Lecture 26 of 41

Picking
Videos 5: More CGA

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KSOL course pages: http://bit.ly/hGvXlH / http://bit.ly/eVizrE
Public mirror web site: http://www.kddresearch.org/Courses/CIS636
Instructor home page: http://www.cis.ksu.edu/~bhsu

Readings:

Today: Chapter 7, §8.4, Eberly *2e* – see **http://bit.ly/ieUq45**
Next class: §8.3 – 8.4, 4.2, 5.0, 5.6, 9.1, Eberly *2e*
Lighthouse 3-D picking tutorial by A. R. Fernandes: **http://bit.ly/dZud4j**

Lecture Outline

- Reading for Last Class: Chapter 6, Esp. §6.1, Eberly *2e*
- Reading for Today: Chapter 7, §8.4, Eberly *2e*
- Reading for Next Class: §8.3 – 8.4, 4.2, 5.0, 5.6, 9.1, Eberly *2e*
- Last Time: Adaptive Spatial Partitioning
  - Visible Surface Determination (VSD) revisited
  - Constructive Solid Geometry (CSG), Binary Space Partitioning (BSP)
  - Quadtrees (2-D) & octrees (3-D)
- Today: Picking
  - OpenGL modes: rendering (default), feedback, selection
  - Name stack
  - Hit records
  - Rendering in selection mode
  - Using selection buffer
  - Color coding to keep track of what has been picked, what to do
- Next Class: Interaction Handling

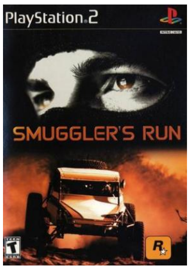
Where We Are

21	**Lab 4a: Animation Basics**	**Flash animation handout**
22	Animation 2: Rotations; Dynamics, Kinematics	Chapter 17, esp. §17.1 – 17.2
23	Demos 4: Modeling & Simulation; Rotations	Chapter 10[1], 13[2], §17.3 – 17.5
24	**Collisions 1: axes, OBBs, Lab 4b**	**§2.4.3, 8.1, GL handout**
25	Spatial Sorting: Binary Space Partitioning	Chapter 6, esp. §6.1
26	**Demos 5: More CGA; Picking; HW/Exam**	**Chapter 7[2]; § 8.4**
27	**Lab 5a: Interaction Handling**	**§ 8.3 – 8.4; 4.2, 5.0, 5.6, 9.1**
28	Collisions 2: Dynamic, Particle Systems	§ 9.1, particle system handout
	Exam 2 review; Hour Exam 2 (evening)	**Chapters 5 – 6, 7[2] – 8, 12, 17**
29	**Lab 5b: Particle Systems**	**Particle system handout**
30	**Animation 3: Control & IK**	**§ 5.3, CGA handout**
31	Ray Tracing 1: intersections, ray trees	Chapter 14
32	Lab 6a: Ray Tracing Basics with POV-Ray	RT handout
33	Ray Tracing 2: advanced topic survey	Chapter 15, **RT handout**
34	Visualization 1: Data (Quantities & Evidence)	Tufte handout (1)
35	**Lab 6b: More Ray Tracing**	**RT handout**
36	Visualization 2: Objects	Tufte handout (2 & 4)
37	Color Basics; Term Project Prep	**Color handout**
38	Lab 7: Fractals & Terrain Generation	**Fractals/Terrain handout**
39	**Visualization 3: Processes; Final Review 1**	Tufte handout (3)
40	**Project presentations 1; Final Review 2**	**–**
41	Project presentations 2	–
	Final Exam	**Ch. 1 – 8, 10 – 15, 17, 20**

Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.

Green, **blue** and **red** letters denote **exam review**, **exam**, and **exam solution review** dates.

Acknowledgements: Collisions, Data Structures, Picking



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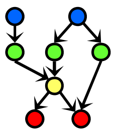
Review [1]: Tree Representations for Scenes

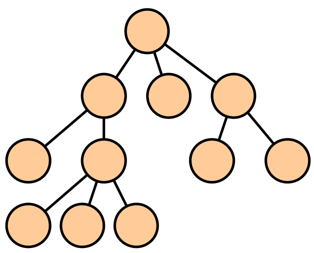
- Scene Graphs
  - Organized by how scene is constructed
  - Nodes hold objects
- Constructive Solid Geometry (CSG) Trees
  - Organized by how scene is constructed
  - Leaves hold 3-D primitives
  - Internal nodes hold set operations
- Binary Space Partitioning (BSP) Trees
  - Organized by spatial relationships in scene
  - Nodes hold facets (in 3-D, polygons)
- Quadtrees & Octrees
  - Organized spatially
  - Nodes represent regions in space
  - Leaves hold objects

Adapted from slides ♥ 2004 G. G. Chappell, UAF
CS 481/681: Advanced Computer Graphics, Spring 2004, http://bit.ly/eivvVc

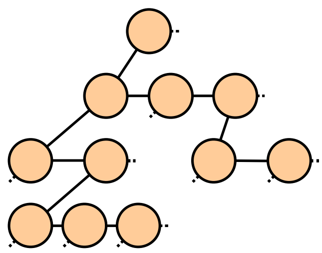


Review [2]: Scene Graphs as B-Trees

- We think of scene graphs as looking like the tree on the left.
- However, it is often convenient to implement them as shown on the right.
  - Implementation is a B-tree.
  - Child pointers are first-logical-child and next-logical-sibling.
  - Then traversing the logical tree is a simple pre-order traversal of the physical tree. This is how we draw.



Logical Tree



Physical Tree

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Review [3]: Binary Space Partitioning (BSP) Tree

- **BSP tree: type of binary tree**
  - Nodes can have 0, 1, or two children
  - Order of child nodes matters, and if a node has just 1 child, it matters whether this is its left or right child
- **Each node holds a facet**
  - This may be only part of a facet from original scene
  - When constructing a BSP tree, we may need to split facets
- **Organization**
  - Each facet lies in a unique plane
    - In 2-D, a unique line
  - For each facet, we choose one side of its plane to be "outside" Other direction: "inside"
    - This can be the side the normal vector points toward
  - Rule: For each node
    - Its left descendant subtree holds only facets "inside" it
    - Its right descendant subtree holds only facets "outside" it

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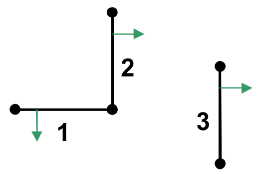
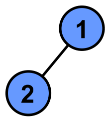
Review [4]: BSP Tree Construction Example

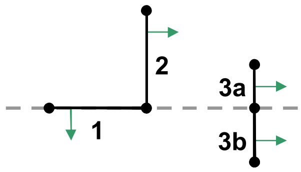
- Suppose we are given the following (2-D) facets and "outside" directions:



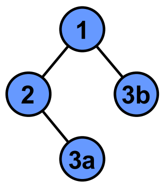
- We iterate through the facets in numerical order
  - Facet 1 becomes the root
  - Facet 2 is inside of 1
  - Thus, after facet 2, we have the following BSP tree:



- Facet 3 is partially inside facet 1 and partially outside.
  - We split facet 3 along the line containing facet 1
  - The resulting facets are 3a and 3b
  - They inherit their "outside" directions from facet 3



- We place facets 3a and 3b separately
  - Facet 3a is inside facet 1 and outside facet 2
  - Facet 3b is outside facet 1
- The final BSP tree looks like this:



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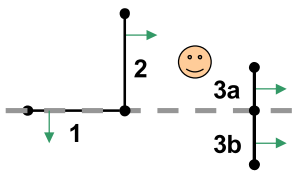
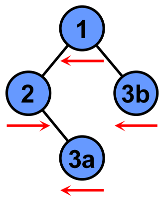
Review [5]: BSP Tree Traversal Example

- Procedure:
  - For **each facet**, determine on which side of it the observer lies.
  - Back-to-front ordering: Do an in-order traversal of the tree in which the subtree opposite from the observer comes before the subtree on the same side as the observer.
- Our observer is inside 1, outside 2, inside 3a, inside 3b.





- Resulting back-to-front ordering: 3b, 1, 2, 3a.
- Is this really back-to-front?

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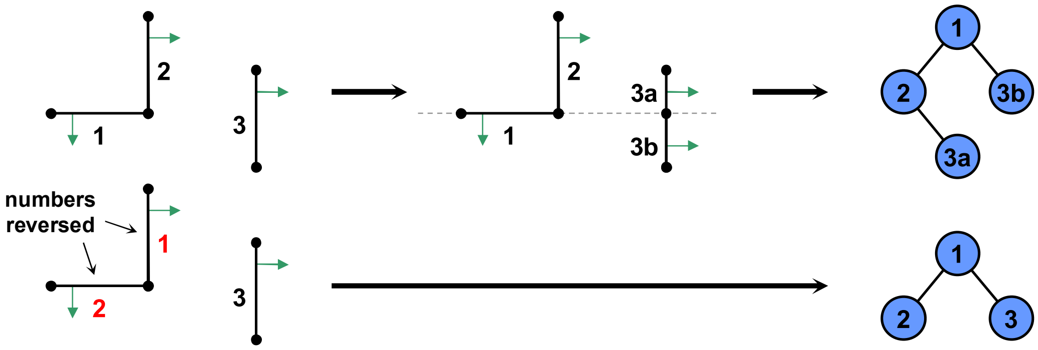
Review [6]: BSP Tree Optimization Example

- Order in which we iterate through the facets can matter a great deal
  - Consider our simple example again
  - If we change the ordering, we can obtain a simpler BSP tree



- If a scene is not going to change, and the BSP tree will be used many times, then it may be worth a large amount of preprocessing time to find the best possible BSP tree

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Review [7]: Quadtrees & Octrees – Definition

- In general
  - Quadtree: tree in which each node has at most 4 children
  - Octree: tree in which each node has at most 8 children
  - Binary tree: tree in which each node has at most 2 children
- In practice, however, we use "quadtree" and "octree" to mean something more specific
  - Each node of the tree corresponds to a square (quadtree) or cubical (octree) region
  - If a node has children, think of its region being chopped into 4 (quadtree) or 8 (octree) equal subregions
  - Child nodes correspond to these smaller subregions of parent's region
  - Subdivide as little or as much as is necessary
  - Each internal node has exactly 4 (quadtree) or 8 (octree) children

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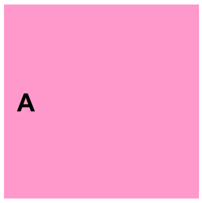
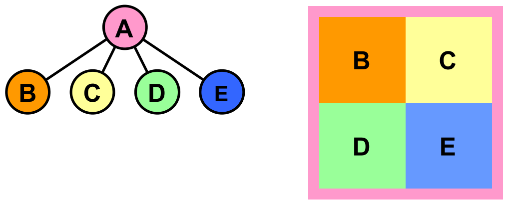
Review [8]: Quadtree Construction Example

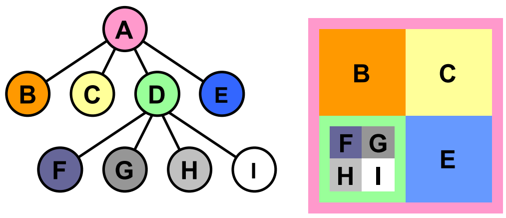
- **Root node of quadtree corresponds to square region in space**
  - Generally, this encompasses entire "region of interest"



- **If desired, subdivide along lines parallel to the coordinate axes, forming four smaller identically sized square regions**
  - Child nodes correspond to these



- **Some or all of these children may be subdivided further**
- **Octrees work in a similar fashion, but in 3-D, with cubical regions subdivided into 8 parts**



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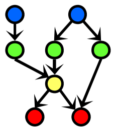


Interactive CG Programming: Objectives

- More Sophisticated Interactive Programs
  - Modes of interaction
  - Tools for building
- Techniques
  - Picking: select objects from display (three methods covered)
  - Rubberbanding: interactive drawing of lines, rectangles
  - Display lists: retained mode graphics

Picking [1]: Definition & Challenges

- Identify User-Defined Object on Display
- In Principle, Should Be Simple
  - Mouse gives position
  - We should be able to determine object-position correspondence
- Practical Difficulties
  - Pipeline architecture: feed forward
  - Hard to map screen back to world
  - Complicated by screen being 2-D, world 3-D
  - How close do we have to come to object to say we selected it?

Picking [2]: Three Approaches

- **1. Hit List**
  - Most general approach
  - Difficult to implement
- **2. Buffered Object IDs**
  - Write to back buffer or some other buffer
  - Store object IDs as objects rendered
- **3. Rectangular Maps**
  - Easy to implement for many applications
  - *e.g.*, simple paint programs

Rendering Modes

- OpenGL: Can Render in One of Three Modes
  - `GL_RENDER`
    - Normal rendering to frame buffer
    - Default
  - `GL_FEEDBACK`
    - Provides list of primitives rendered
    - No output to frame buffer
  - `GL_SELECTION`
    - Each primitive in view volume generates *hit record*
    - Record placed in *name stack*
    - Stack can be examined later
- Mode Selected by `glRenderMode(mode)`

Selection Mode Functions

- `glSelectBuffer()`: Specifies Name Buffer *aka* Name Stack
- `glInitNames()`: Initializes Name Buffer
- `glPushName(id)`: Push ID on Name Buffer
- `glPopName()`: Pop Top of Name Buffer
- `glLoadName(id)`: Replace Top Name on Buffer
- `id` set by application program to identify objects

OpenGL Functions for Manipulating Name Stack

- `void glInitNames(void);`
  - Creates empty name stack
  - Must call to initialize stack prior to pushing names
- `void glPushName(GLuint name);`
  - Adds name to top of stack
  - Maximum dimension: implementation-dependent
  - Must contain at least 64 names
  - Can query state variable `GL_NAME_STACK_DEPTH`
  - Pushing too many values causes `GL_STACK_OVERFLOW`
- `void glPopName();`
  - Removes name from top of stack
  - Popping value from empty stack causes `GL_STACK_UNDERFLOW`
- `void glLoadName(GLunit name);`
  - Replaces top of stack with `name`
  - Same as calling `glPopName(); glPushName(name);`

Rendering in Selection Mode: Example

- `#define BODY 1`
- `#define HEAD 2`

…

- `void renderInSelectionMode()`

```
{
    glInitNames();          // 1. create empty name stack (NS)
    glPushName(BODY);       // 2. push first name
   // 3. hit record (HR) for each primitive intersecting view volume
   drawBody();
   // 4. empty stack & save HRs to selection buffer (SB)
   glPopName();
    glPushName(HEAD);       // 5. new name; no HR, same SB
    drawHead();             // 6. new HR for each primitive in VV
    drawEyes();             // 7. update HR with new max/min depths
    glPopName();            // 8. empty NS; write HRs to SB
    drawGround();           // 9. new HRs; empty NS, depth update only
}
```

Same as `glLoadName(HEAD);`

Adapted from tutorial ♥ 2001-2009 A. R. Fernandes
Lighthouse 3D, http://www.lighthouse3d.com

Lighthouse3d.com

Using Selection Mode

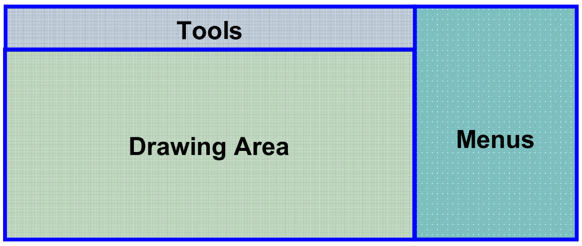
- Initialize Name Buffer *aka* Name Stack
- Enter Selection Mode (using Mouse)
- Render Scene with User-Defined Identifiers
  - Accumulates hits
  - Create new hit record *iff* needed (otherwise update depth)
- Reenter Normal Render Mode
  - Returns number of hits
  - Objects rendered on small area of screen around cursor
- Examine contents of name buffer
  - Hit records written to selection buffer
  - Include information about each hit
    - ID
    - Depth

Selection Mode: Redefining View Volume

- **Caveat**
  - As just described, selection mode won't work for picking – why?
  - Because every primitive in view volume will generate a hit
  - Need to change viewing parameters
    - Only those primitives near cursor are in altered view volume
    - Use `gluPickMatrix` (see Angel *5e* or *6e* for details)
- **New Procedure (*cf.* Fernandes Tutorial)**
  - 1. Get the window coordinates of the mouse
  - 2. Enter selection mode
  - 3. Redefine viewing volume so that only small area of window around cursor is rendered
  - 4. Render scene, either using all primitives or only those relevant to picking operation
  - 5. Exit selection mode and identify objects which were rendered on that small part of screen

Graphical User Interface Design: Using Regions of Screen

- **Rectangular Arrangement**
  - Used by many applications
  - *e.g.*, paint & computer-aided design (CAD) programs

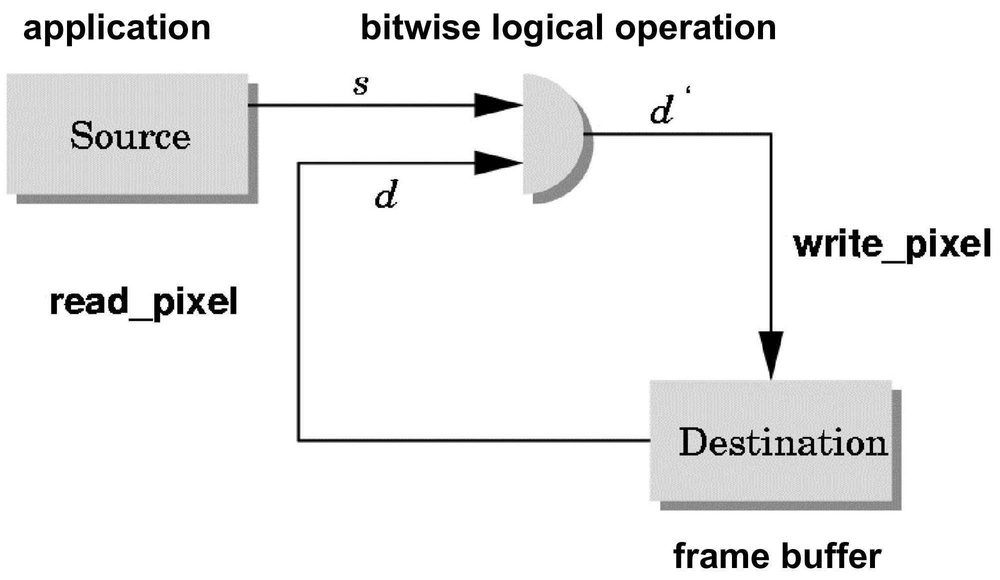


- **Advantages**
  - Compared to: selection mode picking
  - Easier to look at cursor position, determine part of window it is in
- **Common Graphical User Interface (GUI) Design**
  - Xerox Palo Alto Research Center (PARC) – http://bit.ly/dSAr1O
  - Human Interface Guidelines – Wikipedia: http://bit.ly/dO6I5F

Picking: Using Second Buffer & Color-Coding

- Color Coding
  - For small number of objects
  - Can assign a unique color to each object
  - Often assigned in color index mode
- Using Color Coding for Picking
  - Render scene to color buffer other than front buffer
  - Results of rendering not visible
  - Get mouse position
  - Use `glReadPixels()` to read color in buffer written at position of cursor
  - Returned color gives ID of object

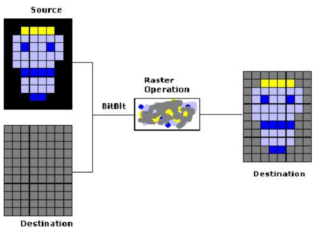
Writing Modes



Adapted from slides ♥ 2005-2008 E. Angel, University of New Mexico
Interactive Computer Graphics, 4th & 5th edition slides, http://bit.ly/gvxfPV

Exclusive OR (XOR) Write

- **Usual (Default) Mode**
  - Source replaces destination: `d′ = s`
  - Cannot write temporary lines this way – why?
    - Cannot recover what was "under" line in fast, simple way
    - Consequence: cannot *deselect* (toggle select) easily
- **Solution: Exclusive OR Mode (XOR)**
  - `d′ = d ⊕ s`
  - Suppose we use XOR mode to scan convert line $\overline{P_0 P_1}$
  - Can draw it again to erase it!



Visual Basic Explorer © 2002 S. Christensen & B. Abreu
http://bit.ly/gXstAM

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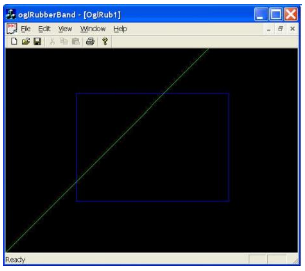
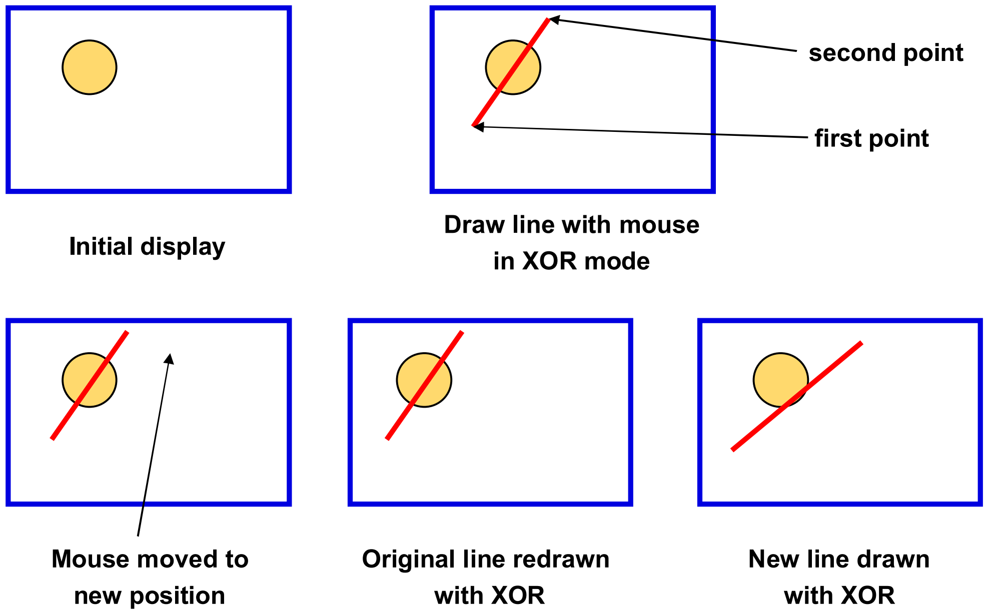
Rubberbanding

- **Switch to XOR Write Mode**
- **Draw Object**
  - **Line**
    - **Can use first mouse click to fix one endpoint**
    - **Then use motion callback to continuously update second endpoint**
    - **Each time mouse is moved, redraw line which erases it**
    - **Then draw line from fixed first position to new second position**
    - **At end, switch back to normal drawing mode and draw line**
  - **Works for other objects**
    - **Rectangles**
    - **Circles**



"Rubber-Banding with OpenGL"
© 2009 J. Xu
The Code Project
http://bit.ly/hGvFkB

Rubberband Lines: Example



XOR in OpenGL

- **Logical Operations between Two Bits *X*, *Y***
  - 2 bits ⇒ $2^2 = 4$ values
  - 4 values ⇒ $2^4 = 16$ pairwise functions
    - X, Y, $\neg X \equiv \overline{X}$, $X \wedge Y \equiv XY$, $X \vee Y \equiv X + Y$, $X \oplus Y \equiv X\overline{Y} + \overline{X}Y$
    - *etc.*
    - In general: 2^{2^b} functions for *b* bits
- **All 16 Operations Supported by OpenGL**
  - Must enable logical operations: `glEnable(GL_COLOR_LOGIC_OP)`
  - Choose logical operation
    - `glLogicOp(GL_XOR)`
    - `glLogicOp(GL_COPY)` – default

Immediate *versus* Retained Modes

- OpenGL Standard: Immediate Mode Graphics
  - OpenGL programs use immediate mode by default
  - Once object is rendered, there is no memory of it
  - In order to redisplay it, must re-execute its rendering code
  - Can be especially slow if objects
    - are complex
    - must be sent over network
- Alternative: Retained Mode Graphics
  - Accomplished in OpenGL via display lists, vertex buffer objects
  - Define objects
  - Keep them in some form that is easy to redisplay

Display Lists in OpenGL

- **Conceptually Similar to Graphics Files**
  - Compare: Flexible Vertex Format (FVF) definitions in Direct3D
  - Also compare: mesh formats for OpenGL itself, other CG libraries
- **Requirements**
  - Define each display list (DL)
    - Name
    - Create
  - Populate: add contents by
    - reading in file
    - generating mesh automatically
  - Close
- **Client-Server Environment**
  - DL placed on server
  - Can redisplay without sending primitives over network each time

Display List Functions

- **Creating Display List**
  - `GLuint id;`
  - `void init()`

```
{
  id = glGenLists( 1 );
  glNewList( id, GL_COMPILE );
  /* other OpenGL routines */
  glEndList();
}
```

- **Calling Created List**
  - `void display()`

```
{
  glCallList(id);
}
```

  - **Documentation: http://bit.ly/gJYana**
  - **Tutorial © 2005 S. H. Ahn: http://bit.ly/eN3R8c**

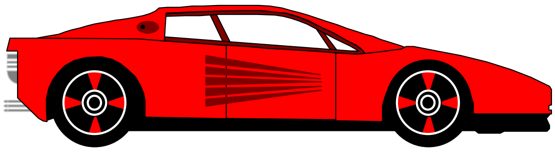
Display Lists & State

- Using Display Lists as Macros (http://bit.ly/hPPBVo)
  - DLs are syntactic sugar (text abbreviations) for
    - Rendering commands (especially mesh traversal)
    - Parameters
  - Now deprecated! Use vertex buffer objects (VBOs) instead
- Side Effects: State Changes within DLs
  - Most OpenGL functions can be put in display lists
  - State changes made inside DL persist after DL is executed
- Avoiding Unexpected Results
  - Use `glPushAttrib` and `glPushMatrix` upon entering DL
  - Use `glPopAttrib` and `glPopMatrix` before exiting

Hierarchy & Display Lists

- **Consider: Model of Car**
  - Similar hierarchy to that for general scene graphs
  - Describes relative modelview transformation (MVT)
    - translation
    - rotation (relative Euler angle or quaternion)
- **Need to Create Display Lists**
  - Chassis
  - Wheel

```
glCallList( CHASSIS );
glTranslatef( … );
glCallList( WHEEL );
glTranslatef( … );
glCallList( WHEEL );
…
glEndList();NewList( CAR, GL_COMPILE );
```



Picking in Action

FarmVille ♥ 2009 – 2011 Zynga, Inc.
http://bit.ly/f1Ct3C

Summary

- Reading for Last Class: §2.4.3, 8.1, Eberly *2e*, GL handout
- Reading for Today: Chapter 6, Esp. §6.1, Eberly *2e*
- Reading for Next Class: Chapter 7, §8.4, Eberly *2e*
- Last Time: Adaptive Spatial Partitioning
  - Trees: VSD, CSG, BSP
  - Spatial partitioning (SP)
    - Examples: BSP trees, quad/octrees (adaptive); voxels (uniform)
    - Scenes: spatial partitioning *vs.* boundary representation (B-rep)
- Today: Picking
  - OpenGL modes: rendering (default), feedback, selection
  - Name stack
  - Hit records
  - Rendering in selection mode using selection buffer
  - Color coding of pickable objects
- Next Class: Interaction Handling

Terminology

- Spatial Partitioning (SP): Calculating Intersection, Visibility
  - Binary Space Partitioning tree – 2-way decision tree/surface
  - Quadtree – 4-way for 2-D
  - Octree – 8-way for 3-D
- Volume Graphics *aka* Volumetric Representation: Uniform SP (Voxels)
- Boundary Representation: Describing Enclosing Surface
  - Meshes
  - Implicit surfaces
  - Sweeps (*e.g.*, sphere-swept volumes: sphere, capsule, lozenge)
- Picking: Allowing User to Select Objects in Scene
  - Selection mode: mode when cursor ("mouse") is active
  - Name stack: last in, first out data structure holding object names
  - Hit records: ID, depth info for intersections with view volume
  - Selection buffer: holds hits, depth (compare: frame/z-buffer)
  - Color coding: using color to represent pickable object ID