Scene Graphs

COMP 575 / COMP 770

Scene Graphs

- Good background at Wikipedia:

http://en.wikipedia.org/wiki/Scene_graph

1. A scene graph is a collection of nodes in a graph or tree structure
2. Nodes in a scene graph (generally) represent entities or objects in the scene
3. Define logical relationships

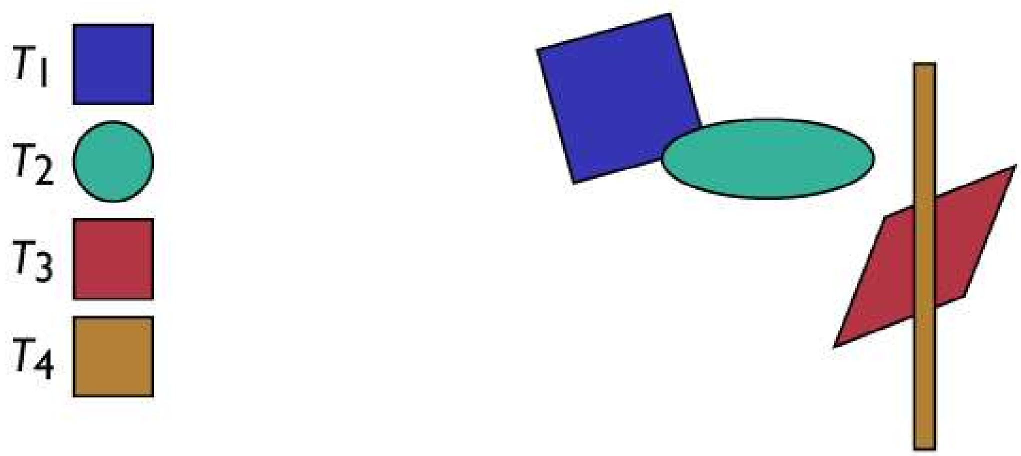
   e.g. between a knight and a horse so that the knight is considered an extension to the horse;

4. Define spatial relationships

5. Spatial hierarchies and memory overhead

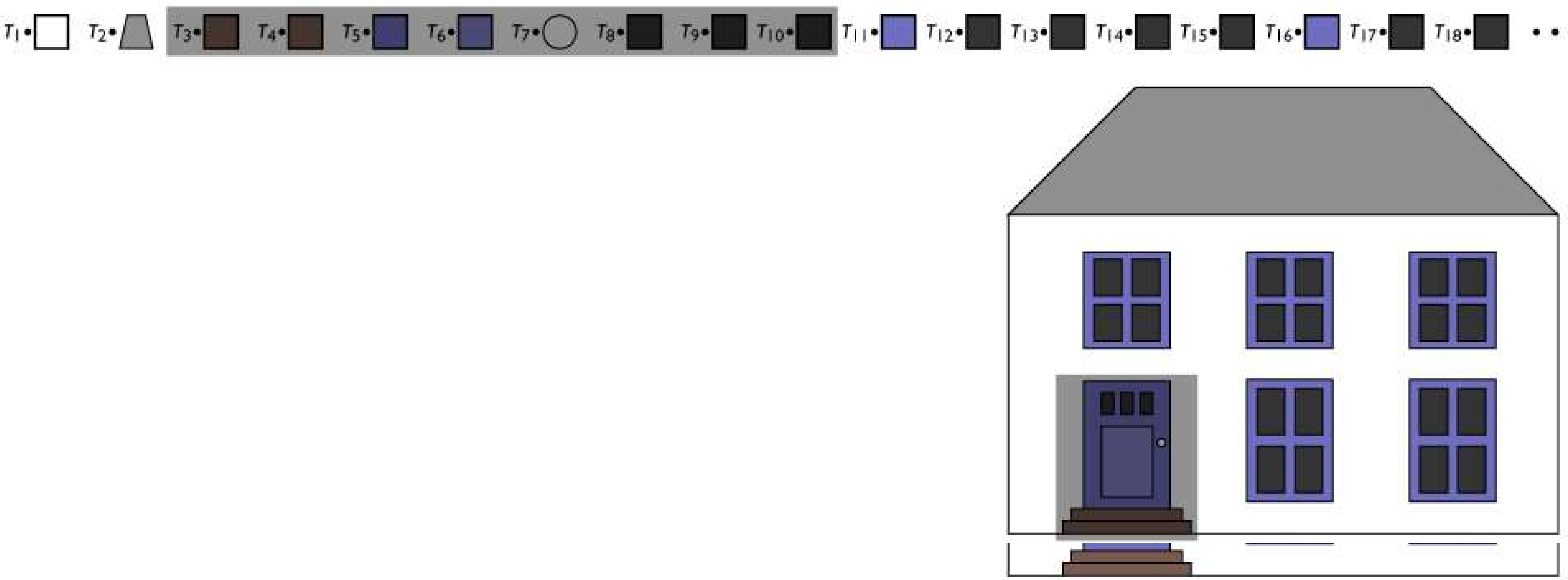
Data structures with transforms

- 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

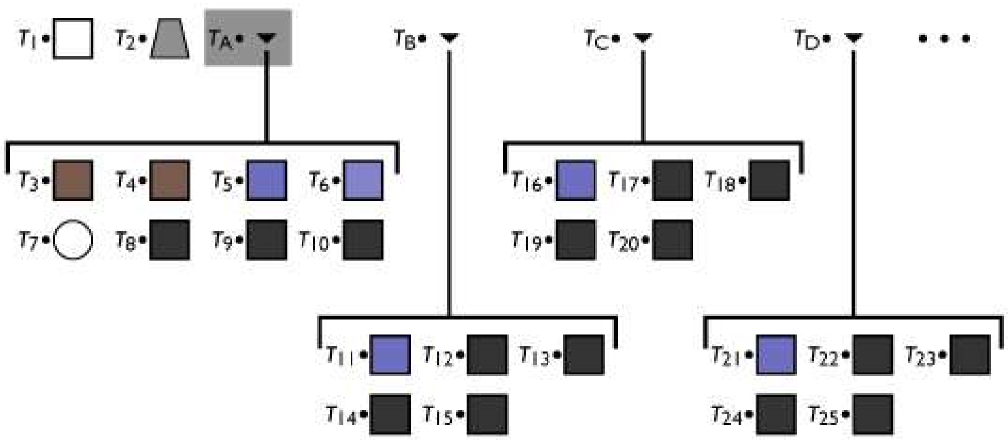


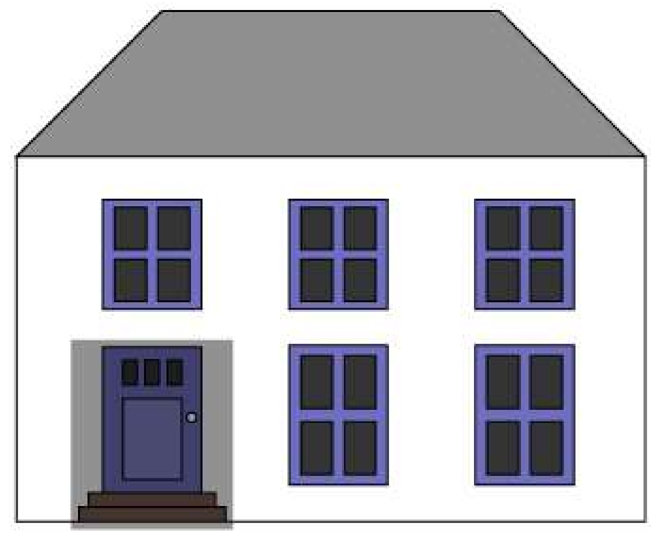
Groups of objects

- 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

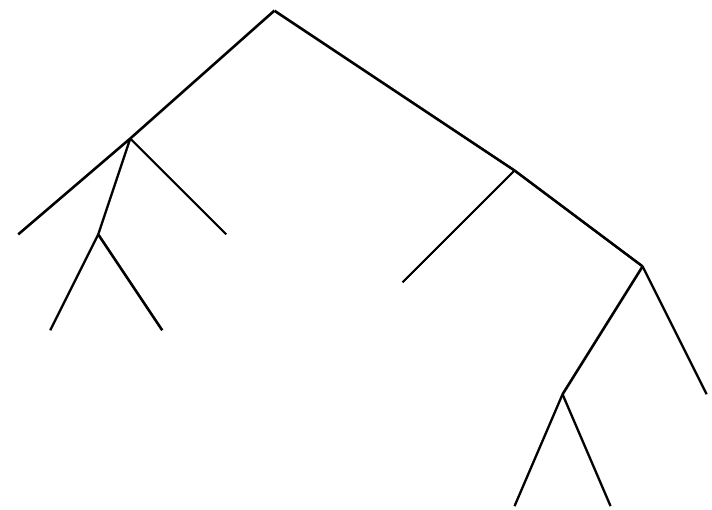
- Add group as a new object type
  - lets the data structure reflect the drawing structure
  - enables high-level editing by changing just one node





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

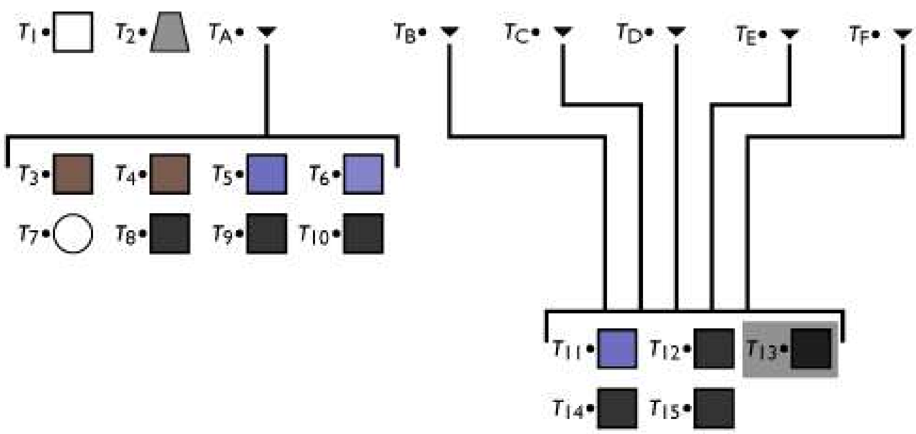
- Transforms associated with nodes or edges
- Each transform applies to all geometry below it
  - want group transform to transform each member
  - members already transformed—concatenate
- Frame transform for object is product of all matrices along path from root
  - each object's transform describes 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

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

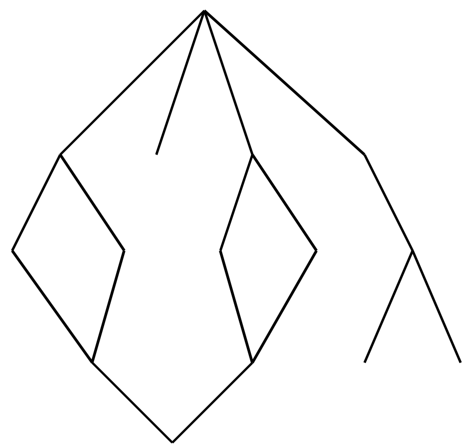
Example

- 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
  - **d**irected **a**cyclic **g**raph
  - 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

```
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

```
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

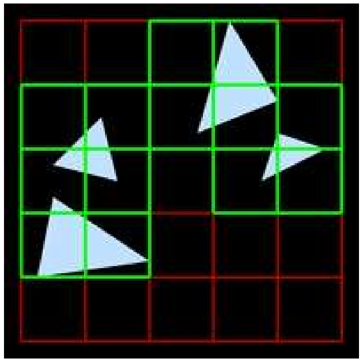
- Where transforms go
  - in every node
  - on edges
  - in group nodes only
  - in special Transform nodes
- Tree vs. DAG
- Nodes for cameras and lights?

Spatial Hierarchies

- Broad classification:
  - Spatial hierarchies
    - Grids
    - Octrees
    - Kd-trees, BSP trees
  - Object hierarchies
    - Bounding volume hierarchies
    - Spatial kd-trees

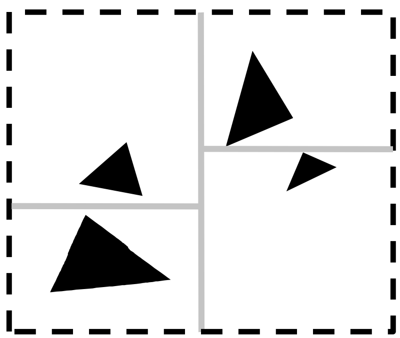
Spatial hierarchies: grids

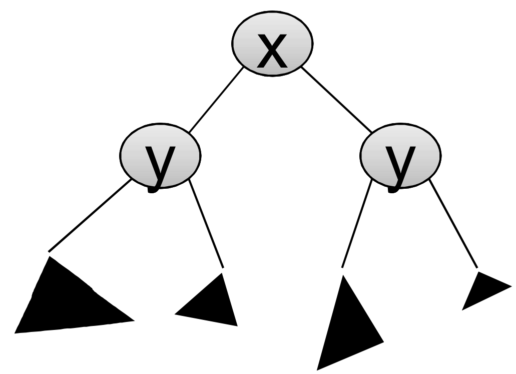
- Regular subdivision of space into cells
  - Cells almost always cubes
  - Each object is referenced in each cell it overlaps
  - Nested grids also possible



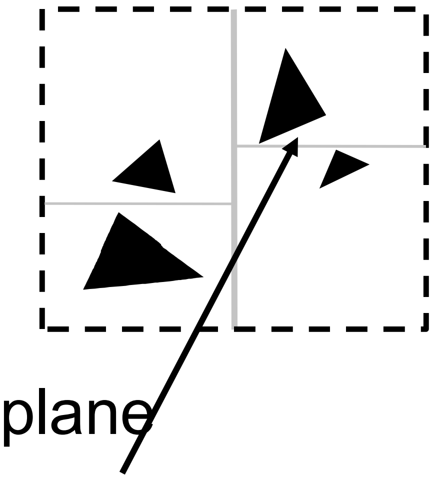
Spatial hierarchies: kd-trees

- Binary tree of space subdivisions
  - Each is axis-aligned plane





Spatial hierarchies: kd-trees



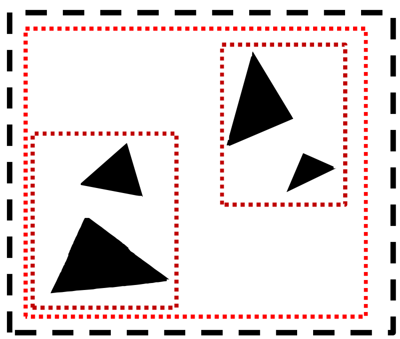
- Traversing a kd-tree: recursive
  - Start at root node
  - For current node:
    - If inner node (for ray tracing):
      - Find intersection of ray with plane
      - If ray intersects both children, recurse on near side, then far side
      - Otherwise, recurse on side it intersects
    - If leaf node:
      - Intersect with all object. If hit, terminate.

Kd-tree traversal

- Simple and fast implementation
  - In practice: using stack, not recursion
  - Very quick intersection test (couple FLOPS + tests)
- Overall: logarithmic complexity for each ray or intersection test

Object hierarchies: BVHs

- Different approach:
  subdivide objects, not space
  - Hierarchical clustering of objects
  - Each cluster represented by bounding volume



  - Binary tree
    - Each parent node fully contains children

Bounding volumes

- Practically anything can be bounding volume
  - Just need ray intersection method
- Typical choices:
  - Spheres
  - Axis-aligned bounding boxes (AABBs)
  - Oriented bounding boxes (OBBs)
  - k-DOPs
- Trade-off between intersection speed and how closely the BV encloses the geometry

BVH traversal

- Recursive algorithm:
  - Start with root node
  - For current node (ray tracing):
    - Does ray intersect node's BV? If no, return
    - Is inner node?
      - Yes, recurse on children
    - Is leaf node?
      - Intersect with object(s) in node, store intersection results
- Widely used for view frustum culling or collision checking

Choosing a structure

- There is no ‘best’ acceleration structure
  - All have pros and cons
- Grid:
  + fast construction
  - bad for high local detail (teapot/stadium)

Choosing a structure

- There is no ‘best’ acceleration structure
  - All have pros and cons
- kd-tree:
  + fast traversal
  - expensive build, only static scenes

Choosing a structure

- There is no ‘best’ acceleration structure
  – All have pros and cons
- BVH:
  + can be updated for dynamic scenes
  - traversal more expensive than kd-tree