PUC RIO

Universidade Federal Fluminense

Computer Graphics for Engineering

TU Graz
Graz University of Technology

ifb

numsim
Numerical simulation in technical sciences

Color / OpenGL

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Graz, Austria
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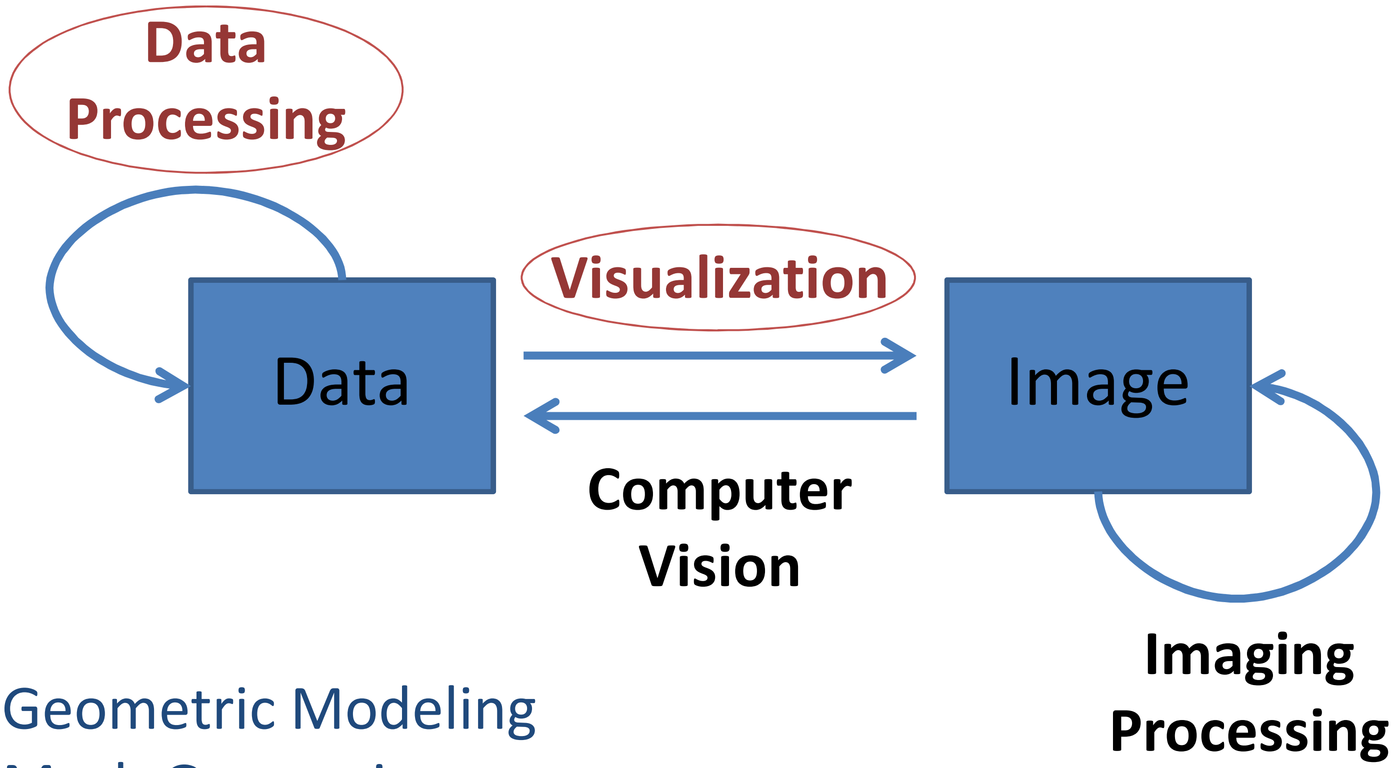
To Remember

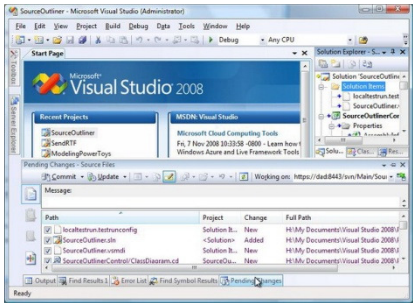
Computer Graphics

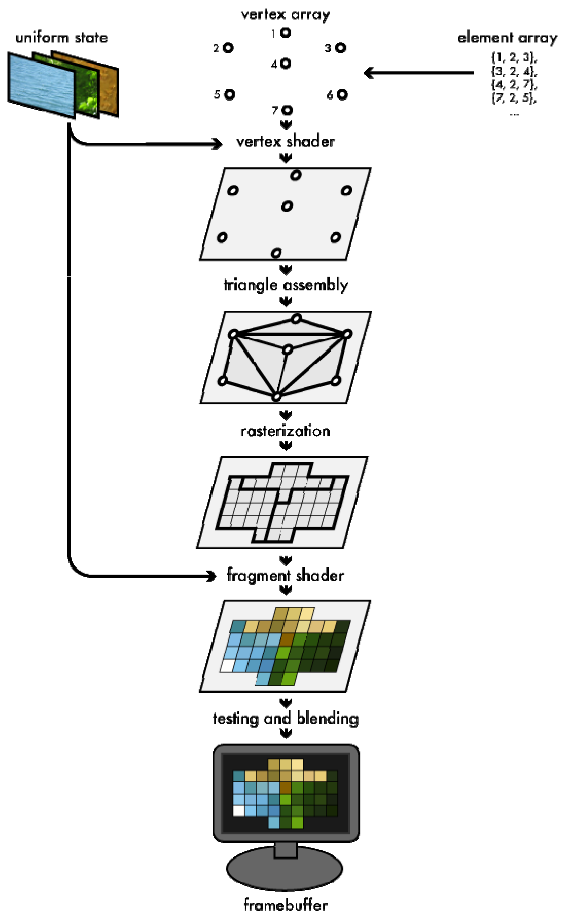


- Geometric Modeling
- Mesh Generation
- Computational Geometry
- Visualization Techniques (Post-processing)

Development Environment

C++





Color

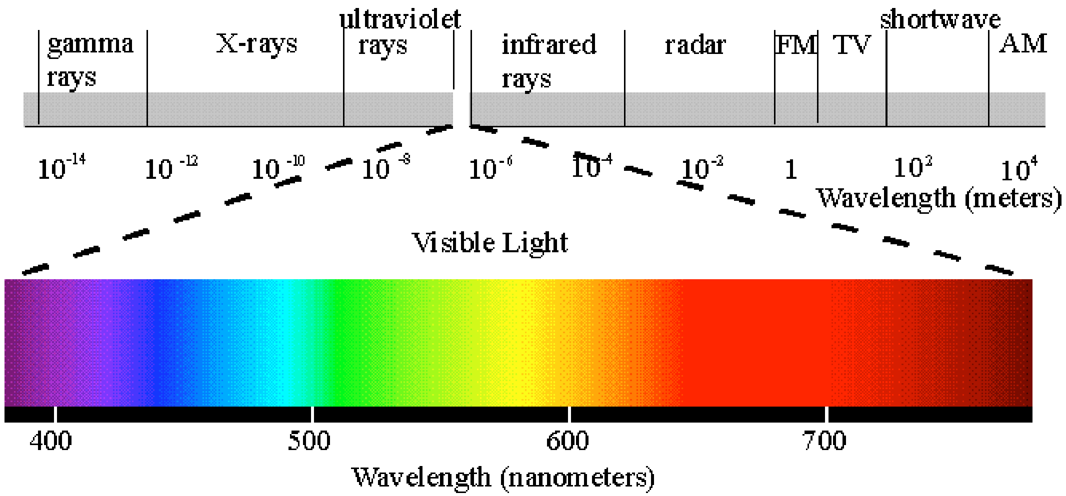
COLOR

How can one perceive and how to quantify the color?

COLOR

How can one perceive and how to quantify the color?

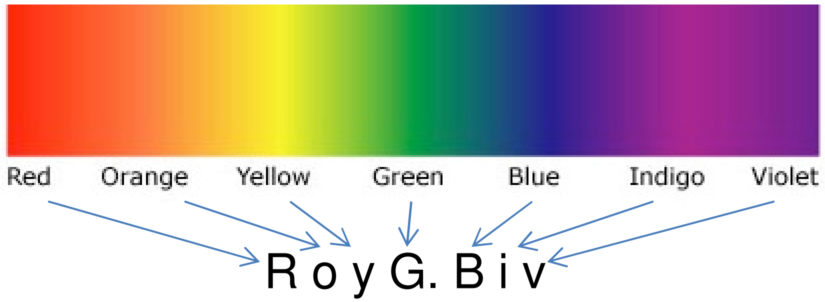
Lìght: radiation in a particular range of wavelengths.



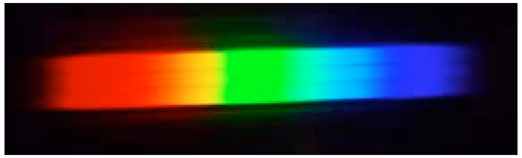
Light of a single wavelength is called **monochormatic**.

Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Light at a single frequency



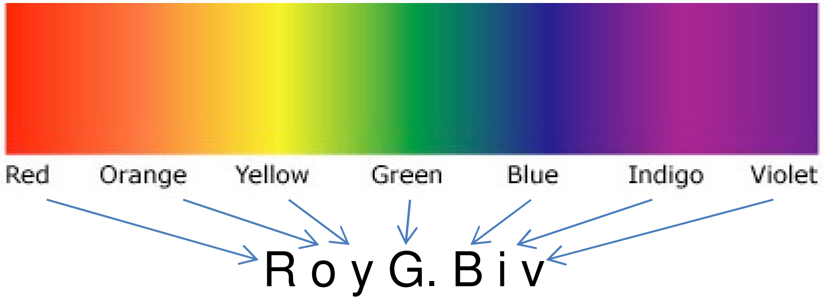
Bright and distinct in appearance



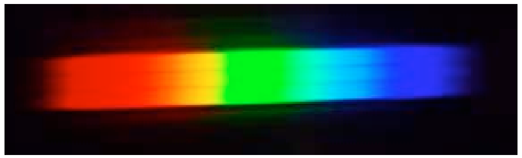
Reproduction only,
not a real spectral color!

Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Light at a single frequency



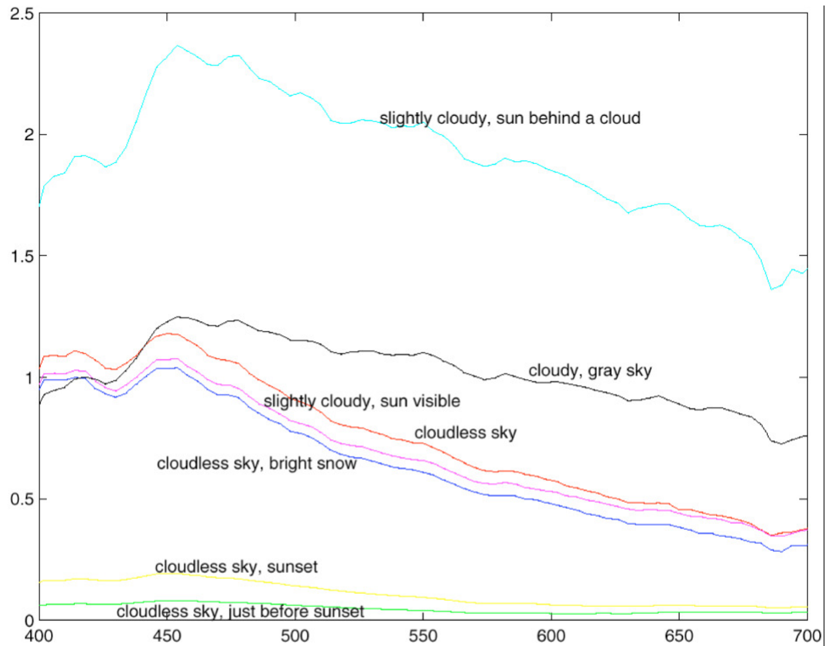
Bright and distinct in appearance



Reproduction only,
not a real spectral color!

Most colors seen are a mix light of several wavelengths .

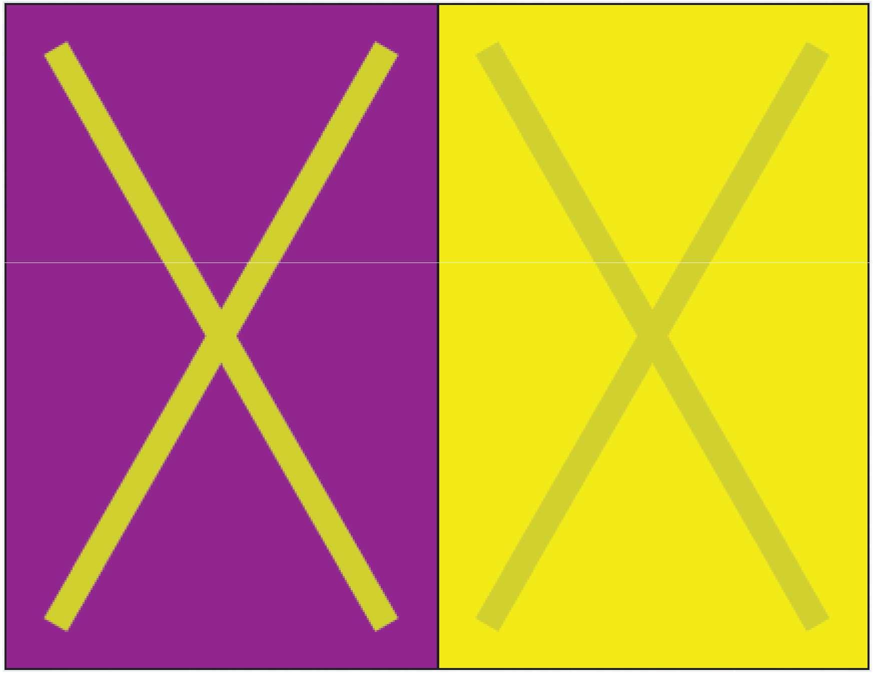
Curves describe spectral composition $\Phi(\lambda)$ of stimulus



Perception -vs- Measurement

You do not “see” the spectrum of light

Everything is Relative!



Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Perception -vs- Measurement

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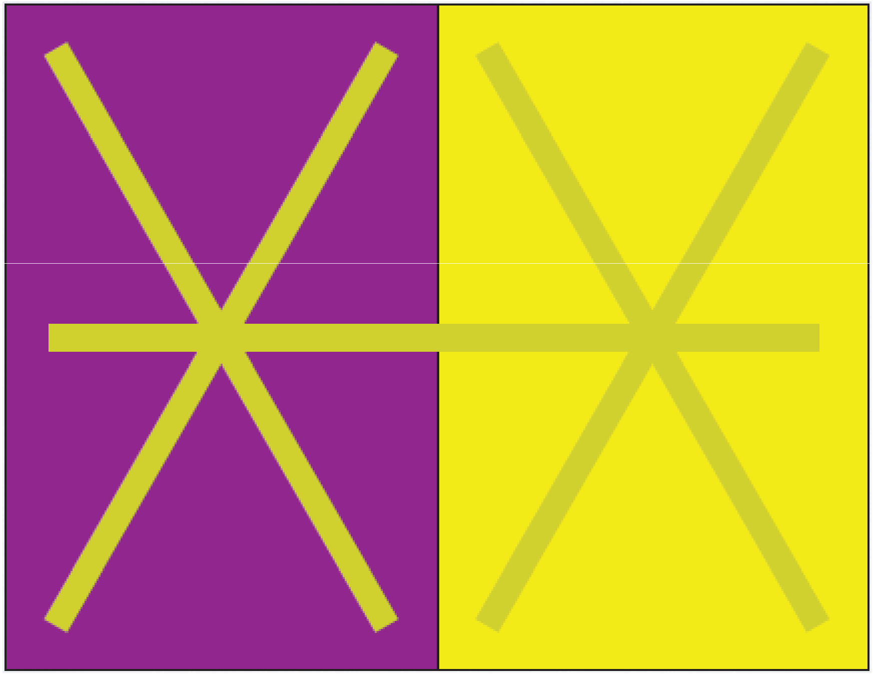
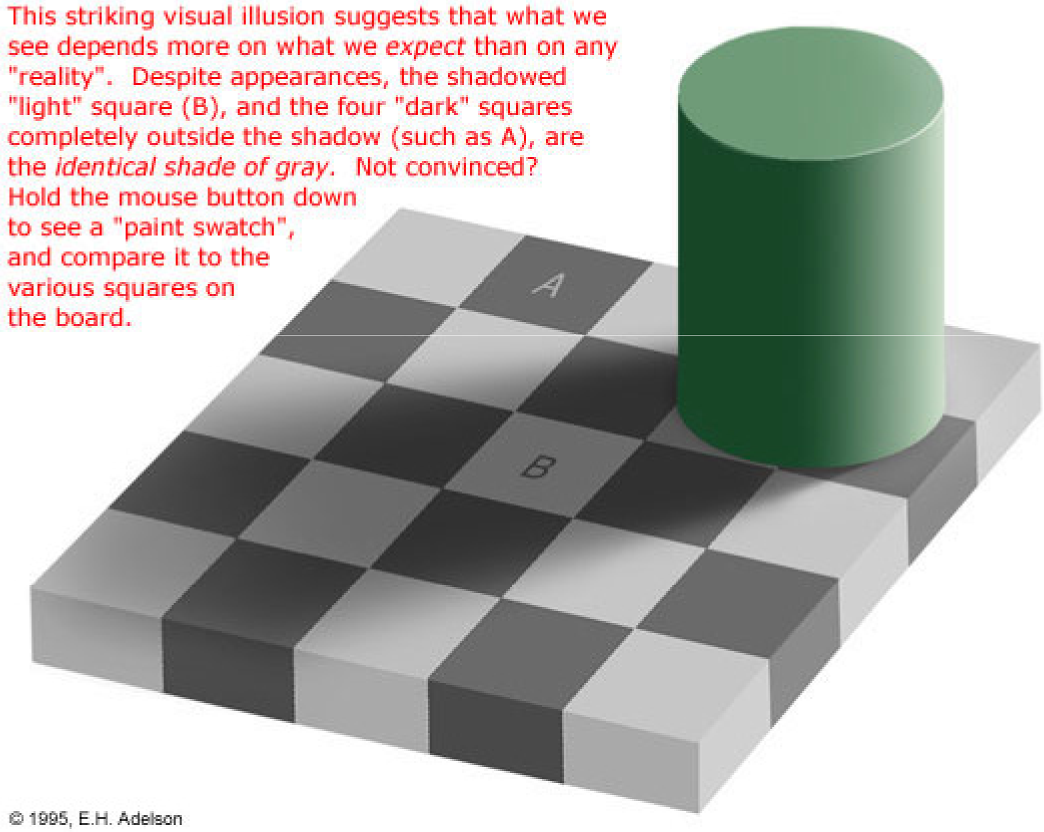


Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

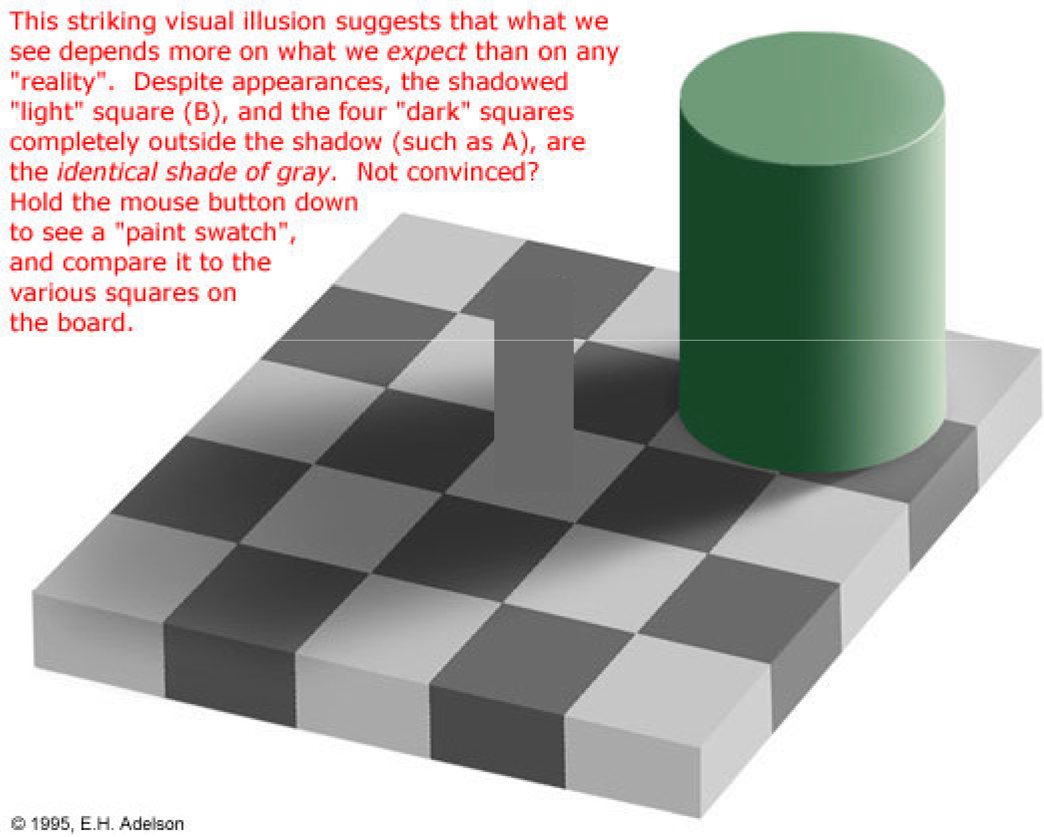
Perception

The eye does not see intensity values…



Perception

The eye does not see intensity values…



Eyes as Sensors

Eye records color by 3 measurements
We can “fool” it with combination of 3 signals

So display devices (monitors, printers, etc.) can generate perceivable colors as mix of 3 primaries

Response to stimulus $\Phi 1$ is (L1, M1, S1)
Response to stimulus $\Phi 2$ is (L2, M2, S2)

Then response to $\Phi 1 + \Phi 2$ is (L1+L2, M1+M2, S1+S2)

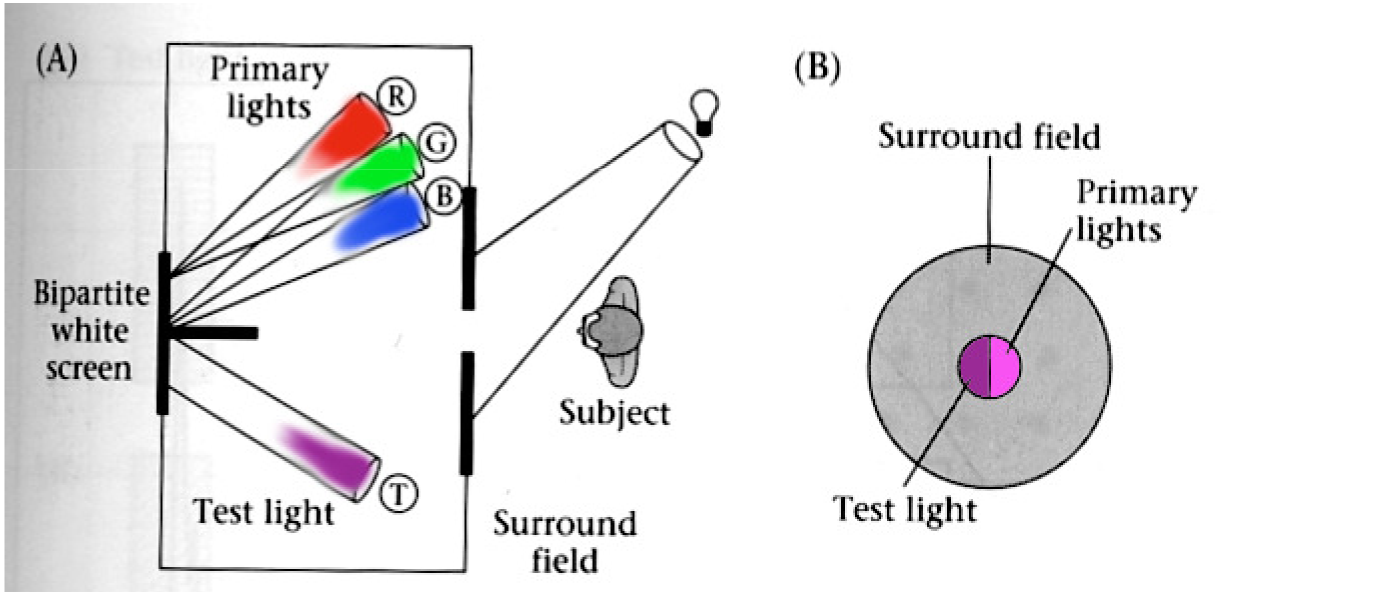
Response to n $\Phi 1$ is (n L1, n M1, n S1)

System that obeys **superposition** and **scaling** is called a **linear system**

Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Additive Mixing

Given three primaries we agree on p1, p2, p3
Match generic input light with $\Phi = \alpha\ p1 + \beta\ p2 + \gamma\ p3$
Negative not realizable, but can add primary to test light.
Color now described by α, β, γ
Example: computer monitor [R,G,B]

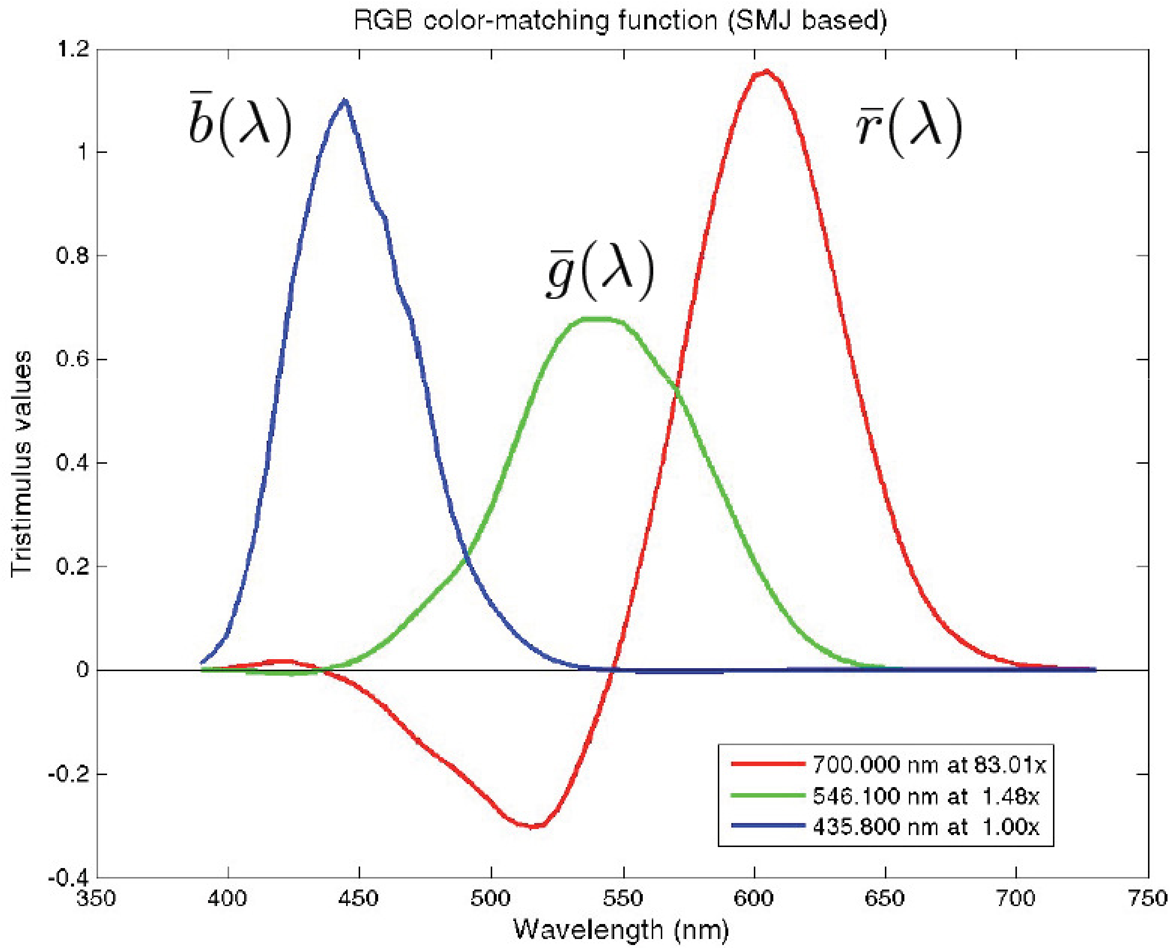


4.10 THE COLOR-MATCHING EXPERIMENT. The observer views a bipartite field and adjusts the intensities of the three primary lights to match the appearance of the test light. (A) A top view of the experimental apparatus. (B) The appearance of the stimuli to the observer. After Judd and Wyszecki, 1975.

Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Color Matching Functions

Input wavelengths are CIE 1931 monochromatic primaries

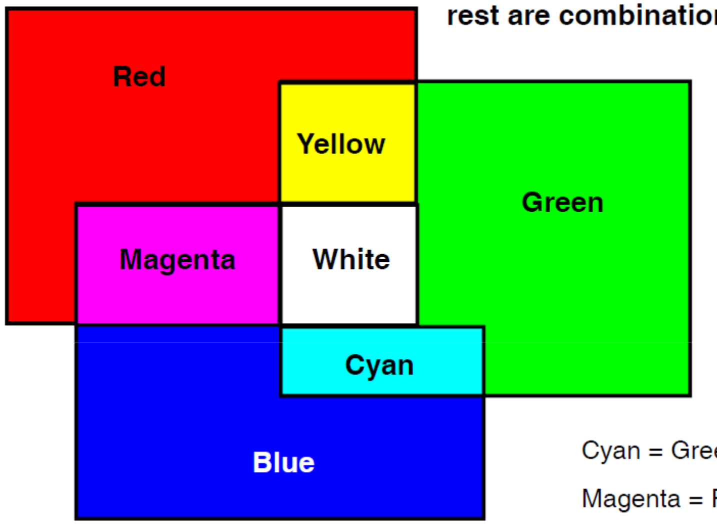


Source: Agrawala , 2014 – Lecture Notes on Computer Graphics at UCBerkley

Color Representation

The Framebuffer Uses Additive Colors (RGB)

Red, Green, and Blue are provided. The rest are combinations of those three.

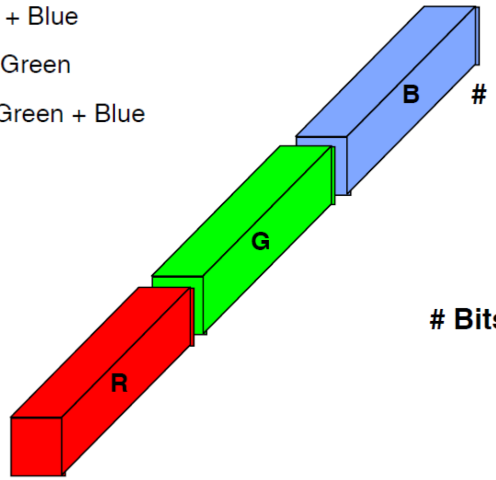


Cyan = Green + Blue

Magenta = Red + Blue

Yellow = Red + Green

White = Red + Green + Blue

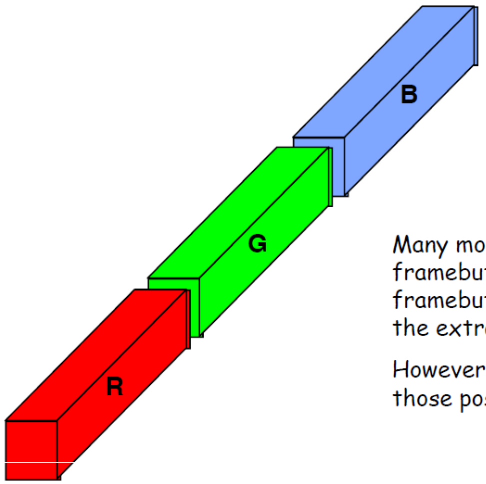


# Bits/color	# Intensities per color
8	2^8 = 256
10	2^{10} = 1024
12	2^{12} = 4096

# Bits/pixel	Total colors:
24	2^{24} = 16.7 M
30	2^{30} = 1 B
36	2^{36} = 69 B

The Framebuffer:
Floating Point Color Storage

- *16- or 32-bit floating point for each color component*



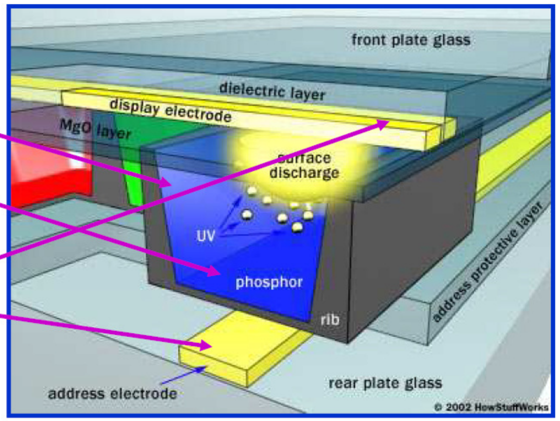
Why so much?

Many modern algorithms do arithmetic on the framebuffer color components, or treat the framebuffer color components as data. They need the extra precision during the arithmetic.

However, the display system cannot display all of those possible colors.

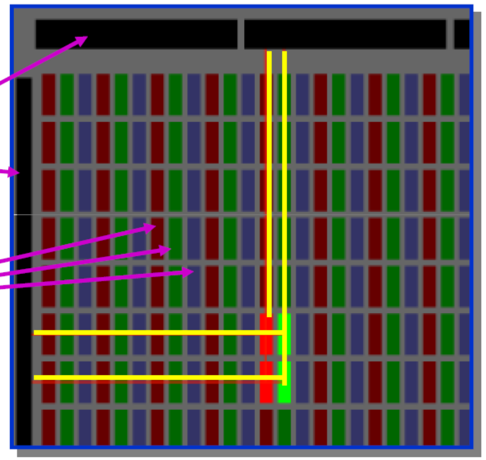
Displaying Color on a Plasma Monitor

- **Gas cell**
- **Phosphor**
- **Grid of electrodes**

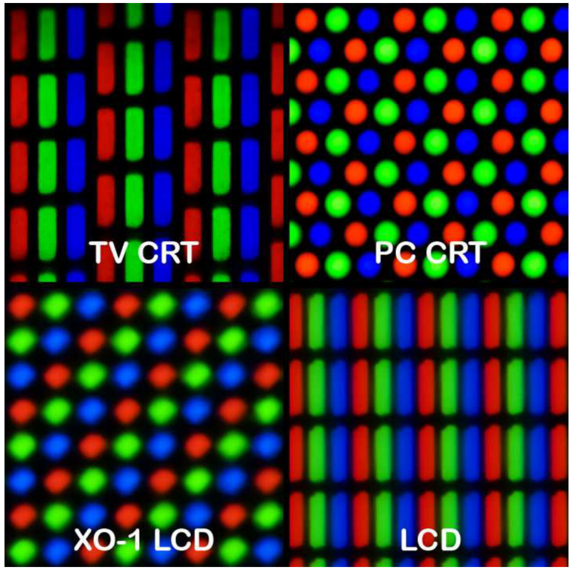


Displaying Color on a Computer Graphics LCD Monitor

- Grid of electrodes
- Color filters



Source: http://electronics.howstuffworks.com

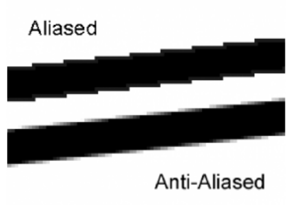


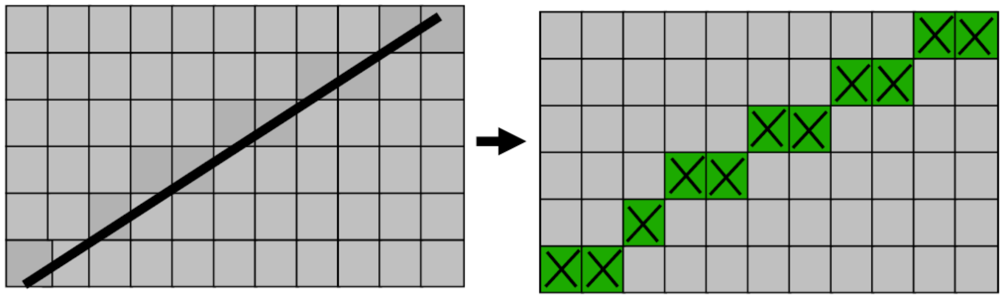
Display Resolution

- ***Pixel*** resolutions (1280x1024, 1600x1200, 1920x1152 are common on the desktop)
- Screen size (13", 16", 19", 21" are common)
- Human acuity: 1 arc-minute is achieved by viewing a 19" monitor with 1280x1024 resolution from a distance of ~40 inches

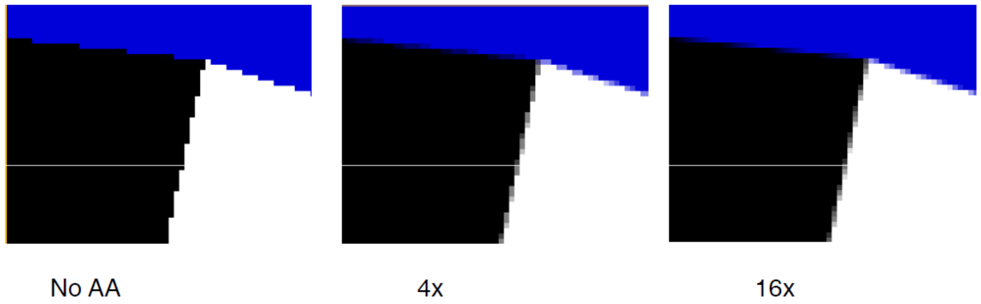
Rasterization

- Turn screen space vertex coordinates into pixels that make up lines and polygons
- A great place for custom electronics
- Anti-aliasing is often built-in





Anti-aliasing is Implemented by Oversampling within Each Pixel



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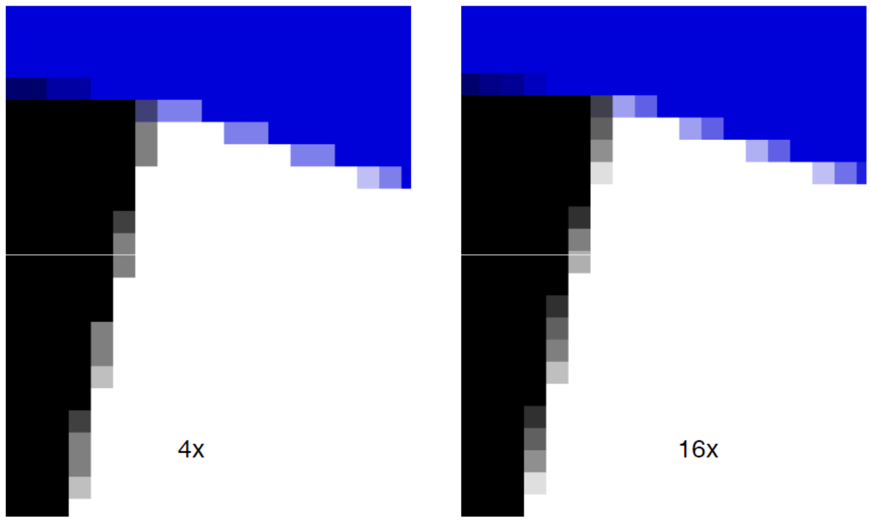


OpenGL

OpenGL

OpenGL

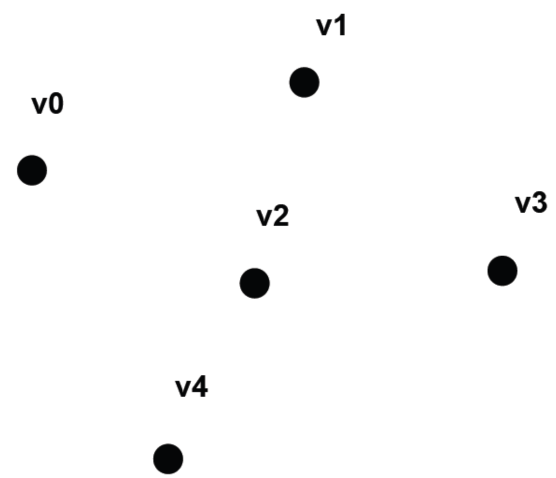
- Programming API (API) for hardware accelerated 2D/3D graphics
- Platform independent
- Generic
- Flexible
- Low level...

Drawing

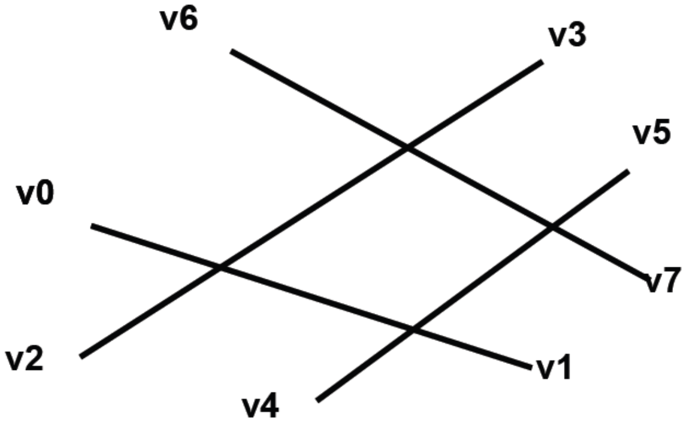
- All drawing accomplished using 10 primitives
- Same basic principle

```
// Draw 4 points
glBegin(GL_POINTS)
glVertex2i(-50,-50)
glVertex2i(50,-50)
glVertex2i(50,50)
glVertex2i(-50,50)
glEnd()
```

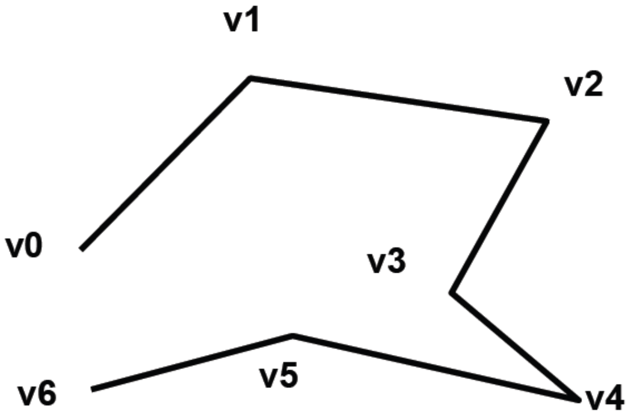
GL_POINTS



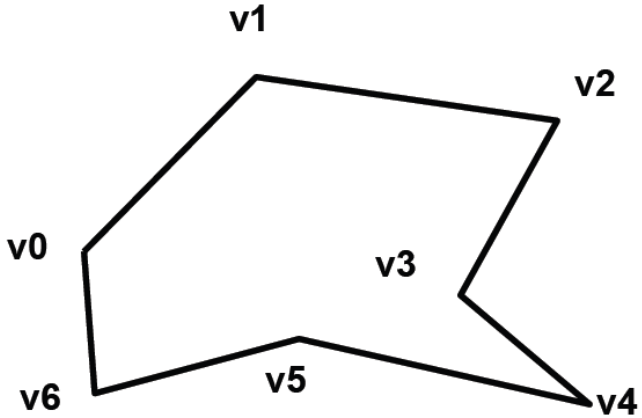
GL_LINES



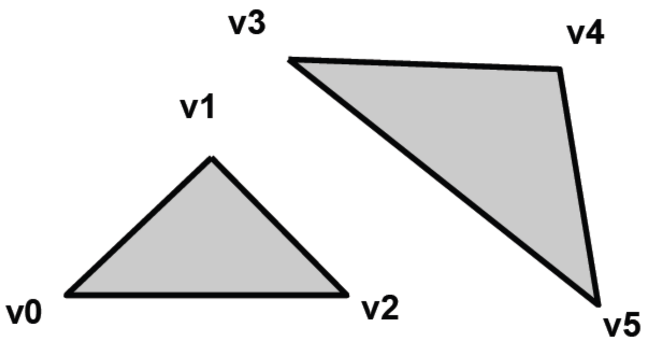
GL_LINE_STRIP



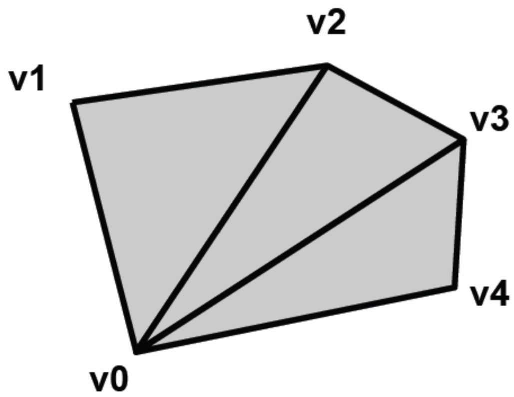
GL_LINE_LOOP



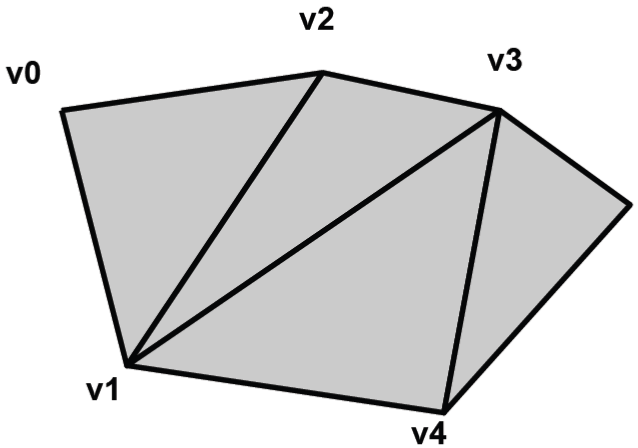
GL_TRIANGLES



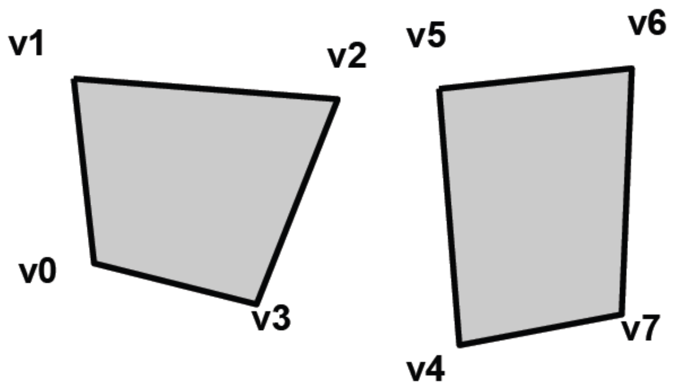
GL_TRIANGLE_FAN



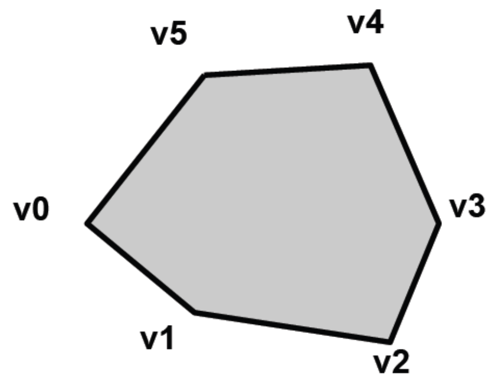
GL_TRIANGLE_STRIP



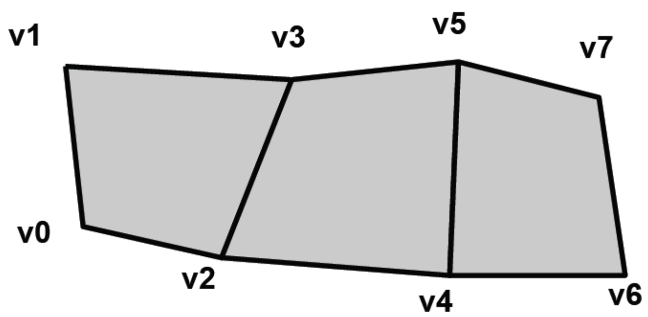
GL_QUADS



GL_POLYGON

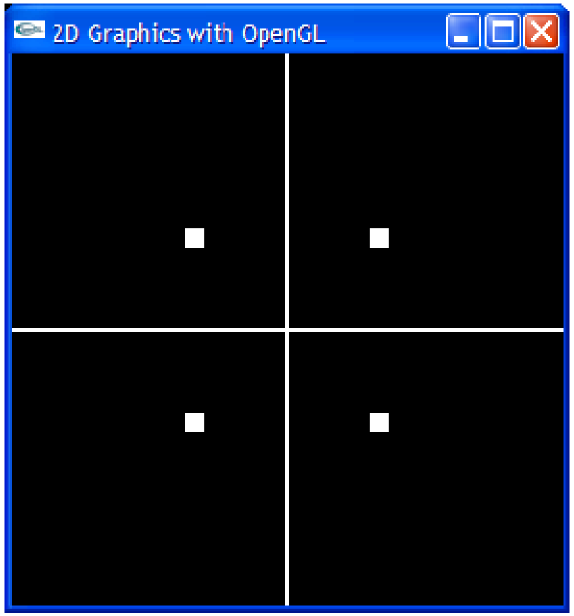


GL_QUAD_STRIP



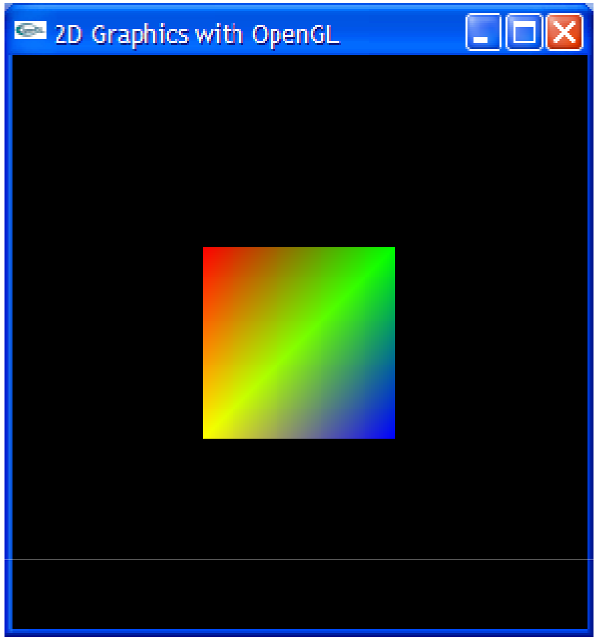
Primitive properties

- Points and lines
  – Outside glBegin()/glEnd()
  – line width, glLineWidth(2.0)
  – Point size
- Color
  – Given on a vertex level
  – Inside glBegin()/glEnd()
  – Given in RGB, where 1.0 max intensity and 0.0 is minimum intensity
  – Color is interpolated between vertices




```
// Set white color
glColor3f(1.0, 1.0, 1.0);
// Set the line width
glLineWidth(2.0);
glBegin(GL_LINES);
glVertex2i(-1000,0);
glVertex2i(1000,0);
glVertex2i(0,-1000);
glVertex2i(0, 1000);
glEnd();
// Set point size
glPointSize(5);
glBegin(GL_POINTS);
glVertex2i(-50, -50);
glVertex2i( 50, -50);
glVertex2i( 50, 50);
glVertex2i(-50, 50);
glEnd();
```

```
glBegin(GL_QUADS);
glColor3f(1.0, 0.0, 0.0); // Red color
glVertex2i(-50, -50);
glColor3f(0.0, 1.0, 0.0); // Green color
glVertex2i( 50, -50);
glColor3f(0.0, 0.0, 1.0); // Blue color
glVertex2i( 50, 50);
glColor3f(1.0, 1.0, 0.0); // Yellow color
glVertex2i(-50, 50);
glEnd();
```



Geometric transformations

• Transformations are important in computer graphics

– Translation

– Rotation

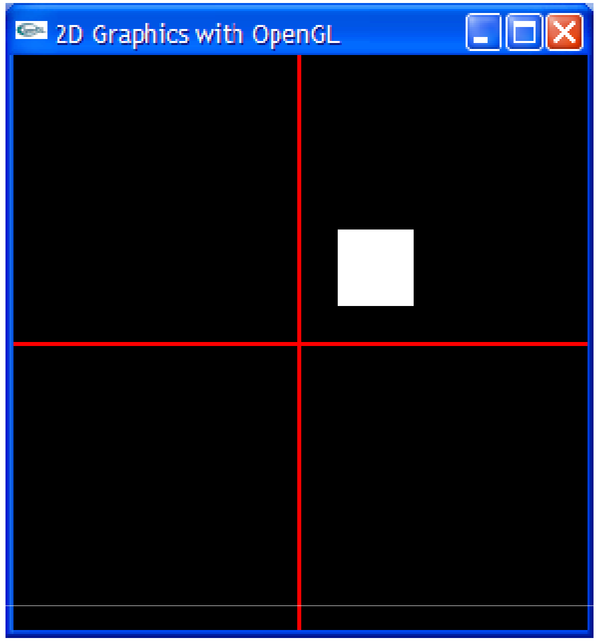
– Scaling

• OpenGL

– Transformation matrices implemented in hardware

– Model matrix - glMatrixMode(GL_MODELVIEW)

– Project matrix - glMatrixMode(GL_PROJECTION)



Initialising matrices

```
// Initialise model view matrix to identity
glMatrixMode(GL_MODELVIEW)
glLoadIdentity()
```

Translation

• Translating coordinate systems

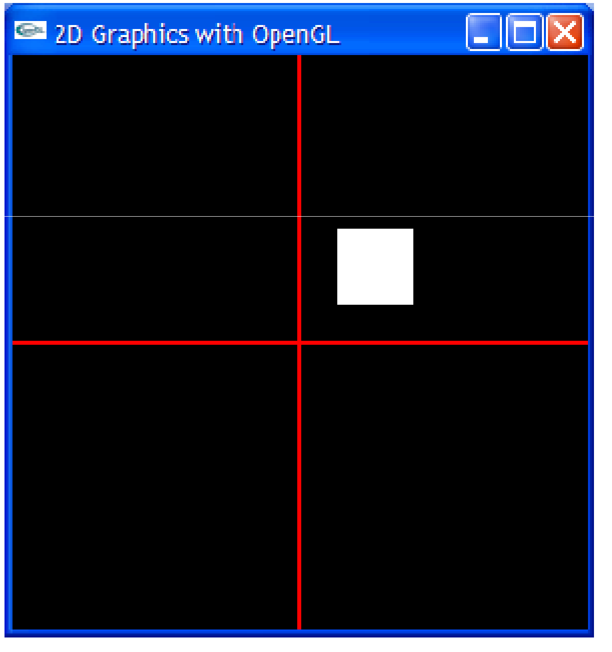
• glTranslatef(x, y, z)

• Current matrix in multiplied by a translation matrix

```
glTranslatef(40.0,40.0,0.0);
glBegin(GL_QUADS);
glColor3f(1.0,1.0,1.0);
glVertex2i(-20, -20);
glVertex2i(20,-20);
glVertex2i(20,20);
glVertex2i(-20,20);
glEnd();
```

Rotation

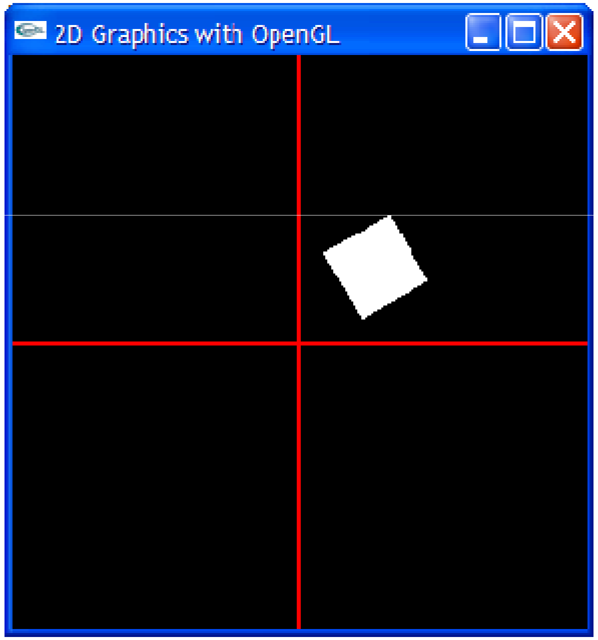
• Rotates coordinate system
• glRotatef(angle, axis_x, axis_y, axis_z)
• Right-hand rule
• Positive Z-axis out of the screen



Rotation

- Rotates coordinate system
- glRotatef(angle, axis_x, axis_y, axis_z)
- Right-hand rule
- Positive Z-axis out of the screen

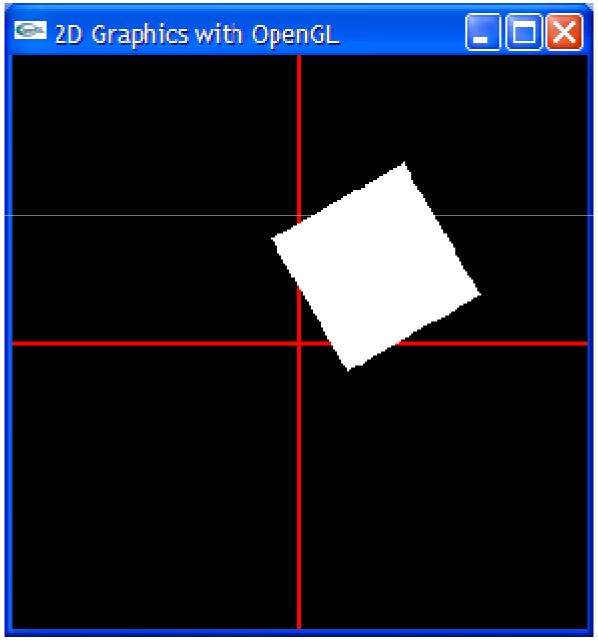
```
glTranslatef(40.0,40.0,0.0);
glRotatef(30.0,0.0,0.0,1.0);
glBegin(GL_QUADS);
glColor3f(1.0,1.0,1.0);
glVertex2i(-20,-20);
glVertex2i(20,-20);
glVertex2i(20,20);
glVertex2i(-20,20);
glEnd();
```



Scaling

- Scales current coordinate system
- glScalef(scale_x, scale_y, scale_z)

```
glTranslatef(40.0,40.0,0.0);
glRotatef(30.0,0.0,0.0,1.0);
glScalef(2.0,2.0,0.0);
glBegin(GL_QUADS);
glColor3f(1.0,1.0,1.0);
glVertex2i(-20,-20);
glVertex2i(20,-20);
glVertex2i(20,20);
glVertex2i(-20,20);
glEnd();
```



Problem with current method

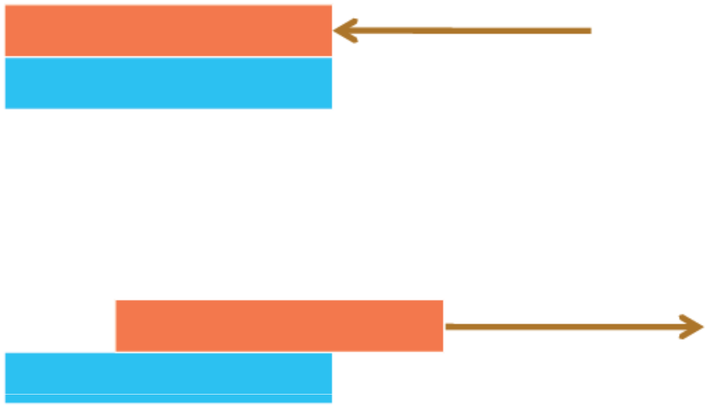
- Matrices constantly needs initialising
- Difficult implement hierarchical tranformations
- Many matrix multiplications

OpenGL Matrix stack

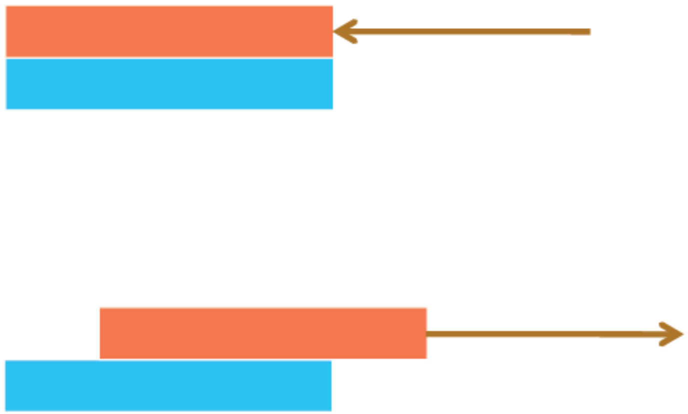
- Stack of matrices
- Top is the current matrix
- If a matrix is added it is assigned the values of the top level matrix.
  - glPushMatrix()
- Matrices can be discarded using glPopMatrix()
- Reduce the matrix multiplications
- Speeds up the code
- Implemented in hardware

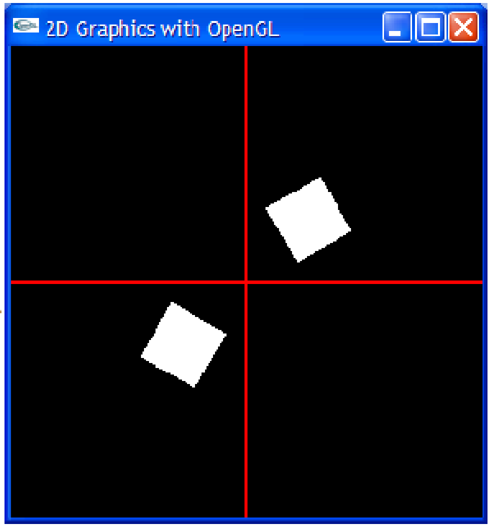
glPushMatrix()/glPopMatrix()

```
glPushMatrix()
glTranslatef(40.0, 40.0, 0.0)
glRotatef(30.0, 0.0, 0.0, 1.0)

glBegin(GL_QUADS)
glColor3f(1.0, 1.0, 1.0)
glVertex2i(-20, -20)
glVertex2i( 20, -20)
glVertex2i( 20,  20)
glVertex2i(-20,  20)
glEnd()
glPopMatrix()
```



```
glPushMatrix()
glTranslatef(-40.0, -40.0, 0.0)
glRotatef(-30.0, 0.0, 0.0, 1.0)

glBegin(GL_QUADS)
glColor3f(1.0, 1.0, 1.0)
glVertex2i(-20, -20)
glVertex2i( 20, -20)
glVertex2i( 20,  20)
glVertex2i(-20,  20)
glEnd()
glPopMatrix()
```





Drawing in the screen buffer

- Must be cleared for every frame
- glClear(GL_COLOR_BUFFER_BIT)
- Background color
  - glClearColor(red, green, blue)
- Double buffering
  - Reduces flickering
  - All drawing in back buffer
  - Switch between front and back buffer after drawing

Projection and screen view

- The projection matrix maps model coordinates to screen coordinates
- glMatrixMode(GL_PROJECTION)
- 2D = Orthographic projection
  - gluOrtho2D(left, right, top, bottom)

Initializing project matrix

```
// Initiate project matrix
glMatrixMode(GL_PROJECTION)
glLoadIdentity()
// Create a 2D projection matrix
gluOrtho2D(0, width, 0, height)
// Initialize the modelview matrix to identity
glMatrixMode(GL_MODELVIEW)
glLoadIdentity()
```

Viewport

- Defines where in a window the drawing is to be done
  - glViewport(x,y,width,height)
- Enables multiple views in a single window
- Must be updated when window is resized