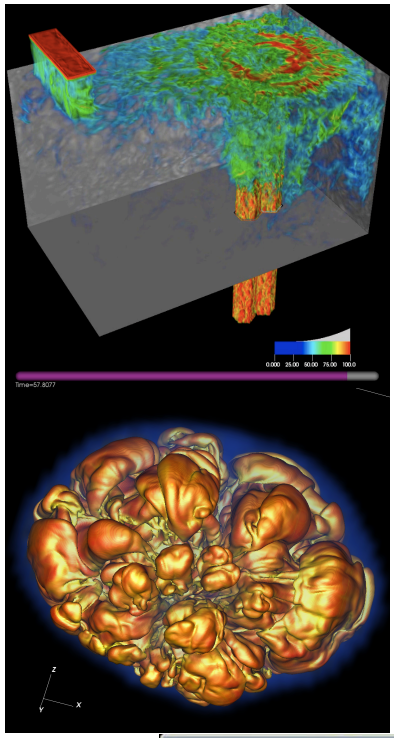
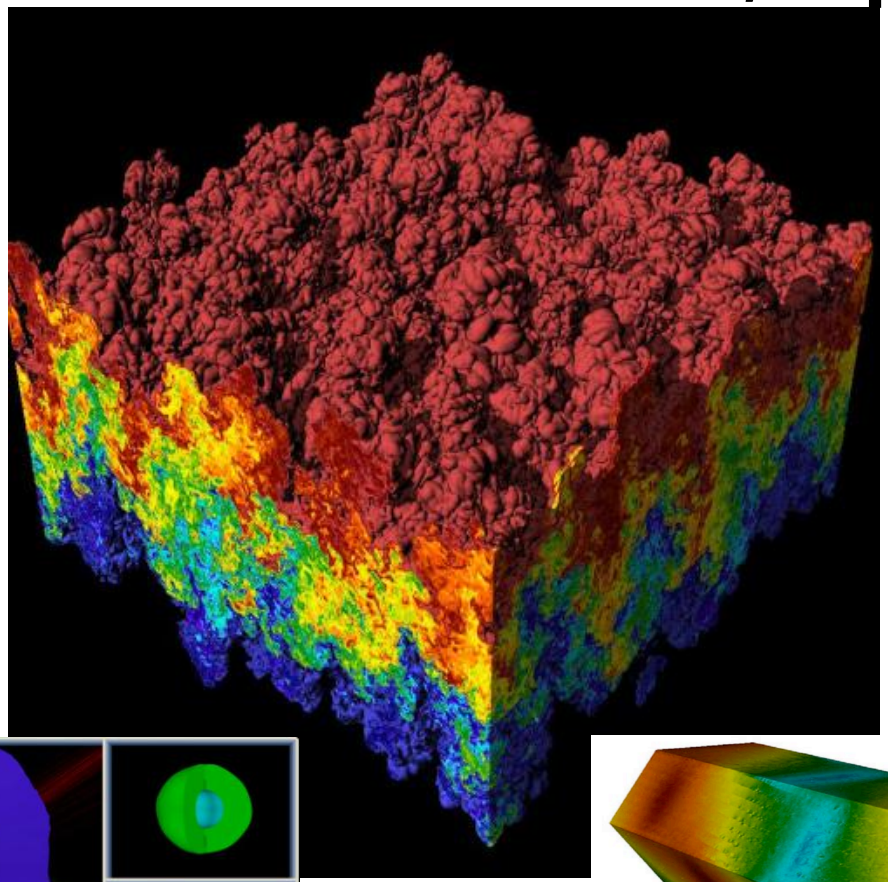
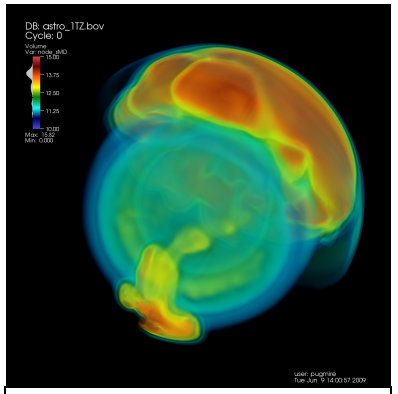
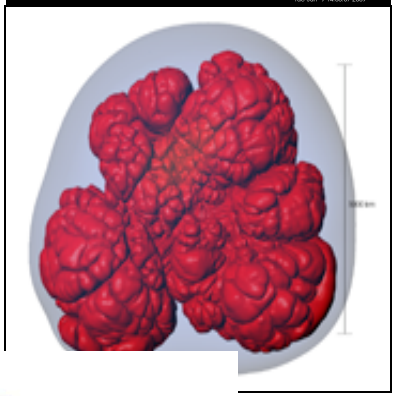
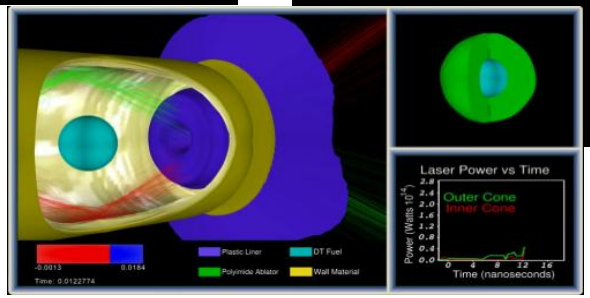
CIS 441/541: Intro to Computer Graphics
Lecture 8: 1F overview, OpenGL

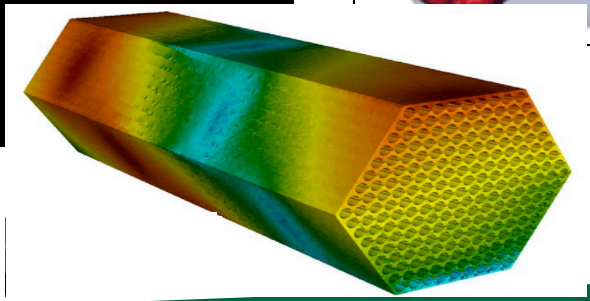












February 5, 2019

Hank Childs, University of Oregon

Office Hours: Week 5

- Monday: 1-2 (Roscoe)
- Tuesday: 1-2 (Roscoe)
- Wednesday: 1-3 (Roscoe)
- Thursday: 1130-1230 (Hank)
- Friday: 1130-1230 (Roscoe)

Timeline (1/2)

- 1E: assigned Thurs Jan 31st, due Weds Feb 6th
  - → will be extra support with this. Tough project.
- 1F: assigned Feb 7th (Feb 1), due Feb 19th
  - → shading is easier than camera, but: movie
- 2A: posted now, due Feb 21st
- → you need to work on both 1F and 2A during Week 6 (Feb 11-15)
- 2B: posted now, due Feb 27th
- YouTube lectures for Feb 12th and 14th

Timeline (2/2)

Sun	Mon	Tues	Weds	Thurs	Fri	Sat
LIII SUPER BOWL	Feb 4	Feb 5 Lec 8	Feb 6 1E due	Feb 7 Begin 1F, begin 2A	Feb 8	Feb 9
Feb 10	Feb 11	YouTube	Feb 13	YouTube??	Feb 15	Feb 16
Feb 17	Feb 18	Feb 19 1F due	Feb 20	Feb 21 2A due, begin 2B	Feb 22	Feb 23

Comparing to previous terms (1/3)

- Way ahead on lecture
  - If I complete today's lecture, we will be 1.5 lectures ahead of the pace from previous term
  - Why?:
    - YouTube videos saving on material repeat
    - Bad materials in previous terms, and then have to waste class time fixing things
  - May only need 1 YouTube lecture from Japan

Comparing to previous terms (2/3)

- A little behind on project pace

Project	Due date (F16)	Due date (W19)
1E	Monday of Week 5	Weds of Week 5
1F	Monday of Week 6	Tuesday of Week 7
2A	Monday of Week 7	Thursday of Week 7
2B	Monday of Week 8	Wednesday of Week 8

- *The W19 plan only works if you pursue *both* 1F and 2A during Week 6!*

Comparing to previous terms (3/3)

- Grading way ahead of previous terms
  - Solved a lot of issues & happy about this
- 1E,1F,2A,2B: not quite as prompt

Midterm

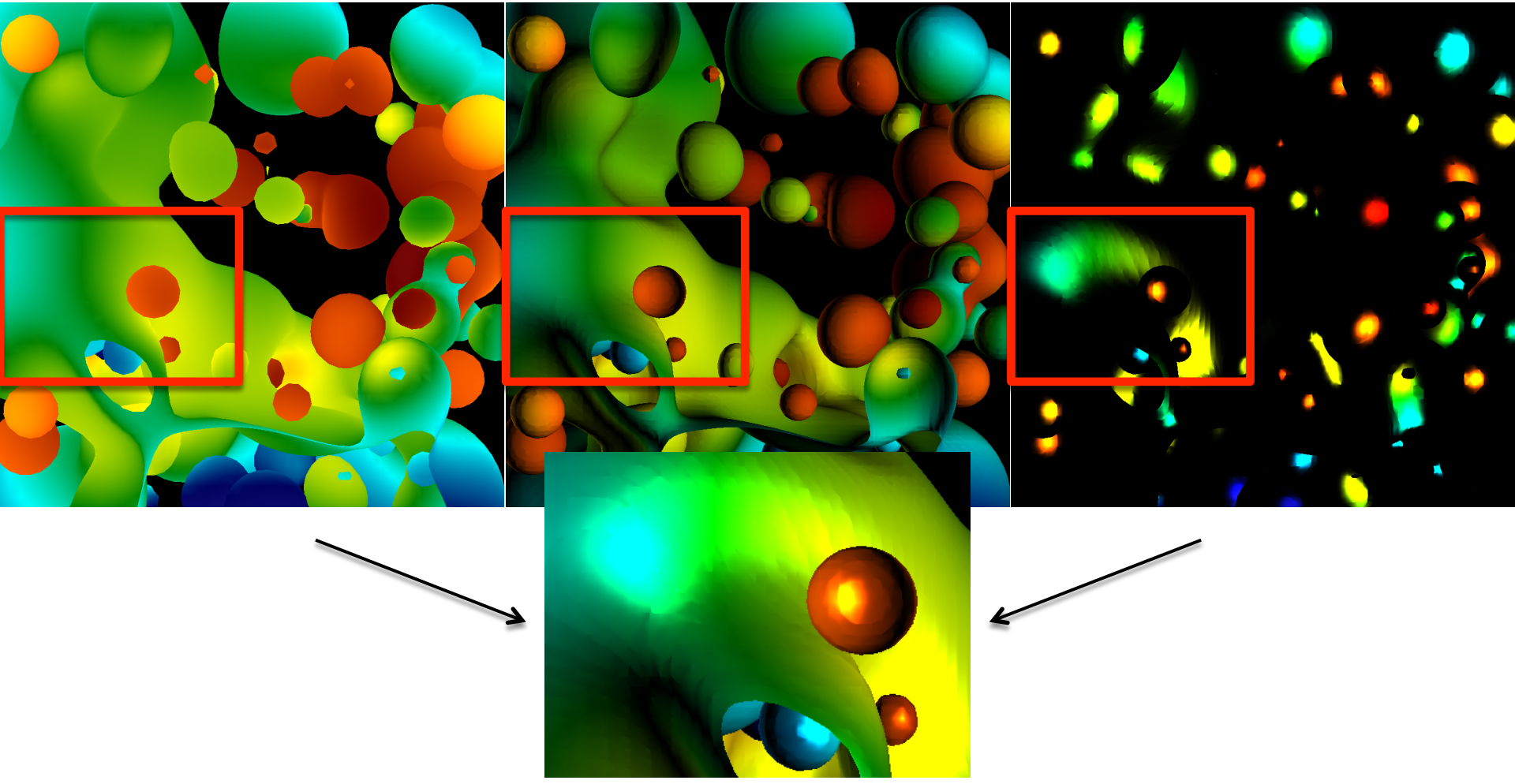
- Date still not set
- Considering different plan: 25 & 5

Asking good questions: my own experience

(start recording)

Phong Model

- Combine three lighting effects: ambient, diffuse, specular



Phong Model

- Simple version: 1 light, with "full intensity" (i.e., don't add an intensity term)
- Phong model
  - Shading_Amount = K_a + K_d*Diffuse + K_s*Specular
- Signature:
  - double CalculatePhongShading(LightingParameters &, double *viewDirection, double *normal)
  - Will have to calculate viewDirection for each pixel!

Specular Term of Phong Model

- Specular part of Phong: K_s*Specular
- and Specular is: (Shininess strength) * cos(α) ^ (shininess coefficient)
- Putting it all together would be:
  - K_s * (Shininess strength) * cos(α) ^ (shininess coefficient)
- But now we have two multipliers, K_s and (Shininess Strength). Not needed.
- So: just use one. Drop Shininess Strength and only use K_s
  - K_s * cos(α) ^ (shininess coefficient)

Lighting parameters

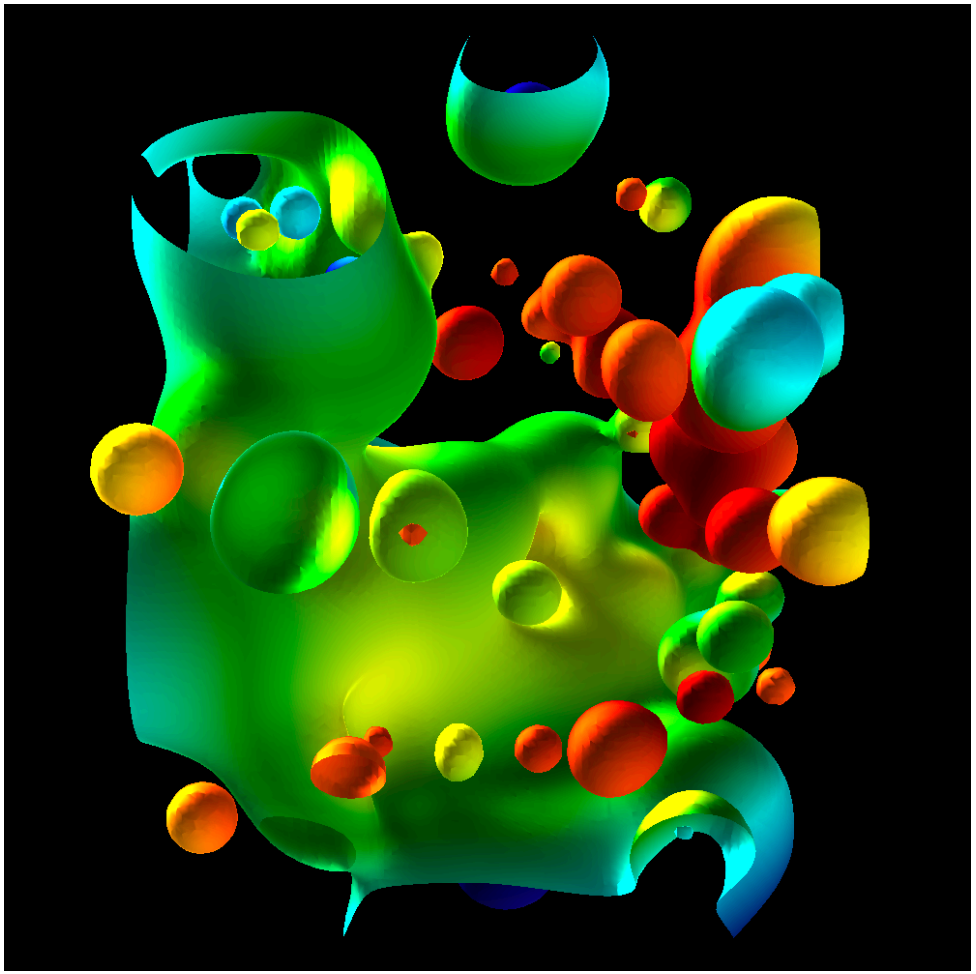
```
struct LightingParameters
{
    LightingParameters(void)
    {
        lightDir[0] = -0.6;
        lightDir[1] = 0;
        lightDir[2] = -0.8;
        Ka = 0.3;
        Kd = 0.7;
        Ks = 2.3;
        alpha = 2.5;
    };


    double lightDir[3]; // The direction of the light source
    double Ka;          // The coefficient for ambient lighting.
    double Kd;          // The coefficient for diffuse lighting.
    double Ks;          // The coefficient for specular lighting.
    double alpha;       // The exponent term for specular lighting.
};

LightingParameters lp;
```

Project #1F (8%), Due Feb 19th

- Goal: add shading, movie
- Extend your project1E code
- Important:
- add #define NORMALS



Changes to data structures

```
class Triangle
{
  public:
      double X[3], Y[3], Z[3];
      double colors[3][3];
      double normals[3][3];
};
```

→reader1e.cxx::GetTriangles() will not compile (with #define NORMALS) until you make these changes

→Now initializes normals at each vertex

More comments (1/3)

- This project in a nutshell:
  - Add method called “CalculateShading”.
    - My version of CalculateShading is about ten lines of code.
  - Call CalculateShading for each vertex
  - This is a new field, which you will LERP.
  - Modify RGB calculation to use shading.

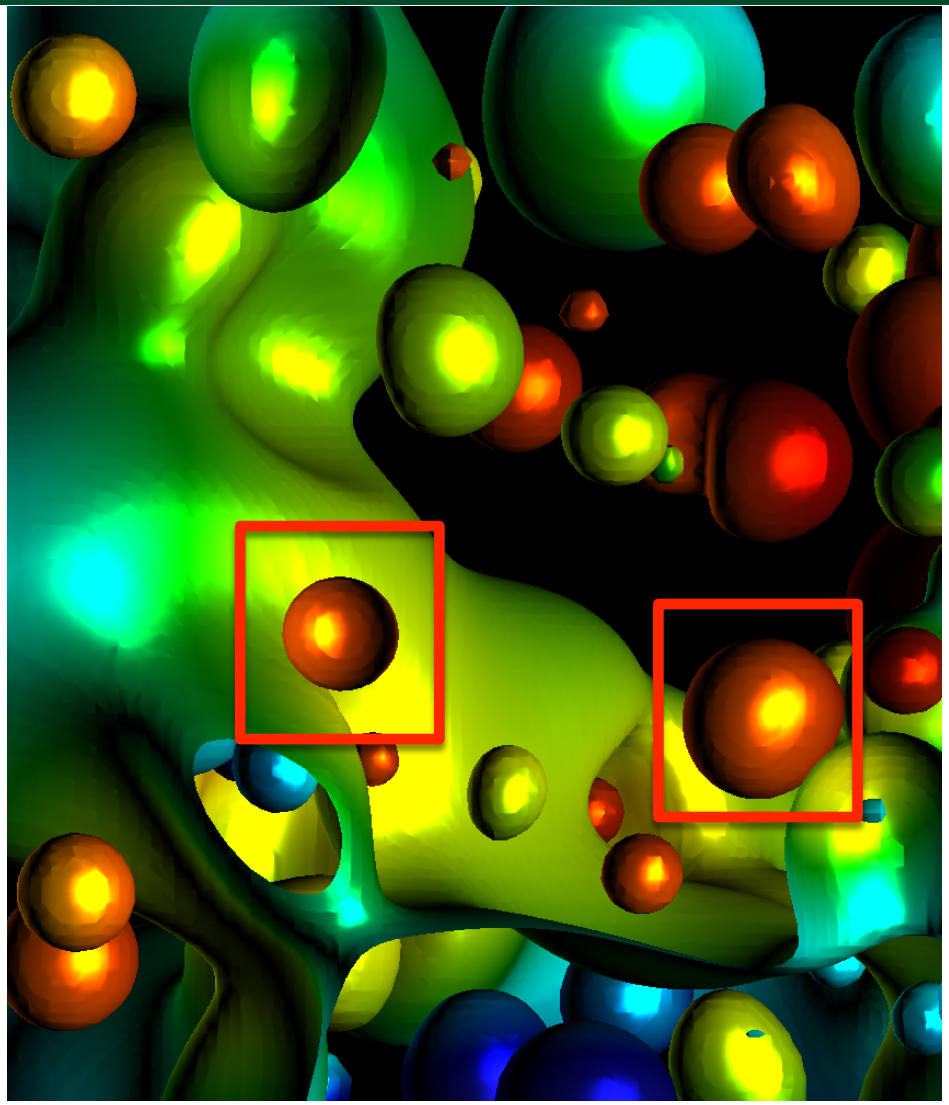
More comments (2/3)

- Data to help debug
  - I will make the shading value for each pixel available.
  - I will also make it available for ambient, diffuse, specular.
- Don't forget to do two-sided lighting for diffuse, one-sided lighting for specular

More comments (3/3)

- I haven't said anything about movie encoders
- ffmpeg

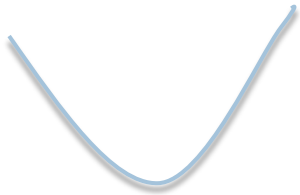
Where Hank spent his debugging time…



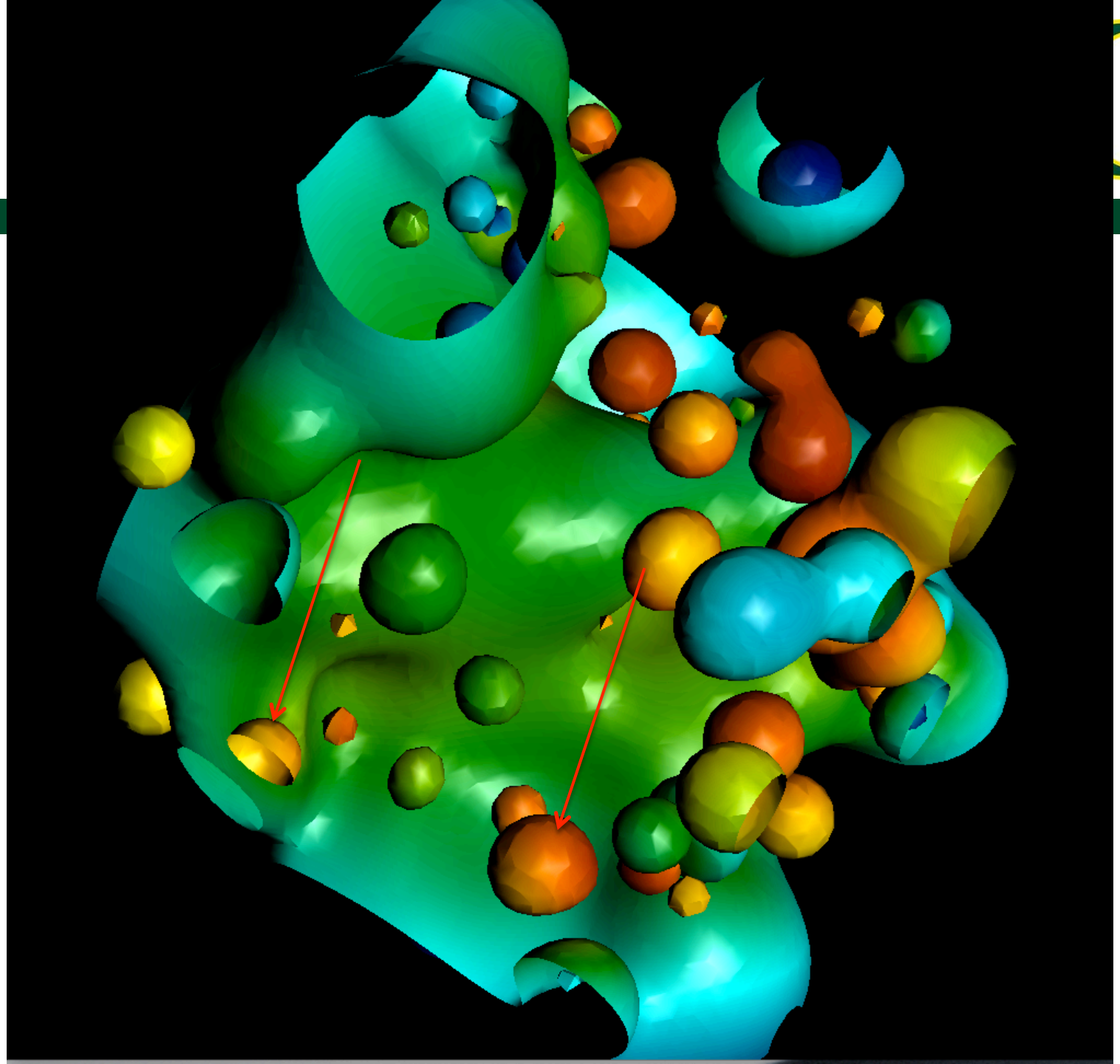
Concave surface

Lighting direction

Convex surface



Lighting direction



(end recording)

Some notes about OpenGL

- OpenGL has evolved a lot over 25+ years
- The slides that follow and the homeworks will detail an early version of OpenGL (OpenGL V1.0)
- This is the easiest version to understand and implement
  - It is also inefficient
- Since efficiency is important, newer versions are more complex and also faster
  - Optional final projects (developed by Roscoe) will let you play with this

OOPS

- Problem! (big one)
  - VTK8 does not work with OpenGL1
  - And learning OpenGL3 would require weeks of time
  - So we have to roll back to VTK6
  - I am very sorry for this

  - IMPORTANT: I installed VTK6 in Room 100. You can use that for 2A/2B if you don't want to install again.

Models and Architectures

Ed Angel

Professor of Computer Science, Electrical and Computer Engineering, and Media Arts

University of New Mexico

Objectives

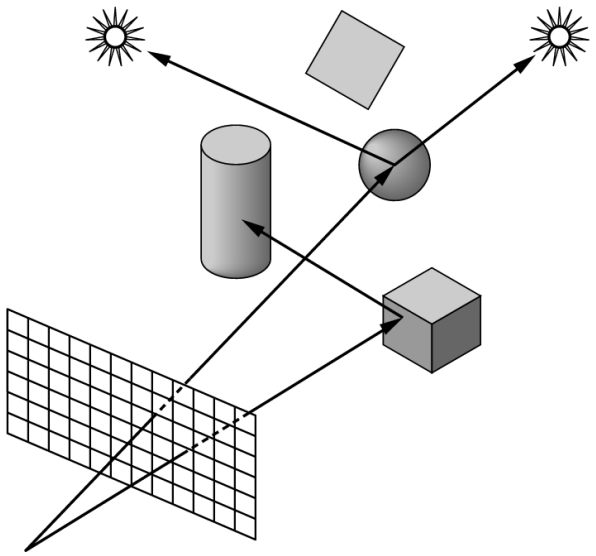
- Learn the basic design of a graphics system
- Introduce pipeline architecture
- Examine software components for an interactive graphics system

Image Formation Revisited

- Can we mimic the synthetic camera model to design graphics hardware software?
- Application Programmer Interface (API)
  - Need only specify
    - Objects
    - Materials
    - Viewer
    - Lights
- But how is the API implemented?

Physical Approaches

- **Ray tracing**: follow rays of light from center of projection until they either are absorbed by objects or go off to infinity
  - Can handle global effects
    - Multiple reflections
    - Translucent objects
  - Slow
  - Must have whole data base available at all times



- **Radiosity**: Energy based approach
  - Very slow

Practical Approach

- Process objects one at a time in the order they are generated by the application
  - Can consider only local lighting
- Pipeline architecture

application program

display

- All steps can be implemented in hardware on the graphics card

Vertex Processing

- Much of the work in the pipeline is in converting object representations from one coordinate system to another
  - Object coordinates
  - Camera (eye) coordinates
  - Screen coordinates
- Every change of coordinates is equivalent to a matrix transformation
- Vertex processor also computes vertex colors

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Projection

- *Projection* is the process that combines the 3D viewer with the 3D objects to produce the 2D image
  - Perspective projections: all projectors meet at the center of projection
  - Parallel projection: projectors are parallel, center of projection is replaced by a direction of projection

Primitive Assembly

Vertices must be collected into geometric objects before clipping and rasterization can take place

- Line segments
- Polygons
- Curves and surfaces

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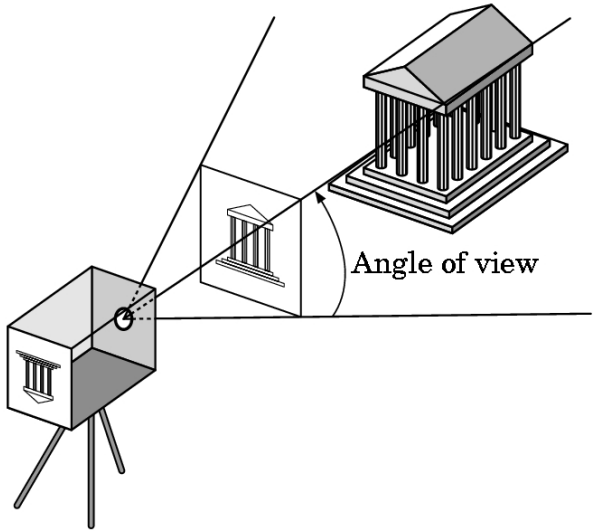
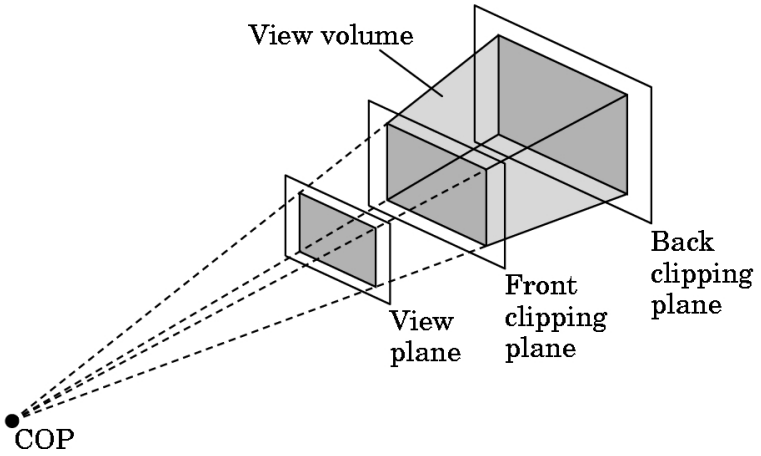
Clipping

Just as a real camera cannot "see" the whole world, the virtual camera can only see part of the world or object space

- Objects that are not within this volume are said to be *clipped* out of the scene





Rasterization

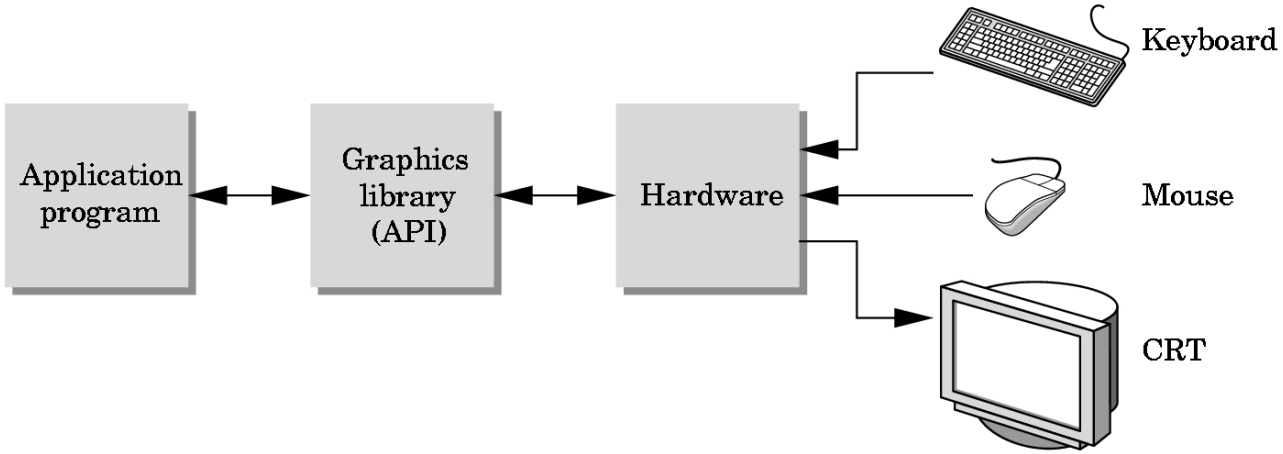
- If an object is not clipped out, the appropriate pixels in the frame buffer must be assigned colors
- Rasterizer produces a set of fragments for each object
- Fragments are “potential pixels”
  - Have a location in frame bufffer
  - Color and depth attributes
- Vertex attributes are interpolated over objects by the rasterizer

Fragment Processing

- Fragments are processed to determine the color of the corresponding pixel in the frame buffer
- Colors can be determined by *texture mapping* or interpolation of vertex colors
- Fragments may be blocked by other fragments closer to the camera
  - Hidden-surface removal

The Programmer's Interface

- Programmer sees the graphics system through a software interface: the Application Programmer Interface (API)



API Contents

- Functions that specify what we need to form an image
  - Objects
  - Viewer
  - Light Source(s)
  - Materials
- Other information
  - Input from devices such as mouse and keyboard
  - Capabilities of system

Object Specification

- Most APIs support a limited set of primitives including
  - Points (0D object)
  - Line segments (1D objects)
  - Polygons (2D objects)
  - Some curves and surfaces
    - Quadrics
    - Parametric polynomials
- All are defined through locations in space or *vertices*

Example

type of object

location of vertex

```
glBegin(GL_POLYGON);
 glVertex3f(0.0, 0.0, 0.0);
 glVertex3f(0.0, 1.0, 0.0);
 glVertex3f(0.0, 0.0, 1.0);
glEnd( );
```

end of object definition

Lights and Materials

- Types of lights
  - Point sources vs distributed sources
  - Spot lights
  - Near and far sources
  - Color properties
- Material properties
  - Absorption: color properties
  - Scattering
    - Diffuse
    - Specular

Programming with OpenGL Part 1: Background

Ed Angel

Professor of Computer Science, Electrical and Computer Engineering, and Media Arts

University of New Mexico

Objectives

- Development of the OpenGL API
- OpenGL Architecture
  - OpenGL as a state machine
- Functions
  - Types
  - Formats
- Simple program

Early Graphics APIs

- IFIPS
- FKS
- PHIGS

SGI and GL

- Silicon Graphics (SGI) revolutionized the graphics workstation by implementing the pipeline in hardware (1982)
- To access the system, application programmers used a library called GL
- With GL, it was relatively simple to program three dimensional interactive applications

OpenGL

The success of GL lead to OpenGL (1992), a platform-independent API that was

- Easy to use
- Close enough to the hardware to get excellent performance
- Focus on rendering
- Omitted windowing and input to avoid window system dependencies

OpenGL Evolution

- Originally controlled by an Architectural Review Board (ARB)
  - Members included SGI, Microsoft, Nvidia, HP, 3DLabs, IBM,…….
  - Relatively stable
    - Evolution reflects new hardware capabilities
      - 3D texture mapping and texture objects
      - Vertex programs
  - Allows for platform specific features through extensions
  - ARB replaced by Kronos

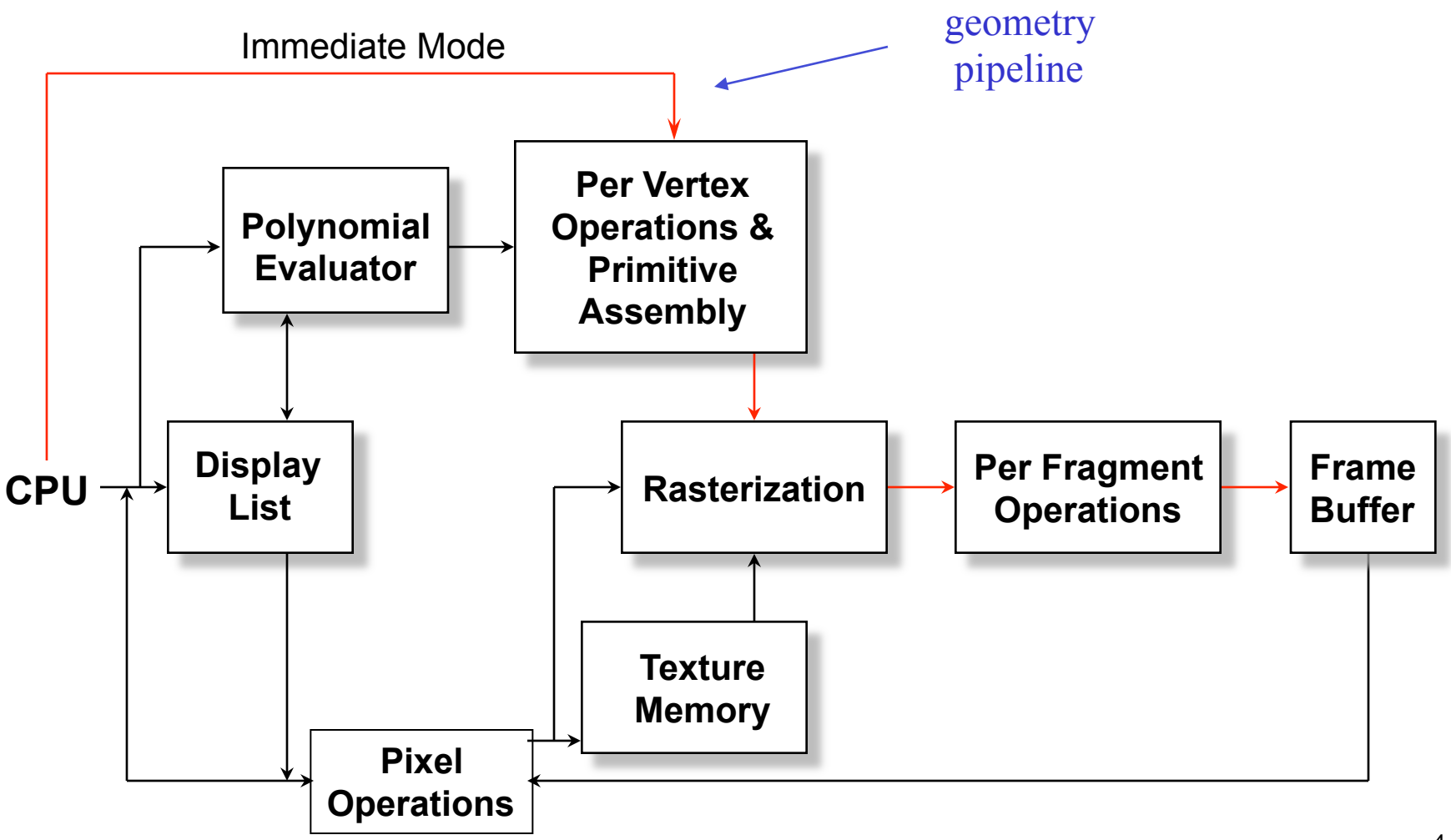
OpenGL Libraries

- OpenGL core library
  - OpenGL32 on Windows
  - GL on most unix/linux systems (libGL.a)
- OpenGL Utility Library (GLU)
  - Provides functionality in OpenGL core but avoids having to rewrite code
- Links with window system
  - GLX for X window systems
  - WGL for Windows
  - ~~AGL for Macintosh~~

GLUT

- OpenGL Utility Toolkit (GLUT)
  - Provides functionality common to all window systems
    - Open a window
    - Get input from mouse and keyboard
    - Menus
    - Event-driven
  - Code is portable but GLUT lacks the functionality of a good toolkit for a specific platform
    - No slide bars
- <GLUT no longer well maintained, we will use VTK>

OpenGL Architecture



OpenGL Functions

- Primitives
  - Points
  - Line Segments
  - Polygons
- Attributes
- Transformations
  - Viewing
  - Modeling
- Control (GLUT)
- Input (GLUT)
- Query

} VTK

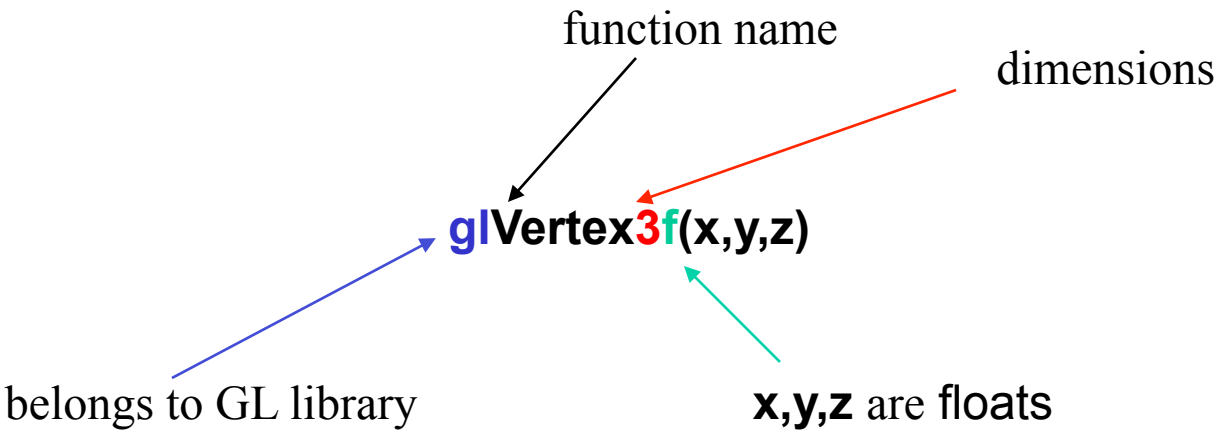
OpenGL State

- OpenGL is a state machine
- OpenGL functions are of two types
  - Primitive generating
    - Can cause output if primitive is visible
    - How vertices are processed and appearance of primitive are controlled by the state
  - State changing
    - Transformation functions
    - Attribute functions

Lack of Object Orientation

- OpenGL is not object oriented so that there are multiple functions for a given logical function
  - **`glVertex3f`**
  - **`glVertex2i`**
  - **`glVertex3dv`**
- Underlying storage mode is the same
- Easy to create overloaded functions in C++ but issue is efficiency

OpenGL function format



glVertex3fv(p)

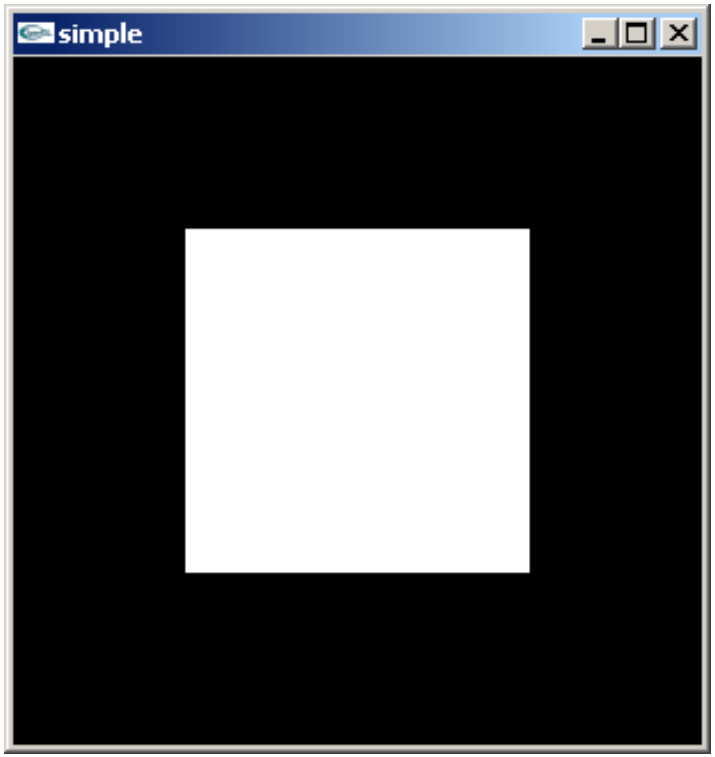
p is a pointer to an array

OpenGL #defines

- Most constants are defined in the include files **`gl.h`**, **`glu.h`** and ~~**`glut.h`**~~
  - ~~Note **`#include <GL/glut.h>`** should automatically include the others~~
  - Examples
  - **`glBegin(GL_POLYGON)`**
  - **`glClear(GL_COLOR_BUFFER_BIT)`**
- include files also define OpenGL data types: **`GLfloat`**, **`GLdouble`**,….

A Simple Program

Generate a square on a solid background



simple.c

```
#include <GL/glut.h>
void mydisplay(){
    glClear(GL_COLOR_BUFFER_BIT);
     glBegin(GL_POLYGON);
          glVertex2f(-0.5, -0.5);
          glVertex2f(-0.5, 0.5);
          glVertex2f(0.5, 0.5);
          glVertex2f(0.5, -0.5);
     glEnd();
     glFlush();
}
int main(int argc, char** argv){
     glutCreateWindow("simple");
     glutDisplayFunc(mydisplay);
     glutMainLoop();
}
```

Event Loop

- Note that the program defines a *display callback* function named **`mydisplay`**
  - Every glut program must have a display callback
  - The display callback is executed whenever OpenGL decides the display must be refreshed, for example when the window is opened
  - The **`main`** function ends with the program entering an event loop

```
VTK will be similar … callback
issued to render geometry
```

Defaults

- `simple.c` is too simple
- Makes heavy use of state variable default values for
  - Viewing
  - Colors
  - Window parameters
- Next version will make the defaults more explicit

How to make a graphics program?

- Need to create a window
  - This window contains a “context” for OpenGL to render in.
- Need to be able to deal with events/ interactions
- Need to render graphics primitives
  - OpenGL!

Windows and Events

- Creating windows and dealing with events varies from platform to platform.

- "Hello World" with X-Windows.

Compile with:

- gcc -L/usr/X11R6/lib -lX11 hello-x.c -o hello-x

```c
#include <X11/Xlib.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

int main(void) {
   Display *d;
   Window w;
   XEvent e;
   char *msg = "Hello, World!";
   int s;

   d = XOpenDisplay(NULL);
   if (d == NULL) {
      fprintf(stderr, "Cannot open display\n");
      exit(1);
   }

   s = DefaultScreen(d);
   w = XCreateSimpleWindow(d, RootWindow(d, s), 10, 10, 100, 100, 1,
                           BlackPixel(d, s), WhitePixel(d, s));
   XSelectInput(d, w, ExposureMask | KeyPressMask);
   XMapWindow(d, w);

   while (1) {
      XNextEvent(d, &e);
      if (e.type == Expose) {
         XFillRectangle(d, w, DefaultGC(d, s), 20, 20, 10, 10);
         XDrawString(d, w, DefaultGC(d, s), 10, 50, msg, strlen(msg));
      }
      if (e.type == KeyPress)
         break;
   }

   XCloseDisplay(d);
   return 0;
}
```

Windows and Events

- Creating windows and dealing with events varies from platform to platform.
- Some packages provide implementations for key platforms (Windows, Unix, Mac) and abstractions for dealing with windows and events.
- GLUT: library for cross-platform windowing & events.
  - My experiments: doesn't work as well as it used to.
- VTK: library for visualization
  - But also contains cross-platform windowing & events.

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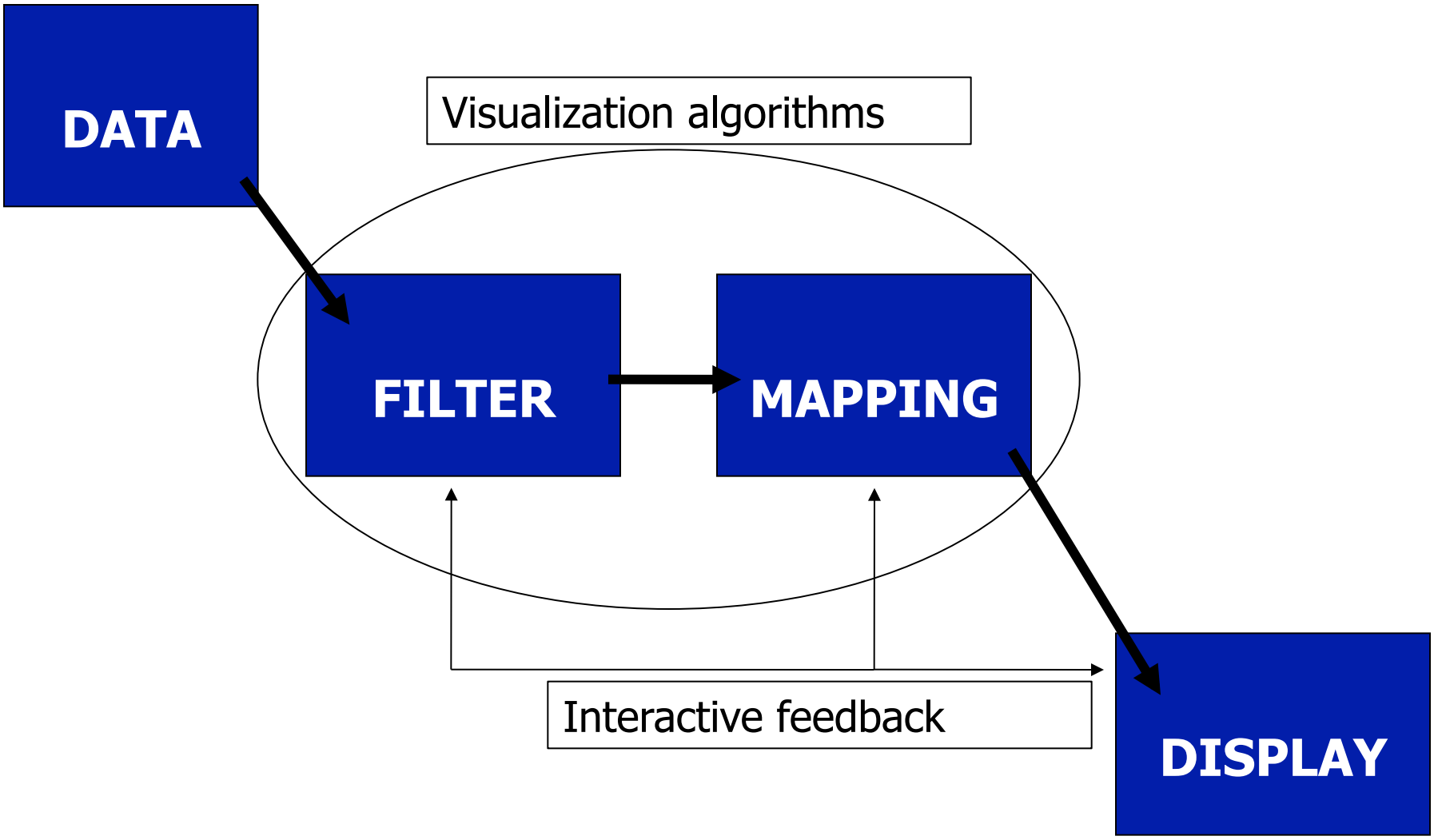
Visualization with VTK

Content from: Erik Vidholm, Univ of Uppsula, Sweden
David Gobbi, Robarts Research Institute, London, Ontario, Canada

VTK – The Visualization ToolKit

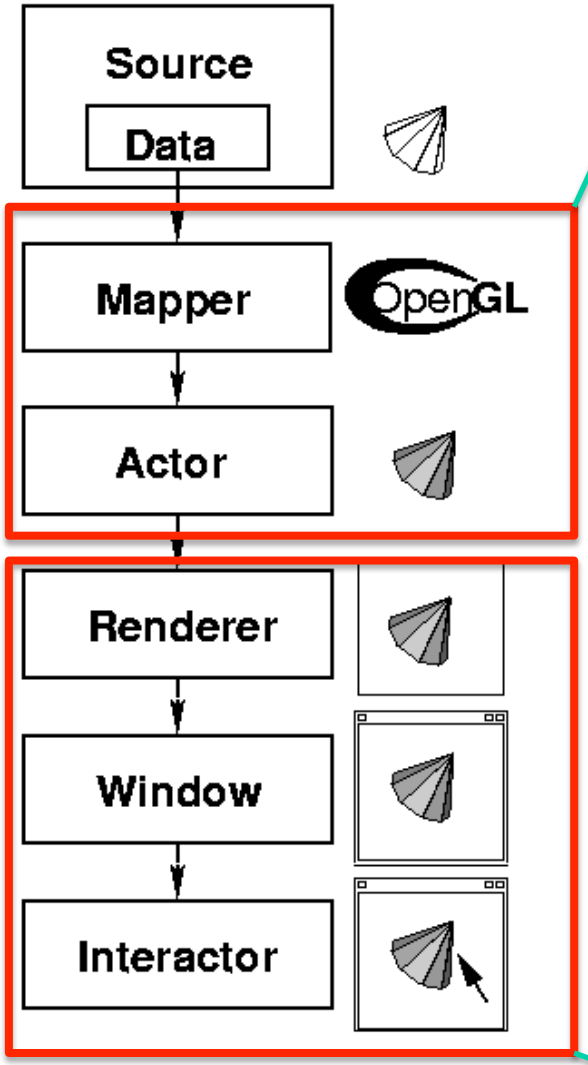
- Open source, freely available software for 3D computer graphics, image processing, and visualization
- Managed by Kitware Inc.
- Use C++, Tcl/Tk, Python, Java

The visualization pipeline



We will replace these and write our own GL calls.

Cone.py Pipeline Diagram (type "python Cone.py" to run)



Either reads the data from a file or creates the data from scratch.

```
from vtkpython import *

cone = vtkConeSource()
cone.SetResolution(10)
```

Moves the data from VTK into OpenGL.

```
coneMapper = vtkPolyDataMapper()
coneMapper.SetInput(cone.GetOutput())
```

For setting colors, surface properties, and the position of the object.

```
coneActor = vtkActor()
coneActor.SetMapper(coneMapper)
```

The rectangle of the computer screen that VTK draws into.

```
ren = vtkRenderer()
ren.AddActor(coneActor)
```

The window, including title bar and decorations.

```
renWin = vtkRenderWindow()
renWin.SetWindowName("Cone")
renWin.SetSize(300,300)
renWin.AddRenderer(ren)
```

Allows the mouse to be used to interact wth the data.

```
iren = vtkRenderWindowInteractor()
iren.SetRenderWindow(renWin)
iren.Initialize()
iren.Start()
```

We will re-use these.

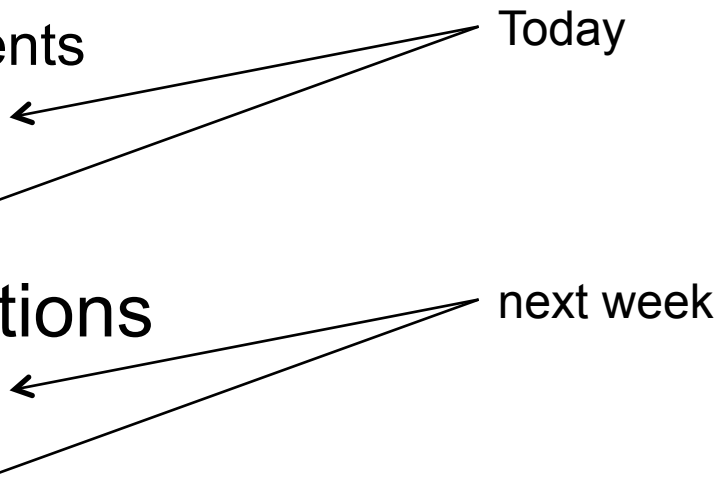
How to make a graphics program?

- Need to create a window
  - This window contains a “context” for OpenGL to render in.
- Need to be able to deal with events/ interactions
- Need to render graphics primitives
  - OpenGL!

Borrow Build

OpenGL Functions

- Primitives
  - Points
  - Line Segments
  - Polygons
- Attributes
- Transformations
  - Viewing
  - Modeling
- Control (VTK)
- Input (VTK)
- Query

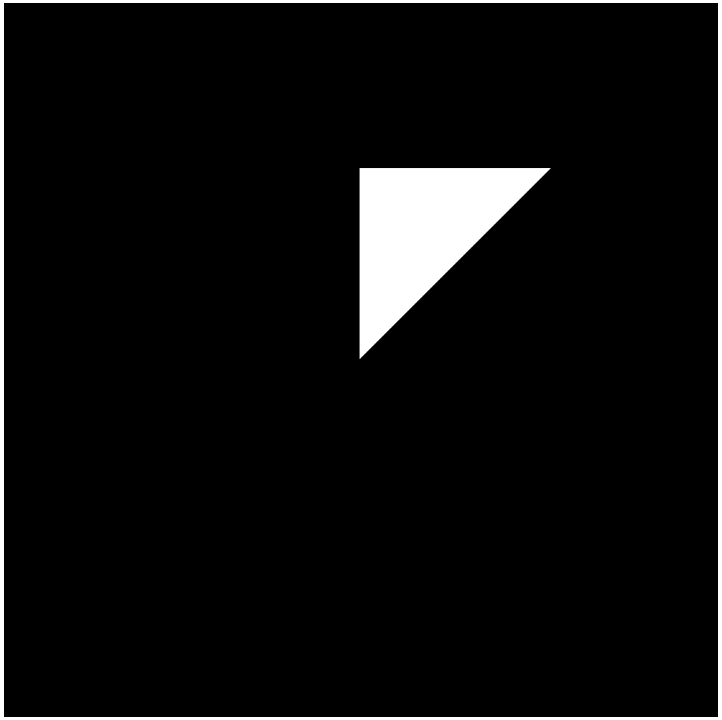


First OpenGL programs

- Remember: none of these programs have windowing or events
- They contain just the code to put primitives on the screen, with lighting and colors.

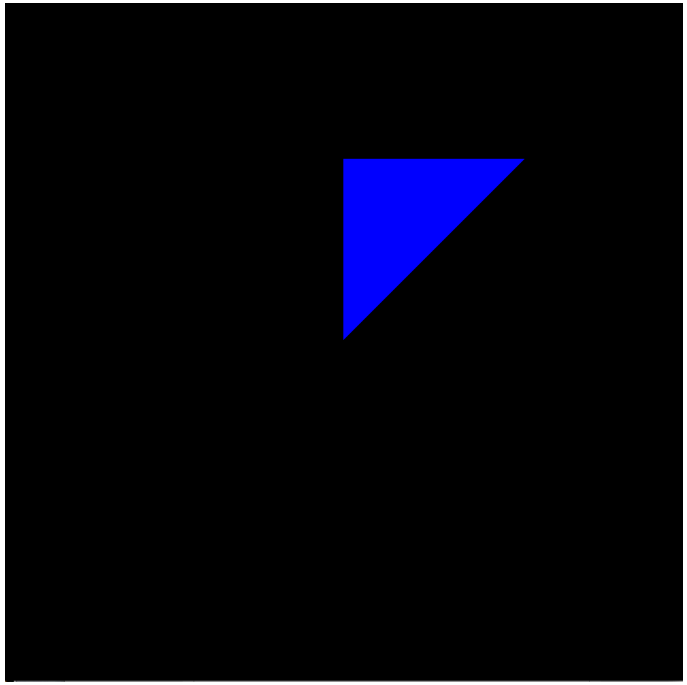
First OpenGL programs

```
class vtk441PolyDataMapper : public vtkOpenGLPolyDataMapper
{
 public:
   static vtk441PolyDataMapper *New();
   virtual void RenderPiece(vtkRenderer *ren, vtkActor *act)
   {
     float ambient[3] = { 1, 1, 1 };
     glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);
     glBegin(GL_TRIANGLES);
     glVertex3f(0,0,0);
     glVertex3f(0,1,0);
     glVertex3f(1,1,0);
     glEnd();
   }
};
```



First OpenGL programs

```
class vtk441PolyDataMapper : public vtkOpenGLPolyDataMapper
{
 public:
   static vtk441PolyDataMapper *New();
   virtual void RenderPiece(vtkRenderer *ren, vtkActor *act)
   {
     glEnable(GL_COLOR_MATERIAL);
     float ambient[3] = { 1, 1, 1 };
     glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);
     glBegin(GL_TRIANGLES);
     glColor3ub(0, 0, 255);
     glVertex3f(0,0,0);
     glVertex3f(0,1,0);
     glVertex3f(1,1,0);
     glEnd();
   }
};
```



glEnable/glDisable: important functions

www.opengl.org/sdk/docs/man/xhtml/glEnable.xml

Name

glEnable — enable or disable server-side GL capab

C Specification

```
void glEnable(GLenum cap);
```

Parameters

cap

Specifies a symbolic constant indicating a GL capability.

C Specification

```
void glDisable(GLenum cap);
```

Parameters

cap

Specifies a symbolic constant indicating a GL capability.

Both `glEnable` and glDisable take a single argument, *`cap`*, which can assume one of the following values:

`GL_BLEND`

If enabled, blend the computed fragment color values with the values in the color buffers. See glBlendFunc.

`GL_CULL_FACE`

If enabled, cull polygons based on their winding in window coordinates. See glCullFace.

`GL_DEPTH_TEST`

If enabled, do depth comparisons and update the depth buffer. Note that even if the depth buffer exists and the depth mask is non-zero, the depth buffer is not updated if the depth test is disabled. See glDepthFunc and glDepthRangef.

`GL_DITHER`

If enabled, dither color components or indices before they are written to the color buffer.

`GL_POLYGON_OFFSET_FILL`

If enabled, an offset is added to depth values of a polygon's fragments produced by rasterization. See glPolygonOffset.

`GL_SAMPLE_ALPHA_TO_COVERAGE`

If enabled, compute a temporary coverage value where each bit is determined by the alpha value at the corresponding sample location. The temporary coverage value is then ANDed with the fragment coverage value.

`GL_SAMPLE_COVERAGE`

If enabled, the fragment's coverage is ANDed with the temporary coverage value. If `GL_SAMPLE_COVERAGE_INVERT` is set to `GL_TRUE`, invert the coverage value. See glSampleCoverage.

`GL_SCISSOR_TEST`

If enabled, discard fragments that are outside the scissor rectangle. See glScissor.

`GL_STENCIL_TEST`

If enabled, do stencil testing and update the stencil buffer. See glStencilFunc and glStencilOp.

First OpenGL programs

```
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{
 public:
   static vtk441PolyDataMapper *New();
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   {
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     float ambient[3] = { 1, 1, 1 };
     glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);
     glBegin(GL_TRIANGLES);
     glColor3ub(0, 0, 255);
     glVertex3f(0,0,0);
     glColor3ub(0, 255, 0);
     glVertex3f(0,1,0);
     glColor3ub(255, 0, 0);
     glVertex3f(1,1,0);
     glEnd();
   }
};
```
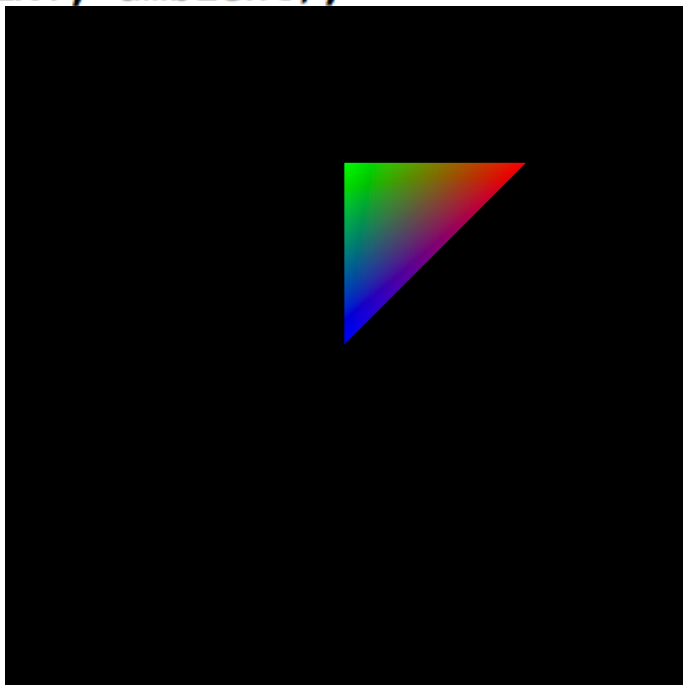
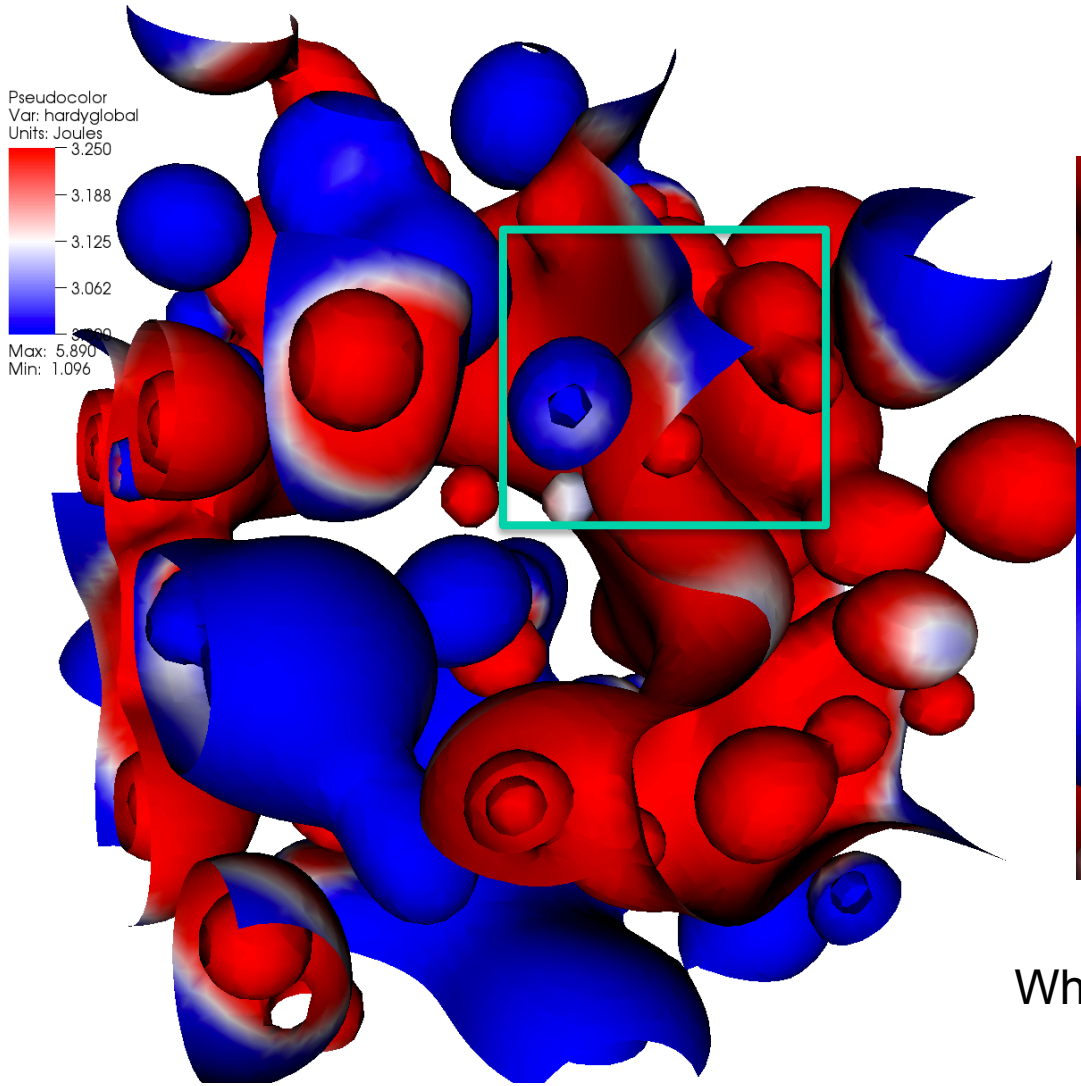
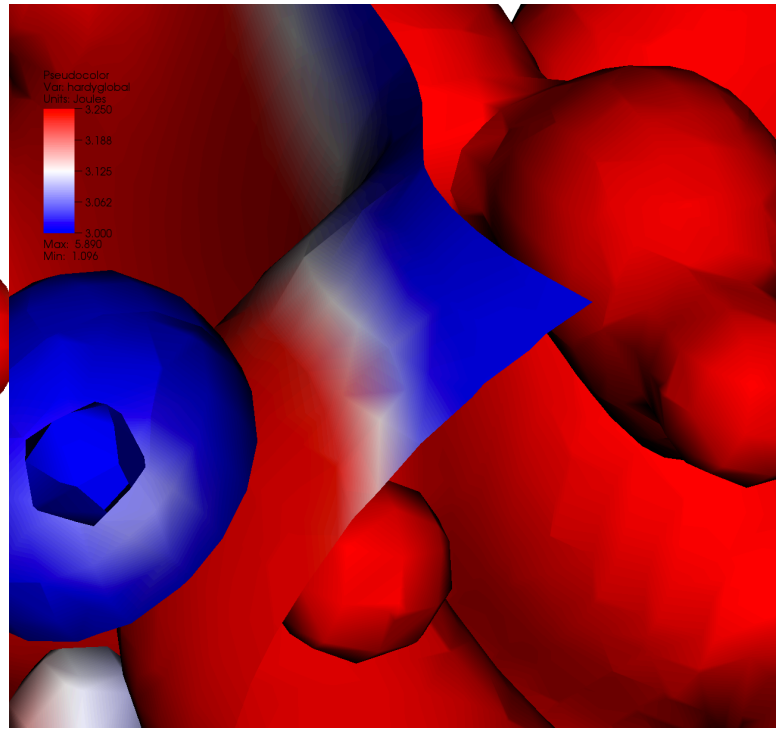



The University of New Mexico

Visualization use case





Why is there purple in this picture?

First OpenGL programs

```
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{
 public:
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     float ambient[3] = { 1, 1, 1 };
     glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);
     glBegin(GL_TRIANGLES);
     glColor3ub(0, 0, 255);
     glVertex3f(0,0,0);
     glColor3ub(0, 255, 0);
     glVertex3f(0,1,0);
     glColor3ub(255, 0, 0);
     glVertex3f(1,1,0);
     glEnd();
   }
};
```