Culling

Computer Graphics

CSE 167

Lecture 12

CSE 167: Computer graphics

- Culling
  - Definition: selecting from a large quantity
  - In computer graphics: selecting primitives (or batches of primitives) that are visible
- If culling is performed early in the graphics pipeline, then rejected invisible objects are not fetched, transformed, rasterized, or shaded

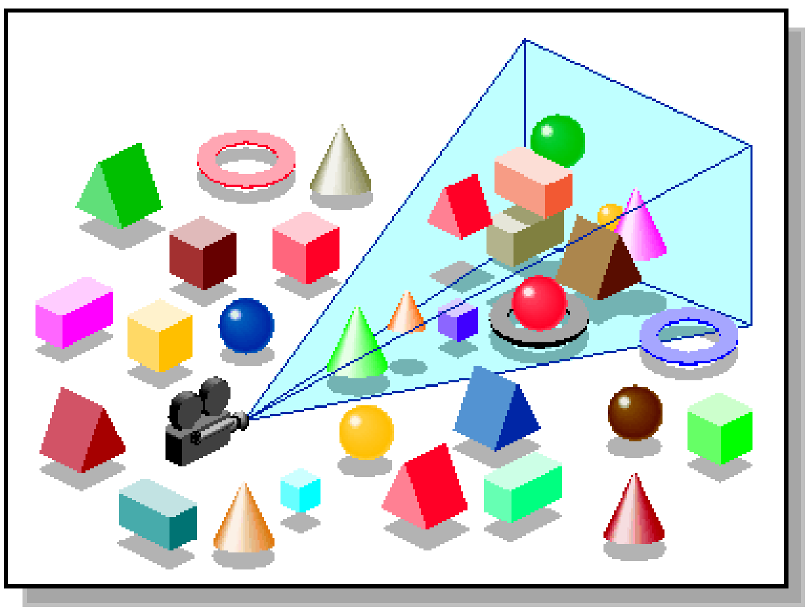
Types of culling

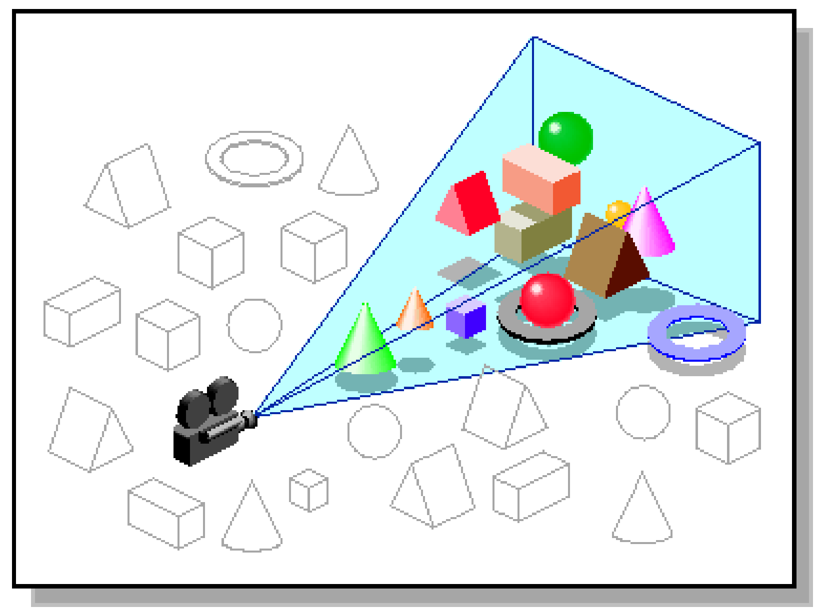
- View frustum culling
- Backface culling
- Contribution (or small object) culling
- Degenerate culling
- Occlusion culling

Based on slides courtesy of Jurgen Schulze

View frustum culling

- Triangles outside of view frustum are off-screen

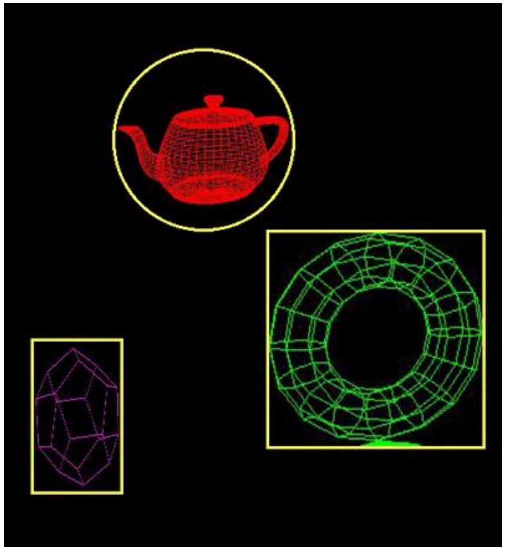


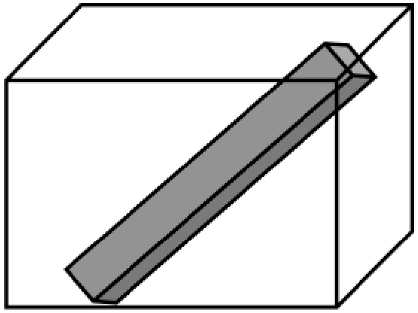


Images: SGI OpenGL Optimizer Programmer's Guide

Bounding volumes

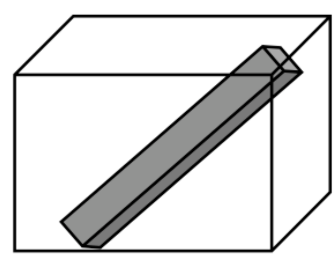
- How to cull objects consisting of many polygons?
- Intersect bounding volume with view frustum instead of each primitive
- Simple shape that completely encloses an object

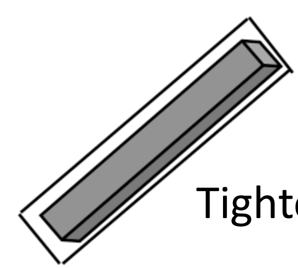




Bounding volumes

- Commonly, a cuboid or sphere
  - Easier to calculate tight fits for cuboids (boxes)
  - Easier to calculate culling for spheres
- Cull bounding box
  - Box is smallest box containing the entire object
  - Simple approach: rectangular box, axis-aligned to object space coordinate system
    - May not be tightest fit

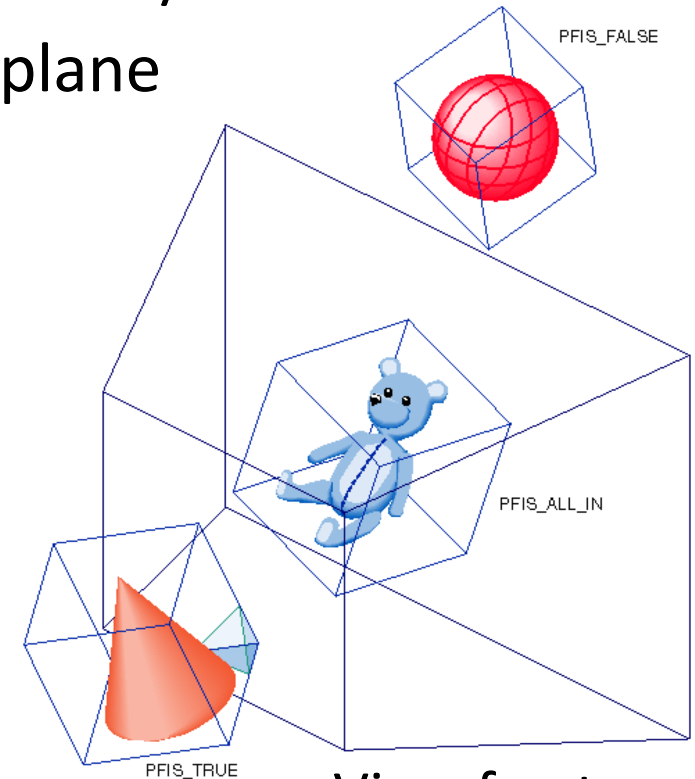




Tighter fit

View frustum culling

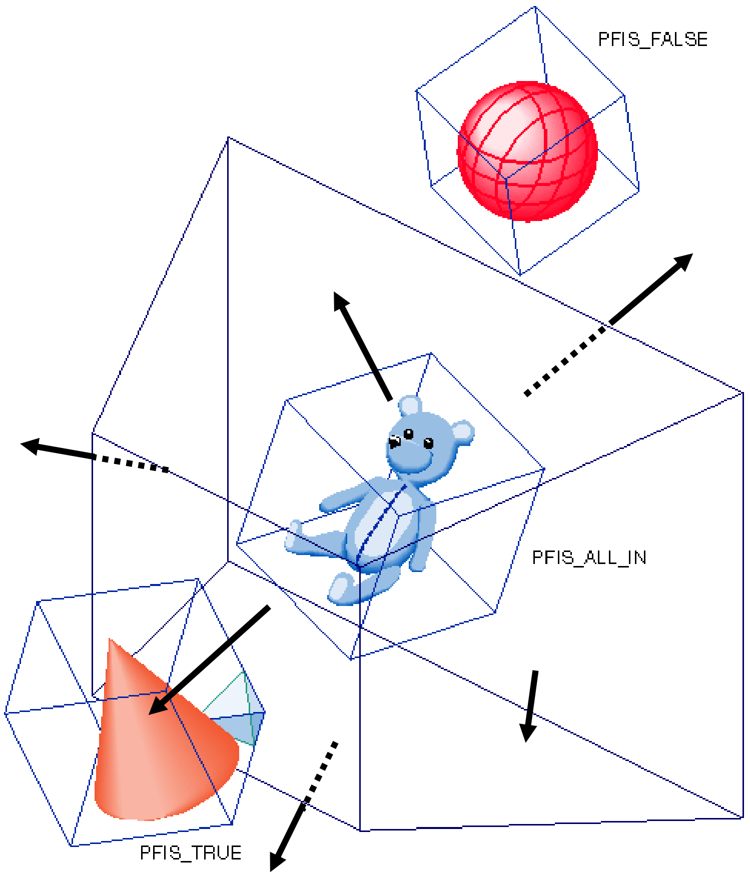
- Frustum is defined by 6 planes
- Each plane divides space into outside/inside
- Check each object against each plane
  - Outside, inside, intersecting
- If outside all planes
  - Outside the frustum
- If inside all planes
  - Inside the frustum
- Else, partially inside frustum
  - Intersecting the frustum



View frustum

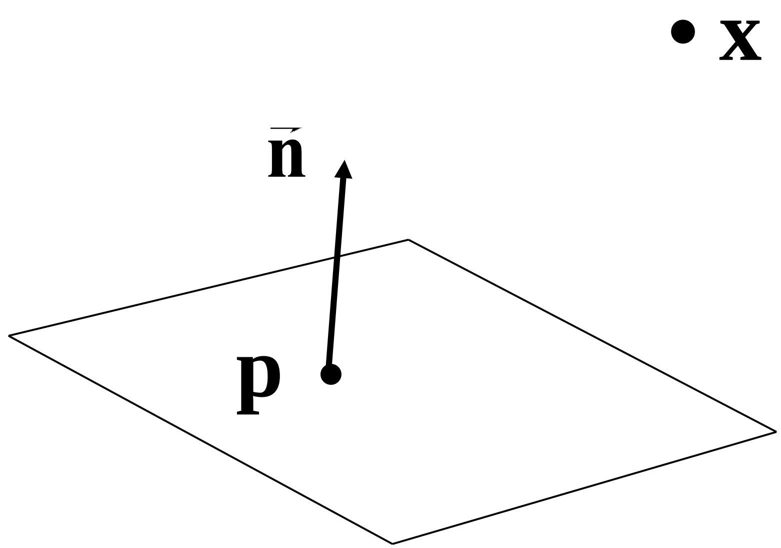
Frustum with oriented planes

- Normal of each plane points outside of frustum
  - Outside is positive distance
  - Inside is negative distance



Distance to plane

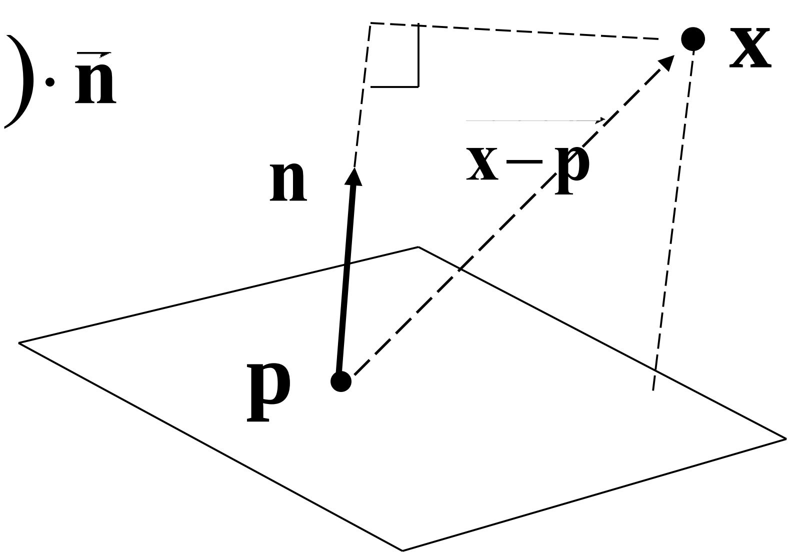
- A plane is described by a point **p** on the plane and a unit normal **n**
- Find the (perpendicular) distance from point **x** to the plane



Distance to plane

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

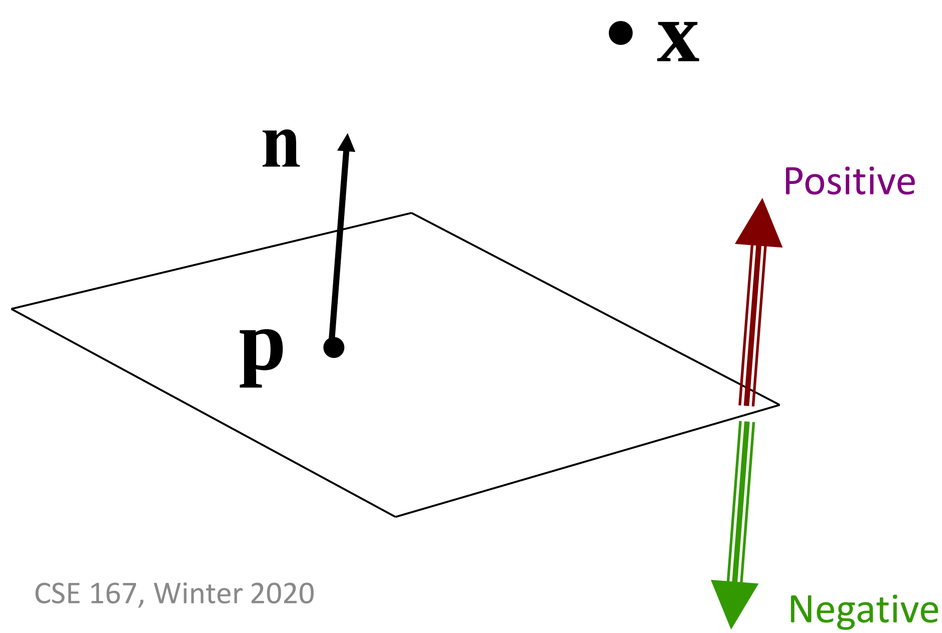
$$dist = (\mathbf{x} - \mathbf{p}) \cdot \bar{\mathbf{n}}$$



Distance to plane

- The distance has a sign (oriented plane)
  - 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

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



Distance to plane

- Simplification

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

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

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

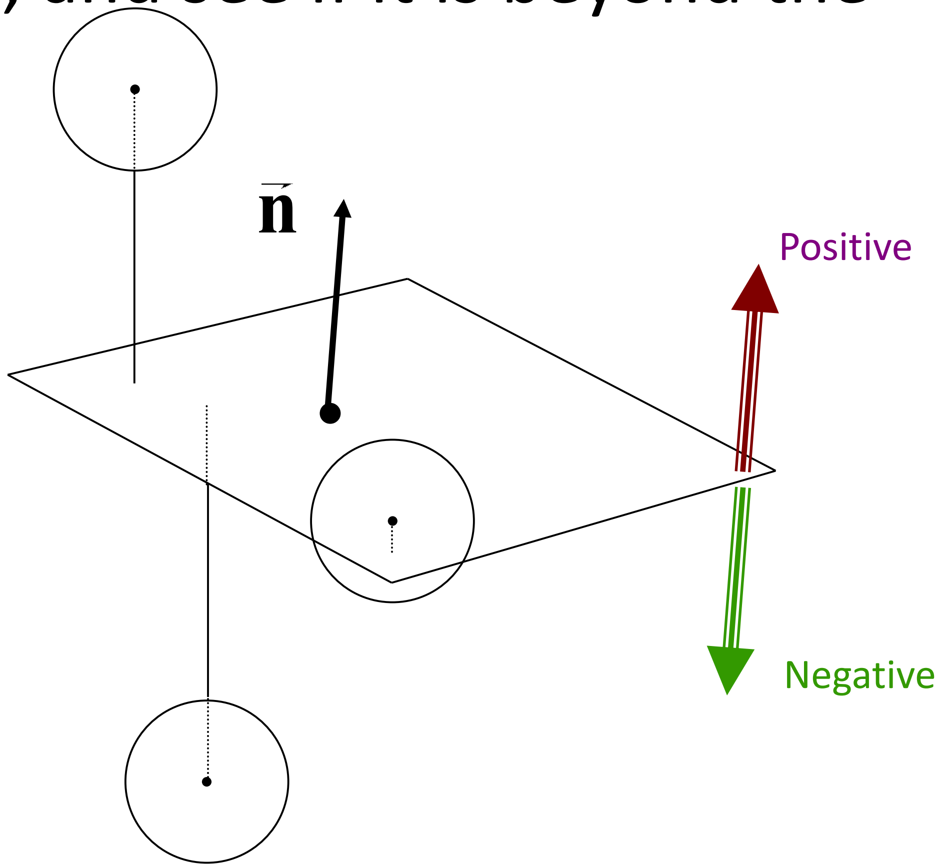
Sphere-plane test

- For sphere with radius r and origin 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



View frustum culling using spheres

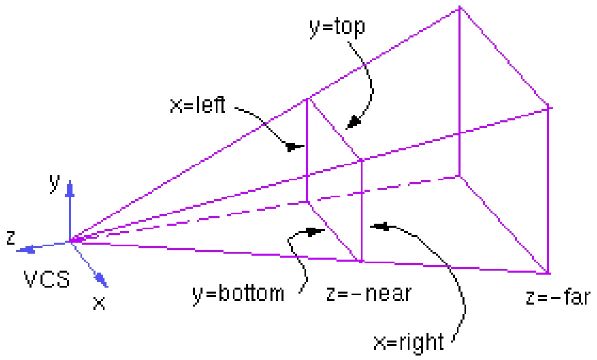
- Pre-compute the normal **n** and value *d* for each of the six planes.
- Given a sphere with center **x** and radius *r*
- For each of the six clipping planes
  - If $dist(\mathbf{x}) > r$, then sphere is outside (terminate loop)
  - Else if $dist(\mathbf{x}) < -r$, then add 1 to count
    - (Alternatively, set a flag if $dist(\mathbf{x}) \geq -r$)
- If we did not terminate the loop early, check the count
  - If the count is 6 (or flag was not set), then the sphere is completely inside
  - Otherwise, the sphere intersects the frustum

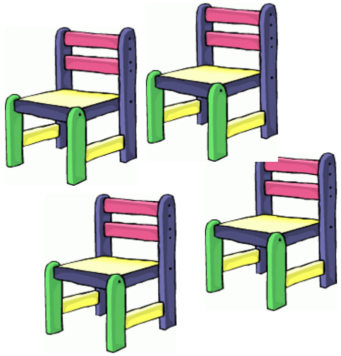
View frustum culling using spheres

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

View frustum culling groups of objects

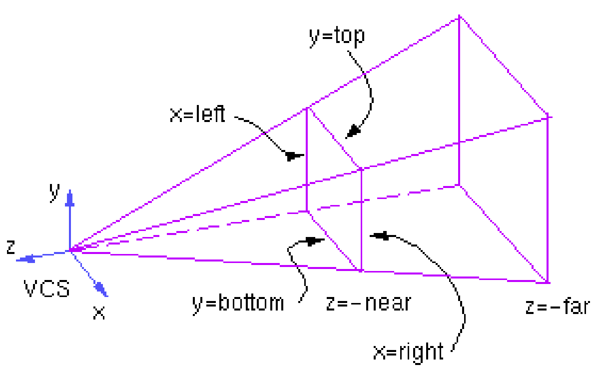
- Able to cull a whole group quickly
- But, if the group is partly in and partly out, able to cull individual objects

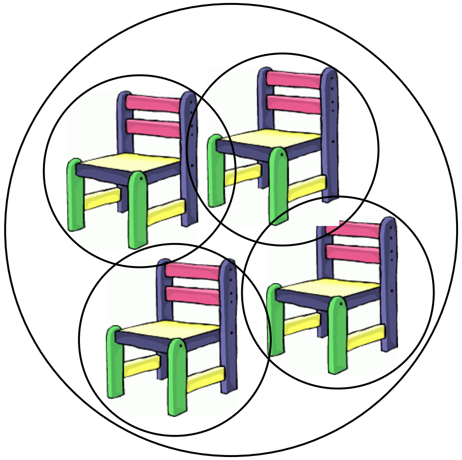




View frustum culling using hierarchical bounding volumes

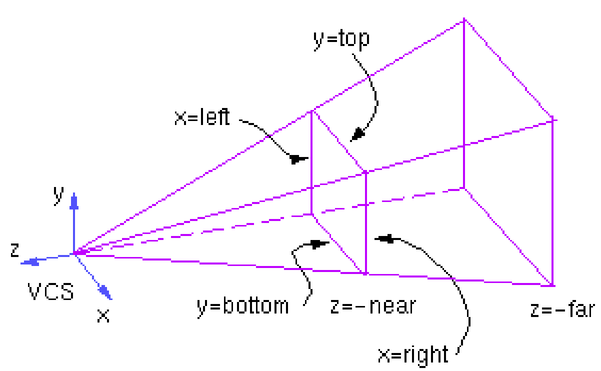
- Given hierarchy of objects
- Bounding volume of each node encloses the bounding volumes of all its children
- Start by testing the outermost bounding volume
  - If it is entirely outside, do not draw the group at all
  - If it is entirely inside, draw the whole group

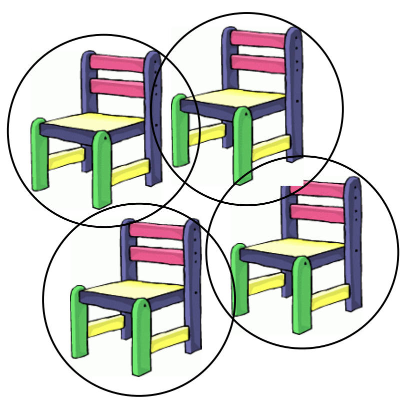




View frustum culling using hierarchical bounding volumes

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



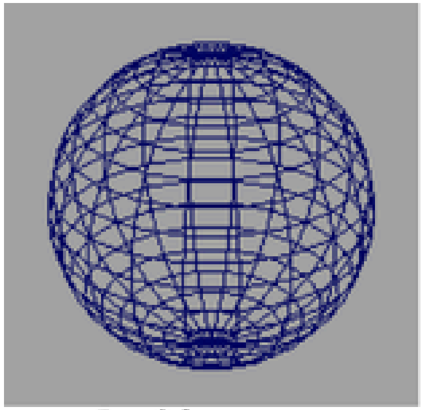


View frustum culling

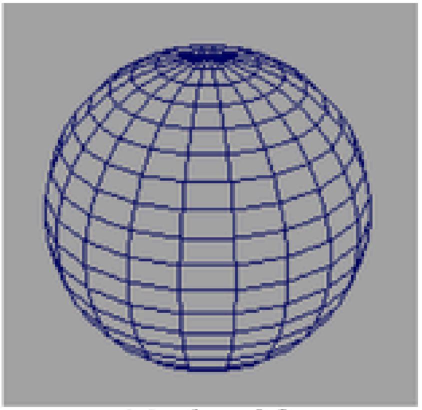
- Rendering Optimizations - Frustum Culling
  - https://www.youtube.com/watch?v=kvVHp9wMAO8
- View Frustum Culling Demo
  - https://www.youtube.com/watch?v=bJrYTBGpwic

Backface culling

- Consider triangles as “one-sided” (oriented triangle) and 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



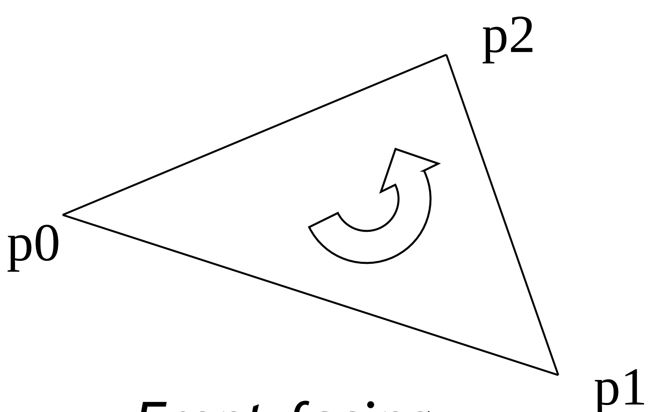
Backfaces



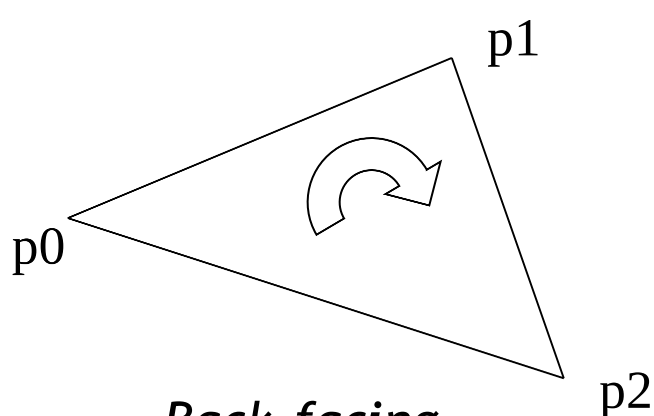
No backfaces

Backface culling

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



Front-facing



Back-facing

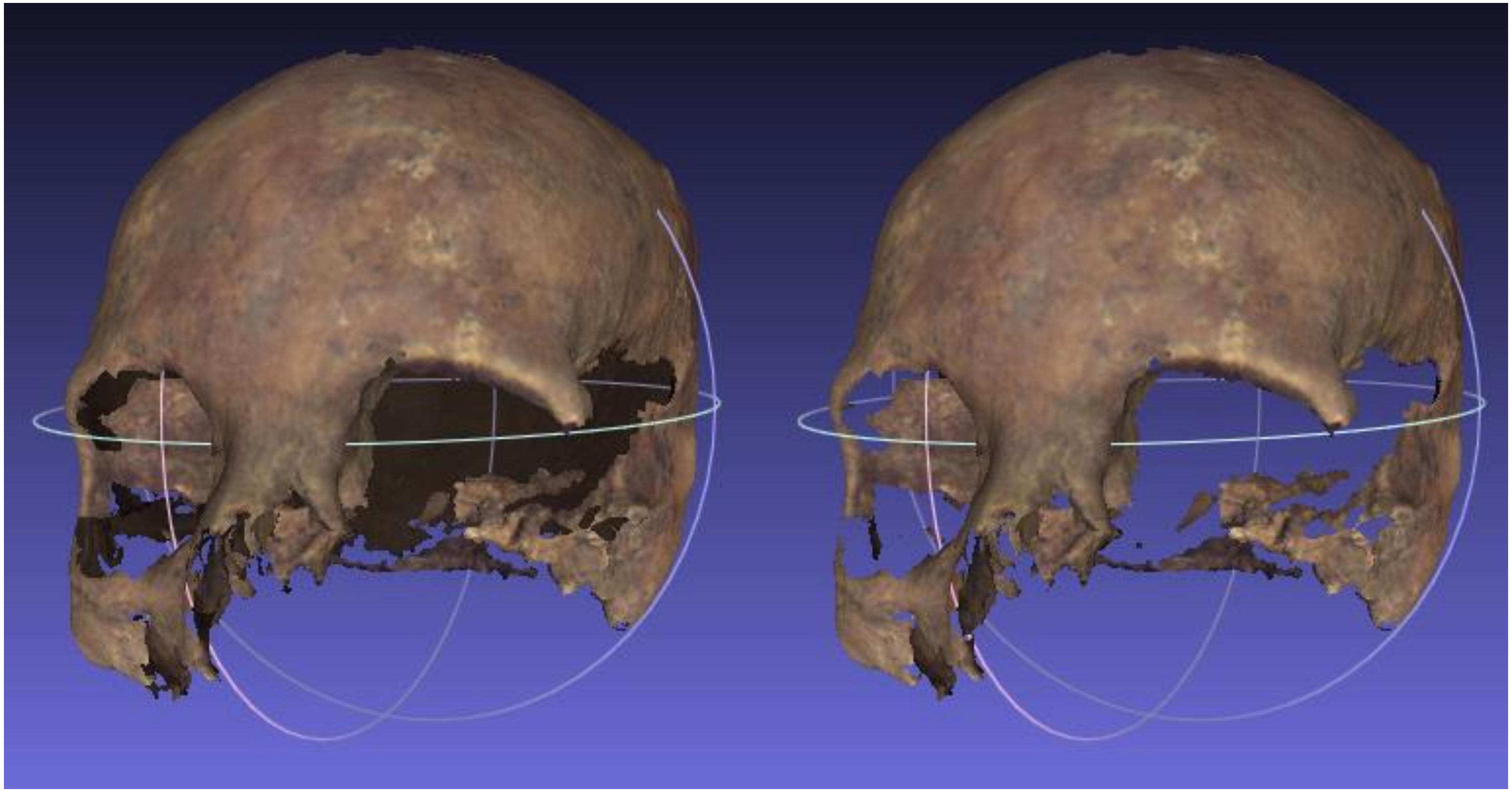
Backface culling

- Compute triangle normal after projection (homogeneous division)

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

- If the third component of **n** negative, then front-facing; otherwise, back-facing
  – Remember: projection matrix is such that homogeneous division flips sign of third component

Backface culling

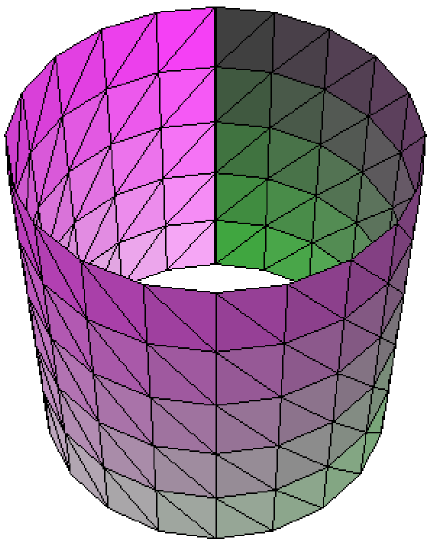


Without backface culling With backface culling

Backface culling

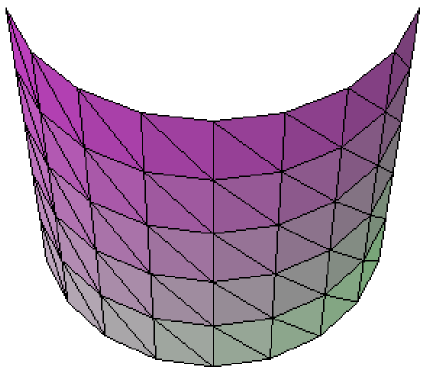
- Allow one- or two-sided triangles

Two-sided triangles
(no backface culling)



```
glDisable(GL_CULL_FACE);
```

One-sided triangles
(backface culling)



```
glEnable(GL_CULL_FACE);
glCullFace(GL_BACK);
```

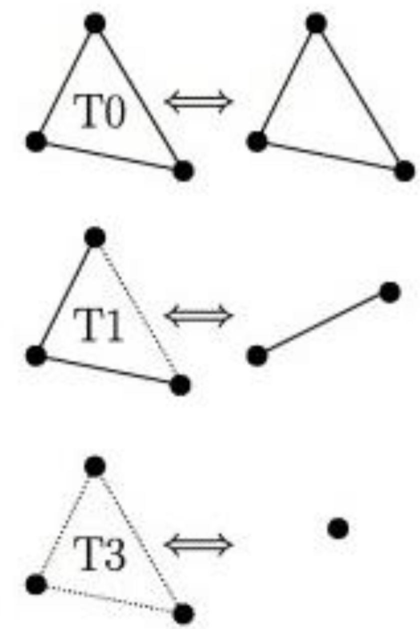
In OpenGL

Contribution (or 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, as these objects do not contribute significantly to the final image

Degenerate culling

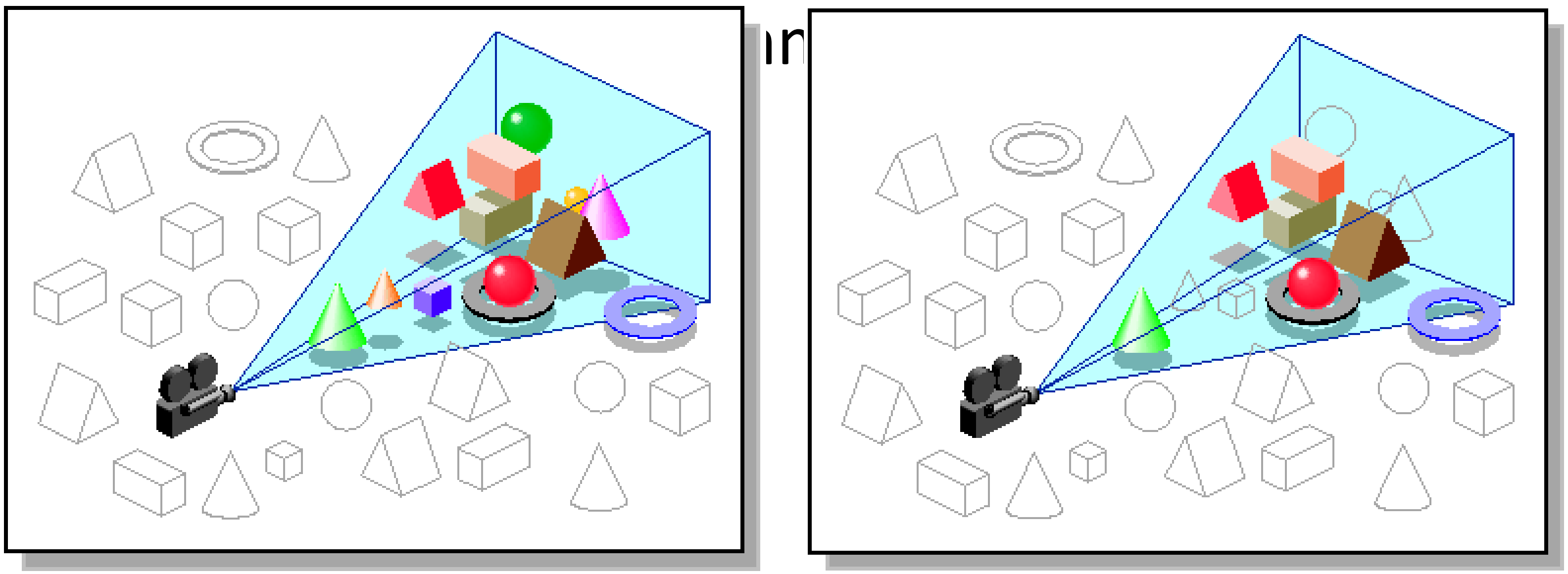
- Projected triangle is degenerate
  - Normal **n** = 0
    - Plane at infinity
      - Not really degenerate
  - All vertices in a straight line
    - Colinear
  - All vertices in the same place
    - Coincident



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

Occlusion culling

- Geometry hidden behind occluder cannot be seen



Images: SGI OpenGL Optimizer Programmer's Guide

Occlusion culling

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