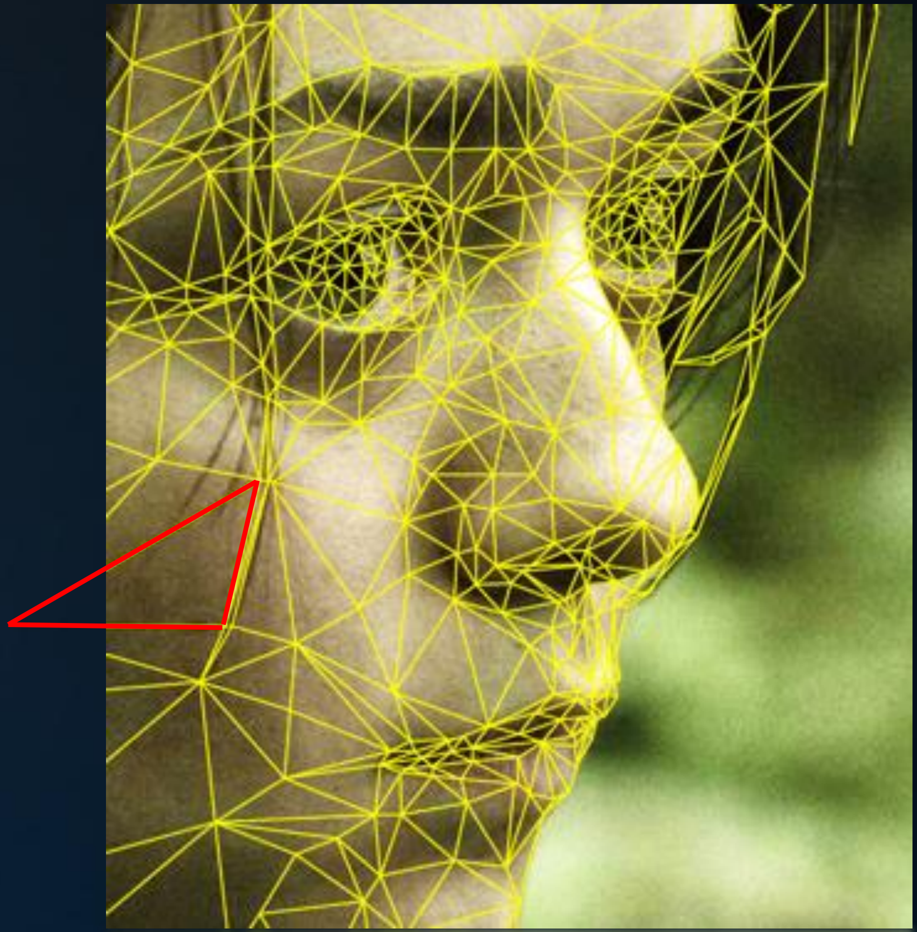
# Clipping

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

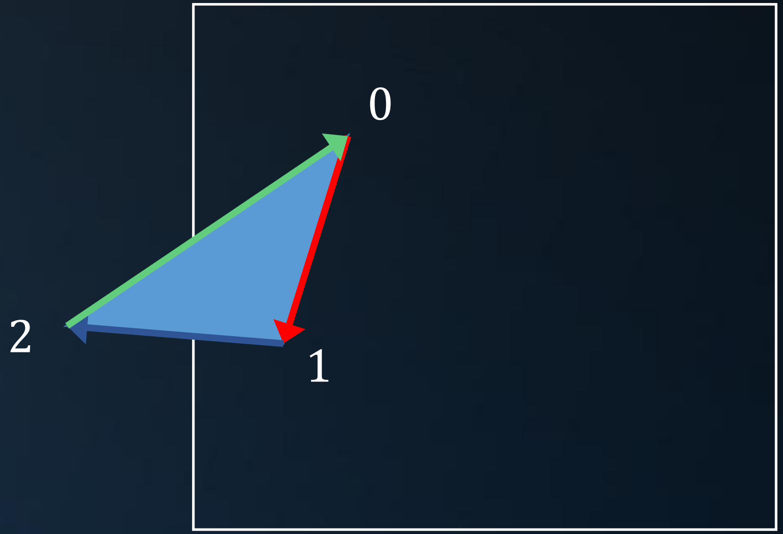
Algorithm:

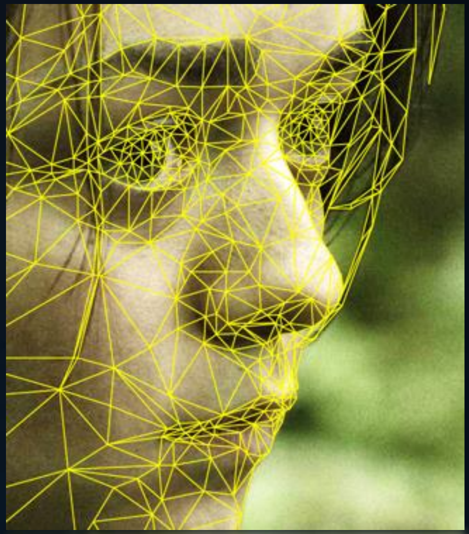
Per edge with vertices $v_0$ and $v_1$:

- 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

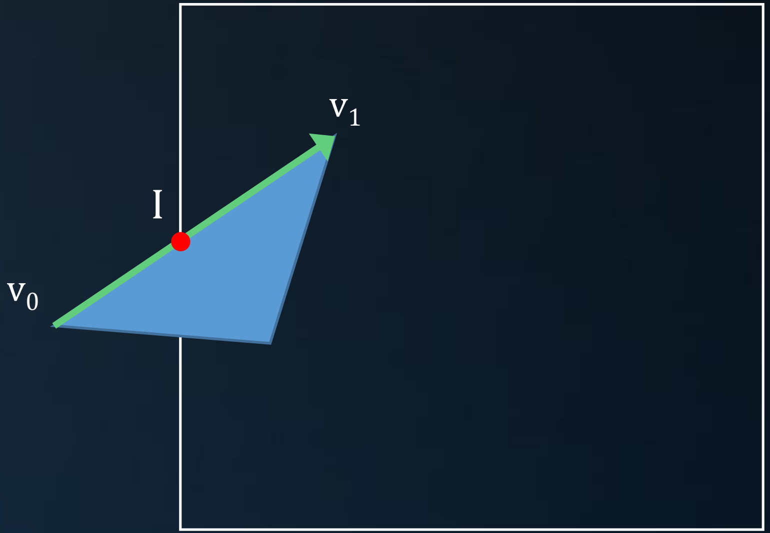
Sutherland-Hodgeman

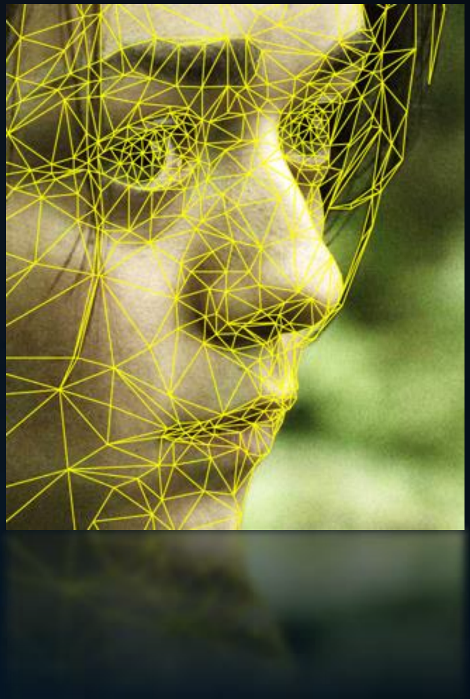
Calculating the intersections with plane $ax + by + cz + d = 0$:

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

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

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





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

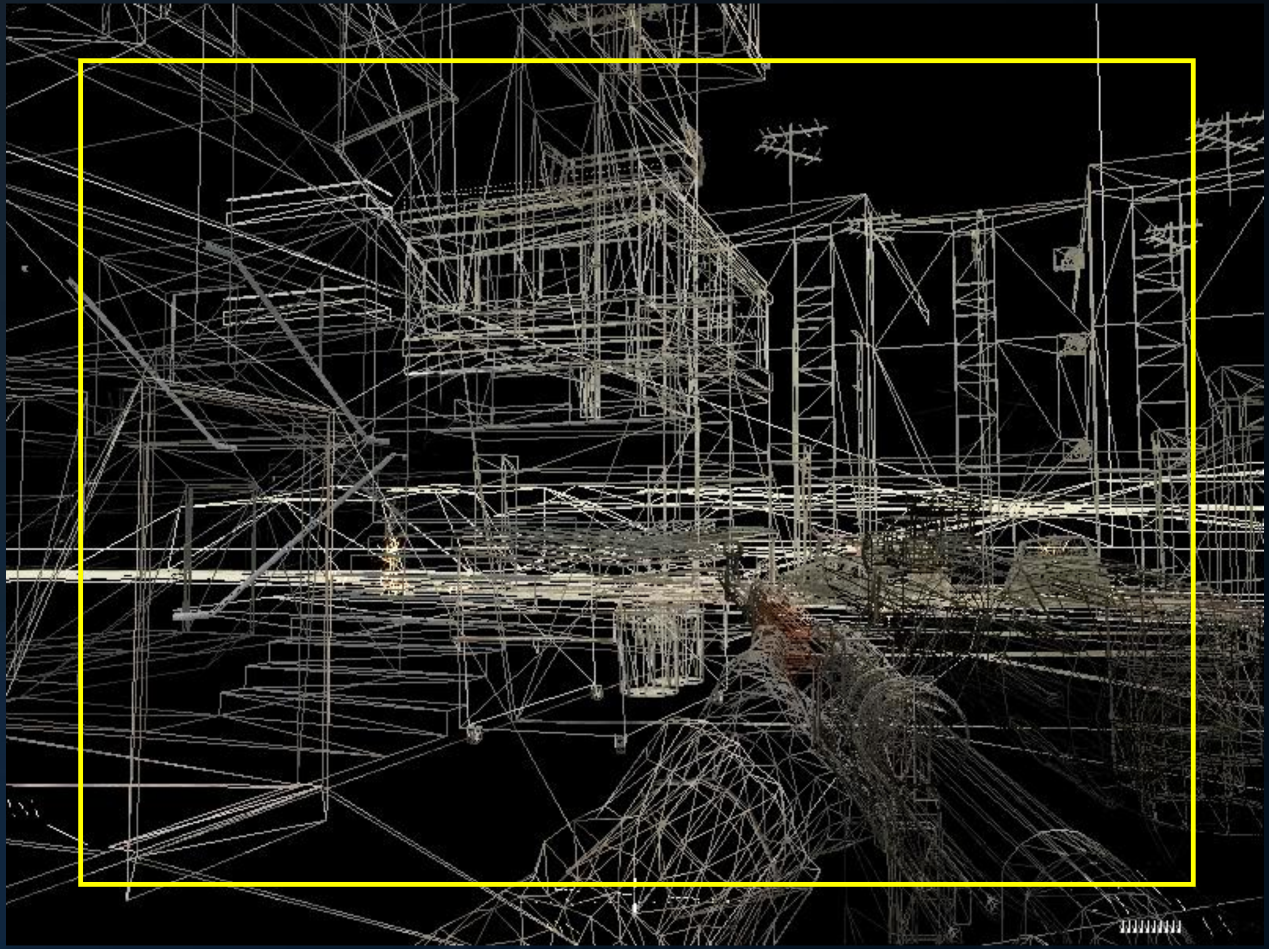
0,1,2,3,4 ➔ 0, 1, 2 + 0, 2, 3 + 0, 3, 4.

# 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.

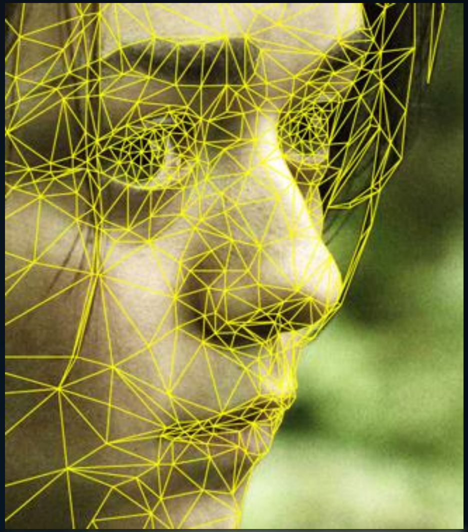
- Polygons outside the screen are discarded, even if they touch the guard band;
- Polygons partially inside, partially in the guard band are drawn without clipping;
- Polygons partially inside the screen, partially outside the guard band are clipped.

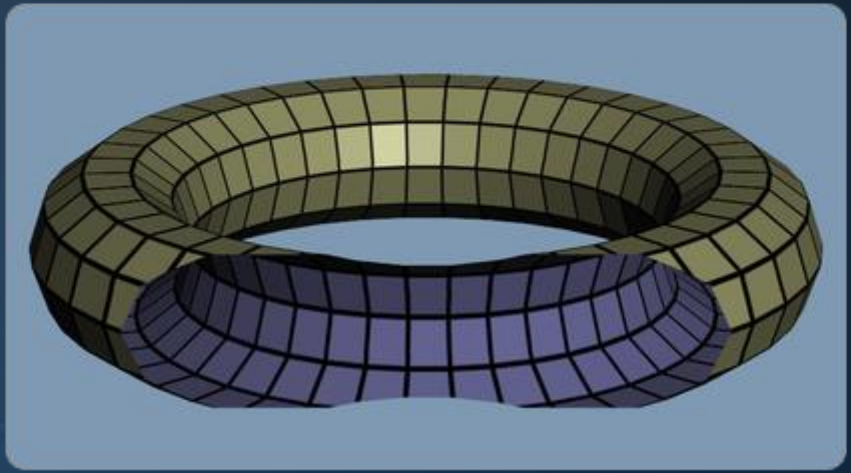


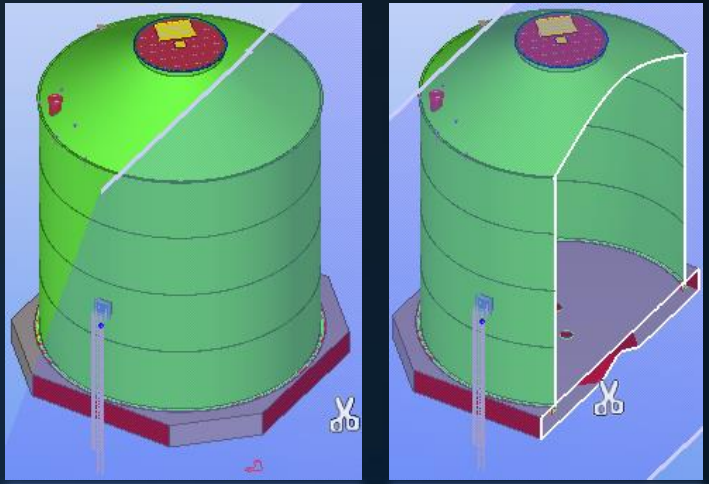
# Clipping

Sutherland-Hodgeman

Clipping can be done against arbitrary planes.







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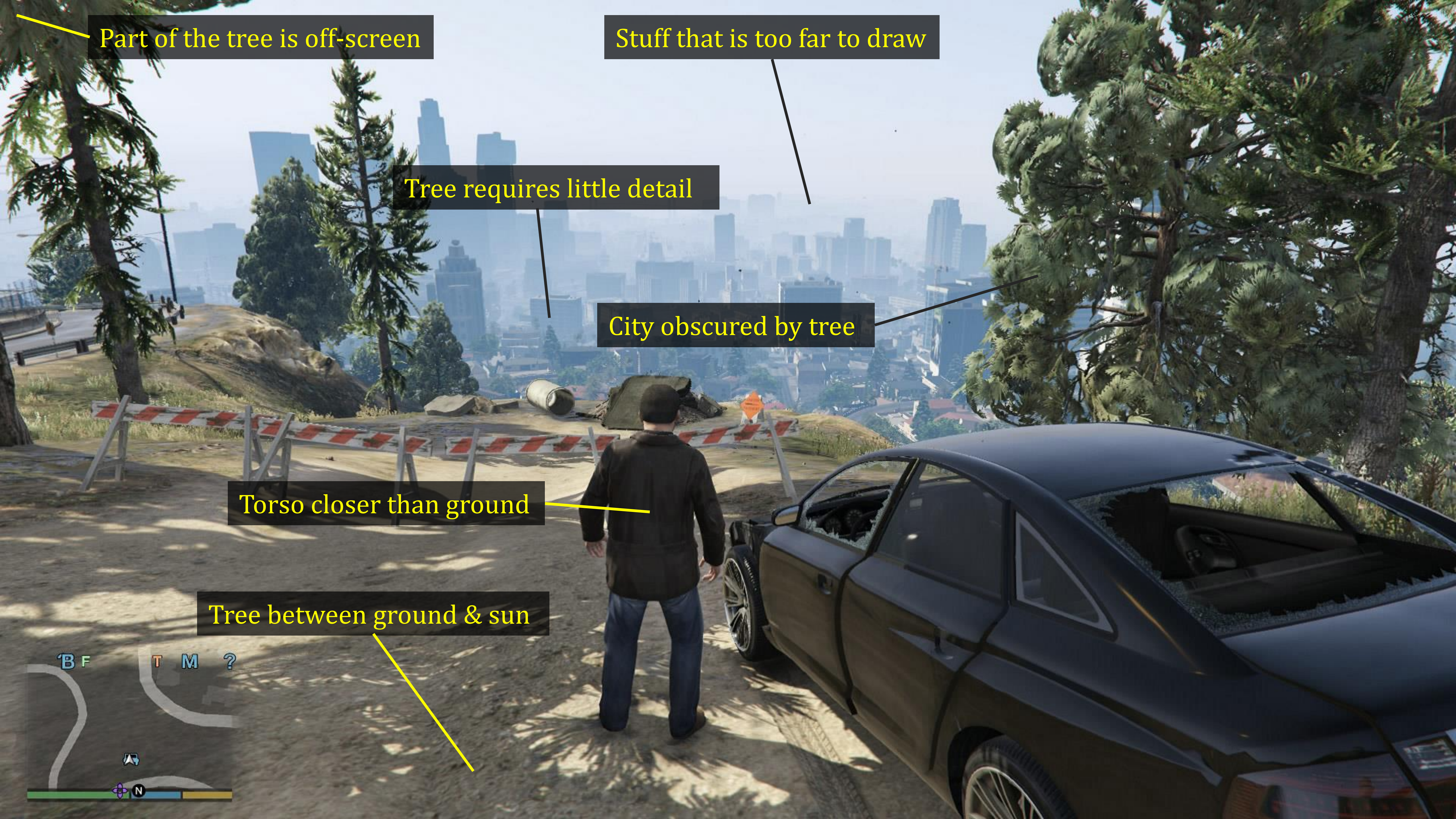

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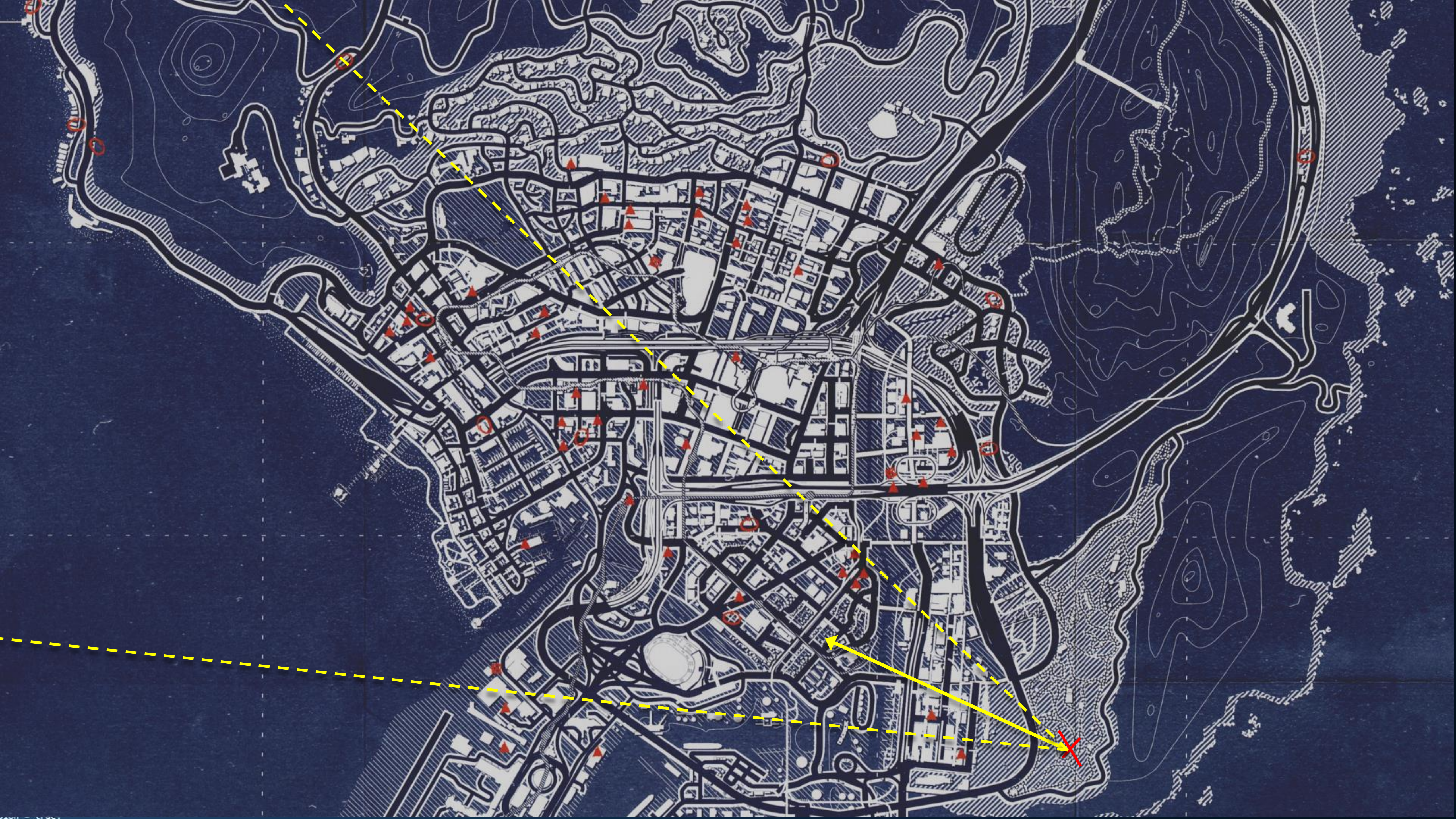
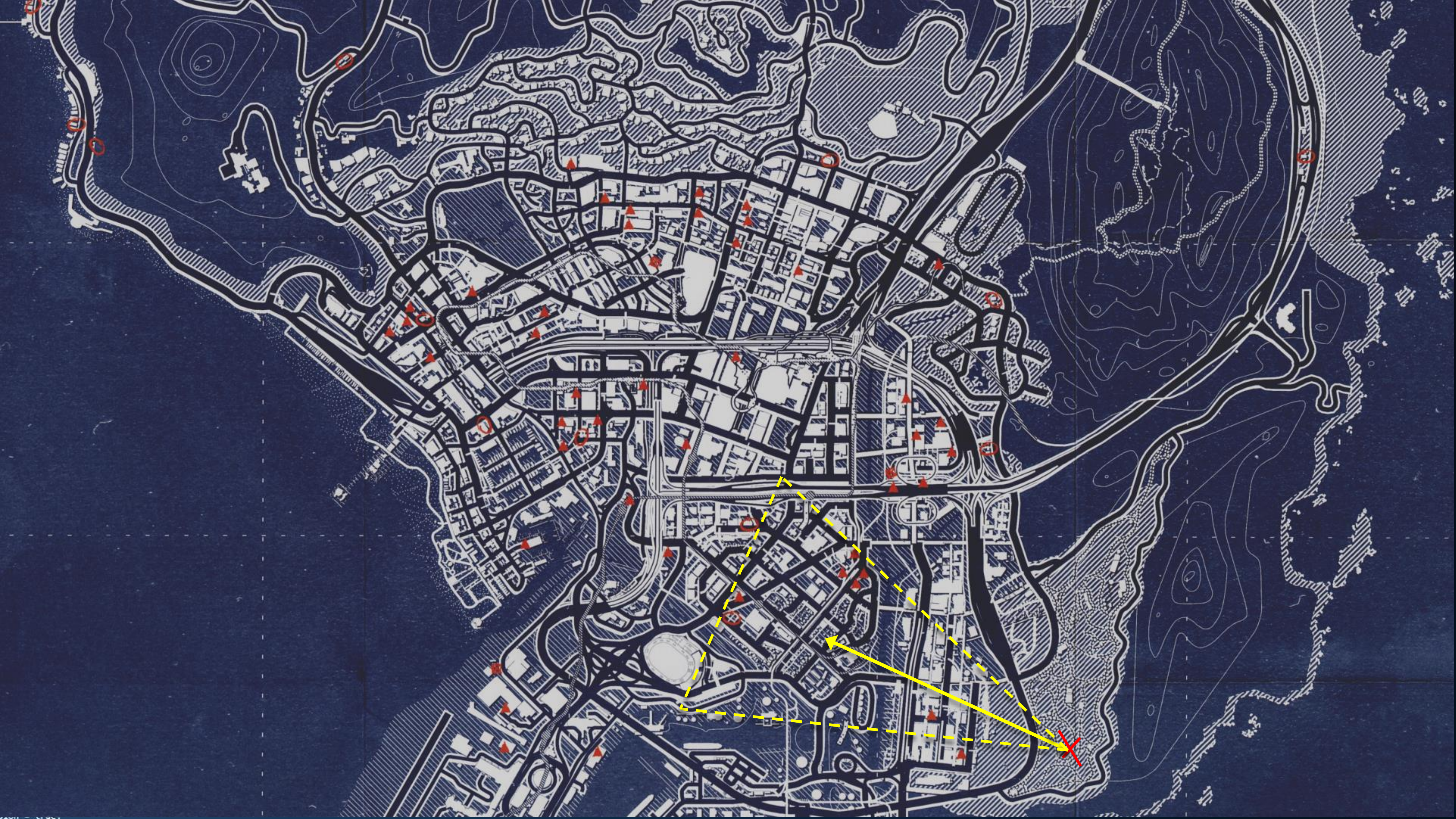




# Visibility

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.

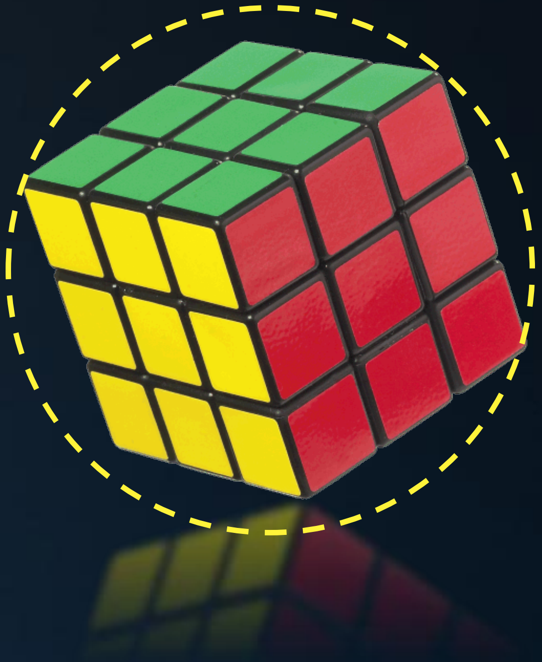
Culling ‘backfaces’:

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

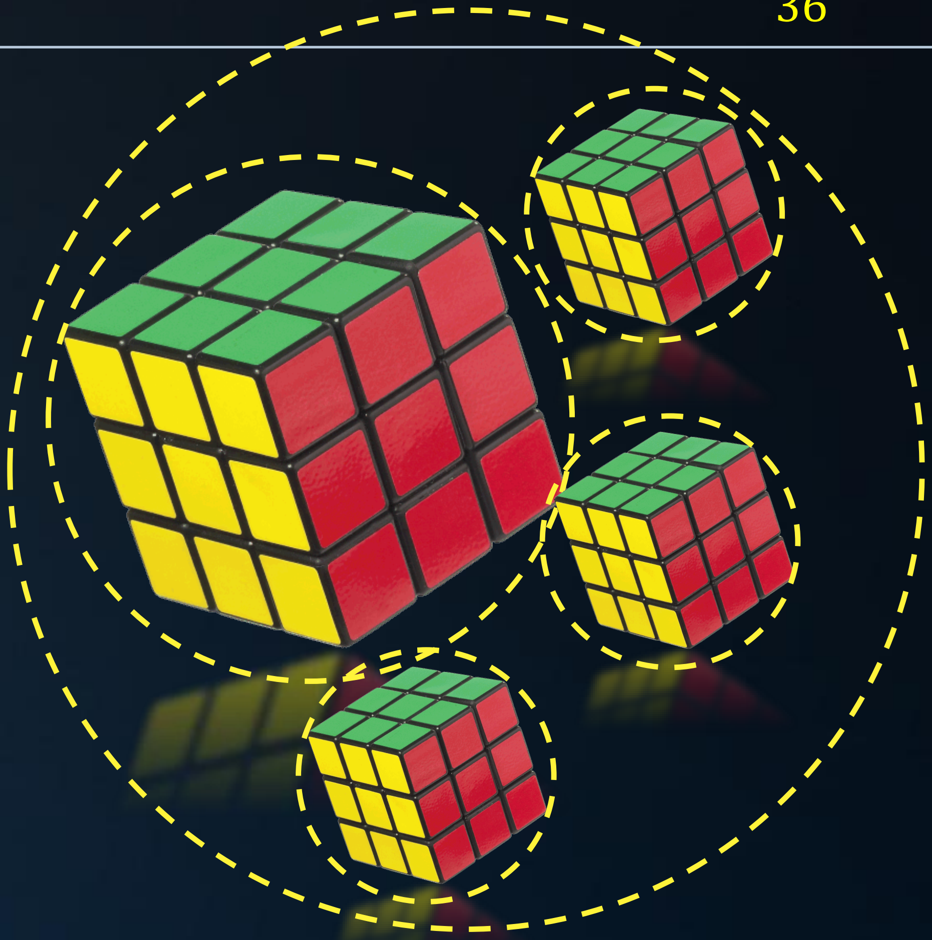
Culling

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.**

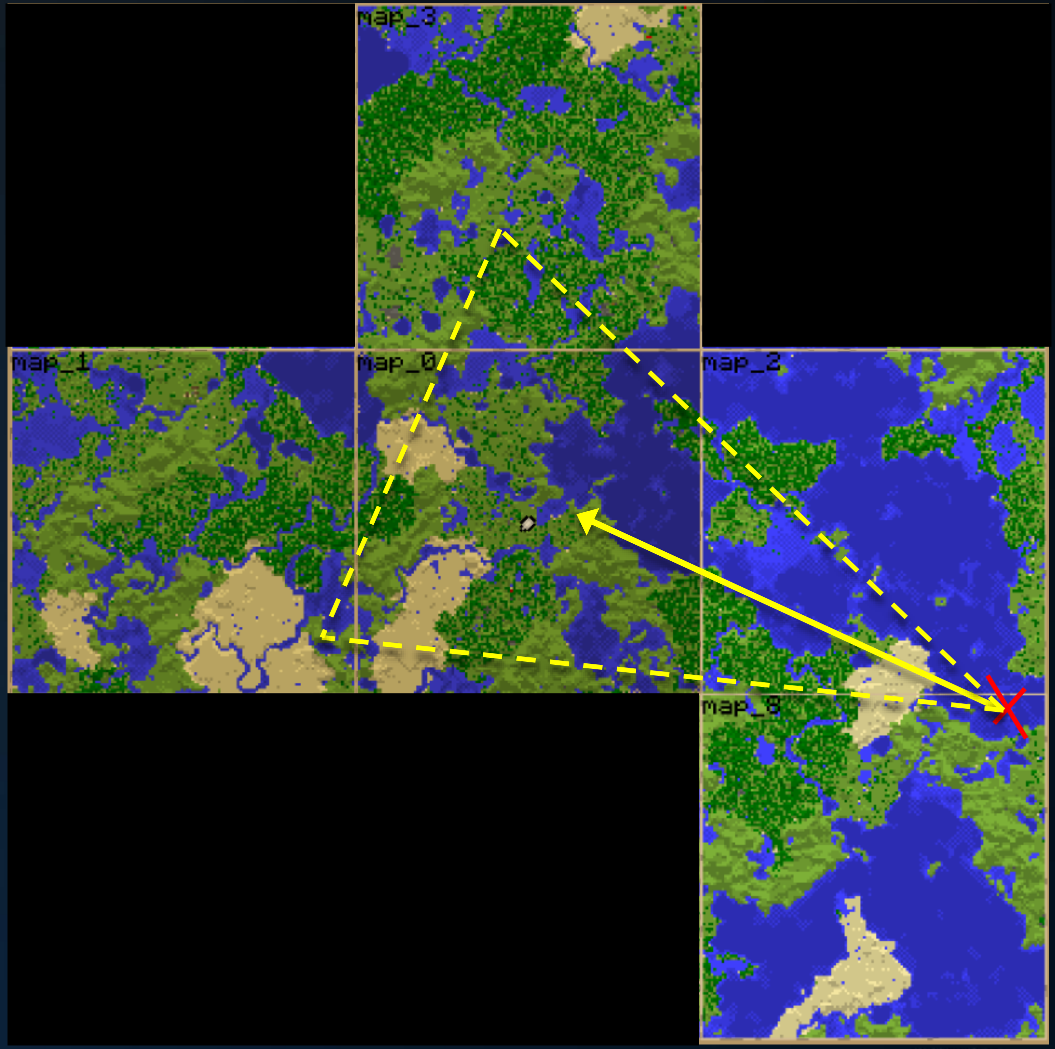


# Visibility

Culling

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

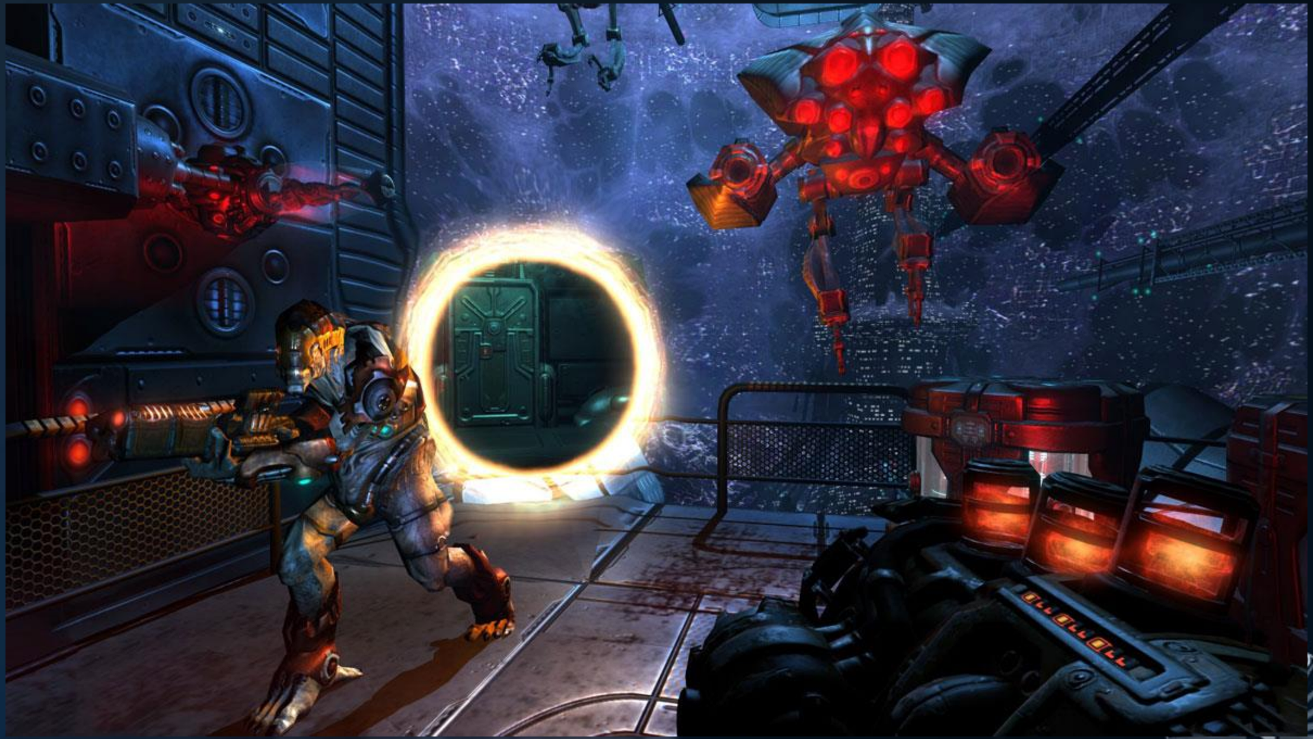
**Cost: 0 for out-of-range grid cells.**

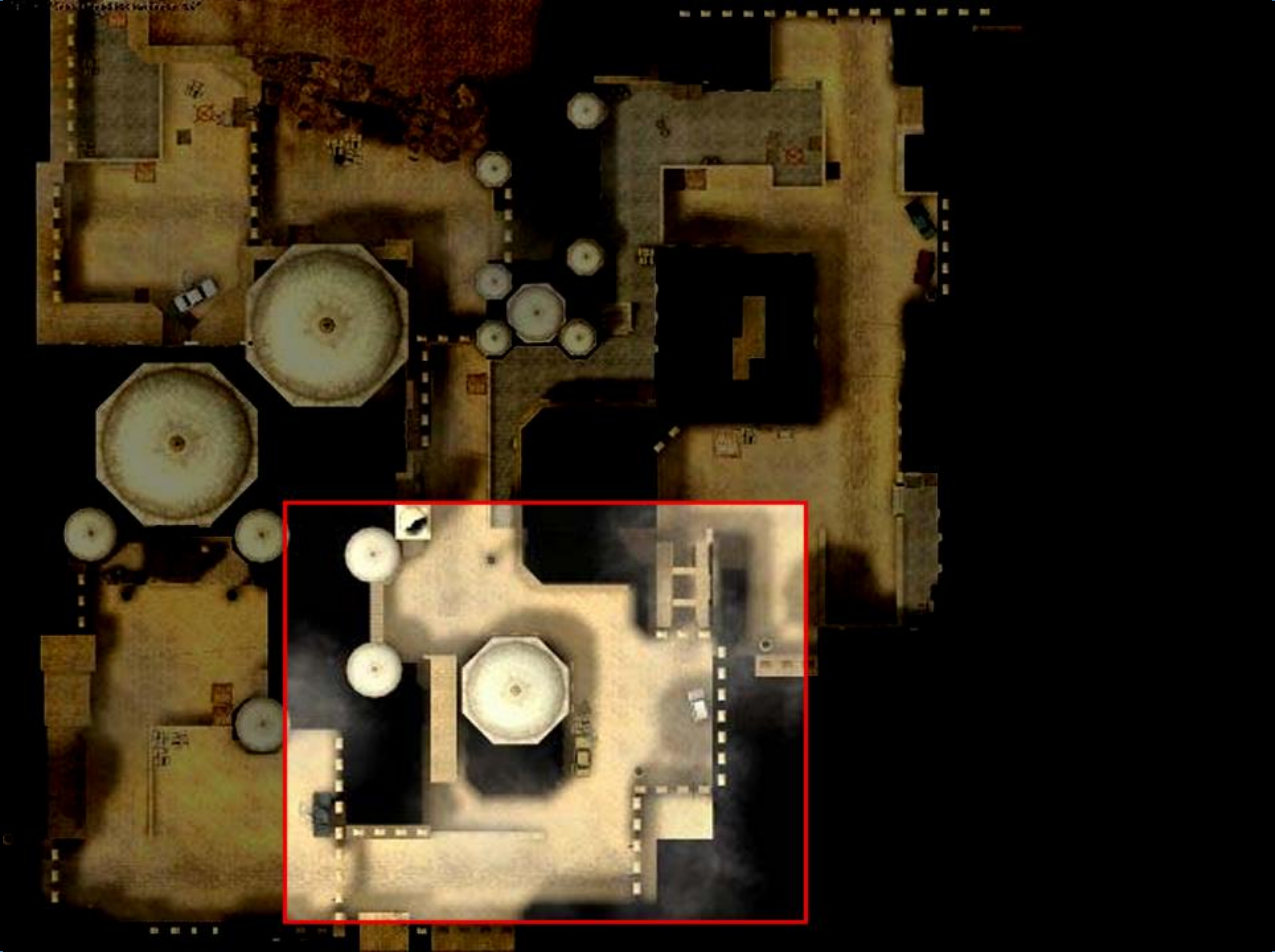


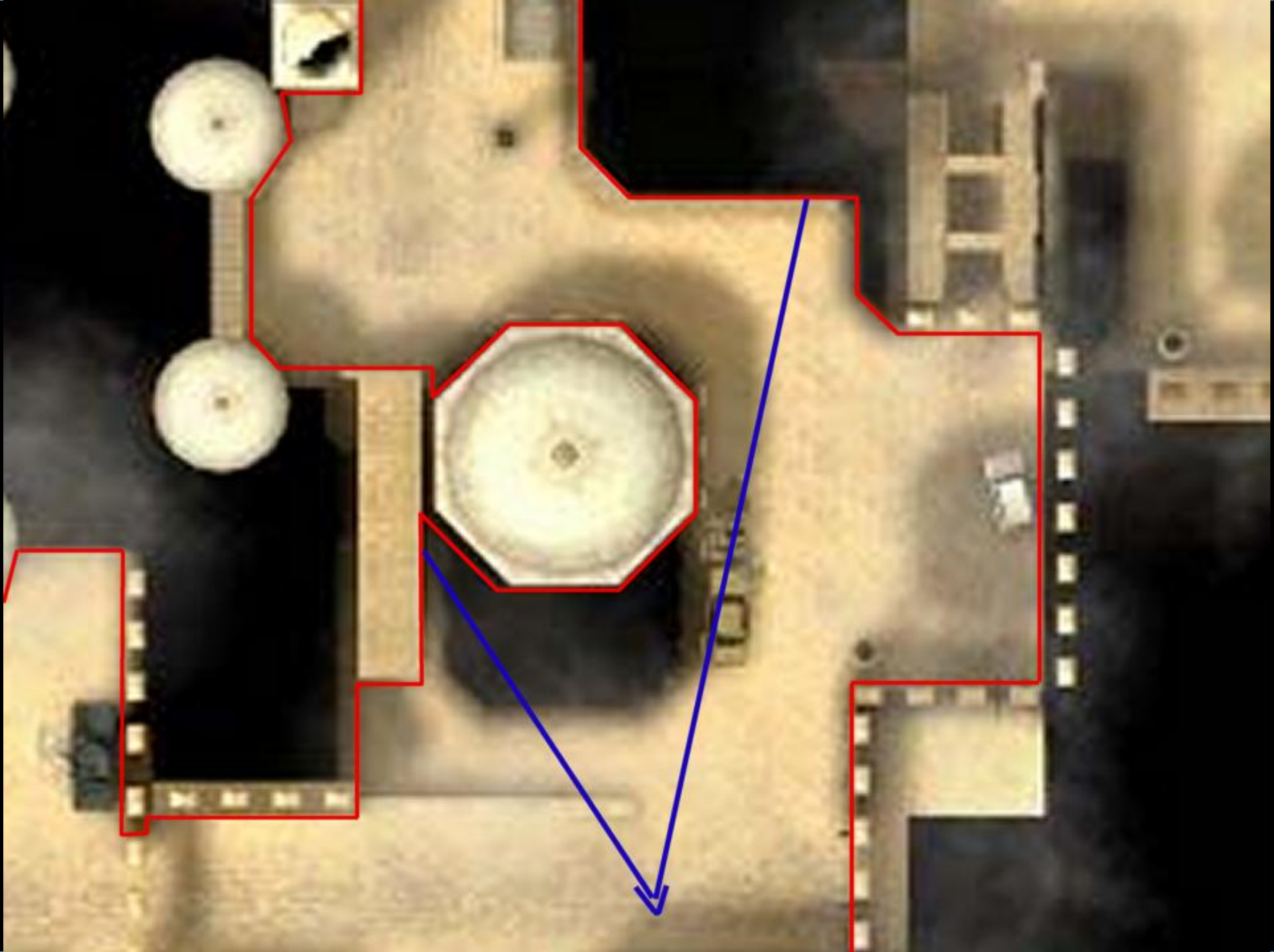
# Visibility

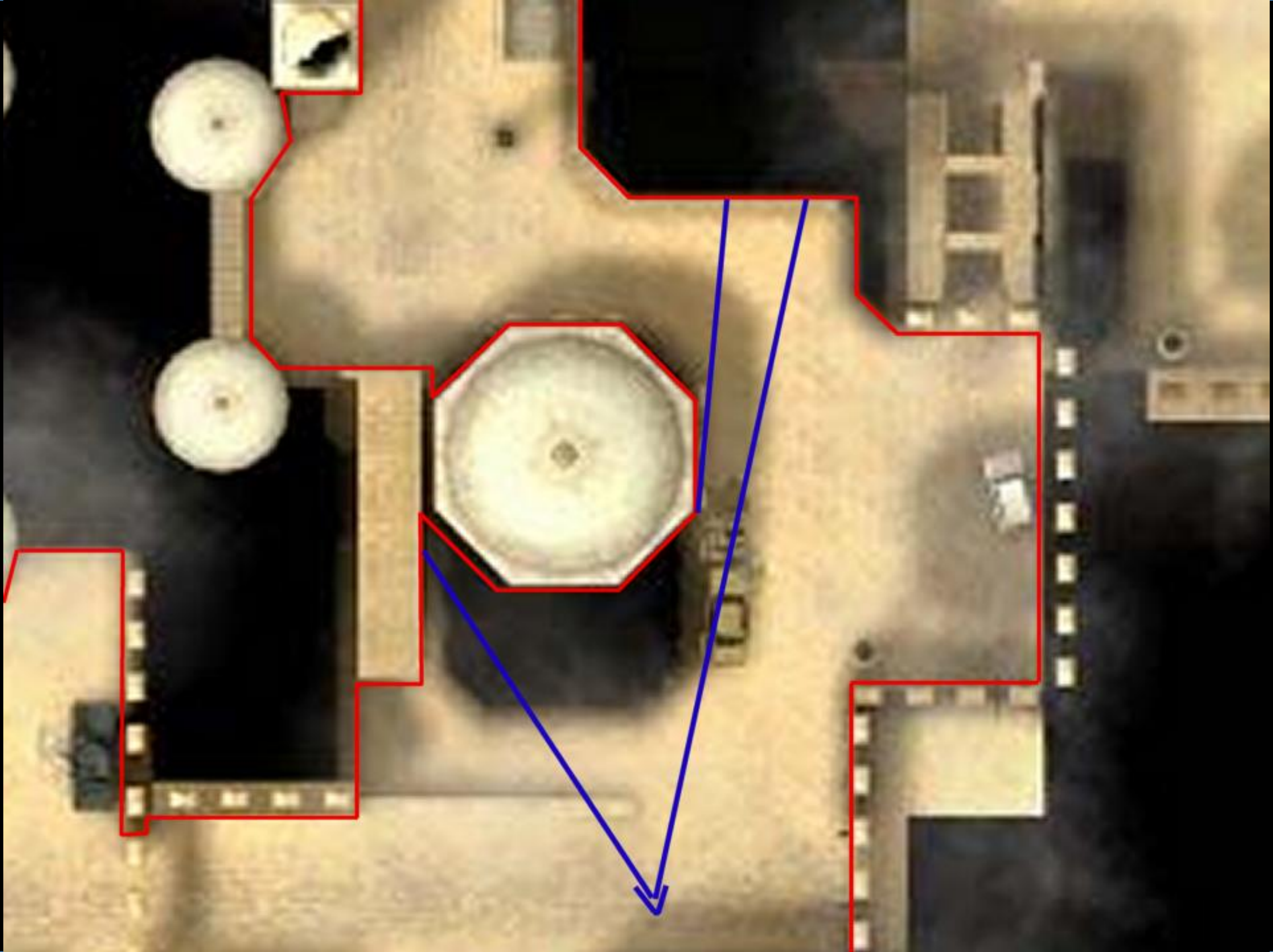
Indoor visibility: Portals

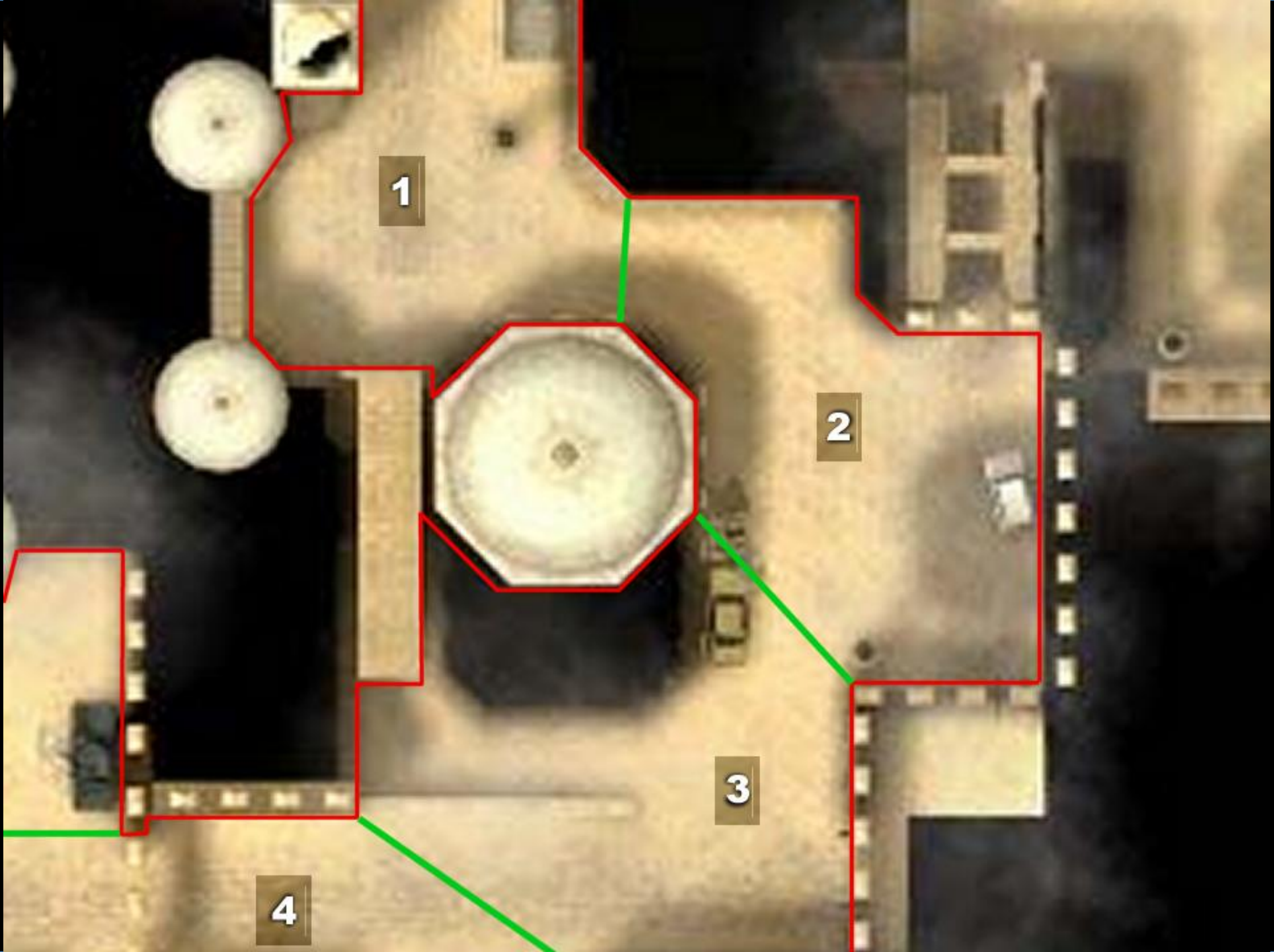
Observation: if a window is invisible, the room it links to is invisible.

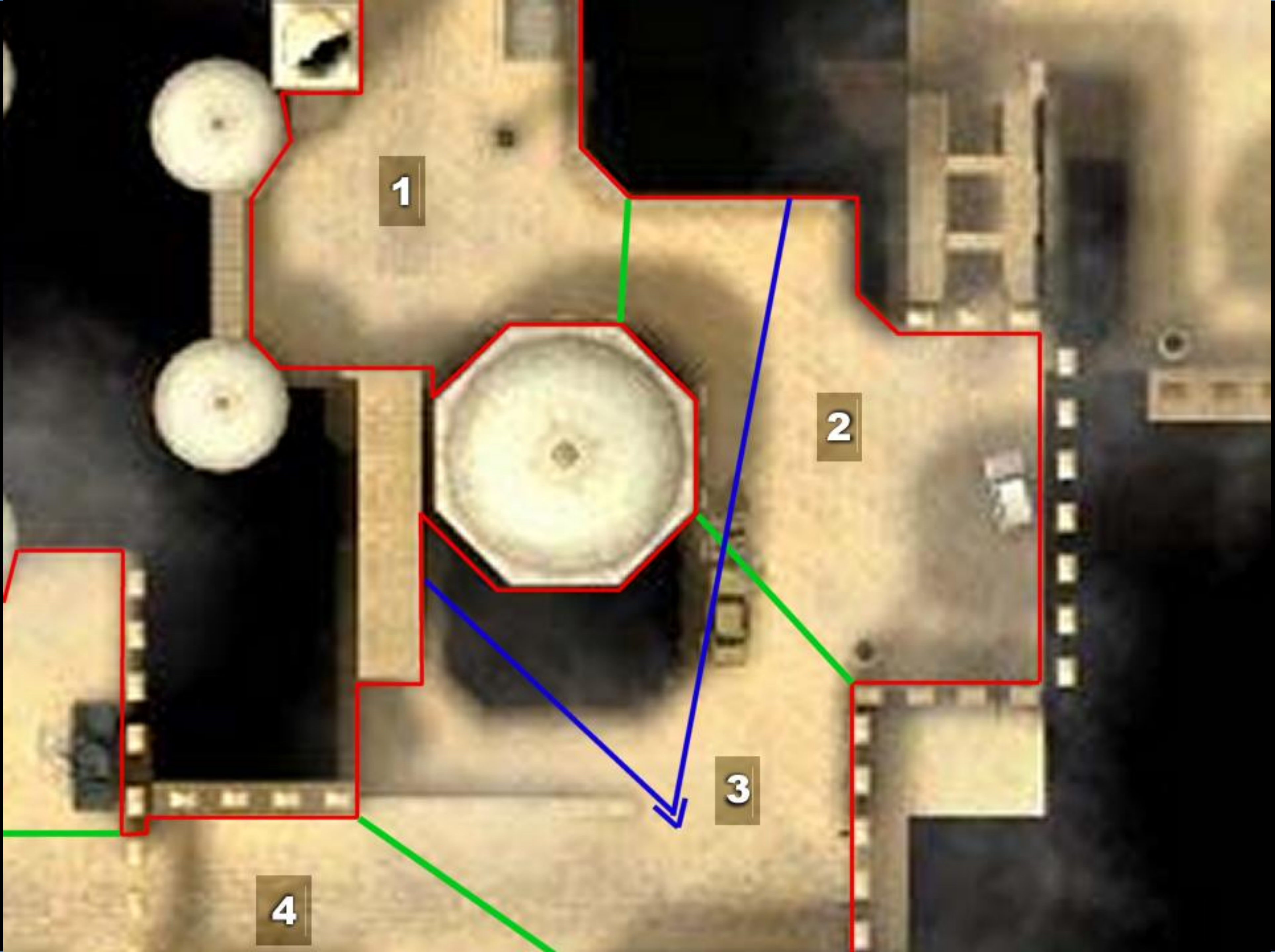









1
2
3
4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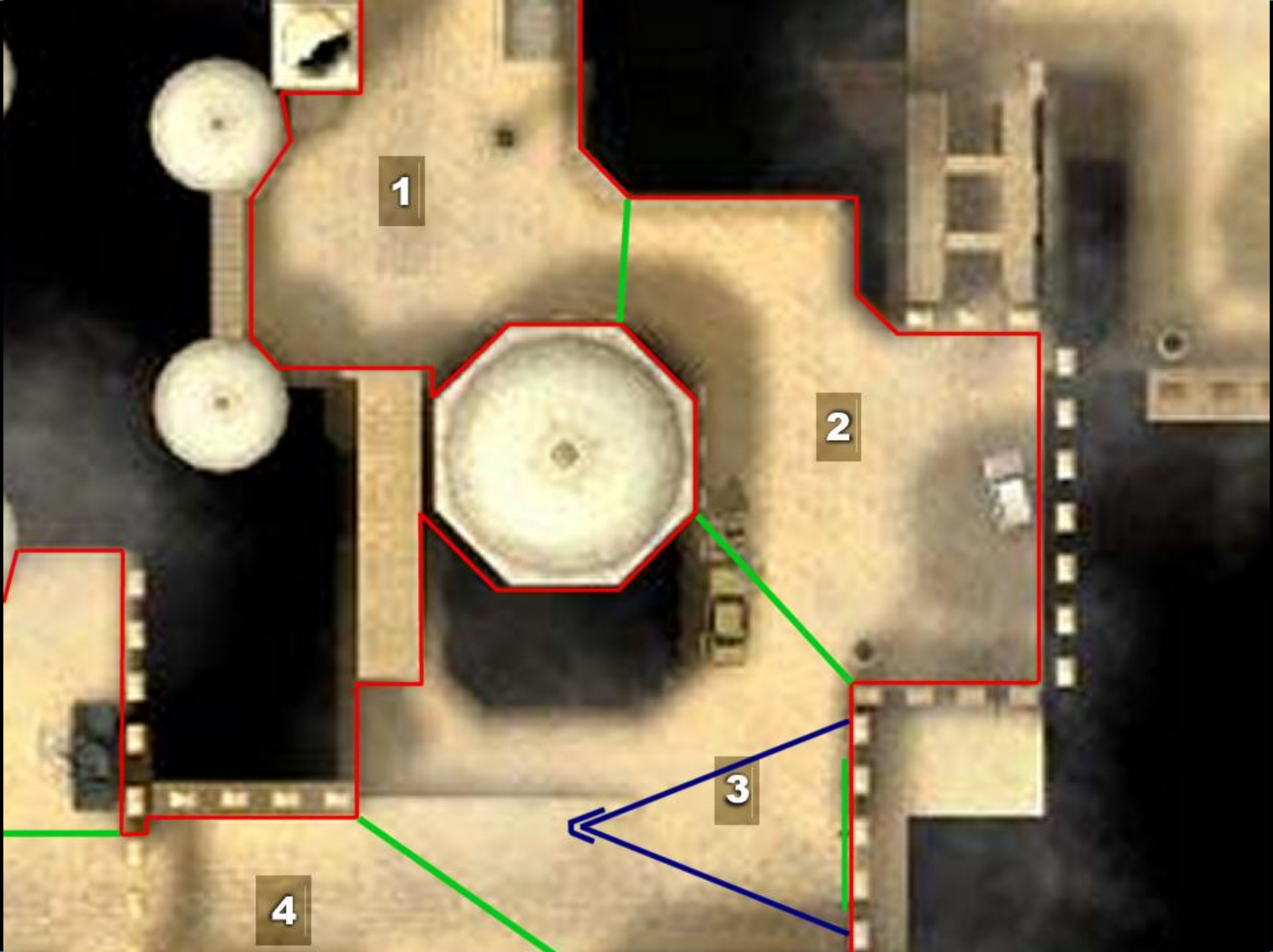
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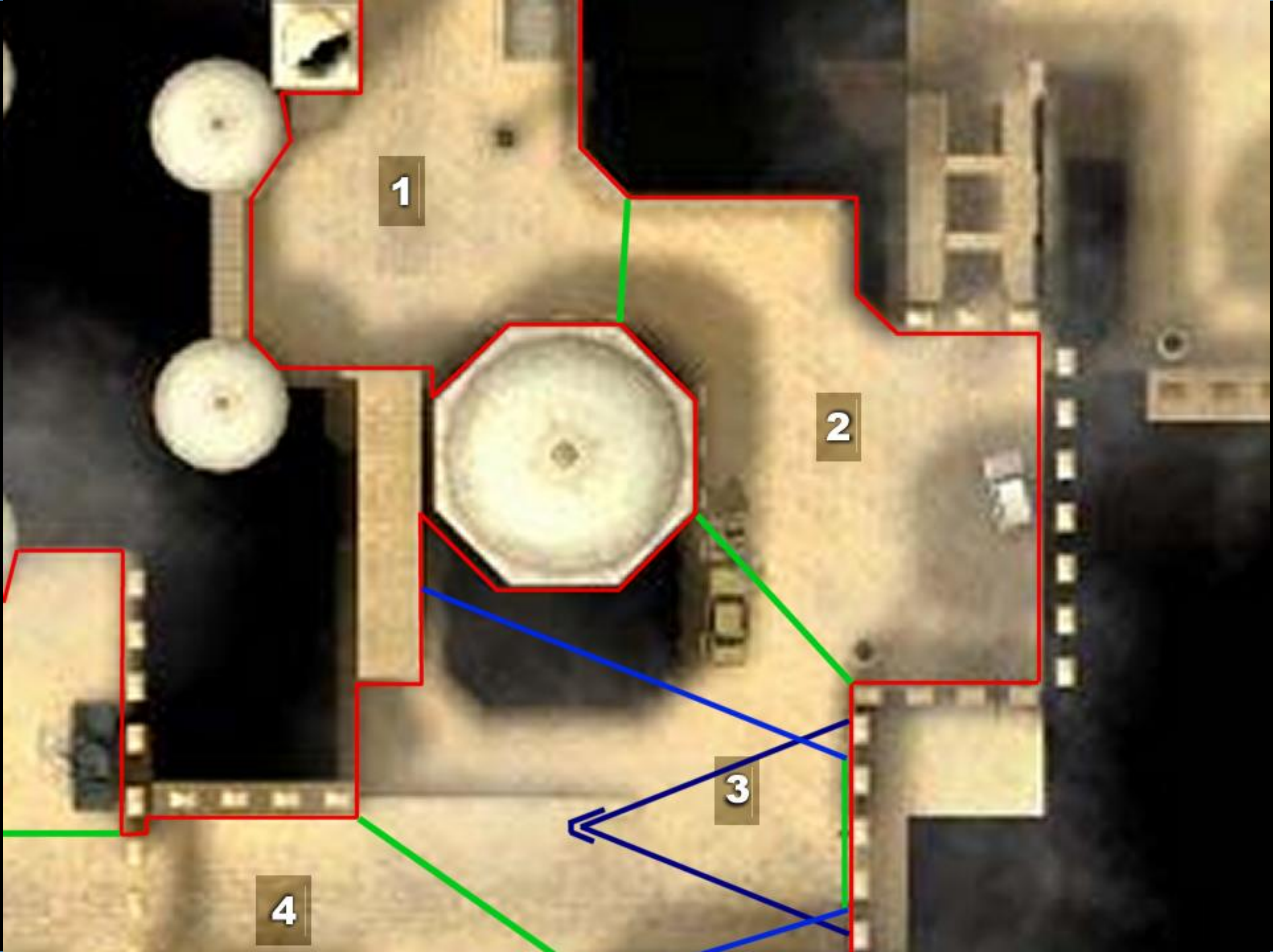
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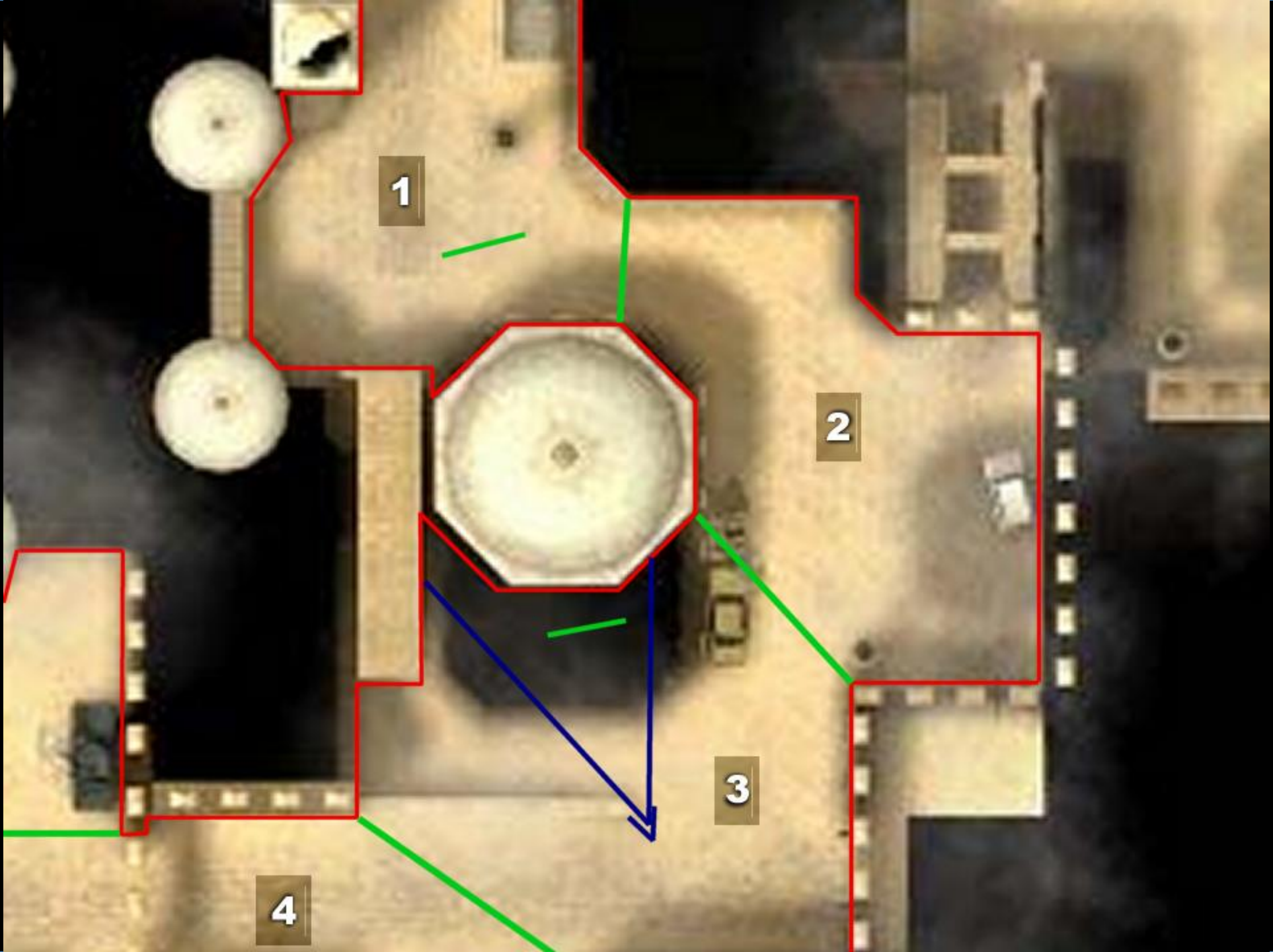
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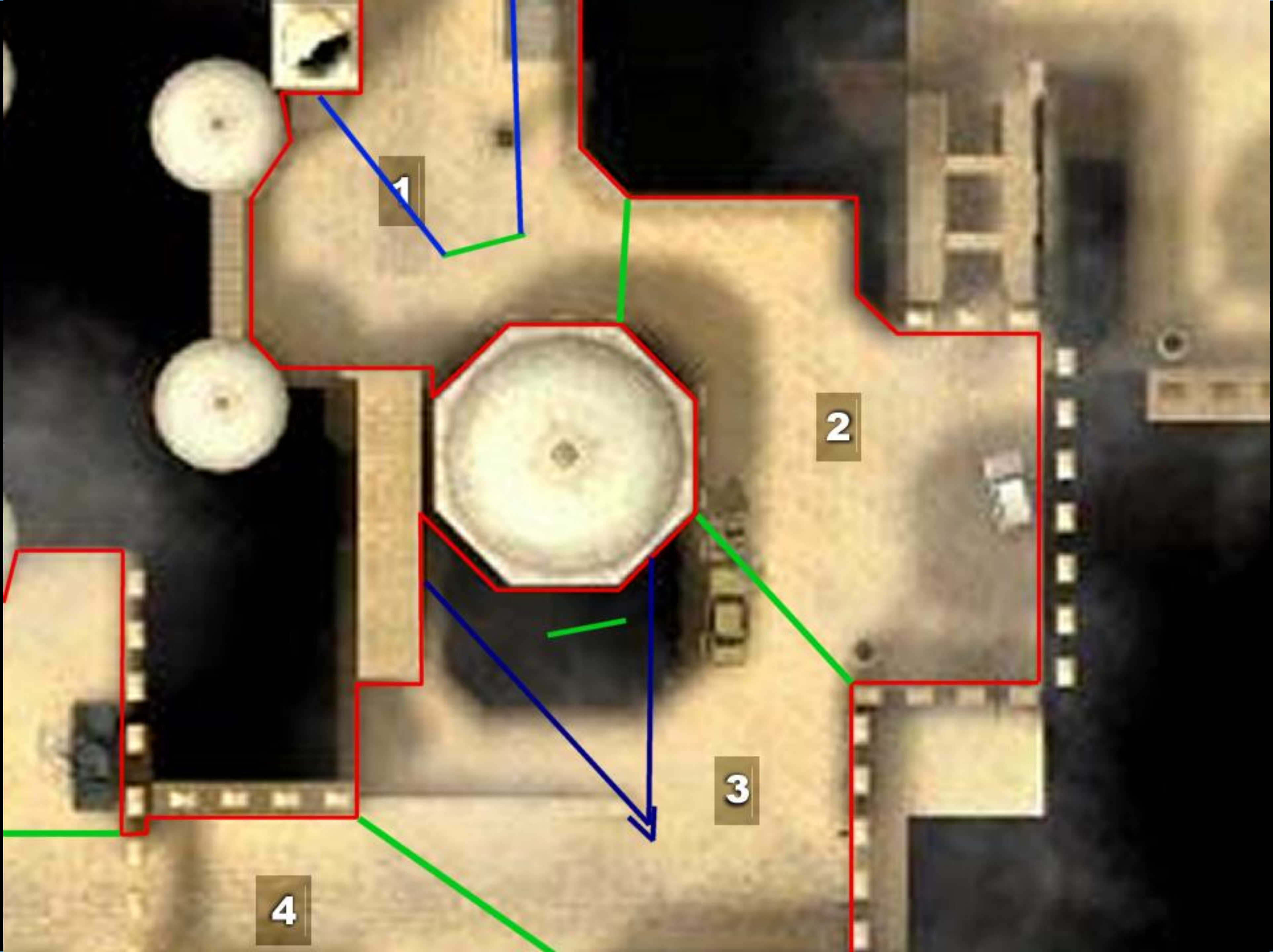

1
2
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# Visibility

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
- The Midterm Exam

# Midterm Exam

Time for your examination.

Where: EDUC-GAMMA
When: Thursday, May 21st, 2015, at 13.30
Duration: Two hours, three for dyslexia

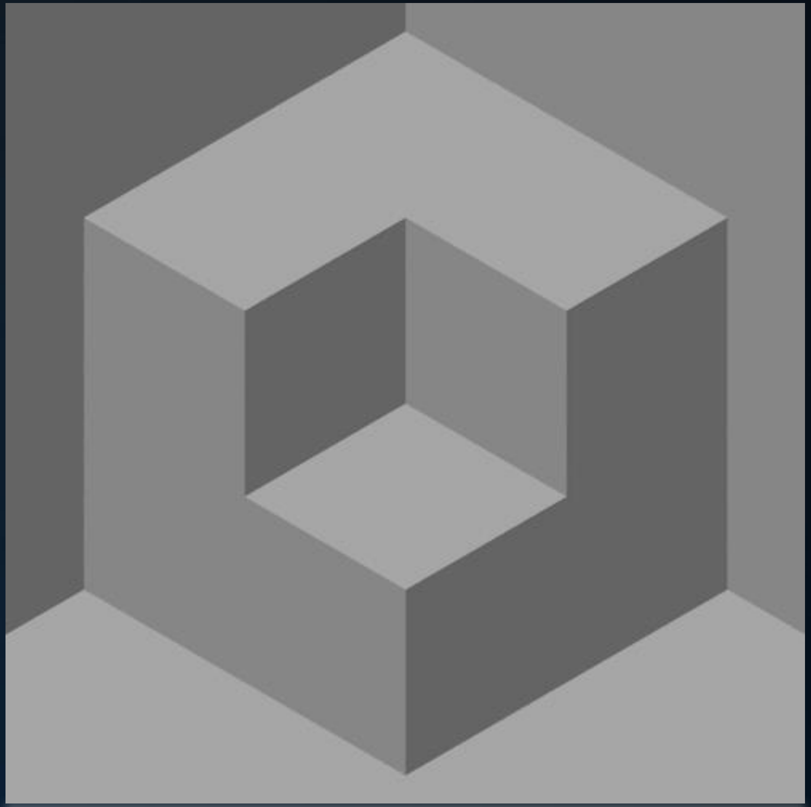
Contents:

- Mathematics (lectures 1..5 + slides, tutorial sheets)
- Graphics theory (lectures 1..7 + slides)

What to study:

- Slides
- Book can be helpful too
- Tutorial sheets

Need extra time? Entitled to it? Notify me!



WAARSCHUWING
BESMETTE ZONE
BIOHAZARD
EATING, DRINKING, SMOKING, APPLYING COSMETICS AND HANDLING CONTACT LENSES ARE PROHIBITED IN THIS AREA
RADIOACTIVE
7
GASMASKER VERPLICHT
RADIOACTIEF BESMET