CSE 167: Introduction to Computer Graphics Lecture #9: Visibility

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Announcements

- Midterm
  - Scores are on TritonEd
  - Exams to be returned and discussed this Thursday in class
- Discussion tomorrow
  - Tips for project 3
- Project 3 due this Friday at 2pm
  - Grading in CSE basement labs B260 and B270
  - Upload code to TritonEd by 2pm
  - Grading order managed by Autograder
  - Vote for best robot: instructions on Piazza

Topics

- Visibility Culling
- Occlusion

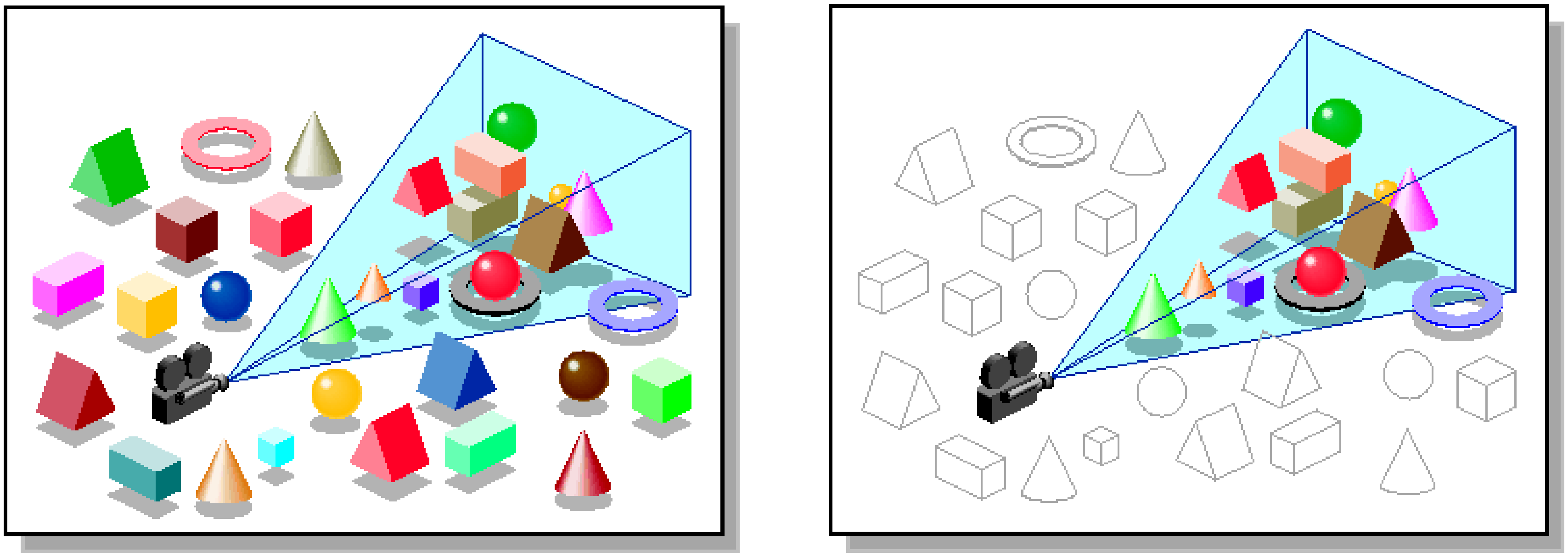
Visibility Culling

Visibility Culling

- Goal:
  Discard geometry that does not need to be drawn to speed up rendering
- Types of culling:
  - View frustum culling
  - Small object culling
  - Degenerate culling
  - Backface culling
  - Occlusion culling

View Frustum Culling

- Triangles outside of view frustum are off-screen



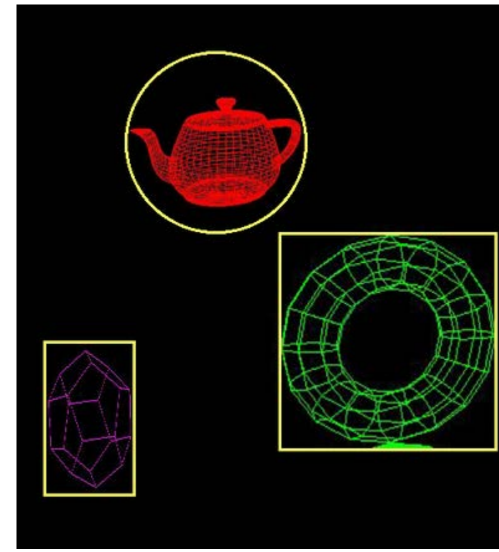
Images: SGI OpenGL Optimizer Programmer's Guide

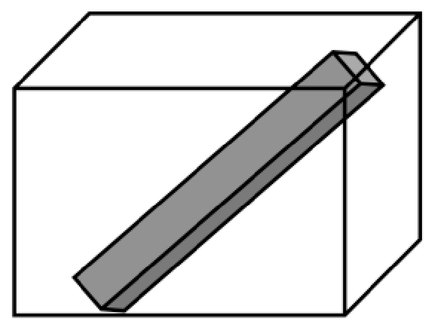
Videos

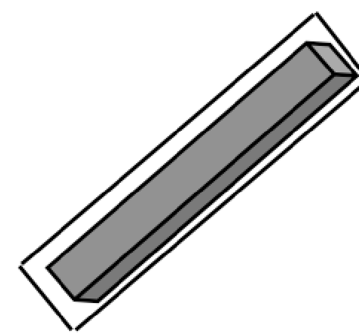
- Rendering Optimizations - Frustum Culling
  - http://www.youtube.com/watch?v=kvVHp9wMAO8
- View Frustum Culling Demo
  - http://www.youtube.com/watch?v=bJrYTBGpwic

Bounding Volumes

- Simple shape that completely encloses an object
- Generally a box or sphere
  - Easier to calculate culling for spheres
  - Easier to calculate tight fits for boxes
- Intersect bounding volume with view frustum instead of each primitive







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Bounding Box

- How to cull objects consisting of may polygons?
- Cull bounding box
  - Rectangular box, parallel to object space coordinate planes
  - Box is smallest box containing the entire object

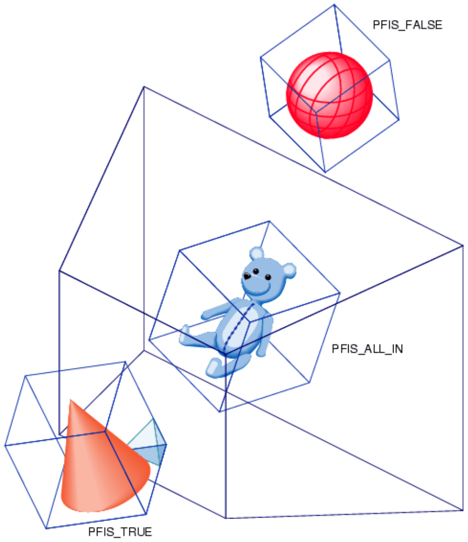
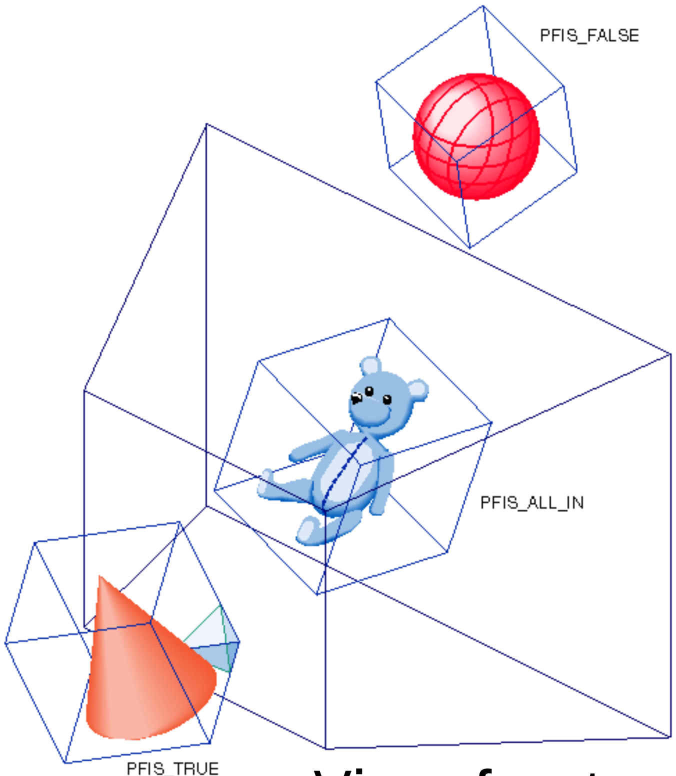


Image: SGI OpenGL Optimizer Programmer's Guide

View Frustum Culling

- Frustum defined by 6 planes
- Each plane divides space into "outside", "inside"
- Check each object against each plane
  - Outside, inside, intersecting
- If "outside" of at least one plane
  - Outside the frustum
- If "inside" all planes
  - Inside the frustum
- Else partly inside and partly out



View frustum

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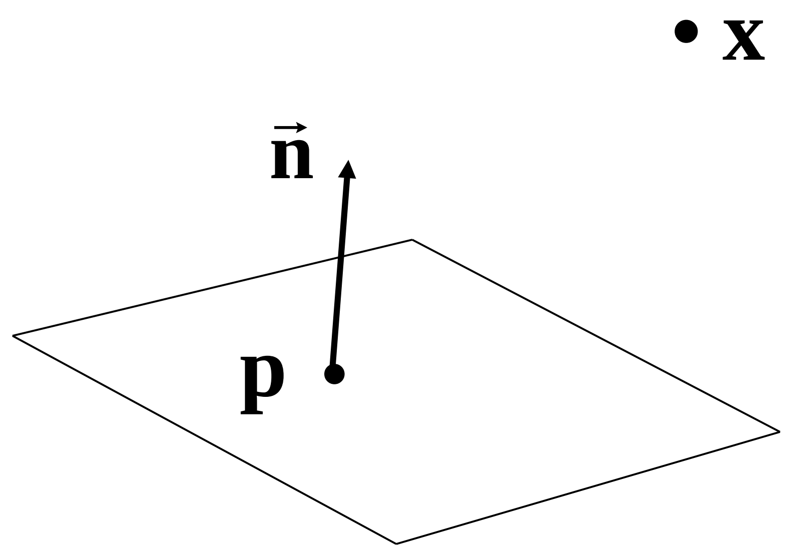
Distance to Plane

- A plane is described by a point **p** on the plane and a unit normal **n**
- Find the (perpendicular) distance from point **x** to the plane



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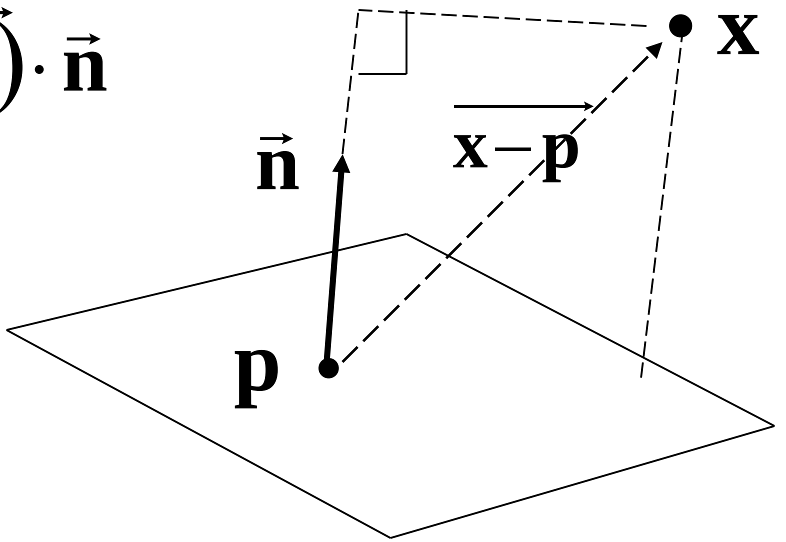
Distance to Plane

- The distance is the length of the projection of **x-p** onto **n**

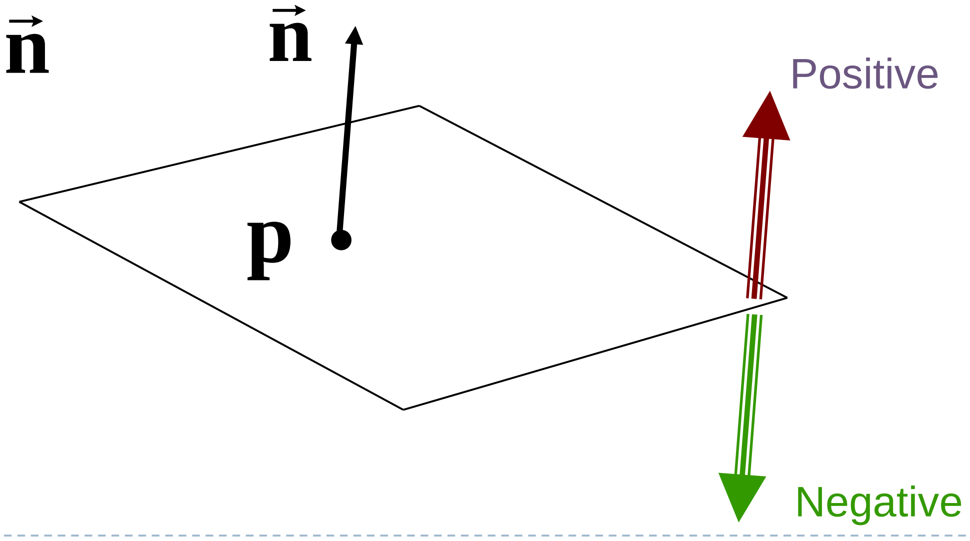
$$dist = \overrightarrow{(\mathbf{x}-\mathbf{p})} \cdot \vec{\mathbf{n}}$$



Distance to Plane

- The distance has a sign
  - positive on the side of the plane the normal points to
  - negative on the opposite side
  - zero exactly on the plane
- Divides 3D space into two infinite half-spaces

$$dist(\mathbf{x}) = \overrightarrow{(\mathbf{x} - \mathbf{p})} \cdot \vec{\mathbf{n}}$$



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Distance to Plane

- Simplification

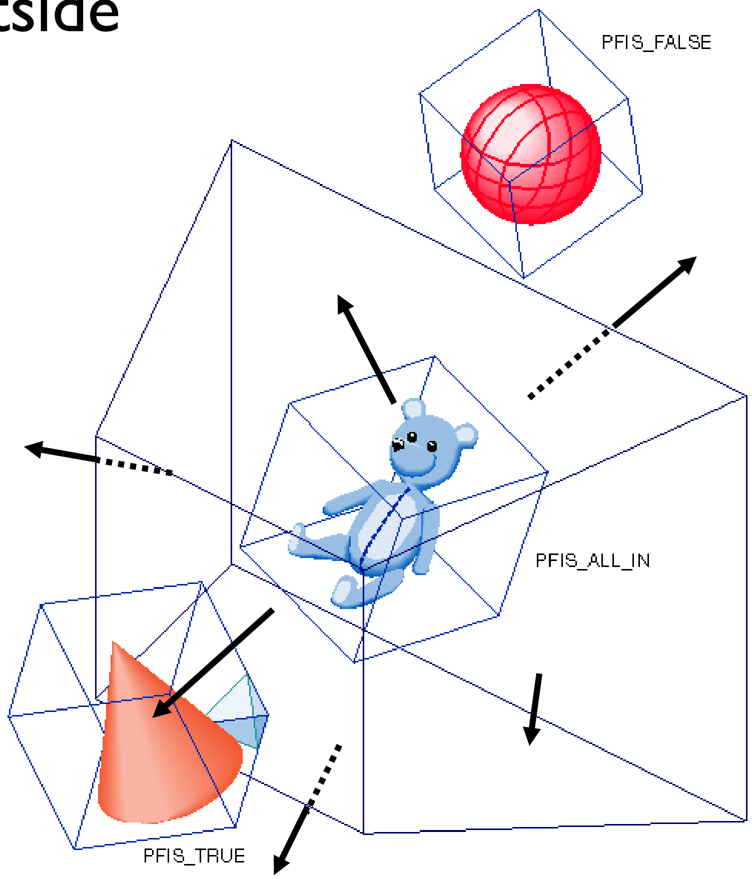
$$\begin{aligned} dist(\mathbf{x}) &= (\mathbf{x} - \mathbf{p}) \cdot \mathbf{n} \\ &= \mathbf{x} \cdot \mathbf{n} - \mathbf{p} \cdot \mathbf{n} \end{aligned}$$

$$dist(\mathbf{x}) = \mathbf{x} \cdot \mathbf{n} - d, \quad d = \mathbf{pn}$$

- *d* is independent of **x**
- *d* is distance from the origin to the plane
- We can represent a plane with just *d* and **n**

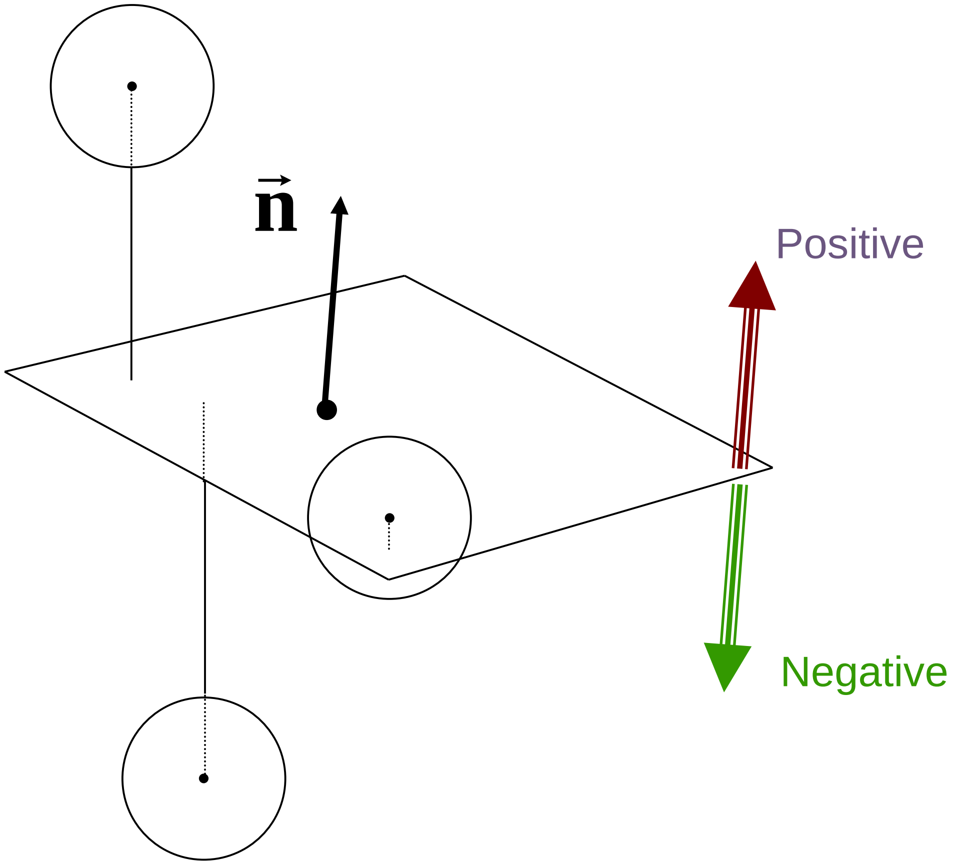
Frustum With Signed Planes

- Normal of each plane points outside
  - "outside" means positive distance
  - "inside" means negative distance



Test Sphere and Plane

- For sphere with radius r and origin $\mathbf{x}$, test the distance to the origin, and see if it is beyond the radius
- Three cases:
  - $dist(\mathbf{x})>r$
    - completely above
  - $dist(\mathbf{x})<-r$
    - completely below
  - $-r<dist(\mathbf{x})<r$
    - intersects

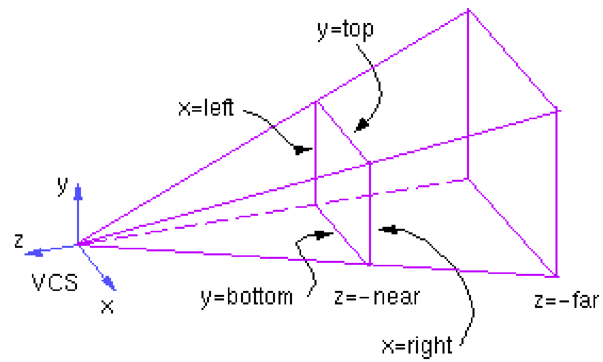


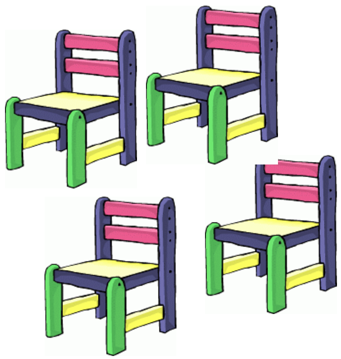
Culling Summary

- Transform view frustum plane equations in camera space.
- Pre-compute the normal $\mathbf{n}$ and value d for each of the six planes.
- Given a sphere with center $\mathbf{x}$ and radius r in camera space.
- For each plane:
  - if $dist(\mathbf{x}) > r$: sphere is outside! (no need to continue loop)
  - add 1 to count if $dist(\mathbf{x}) < -r$
- If we made it through the loop, check the count:
  - if the count is 6, the sphere is completely inside
  - otherwise the sphere intersects the frustum
  - *(can use a flag instead of a count)*

Culling Groups of Objects

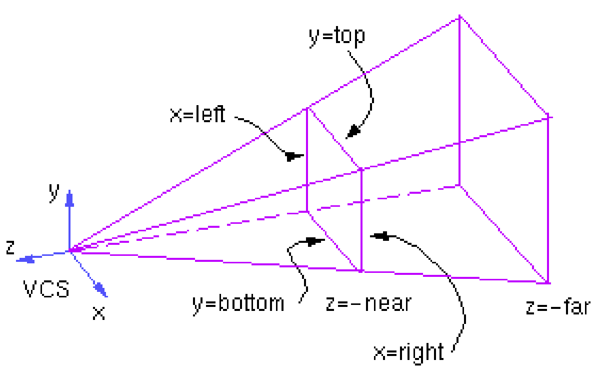
- Want to be able to cull the whole group quickly
- But if the group is partly in and partly out, want to be able to cull individual objects

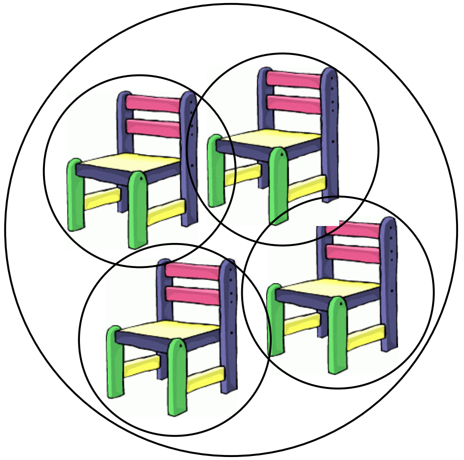




Hierarchical Bounding Volumes

- Given hierarchy of objects
- Bounding volume of each node encloses the bounding volumes of all its children
- Start by testing the outermost bounding volume
  - If it is entirely outside, don't draw the group at all
  - If it is entirely inside, draw the whole group





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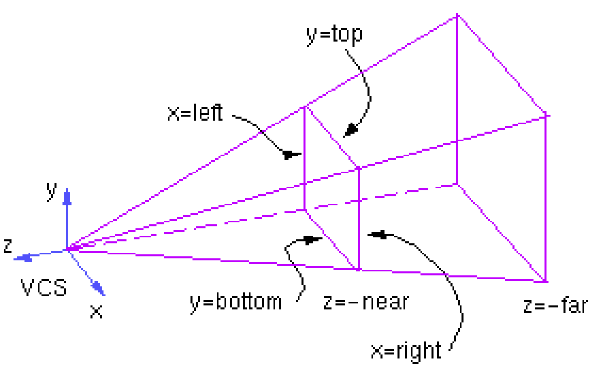
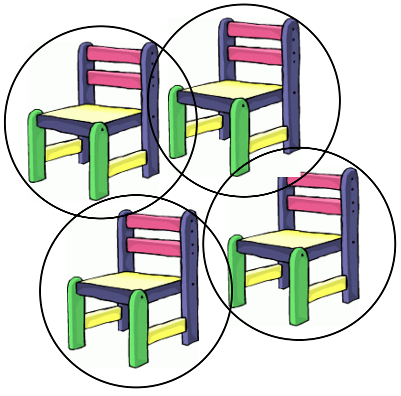
Hierarchical Culling

- If the bounding volume is partly inside and partly outside
  - Test each child's bounding volume individually
  - If the child is in, draw it; if it's out cull it; if it's partly in and partly out, recurse.
  - If recursion reaches a leaf node, draw it normally





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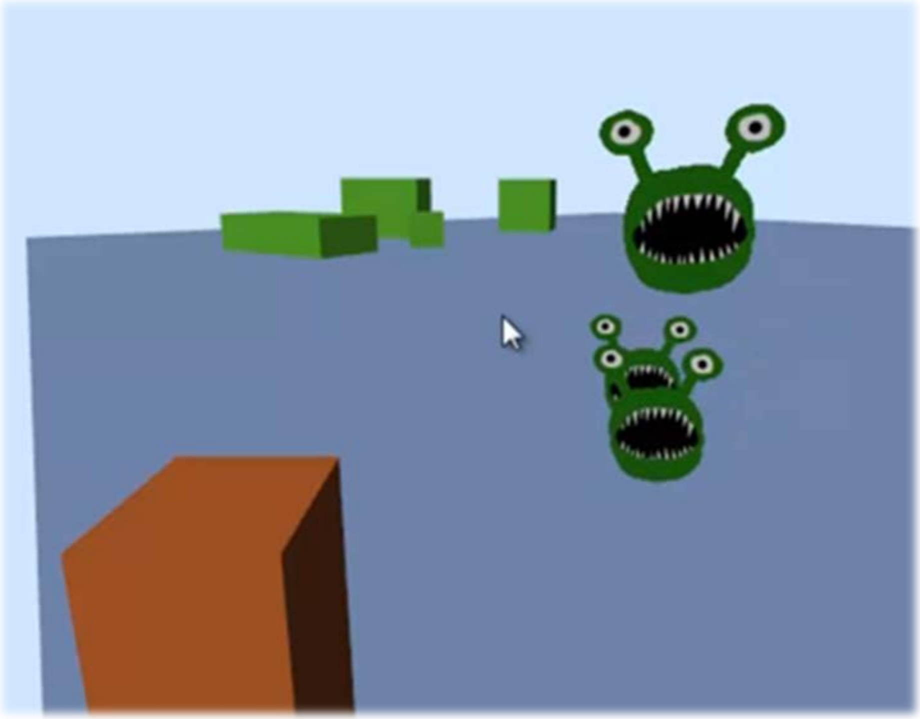
Video

- Math for Game Developers - Frustum Culling
  - http://www.youtube.com/watch?v=4p-E_31XOPM



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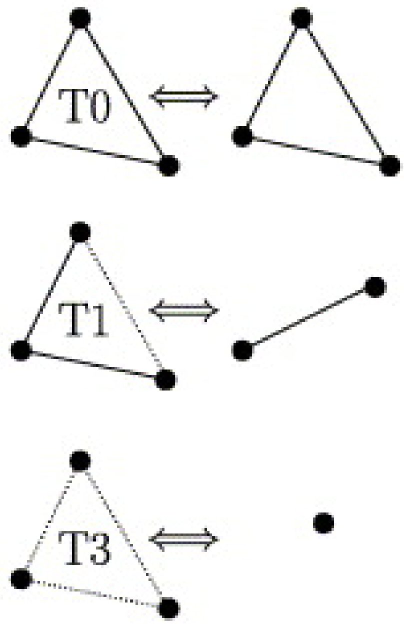
Small Object Culling

- Object projects to less than a specified size
  - Cull objects whose screen-space bounding box is less than a threshold number of pixels

Degenerate Culling

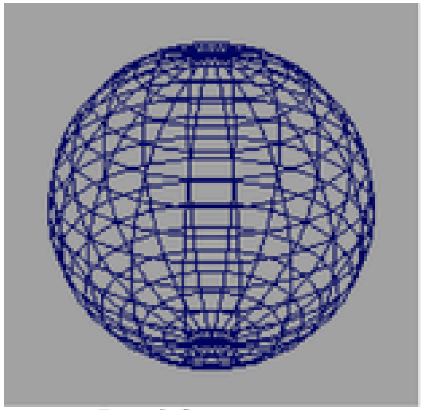
- Degenerate triangle has no area
  - Normal **n**=0
  - All vertices in a straight line
  - All vertices in the same place

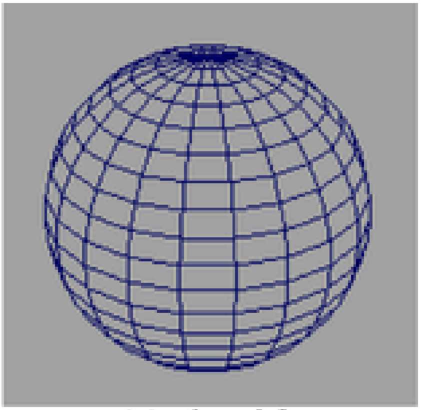


Source: Computer Methods in Applied Mechanics and Engineering, Volume 194, Issues 48–49

Backface Culling

- Consider triangles as "one-sided", i.e., only visible from the "front"
- Closed objects
  - If the "back" of the triangle is facing away from the camera, it is not visible
  - Gain efficiency by not drawing it (culling)
  - Roughly 50% of triangles in a scene are back facing


Backfaces


No backfaces

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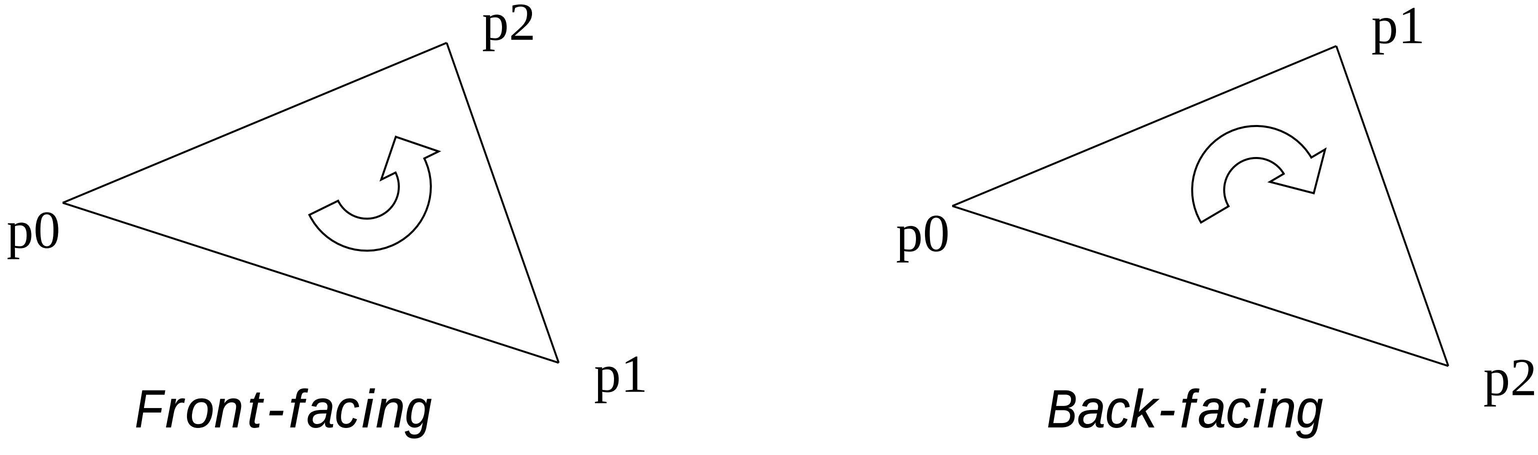
Backface Culling

- Convention:
  Triangle is front facing if vertices are ordered counterclockwise



Backface Culling

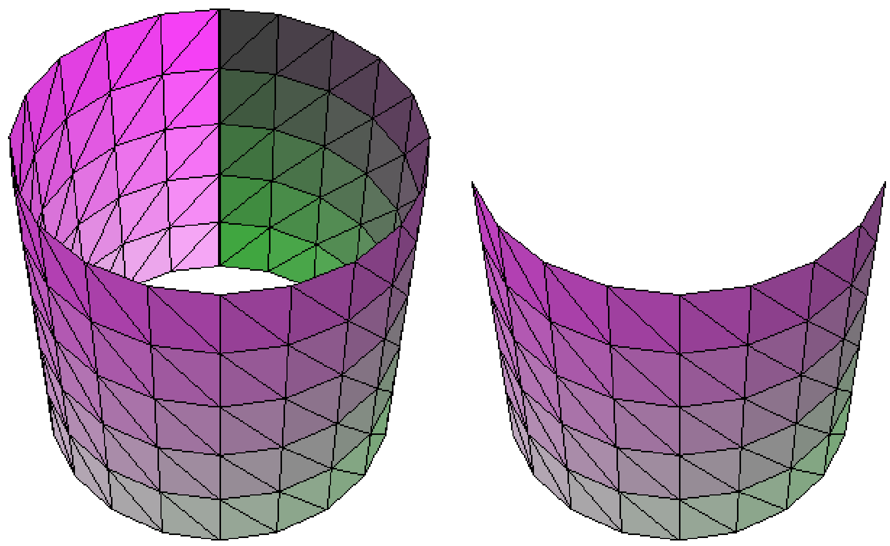
- Compute triangle normal after projection (homogeneous division)

$$\mathbf{n} = (\mathbf{p}_1 - \mathbf{p}_0) \times (\mathbf{p}_2 - \mathbf{p}_0)$$

- Third component of $\mathbf{n}$ negative: front-facing, otherwise back-facing
  - Remember: projection matrix is such that homogeneous division flips sign of third component

OpenGL

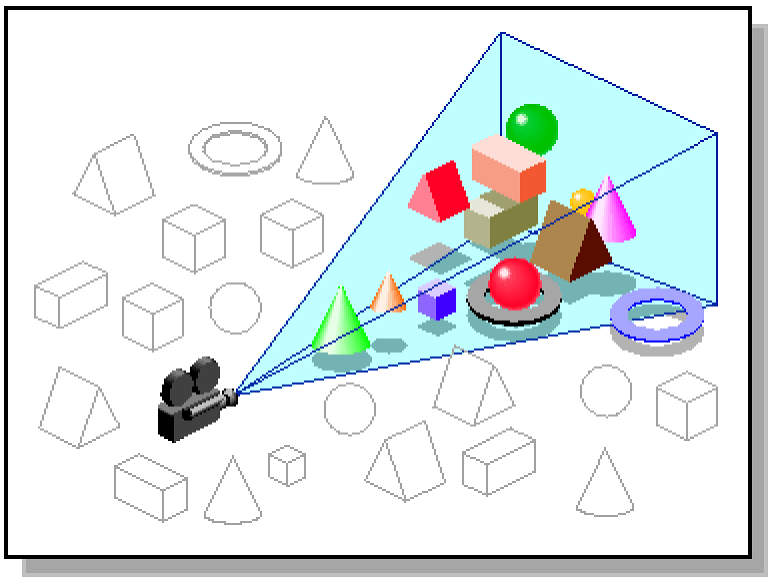
- OpenGL allows one- or two-sided triangles
  - One-sided triangles:
    glEnable(GL_CULL_FACE); glCullFace(GL_BACK)
  - Two-sided triangles (no backface culling):
    glDisable(GL_CULL_FACE)

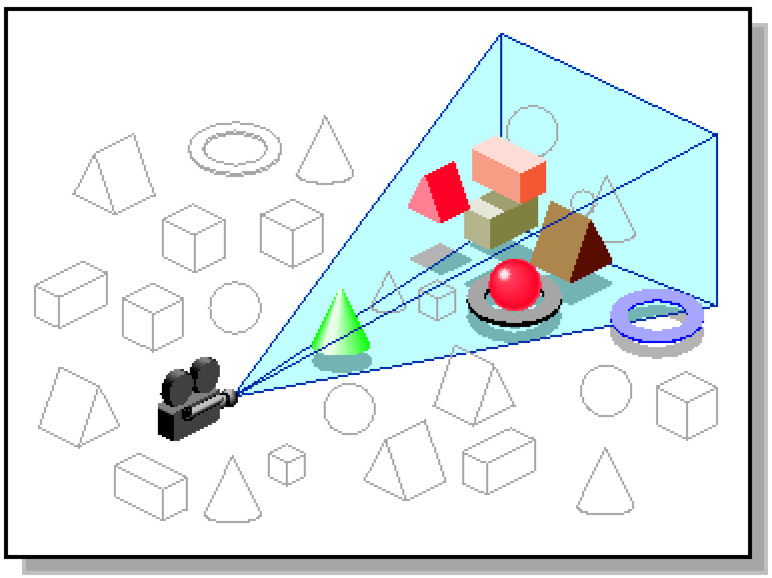


glDisable(GL_CULL_FACE);   glEnable(GL_CULL_FACE);

Occlusion Culling

- **Geometry hidden behind occluder cannot be seen**
  - Many complex algorithms exist to identify occluded geometry





Images: SGI OpenGL Optimizer Programmer's Guide

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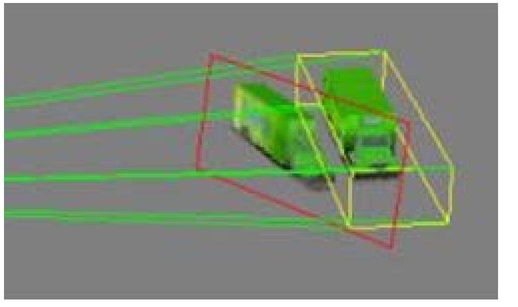
Video

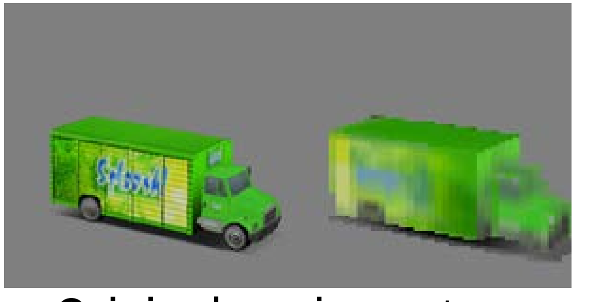
- Umbra 3 Occlusion Culling explained
  - http://www.youtube.com/watch?v=5h4QgDBwQhc

Level-of-Detail Techniques

- Don't draw objects smaller than a threshold
  - Small feature culling
  - Popping artifacts
- Replace 3D objects by 2D impostors
  - Textured planes representing the objects



Impostor generation



Original vs. impostor

- Adapt triangle count to projected size

Size dependent mesh reduction
(Data: Stanford Armadillo)

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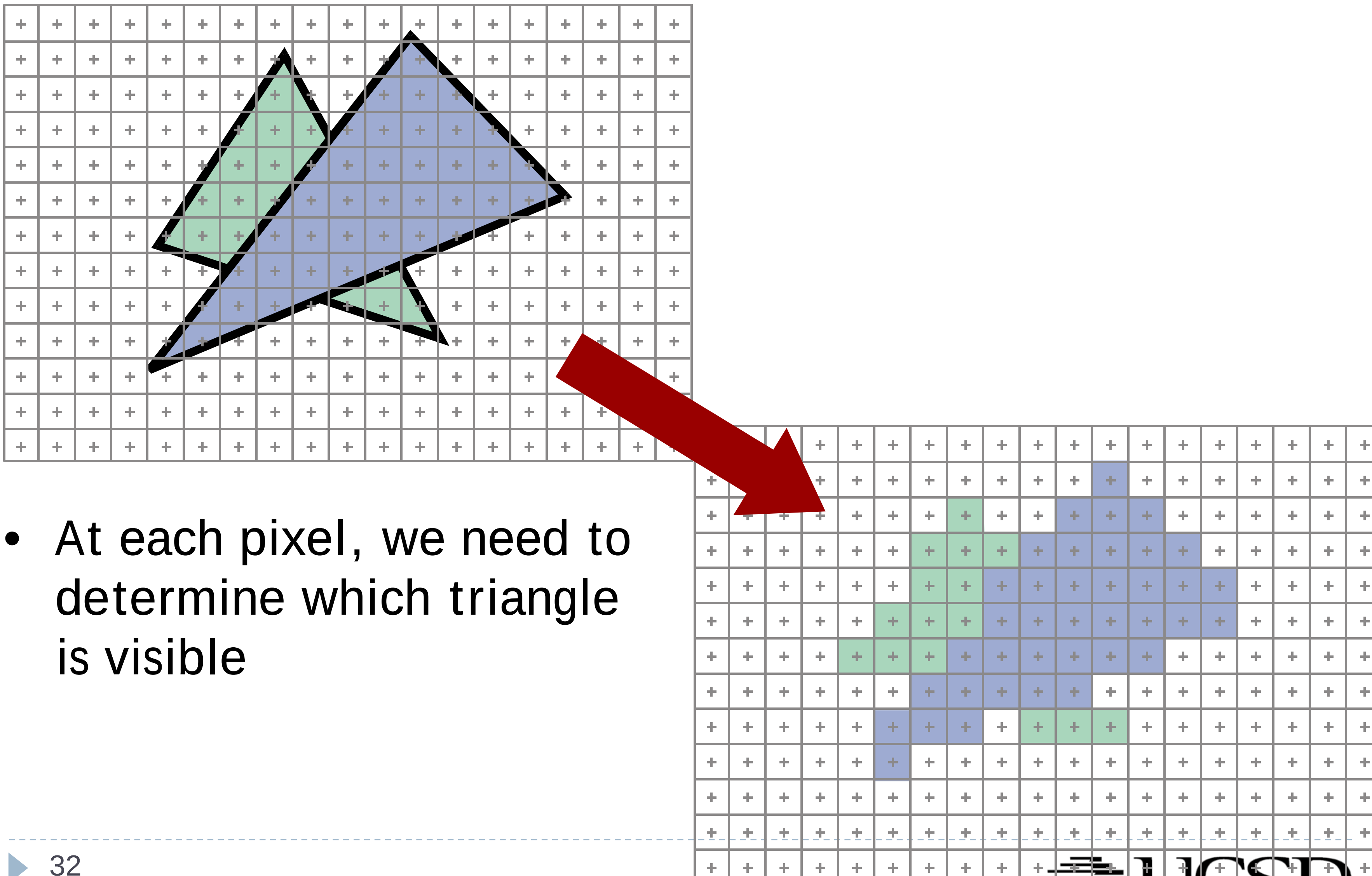
Occlusion

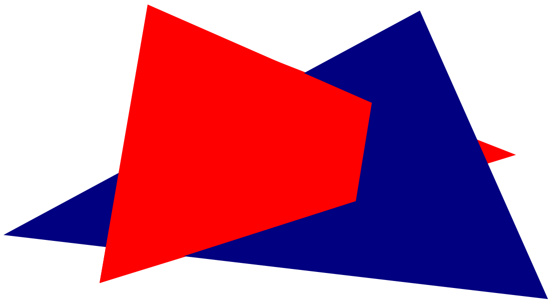
Occlusion



- At each pixel, we need to determine which triangle is visible

Painter's Algorithm

- Paint from back to front
- Need to sort geometry according to depth
- Every new pixel always paints over previous pixel in frame buffer
- May need to split triangles if they intersect



- Intuitive, but outdated algorithm - created when memory was expensive
- Needed for translucent geometry even today

Z-Buffering

- Store z-value for each pixel
- Depth test
  - Initialize z-buffer with farthest z value
  - During rasterization, compare stored value to new value
  - Update pixel only if new value is smaller

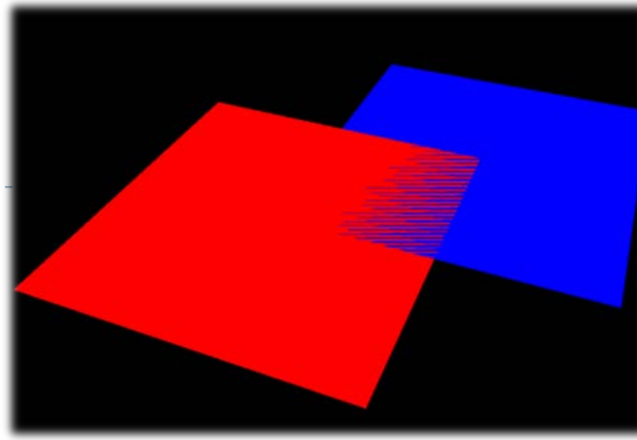
```
setpixel(int x, int y, color c, float z)
if(z<zbuffer(x,y)) then
  zbuffer(x,y) = z
  color(x,y) = c
```

- z-buffer is dedicated memory reserved in GPU memory
- Depth test is performed by GPU → very fast

Z-Buffering in OpenGL

- In OpenGL applications:
  - Ask for a depth buffer when you create your GLFW window.
    - glfwOpenWindow(512, 512, 8, 8, 8, 0, **16**, 0, GLFW_WINDOW)
  - Place a call to glEnable(GL_DEPTH_TEST) in your program's initialization routine.
  - Ensure that your *zNear* and *zFar* clipping planes are set correctly (glm::perspective(fovy, aspect, zNear, zFar)) and in a way that provides adequate depth buffer precision.
  - Pass GL_DEPTH_BUFFER_BIT as a parameter to glClear.
- Note that the z buffer is non-linear: it uses smaller depth bins in the foreground, larger ones further from the camera.

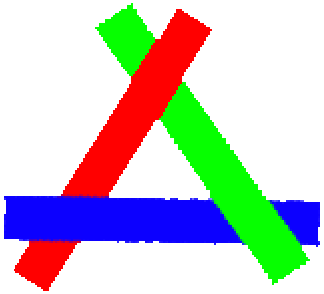
Z-Buffer Fighting



- Problem: polygons which are close together don't get rendered correctly. Errors change with camera perspective → flicker
- Cause: differently colored fragments from different polygons are being rasterized to same pixel and depth → not clear which is in front of which
- Solutions:
  - move surfaces farther apart, so that fragments rasterize into different depth bins
  - bring near and far planes closer together
  - use a higher precision depth buffer. Note that OpenGL often defaults to 16 bit even if your graphics card supports 24 bit or 32 bit depth buffers

Translucent Geometry

- Need to depth sort translucent geometry and render with Painter's Algorithm (back to front)
- Problem: incorrect blending with cyclically overlapping geometry



- Solutions:
  - Back to front rendering of translucent geometry (Painter's Algorithm), after rendering opaque geometry
    - Does not always work correctly: programmer has to weigh rendering correctness against computational effort
  - Theoretically: need to store multiple depth and color values per pixel (not practical in real-time graphics)