

CSE 167:
Introduction to Computer Graphics
Lecture #11: Visibility Culling

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Announcements

- ▶ **Project 3 due Monday Nov 13th at 2pm**
 - ▶ Grading in basement labs starts at 2pm
- ▶ **Tutoring hours will be in B270 until B260 reopens**
- ▶ **Project 3 late grading is on Friday Nov 17th**

Mentoring for VR Club

Connor Smith, VR Club President, c3smith@ucsd.edu:

“We have a bunch of really interesting projects going on this quarter, and helping them is a very high-impact and rewarding job.

Mentoring would only be a commitment of a few hours each weekend (3-5 hours on a Saturday or Sunday). We're specifically looking for people with a wealth of Unity experience. VR in Unity experience is preferred, but not required.”

Visibility Culling

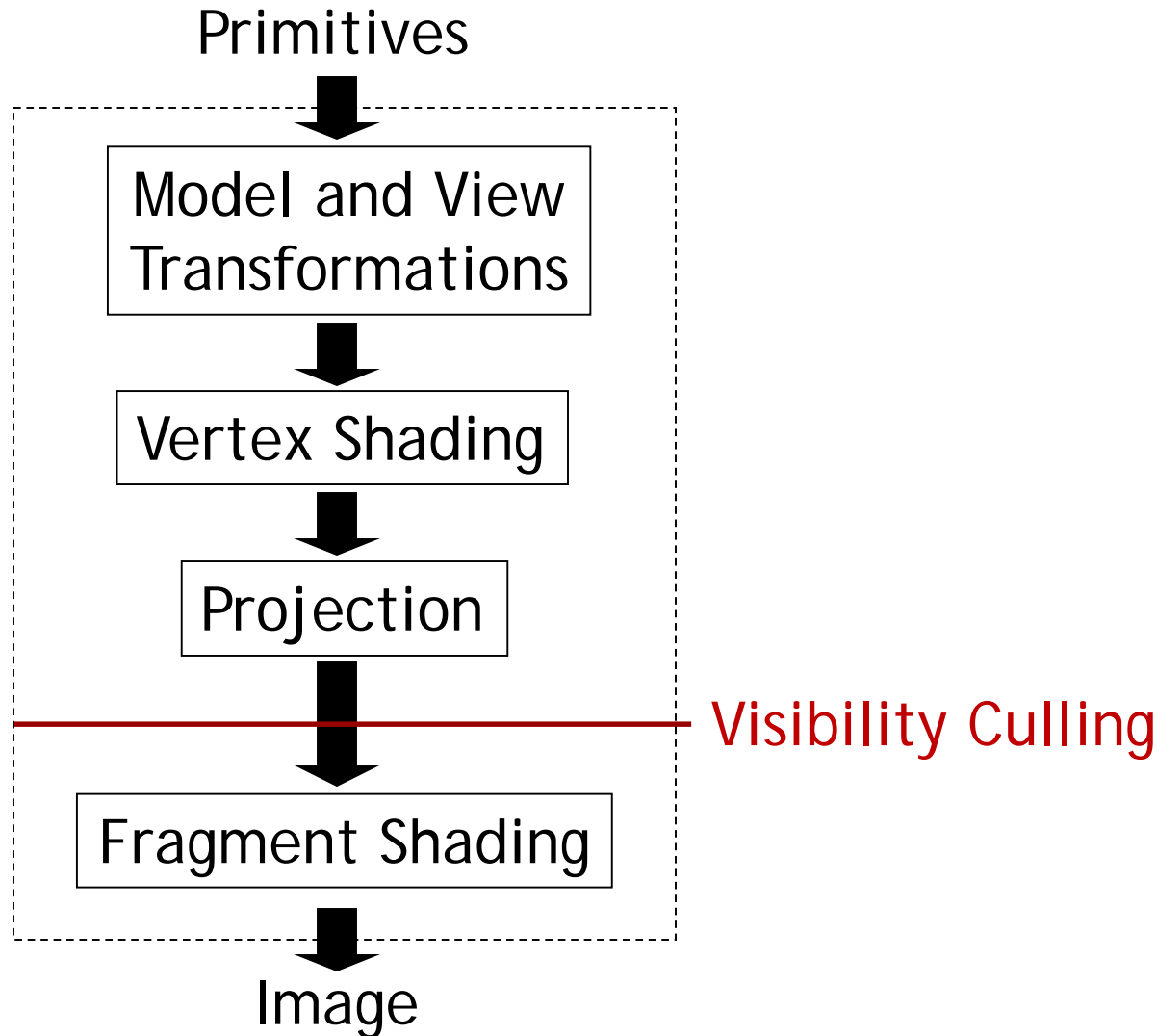
- ▶ **Goal:**

Discard geometry that does not need to be drawn to speed up rendering

- ▶ **Types of culling:**

- ▶ Small object culling
- ▶ Degenerate culling
- ▶ Backface culling
- ▶ View frustum culling
- ▶ Occlusion culling

Rendering Pipeline

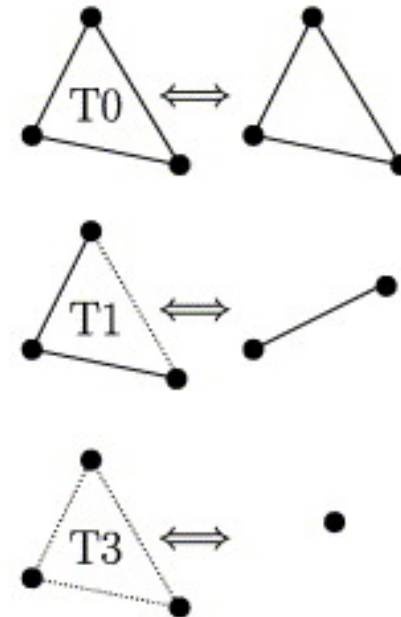


Small Object Culling

- ▶ 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

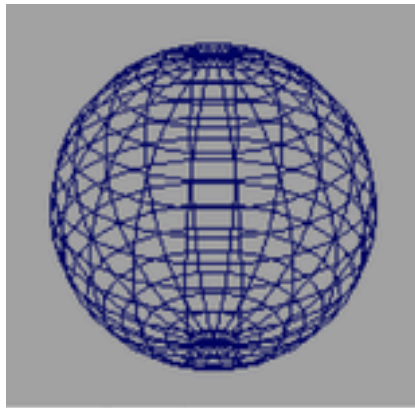
- ▶ Degenerate triangle has no area
 - ▶ Normal $\mathbf{n}=0$
 - ▶ All vertices in a straight line
 - ▶ All vertices in the same place



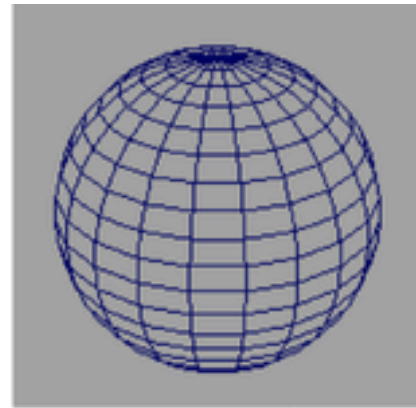
Source: *Computer Methods in Applied Mechanics and Engineering*, Volume 194, Issues 48–49

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

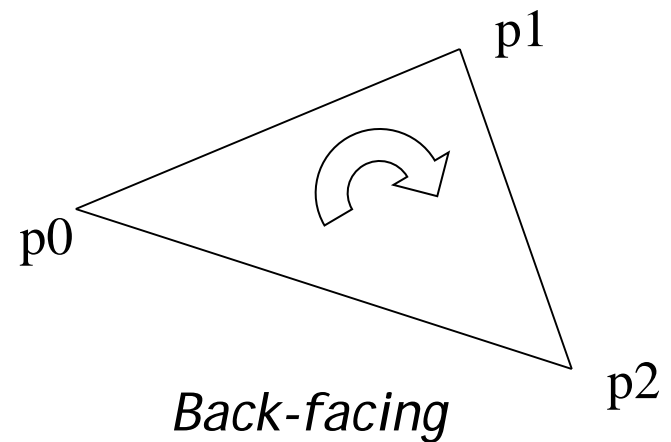
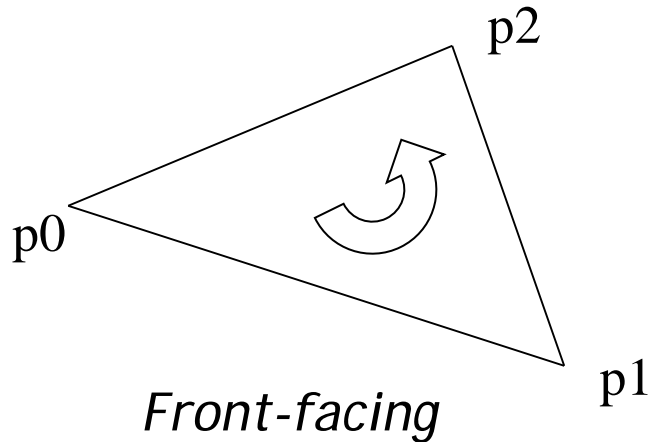


No backfaces

Backface Culling

► **Convention:**

Triangle is front facing if vertices are ordered counterclockwise



Backface Culling

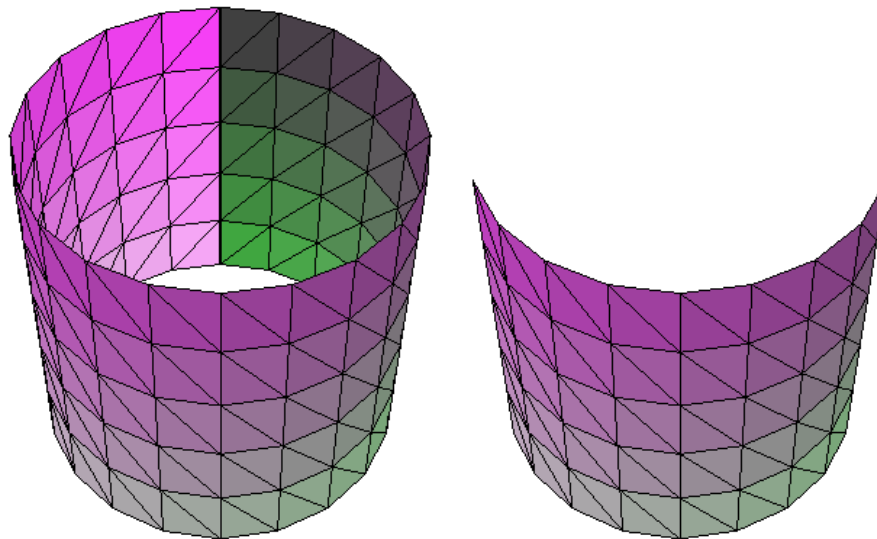
- ▶ Compute triangle normal after projection (homogeneous division)

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

- ▶ 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

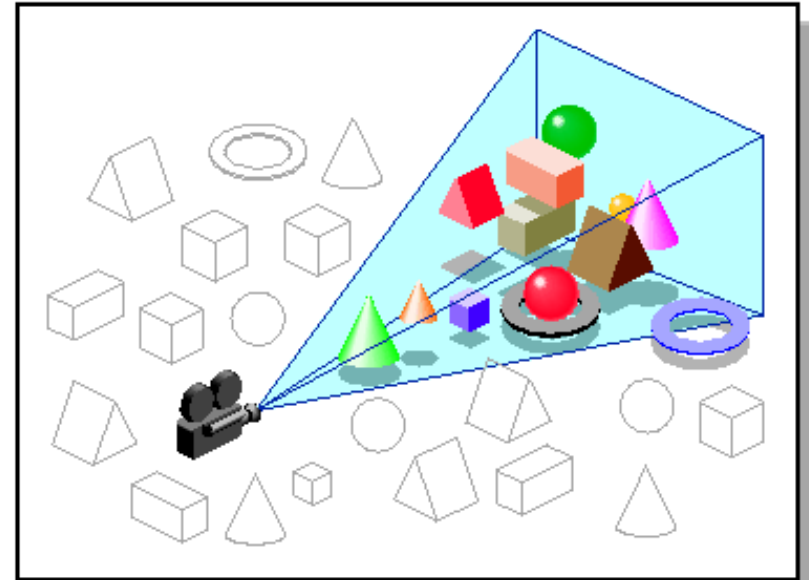
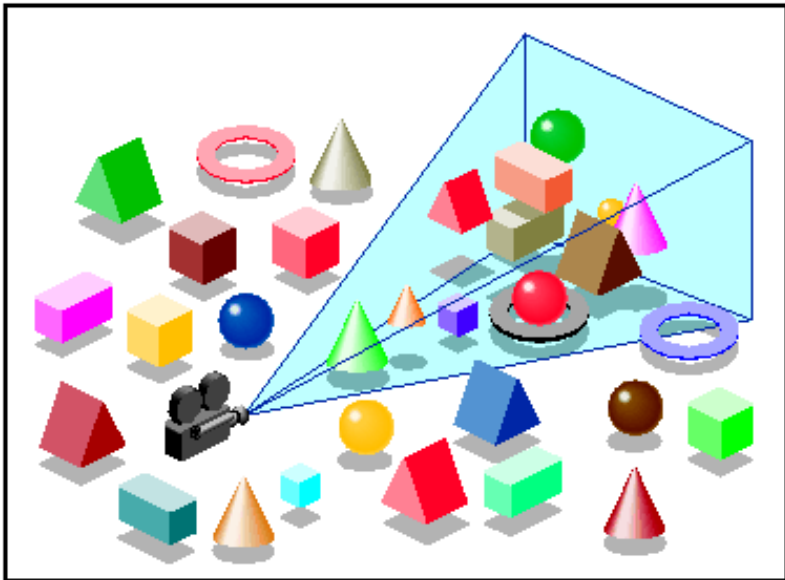
- ▶ OpenGL allows one- or two-sided triangles
 - ▶ One-sided triangles:
`glEnable(GL_CULL_FACE); glCullFace(GL_BACK)`
 - ▶ Two-sided triangles (no backface culling):
`glDisable(GL_CULL_FACE)`



`glDisable(GL_CULL_FACE); glEnable(GL_CULL_FACE);`

View Frustum Culling

- ▶ Triangles outside of view frustum are off-screen
 - ▶ Done on canonical view volume



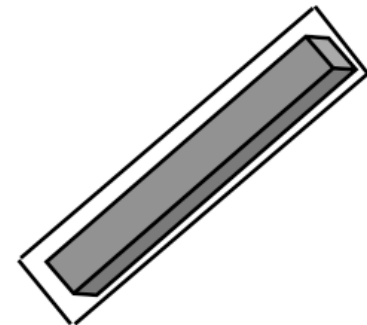
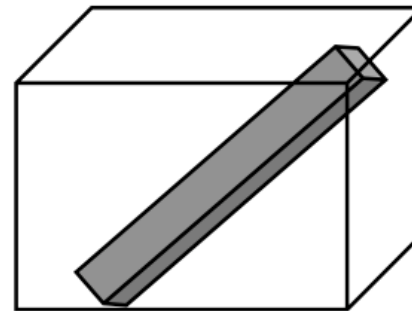
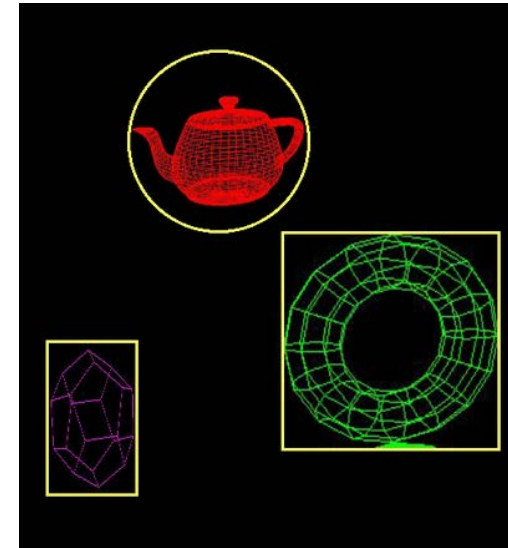
Images: SGI OpenGL Optimizer Programmer's Guide

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



Bounding Box

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

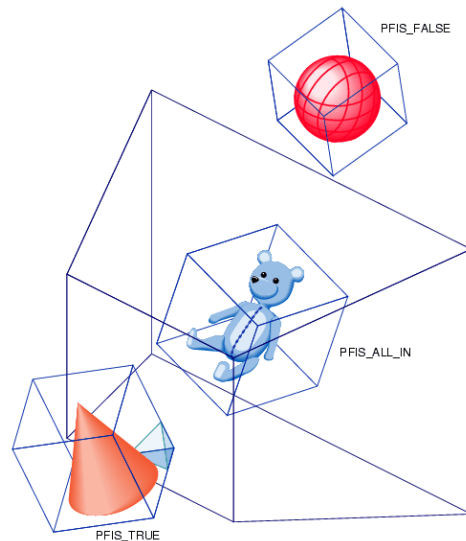
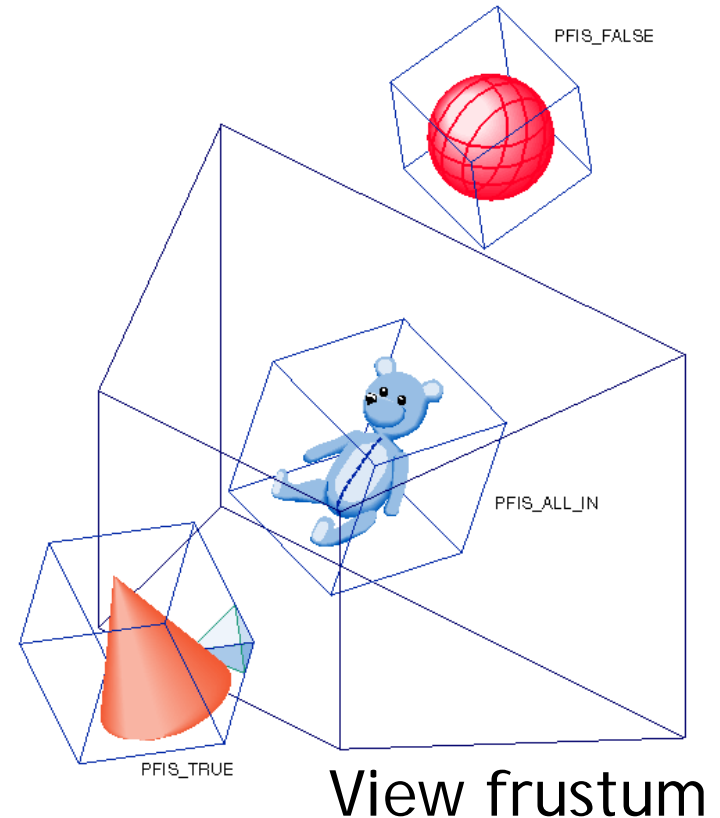


Image: SGI OpenGL Optimizer Programmer's Guide

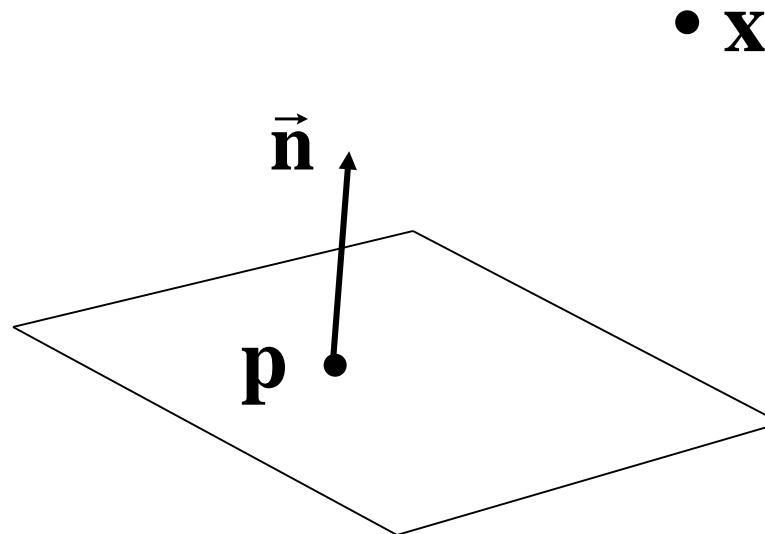
View Frustum Culling

- ▶ Frustum defined by 6 planes
- ▶ Each plane divides space into “outside”, “inside”
- ▶ Check each object against each plane
 - ▶ Outside, inside, intersecting
- ▶ If “outside” all planes
 - ▶ Outside the frustum
- ▶ If “inside” all planes
 - ▶ Inside the frustum
- ▶ Else partly inside and partly out
- ▶ Efficiency



Distance to Plane

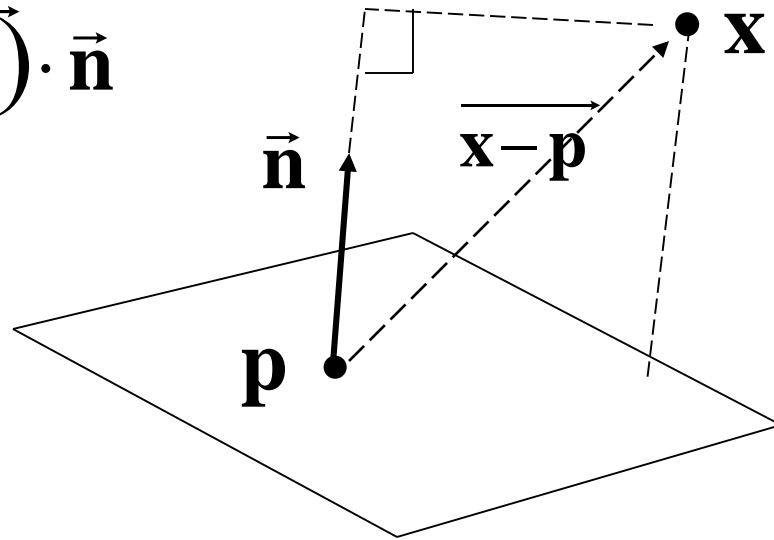
- ▶ A plane is described by a point \mathbf{p} on the plane and a unit normal \mathbf{n}
- ▶ Find the (perpendicular) distance from point \mathbf{x} to the plane



Distance to Plane

- ▶ The distance is the length of the projection of $\mathbf{x} - \mathbf{p}$ onto \mathbf{n}

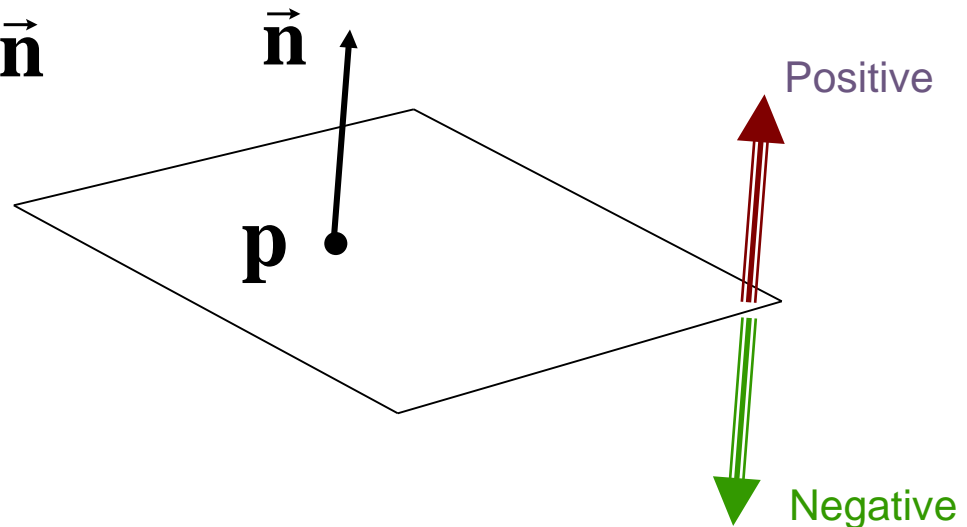
$$dist = \overrightarrow{(\mathbf{x} - \mathbf{p})} \cdot \vec{\mathbf{n}}$$



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

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



Distance to Plane

- ▶ Simplification

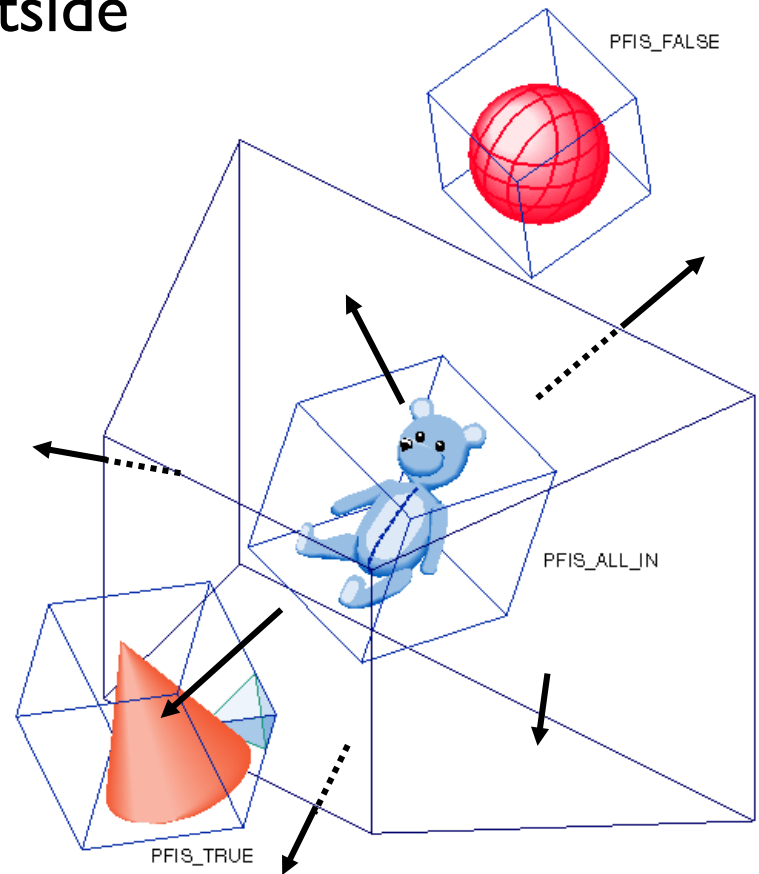
$$\begin{aligned}dist(\mathbf{x}) &= (\mathbf{x} - \mathbf{p}) \cdot \mathbf{n} \\ &= \mathbf{x} \cdot \mathbf{n} - \mathbf{p} \cdot \mathbf{n}\end{aligned}$$

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

- ▶ d is independent of \mathbf{x}
- ▶ d is distance from the origin to the plane
- ▶ We can represent a plane with just d and \mathbf{n}

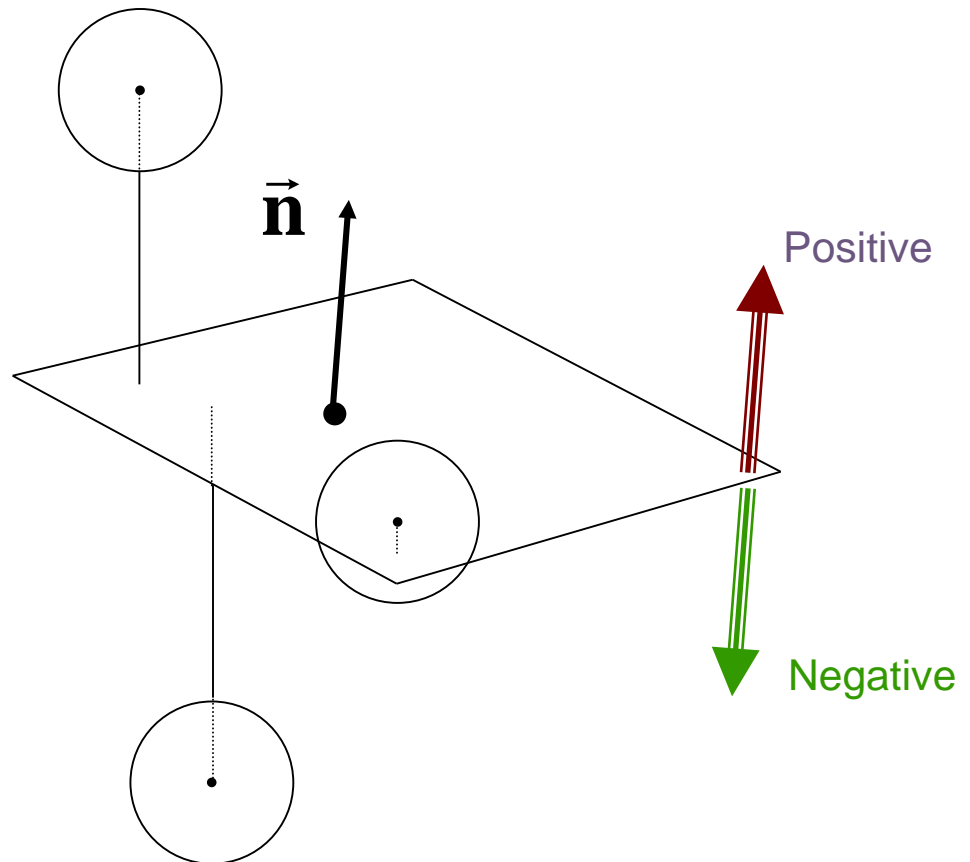
Frustum With Signed Planes

- ▶ 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:
 - ▶ $\text{dist}(\mathbf{x}) > r$
 - ▶ completely above
 - ▶ $\text{dist}(\mathbf{x}) < -r$
 - ▶ completely below
 - ▶ $-r < \text{dist}(\mathbf{x}) < r$
 - ▶ intersects

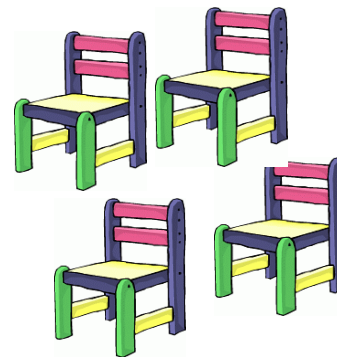
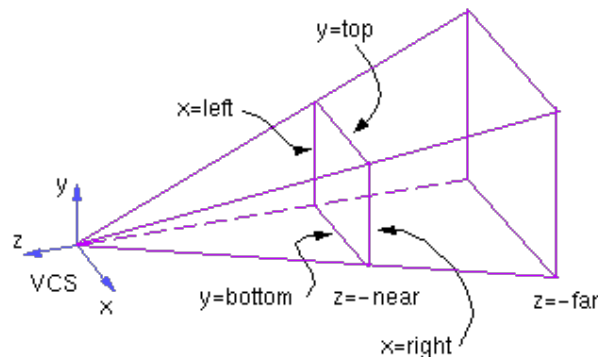


Culling Summary

- ▶ 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
- ▶ 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*)

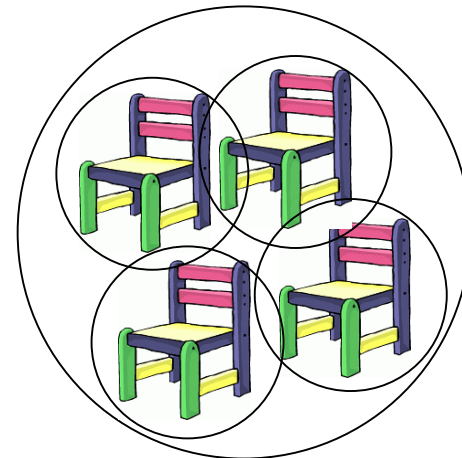
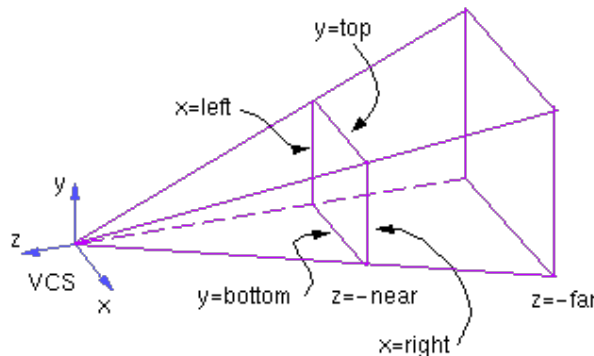
Culling Groups of Objects

- ▶ 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



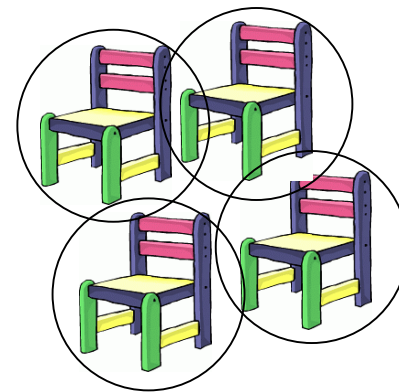
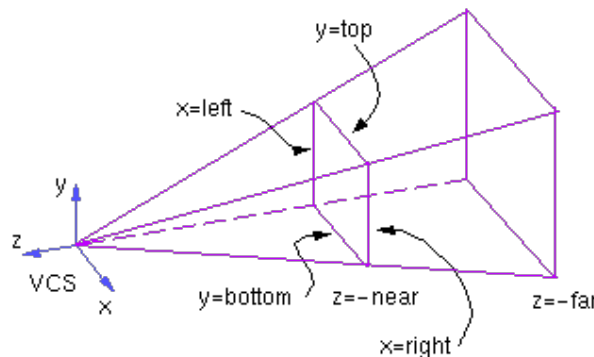
Hierarchical Bounding Volumes

- ▶ 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



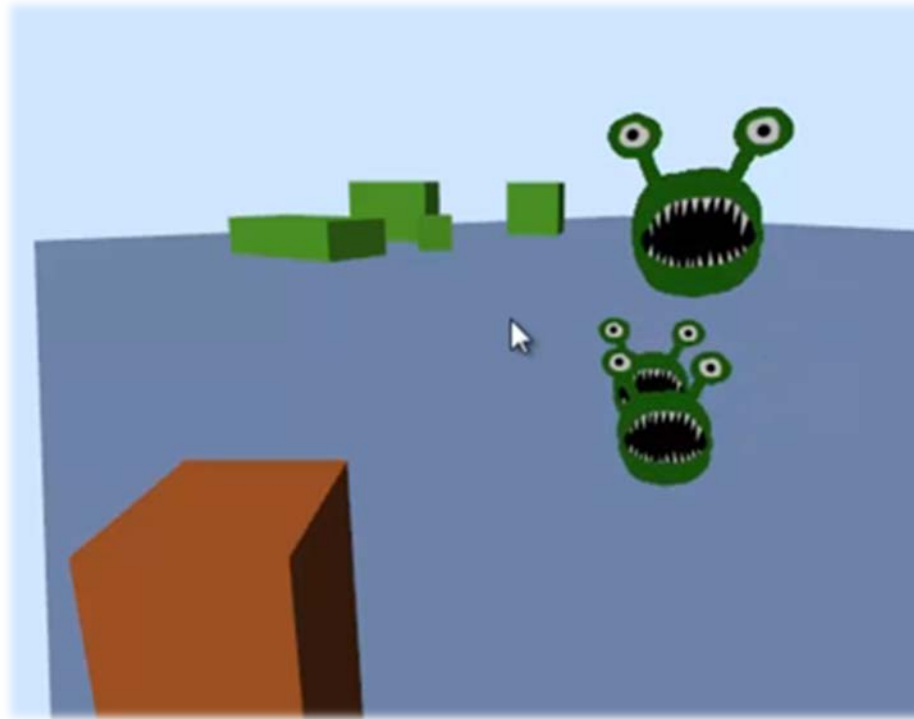
Hierarchical Culling

- ▶ 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



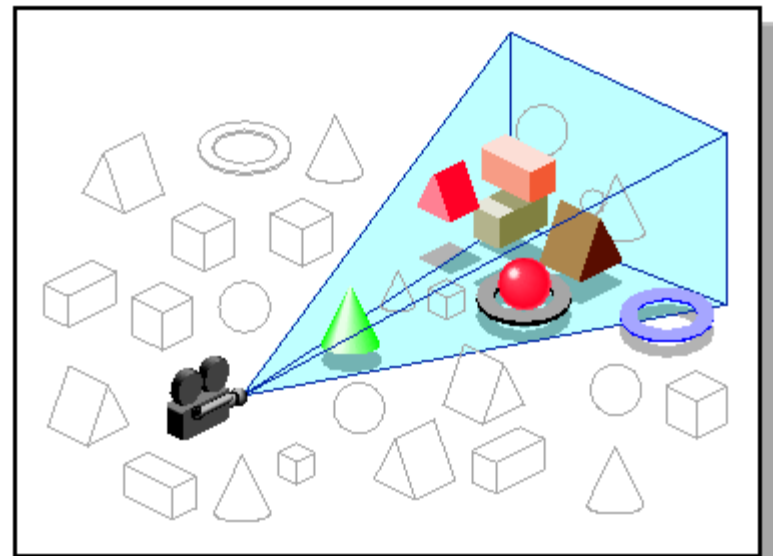
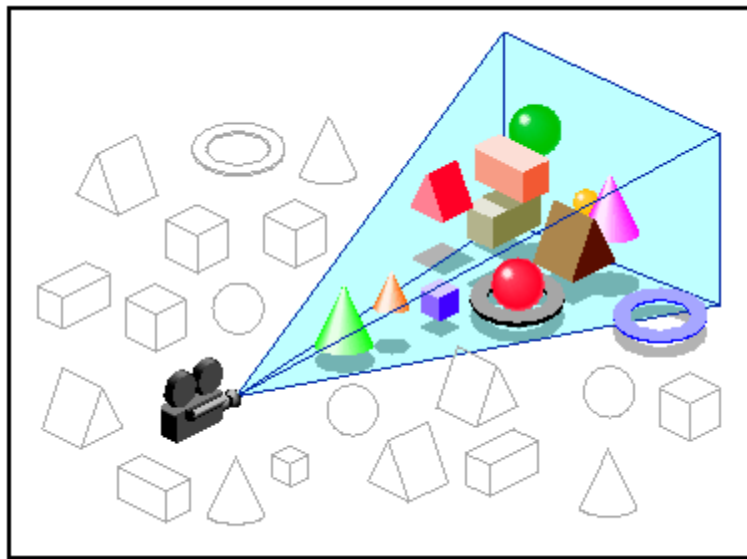
Video

- ▶ Math for Game Developers - Frustum Culling
 - ▶ http://www.youtube.com/watch?v=4p-E_3IXOPM



Occlusion Culling

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



Images: SGI OpenGL Optimizer Programmer's Guide

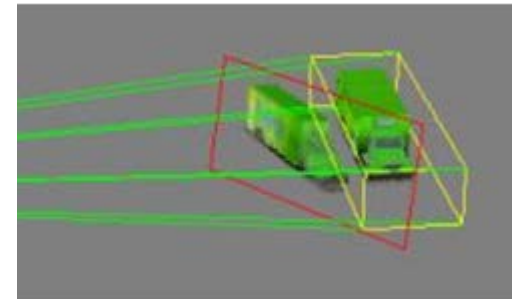
Video

- ▶ 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
- ▶ Adapt triangle count to projected size



Impostor generation



Original vs. impostor



Size dependent mesh reduction
(Data: Stanford Armadillo)