CSE 167:
Introduction to Computer Graphics
Lecture 10: Scene Graph

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Midterm

- Midterm has been graded
  - A score of 90 in the exam will count as a grade of 100
- Please return midterm after review if you want to discuss with me later
  - Otherwise feel free to keep it

# Submissions	112
Average score	60.0
Median score	61.0
Highest score	89.5
Lowest score	9.5

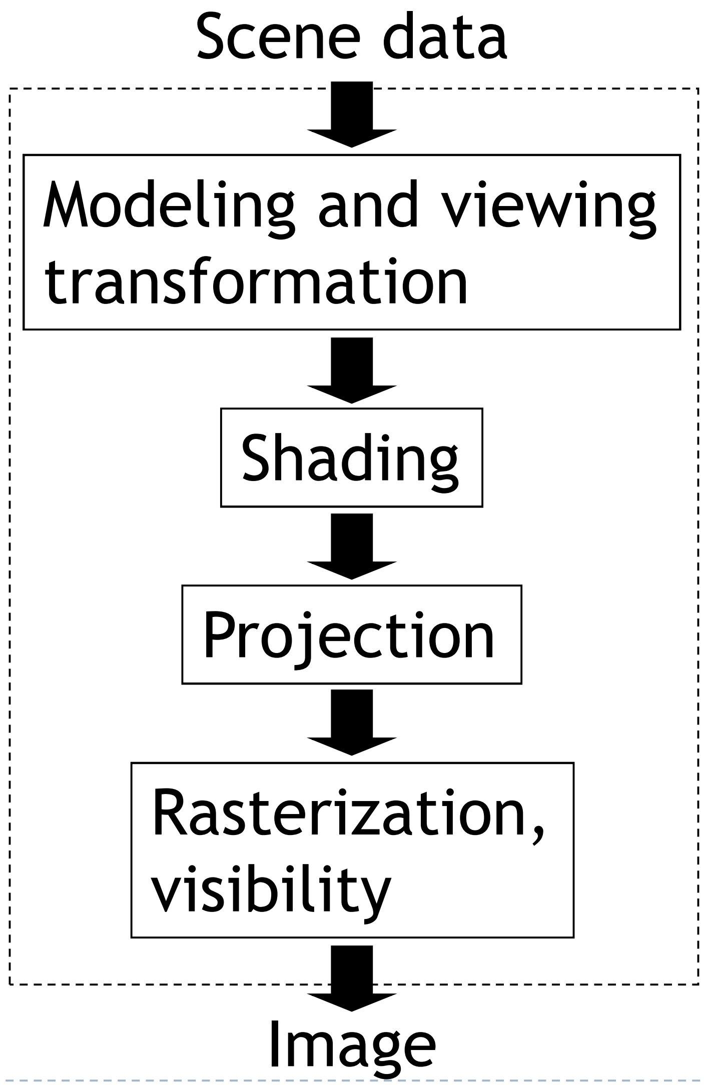
Announcements

- Homework #4:
  Glee web site has been down:
  Matteo put files on Dropbox link: see course forums
- Homework #5 discussion on Monday, Nov 4

Lecture Overview

- Scene Graphs & Hierarchies
  - Introduction
  - Data structures
- Performance Optimization
  - Level-of-detail techniques
  - View Frustum Culling

Rendering Pipeline



Graphics System Architecture

Interactive Applications

- Games, scientific visualization, virtual reality

Rendering Engine, Scene Graph API

- Implement functionality commonly required in applications
- Back-ends for different low-level APIs
- No broadly accepted standards
- Examples: OpenSceneGraph, NVSG, Java3D, Ogre

Low-level graphics API

- Interface to graphics hardware
- Highly standardized: OpenGL, Direct3D

Scene Graph APIs

- APIs focus on different types of applications
- OpenSceneGraph (www.openscenegraph.org)
  - Scientific visualization, virtual reality, GIS (geographic information systems)
- NVIDIA SceniX (https://developer.nvidia.com/scenix)
  - Optimized for shader support
  - Support for interactive ray tracing
- Java3D (http://java3d.java.net)
  - Simple, easy to use, web-based applications
- Ogre3D (http://www.ogre3d.org/)
  - Games, high-performance rendering

Commonly Offered Functionality

- Resource management
  - Content I/O (geometry, textures, materials, animation sequences)
  - Memory management
- High-level scene representation
  - Graph data structure
- Rendering
  - Optimized for efficiency (e.g., minimize OpenGL state changes)

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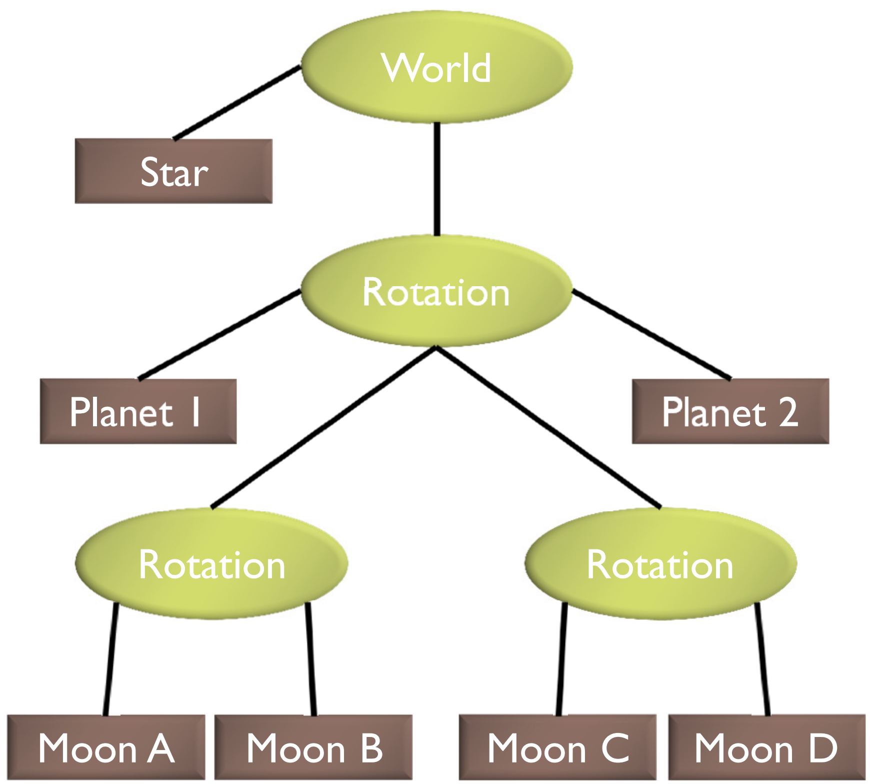
Scene Graphs

- Data structure for intuitive construction of 3D scenes
- So far, our GLUT-based projects store a linear list of objects
- This approach does not scale to large numbers of objects in complex, dynamic scenes

→ Homework Assignment #1 – Animated Objects

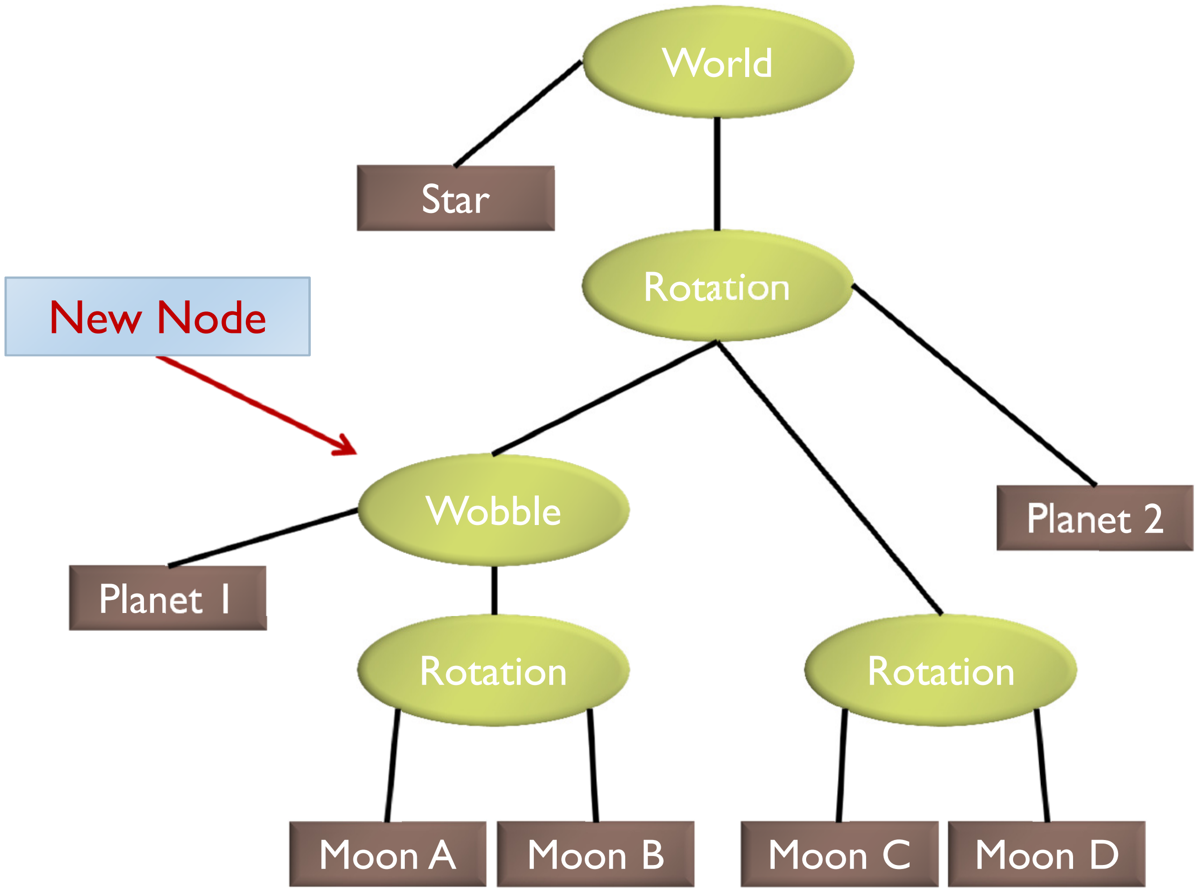
Solar System



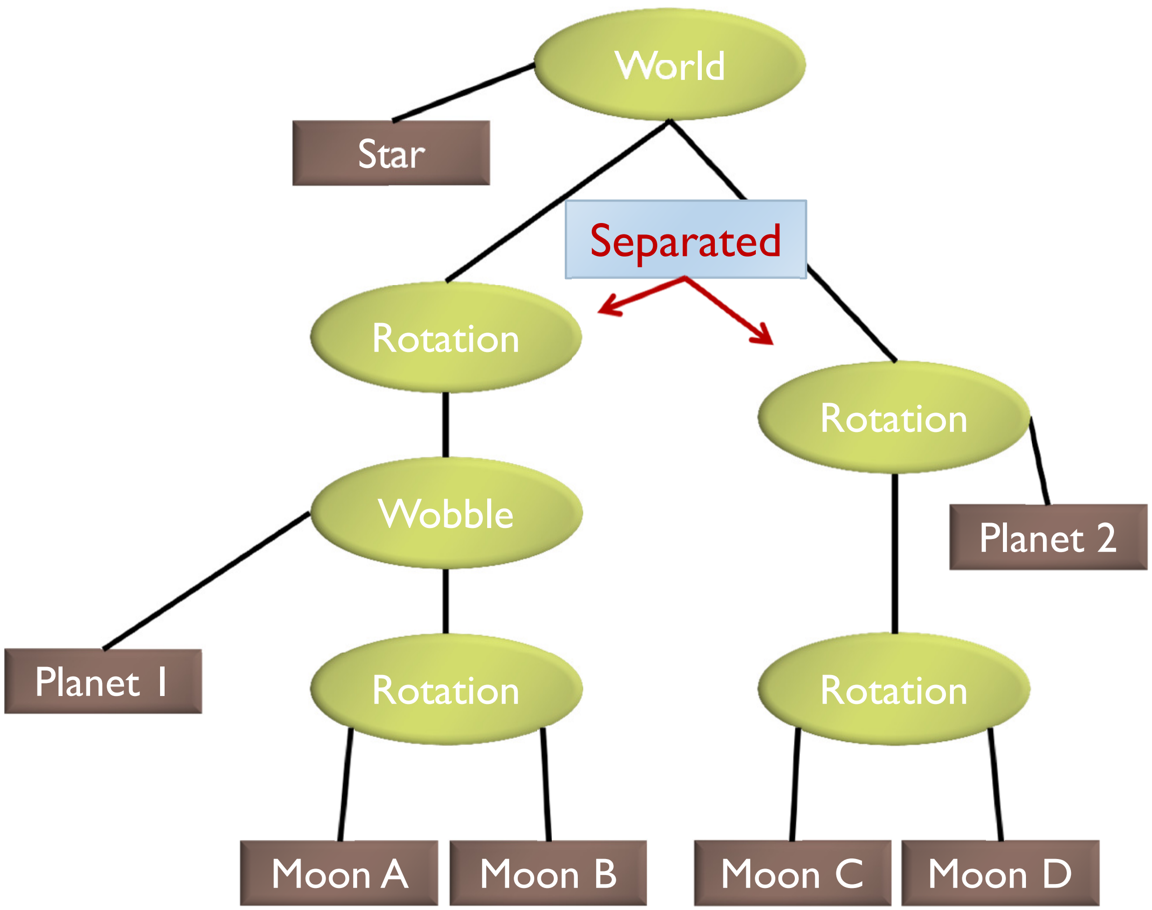
- Draw the star
- Save the current matrix
-
  - Apply a rotation
  - Draw Planet One
  - Save the current matrix
  -
    - Apply a second rotation
    - Draw Moon A
    - Draw Moon B
  - Reset the matrix we saved
  - Draw Planet two
  - Save the current matrix
  -
    - Apply a rotation
    - Draw Moon C
    - Draw Moon D
  - Reset the matrix we saved
- Reset the matrix we saved

Example from http://www.gamedev.net

Solar System with Wobble



Planets rotating at different speeds



- Draw the Star
- Save the current matrix
    - Apply a rotation
        - Save the current matrix
            - Apply a wobble
            - Draw Planet 1
                - Save the current matrix
                    - Apply a rotation
                        - Draw Moon A
                        - Draw Moon B
                - Reset the Matrix
        - Reset the matrix
    - Reset the matrix
- Reset the matrix
- Save the current matrix
    - Apply a rotation
        - Draw Planet 2
        - Save the current matrix
            - Apply a rotation
            - Draw Moon C
            - Draw Moon D
        - Reset the current matrix
    - Reset the current matrix
- Reset the current matrix

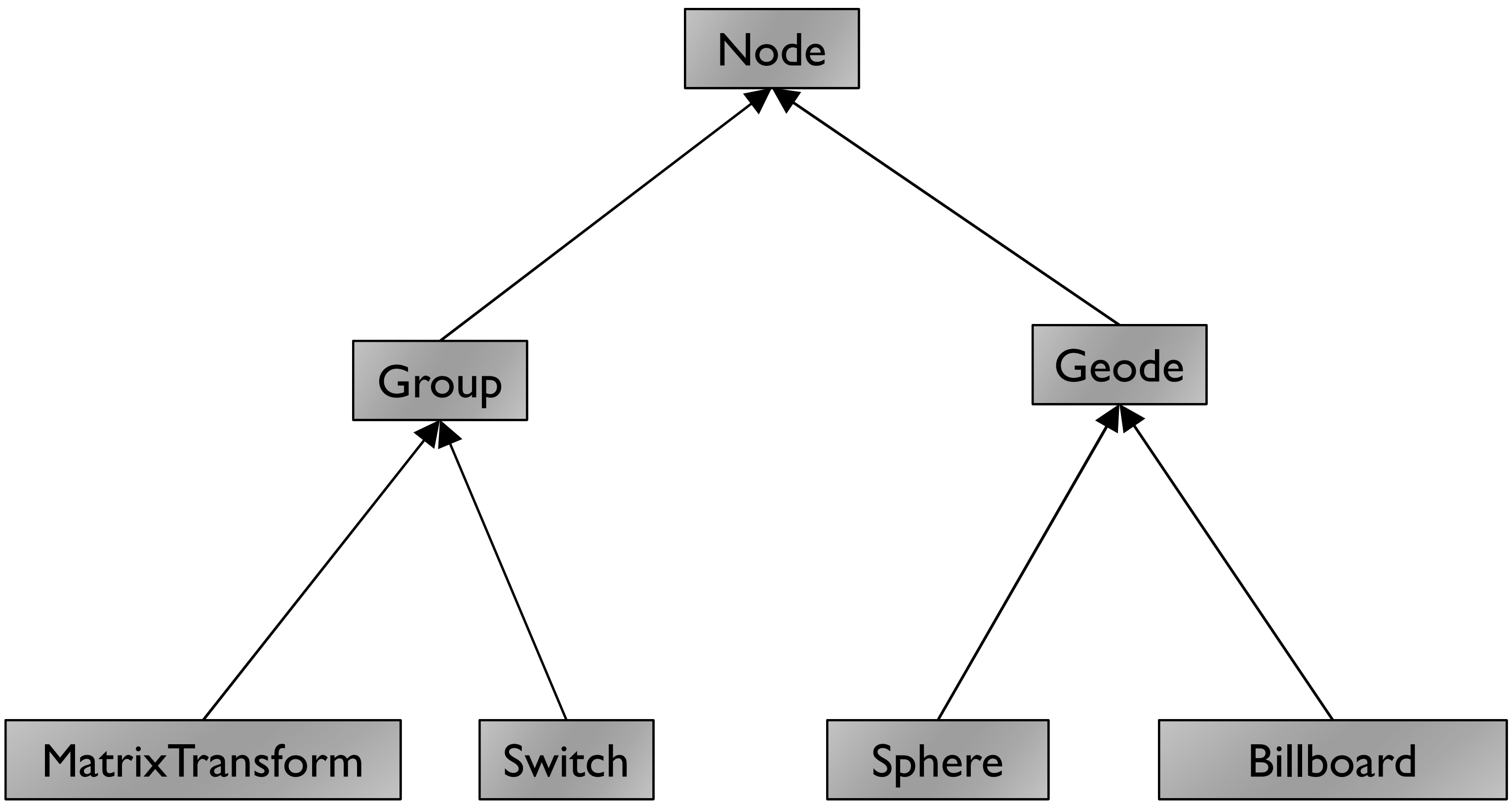
Data Structure

- Requirements
  - Collection of separable geometry models
  - Organized in groups
  - Related via hierarchical transformations
- Use a tree structure
- Nodes have associated local coordinates
- Different types of nodes
  - Geometry
  - Transformations
  - Lights
  - Many more

Class Hierarchy

- Many designs possible
- Design driven by intended application
  - Games
    - Optimized for speed
  - Large-scale visualization
    - Optimized for memory requirements
  - Modeling system
    - Optimized for editing flexibility

Sample Class Hierarchy



Inspired by OpenSceneGraph

Class Hierarchy

`Node`

- Common base class for all node types
- Stores node name, pointer to parent, bounding box

`Group`

- Stores list of children

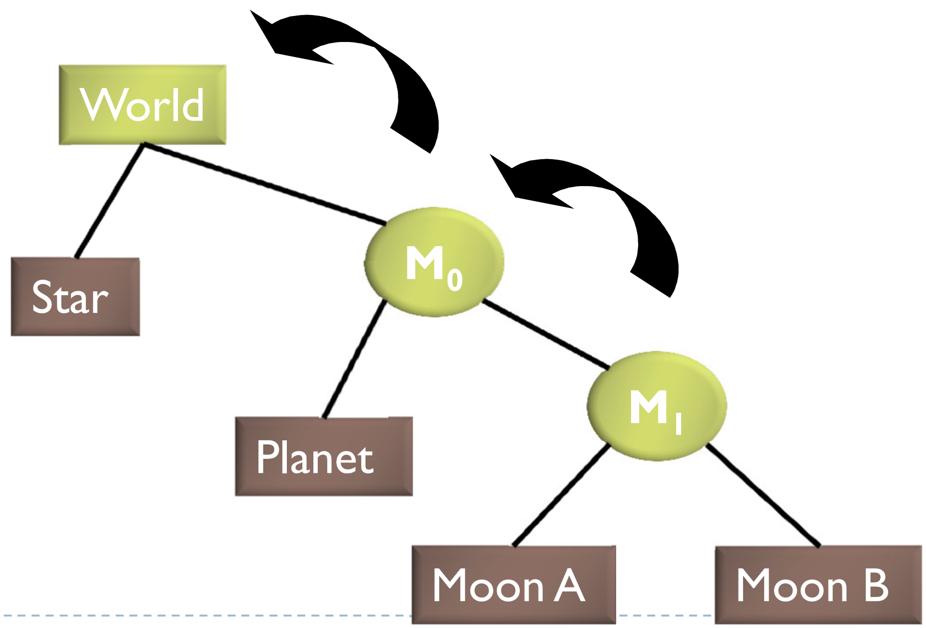
`Geode`

- Geometry Node
- Knows how to render a specific piece of geometry

Class Hierarchy

`MatrixTransform`

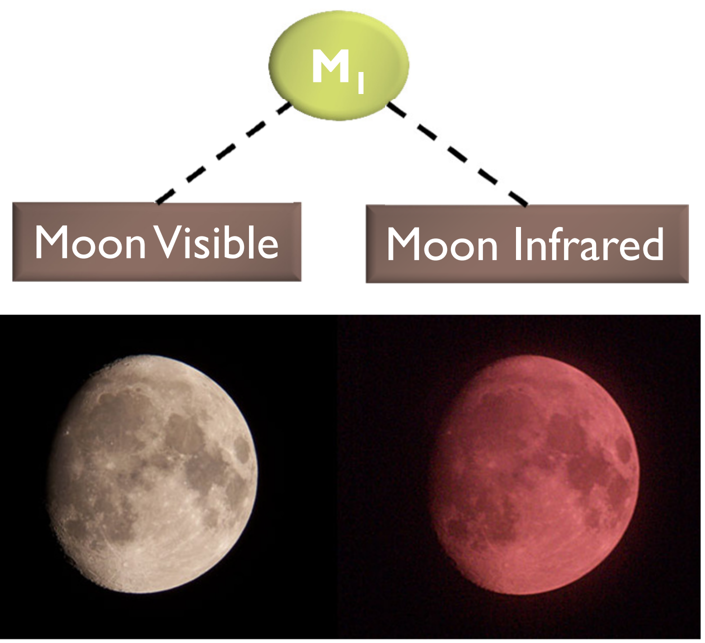
- Derived from Group
- Stores additional transformation **M**
- Transformation applies to sub-tree below node
- Monitor-to-world transformation $\mathbf{M_0 M_1}$



Class Hierarchy

`Switch`

- Derived from Group node
- Allows hiding (not rendering) all or subsets of its child nodes
- Can be used for state changes of geometry, or "key frame" animation



Class Hierarchy

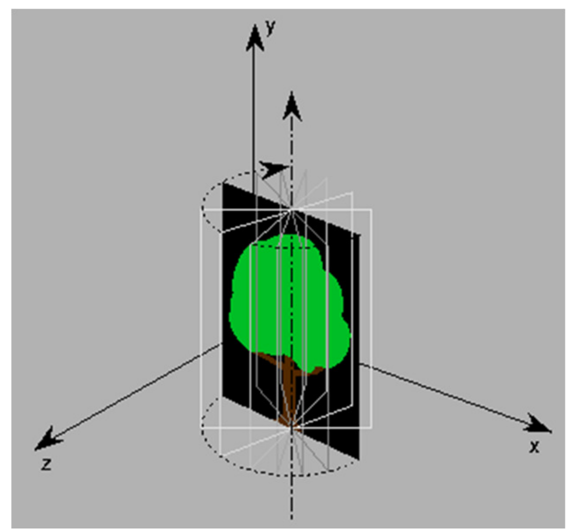
`Sphere`

- Derived from Geode
- Pre-defined geometry with parameters, e.g., for tesselation level, solid/wireframe, etc.

`Billboard`

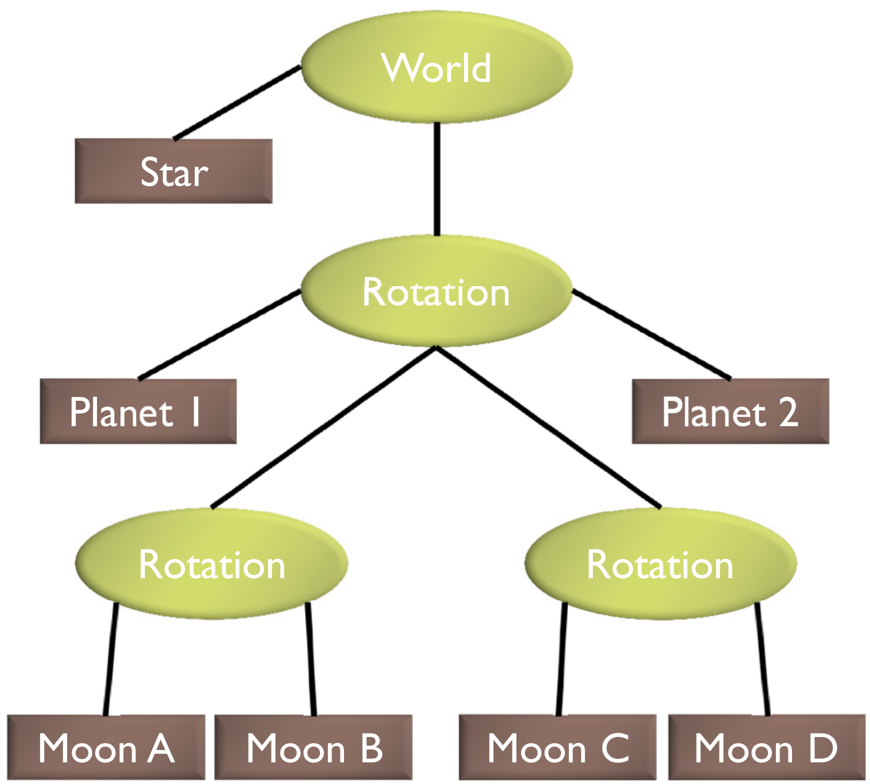
- Special geometry node to display an image always facing the viewer

Sphere at different tessellation levels



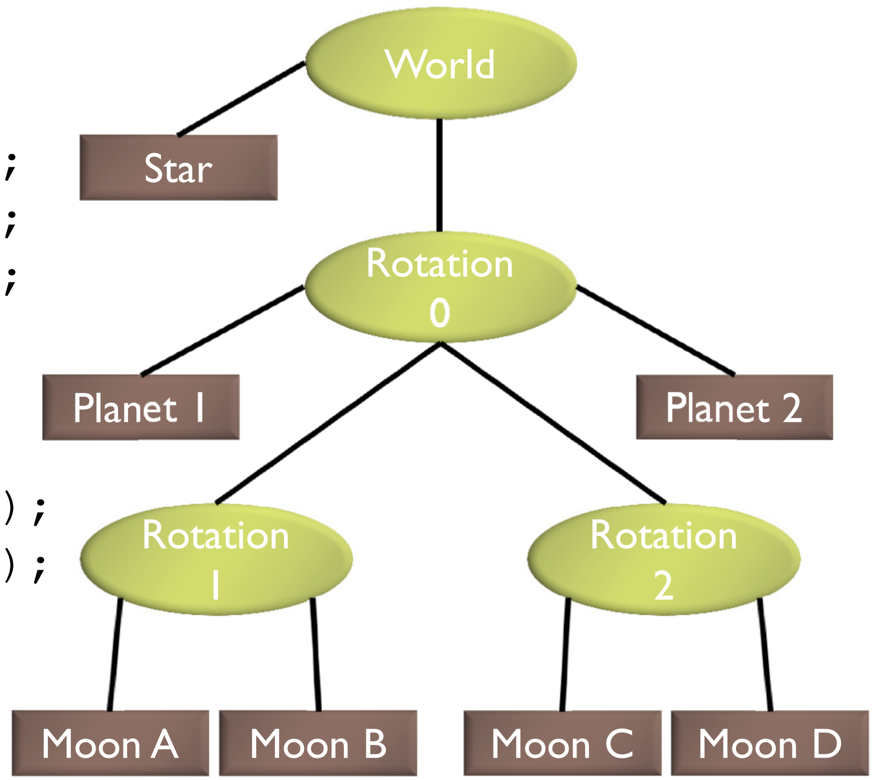
Billboarded Tree

Solar System



Source Code for Solar System

```
world = new Group();
world.addChild(new Star());
rotation0 = new MatrixTransform(…);
rotation1 = new MatrixTransform(…);
rotation2 = new MatrixTransform(…);
world.addChild(rotation0);
rotation0.addChild(rotation1);
rotation0.addChild(rotation2);
rotation0.addChild(new Planet(“1”));
rotation0.addChild(new Planet(“2”));
rotation1.addChild(new Moon(“A”));
rotation1.addChild(new Moon(“B”));
rotation2.addChild(new Moon(“C”));
rotation2.addChild(new Moon(“D”));
```



Basic Rendering

- Traverse the tree recursively

```
Group::draw(Matrix4 C)
{
  for all children
    draw(C);
}

MatrixTransform::draw(Matrix4 C)
{
  C_new = C*M;   // M is a class member
  for all children
    draw(C_new);
}

Geode::draw(Matrix4 C)
{
  setModelView(C);
  render(myObject);
}
```

Initiate rendering with
`world->draw(IDENTITY);`

Modifying the Scene

- Change tree structure
  - Add, delete, rearrange nodes
- Change node parameters
  - Transformation matrices
  - Shape of geometry data
  - Materials
- Create new node subclasses
  - Animation, triggered by timer events
  - Dynamic "helicopter-mounted" camera
  - Light source
- Create application dependent nodes
  - Video node
  - Web browser node
  - Video conferencing node
  - Terrain rendering node

Benefits of a Scene Graph

- Can speed up rendering by efficiently using low-level API
  - Avoid state changes in rendering pipeline
  - Render objects with similar properties in batches (geometry, shaders, materials)
- Change parameter once to affect all instances of an object
- Abstraction from low level graphics API
  - Easier to write code
  - Code is more compact
- Can display complex objects with simple APIs
  - Example: osgEarth class provides scene graph node which renders a Google Earth-style planet surface

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  - Level-of-detail techniques
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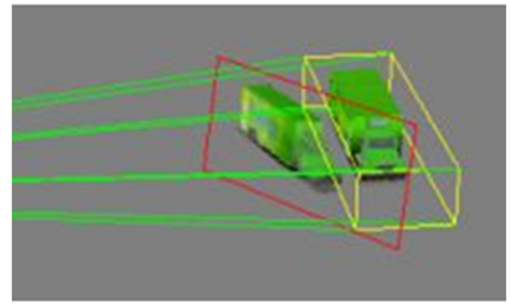
Level-of-Detail Techniques

- 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

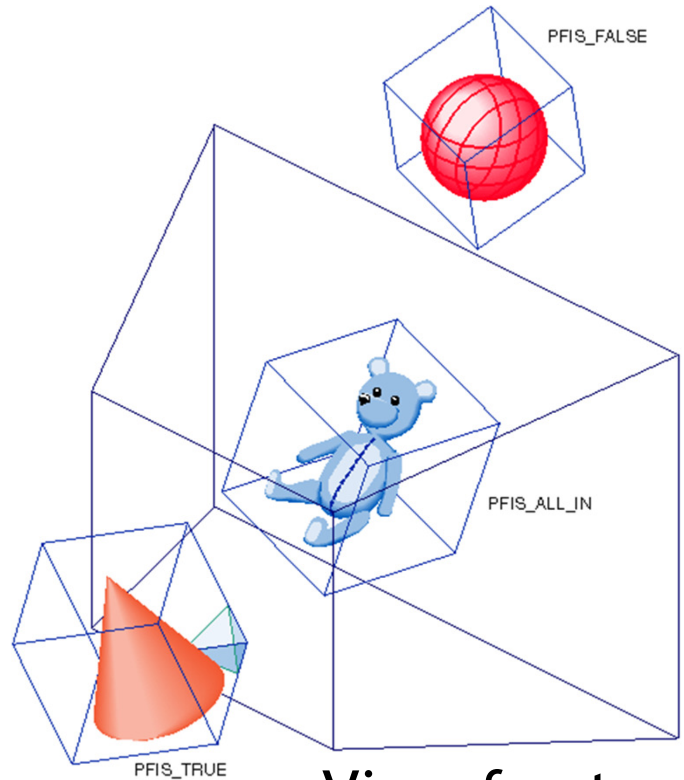
Original vs. impostor

- Adapt triangle count to projected size

Size dependent mesh reduction
(Data: Stanford Armadillo)

View Frustum Culling

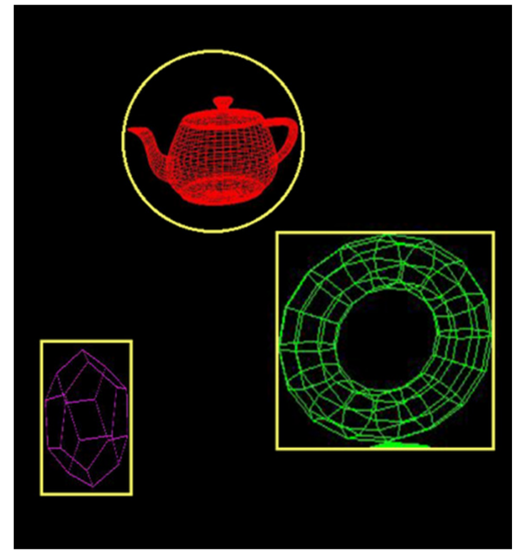
- Frustum defined by 6 planes
- Each plane divides space into "outside", "inside"
- Check each object against each plane
  - Outside, inside, intersecting
- If "outside" all planes
  - Outside the frustum
- If "inside" all planes
  - Inside the frustum
- Else partly inside and partly out
- Efficiency

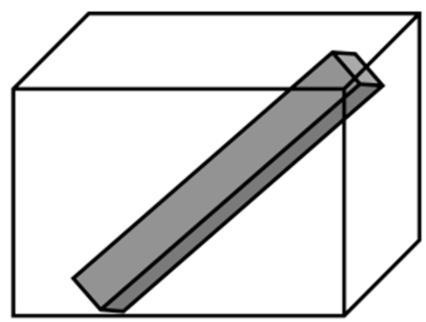


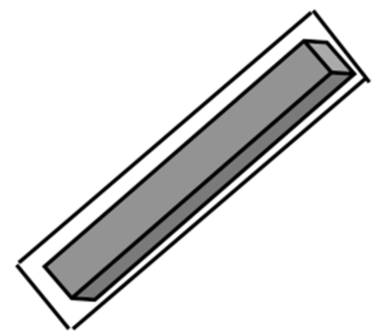
View frustum

Bounding Volumes

- Simple shape that completely encloses an object
- Generally a box or sphere
- We use spheres
  - Easiest to work with
  - But hard to calculate tight fits
- Intersect bounding volume with view frustum instead of each primitive

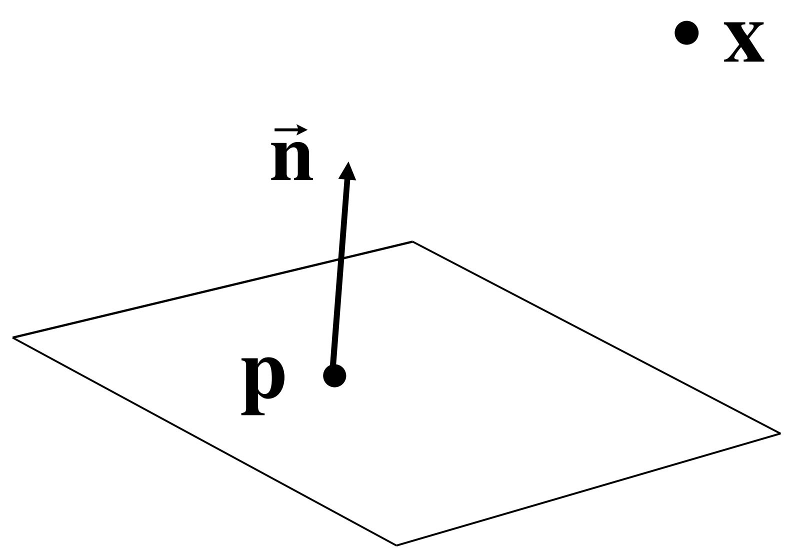






Distance to Plane

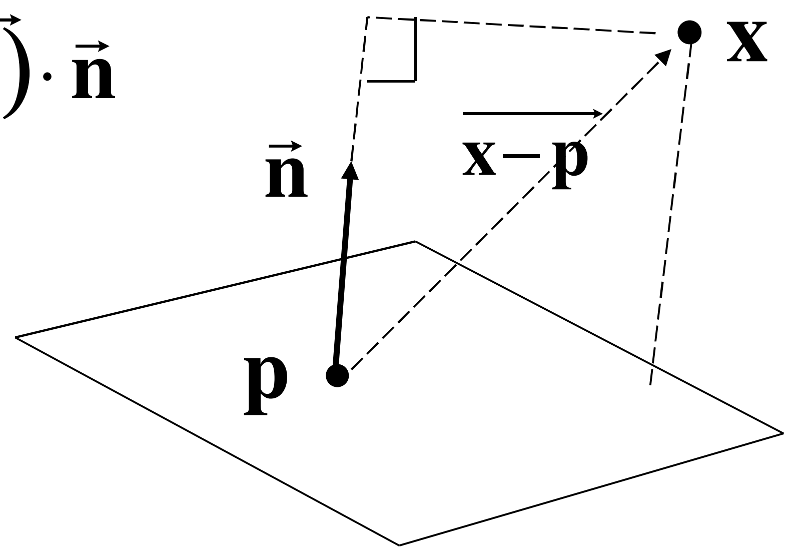
- A plane is described by a point **p** on the plane and a unit normal **n**
- Find the (perpendicular) distance from point **x** to the plane



Distance to Plane

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

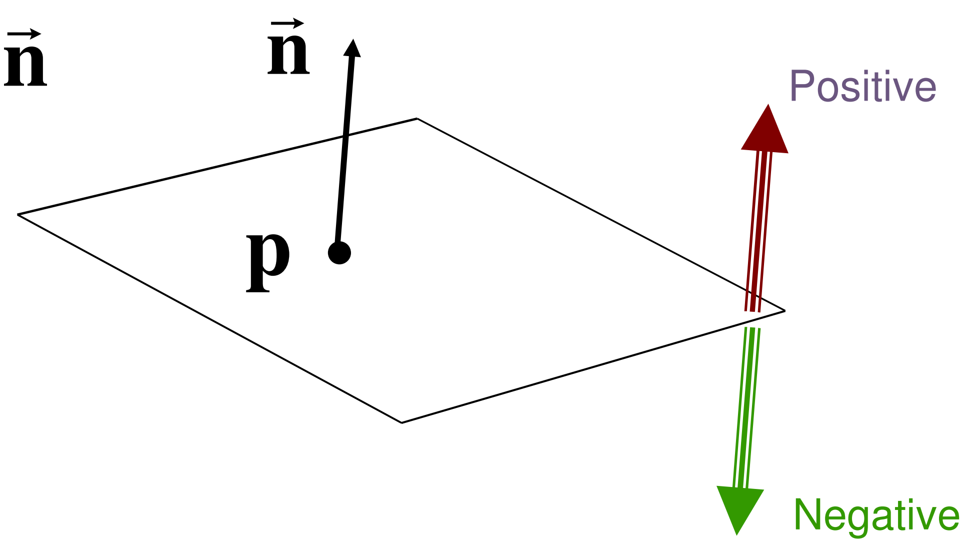
$$dist = \overrightarrow{(\mathbf{x}-\mathbf{p})} \cdot \vec{\mathbf{n}}$$



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

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



Distance to Plane

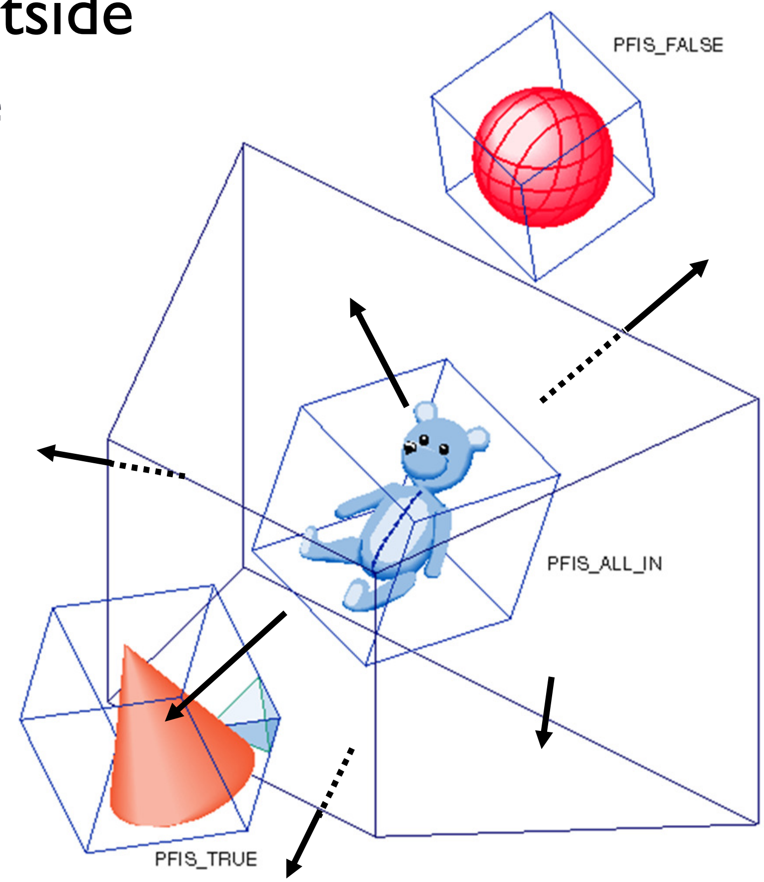
- Simplification

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

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

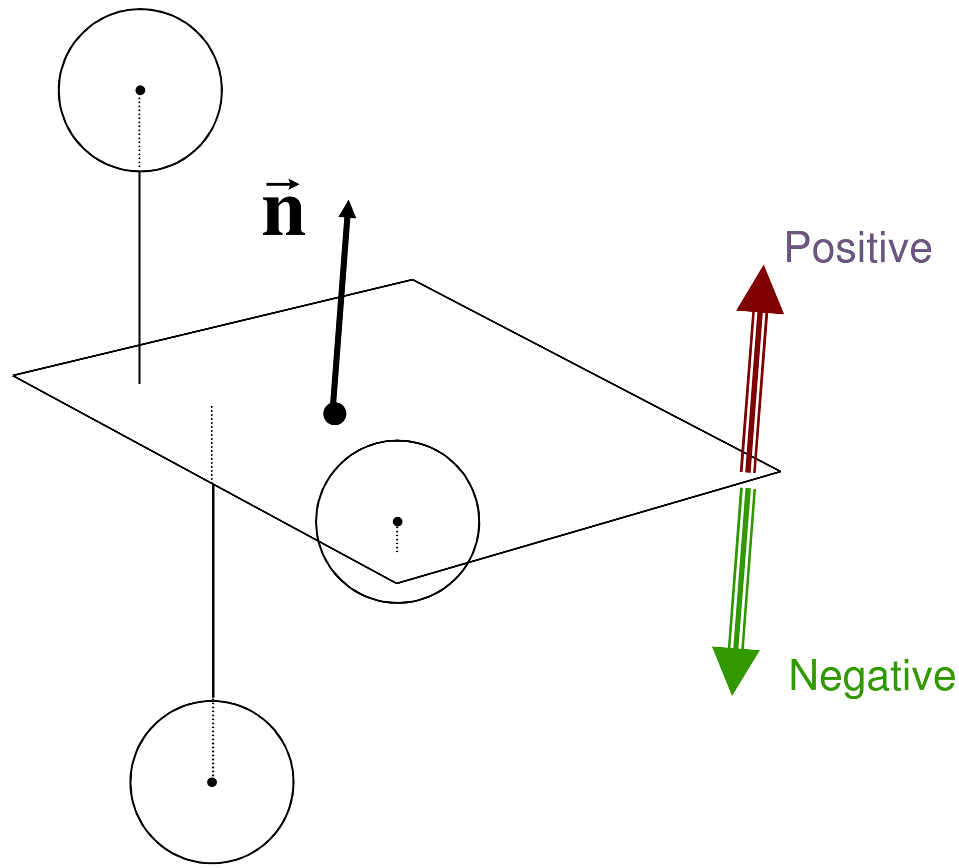
Frustum With Signed Planes

- 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

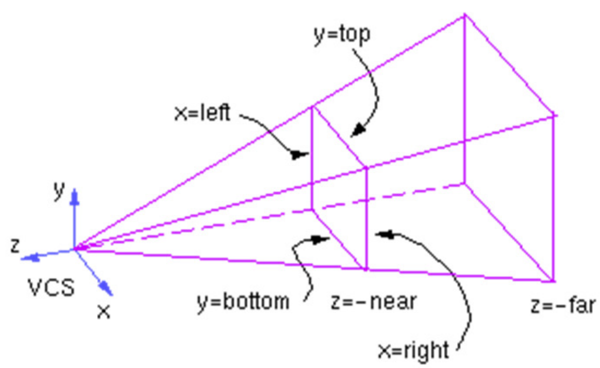


Culling Summary

- Precompute 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)*

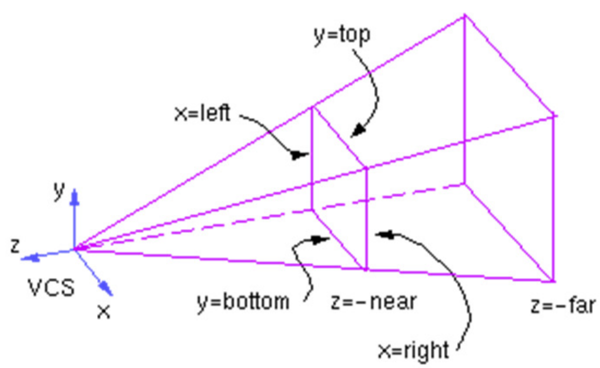
Culling Groups of Objects

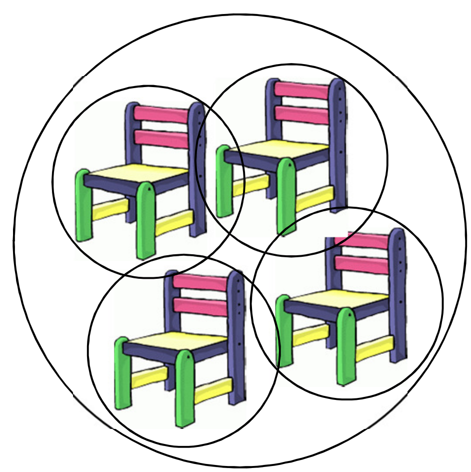
- Want to be able to cull the whole group quickly
- But if the group is partly in and partly out, want to be able to cull individual objects



Hierarchical Bounding Volumes

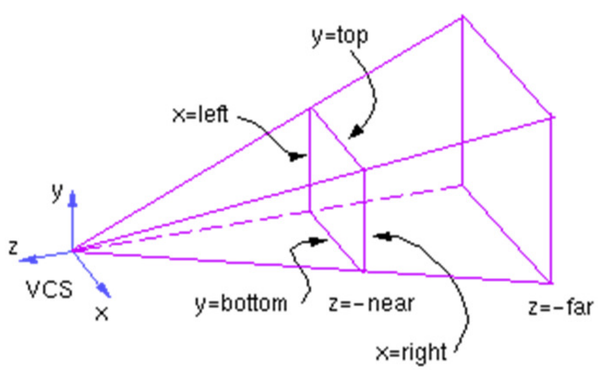
- Given hierarchy of objects
- Bounding volume of each node encloses the bounding volumes of all its children
- Start by testing the outermost bounding volume
  - If it is entirely outside, don't draw the group at all
  - If it is entirely inside, draw the whole group

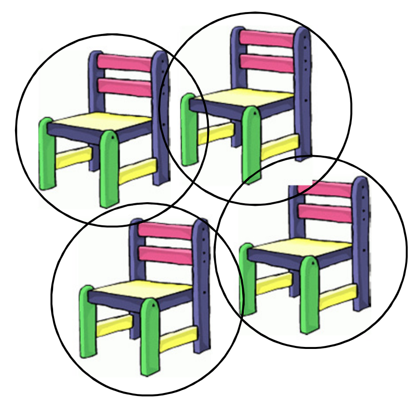




Hierarchical Culling

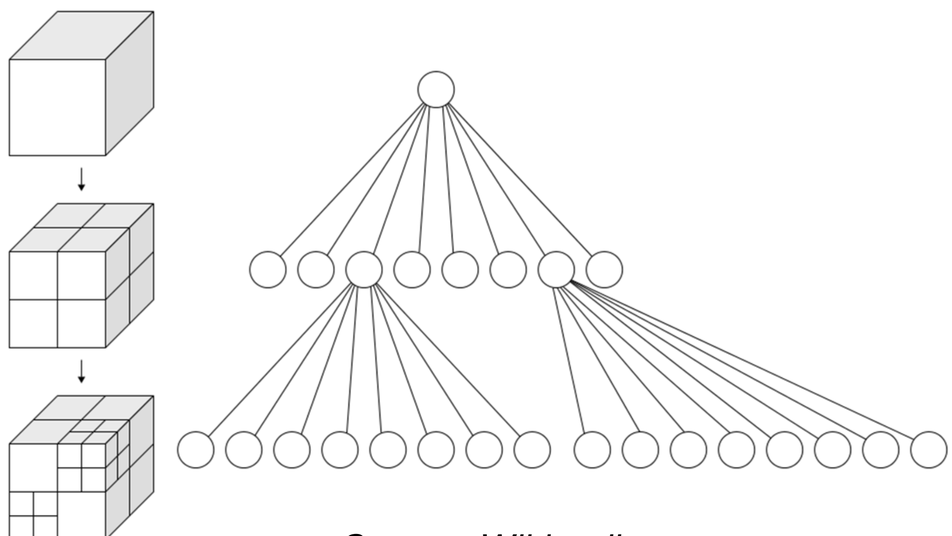
- **If the bounding volume is partly inside and partly outside**
  - Test each child's bounding volume individually
  - If the child is in, draw it; if it's out cull it; if it's partly in and partly out, recurse.
  - If recursion reaches a leaf node, draw it normally





Hierarchical Culling: Octree

- Octrees are the three-dimensional analog of quadtrees.
- An octree is a tree data structure in which each node has exactly eight children.
- Most often used to partition a 3D space by recursively subdividing it into eight octants.



Source: Wikipedia

Video

- An OpenGL Demo - Frustum Culling with Octree
  - http://www.youtube.com/watch?v=H-SsvZZv1sw