CS174A : Introduction to Computer Graphics

Kinsey 1240
MW 4-6pm

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Mid-Term

- Hackathon
  - I will send a link out to participants tonight
  - I am proceeding with my part
  - You will have through next Wednesday
    - Give you enough time to go through them all (41)
    - You do not need to look at code, just the result
      - Did project effectively and meaningfully visualize some data
        - » Wide latitude on definition of ’data’
      - Did project (appear to) use class topics through texture mapping
    - Please be thoughtful about the score you assign
- Written exam
  - Handed off to reader to grade

Project Proposals

- I have reviewed them all (27)
  - Sending feedback to your teams tonight
    - Most look just fine
    - You can always change/evolve your idea
    - Remember there is a time constraint
  - Link will be included to setup your project team and repository (similar to hackathon)
  - Get started if you have not already

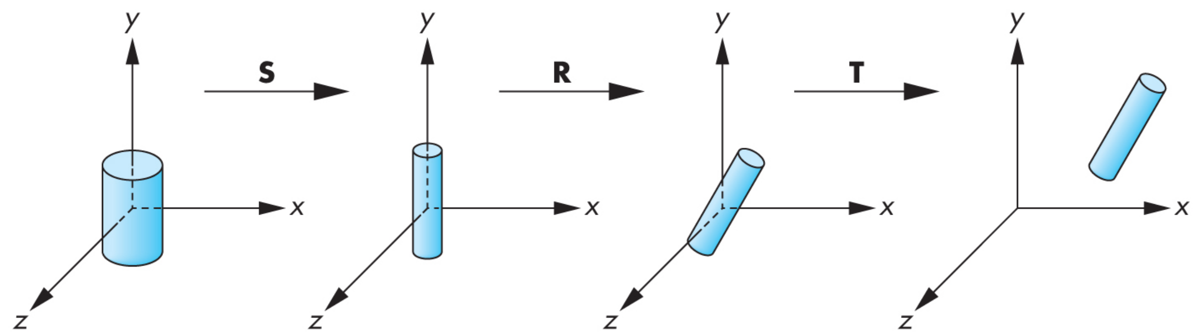
Representing models

- So far we have been rendering models, more or less, resembling the following.

```
mat4 instance;
mat4 modelViewBase;

instance = Trans( x, y, z ) * Rx( rx ) * Ry( ry ) * Rz( rz ) * Scale( sx, sy, sz );
mat4 modelView = modelViewBase * instance;
modelViewToShader( modelView );
drawCylinder( );

Repeat...
```



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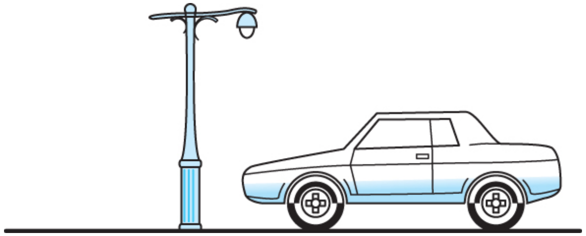
Representing models

- As the number of objects to render increases.
  - This approach quickly becomes unmanageable.
- We also typically render objects that have some relationship to each other.
  - Take the example of a car.
  - Wheels in relation to the chassis.
  - Chassis in relation to the road and light post.



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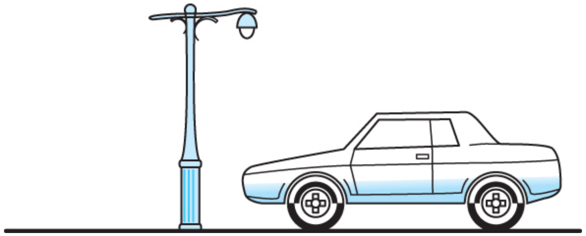
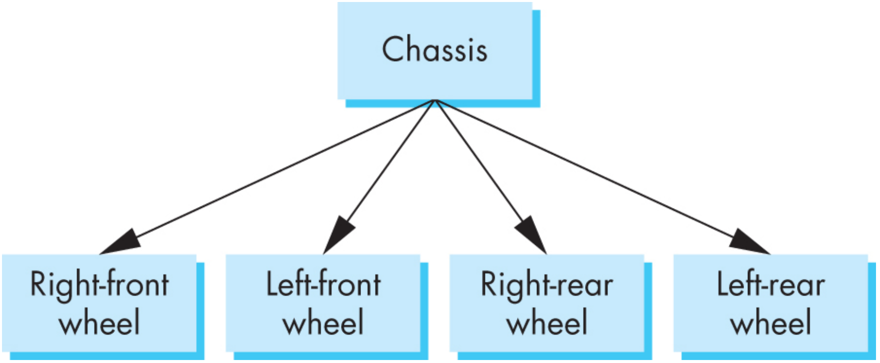
Representing models

- Representing this in straight code will lead to a very long giant mess.
    - Each element has its own copy of transformations.
    - A lot of unnecessary duplication
    - Prone to error and mistakes
- There is a better way.



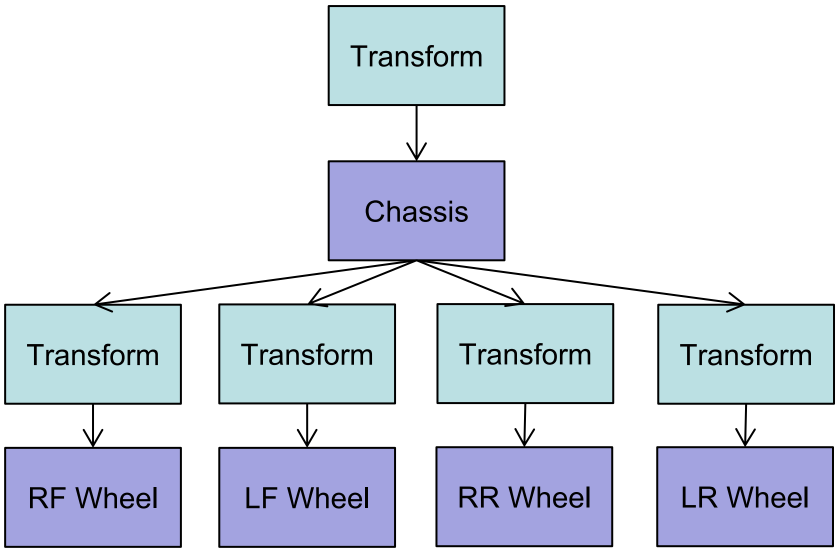
Representing models

- Scene graphs are the better way
  - Here objects can be represented in a logical way
  - Object relationships can be established in relation to other objects in a hierarchical way.
  - Useful as the wheels can now be specified in relation to the chassis, not the whole world.



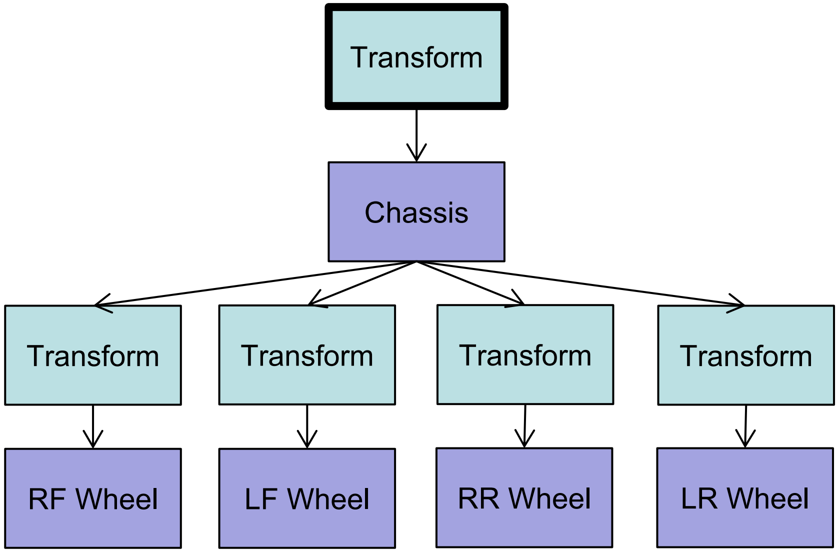
Representing models

- More often the graph (or tree) would look like the following.
  - Each transform node contains a full TRS transformation
    - TRS = Translate, Rotate, Scale



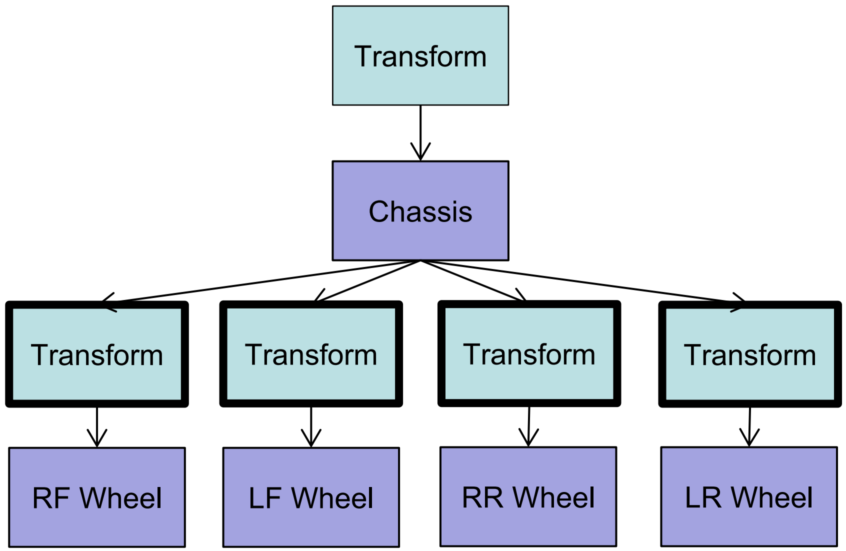
Representing models

- Moving, sizing, orienting the entire car is as simple as manipulating the top transform node.



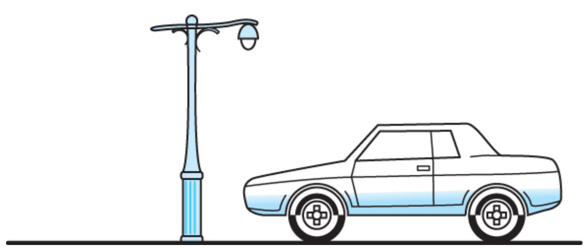
Representing models

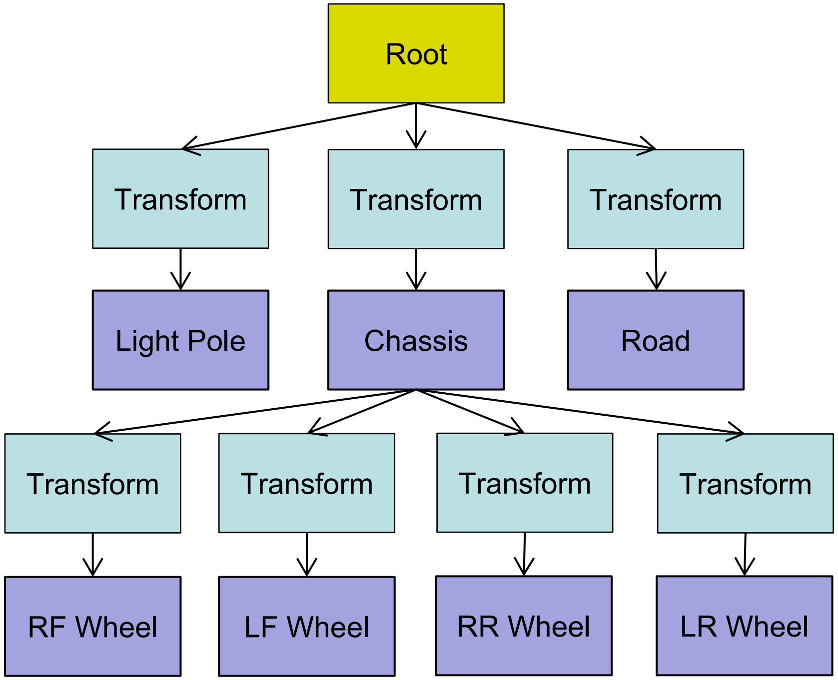
- These transforms are in relation to only the chassis itself.
  - Really, in the coordinate frame of the chassis.



Representing models

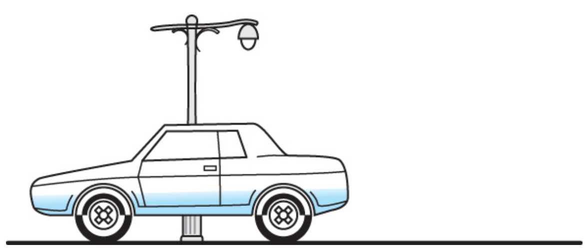
- Let's make the scene graph complete
    - Recall our little scene.

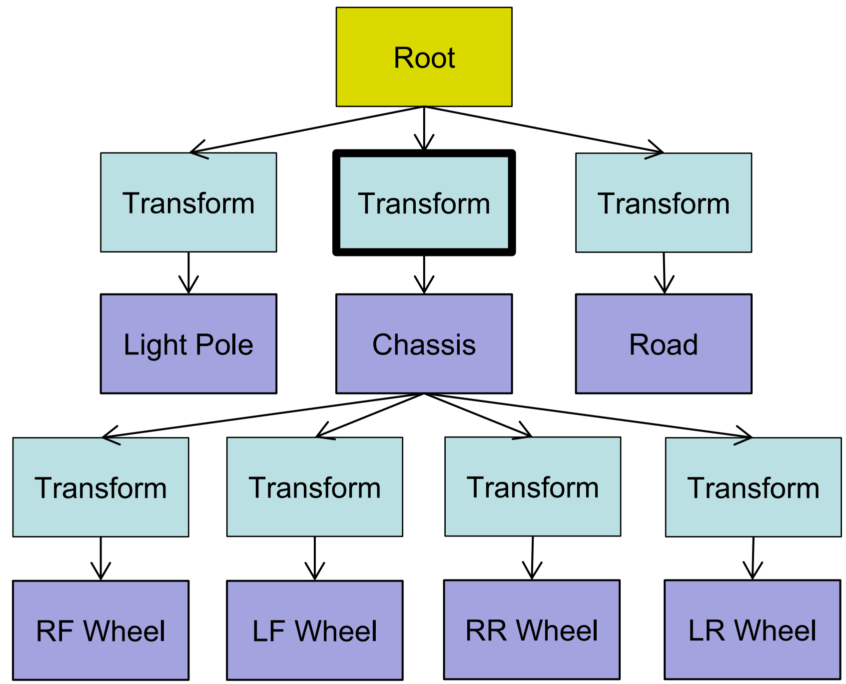




Representing models

- If the car is moved
  - We update the single transformation above the entire car.



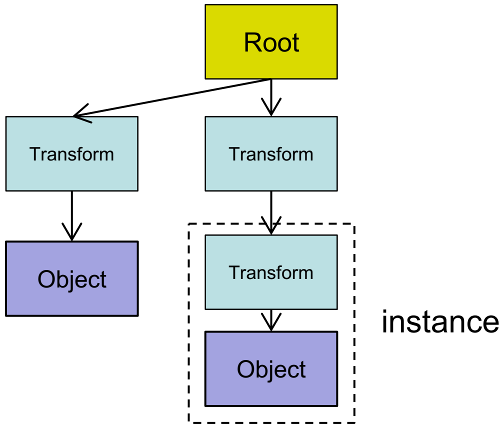


Representing models

- How do we process a scene graph?
    - Traverse the tree structure – depth first.
    - Transformations are processed like a stack as we descend.
    - Pushing (saving) the current transformation on the way down.
    - Popping (restoring) the previous transformation on the way up.
    - There are variations on the exact representation.
        - But the stack metaphor is at its base.
    - You may want to track other application/graphics *state* in this way as well.

Representing models

- Elements of a scene graph?
  - In this example transformations are kept separate from the geometry.
    - This approach gives more flexibility.
    - You could 'flatten' the scene by combining transform nodes or even applying transformations to static geometry.
    - Transform nodes are then removed from the tree and instanced objects is copied. (transformations have been applied to the geometry)



Representing models

- Elements of a scene graph?
  - So far we have seen three types of nodes.
    - Root
    - Transform
    - Object
  - Other types of nodes can be imagined
    - Group
      - » Common parent, collection of children
    - Attribute
      - » Set graphics state (e.g. texture)
    - Predicates or switches
      - » Only render a particular child of the node based on some rule or index.

Representing models

- Elements of a scene graph?
    - Each node type would define some predefined behavior and possibly callbacks for application specific functionality.
    - Let's look at some basic nodes types you would see in a scene graph library (or if you implemented a simple one)
        - Hmm, an advanced topic!

Representing models

- Elements of a scene graph?
  - Root node
    - Parent of all nodes in the scene graph
    - Global state about the scene might be kept here
      - Lighting is an example.
    - You might think storing camera information would go here but it generally does not.
      - The scene graph represents the scene alone.
      - What if you needed more than one camera?

Representing models

- Elements of a scene graph?
  - Group node
    - Groups children nodes/graphs.
    - Usually just a tree structuring element.
    - Often also a base class for many other node types with children.

Representing models

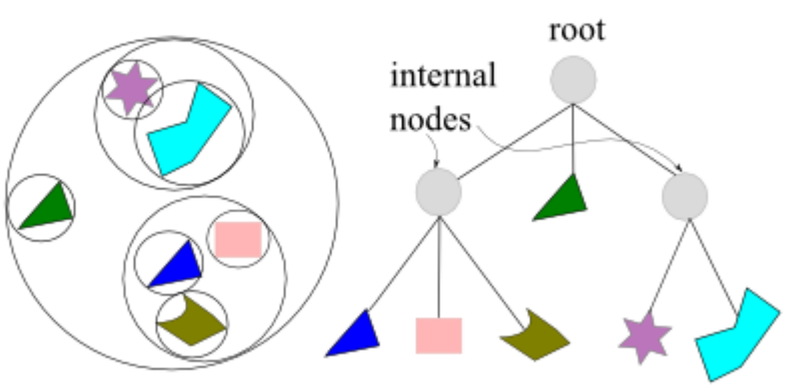
- Elements of a scene graph?
  - Transformation node
    - Usually based on a Group node.
    - Applies a transformation to all child nodes.
    - In some scene graph APIs there are two versions
      - Dynamic, which a transforms that change over time
      - Static, which do not – these often had the option of being flattened. This mattered more when processors were much slower.

Representing models

- Elements of a scene graph?
  - Object node.
    - Stores geometry for an object.
    - A simple scene graph could store references to everything needed to draw here; i.e. state information.
    - Often, what is actually stored are pointers to data structures that represent the data.
      - Vertices, color, normals, texture coordinates, textures, shaders, etc.

Representing models

- Elements of a scene graph?
  - Most scene graphs also compute a ***bounding volume*** for each node of the tree.
  - A bounding sphere for all group based nodes is common.
    - Root, group, transform, etc.
    - We talked about computing bounding volumes around geometry last time.



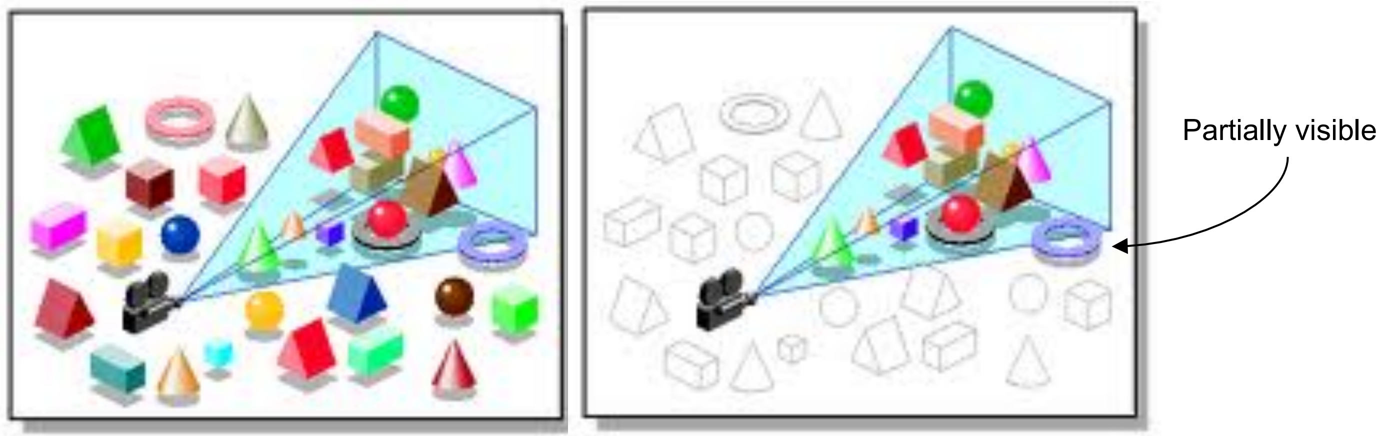
Representing models

- Elements of a scene graph?
    - Object nodes that hold geometry usually use some tighter fitting bounding volume.
        - ***Bounding volumes*** are used for ***culling*** the scene graph
        - Can also be used for *collision detection* with the scene.

Representing models

Representing models

- Elements of a scene graph?
  - **Culling** involves determining which parts of the scene are outside the current view frustum.
  - Only parts that are *inside* or *partially inside* the frustum are drawn.
    - Partially intersecting has to be drawn too!



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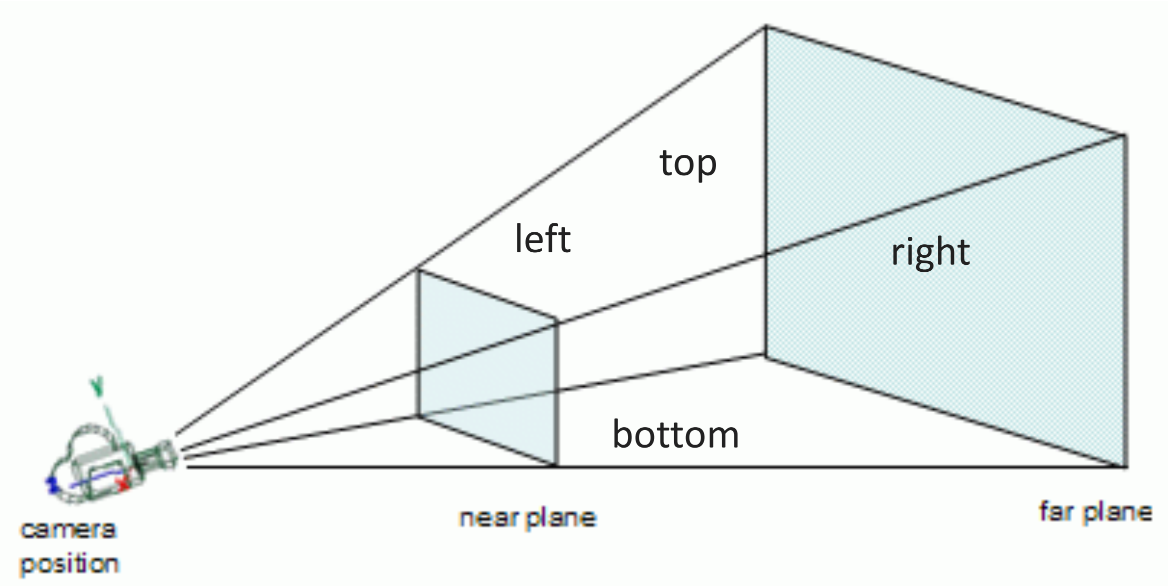
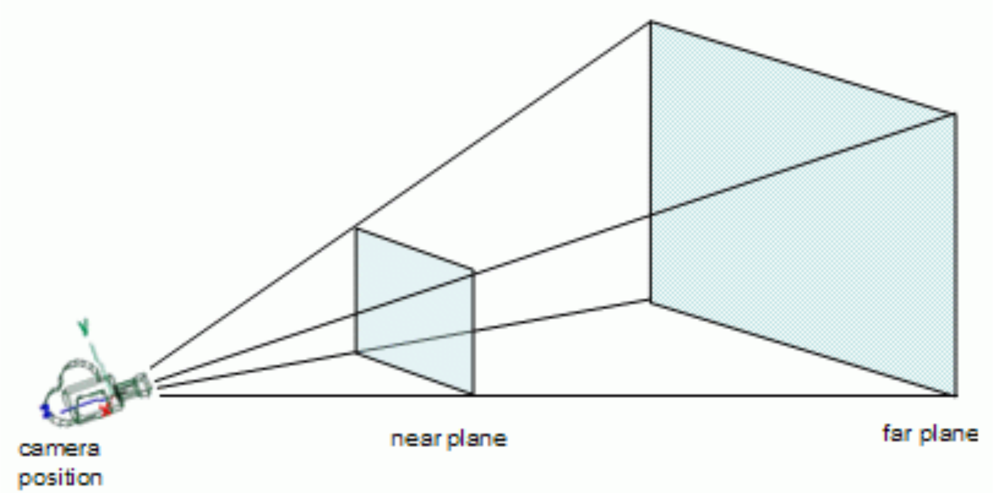
Representing models

- Elements of a scene graph?
  - Culling involves comparing the bounding volumes of the scene with the six planes that make up the view frustum.



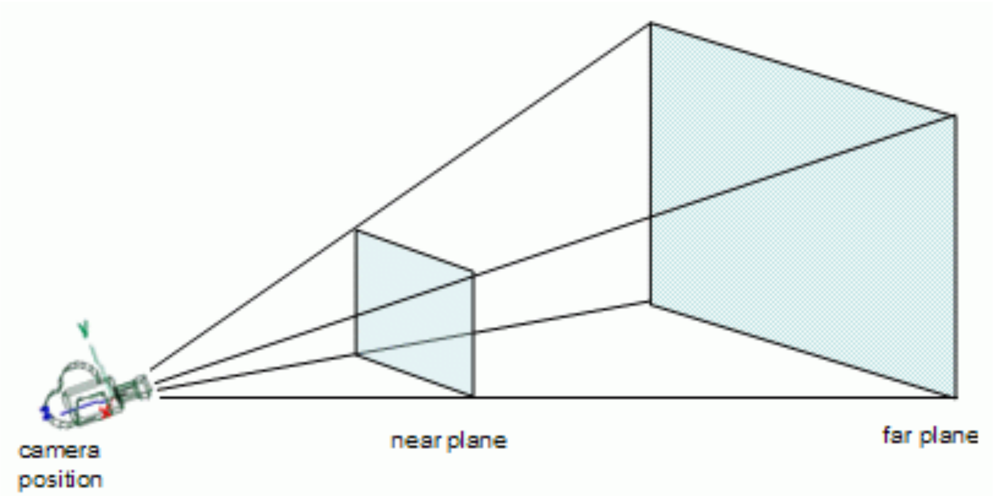
Representing models

- Elements of a scene graph?
  - If an object is ***completely inside*** the six planes of the frustum, we need to *render the object*.
  - If an object ***intersects at least one*** of the six planes of the frustum, we need to *render the object*.
  - All other objects can be ***ignored***.



Representing models

- Elements of a scene graph?
  - Computing the intersections requires that we know the plane equations of all six sides of the frustum.
  - Where do these plane equations come from?



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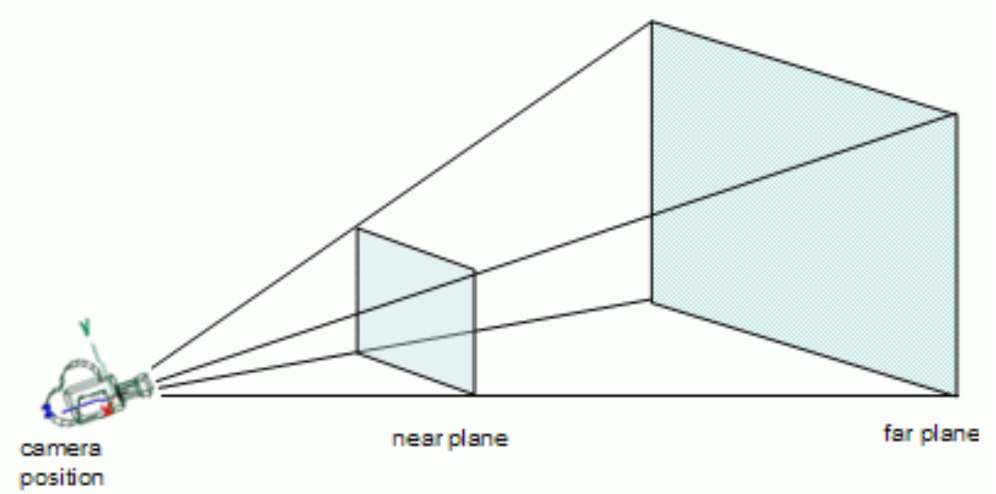
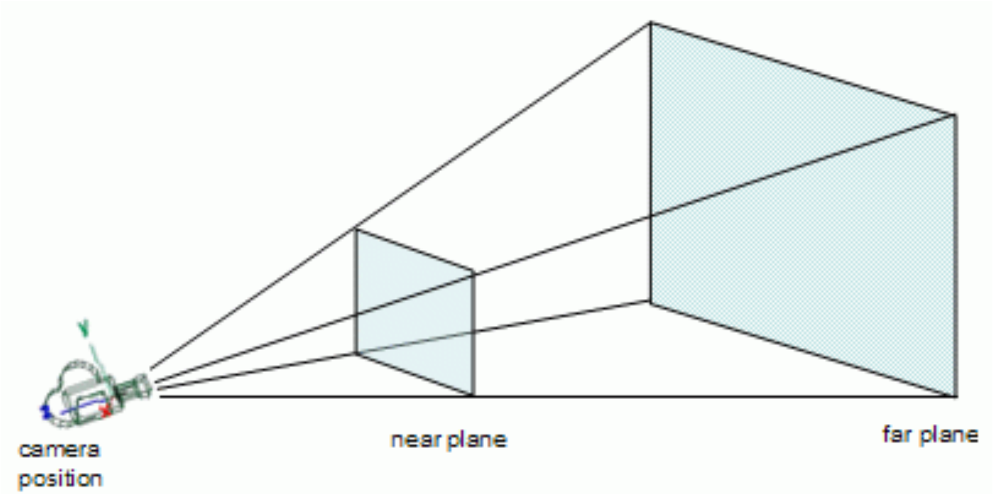
Representing models

- Elements of a scene graph?
  - Can extract the planes directly from the projection matrix!



Representing models

- Elements of a scene graph?
  - It's actually easiest to extract the planes in clip space.
  - Recall that in clip space the view volume (frustum) has become a cube centered around the origin. (-1, -1, -1),(1, 1, 1)
  - However, coordinates there are in homogeneous coordinates still – remember *w? It is not 0 here when using perspective projection!*



Representing models

- Elements of a scene graph?
  - Recall that after applying the model-view and projection matrix vertices are in homogeneous *clip coordinates*.
  - Normalizing performs the perspective division and gets everything back into homogeneous space.

$$pc = (xc, yc, zc, wc) = PMp$$

$$pcn = \left(\frac{xc}{wc}, \frac{yc}{wc}, \frac{zc}{wc}, \frac{wc}{wc}\right) = (x', y', z', 1)$$

Representing models

- Elements of a scene graph?
  - Those normalized coordinates are where the canonical view volume exists
    - From (-1,-1,-1) to (1,1,1)
  - Then, if ***pcn*** is *inside* the view frustum, the following holds

$$pcn = (x', y', z', 1)$$

$$-1 < x' < 1$$

$$-1 < y' < 1$$

$$-1 < z' < 1$$

Representing models

- Elements of a scene graph?
  - But we do not have access to the values after the perspective division
    - It occurs inside the GPU after the vertex shader.
  - What to do?
  - It turns out that the following relationships are equivalent to those on the previous slide, *then*
    - ***pc*** is also *inside* the frustum, if:

$$pc = (xc, yc, zc, wc) = PMp$$

$$-wc < xc < wc$$

$$-wc < yc < wc$$

$$-wc < zc < wc$$

Representing models

- Elements of a scene graph?
    - That’s nice. What does that mean?
    - It means that, for example, the following is true when *pc* is to the right of the left plane of the frustum.

$$-wc < xc$$

- If we recall that *p* and PM are

$$p = (x, y, z, 1) \ \text{ and } \ PM = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

Representing models

- Elements of a scene graph?
  - Again…

$$p = (x, y, z, 1) \text{ and } PM = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

  - Then we have:

$$xc = x \times a_{11} + y \times a_{12} + z \times a_{13} + a_{14}$$
$$yc = x \times a_{21} + y \times a_{22} + z \times a_{23} + a_{24}$$
$$zc = x \times a_{31} + y \times a_{32} + z \times a_{33} + a_{34}$$
$$wc = x \times a_{41} + y \times a_{42} + z \times a_{43} + a_{44}$$

Representing models

- Elements of a scene graph?
  - Example, since

$$xc = x \times a_{11} + y \times a_{12} + z \times a_{13} + a_{14}$$
$$wc = x \times a_{41} + y \times a_{42} + z \times a_{43} + a_{44}$$

  - Then, recall and a little algebra

$$-wc < xc$$
$$xc + wc > 0$$
$$x(a_{11} + a_{41}) + y(a_{12} + a_{42}) + z(a_{13} + a_{43}) + (a_{14} + a_{44}) > 0$$

  - Looks more like a plane equation…

Representing models

- Elements of a scene graph?

$$-wc < xc$$

$$xc + wc > 0$$

$$x(a_{11} + a_{41}) + y(a_{12} + a_{42}) + z(a_{13} + a_{43}) + (a_{14} + a_{44}) > 0$$

- Maybe this form looks more familiar?

$$(Ax + By + Cz + D) = 0$$

$$A = a_{11} + a_{41}$$

$$B = a_{12} + a_{42}$$

$$C = a_{13} + a_{43}$$

$$D = a_{14} + a_{44}$$

Representing models

- Elements of a scene graph?
  - If a point *p* evaluated to 0 the point is *on the plane*.
  - If a point *p* evaluates to >0 we are on the positive side of the plane – or *inside.*
  - If a point *p* evaluates to <0 we are on the negative side of the plane – or *outside.*

$$(Ax + By + Cz + D) = 0$$

$$A = a_{11} + a_{41}$$

$$B = a_{12} + a_{42}$$

$$C = a_{13} + a_{43}$$

$$D = a_{14} + a_{44}$$

Representing models

- Elements of a scene graph?
  - For intersecting with a sphere we need to normalize for the distance values to be meaningful.
  - Remember, also, that the normal to this plane is defined by (A,B,C)

$$(Ax + By + Cz + D) = 0$$

$$A = a_{11} + a_{41}$$

$$B = a_{12} + a_{42}$$

$$C = a_{13} + a_{43}$$

$$D = a_{14} + a_{44}$$

Representing models

- Elements of a scene graph?
    - The planes of the frustum need to be extracted each time the camera or objects in the scene are moved.
        - Every frame, basically.
    - It is trivial to look up the values for all six planes.
    - As the scene graph is traversed the bounding volumes are checked against the frustum.
    - If the volume falls outside the frustum that branch of the scene graph can be skipped entirely.
    - If the volume intersects at all, either more tests against the objects contained within the volume need to be evaluated (hierarchical volumes) or just draw everything.