Transformation Hierarchies

CS 4620 Lecture 9
Data structures with transforms

- Representing a drawing ("scene")
- List of objects
- Transform for each object
  - can use minimal primitives: ellipse is transformed circle
  - transform applies to points of object
Example

- Can represent drawing with flat list
  - but editing operations require updating many transforms
Groups of objects

• Treat a set of objects as one
• Introduce new object type: group
  – contains list of references to member objects
• This makes the model into a tree
  – interior nodes = groups
  – leaf nodes = objects
  – edges = membership of object in group
Example

- Add group as a new object type
  - lets the data structure reflect the drawing structure
  - enables high-level editing by changing just one node
Demo

- Adobe Illustrator as typical 2D drawing program
- Groups create transformation hierarchy
- Selecting inside groups allows editing internal nodes
The Scene Graph (tree)

• A name given to various kinds of graph structures (nodes connected together) used to represent scenes

• Simplest form: tree
  – just saw this
  – every node has one parent
  – leaf nodes are identified with objects in the scene
Concatenation and hierarchy

• Transforms associated with nodes or edges
• Each transform applies to all geometry below it
  – want group transform to transform each member
  – members already transformed—concatenate
• Frame transform for object is product of all matrices along path from root
  – each object’s transform describes relationship between its local coordinates and its group’s coordinates
  – frame-to-canonical transform is the result of repeatedly changing coordinates from group to containing group
Variants of the Scene Graph

• Parenting
  – allow any object to have child objects
  – every object is effectively also a group
  – common in 3D modeling packages

• Instancing
  – allow objects to belong to multiple parents/groups
  – creates multiple copies of geometry
Instances

• Simple idea: allow an object to be a member of more than one group at once
  – transform different in each case
  – leads to linked copies
  – single editing operation changes all instances
Example

- Allow multiple references to nodes
  - reflects more of drawing structure
  - allows editing of repeated parts in one operation
The Scene Graph (with instances)

- With instances, there is no more tree
  - an object that is instanced multiple times has more than one parent

- Transform tree becomes DAG
  - directed acyclic graph
  - group is not allowed to contain itself, even indirectly

- Transforms still accumulate along path from root
  - now paths from root to leaves are identified with scene objects
Implementing a hierarchy

- Object-oriented language is convenient
  - define shapes and groups as derived from single class

```java
abstract class Shape {
    void draw();
}

class Square extends Shape {
    void draw() {
        // draw unit square
    }
}

class Circle extends Shape {
    void draw() {
        // draw unit circle
    }
}
```
Implementing traversal

• Pass a transform down the hierarchy
  – before drawing, concatenate

```java
abstract class Shape {
  void draw(Transform t_c);
}

class Square extends Shape {
  void draw(Transform t_c) {
    // draw t_c * unit square
  }
}

class Circle extends Shape {
  void draw(Transform t_c) {
    // draw t_c * unit circle
  }
}

class Group extends Shape {
  Transform t;
  ShapeList members;
  void draw(Transform t_c) {
    for (m in members) {
      m.draw(t_c * t);
    }
  }
}
```
Basic Scene Graph operations

• Editing a transformation
  – good to present usable UI

• Getting transform of object in canonical (world) frame
  – traverse path from root to leaf

• Grouping and ungrouping
  – can do these operations without moving anything
    – group: insert identity node
    – ungroup: remove node, push transform to children

• Reparenting
  – move node from one parent to another
  – can do without altering position
Adding more than geometry

- Objects have properties besides shape
  - color, shading parameters
  - approximation parameters (e.g. precision of subdividing curved surfaces into triangles)
  - behavior in response to user input
  - ...

- Setting properties for entire groups is useful
  - paint entire window green

- Many systems include some kind of property nodes
  - in traversal they are read as, e.g., “set current color”
Scene Graph variations

• Where transforms go
  – in every node
  – on edges
  – in group nodes only
  – in special Transform nodes

• Tree vs. DAG

• Nodes for cameras and lights?