# Lecture 26 of 41

## Picking
## Videos 5: More CGA

William H. Hsu
Department of Computing and Information Sciences, KSU

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 |

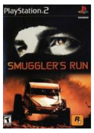
Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.

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

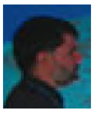




# Acknowledgements: Collisions, Data Structures, Picking




**Steve Rotenberg**
Visiting Lecturer
Graphics Lab
University of California – San Diego
CEO/Chief Scientist, PixelActive
http://graphics.ucsd.edu



**Glenn G. Chappell**
Associate Professor
Department of Computer Science
University of Alaska Fairbanks
http://www.cs.uaf.edu/~chappell/

**Edward Angel**
Professor Emeritus of Computer Science
Founding Director, ARTS Lab
University of New Mexico
http://www.cs.unm.edu/~angel/





# 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

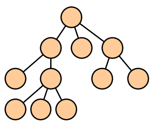
Adapted from slides ♥ 2004 G. G. Chappell, UAF
CS 481/681: Advanced Computer Graphics, Spring 2004, http://bit.ly/eivvVc



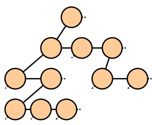


# Review [2]: Scene Graphs as B-Trees

- 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

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

7

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

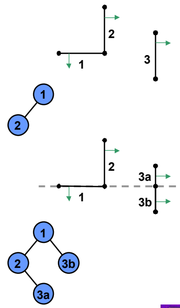
- BSP tree: type of binary tree
  - Nodes can have 0, 1, or two children
  - Order of child nodes matters, and if a node has just 1 child, it matters whether this is its left or right child
- Each node holds a facet
  - This may be only part of a facet from original scene
  - When constructing a BSP 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



8

# 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:

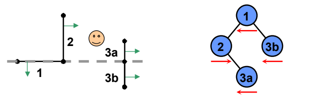





9

# 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.



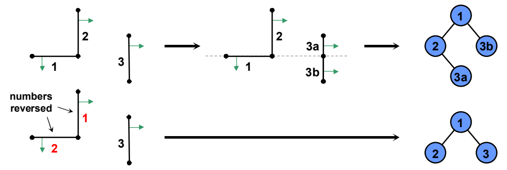

- Resulting back-to-front ordering: 3b, 1, 2, 3a.
- Is this really back-to-front?



10

# 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



11

# Review [7]: Quadtrees & Octrees – Definition

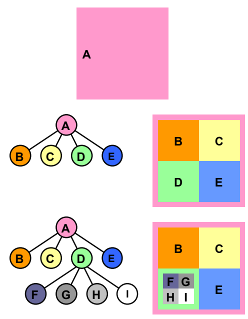
- In general
  - Quadtree: tree in which each node has at most 4 children
  - Octree: tree in which each node has at most 8 children
  - Binary tree: tree in which each node has at most 2 children
- In practice, however, we use "quadtree" and "octree" to mean something more specific
  - Each node of 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



12

# 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



## 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);







# 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

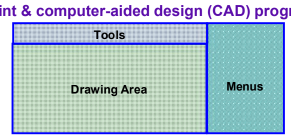






# Graphical User Interface Design: Using Regions of Screen

- 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

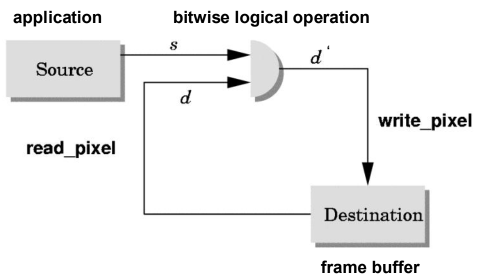
- Color Coding
  - For small number of objects
  - Can assign a unique color to each object
  - Often assigned in color index mode
- Using Color Coding for Picking
  - Render scene to color buffer other than front buffer
  - Results of rendering not visible
  - Get mouse position
  - Use `glReadPixels()`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







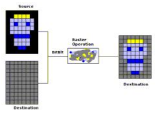
# Writing Modes



25

## 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!



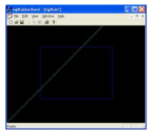

*Visual Basic Explorer* © 2002 S. Christensen & B. Abreu
http://bit.ly/gXstAM



26

## 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

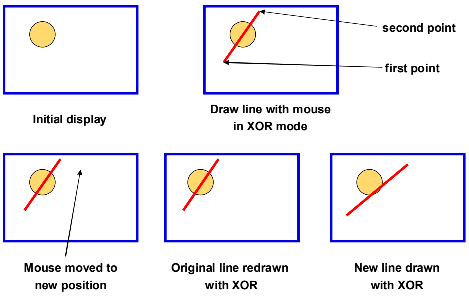


"Rubber-Banding with OpenGL"
© 2009 J. Xu
*The Code Project*
http://bit.ly/hGvFkB



27

## Rubberband Lines: Example






28

## XOR in OpenGL

- Logical Operations between Two Bits *X*, *Y*
  - 2 bits ⇒ $2^2 = 4$ values
  - 4 values ⇒ $2^4 = 16$ pairwise functions
    - $X, Y, \neg X \equiv \bar{X}, X \wedge Y \equiv XY, X \vee Y \equiv X + Y, X \oplus Y \equiv X\bar{Y} + \bar{X}Y$
    - *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



29

## 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



30

## 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

## 31 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

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



## 32 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

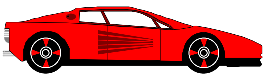
Adapted from slides ♥ 2005-2008 E. Angel, University of New Mexico
*Interactive Computer Graphics*, 4th & 5th edition slides, http://bit.ly/gvxfPV



## 33 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 );
```



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



## 34 Picking in Action

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



## 35 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



## 36 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