1.2 Basic Graphics Programming

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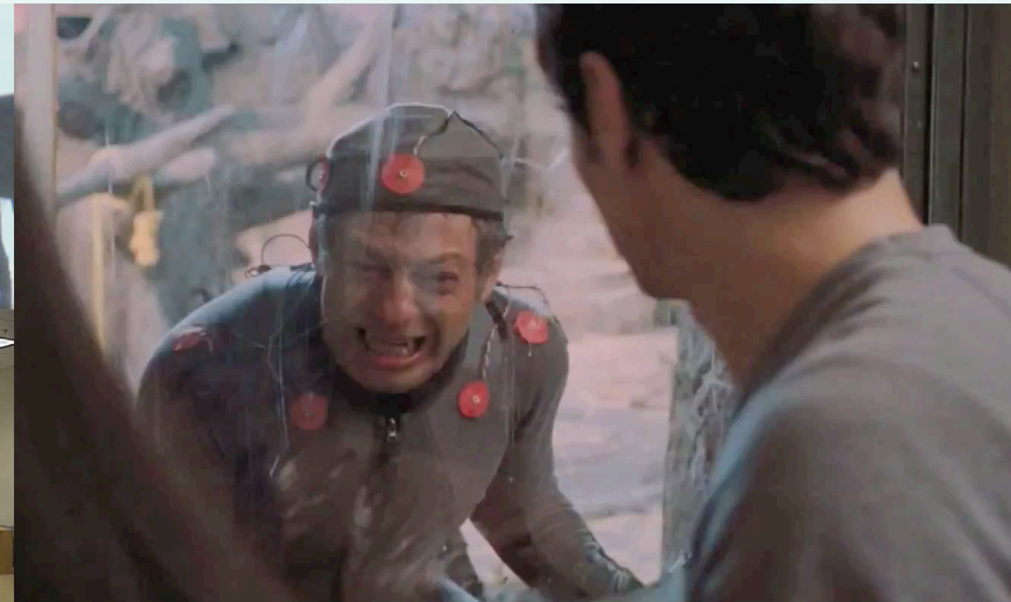
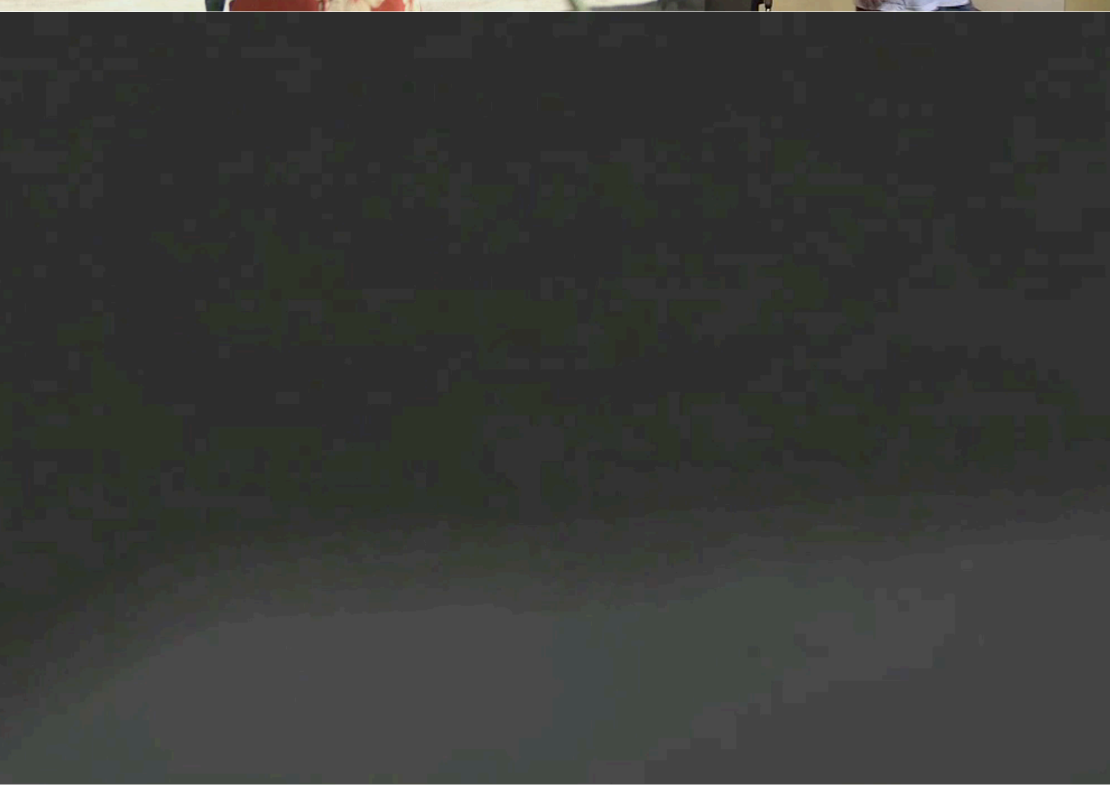
Last time


element



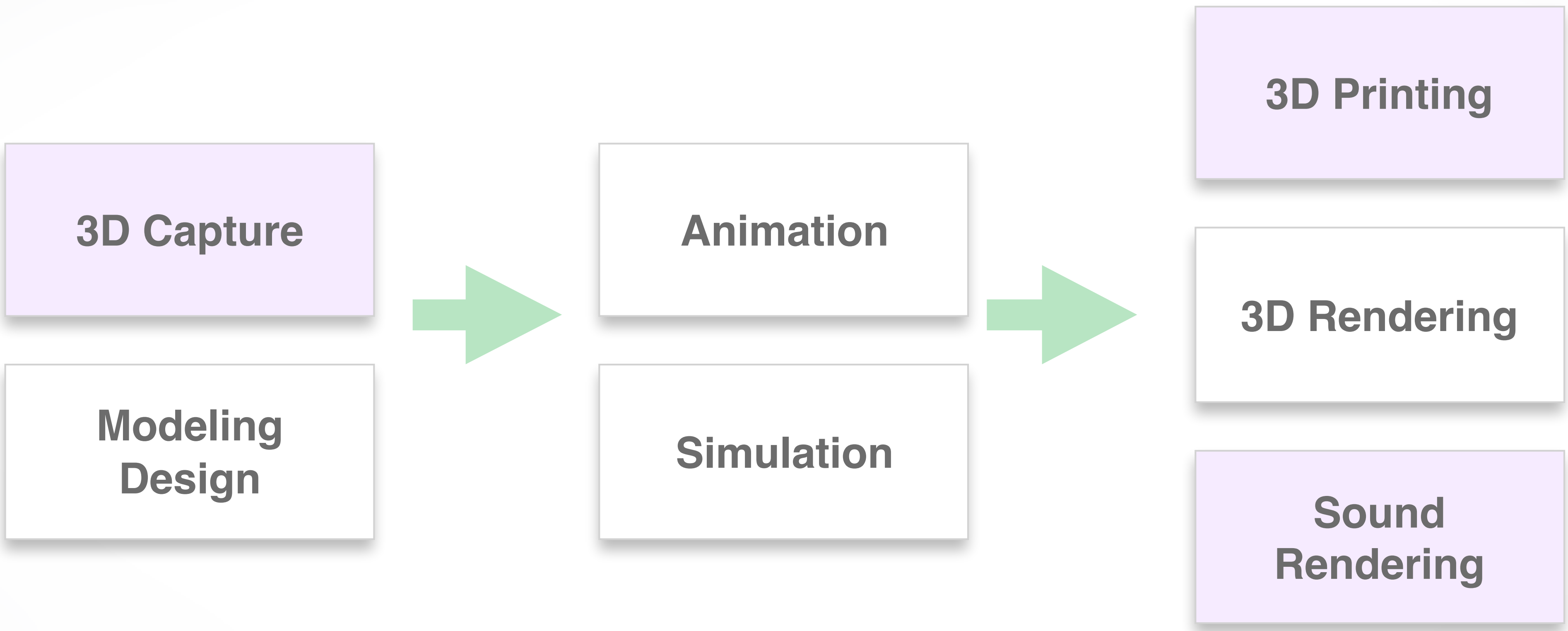



Ps
File Edit Image Layer Type Select Filter 3D View Window Help
Brush Presets
Brush Tip Shape
Shape Dynamics
Scattering
Texture
Dual Brush
Color Dynamics
Transfer
Brush Pose
Noise
Wet Edges
Build-up
Smoothing
Protect Texture
Bristle Qualities
Spacing
Mini Bridge
Timeline

Last Time

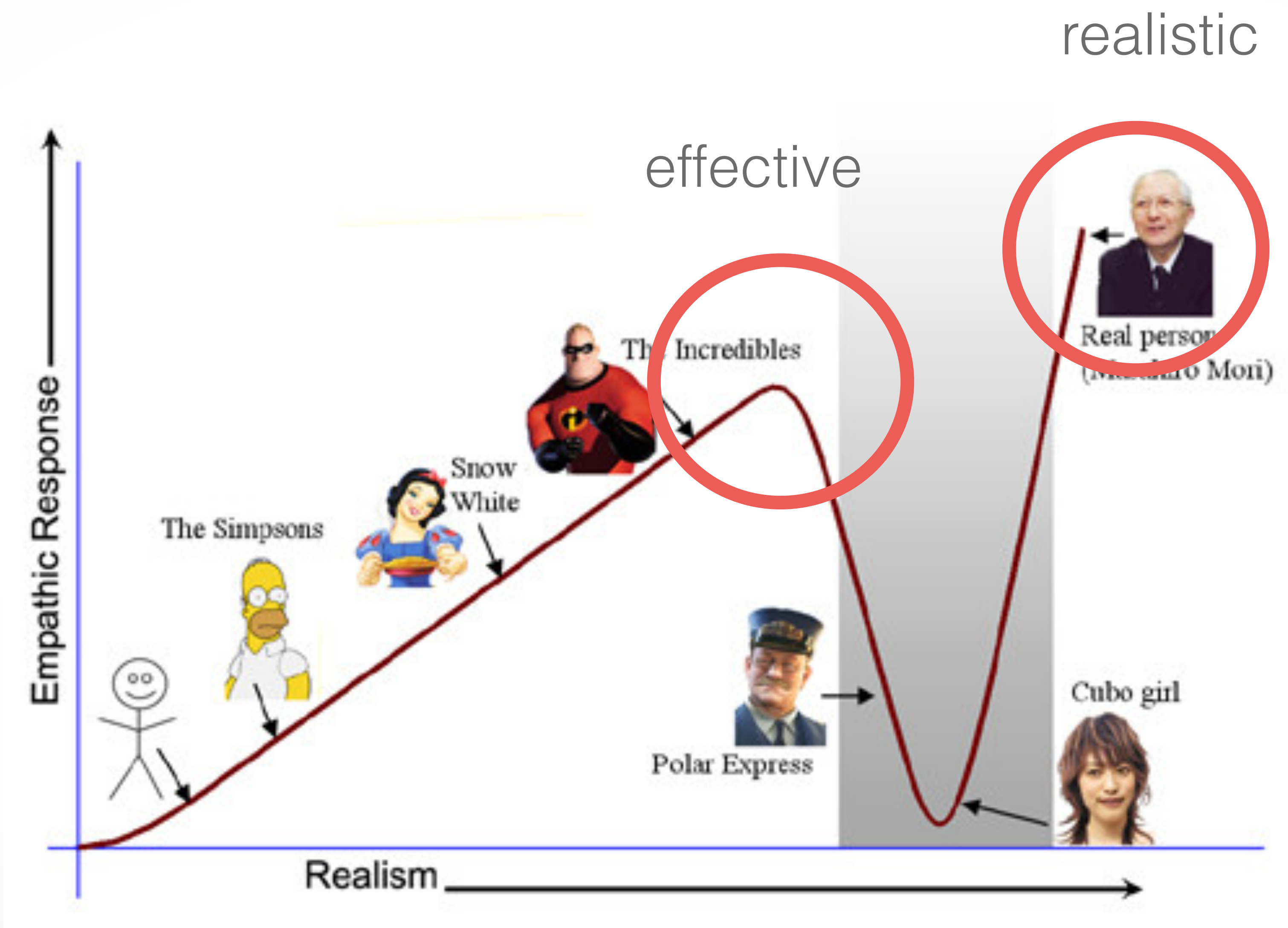
Story → Computer Graphics → Image

Last Time



emerging fields

Last Time



realistic
effective
Incredibles
Real person
Snow White
The Simpsons
Polar Express
Cubo girl
Empathic Response
Realism

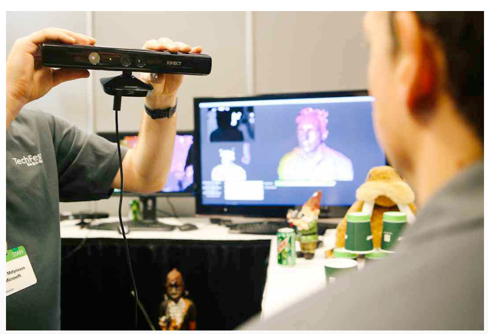
Last Time

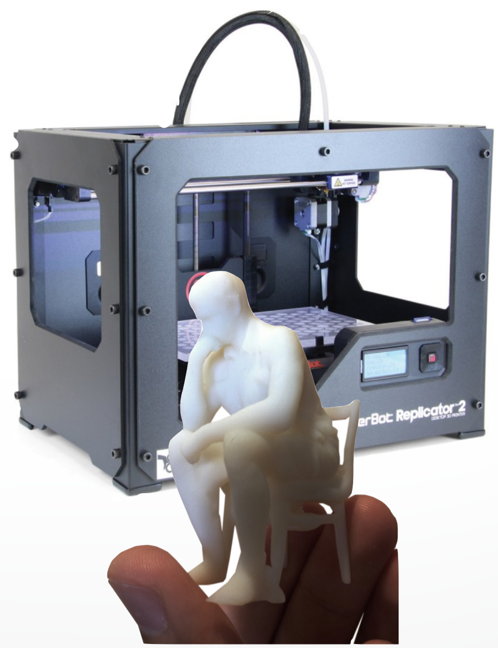
From Offline to Realtime

From Graphics to Vision

From Graphics to Fabrication

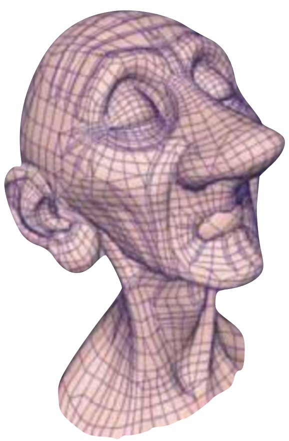
From Production to Consumers

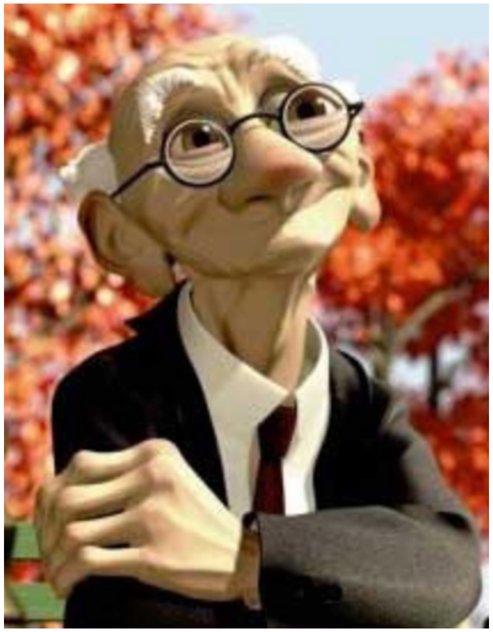




Render [ren-der]

To generate an image or animation





input data

output rendering

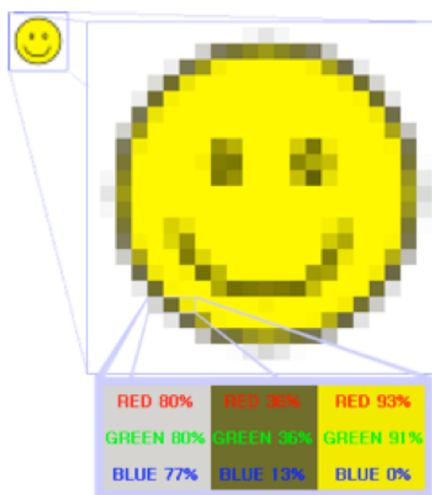
How to make an image?

drawing

photography

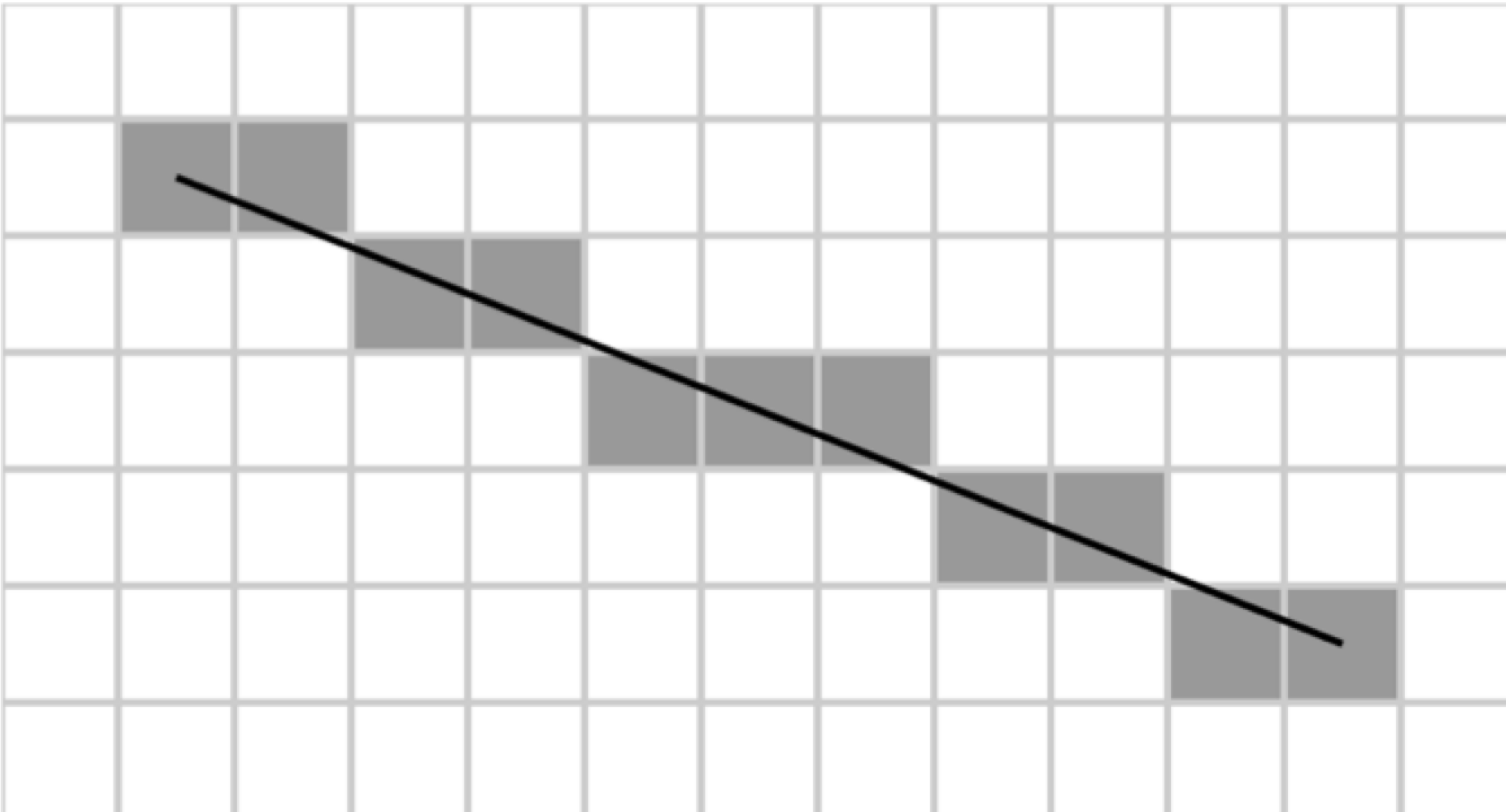
Output: Raster Image

- 2D array of pixels (**pic**ture **el**ements)
  - regular grid sampling of arbitrary 2D function
  - different formats, e.g., bitmaps, grayscale, color
  - different data types, e.g., boolean, int, float
  - color/bit depth: #bits/pixel
  - transparency handled by alpha channel, e.g., RGBA

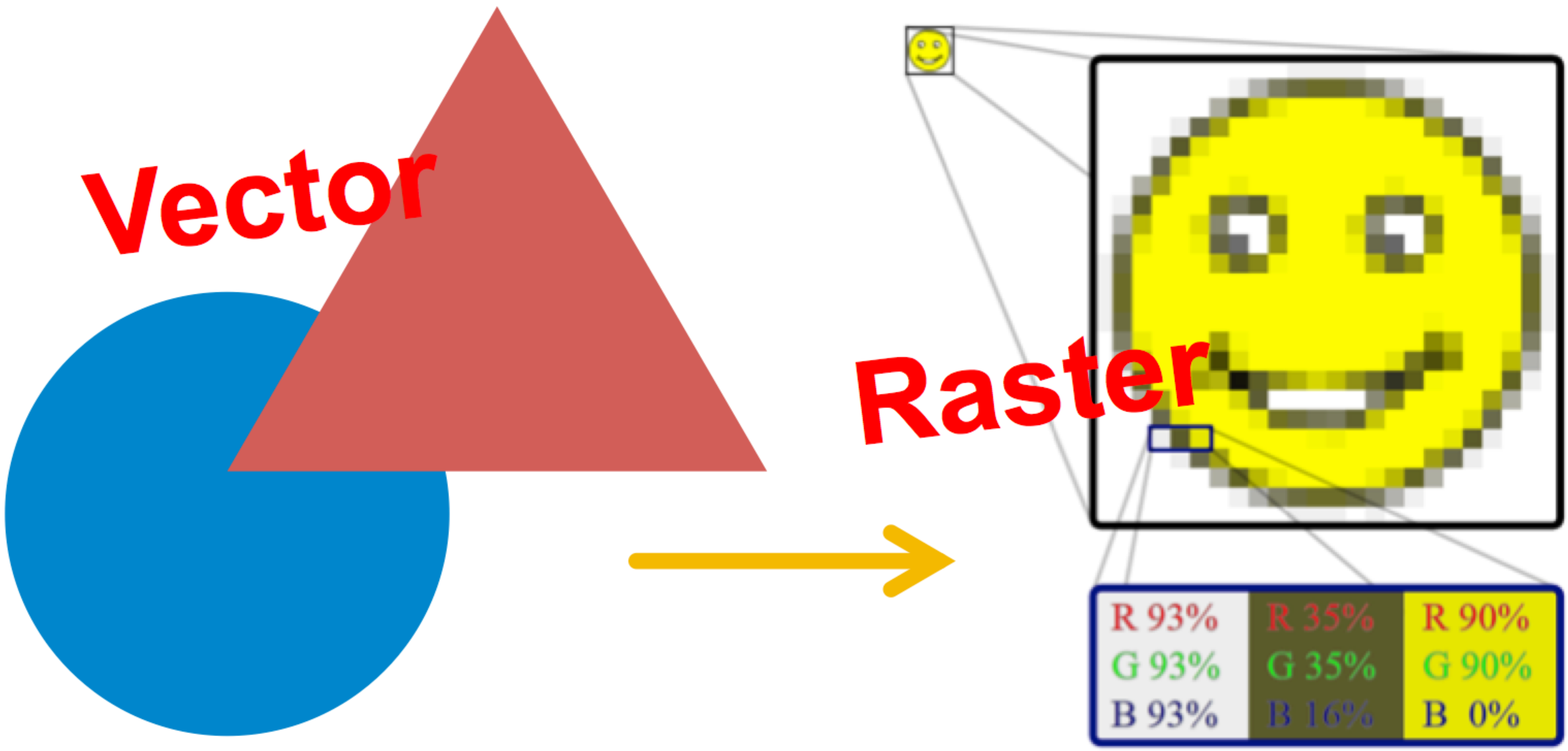


[wikipedia]

Rasterization



Rasterization

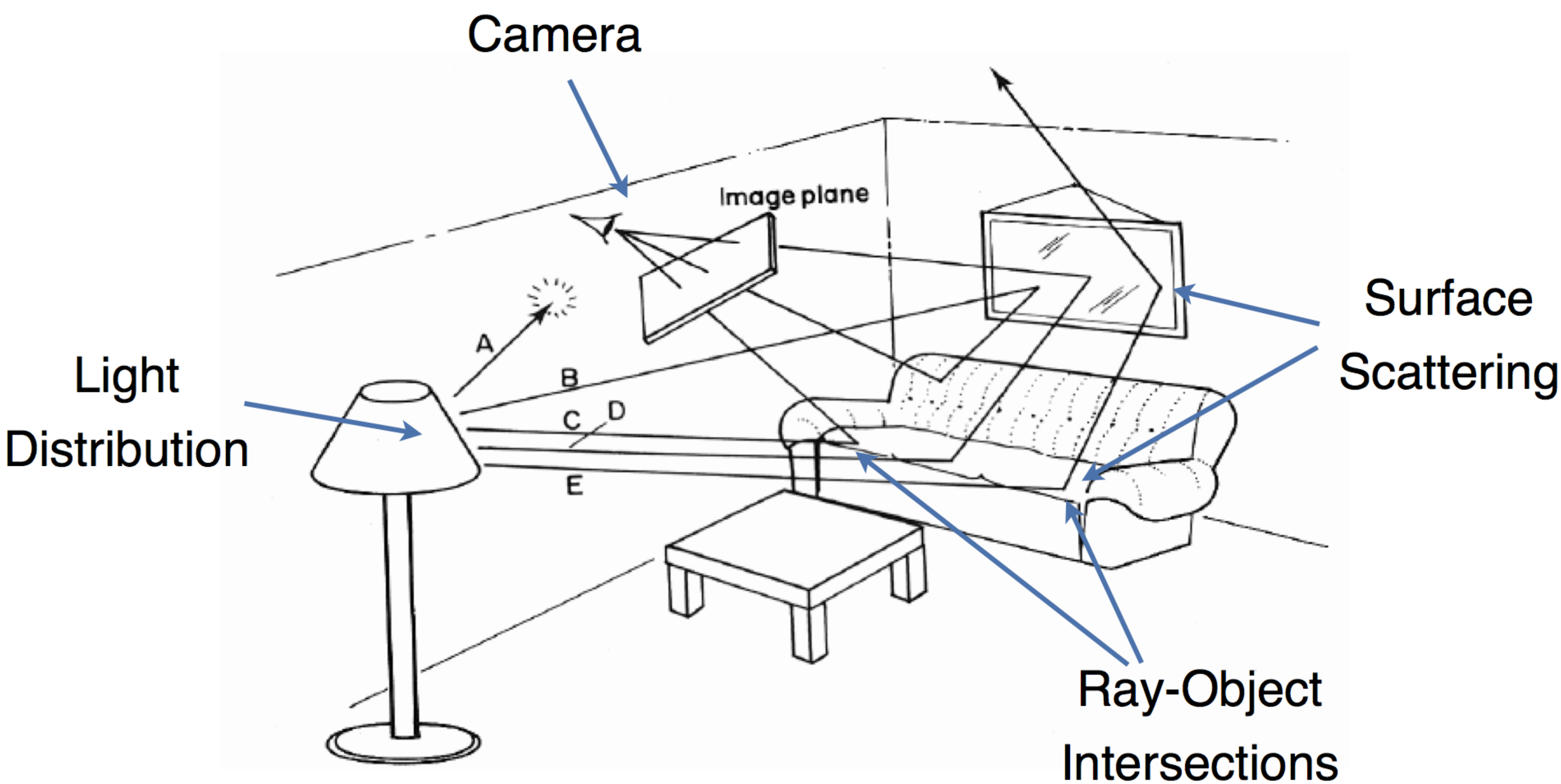


"A triangle is here, a circle is there, …"

"This pixel is yellow…"

Okay… let's take a step back

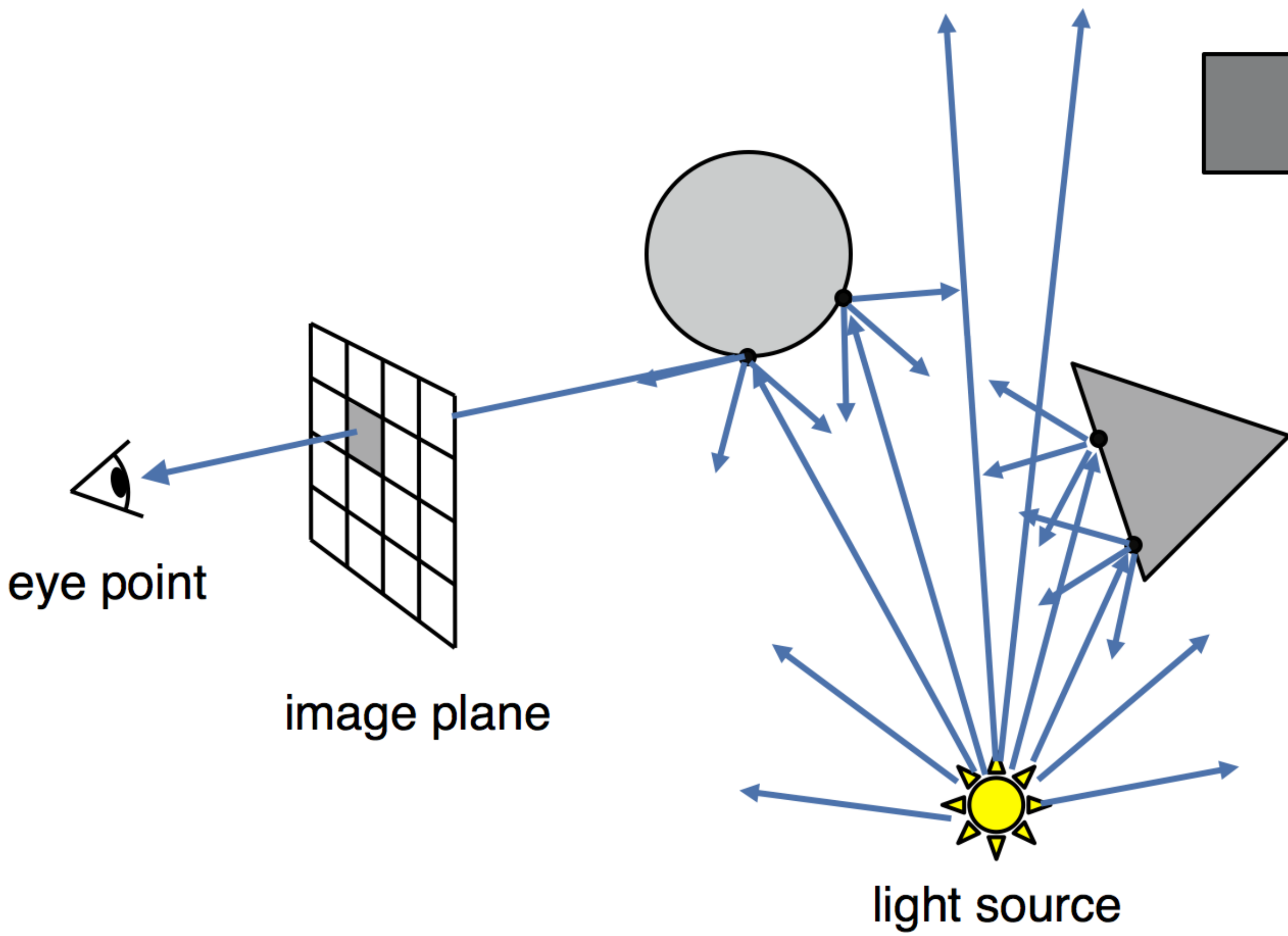
In the physical world



Light Transport

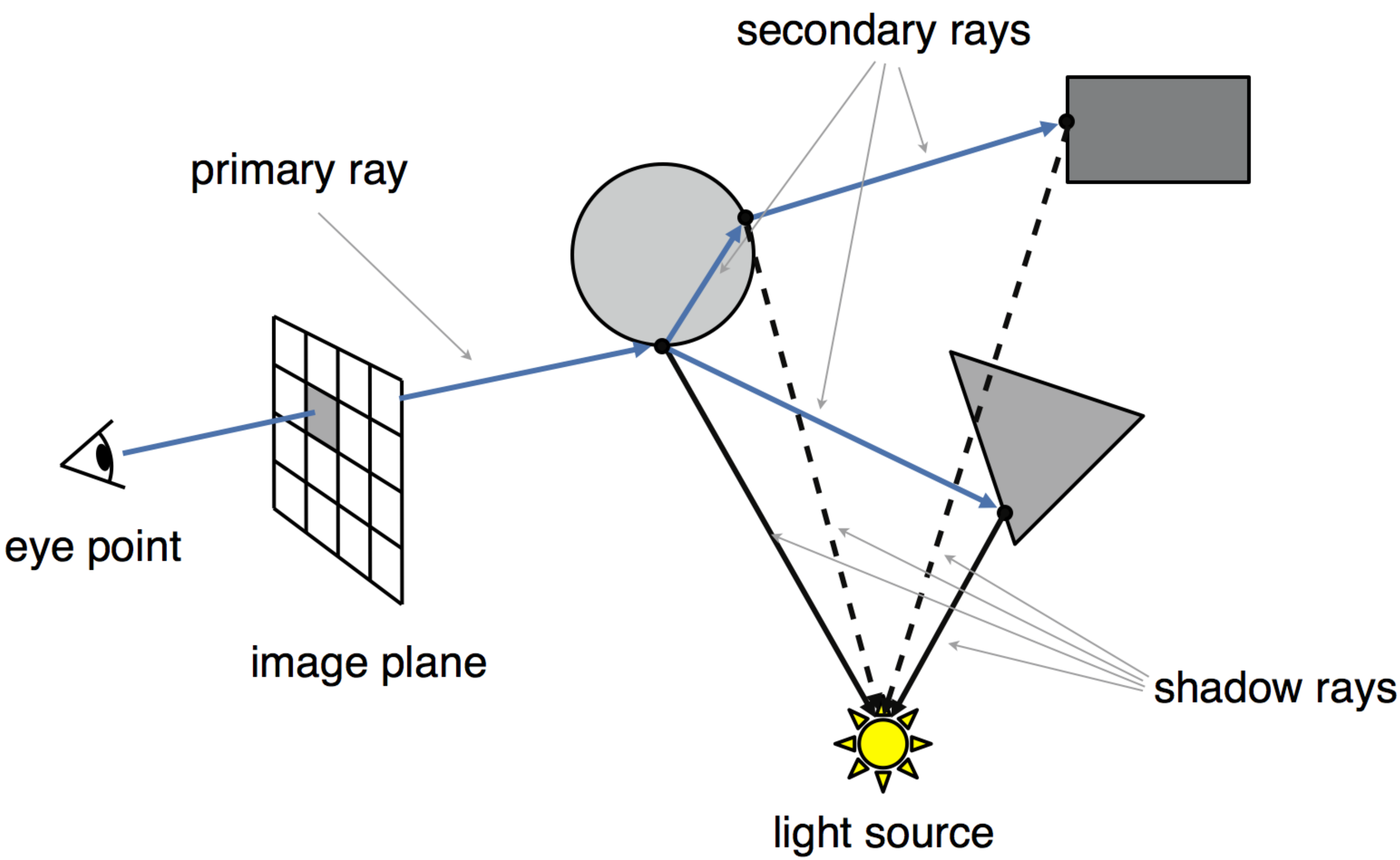
- Light travels in **straight lines**
- Light rays **do not interfere** with each other if they cross
- Light travels from the **light sources to the eye** (physics is invariant under path reversal reciprocity)

Light-Oriented (Forward Raytracing)



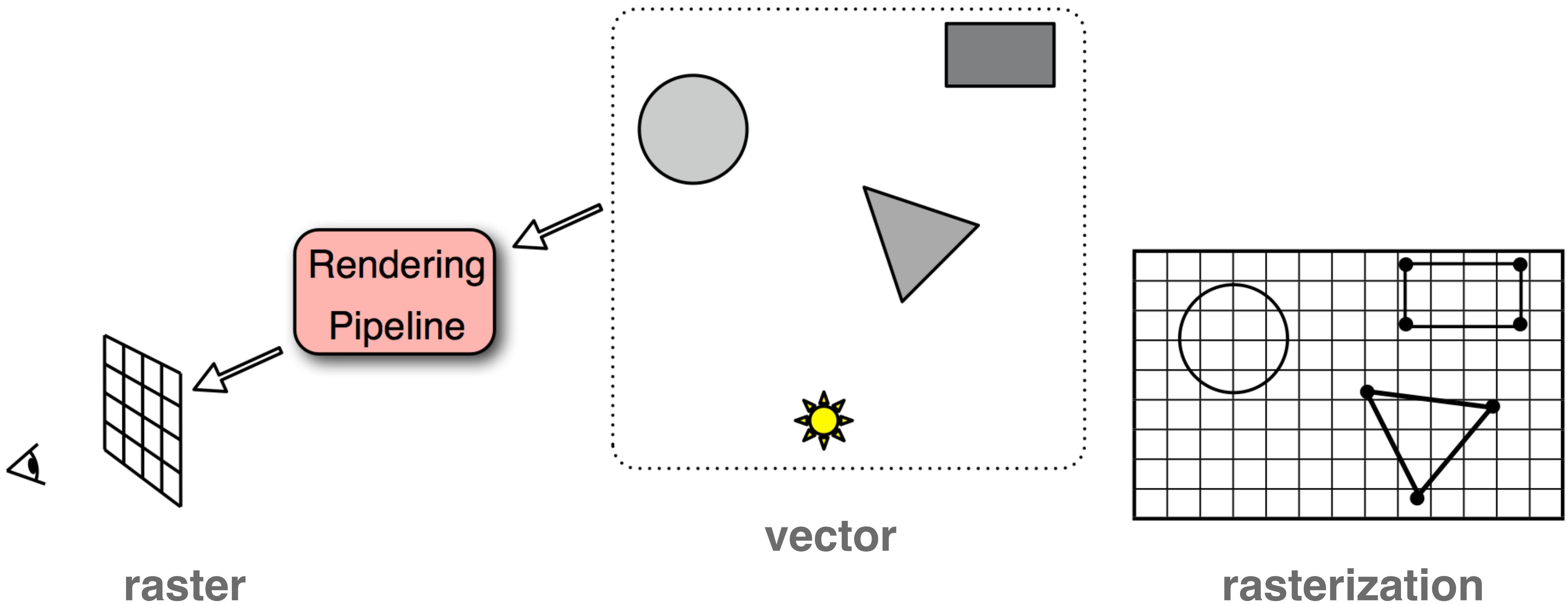
Only a **fraction** of light rays reach the image

Eye-Oriented (Backward Raytracing)



or simply “**Raytracing**”

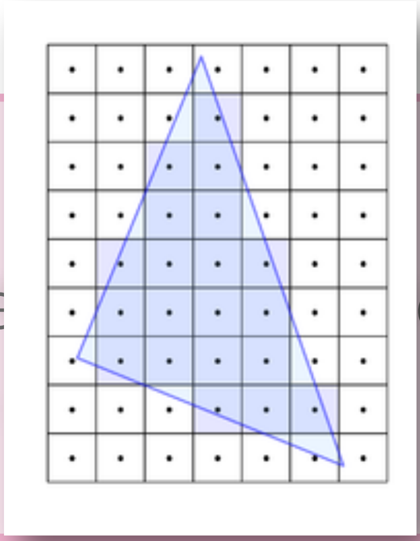
Object-Oriented (Forward Rendering)



Scene is composed of **geometric structures** with the buiding block of **a triangle**. Each triangle is projected, colored, and painted on the screen

Light vs. Eye vs. Object-Oriented Rendering

- **Light-oriented (Forward Raytracing)**
  - light sources send off photons in all directions and hits camera
- **Eye-oriented (Backward Raytracing or simply Raytracing)**
  - walk through each pixel looking for what object (if any) should be shown there
- **Object-oriented (OpenGL):**
  - walk through objects, transforming and the ch one unless the z-buffer says that it's not in



Let's leave rasterization to the GPU

OpenGL

Industry Standard API for Computer Graphics

Alternatives

Microsoft® DirectX®

PIXAR's RenderMan

3dfx Glide API

interactive, but not cross-platform

OpenGL Family

WebGL™

OpenGL|ES™

OpenGL|SC™

WebCL™

OpenVG™

OpenCL

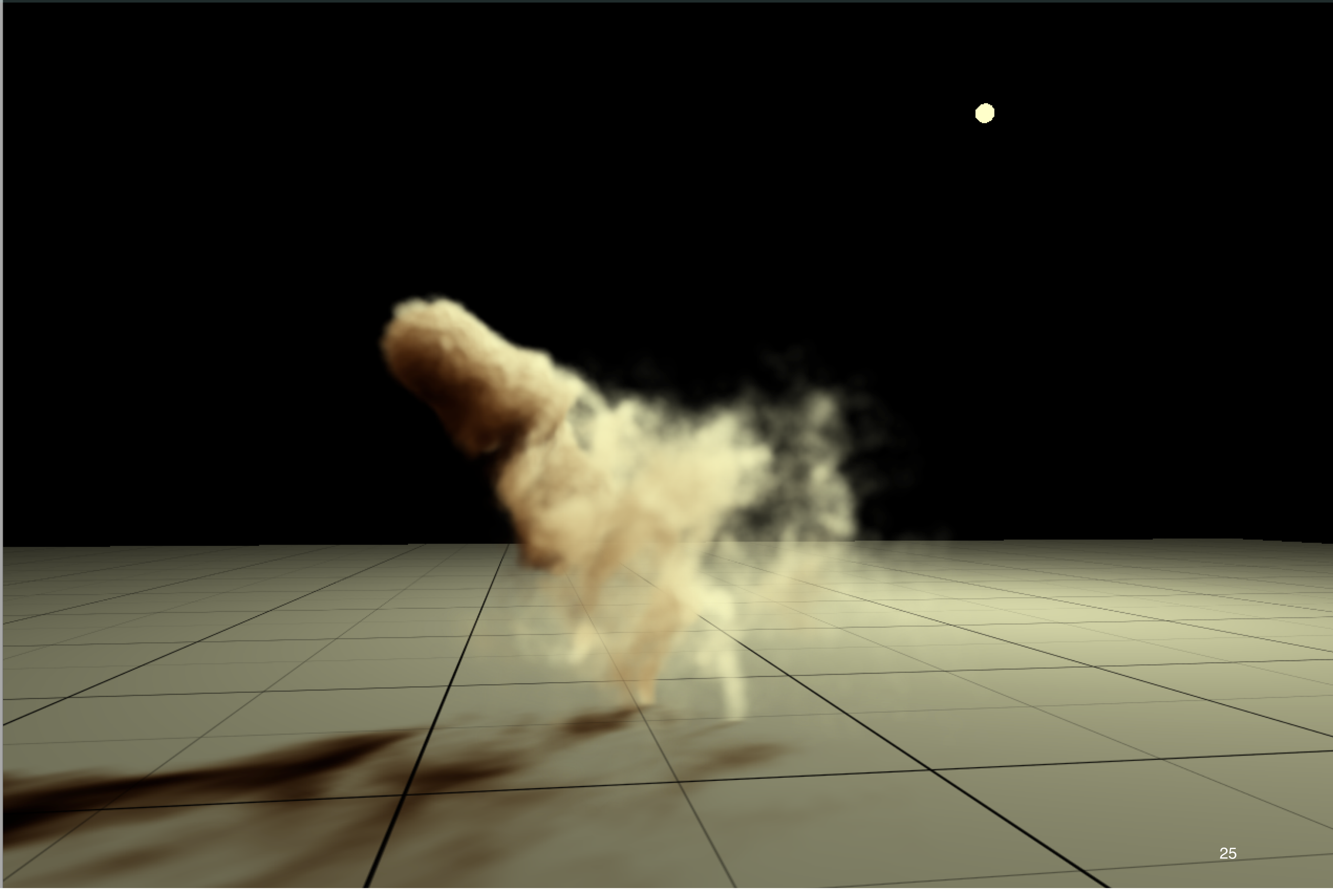
What is OpenGL?

- **Low-level graphics library (API)** for 2D and 3D interactive Graphics.
- Descendent of GL (from SGI)
- First version in 1992; now: 4.2 (2012)
- Managed by Khronos Group (non-profit consortium)
- API is governed by Architecture Review Board (part of Khronos)

Where is OpenGL used?

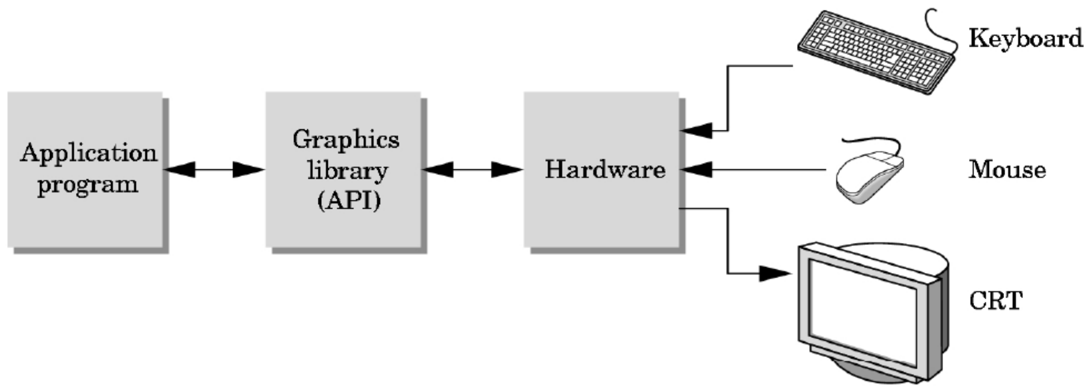
- CAD
- VR
- Scientific Visualization
- Simulators
- Video games

Realtime Graphics Demo



Graphics Library (API)

- **Interface** between Application and Graphics Hardware



- Other popular APIs:
  - Direct3D (Microsoft) → XBox
  - OpenGL ES (embedded Devices)
  - X3D (successor of VRML)

OpenGL is cross-platform

- **Same code** works with little/no modifications

- **Implementations:**

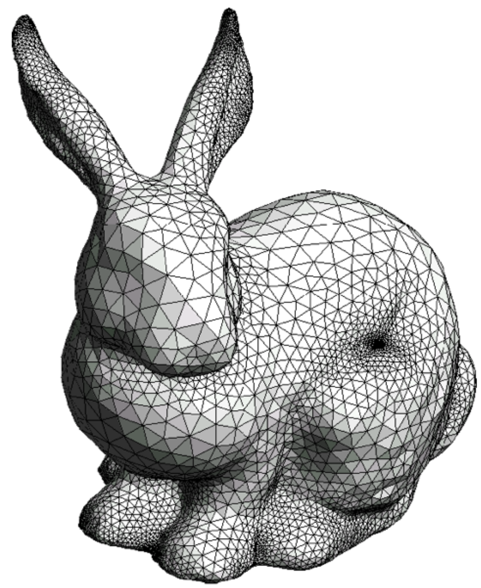
Mac, Linux, Windows: ships with the OS
Linux: Mesa, freeware implementation

```
#if defined(WIN32) || defined(linux)
  #include <GL/gl.h>
  #include <GL/glu.h>
  #include <GL/glut.h>
#elif defined(__APPLE__)
  #include <OpenGL/gl.h>
  #include <OpenGL/glu.h>
  #include <GLUT/glut.h>
#endif
```

How does OpenGL work

From the programmer's point of view:

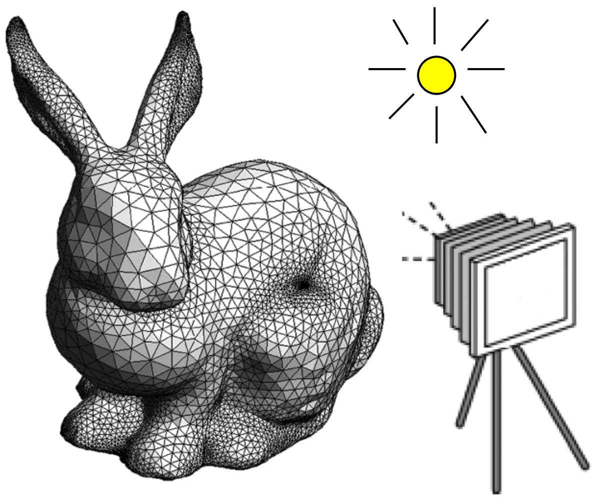
- Specify **geometric objects**
- Describe **object properties**
  - Color
  - How objects reflect light



How does OpenGL work (continued)

Define how objects should be viewed

- where is the camera?
- what type of camera?

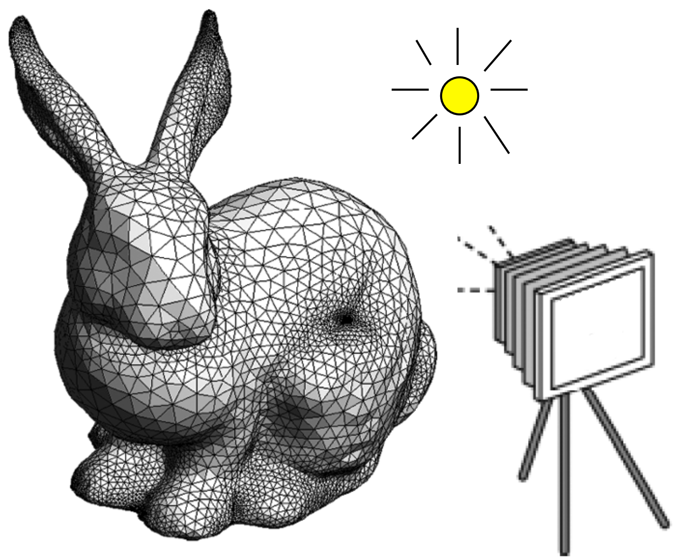


Specify light sources

- where, what kind?

Move camera or objects around for animation

The result



the scene

the result

OpenGL is a state machine

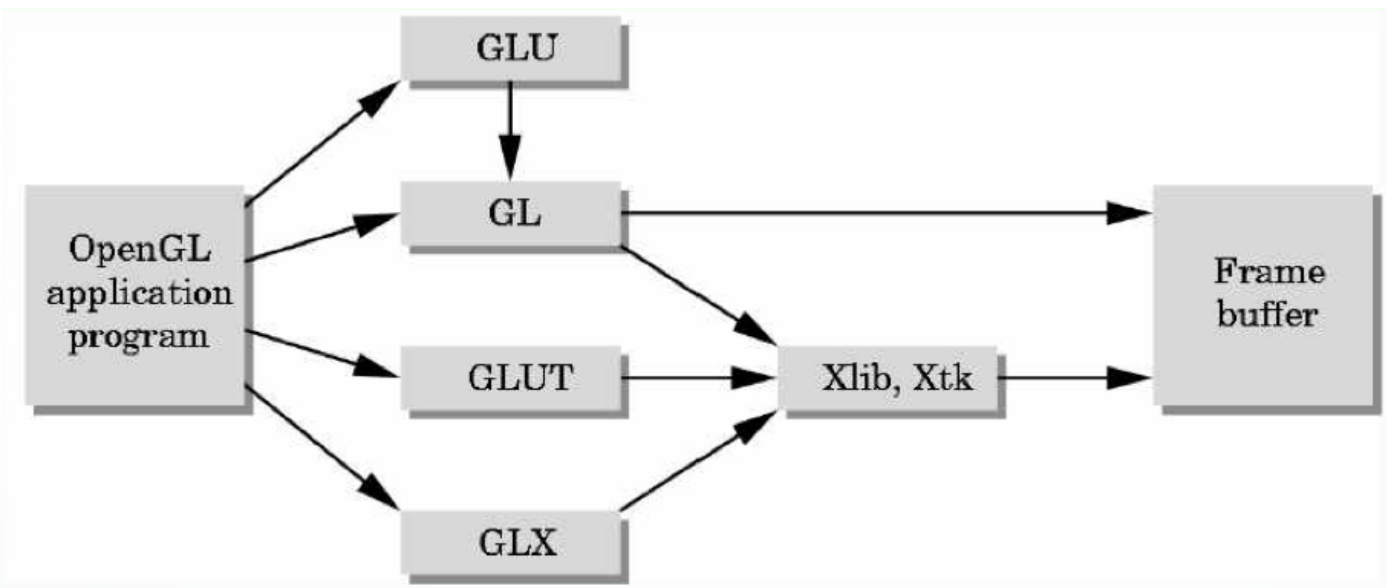
State variables: color, camera position, light position, material properties…

These variables (**the state**) then apply to every subsequent drawing command.

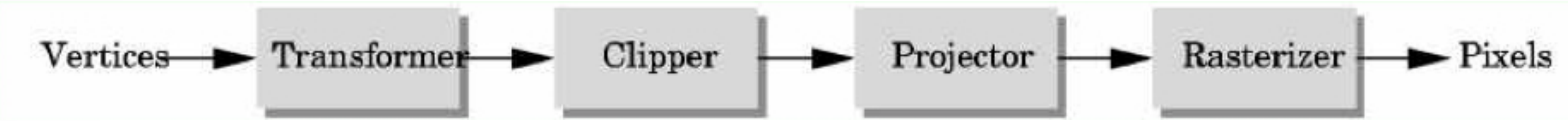
They **persist** until set to new values by the programmer.

OpenGL Library Organization

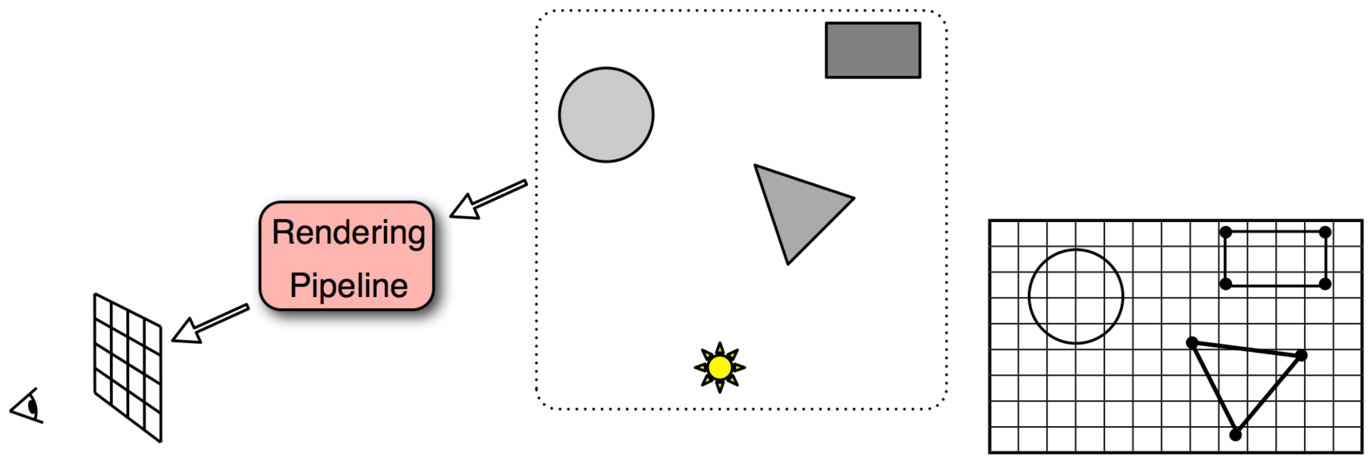
- **GL (Graphics Library):** core graphics capabilities
- **GLU (OpenGL Utility Library):** utilities on top of GL
- **GLUT (OpenGL Utility Toolkit):** input and windowing wrapper



OpenGL **Graphics Pipeline**



primitives+ material properties	**translate rotate scale**	**is it visible on screen?**	**3D to 2D**	**convert to pixels**	**shown on the screen (framebuffer)**



OpenGL uses immediate-mode rendering

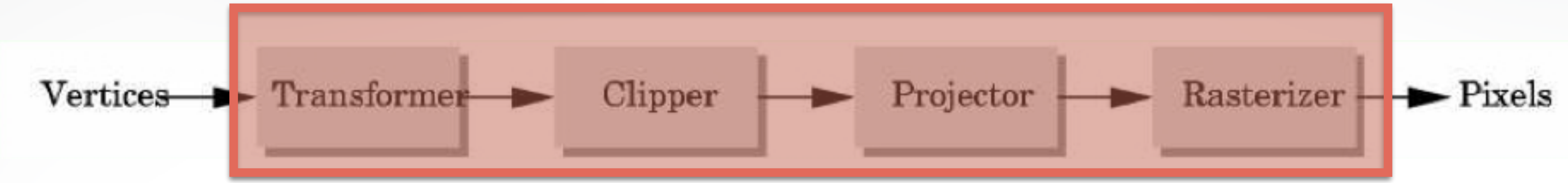
Application generates **stream of geometric primitives** (polygons, lines)

System **draws** each one into the the **frame buffer**

Entire scene is **redrawn** for every frame

Compare to: offline rendering (e.g., Pixar Renderman, ray tracers…)

OpenGL **Graphics Pipeline**

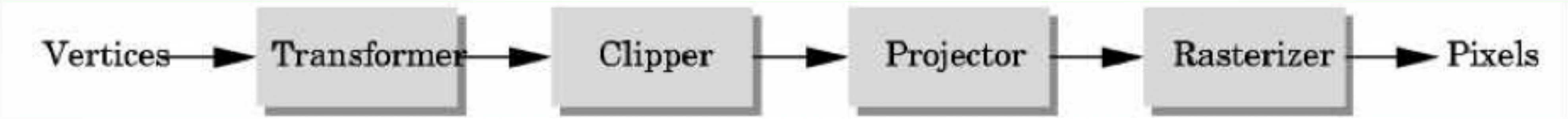


primitives+ material properties	translate rotate scale	is it visible on screen?	3D to 2D	convert to pixels	shown on the screen (framebuffer)

implemented by **OpenGL, graphics driver, graphics hardware**

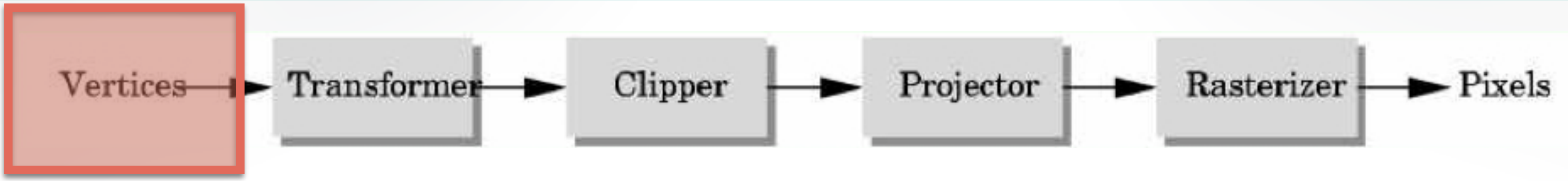
OpenGL programmer does not need to implement the pipeline, but can **reconfigure it through shaders**

OpenGL **Graphics Pipeline**



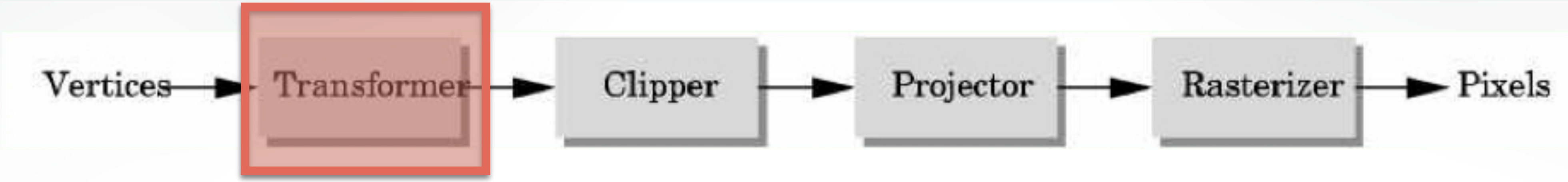
- **Efficiently implementable in hardware** (but not in software)
- Each stage can employ **multiple** specialized processors, working in **parallel**, busses between stages
- **#processors per stage**, bus bandwidths are fully tuned for typical graphics use
- **Latency vs throughput**

Vertices



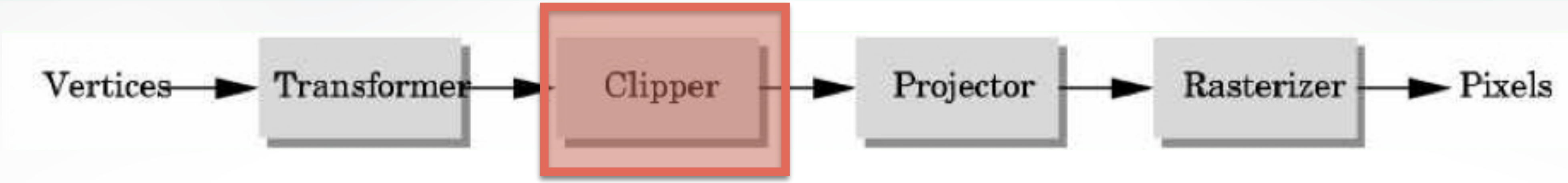
- Vertices in **world coordinates**
- **void glVertex3f(GLfloat x, GLfloat y, GLfloat z)**
  - Vertex(x,y,z) is sent down the pipeline.
  - Function call then returns
- Use **GLtype (e.g., GLfloat)** for portability and consistency
- glVertex{234}{sfid}(TYPE coords)

Transformer

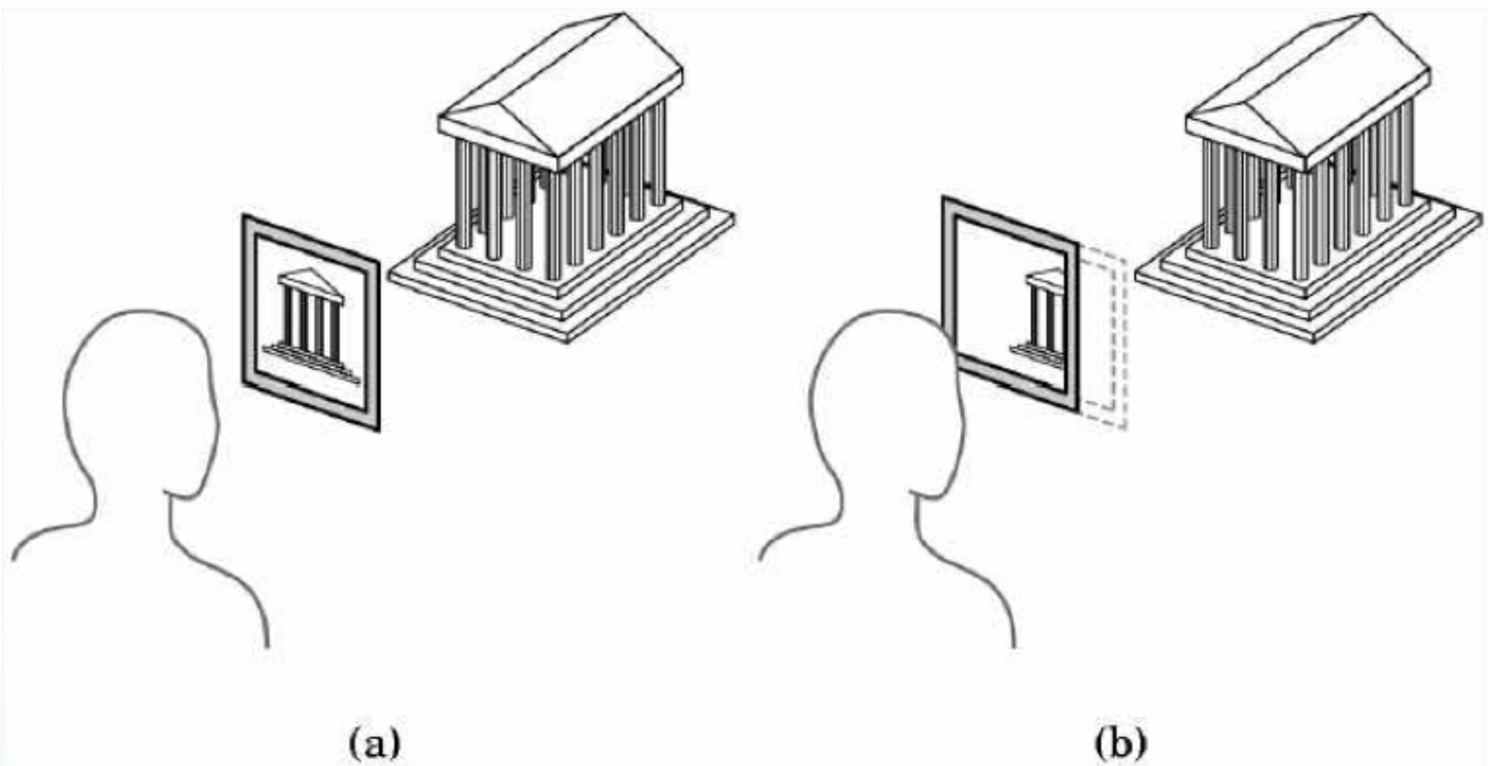


- Transformer in **world coordinates**
- **Must be set before object is drawn!**
  - glRotate (45.0, 0.0, 0.0, -1.0);
  - glVertex2f(1.0, 0.0);
- Complex [Angel Ch. 4]

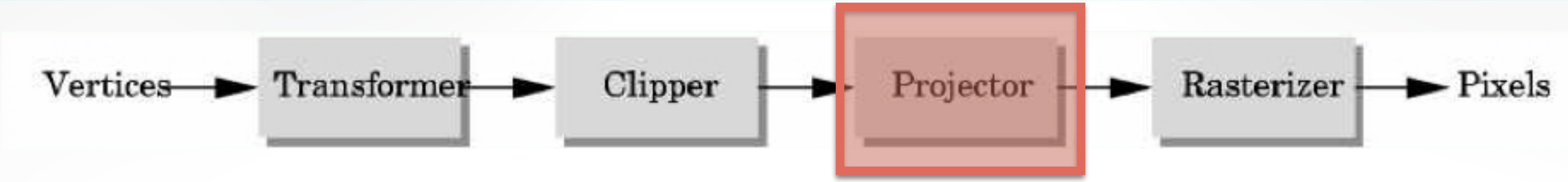
Clipper



- Mostly automatic (**must set viewport**)

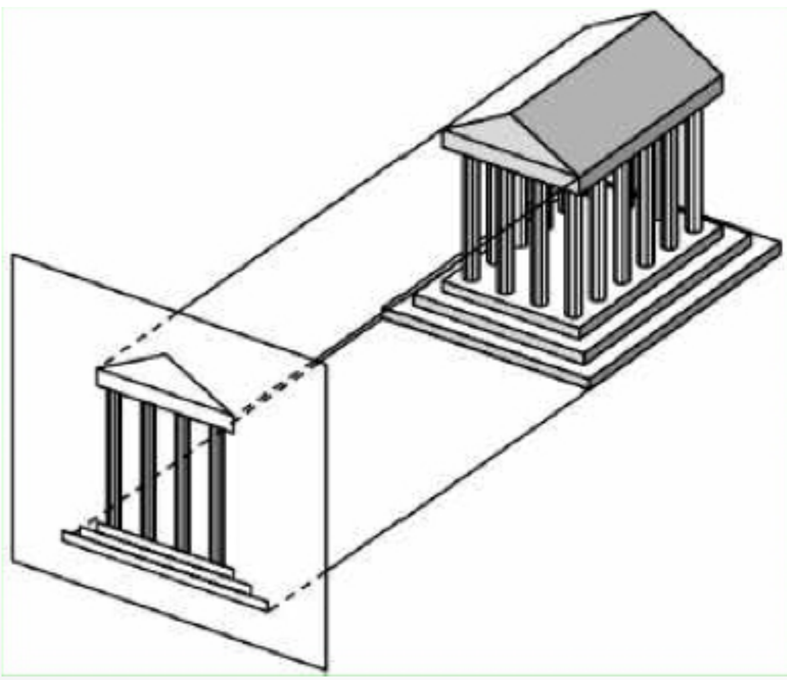


Projector

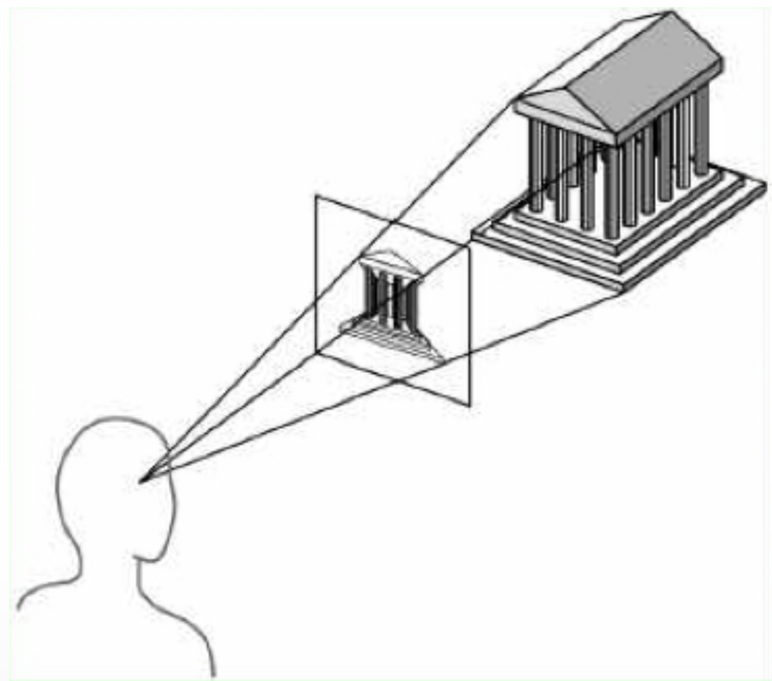


- Complex transformation [Angel Ch. 5]

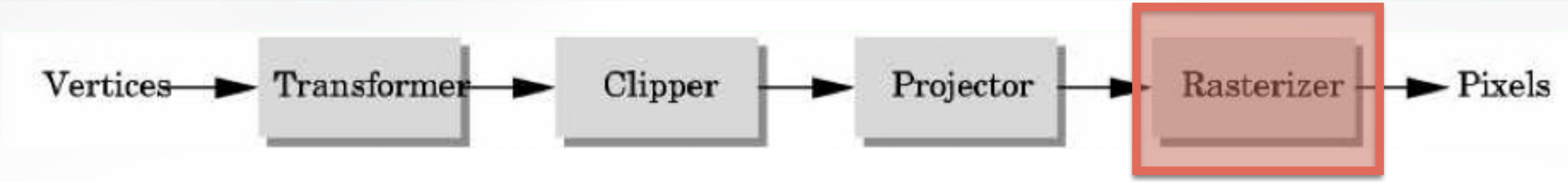
orthographic



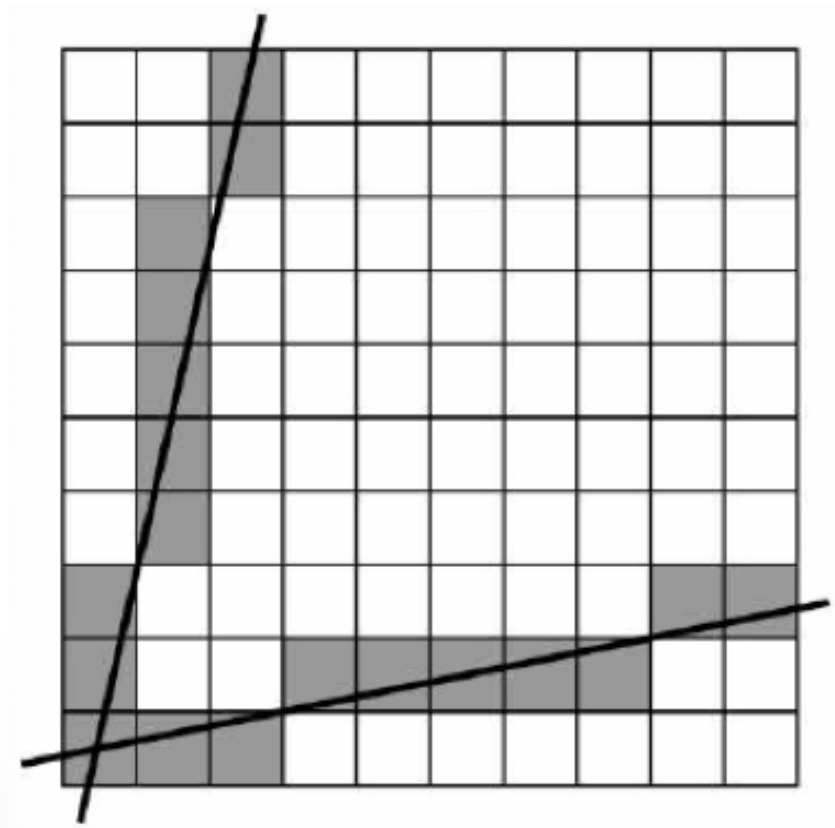
perspective



Rasterizer



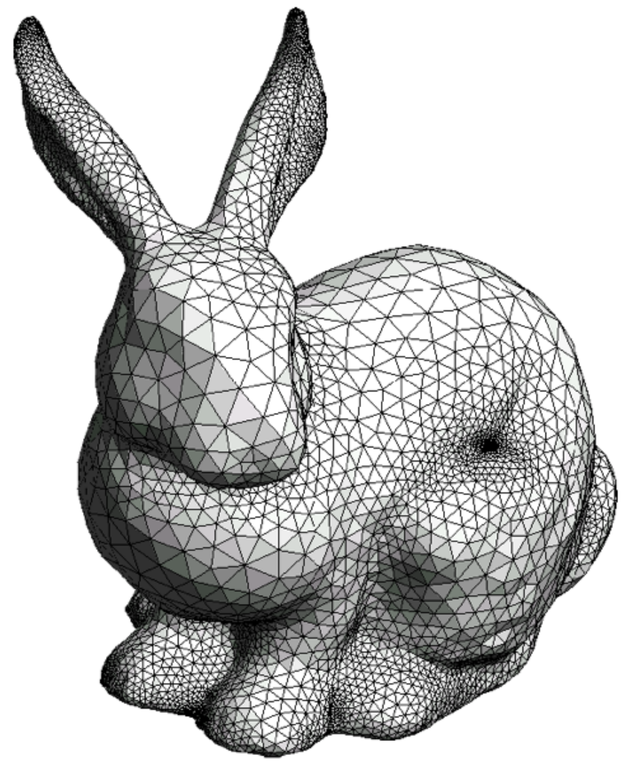
- Interesting algorithms [Angel Ch. 7]
- **To window coordinates**
- Antialiasing



Primitives

- Specified via vertices
- General scheme

```
glBegin(type):
    glVertex3f(x1,y1,z1);
    …
    glVertex3f(xN,yN,zN);
glEnd();
```

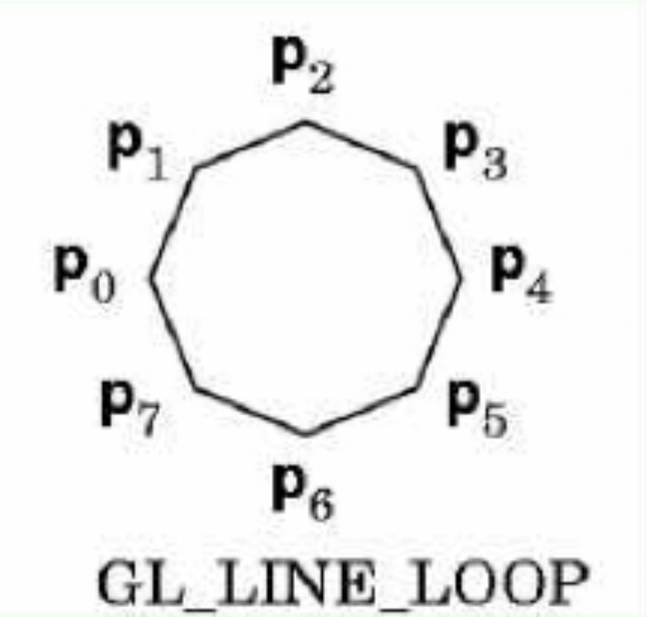


- **type** determines interpretation of vertices
- Can use glVertex2f(x,y) in 2D

Example: Draw Square Outline

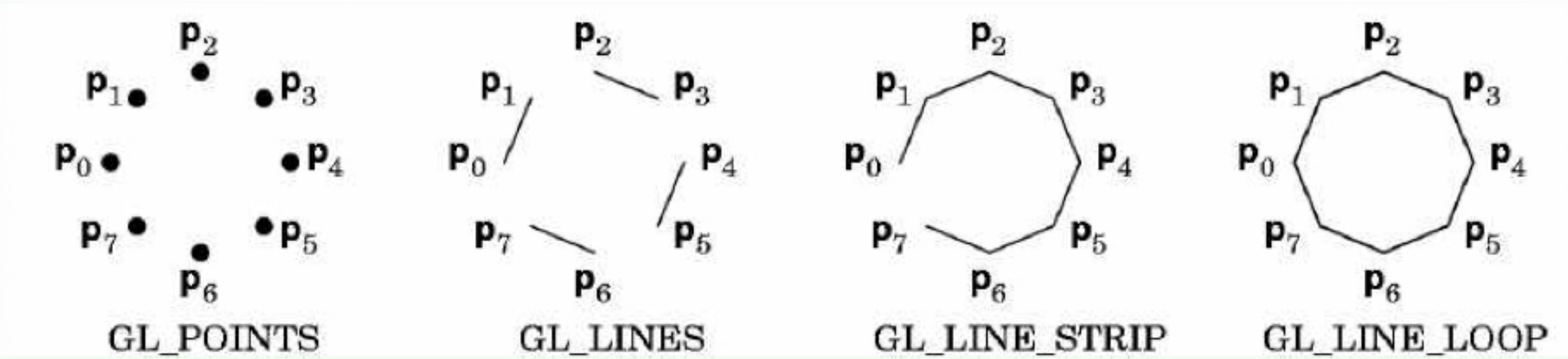
- **Type = GL_LINE_LOOP**

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



- Calls to other functions are allowed betwen glBegin(Type) and glEnd()

Points and Line Segments

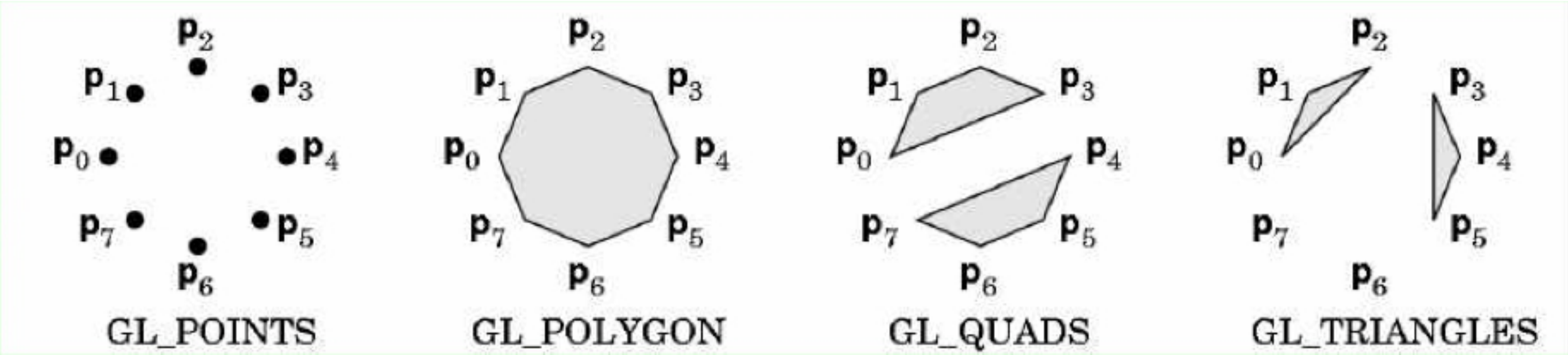



```
glBegin(GL_POINTS);
   glVertex3f(…);
   …
   glVertex3f(…);
glEnd()
```

draw points

Polygons

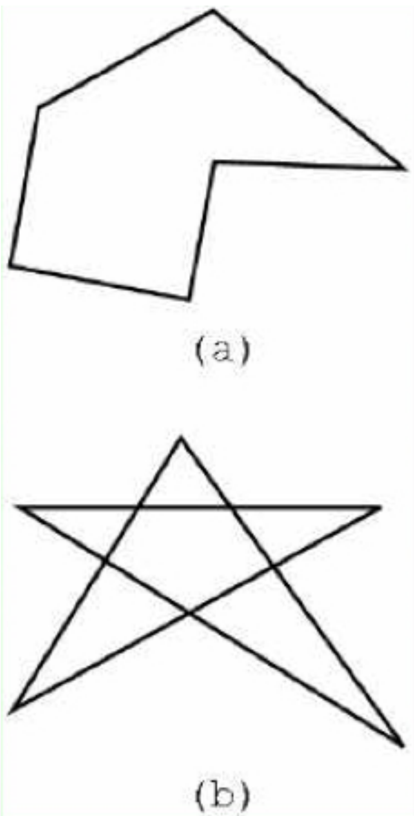
- **Polygons enclose an area**



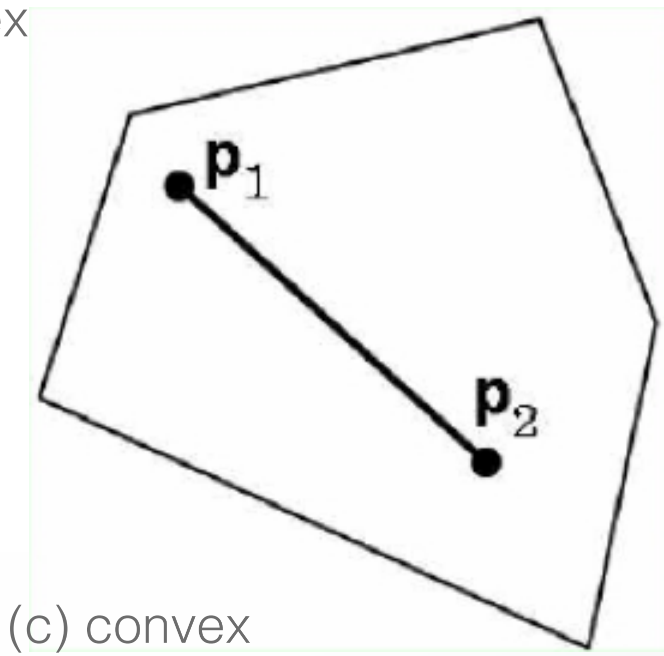
- Rendering of area (fill) depends on attributes
- **All vertices must be in one plane in 3D**

Polygons Restrictions

- OpenGL Polygons must be **simple**
- OpenGL Polygons must be **convex**



(a) simple, but not convex



(b) non-simple

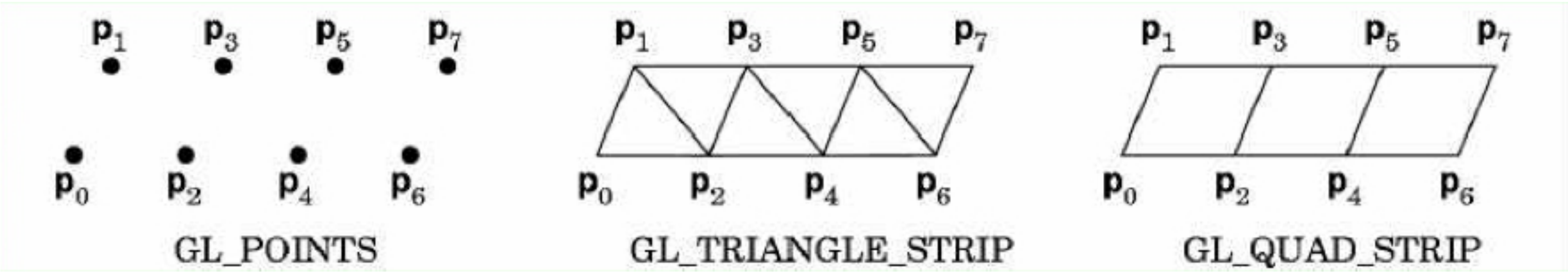
(c) convex

Why **Polygons Restrictions?**

- Non-convex and non-simple polygons are **expensive to process and render**
- Convexity and simplicity is **expensive to test**
- Behavior of **OpenGL** implementation on disallowed polygons is **“undefined”**
- Some tools in GLU for decomposing complex polygons (**tesselation**)
- **Triangles are most efficient**

Polygons Strips

- **Efficiency in space and time**
- Reduces visual **artefacts**



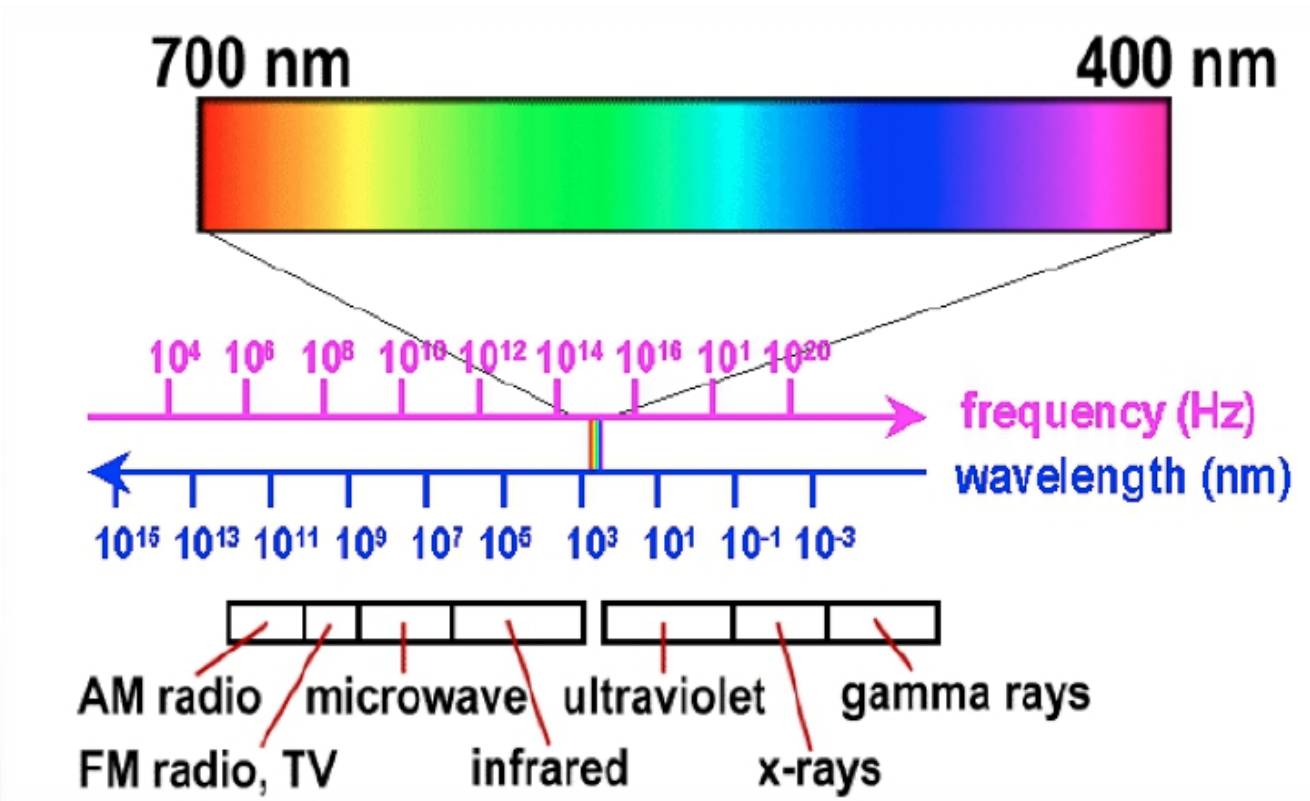
- Polygons have a **front and a back**, possibly with different attributes!

Attributes: Color, Shading, Reflections

- Part of the OpenGL **state**
- Set **before** primitives are drawn
- **Remain in effect until changed!**

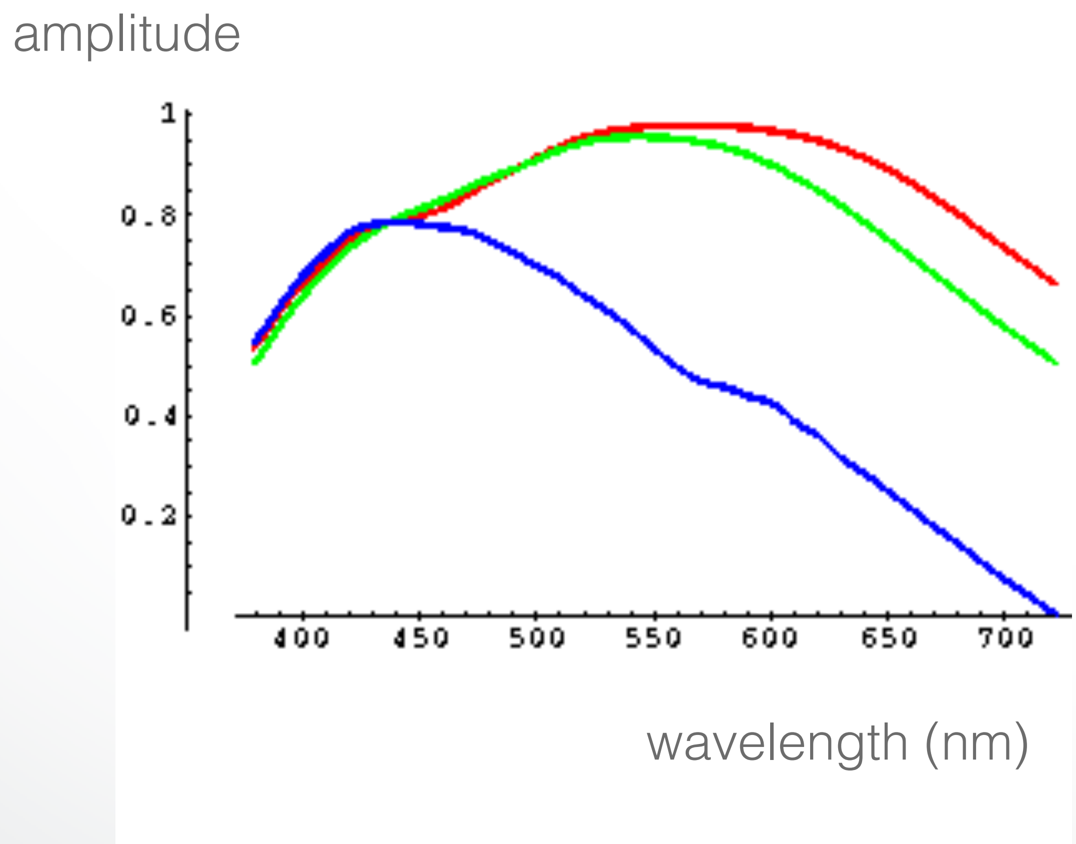
Physics of Color

- Electromagnetic radiation
- Can see only tiny piece of the **spectrum**



Color Filters

- Eye can perceive only **3 basic colors**
- **Computer screens** are designed accordingly



Cone response

Source: VOS & Walraven

Color Spaces

- **RGB (Red, Green, Blue)**

  Convenient for display

  Can be unintuitive (3 floats in OpenGL)

- **HSV (Hue, Saturation, Value)**

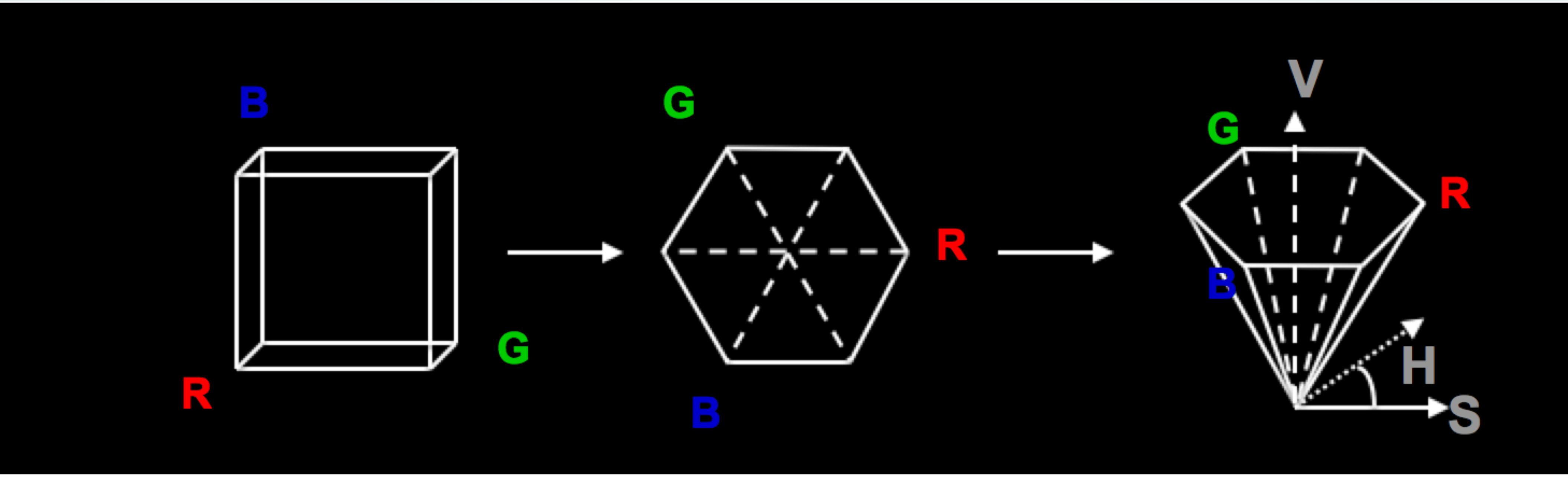
  Hue: what color?

  Saturation: how far away from gray?

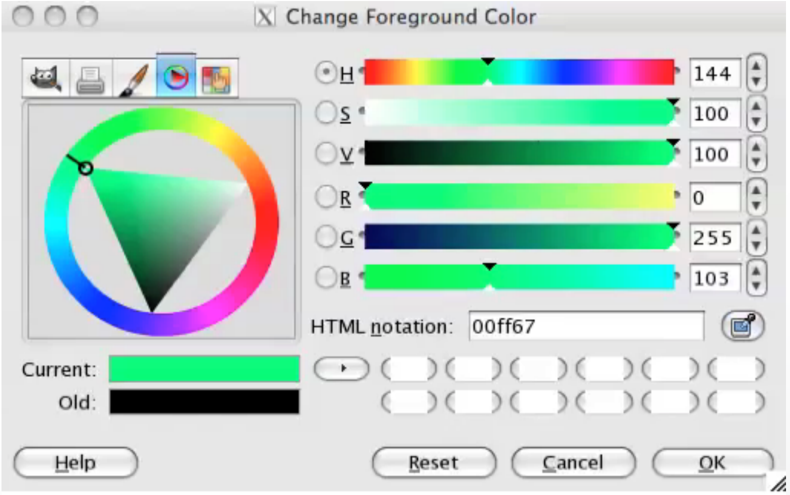
  Value: how bright?

- Other formats for **movies and printing**

RGB vs HSV



Gimp Color Picker



Example: Drawing a shaded polygon

- Initialization: the “main” function

```
int main(int argc, char ** argv)
{
    glutInit(&argc,argv);
    glutInitDisplayMode(GLUT_DOUBLE|GLUT_RGB);
    glutInitWindowSize(500,500);
    glutInitWindowPosition(100,100);
    glutCreateWindow(argv[0]);
    init();
…
```

GLUT Callbacks

- Window system **independent** interaction
- glutMainLoop processes events

```
…
    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMainLoop();
    return 0;
}
```

Initializing Attributes

- Separate in “init” function

```
void init()
{
   glClearColor (0.0,0.0,0.0,0.0);
   // glShadeModel (GL_FLAT);
   glShadeModel (GL_SMOOTH);
}
```

The Display Callback

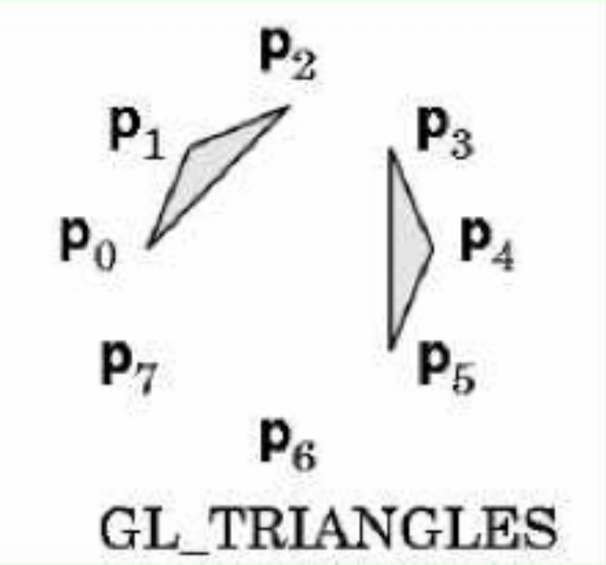
- The routine where you render the object
- Install with glutDisplayFunc(display)

```
void display()
{
    glClear(GL_COLOR_BUFFER_BIT); // clear buffer
    setupCamera();                // set up camera
    triangle();                   // draw triangle
    glutSwapBuffers();            // force display
}
```

Drawing

- In world coordinates; remember state!

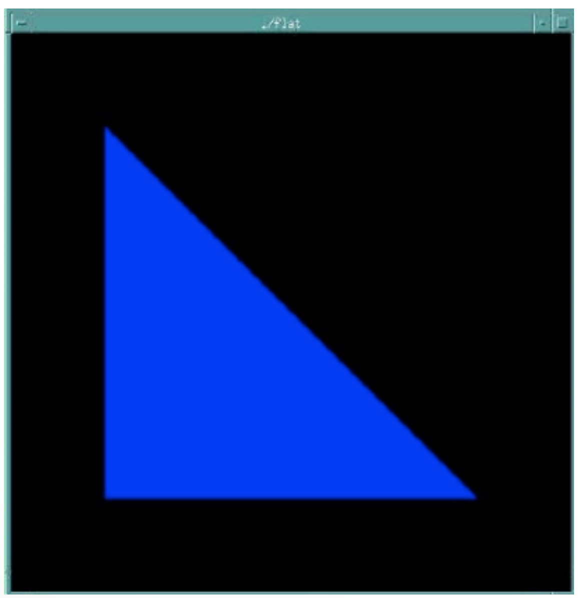
```
void triangle()
{
   glBegin(GL_TRIANGLES);
      glColor3f(1.0,0.0,0.0); // red
      glVertex2f(5.0,5.0);
      glColor3f(0.0,1.0,0.0); // green
      glVertex2f(25.0,5.0);
      glColor3f(0.0,0.0,1.0); // blue
      glVertex2f(5.0,25.0);
   glEnd();
}
```



The Image

glShadeModel(GL_FLAT)

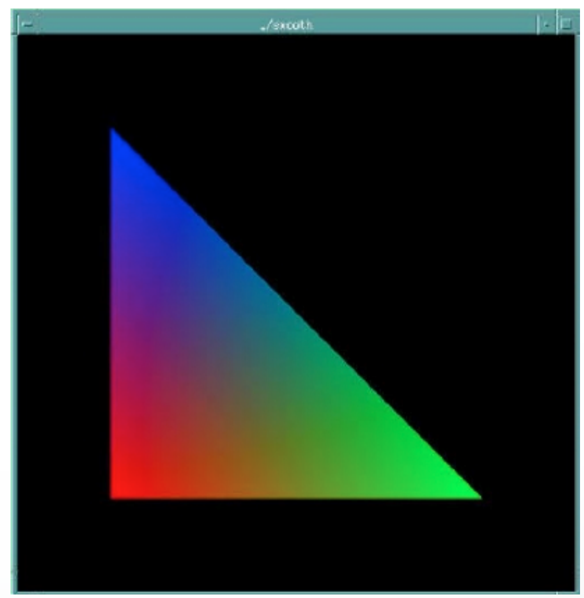
color of last vertex



glShadeModel(GL_SMOOTH)

each vertex separate color

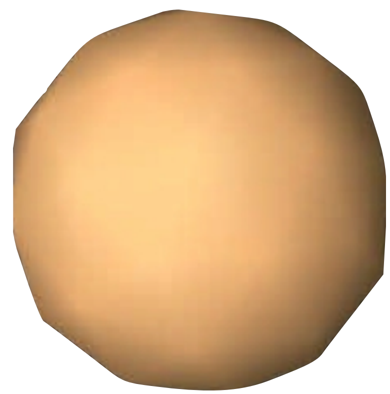
smoothly interpolated



Flat vs Smooth Shading

Flat Shading

Smooth Shading



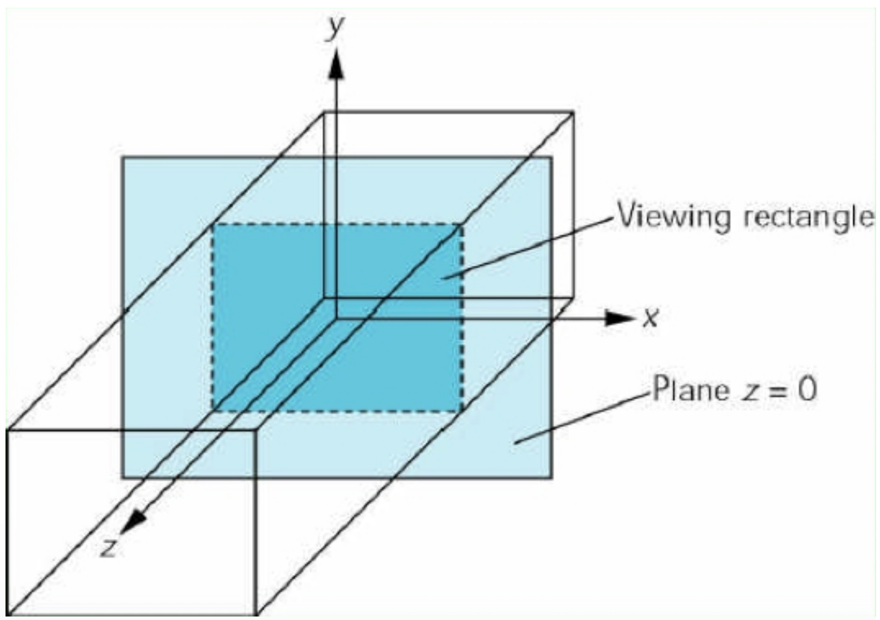
Projection

- Mapping world to screen coordinates

```
void reshape (int w, int h)
{
   glViewport(0, 0, (GLsizei) w, (GLsizei) h);
   glMatrixMode(GL_PROJECTION);
   glLoadIdentity();
   if(w<=h)
      gluOrtho2D(0.0,30.0,0.0,30.0 * (GLfloat) h/(GLfloat) w);
   else
      gluOrtho2D(0.0,30.0 * (GLfloat) w/(GLfloat) h, 0.0,30.0);
   glMatrixMode(GL_MODELVIEW);
}
```

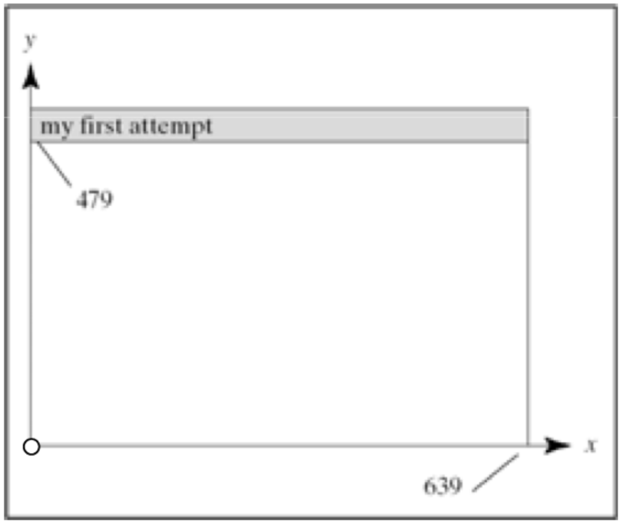
Orthographic Projection

- 2D and 3D versions
- glOrtho2D(left, right, bottom, top)
- In world coordinates!



Screen coordinates

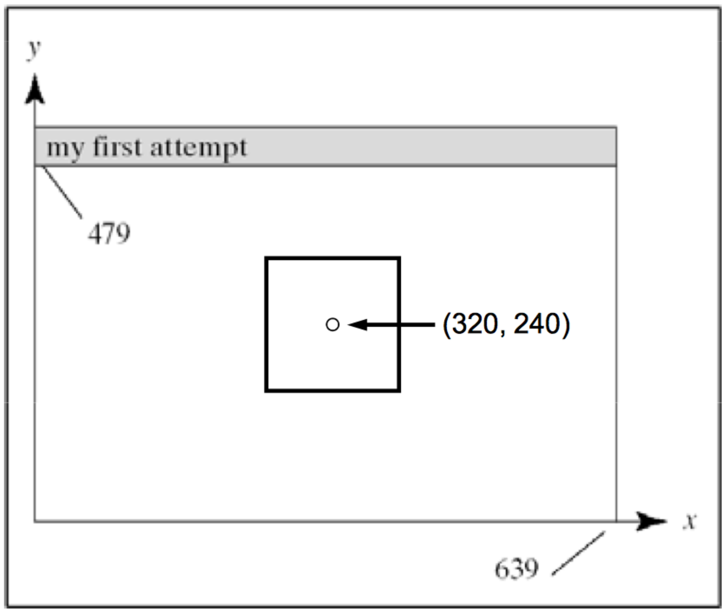
- Bottom left corner is origin
- `gluOrtho2D()` sets the units of the screen coordinate system
  - `gluOrtho2D(0, w, 0, h)` means the coordinates are in units of pixels
  - `gluOrtho2D(0, 1, 0, 1)` means the coordinates are in units of "fractions of window size" (regardless of actual window size)



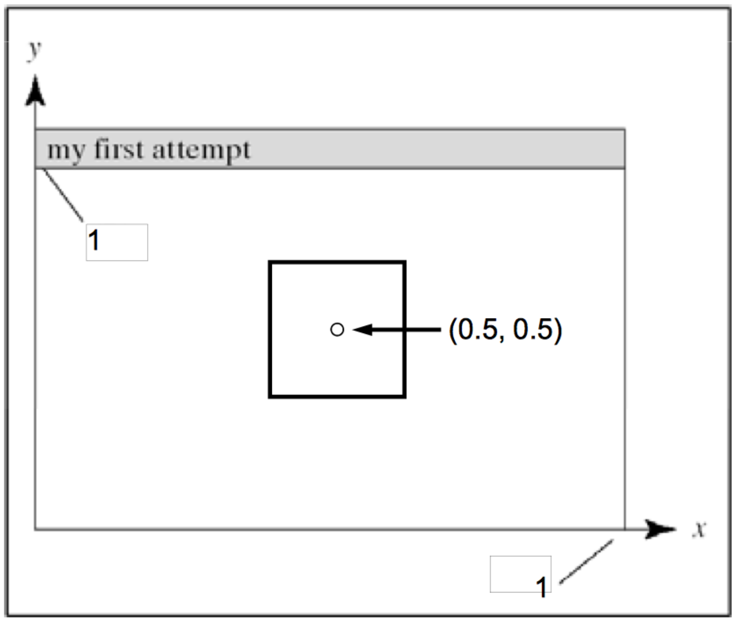
from Hill

Screen coordinates

`gluOrtho2D(0, 640, 0, 480)`

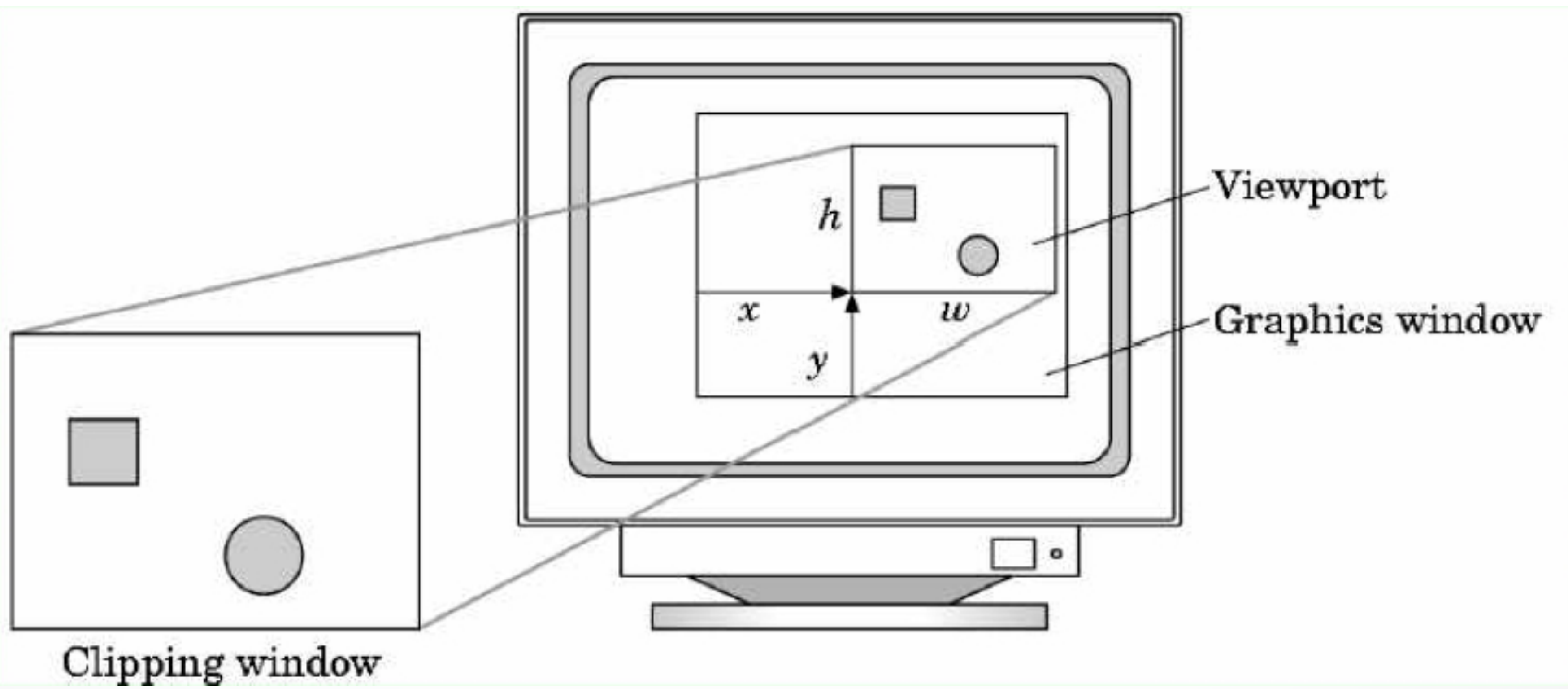


`gluOrtho2D(0, 1, 0, 1)`



Viewport

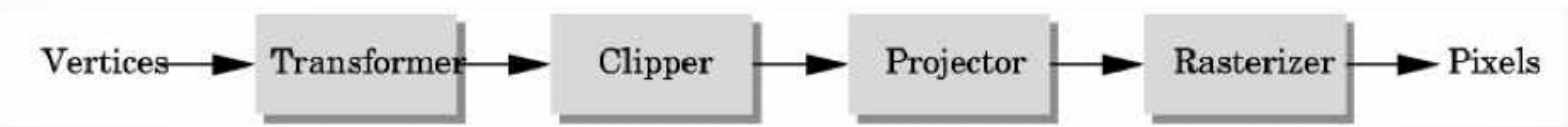
- Determines clipping in window coordinates
- glViewPort(x,y,w,h)



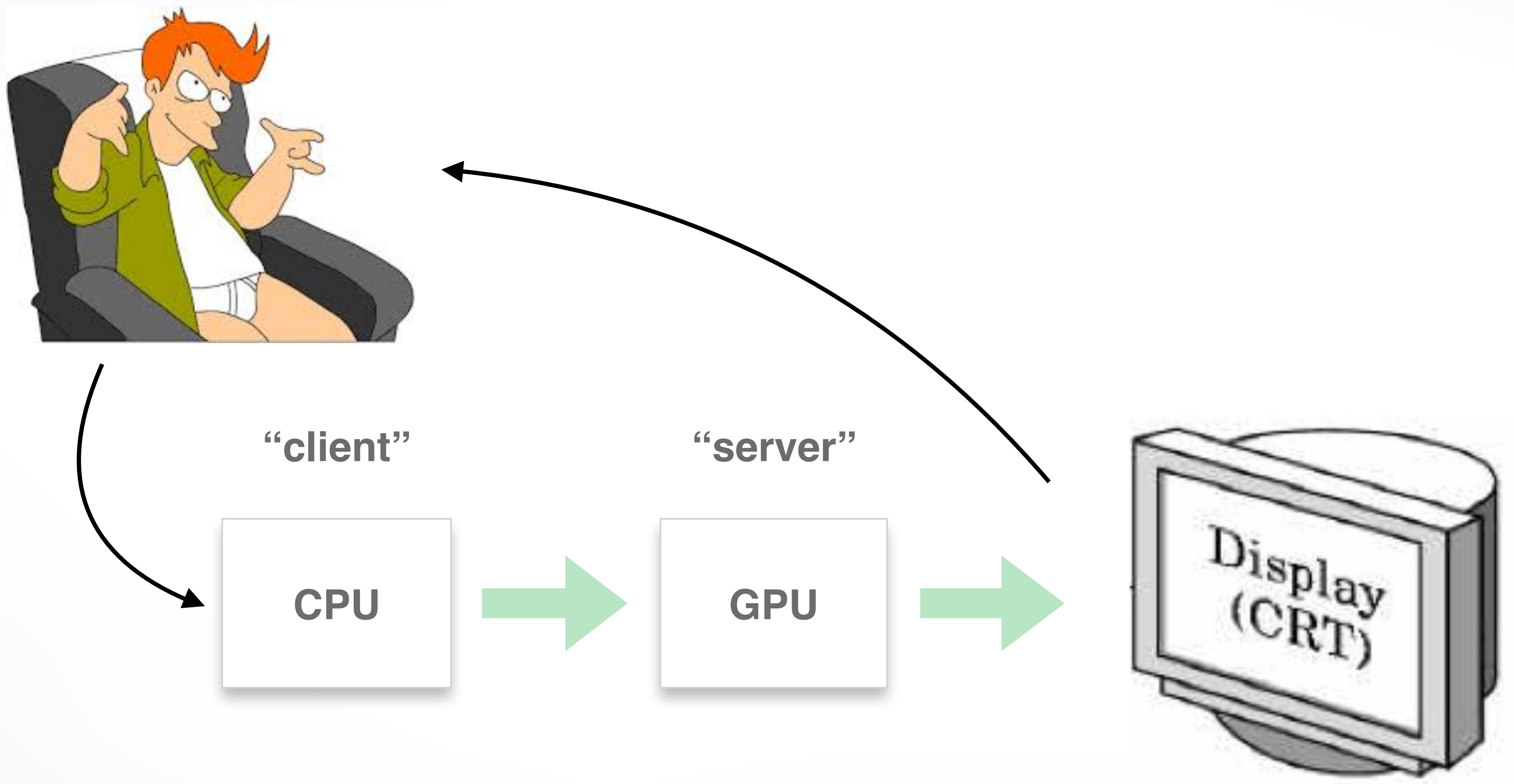
Let’s code a triangle!

Summary

- **A Graphics Pipeline**
- The OpenGL **API**
- **Primitives**: vertices, lines, polygons
- **Attributes**: color
- Example: drawing a **shaded triangle**



Next Time: Input & Interaction



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Thanks!