Introduction to Computer Graphics with WebGL

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Graphical Objects and Scene Graphs 1

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Objectives

- Introduce graphical objects
- Generalize the notion of objects to include lights, cameras, attributes
- Introduce scene graphs

Limitations of Immediate Mode Graphics

- When we define a geometric object in an application, upon execution of the code the object is passed through the pipeline
- It then disappeared from the graphical system
- To redraw the object, either changed or the same, we had to reexecute the code
- Display lists provided only a partial solution to this problem

Retained Mode Graphics

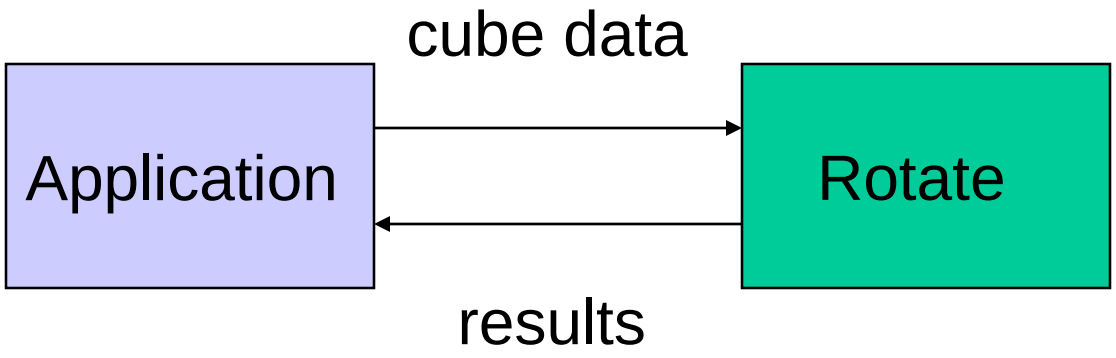
- Display lists were server side
- GPUs allowed data to be stored on GPU
- Essentially all immediate mode functions have been deprecated
- Nevertheless, OpenGL is a low level API

OpenGL and Objects

- OpenGL lacks an object orientation
- Consider, for example, a green sphere
  - We can model the sphere with polygons
  - Its color is determined by the OpenGL state and is not a property of the object
  - Loose linkage with vertex attributes
- Defies our notion of a physical object
- We can try to build better objects in code using object-oriented languages/techniques

Imperative Programming Model

- Example: rotate a cube



- The rotation function must know how the cube is represented
  - Vertex list
  - Edge list

Object-Oriented Programming Model

- In this model, the representation is stored with the object

- The application sends a *message* to the object
- The object contains functions (*methods*) which allow it to transform itself

C/C++/Java/JS

- Can try to use C structs to build objects
- C++/Java/JS provide better support
  - Use class construct
  - With C++ we can hide implementation using public, private, and protected members i
  - JS provides multiple methods for object

Cube Object

- Suppose that we want to create a simple cube object that we can scale, orient, position and set its color directly through code such as

```
var mycube = new Cube();
mycube.color[0]=1.0;
mycube.color[1]= mycube.color[2]=0.0;
mycube.matrix[0][0]=.....
```

Cube Object Functions

- We would also like to have functions that act on the cube such as
  - `mycube.translate(1.0, 0.0,0.0);`
  - `mycube.rotate(theta, 1.0, 0.0, 0.0);`
  - `setcolor(mycube, 1.0, 0.0, 0.0);`
- We also need a way of displaying the cube
  - `mycube.render();`

Building the Cube Object

```
var cube {
      var color[3];
      var matrix[4][4];

}
```

The Implementation

- Can use any implementation in the private part such as a vertex list
- The private part has access to public members and the implementation of class methods can use any implementation without making it visible
- Render method is tricky but it will invoke the standard OpenGL drawing functions

Other Objects

- Other objects have geometric aspects
  - Cameras
  - Light sources
- But we should be able to have nongeometric objects too
  - Materials
  - Colors
  - Transformations (matrices)

JS Objects

```
cube mycube;

material plastic;
mycube.setMaterial(plastic);

camera frontView;
frontView.position(x ,y, z);
```

JS Objects

- Can create much like Java or C++ objects
  - constructors
  - prototypes
  - methods
  - private methods and variables

```
var myCube = new Cube();
myCube.color = [1.0, 0.0, 0.0]’
myCube.instance = …….
```

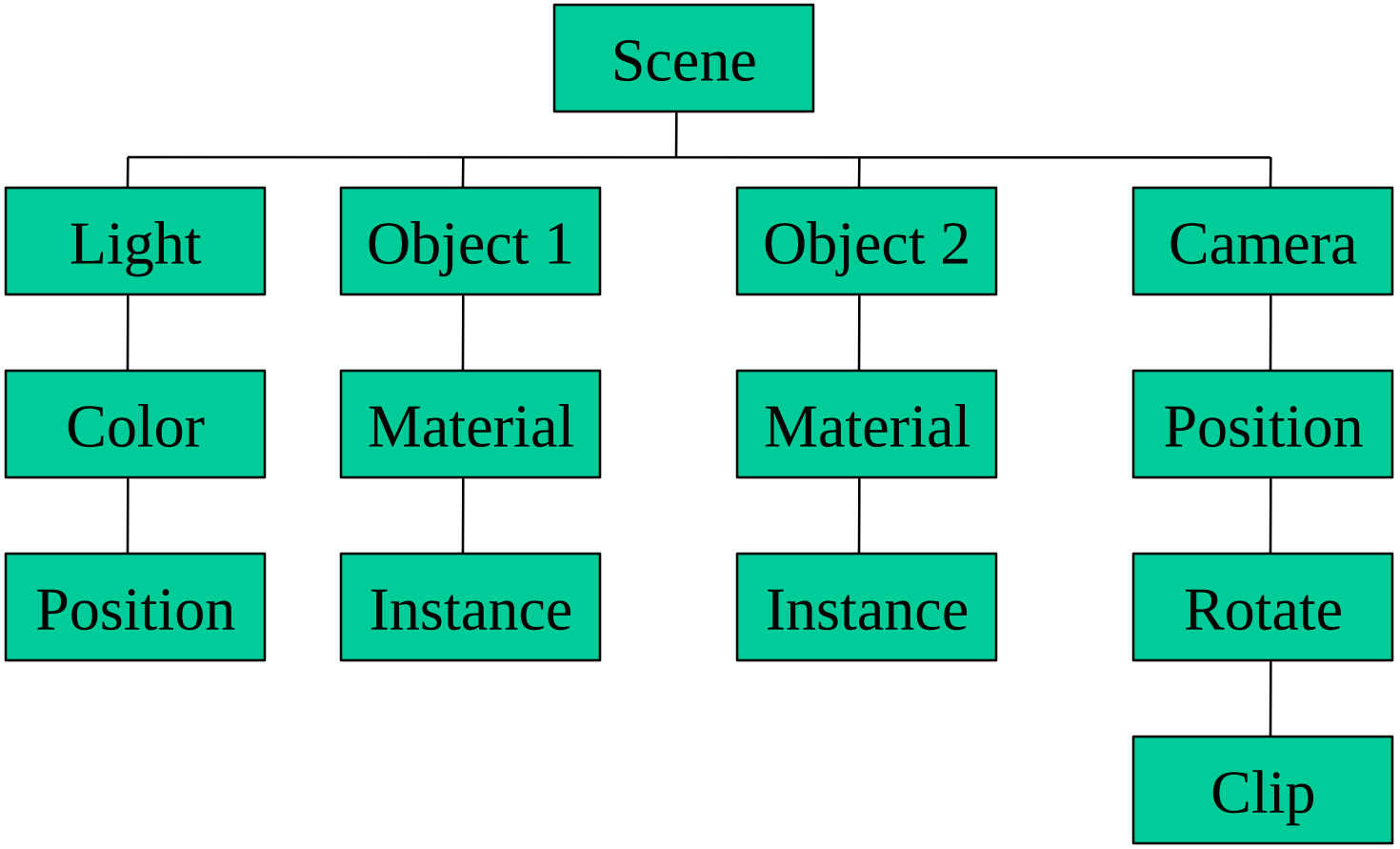
Light Object

```
var myLight = new Light();

// match Phong model

    myLight.type = 0; //directional
    myLight.position = ……;
    myLight.orientation = ……;
    myLight.specular = ……;
    myLight.diffuse = ……;
    myLight.ambient = ……;
}
```

Scene Descriptions

- If we recall figure model, we saw that
  - We could describe model either by tree or by equivalent code
  - We could write a generic traversal to display
- If we can represent all the elements of a scene (cameras, lights,materials, geometry) as JS objects, we should be able to show them in a tree
  - Render scene by traversing this tree

Scene Graph


Scene
Light
Object 1
Object 2
Camera
Color
Material
Material
Position
Position
Instance
Instance
Rotate
Clip

Traversal

```
myScene = new Scene();
myLight = new Light();
myLight.Color = ……;
…
myscene.Add(myLight);
object1 = new Object();
object1.color = …
myscene.add(object1);
…
…
myscene.render();
```

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Graphical Objects and Scene Graphs 2

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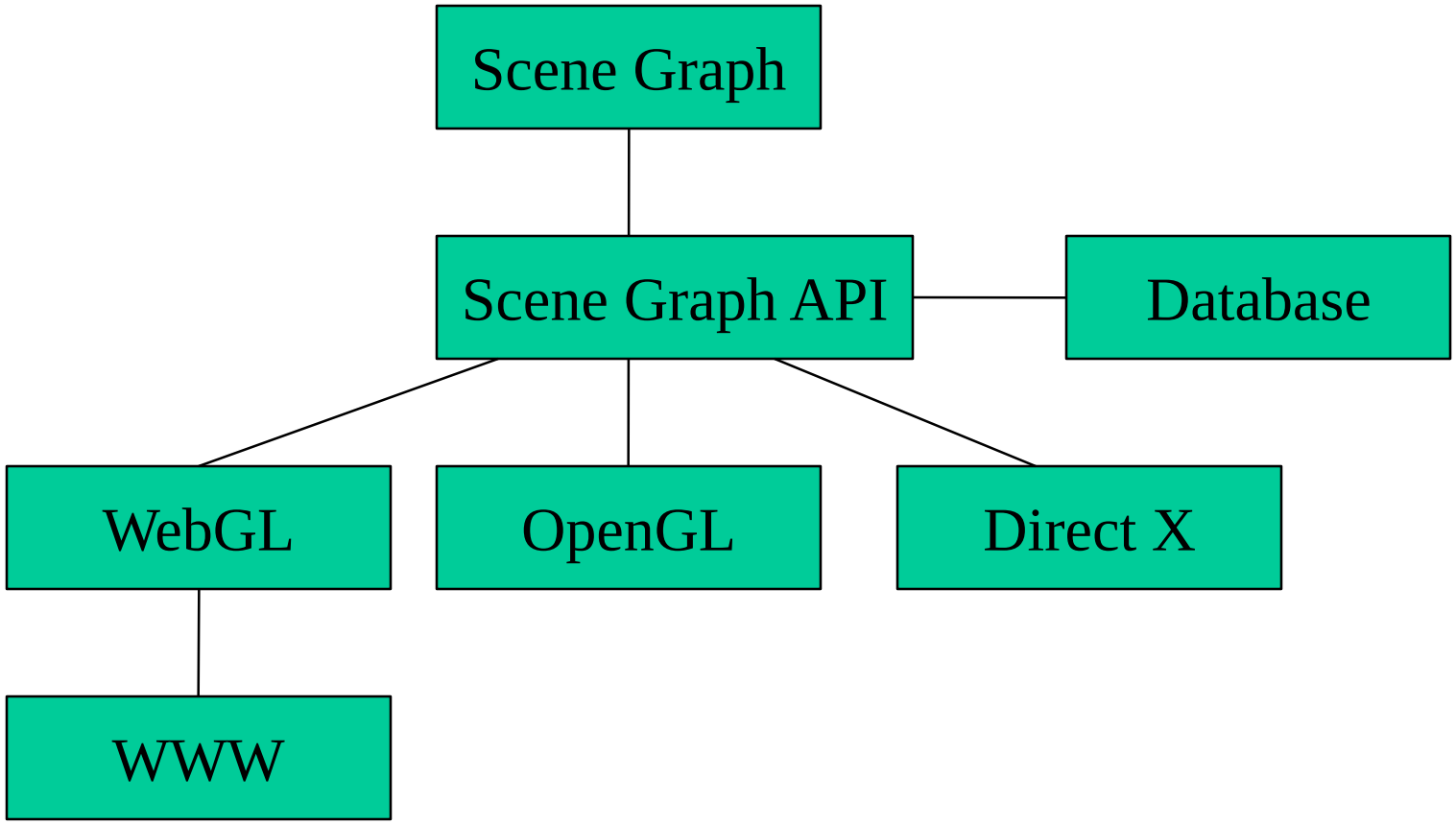
Objectives

- Look at some real scene graphs
- three.js (threejs.org)
- Scene graph rendering

Scene Graph History

- OpenGL development based largely on people who wanted to exploit hardware
  - real time graphics
  - animation and simulation
  - stand-alone applications
- CAD community needed to be able to share databases
  - real time not and photorealism not issues
  - need cross-platform capability
  - first attempt: PHIGS

Scene Graph Organization



Inventor and Java3D

- Inventor and Java3D provide a scene graph API
- Scene graphs can also be described by a file (text or binary)
  - Implementation independent way of transporting scenes
  - Supported by scene graph APIs
- However, primitives supported should match capabilities of graphics systems
  - Hence most scene graph APIs are built on top of OpenGL, WebGL or DirectX (for PCs)

VRML

- Want to have a scene graph that can be used over the World Wide Web
- Need links to other sites to support distributed data bases
- Virtual Reality Markup Language
  - Based on Inventor data base
  - Implemented with OpenGL

Open Scene Graph

- Supports very complex geometries by adding occulusion culling in first pass
- Supports translucently through a second pass that sorts the geometry
- First two passes yield a geometry list that is rendered by the pipeline in a third pass

three.js

- Popular scene graph built on top of WebGL
  - also supports other renderers
- See threejs.org
  - easy to download
  - many examples
- Also Eric Haines' Udacity course
- Major differences in approaches to computer graphics

three.js scene

```
var scene = new THREE.Scene();
var camera = new THREE.PerspectiveCamera(75,
window.innerWidth/          window.innerHeight, 0.1, 1000);

 var renderer = new THREE.WebGLRenderer();
 renderer.setSize(window.innerWidth, window.innerHeight);
 document.body.appendChild(renderer.domElement);

 var geometry = new THREE.CubeGeometry(1,1,1);
 var material = new THREE.MeshBasicMaterial({color: 0x00ff00});
 var cube = new THREE.Mesh(geometry, material);
 scene.add(cube);
 camera.position.z = 5;
```

three.js render loop

```
var render = function () {
 requestAnimationFrame(render);
 cube.rotation.x += 0.1;
 cube.rotation.y += 0.1;
 renderer.render(scene, camera);
 };
 render();
```

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Rendering Overview

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Objectives

- Examine what happens between the vertex shader and the fragment shader
- Introduce basic implementation strategies
- Clipping
- Rendering
  - lines
  - polygons
- Give a sample algorithm for each

Overview

- At end of the geometric pipeline, vertices have been assembled into primitives
- Must clip out primitives that are outside the view frustum
  - Algorithms based on representing primitives by lists of vertices
- Must find which pixels can be affected by each primitive
  - Fragment generation
  - Rasterization or scan conversion

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Required Tasks

- Clipping
- Rasterization or scan conversion
- Transformations
- Some tasks deferred until fragment processing
  - Hidden surface removal
  - Antialiasing

Rasterization Meta Algorithms

- Any rendering method process every object and must assign a color to every pixel
- Think of rendering algorithms as two loops
  - over objects
  - over pixels
- The order of these loops defines two strategies
  - image oriented
  - object oriented

Object Space Approach

- **For every object**, determine which pixels it covers and shade these pixels
  - Pipeline approach
  - Must keep track of depths for HSR
  - Cannot handle most global lighting calculations
  - Need entire framebuffer available at all times

Image Space Approach

- **For every pixel**, determine which object that projects on the pixel is closest to the viewer and compute the shade of this pixel
  - Ray tracing paradigm
  - Need all objects available
- Patch Renderers
  - Divide framebuffer into small patches
  - Determine which objects affect each patch
  - Used in limited power devices such as cell phones

Algorithm Experimentation

- Create a framebuffer object and use render-to-texture to create a virtual framebuffer into which you can write individual pixels