COMP3421/9415 Computer Graphics

Introduction

Angela Finlayson
Email: angf@cse.unsw.edu.au

Course Admin

http://www.cse.unsw.edu.au/~cs3421

Labs next week in piano lab/ tutorials normally from week 3 onwards

Course Outline

Robert lectures week 7 – week 13

Second assignment in pairs from same tutorial group

Graphics Then and Now

1963 Sketchpad (4mins 20)

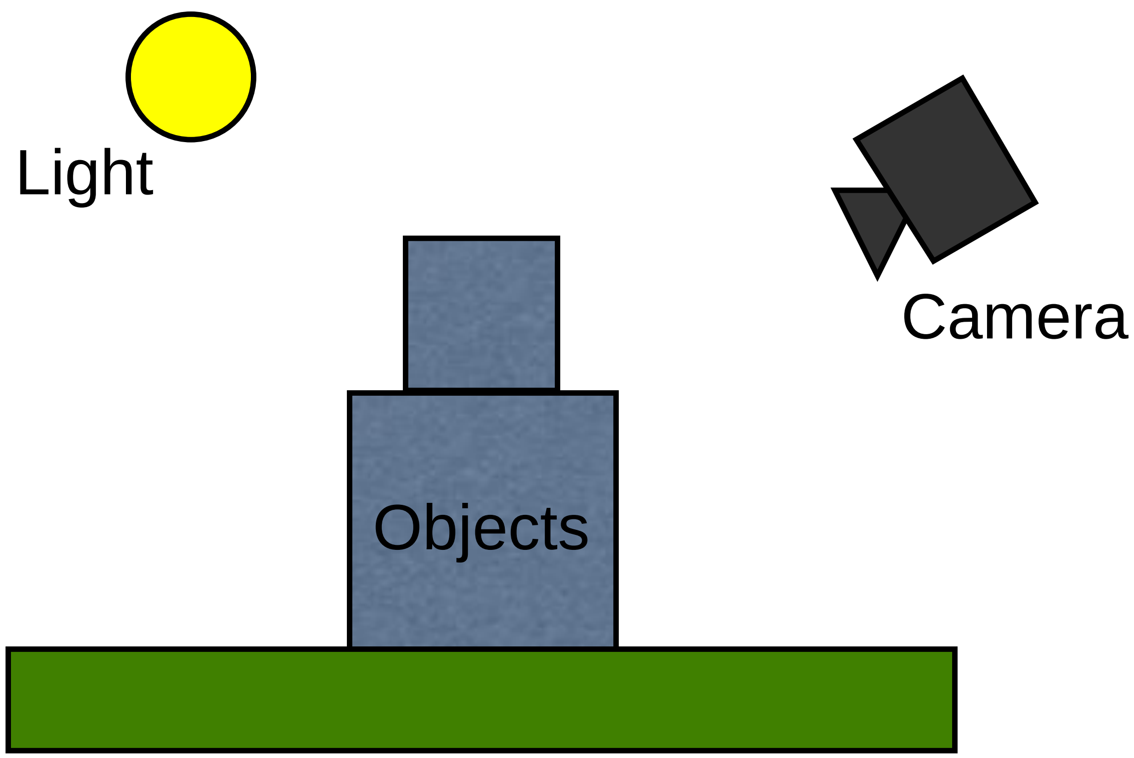
https://www.youtube.com/watch?v=USyoT_Ha_bA

2014 Pixar’s Renderman

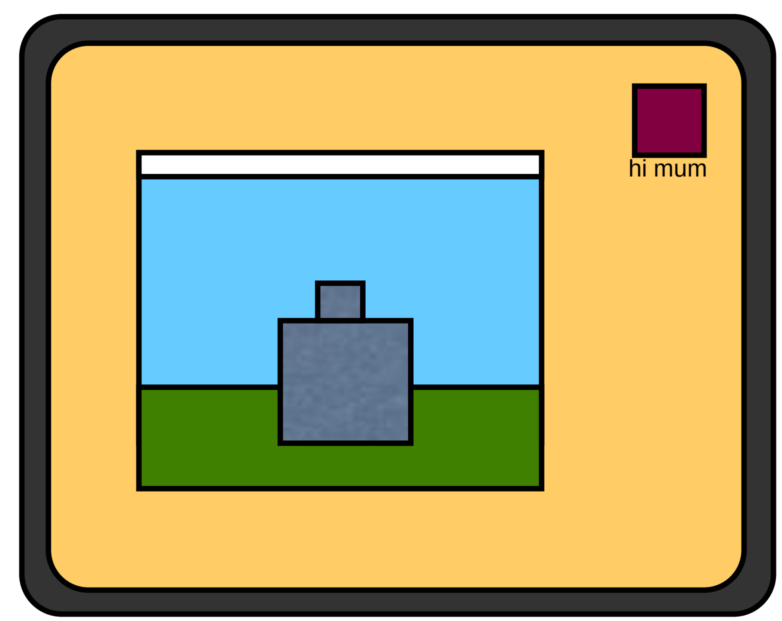
https://www.youtube.com/watch?v=iQaU9UP6dlg

Computer Graphics

Algorithms to automatically render images from models.



model



image

Computer Graphics

Based on:

Geometry

Physics

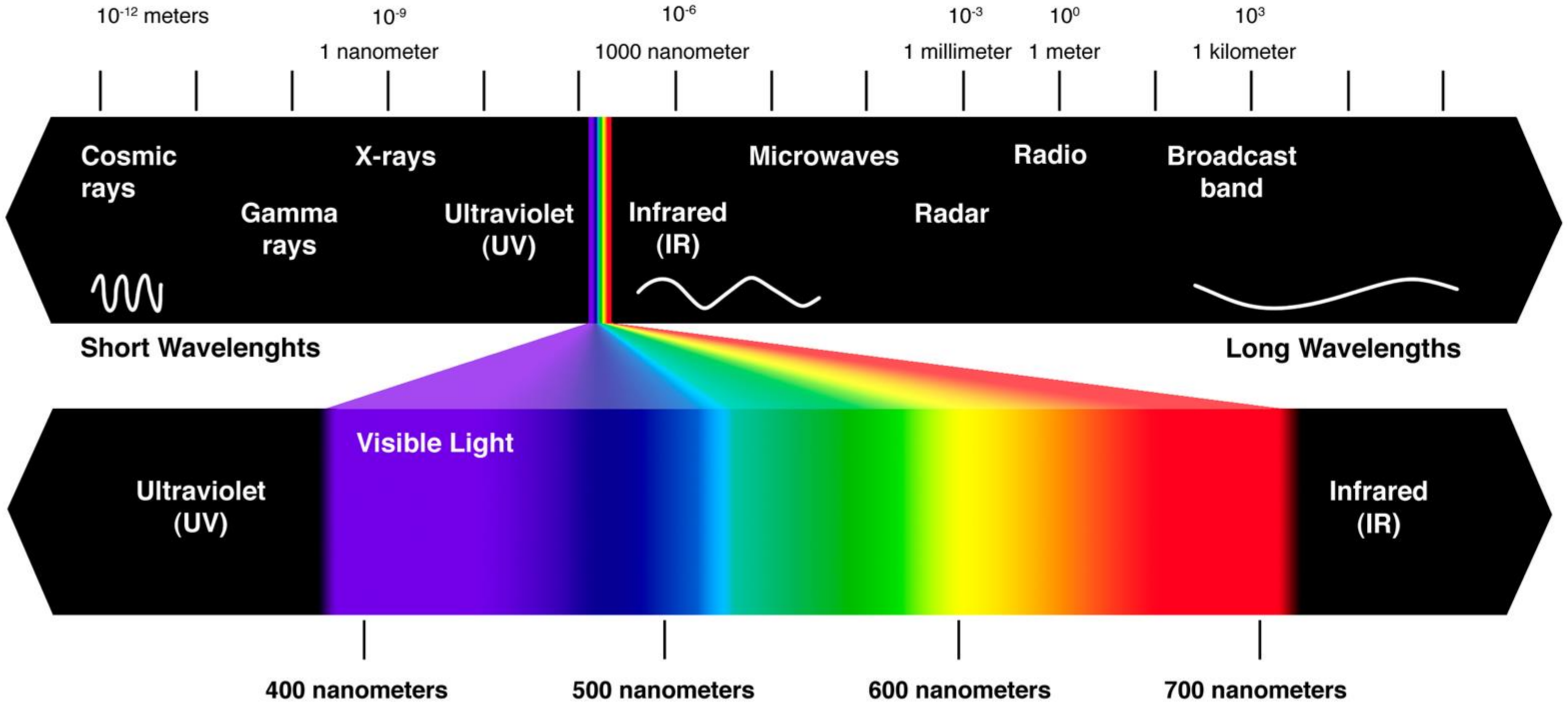
Physiology/Neurology/Psychology

with a lot of simplifications and hacks to make it tractable and look good.

Physics of light

Light is an electromagnetic wave, the same as radio waves, microwaves, X-rays, etc.

The visible spectrum (for humans) consists of waves with wavelength between 400 and 700 nanometers.



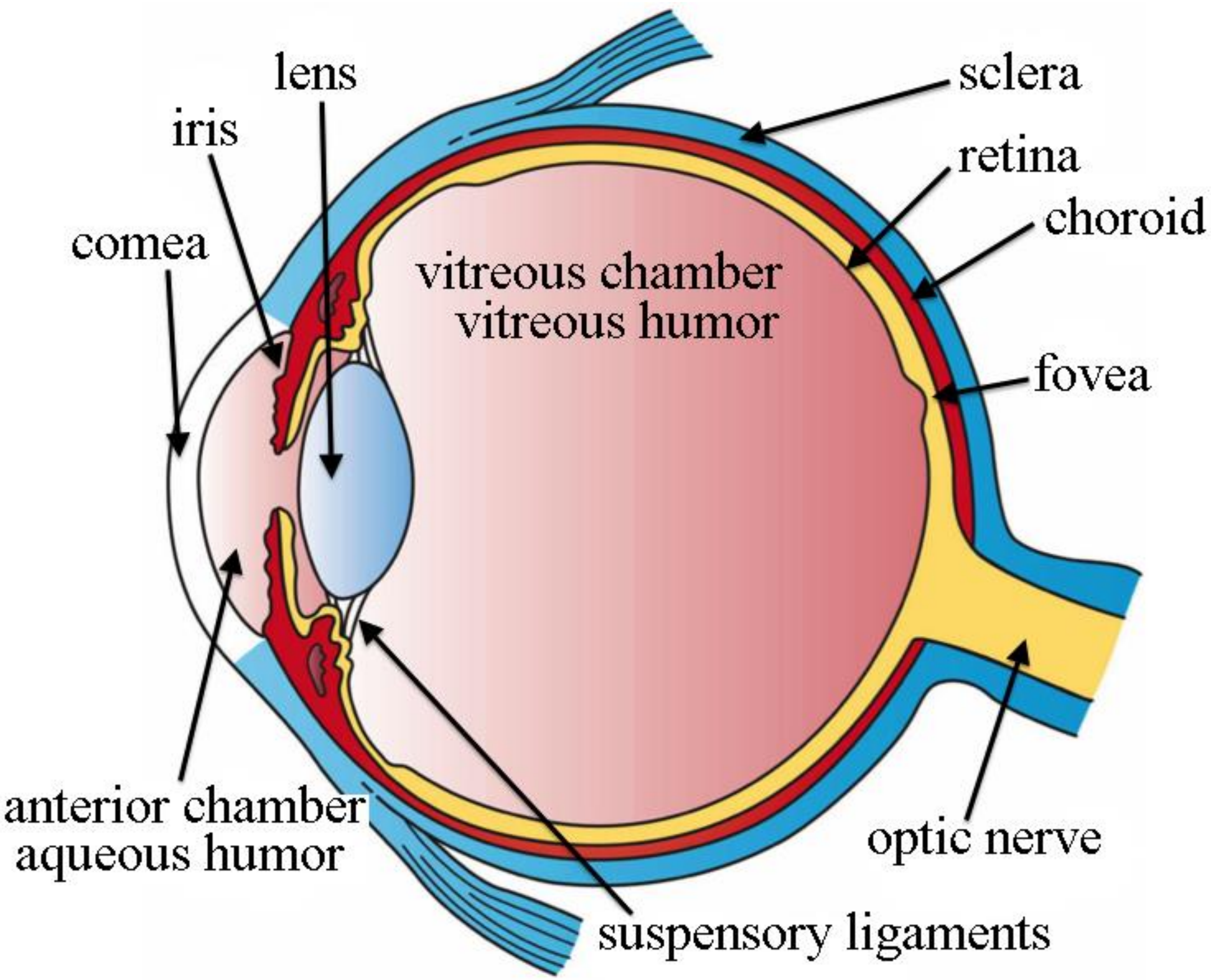
Non-spectral colours

Some light sources, such as lasers, emit light of essentially a single wavelength or "pure spectral" light (red,violet and colors of the rainbow).

Other colours (e.g. white, purple, pink,brown) are non-spectral.

There is no single wavelength for these colours, rather they are mixtures of light of different wavelengths.

The Eye



http://open.umich.edu/education/med/resources/second-look-series/materials

Colour perception

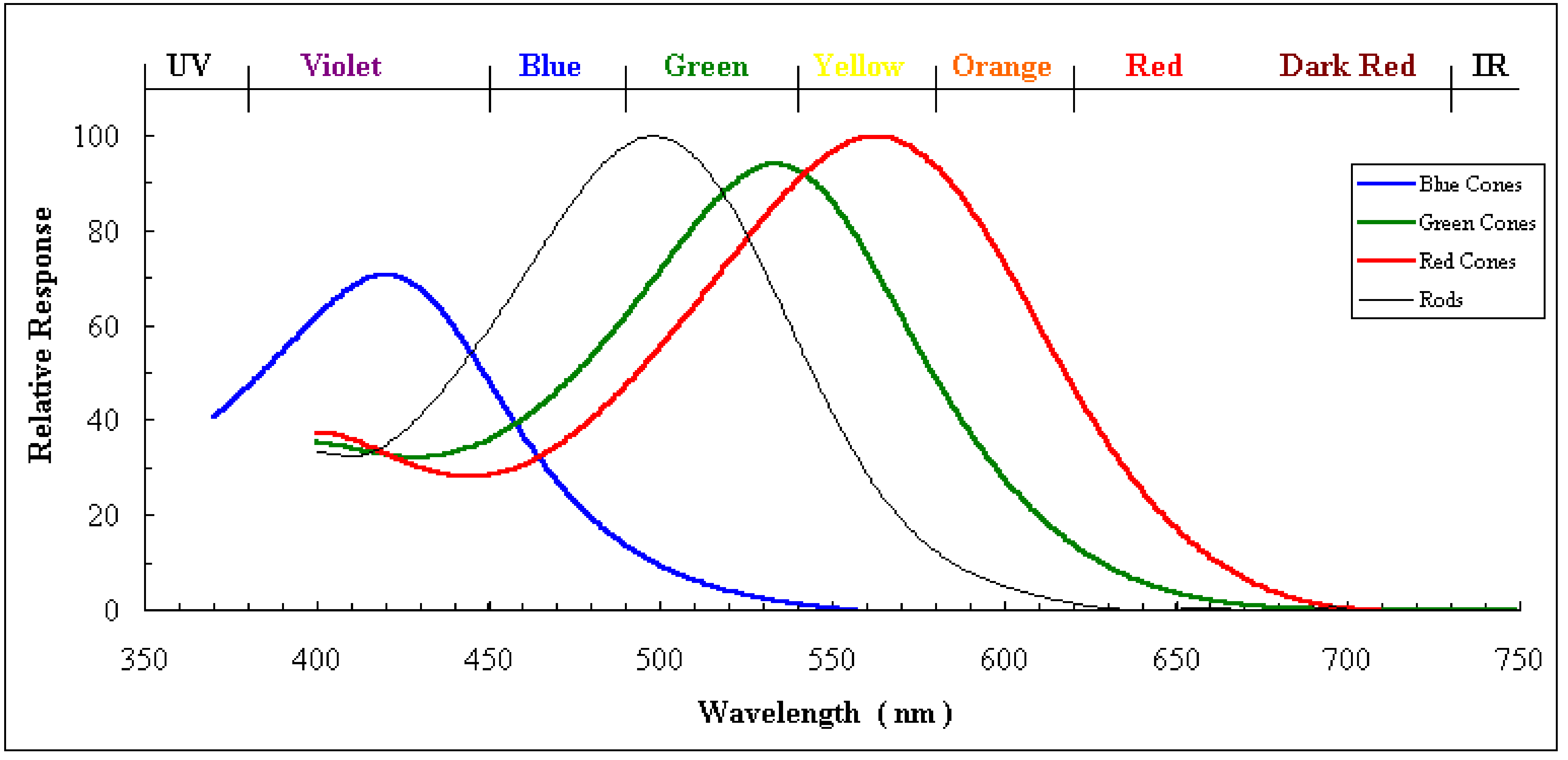
The retina (back of the eye) has two different kinds of photoreceptor cells: rods and cones.

Rods are good at handling low-level lighting (e.g. moonlight). They do not detect different colours and are poor at distinguishing detail.

Cones respond better in brighter light levels. They are better at discerning detail and colour.

Tristimulus Theory

Most people have three different kinds of cones which are sensitive to different wavelengths.



Colour blending

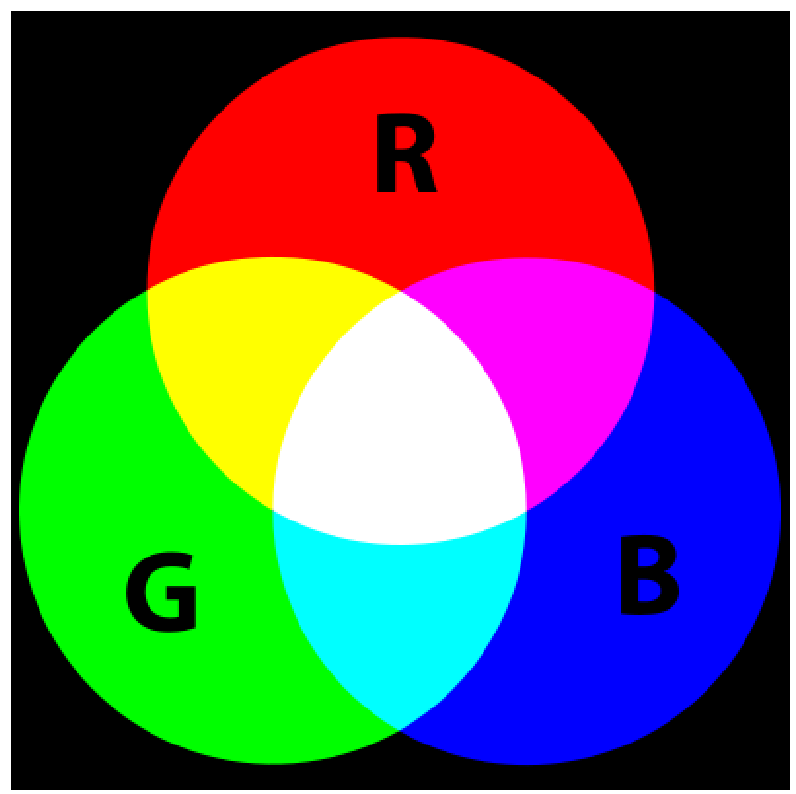
As a result of this, different mixtures of light will appear to have the same colour, because they stimulate the cones in the same way.

For example, a mixture of red and green light will appear to be yellow.

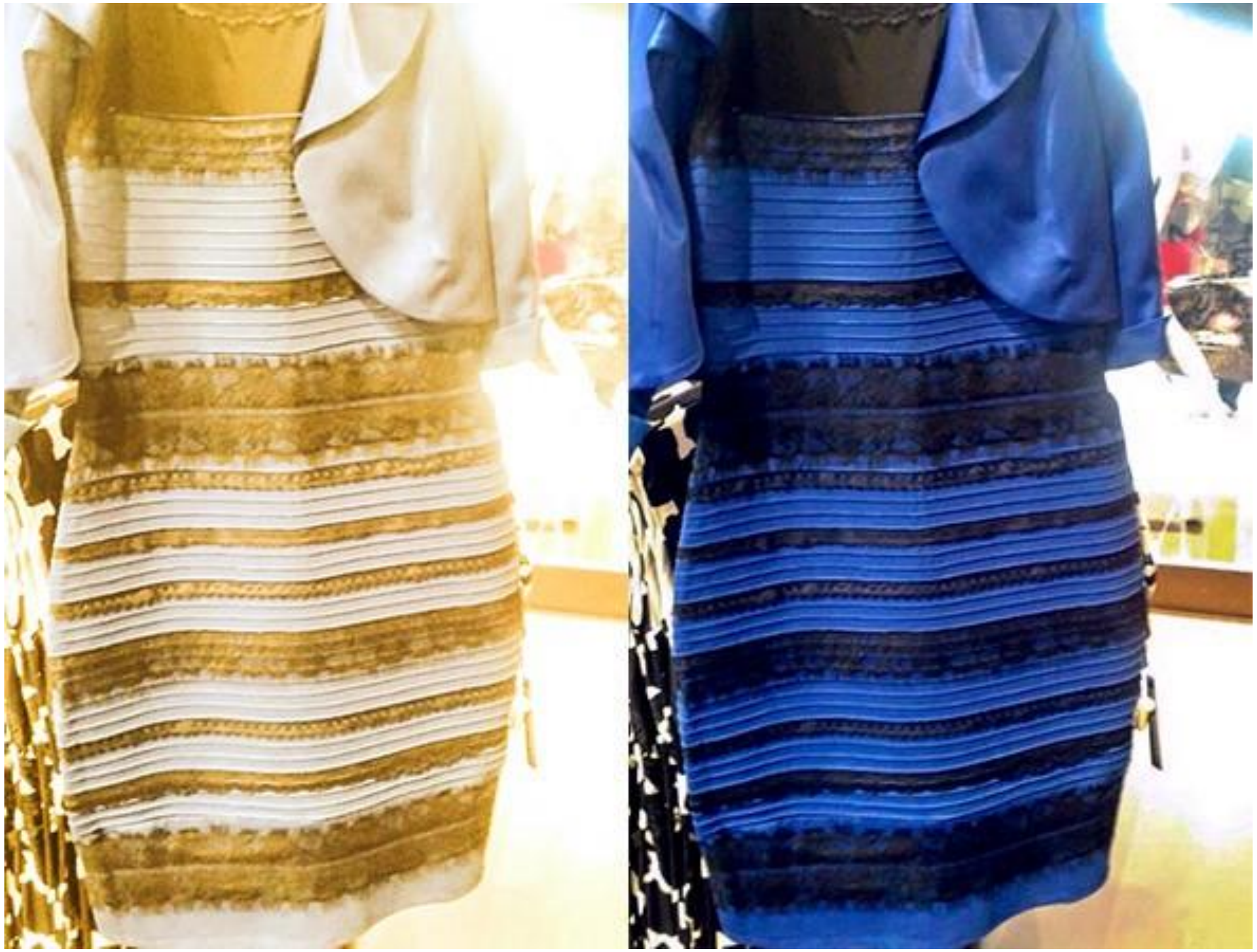
Colour blending

We can take advantage of this in a computer by having monitors with only red, blue and green phosphors in pixels.

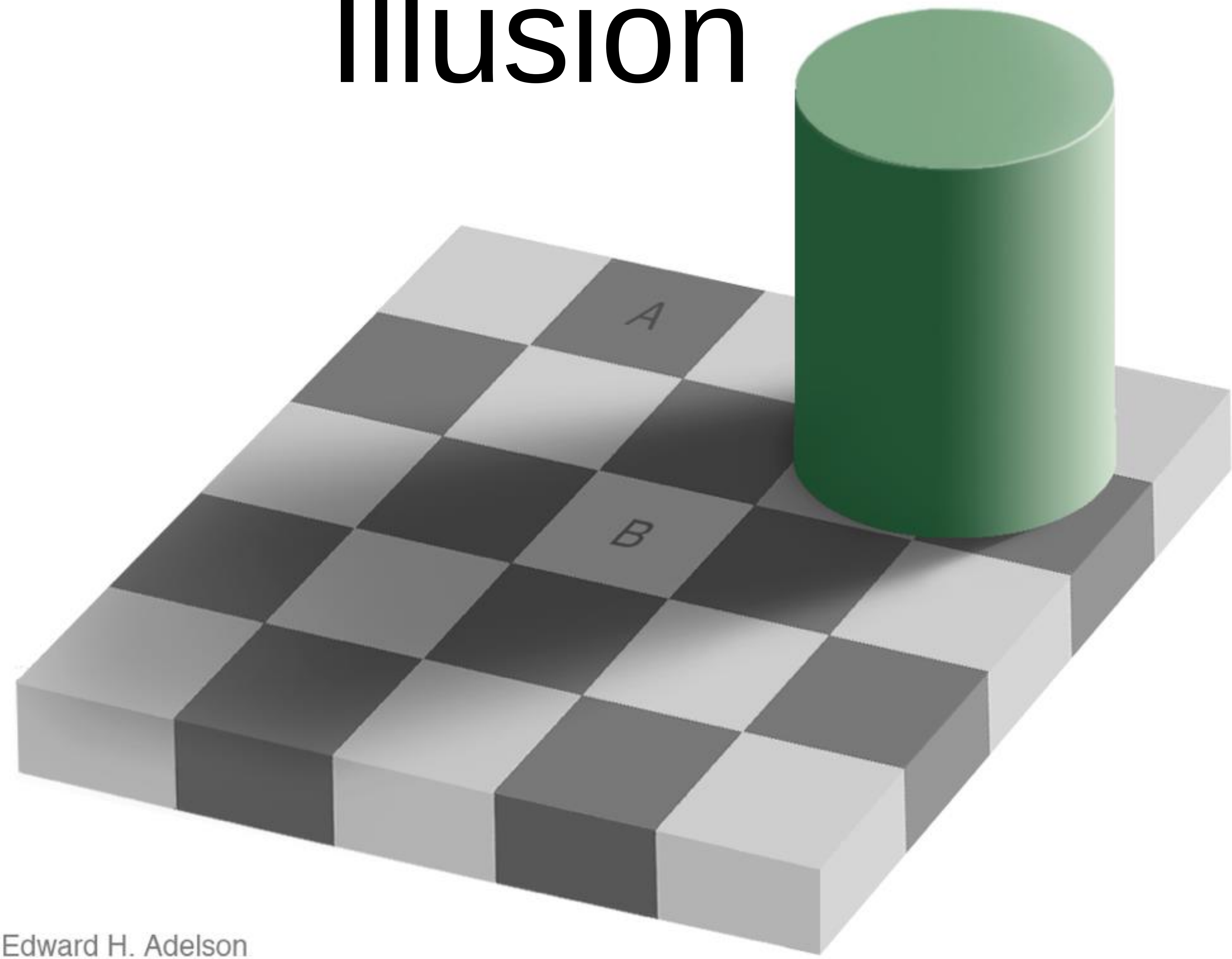
Other colours are made by mixing these lights together.



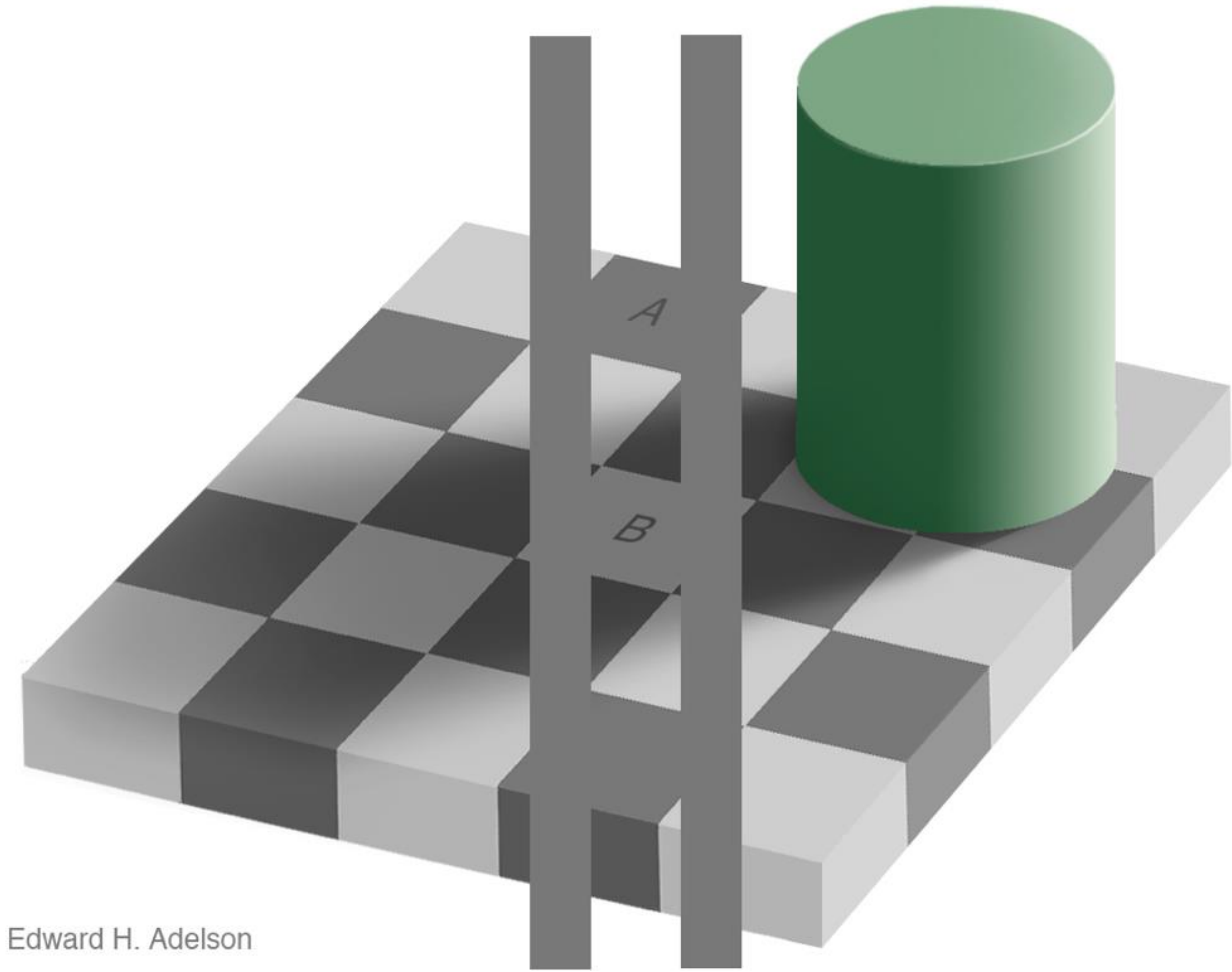
Color Illusions



Checker Shadow Illusion



Edward H. Adelson


A
B
Edward H. Adelson

Corner/Curve Illusions

Best Illusion of the Year Contest 2016

https://www.youtube.com/watch?v=oWfFco7K9v8

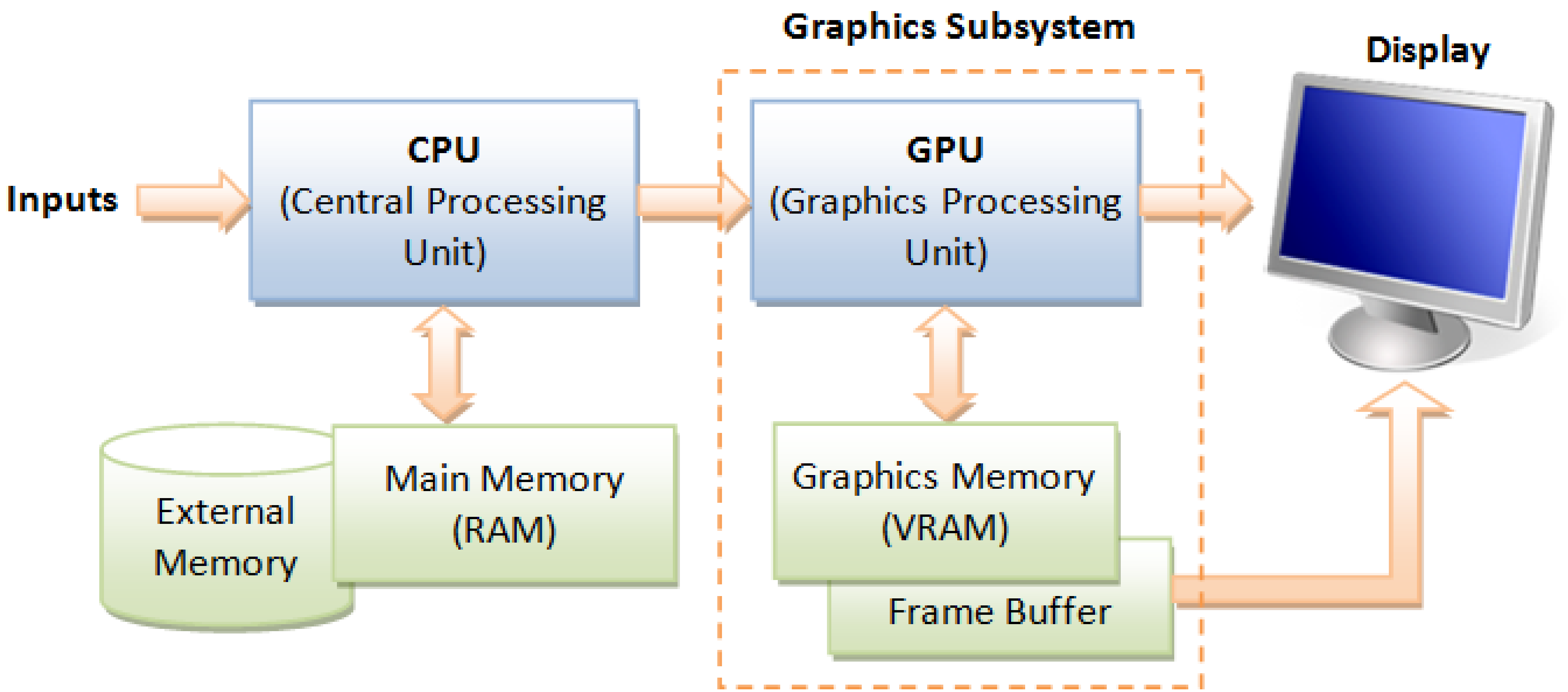
Realistic rendering

Our main focus will be on realistic rendering of 3D models. i.e. Simulating a photographic image from a camera.

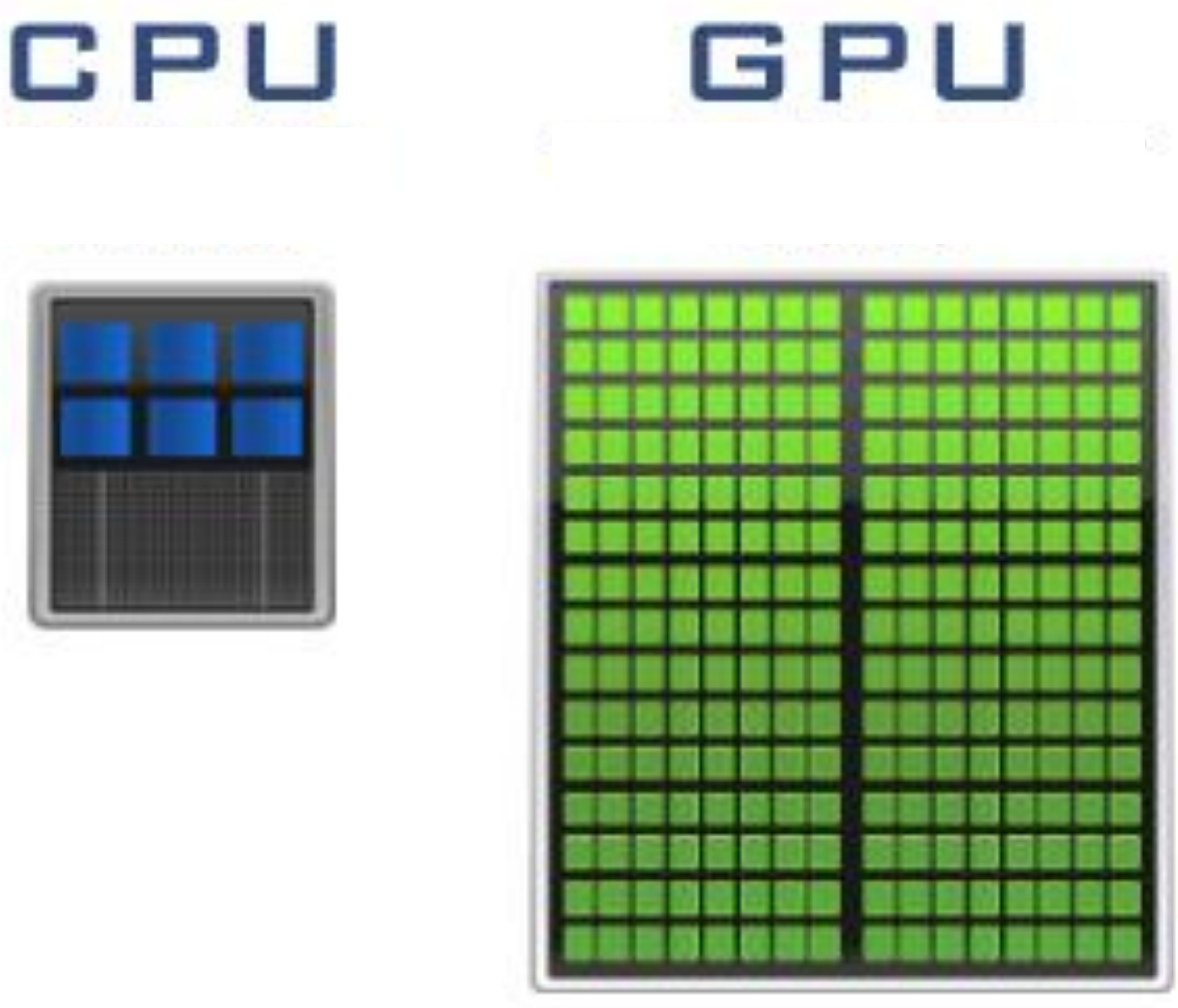
Note however: most art is not realistic but involves some kind of abstraction.

Realism is easier because physics is more predictable than psychology.

Hardware


Graphics Subsystem
Display
Inputs
CPU
(Central Processing
Unit)
GPU
(Graphics Processing
Unit)
External
Memory
Main Memory
(RAM)
Graphics Memory
(VRAM)
Frame Buffer

CPU vs GPU



CPU vs GPU

CPU consists of a few cores optimized for sequential serial processing

GPU has a massively parallel architecture (SIMD/Single Instruction Multiple Data) consisting of smaller special purpose cores designed for handling multiple tasks simultaneously.

OpenGL

A 2D/3D graphics API.

Free, Open source

Cross platform (incl. web and mobile)

Highly optimised

Designed to use special purpose hardware (GPU)

We will be using OpenGL

DirectX

Direct3D

Microsoft proprietary

Only on MS platforms or through emulation (Wine, VMWare)

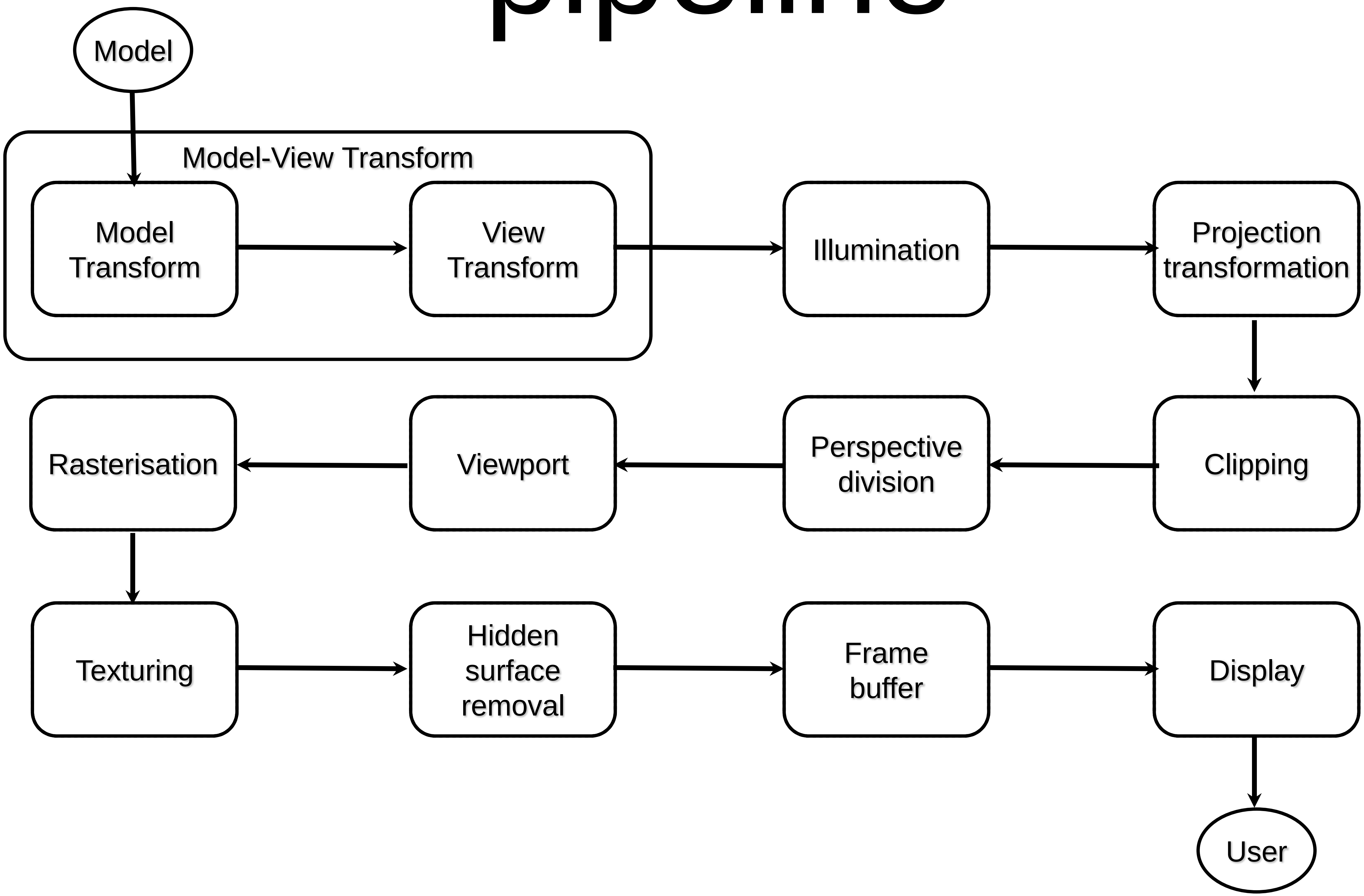
Roughly equivalent features + quality

Do it yourself

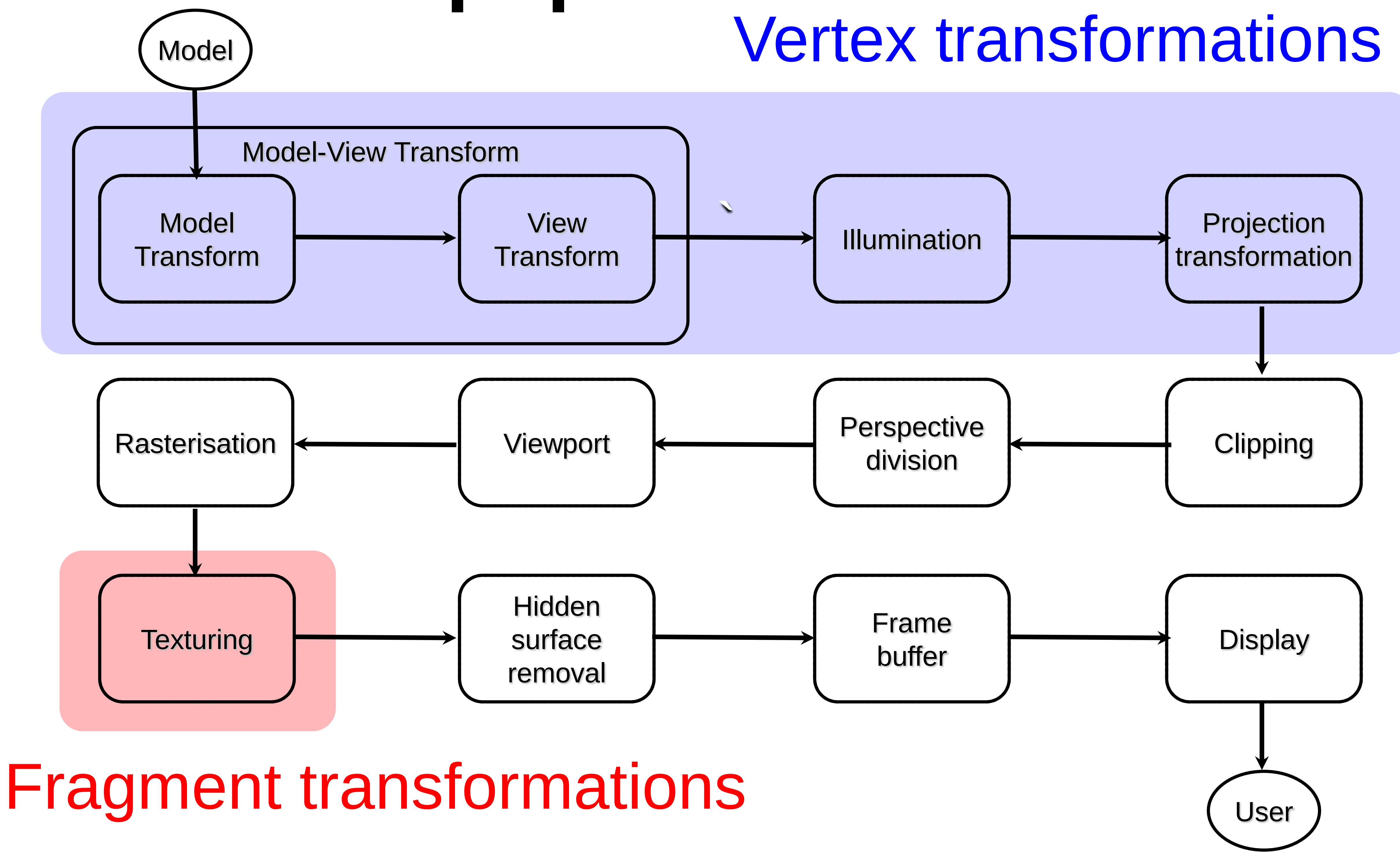
Generally a bad idea:

- Reinventing the wheel
- Numerical accuracy is hard
- Efficiency is also hard

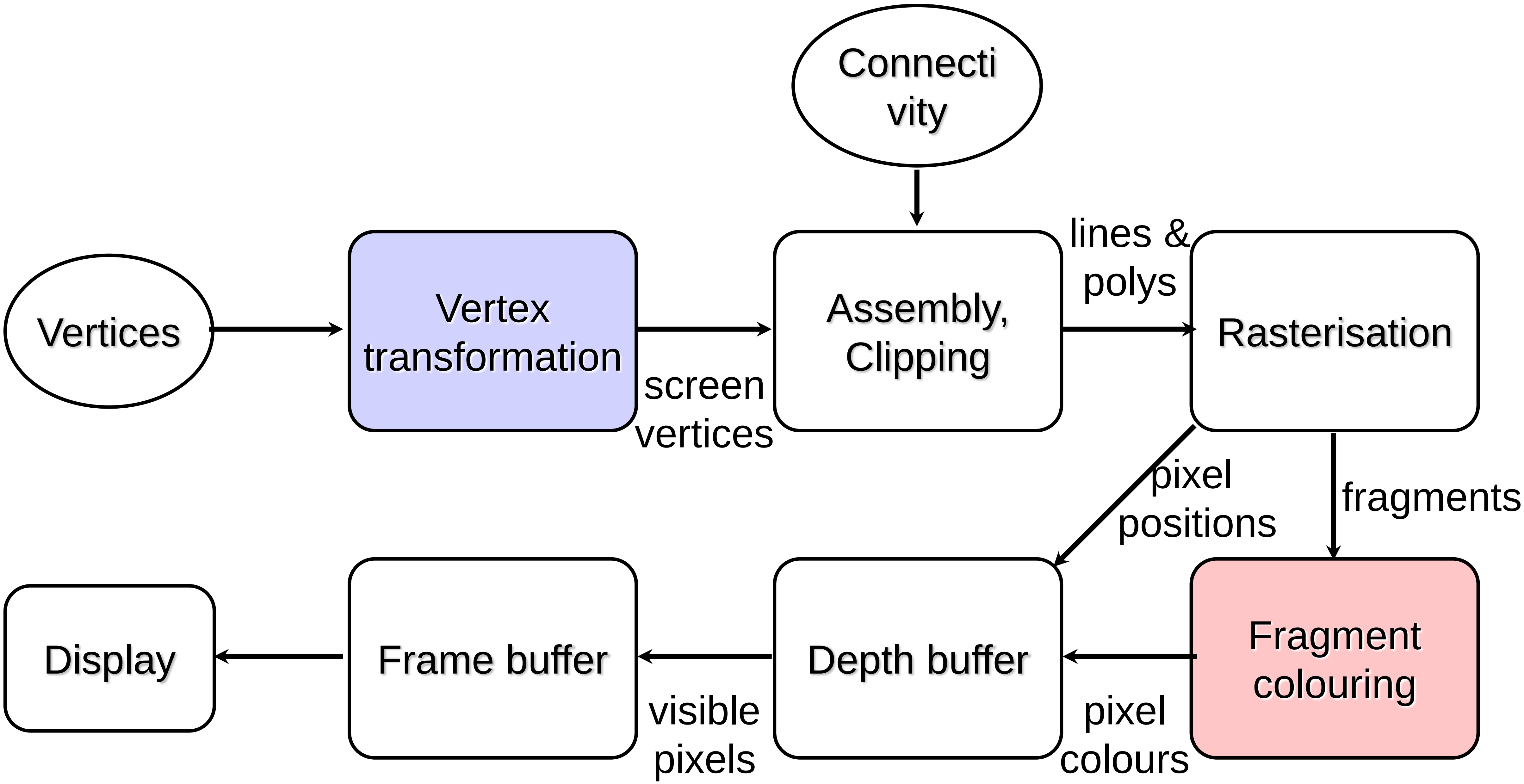
OpenGL fixed function pipeline



OpenGL fixed function pipeline



Programmable pipeline



We do vertex transformations and Fragment colouring ourselves by writing shaders in GLSL (There are also other optional shaders)

Other topics

Global illumination techniques such as

- Ray tracing
- Radiosity

Curves and splines

Fractals

Advanced Topics: You can suggest these for week 11/12

JOGL

OpenGL is a C/C++ library.

JOGL provides a set of Java bindings to the native library.

http://jogamp.org/jogl/www/

http://jogamp.org/deployment/v2.3.2/archive/

http://jogamp.org/deployment/v2.3.2/javadoc/jogl/javadoc/

JOGL at Home

Assuming you use Eclipse

JOGL Home Computing

JOGL at cse

JOGL is available on school machines in:

/home/cs3421/jogamp

Add the following JAR files to your classpath:

/home/cs3421/jogamp/jar/jogl-all.jar

/home/cs3421/jogamp/jar/gluegen-rt.jar

Assignment 1 will be automarked, so you must make sure it runs and compiles on cse machines.

UI Toolkits

JOGL interfaces with a number of different UI toolkits:

AWT, SWT, Swing

OpenGL also has its own UI tools:

GLUT, GLUI

We will be using Swing:
http://docs.oracle.com/javase/tutorial/uiswing/

Initialisation

```
// Get default version of OpenGL This chooses a
profile best suited for your running platform

GLProfile glProfile = GLProfile.getDefault();

// Get the default rendering capabilities

GLCapabilities glCapabilities = new
GLCapabilities(glProfile);
```

Create a GLJPanel

```
// A JPanel that is provides opengl
rendering support.

GLJPanel panel =
     new GLJPanel(glCapabilities);

// Put it in a Swing window

JFrame jframe = new JFrame("Title");

jframe.add(panel);

jframe.setSize(300, 300);
jframe.setVisible(true);
```

Add event handlers

```
// Add a GL event listener
// to handle rendering events

// MyRenderer must implement GLEvenListener

panel.addGLEventListener(new MyRenderer());

// Quit if the window is closed

jframe.setDefaultCloseOperation(
                        JFrame.EXIT_ON_CLOSE);
```

Event-based Programming

Both JOGL and Swing are event driven.

This requires a different approach to programming:

The main body sets up the components and registers event handlers, then quits.

Events are dispatched by the event loop.

Handlers are called when events occur.

GLEventListener

```
// initialise (usually only called once)
init(GLAutoDrawable drawable);

// release resources
dispose(GLAutoDrawable drawable);

// called after init and then in response to
//canvas resizing
reshape(GLAutoDrawable drawable, int x, int y,
int width, int height);

// render the scene, always called after a
reshape
display(GLAutoDrawable drawable);
```

GL2

All drawing is done using a GL2 object.

You can get one from the GLAutoDrawable :

```
GL2 gl = drawable.getGL().getGL2();
```

GL2 provides access to all the normal OpenGL methods and constants.

http://jogamp.org/deployment/v2.2.4/javadoc/jogl/javadoc/javax/media/opengl/GL2.html

GL2 Objects

Do not store GL2 objects as instance variables.

They may be created and destroyed over the lifetime of the program, so always get a fresh one each time display,reshape etc is called.

You can pass it to other functions that display etc uses.

GL is stateful

The GL2 object maintains a large amount of state:

- the pen colour
- the background colour
- the point size, etc

Drawing operations require you to set the state before issuing the drawing command.

Colors in JOGL: RGBA

Colors are defined using Red (R), Green (G), Blue (B) and Alpha (A) values.

For R,G,B values ranges from 0.0(none) to 1.0 (full intensity)

For A: values range from 0.0 (Transparent) to 1.0(Opaque)

```
//Set pen color to brightest red
gl.glColor3f(1, 0, 0); //default alpha of 1
```

GL methods

Because of OpenGL's origins in C, the methods have a distinctive naming convention:

`glColor3f(...)`

GL Library

Function

args

arg type
f = float
i = int
d = double
etc.

Color Buffer

Holds color information about the pixels.

Holds garbage when your program starts and should be cleared.

The default settings clears it with black, resulting in a black background. Or you can set the color first before you clear it

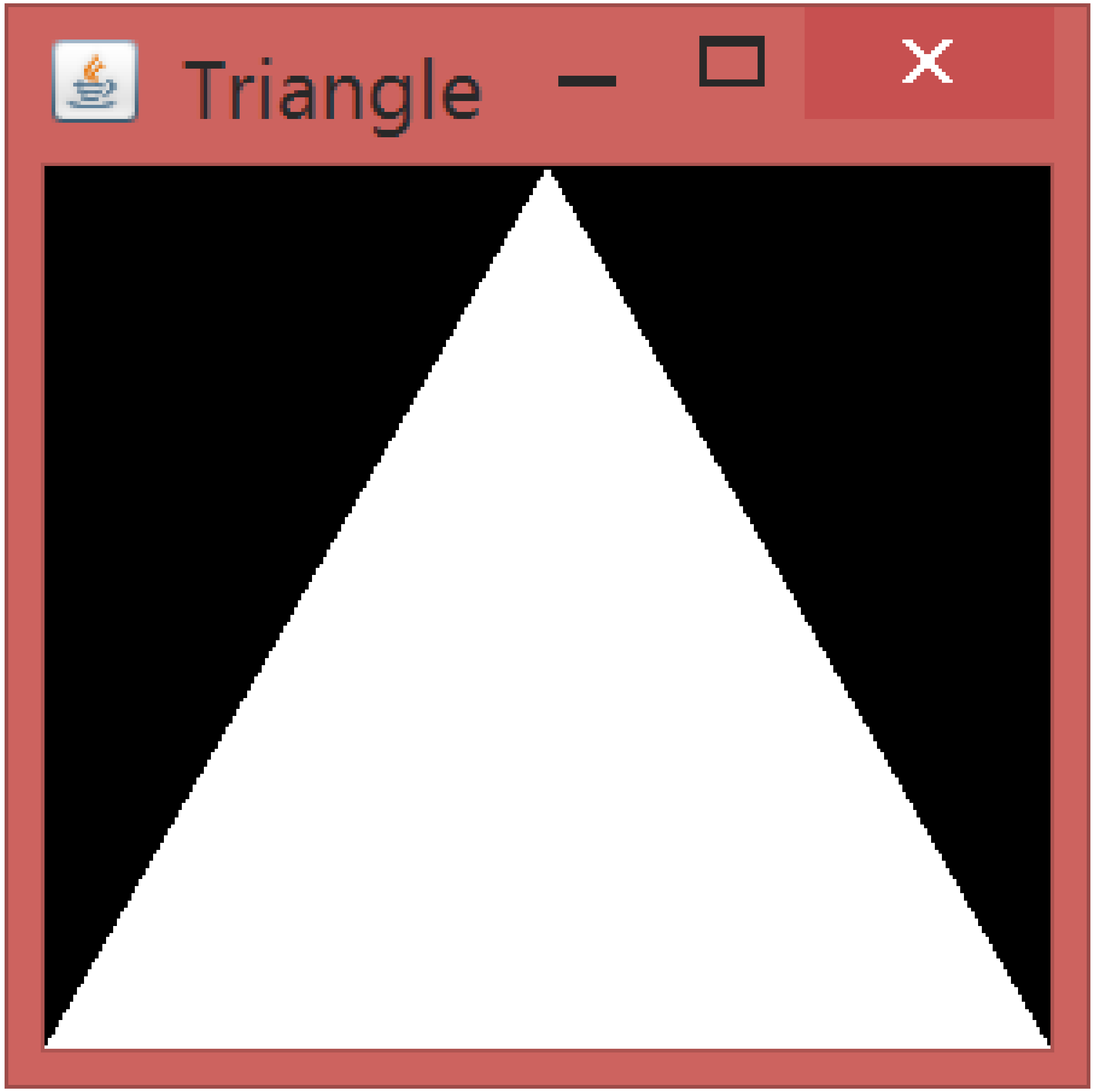
```
gl.glClearColor(1,1,1,1) ; //white
gl.glClear(GL.GL_COLOR_BUFFER_BIT);
```

Our First Triangle

Once we have set the state we can issue drawing commands such as:

```
gl.glBegin(GL2.GL_TRIANGLES);
      gl.glVertex2d(-1, -1);
      gl.glVertex2d(1, -1);
      gl.glVertex2d(0,  1);
gl.glEnd();
```

Screen Shot

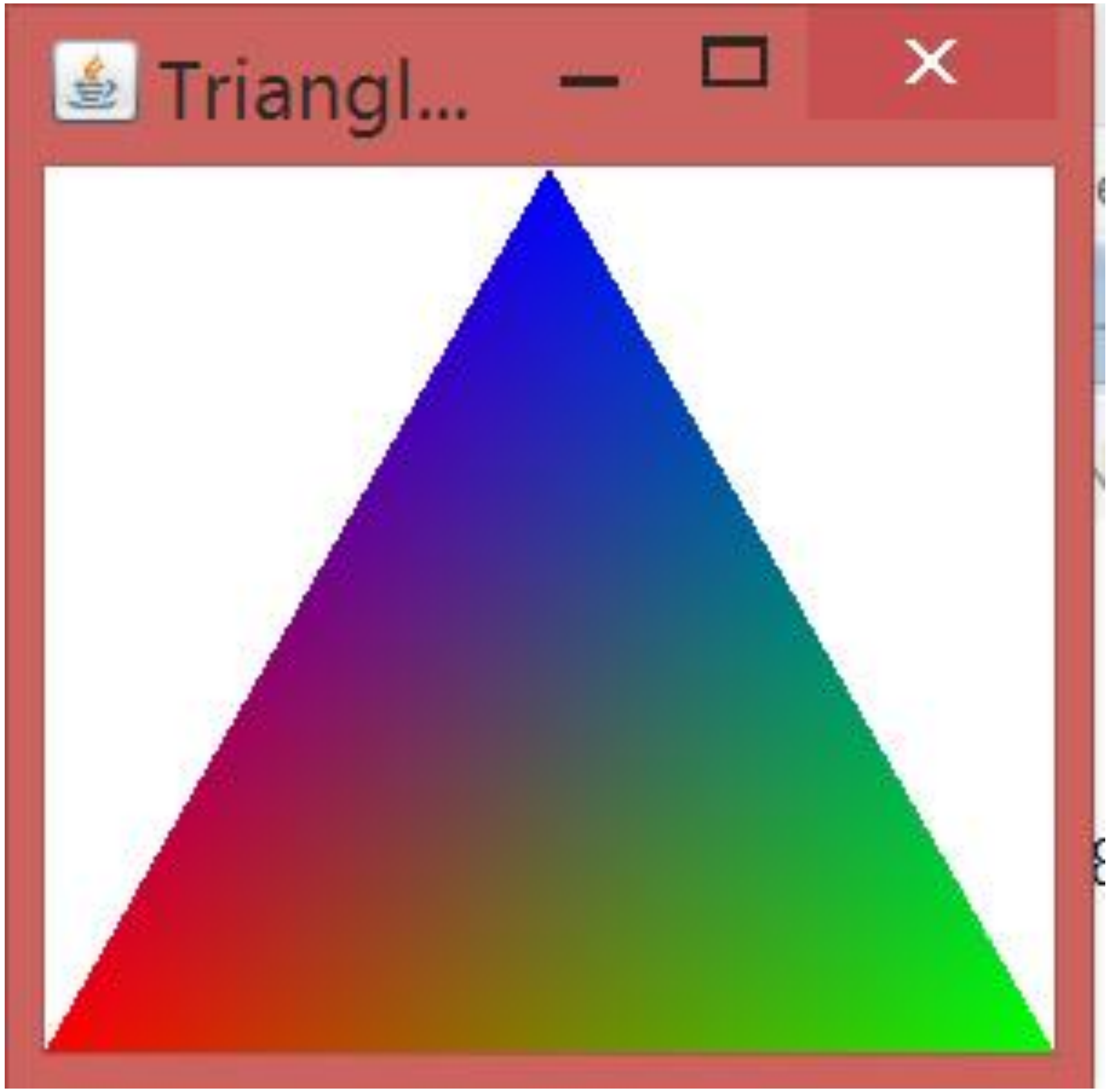


Our Second Triangle

```
gl.glClearColor(1,1,1,1) ; //WHITE
gl.glClear(GL.GL_COLOR_BUFFER_BIT);

gl.glBegin(GL2.GL_TRIANGLES);
      gl.glColor3f(1,0,0);  //RED
      gl.glVertex2d(-1, -1);
      gl.glColor3f(0,1,0);  //GREEN
      gl.glVertex2d(1, -1);
      gl.glVertex2d(0,  1); //BLUE
gl.glEnd();
```

Screen Shot



More drawing

Once we have set the state we can issue drawing commands as:

```
gl.glBegin(GL_POINTS);// draw some points
      gl.glVertex2d(-1, -1);
      gl.glVertex2d(1, -1);
      gl.glVertex2d(0,  1);
glEnd();
```

Note: these will be tiny and hard to see!

Begin and End

Not all commands can be used between Begin and End.

glVertex, glColor can be.

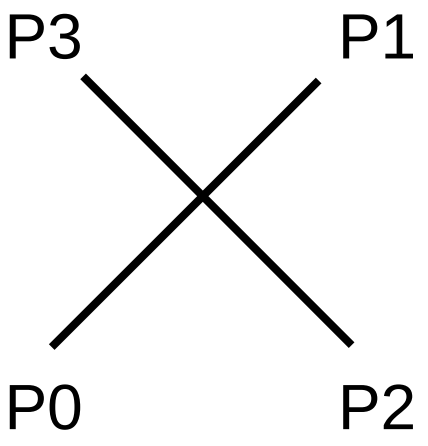
glPointSize, glLineWidth can’t

For complete list see: https://www.opengl.org/sdk/docs/man2/xhtml/glBegin.xml

More drawing commands

Draw unconnected lines:

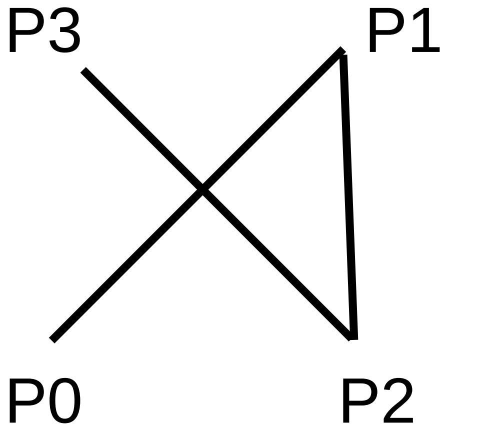
```
glBegin(GL.GL_LINES);
    glVertex2d(-1, -1);   // P0
    glVertex2d(1, 1);     // P1
    glVertex2d(1, -1);    // P2
    glVertex2d(-1, 1);    // P3
glEnd();
```



More drawing commands

Draw connected lines:

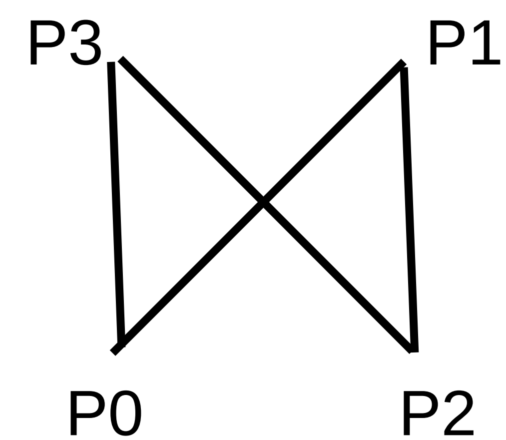
```
glBegin(GL.GL_LINE_STRIP);
   glVertex2d(-1, -1);  // P0
   glVertex2d(1, 1);    // P1
   glVertex2d(1, -1);   // P2
   glVertex2d(-1, 1);   // P3
glEnd();
```



More drawing commands

Draw closed polygons (deprecated):

```
glBegin(GL.GL_POLYGON);
    glVertex2d(-1, -1);   // P0
    glVertex2d(1, 1);     // P1
    glVertex2d(1, -1);    // P2
    glVertex2d(-1, 1);    // P3
glEnd();
//Note: this particular polygon is complex
  and may not be rendered properly
```



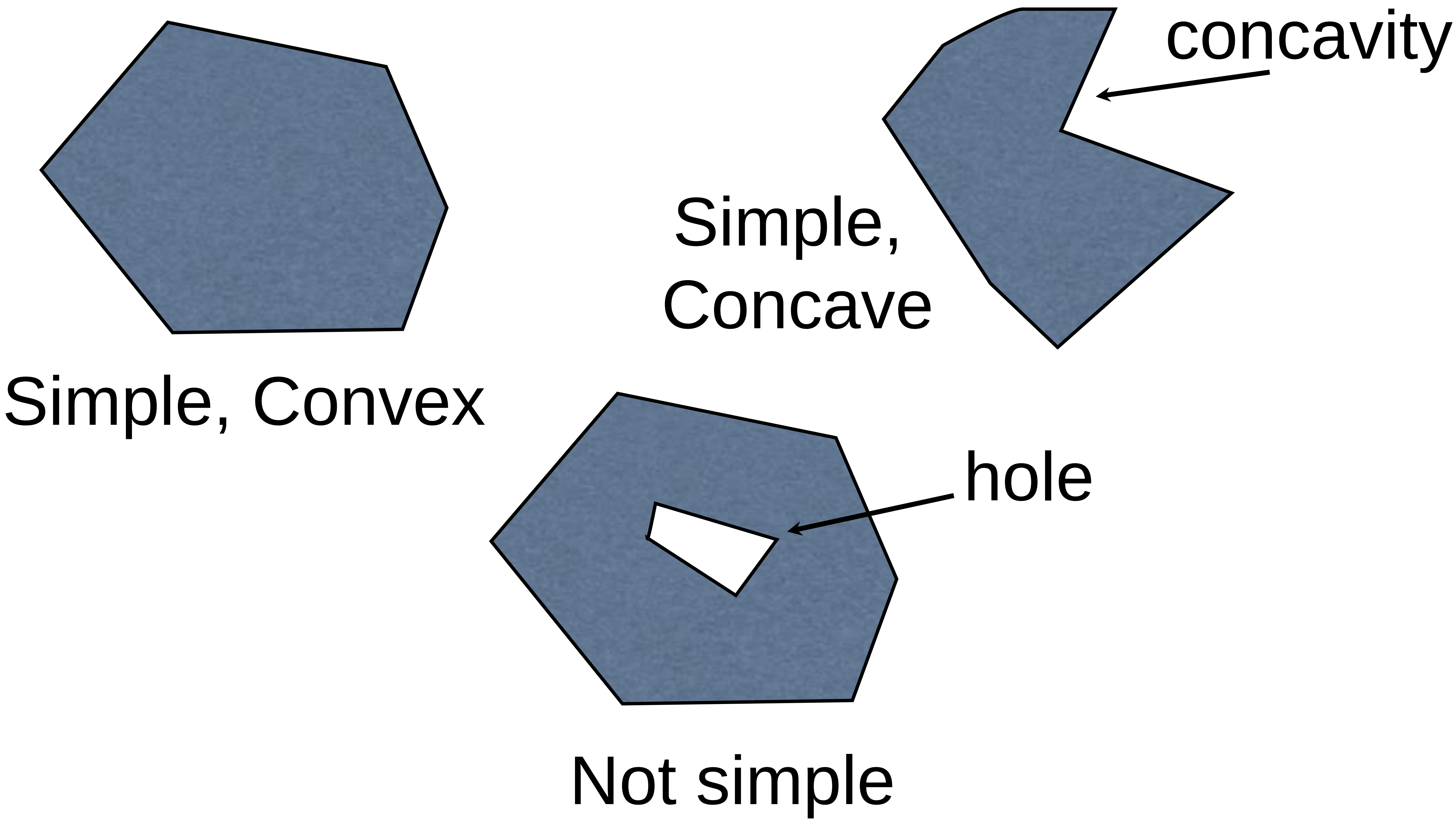
Polygons

OpenGL does not always draw polygons properly. (See week2 tutorial/lab)

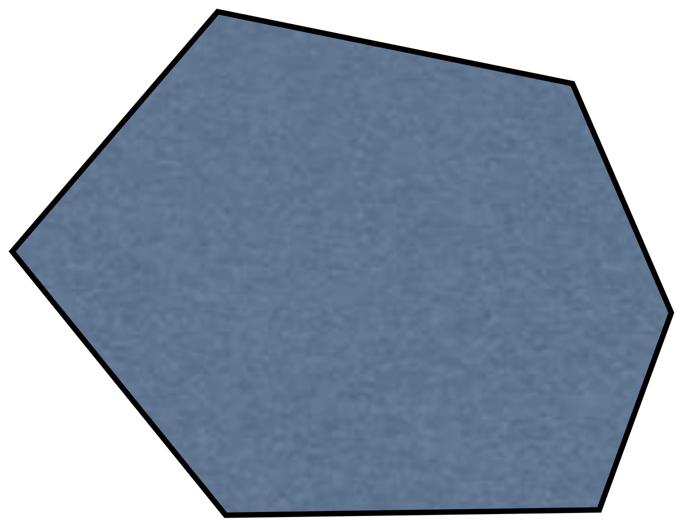
OpenGL only guarantees to draw simple, convex polygons correctly.

Concave and non-simple polygons need to be tessellated into convex parts.

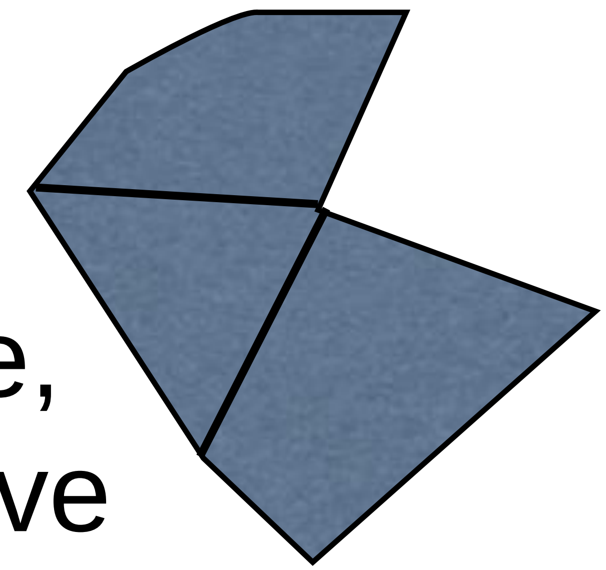
Polygons



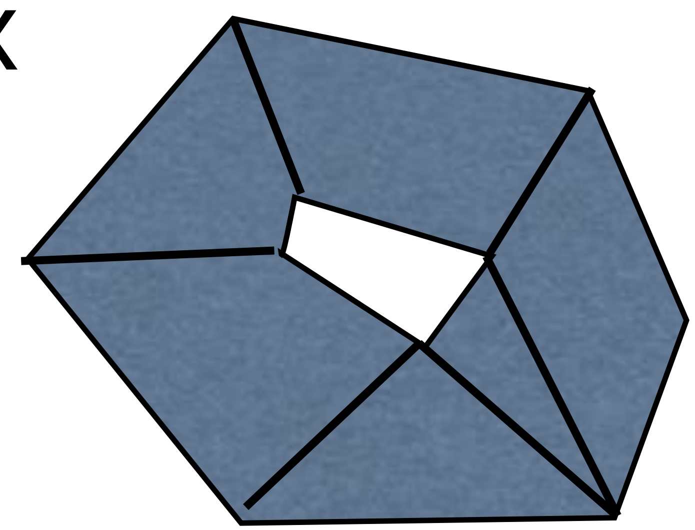
Polygons



Simple, Convex



Simple, Concave



Not simple

possible convex tessellations

More drawing commands

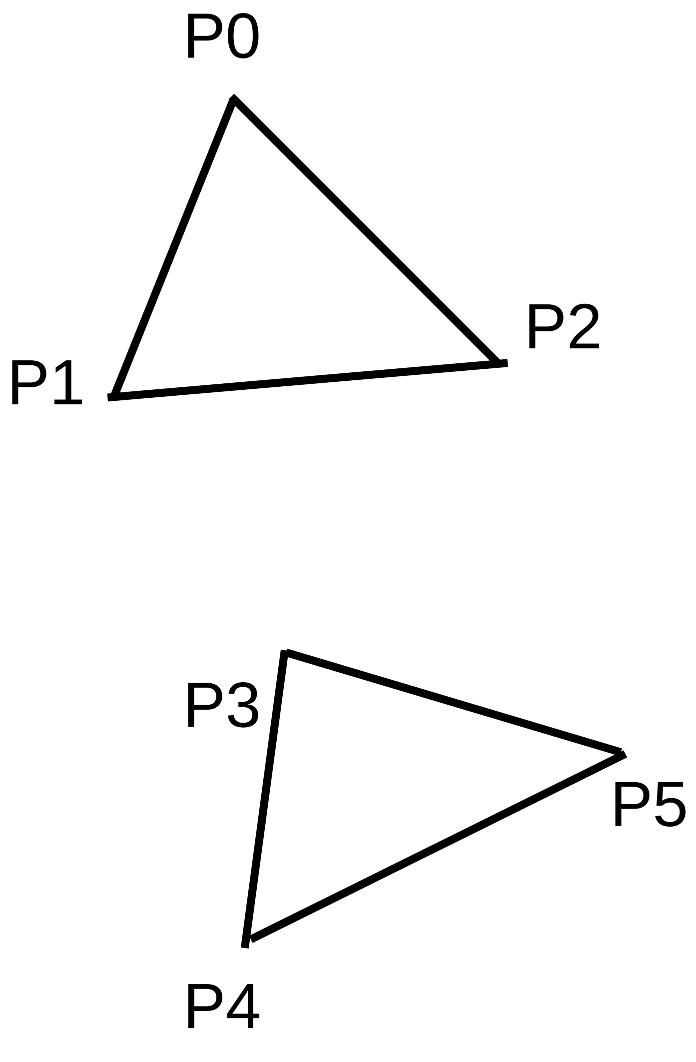
Draw separate triangles:

```
glBegin(GL.GL_TRIANGLES);

    glVertex2d(etc); // P0
    glVertex2d();    // P1
    glVertex2d();    // P2

    glVertex2d();    // P3
    glVertex2d();    // P4
    glVertex2d();    // P5

glEnd();
```



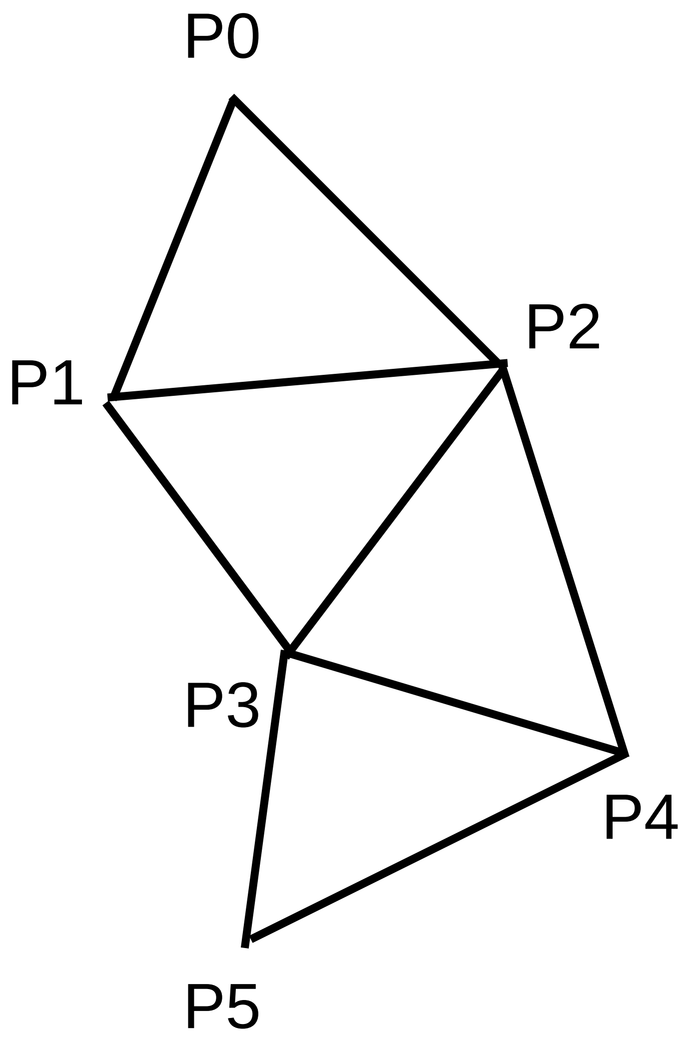
More drawing commands

Draw strips of triangles:

```
glBegin(GL.GL_TRIANGLE_STRIP);

    glVertex2d(etc);  // P0
    glVertex2d();  // P1
    glVertex2d();  // P2
    glVertex2d();  // P3
    glVertex2d();  // P4
    glVertex2d();  // P5

glEnd();
```



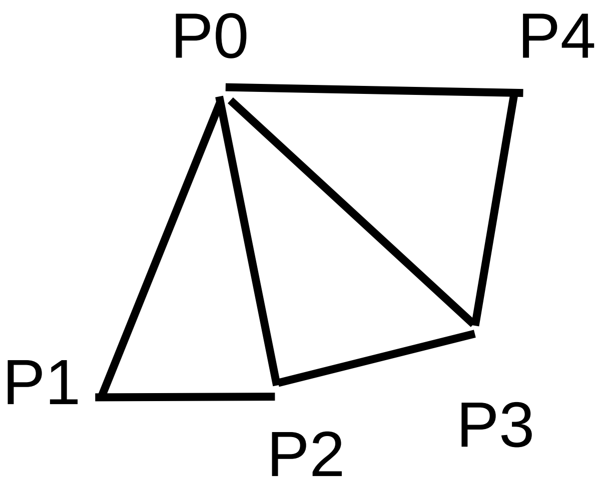
More drawing commands

Draw fans of triangles:

```
glBegin(GL.GL_TRIANGLE_FAN);

  glVertex2d();  // P0
    glVertex2d();  // P1
    glVertex2d();  // P2
    glVertex2d();  // P3
    glVertex2d();  // P4

glEnd();
```



More drawing commands

Similarly for quadrilaterals (deprecated):

```
glBegin(GL.GL_QUADS);
  // draw unconnected quads
glEnd();
glBegin(GL.GL_QUAD_STRIP);
  // draw a connected strip of quads
glEnd();
```

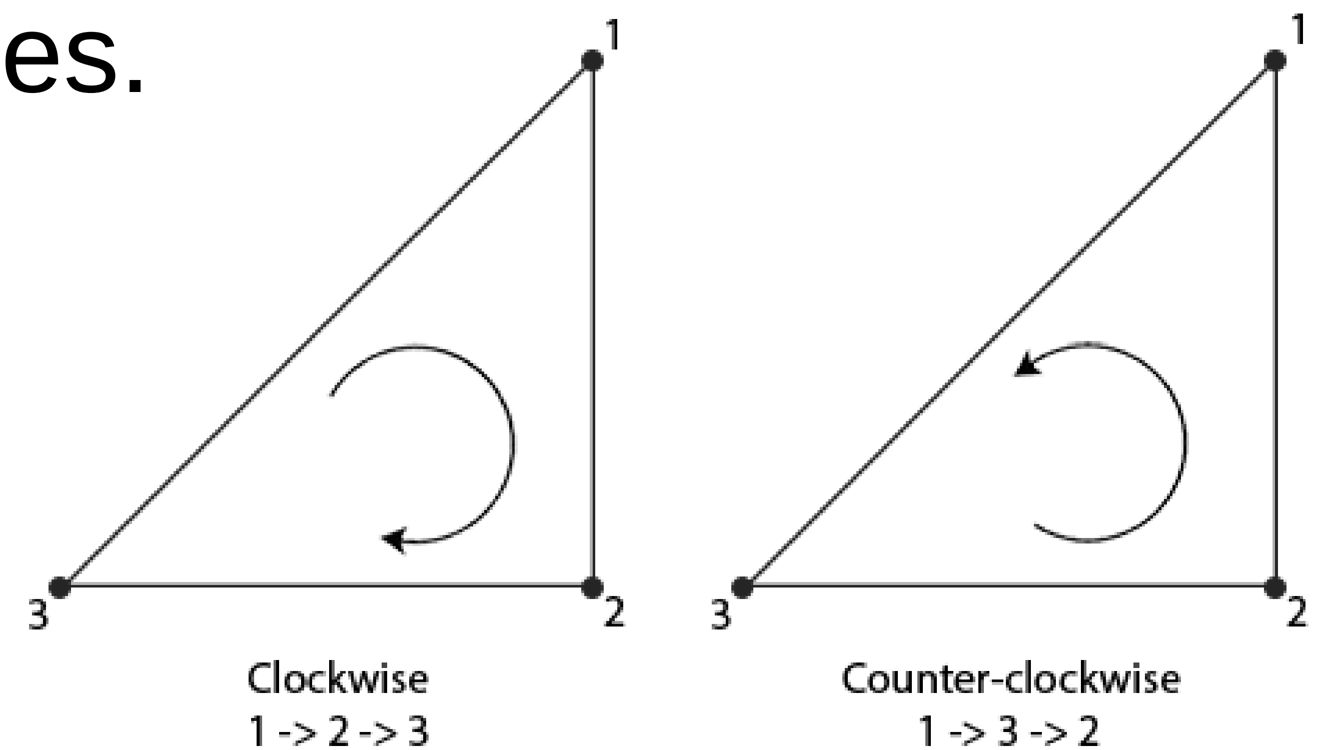
Triangles

Triangles are preferred over quads and polygons as they are guaranteed to lie in one plane.

In 3D we can define four points for our quads (or more for our polygons) which don’t lie on the same plane and different implementations of OpenGL will different results – some of them not great ☺

Winding Order

By default, triangles/quads/polygons etc are **defined** with counter-clockwise vertices are processed as front-facing triangles. Clockwise are processed as back-facing triangles.



Fill or outline

```
// fill the polygon with colour

gl.glColor4d(r, g, b, a);

//This is the default anyway

gl.glPolygonMode(
   GL2.GL_FRONT_AND_BACK, GL2.GL_FILL);

gl.glBegin(GL2.GL_POLYGON);

 // ...points...

gl.glEnd();
```

Fill or outline

```
// outline the polygon with colour

gl.glColor4d(r, g, b, a);

gl.glPolygonMode(
   GL2.GL_FRONT_AND_BACK, GL2.GL_LINE);
gl.glBegin(GL2.GL_POLYGON);
 // ...points...
gl.glEnd();

//Set back to FILL when you are finished - not
needed but is a bug fix for some implementations
on some platforms

gl.glPolygonMode(
   GL2.GL_FRONT_AND_BACK, GL2.GL_FILL);
```

Animation

To handle animation we can separate the display() function into two methods:

```
public void display(GLAutoDrawable drawable) {
    // Update the model
    updateModel();
    // Render the new scene
    render(drawable);
}
```

Animation

Display events are only fired when the image needs to be redrawn.

We can use an FPSAnimator to fire events at a particular rate:

```
// in main()
// create display events at 60fps
FPSAnimator animator = new FPSAnimator(60);
animator.add(panel);
animator.start();
```

Double Buffering

Single Buffering:

One buffer being both drawn to and sent to the monitor. Updated objects would often flicker.

Double Buffering: (default in jogl)

Uses two buffers, draw into back buffer while the front buffer is displayed and then swap buffers after updating finished. Smoother animation.

Input events

We can add keyboard or mouse event listeners to handle input.

http://docs.oracle.com/javase/7/docs/api/java/awt/event/KeyListener.html

http://docs.oracle.com/javase/7/docs/api/java/awt/event/MouseListener.html

Event handling

GL commands should generally only be used within the GLEventListener events

- don’t try to store GL objects and use GL commands in keylistener or mouse events etc.

In multi-threaded code it is easy to create a mess if you write the same variables in different threads.

World vs Viewport

Notice that the coordinate system is independent of the window size.

OpenGL maintains separate coordinate systems for the world and the viewport.

This allows us to make our model independent of the particular window size or resolution of the display.

Viewport

We talk in general about the viewport as the piece of the screen we are drawing on. We can think of it as a 2d array of pixels.

It may be a window, part of a window, or the whole screen. (In jogl by default it is the whole window – minus the border)

It can be any size but we assume it is always a rectangle.

World window

The world window is the portion of the world that we can see.

It is always an axis-aligned rectangle.

By default the bottom-left corner is (-1,-1) and the top-right corner is (1,1).

We can change this using by setting the Projection matrix using glu.Ortho2d

GLU

The GLU class contains a bunch of utility methods. We will introduce some useful methods as they arise.

To create an orthographic projection with the specified boundaries in 2D (in world coordinates):

```
glu.gluOrtho2d(left, right, top, bottom);
```

Resizing the World Window

```
public void reshape(GLAutoDrawable d,
      int x, int y, int w, int h) {

  GL2 gl = drawable.getGL().getGL2();


  gl.glMatrixMode(GL2.GL_PROJECTION);
  gl.glLoadIdentity();

  glu.gluOrtho2d(
       -10, 10,                // left, right
       -10.0, 10.0);           // top, bottom
}
```

Aspect ratio

The aspect ratio of a rectangle is:

aspect = width / height

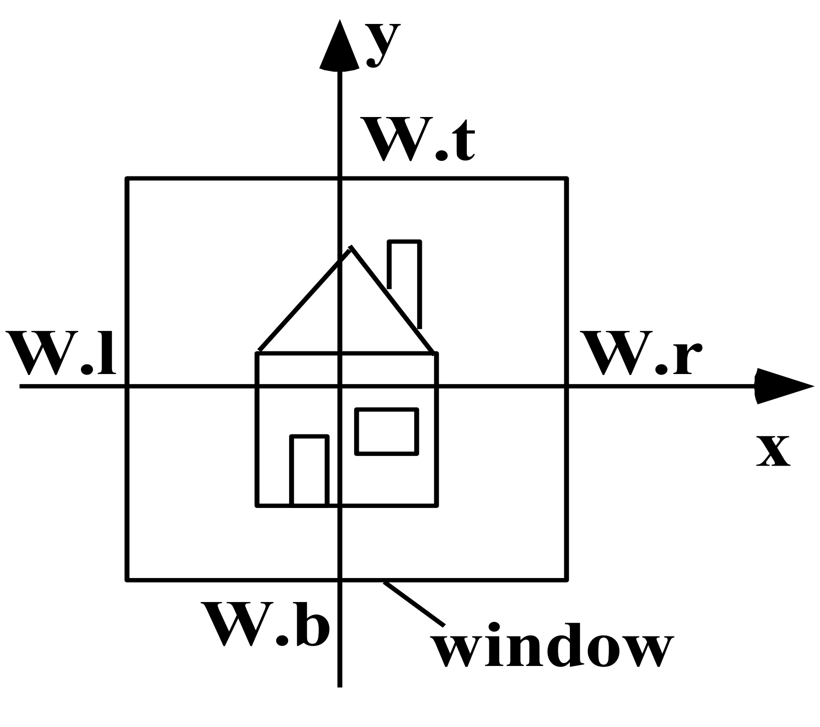
The default world window has aspect 1.0 (i.e. it is a square) – or it can be changed by the programmer to be a rectangle.

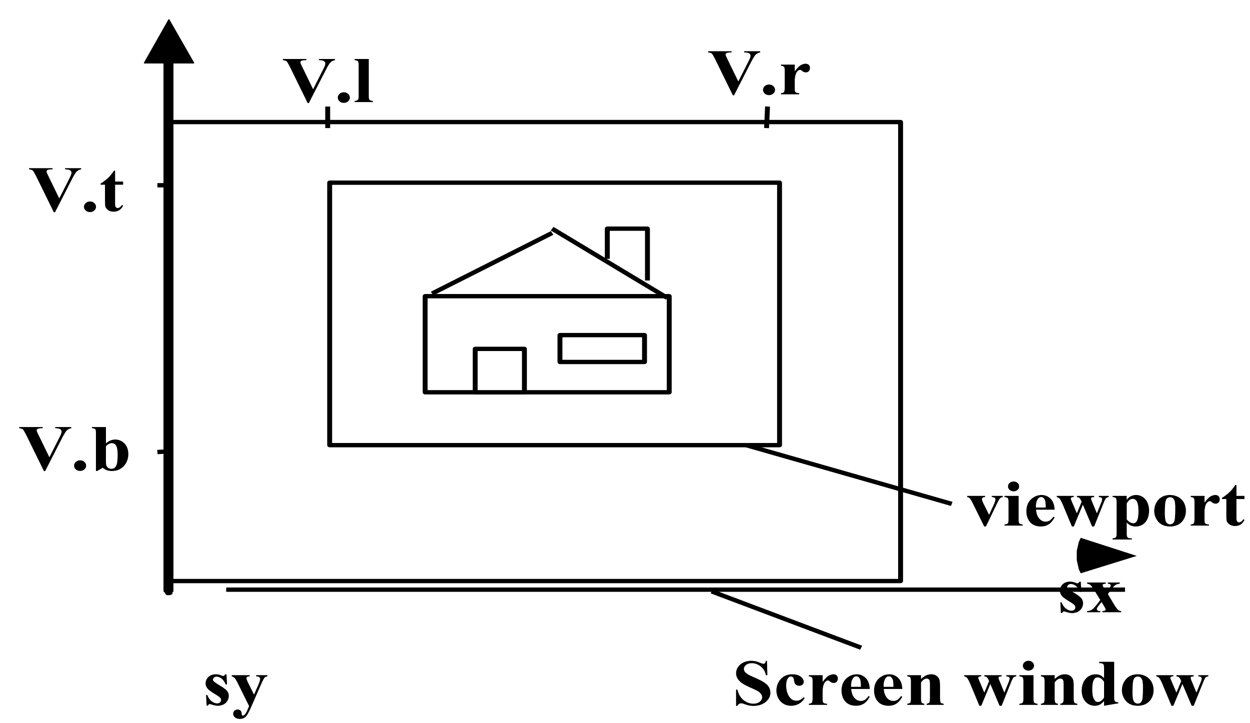
The aspect ratio of the viewport depends on the window shape – which the user can change.

Mapping Windows

Opengl maps the world window to the viewport automatically by stretching the world to fit into the viewport.

If the aspect ratios of the 2 rectangles are not the same, distortion will result.





Maintaining Aspect Ratio

We can resize the world window to match its aspect ratio to viewport.

The reshape() method is called whenever the window/panel changes size.

If the viewport’s width is greater than its height, show more of the world model in the x-direction and vice versa.

gluOrtho2D

```
public void reshape(GLAutoDrawable d,
      int x, int y, int w, int h) {

  GL2 gl = drawable.getGL().getGL2();
  GLU glu = new GLU();

  double aspect = (1.0 * w) / h;
  //Tell gl what matrix to use and
  //initialise it to 1

  gl.glMatrixMode(GL2.GL_PROJECTION);
  gl.glLoadIdentity();
```

gluOrtho2D…

```
double size = 1.0;
if(aspect >=1){
    // left, right, top, bottom
    glu.gluOrtho2d( -size * aspect,
                     size * aspect,
                        -size, size);
} else {
    glu.gluOrtho2d( -size, size,
                    -size/aspect,
                     size/aspect);
}
```

Mouse Events

When we click on the screen we get the mouse co-ordinates in screen co-ordinates.

We need to somehow map them back to world co-ordinates.

We have provided a utility class to help do this as it is little messy/tricky at this point.

Debugging

Can use DebugGL2 or TraceGL2 or both.

In init:

```
drawable.setGL(new DebugGL2(
                    new TraceGL2(
                    drawable.getGL().getGL2(),
                    System.err)));
```