1.2 Basic Graphics Programming

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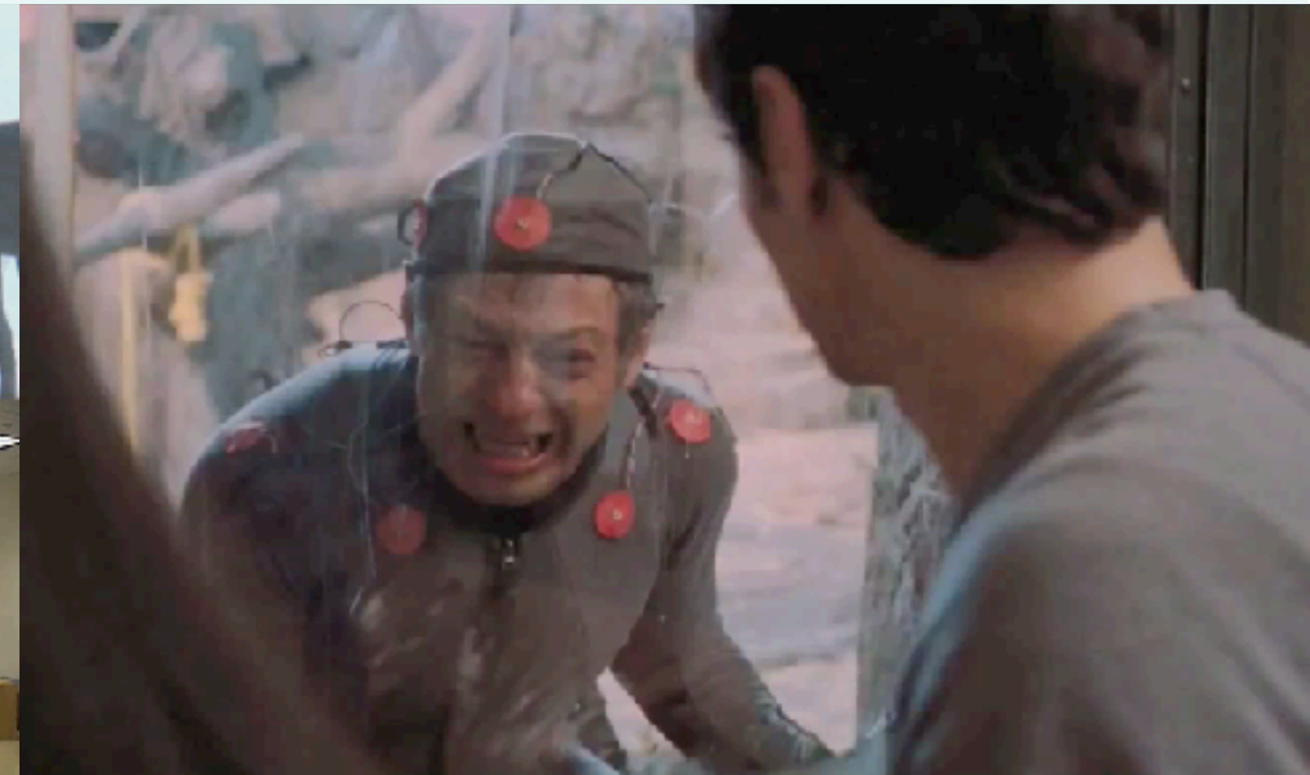
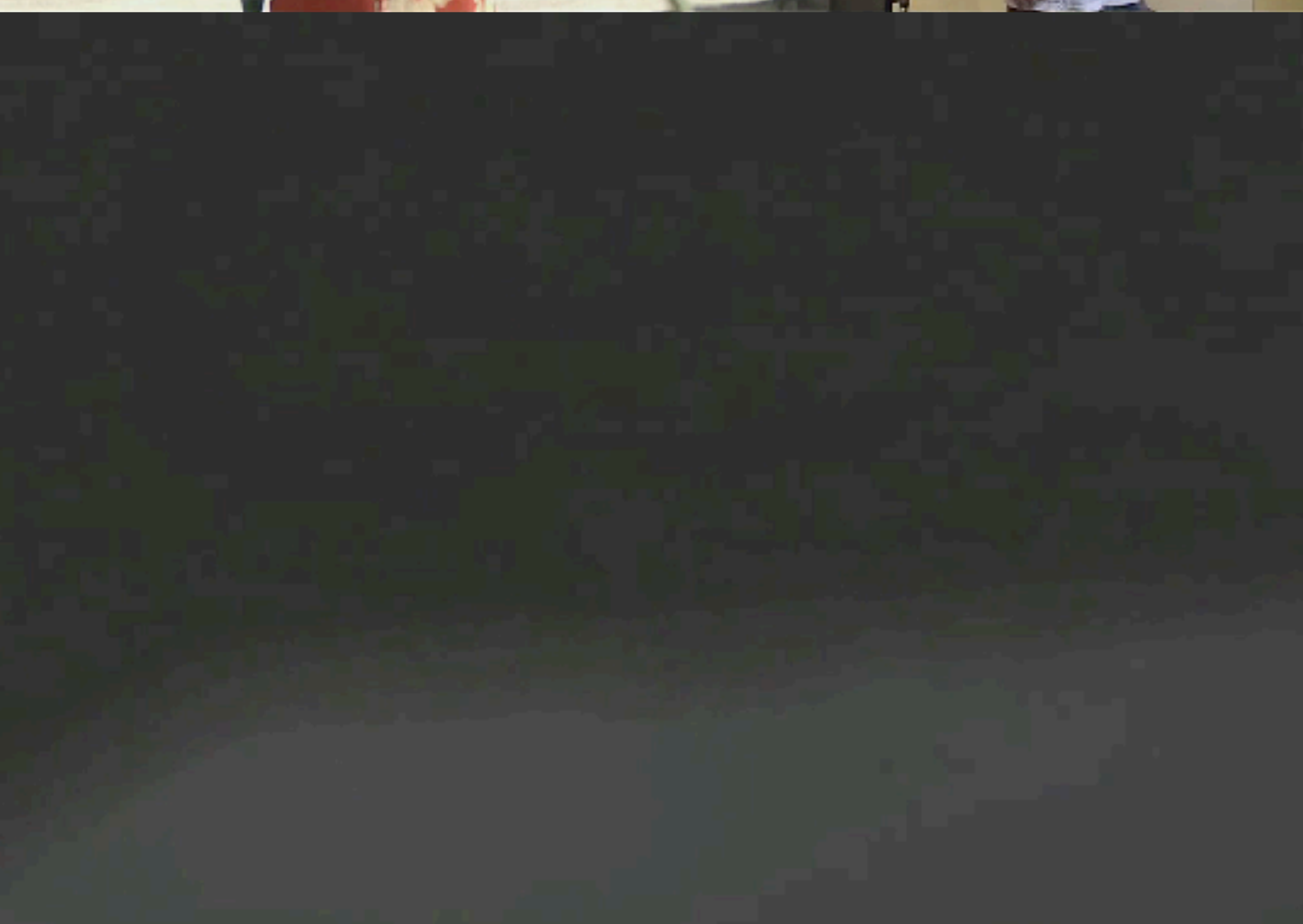
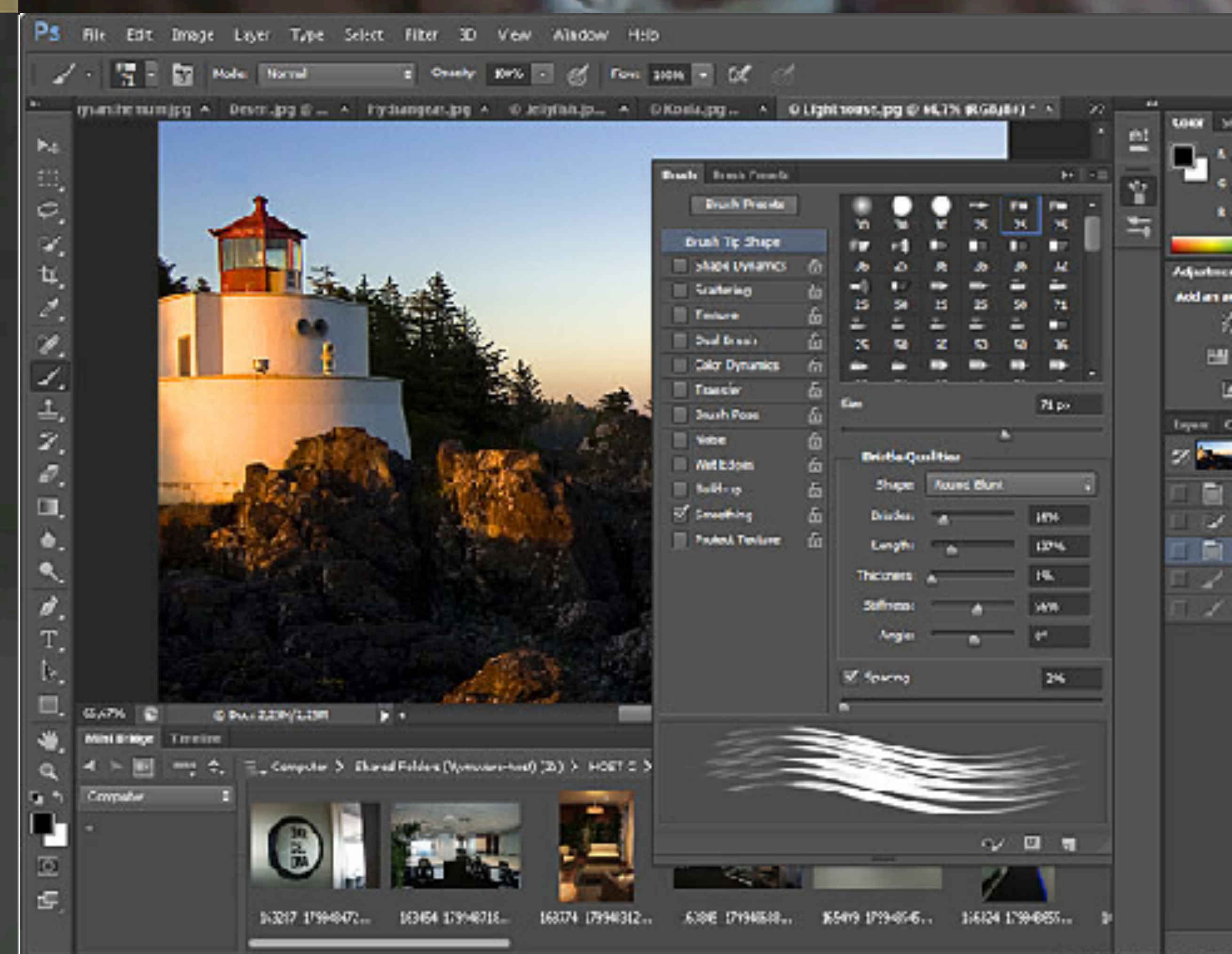
Last time

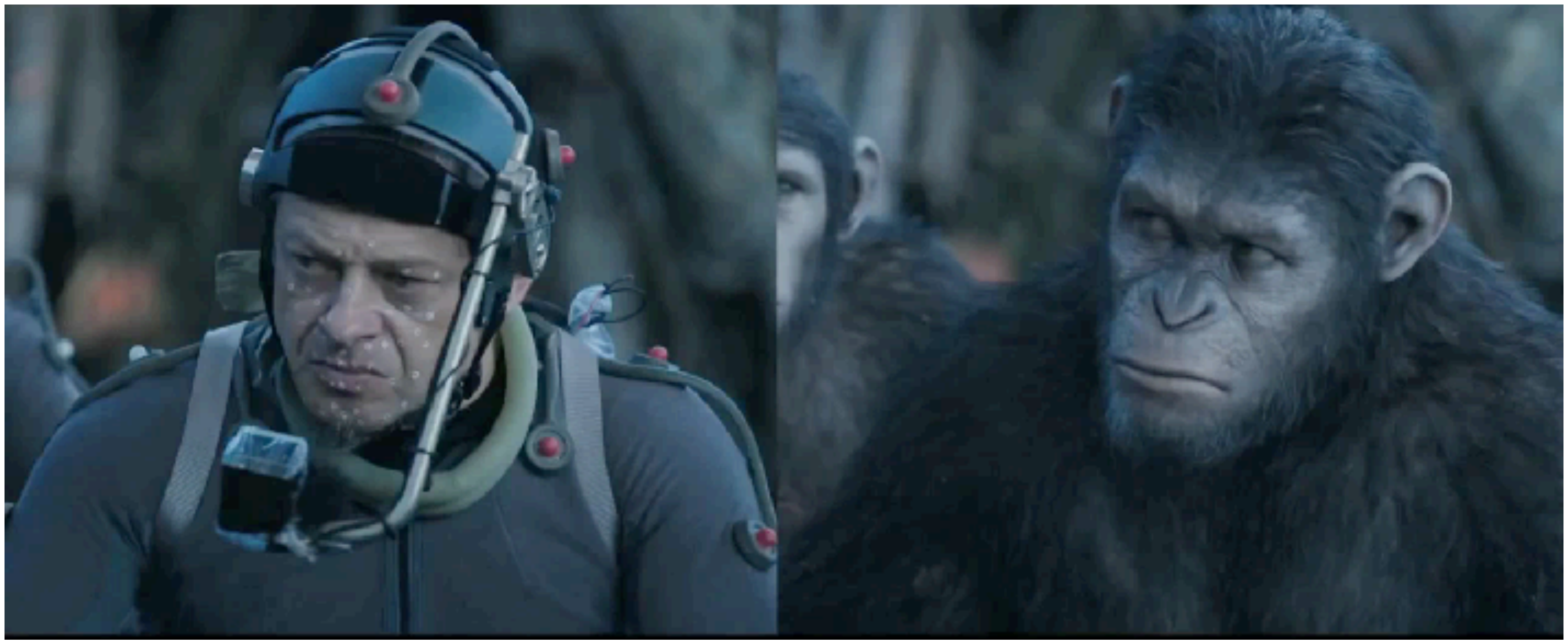

element





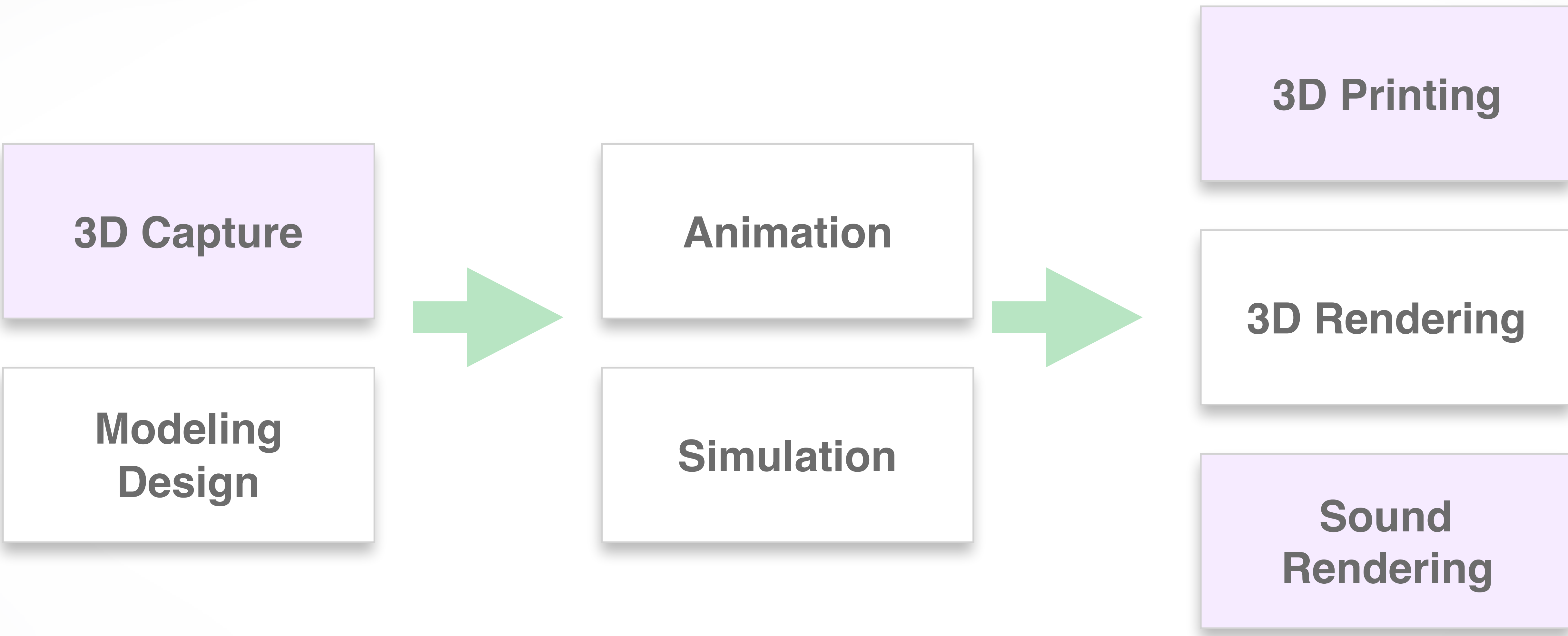

Ps
File Edit Image Layer Type Select Filter 3D View Window Help

Last Time



Story → Computer Graphics → Image

Last Time

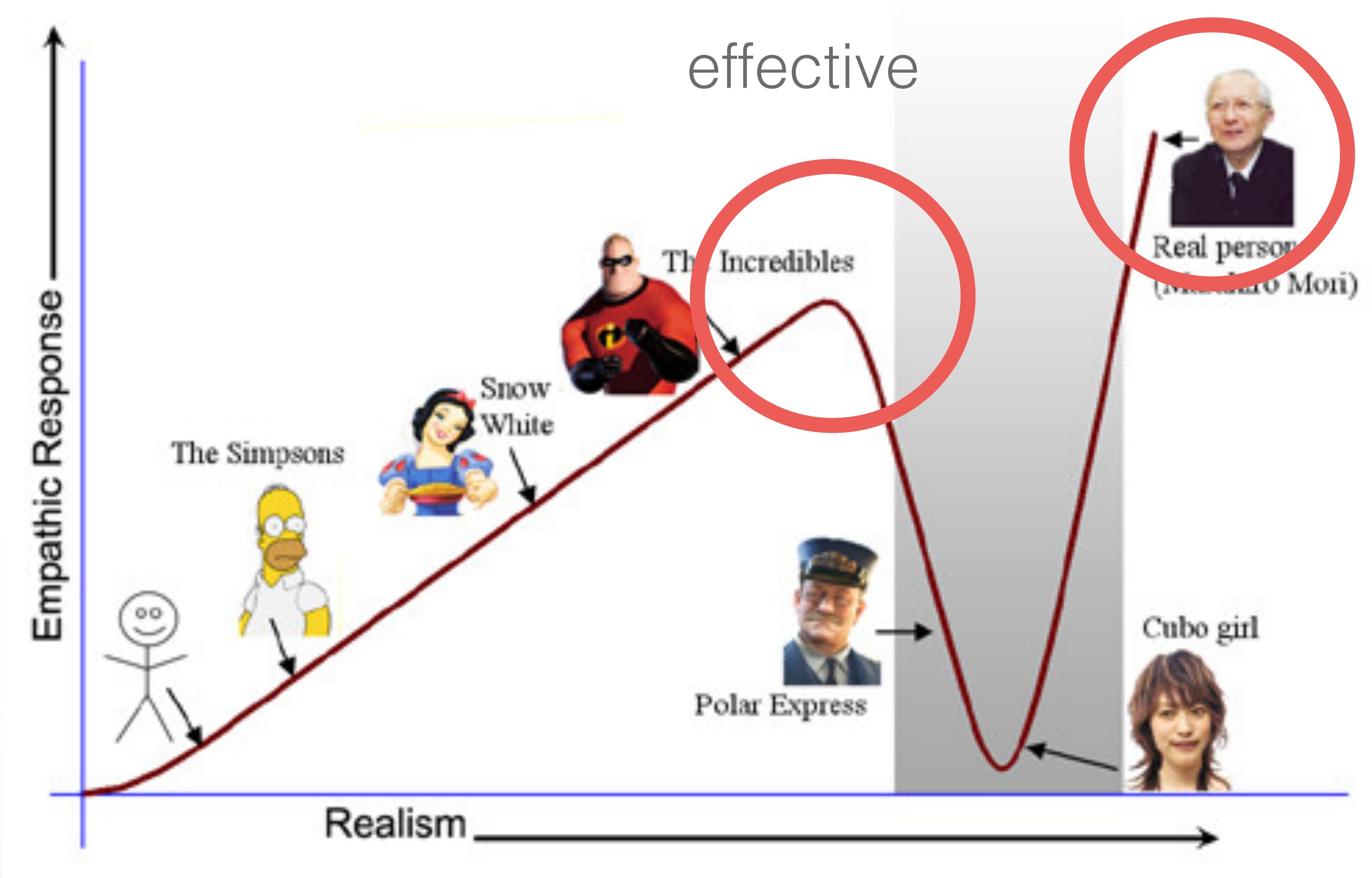


emerging fields

Last Time

realistic

effective



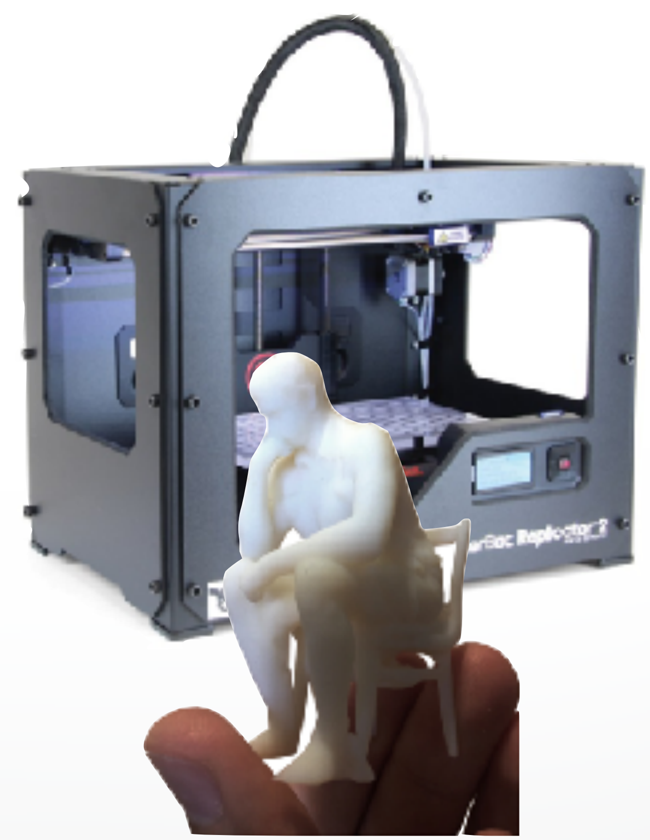
Last Time

From Offline to Realtime

From Graphics to Vision

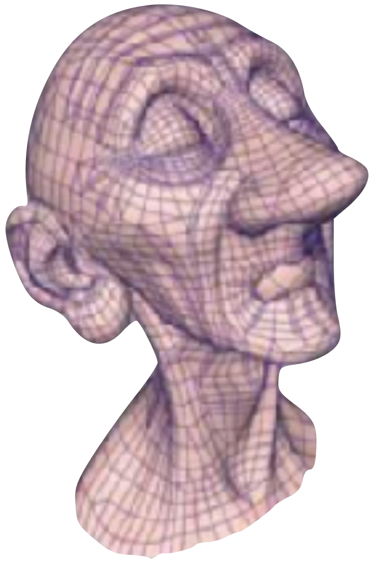
From Graphics to Fabrication

From Production to Consumers



Render [ren-der]

To generate an image or animation



input data

output rendering

How to make an image?

drawing

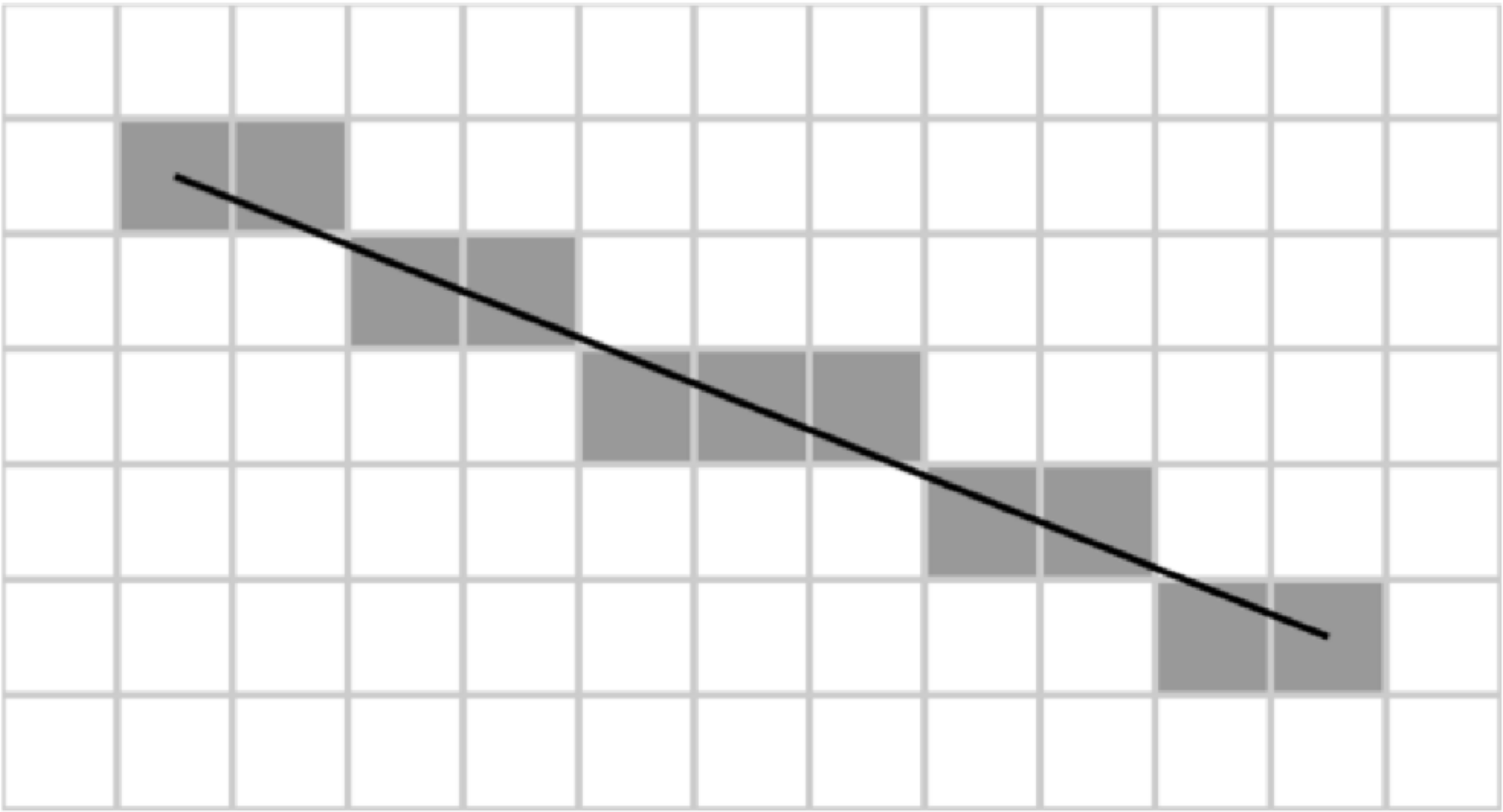
photography

Output: Raster Image

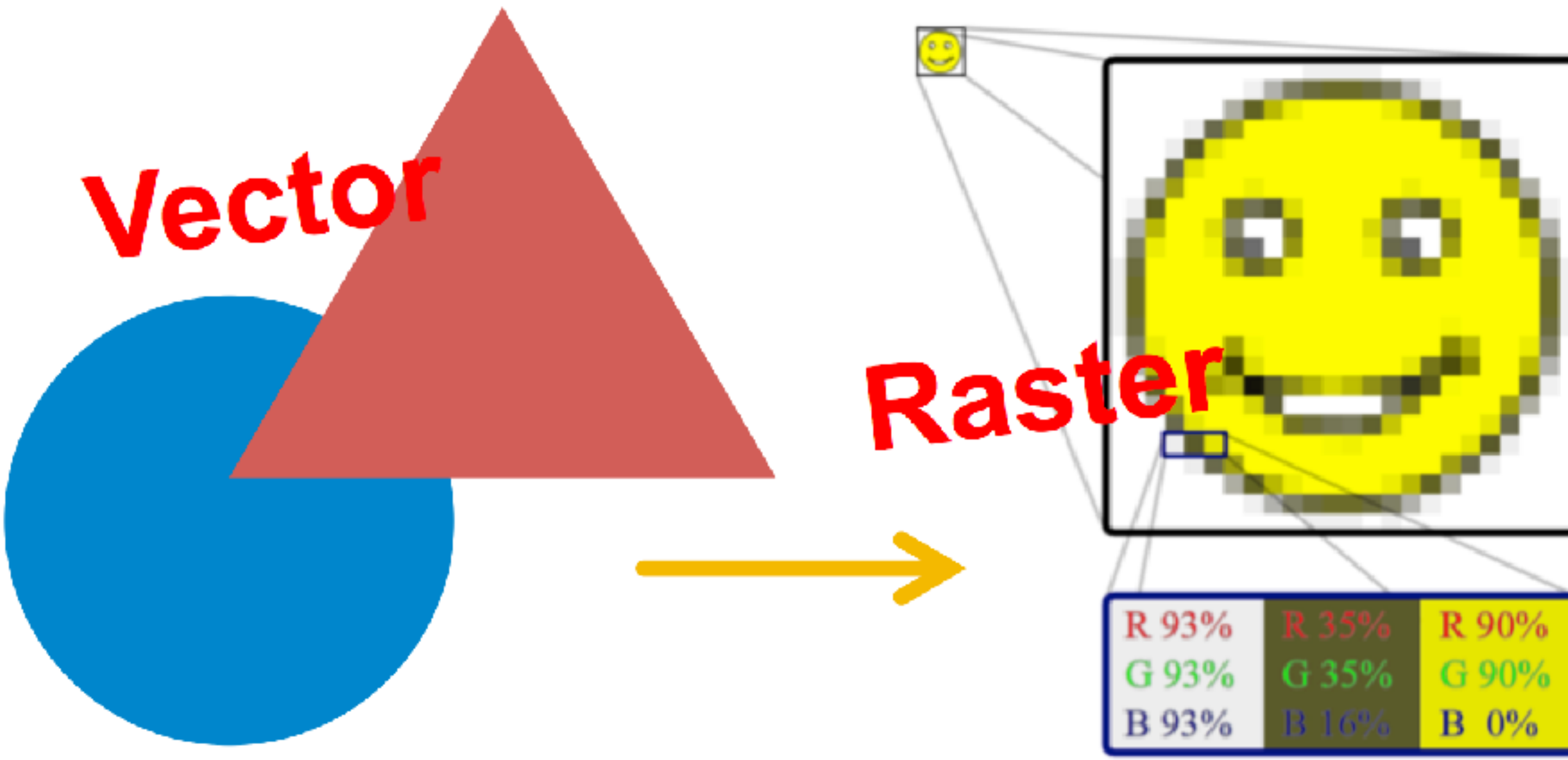
- 2D array of pixels (**pic**ture **el**ements)
  - regular grid sampling of arbitrary 2D function
  - different formats, e.g., bitmaps, grayscale, color
  - different data types, e.g., boolean, int, float
  - color/bit depth: #bits/pixel
  - transparency handled by alpha channel, e.g., RGBA

[wikipedia]

Rasterization



Rasterization

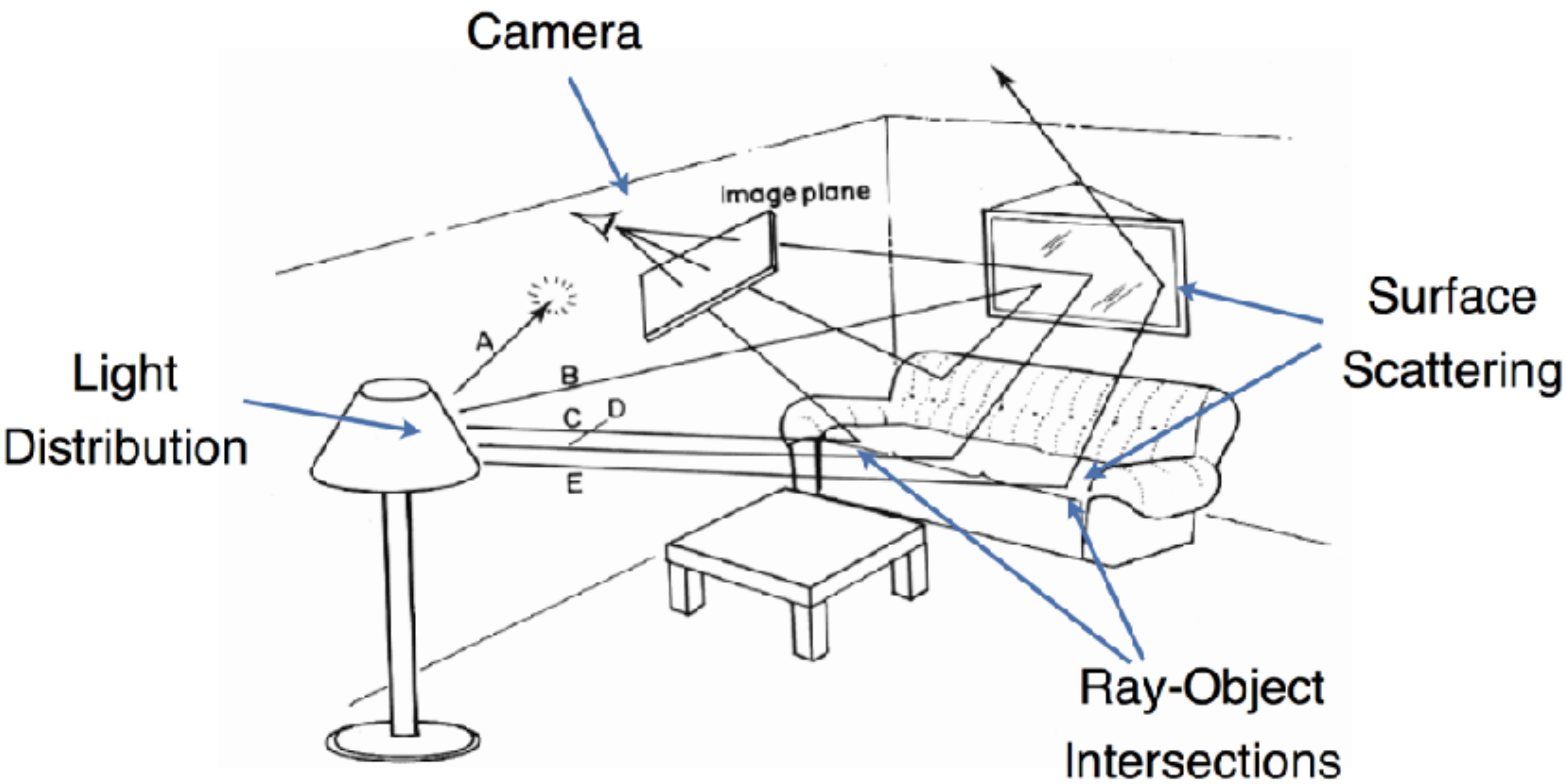


"A triangle is here, a circle is there, …"

"This pixel is yellow…"

Okay… let's take a step back

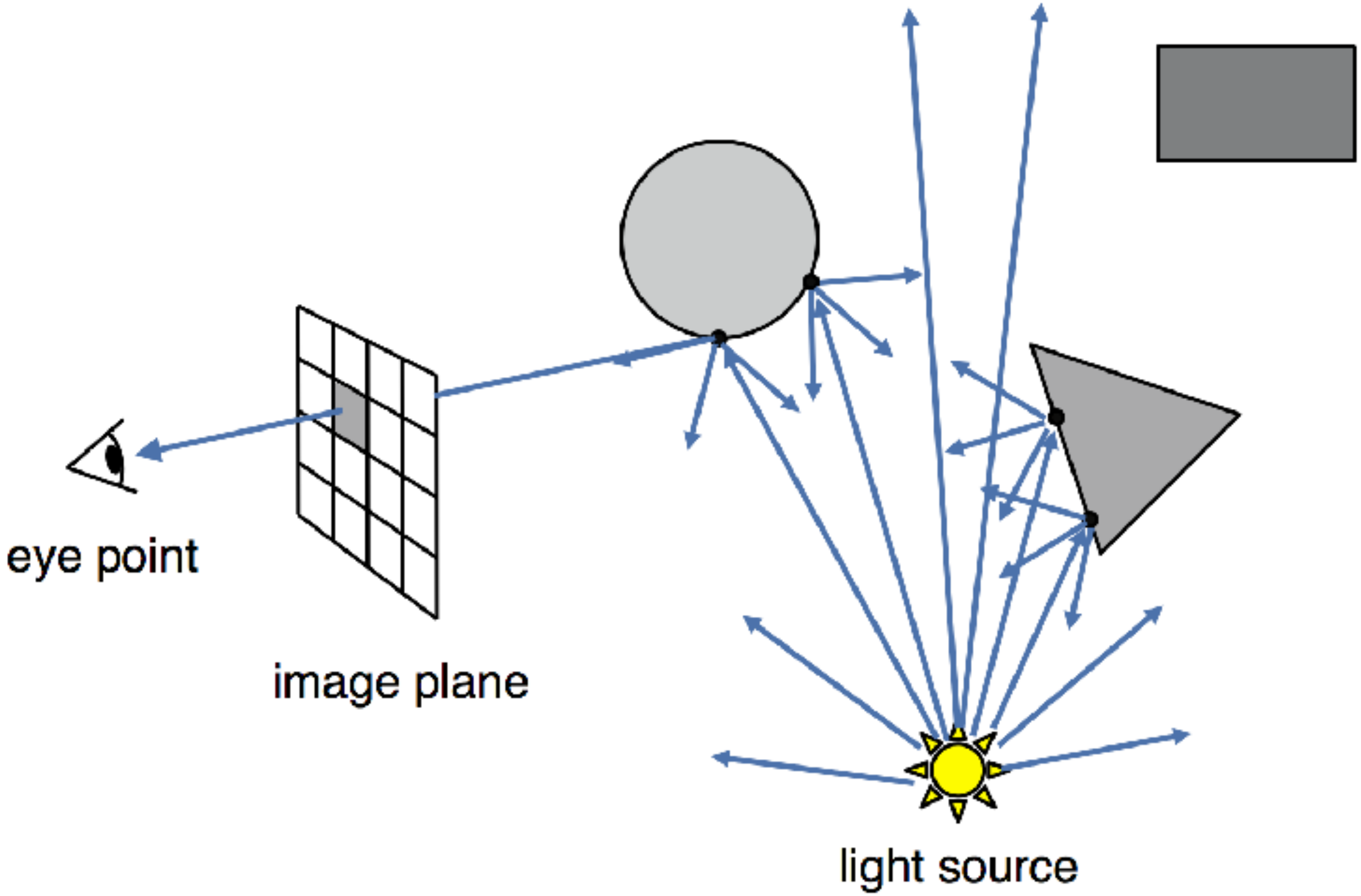
In the physical world



Light Transport

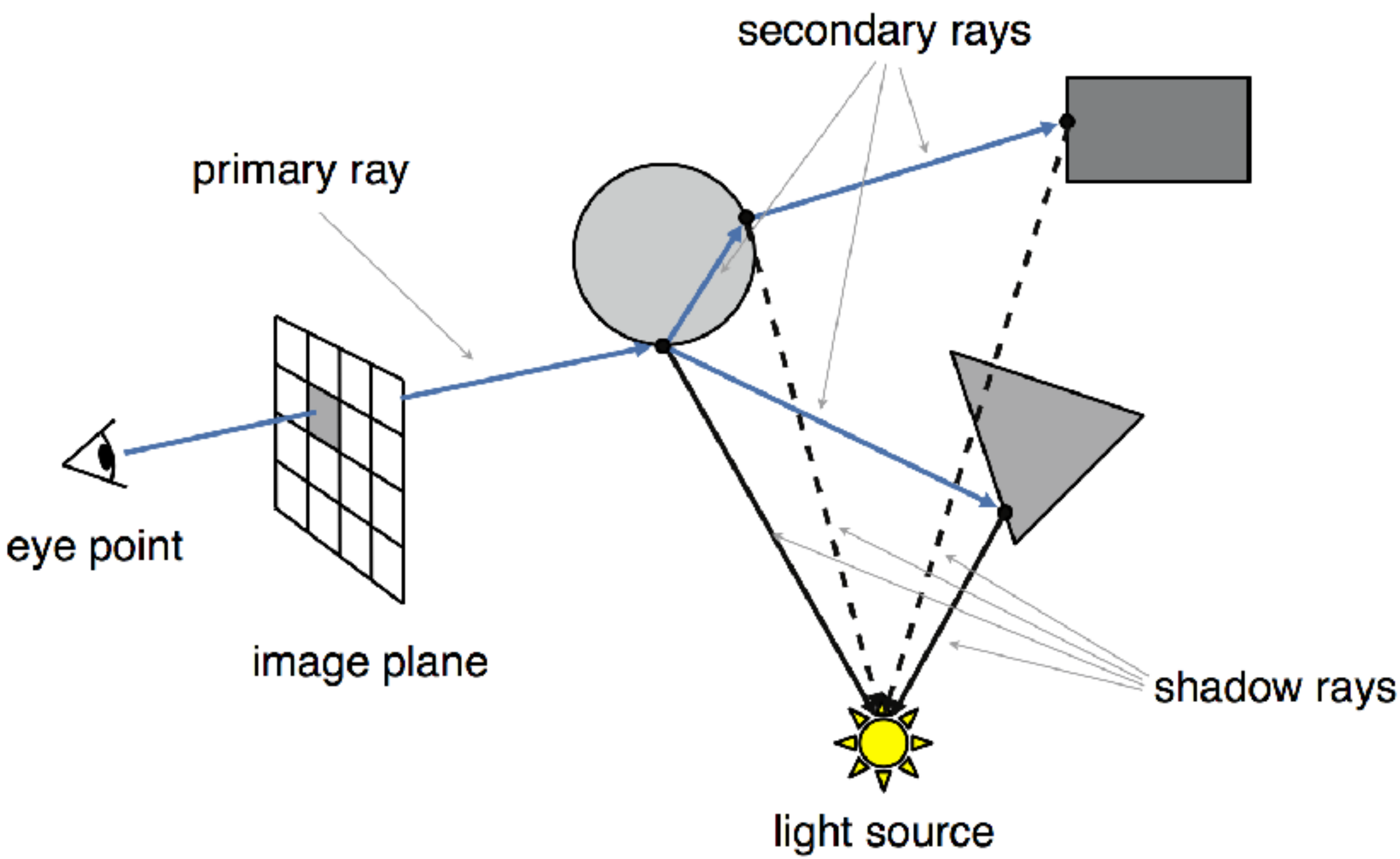
- Light travels in **straight lines**
- Light rays **do not interfere** with each other if they cross
- Light travels from the **light sources to the eye** (physics is invariant under path reversal reciprocity)

Light-Oriented (Forward Raytracing)



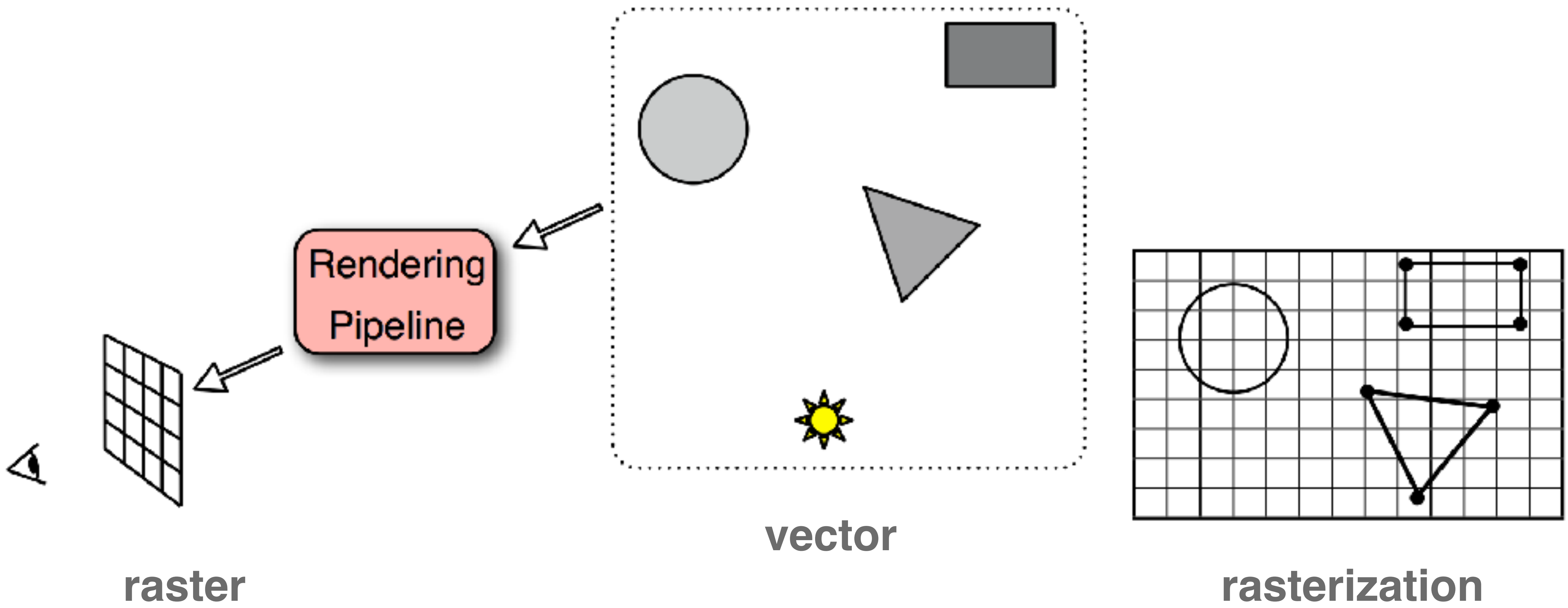
Only a **fraction** of light rays reach the image

Eye-Oriented (Backward Raytracing)



or simply **“Raytracing”**

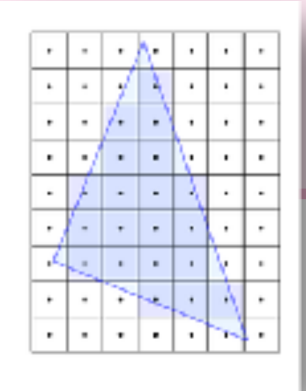
Object-Oriented (Forward Rendering)



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 then drawing each one unless the z-buffer says that it's not in front



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

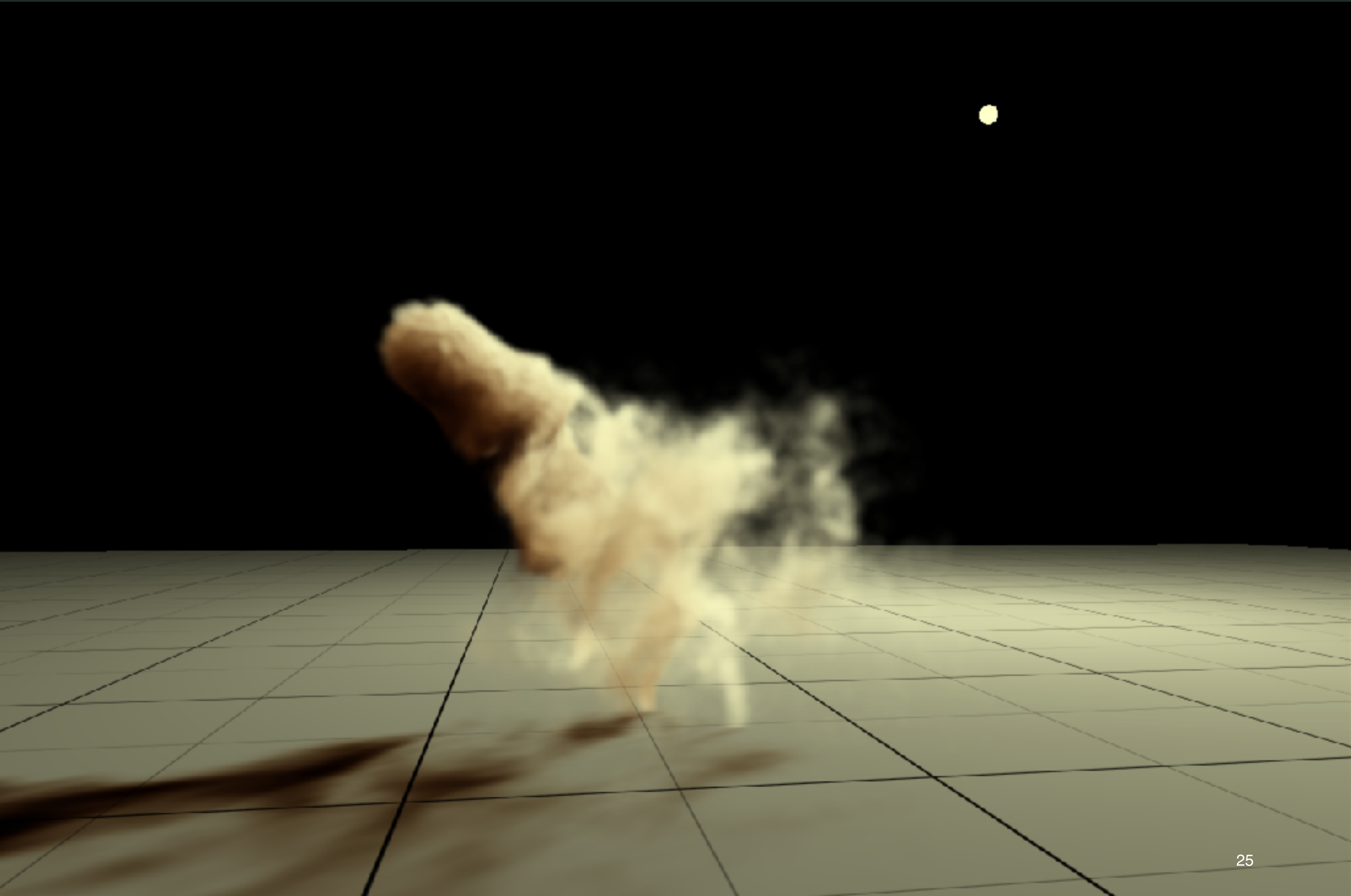
What is OpenGL?

- **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)

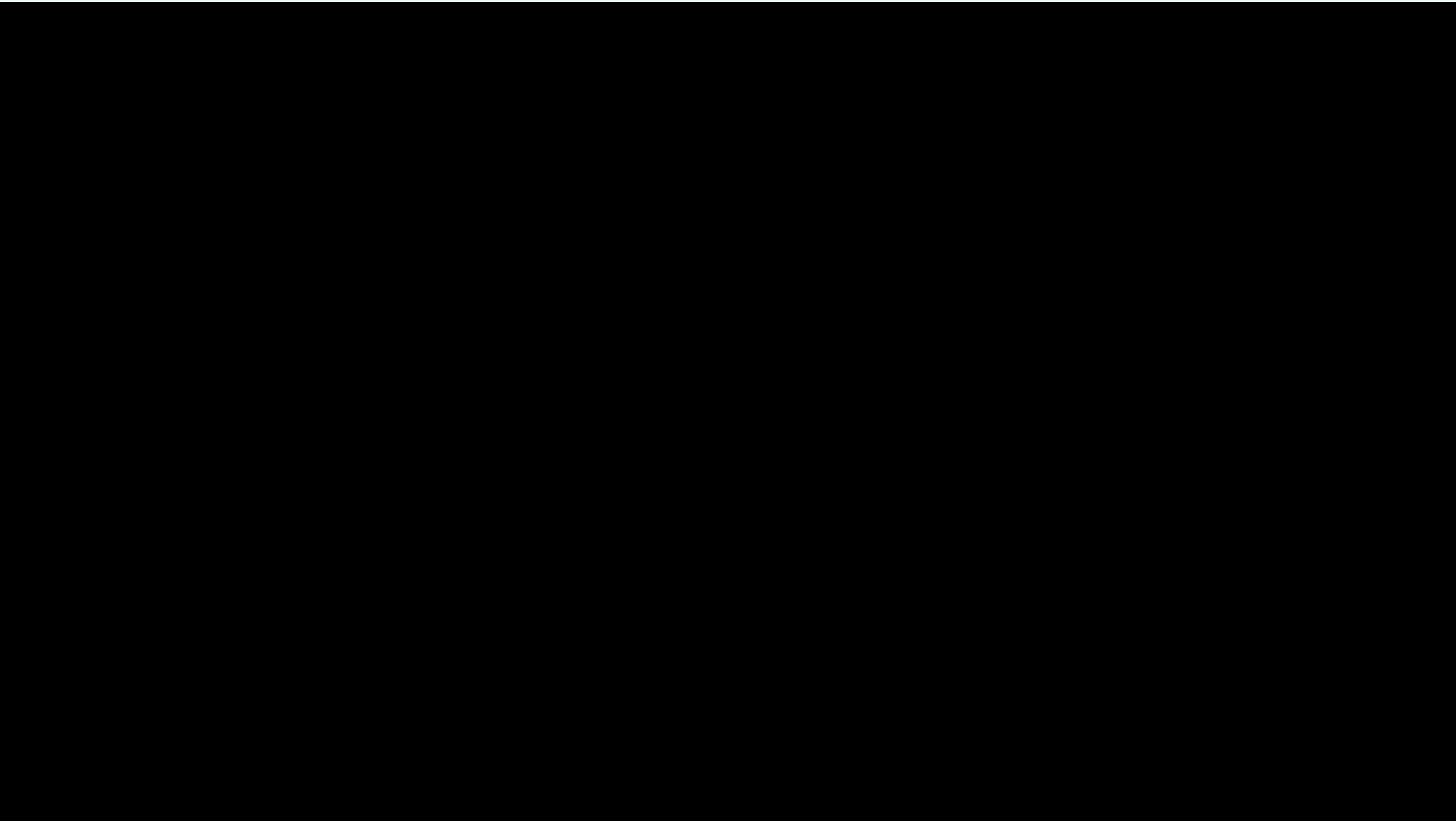
Where is OpenGL used?

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

Realtime Graphics Demo

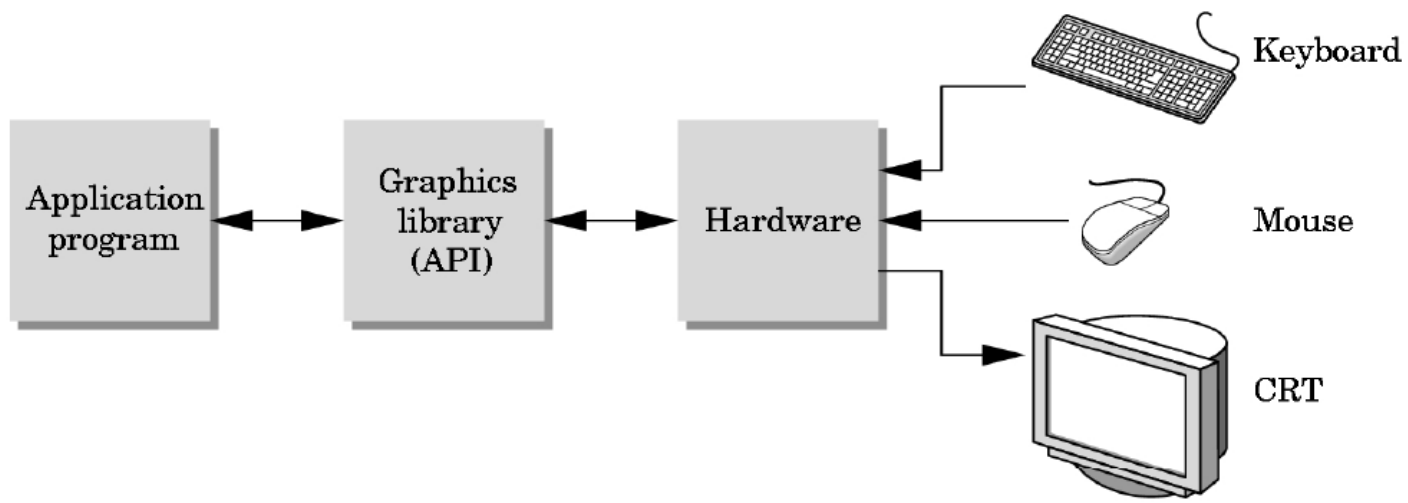


Unreal Kite Demo (GTX TitanX)



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:**

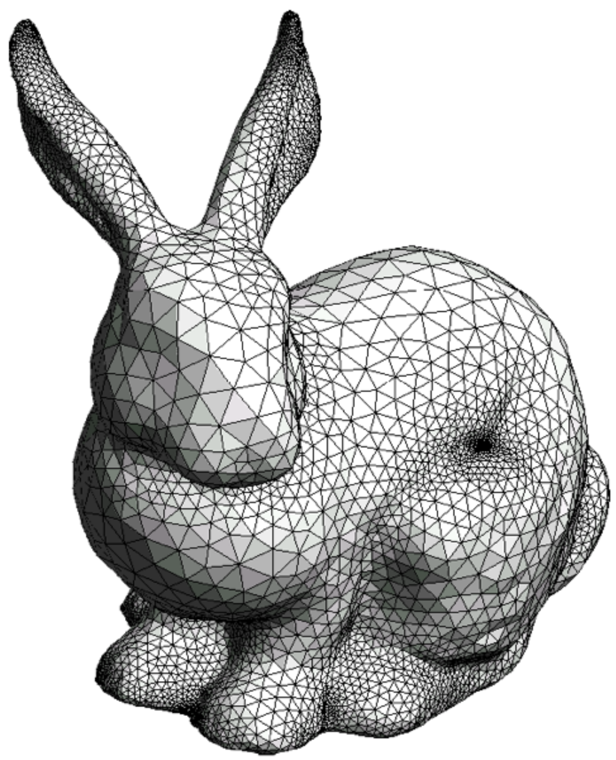
Mac, Linux, Windows: ships with the OS
Linux: Mesa, freeware implementation

```
#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)

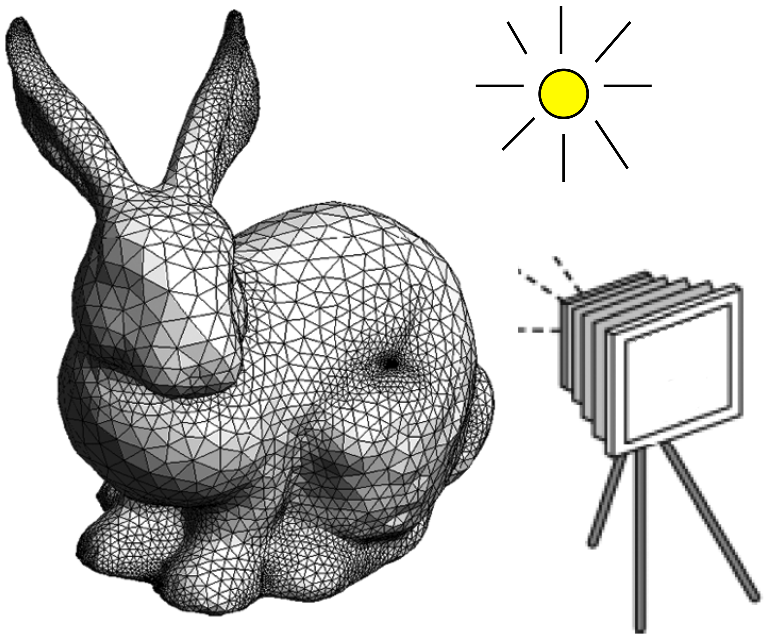
Define how objects should be viewed

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

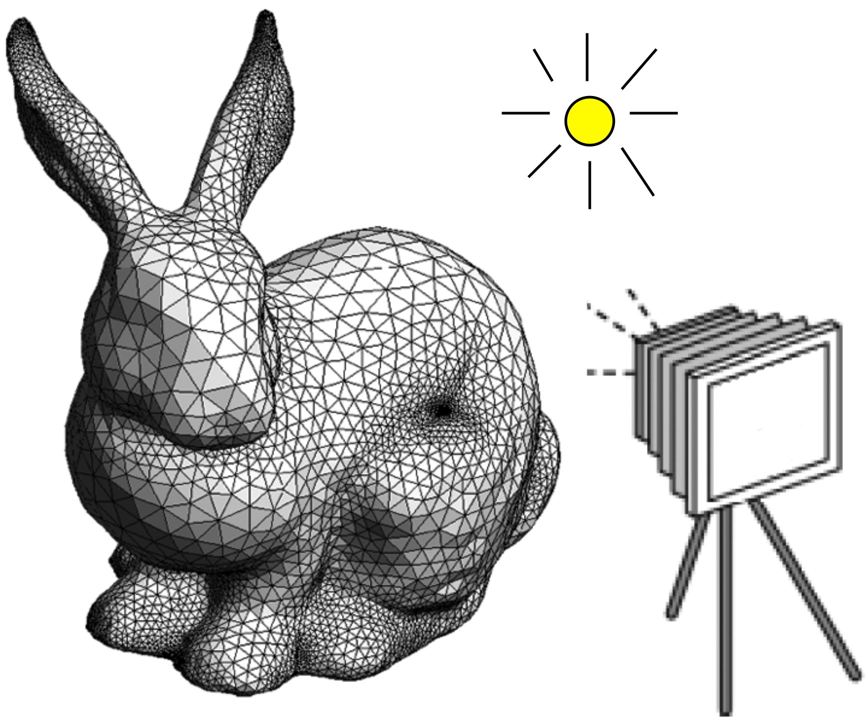
Specify light sources

- where, what kind?

Move camera or objects around for animation



The result



the scene

the result

OpenGL is a state machine

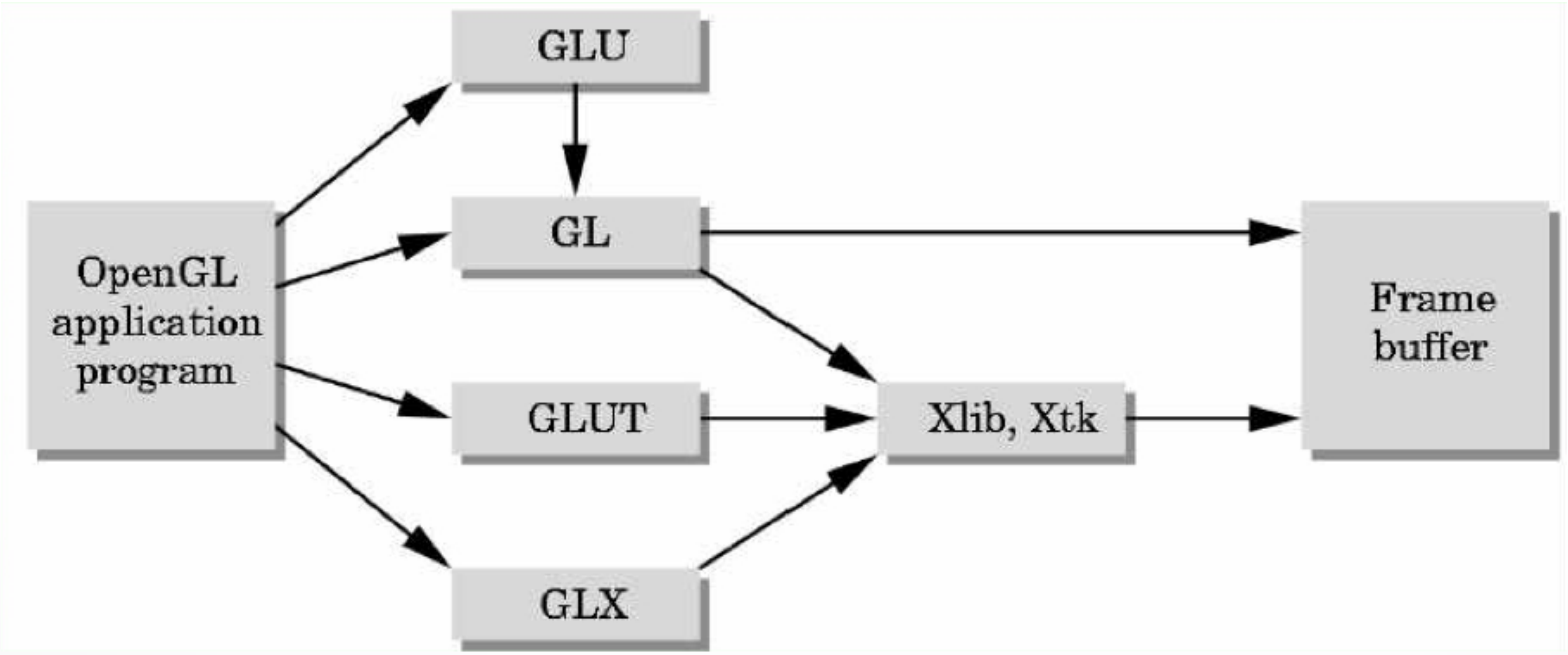
State variables: color, camera position, light position, material properties…

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

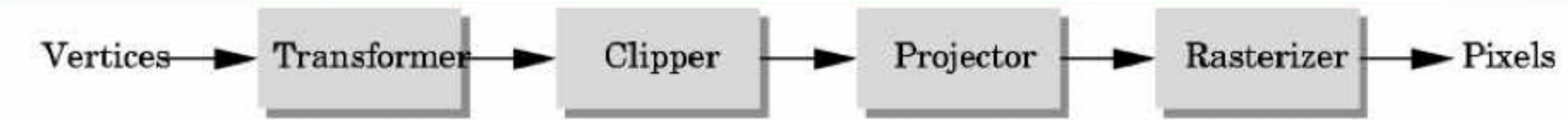
They **persist** until set to new values by the programmer.

OpenGL Library Organization

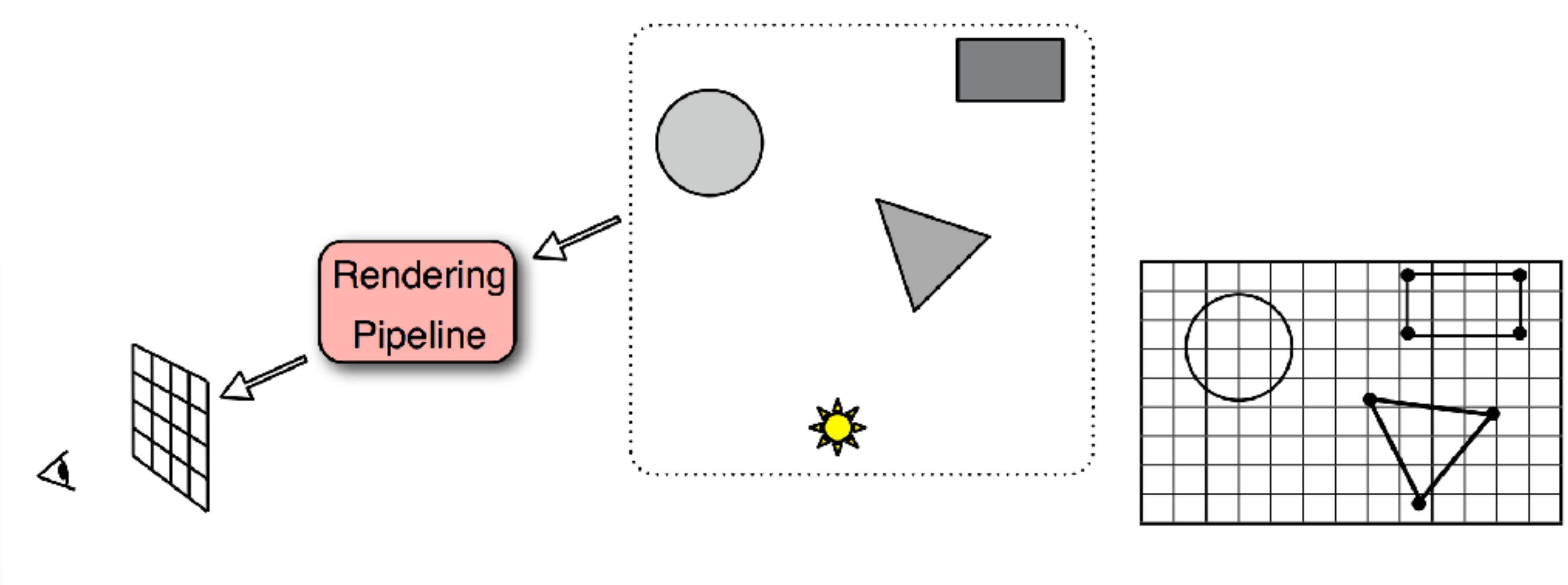
- **GL (Graphics Library):** core graphics capabilities
- **GLU (OpenGL Utility Library):** utilities on top of GL
- **GLUT (OpenGL Utility Toolkit):** input and windowing wrapper



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

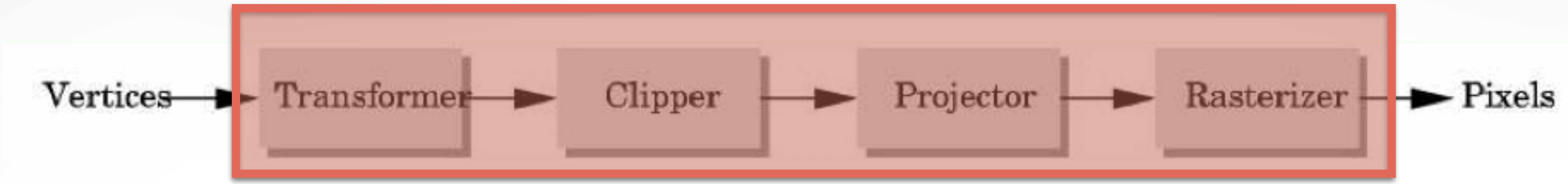
Application generates **stream of geometric primitives** (polygons, lines)

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**

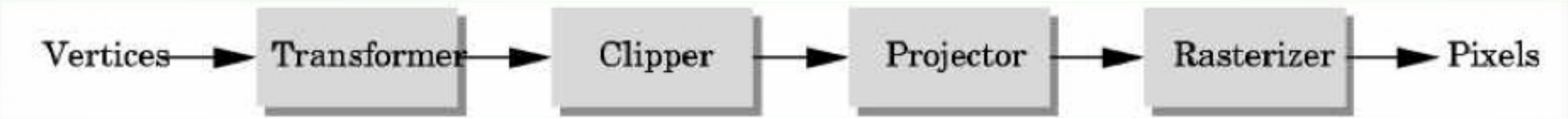


primitives+ material properties	translate rotate scale	is it visible on screen?	3D to 2D	convert to pixels	shown on the screen (framebuffer)

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

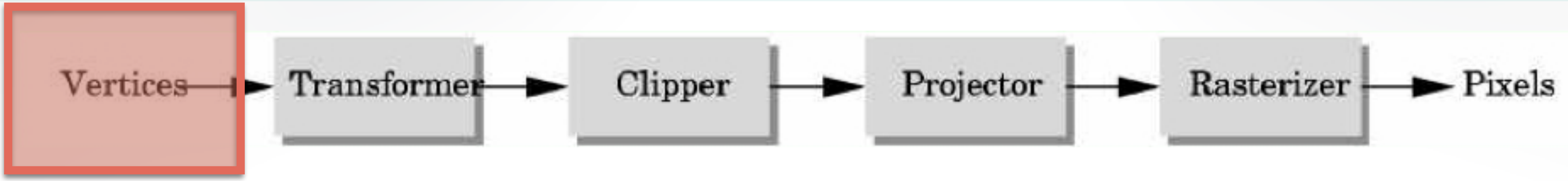
OpenGL programmer does not need to implement the pipeline, but can **reconfigure it through shaders**

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



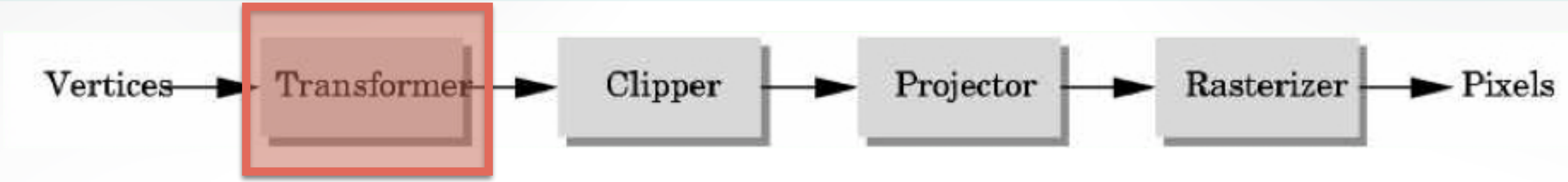
- Vertices in **world coordinates**

- **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

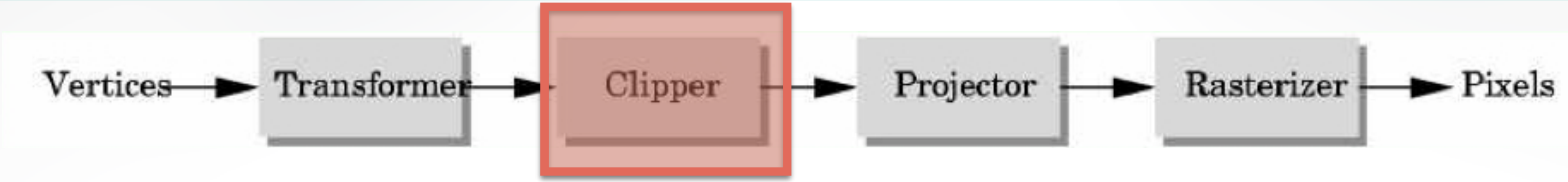
- glVertex{234}{sfid}(TYPE coords)

Transformer

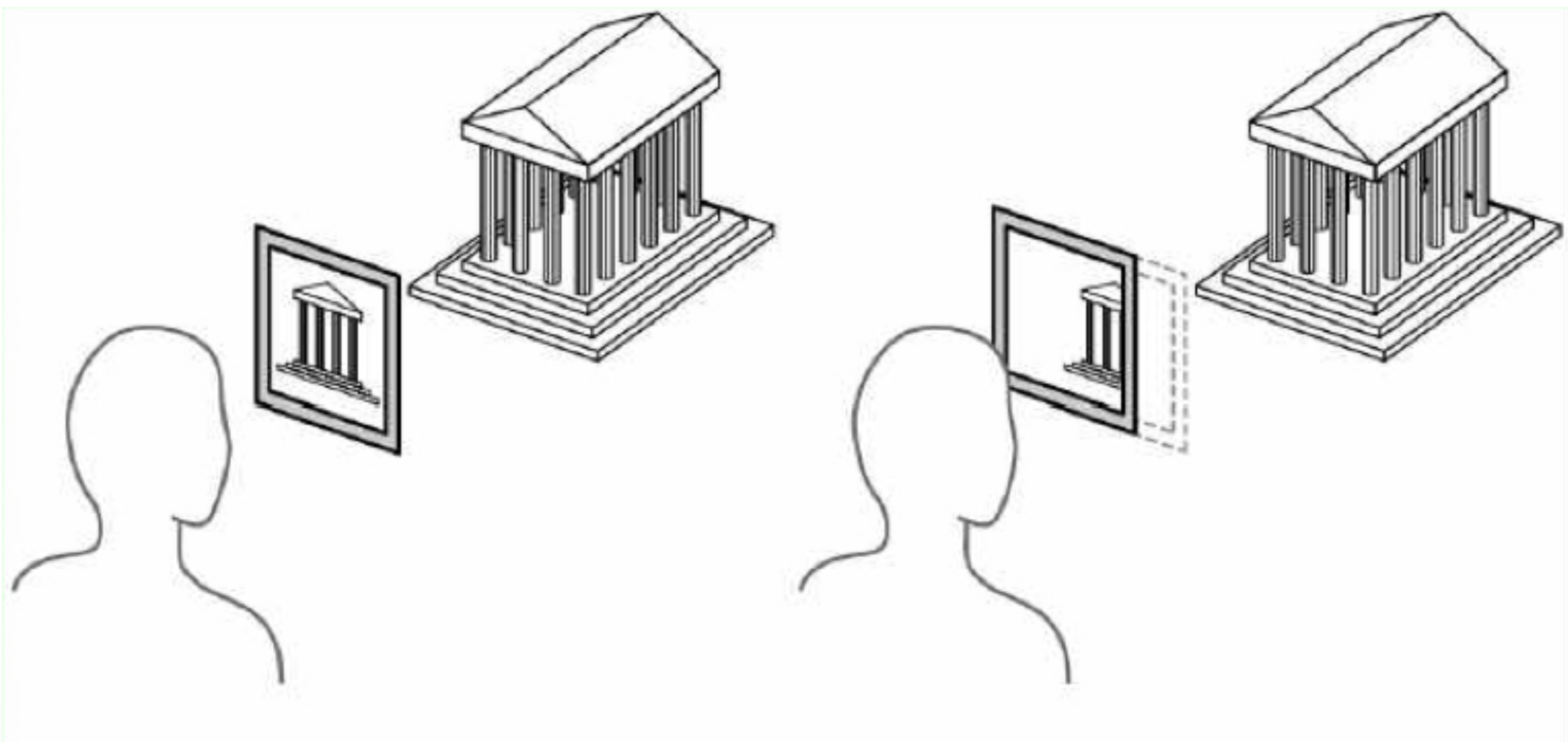


- Transformer in **world coordinates**
- **Must be set before object is drawn!**
  - glRotate (45.0, 0.0, 0.0, -1.0);
  - glVertex2f(1.0, 0.0);
- Complex [Angel Ch. 4]

Clipper

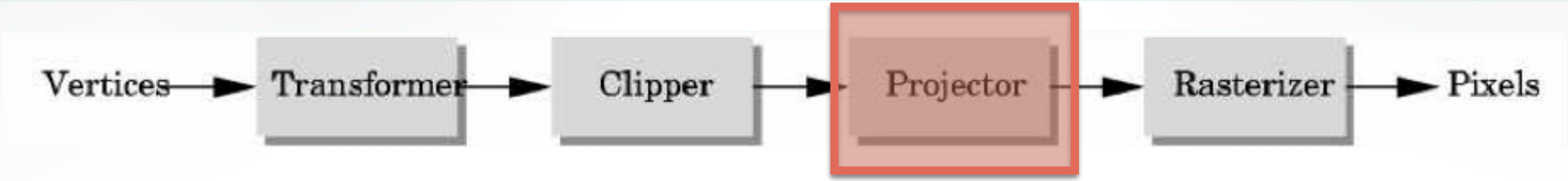


- Mostly automatic (**must set viewport**)



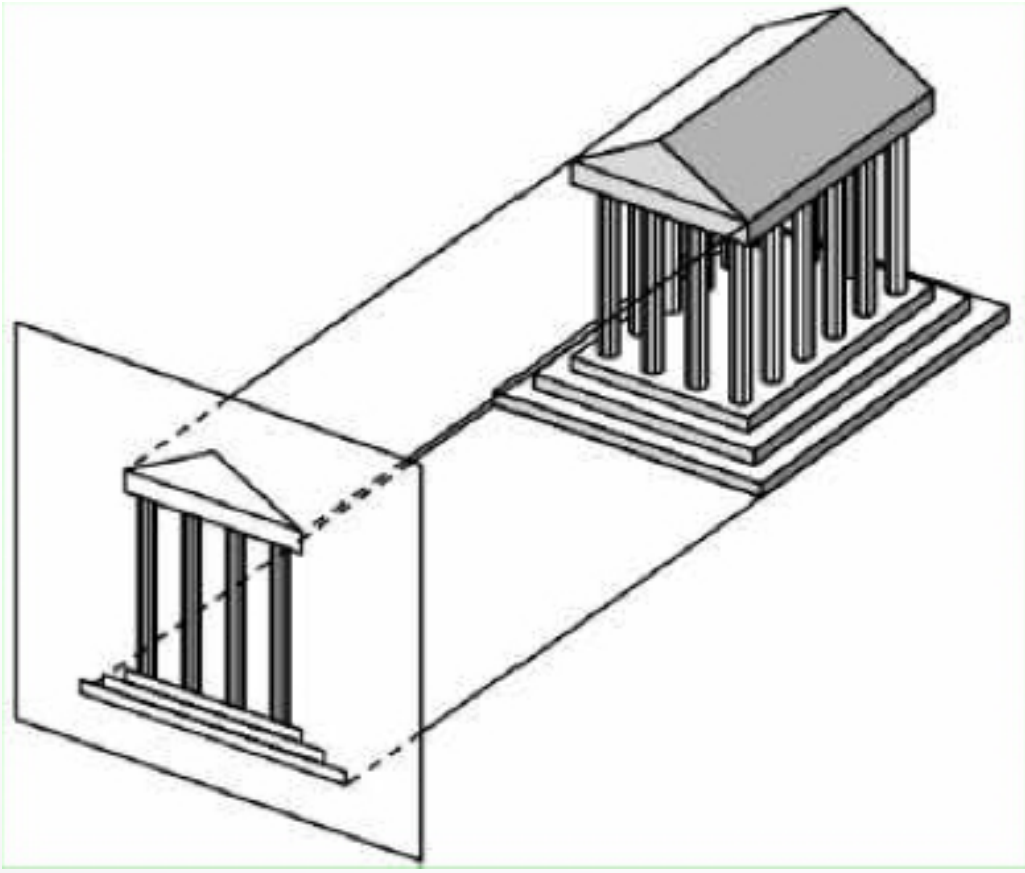
(a) (b)

Projector

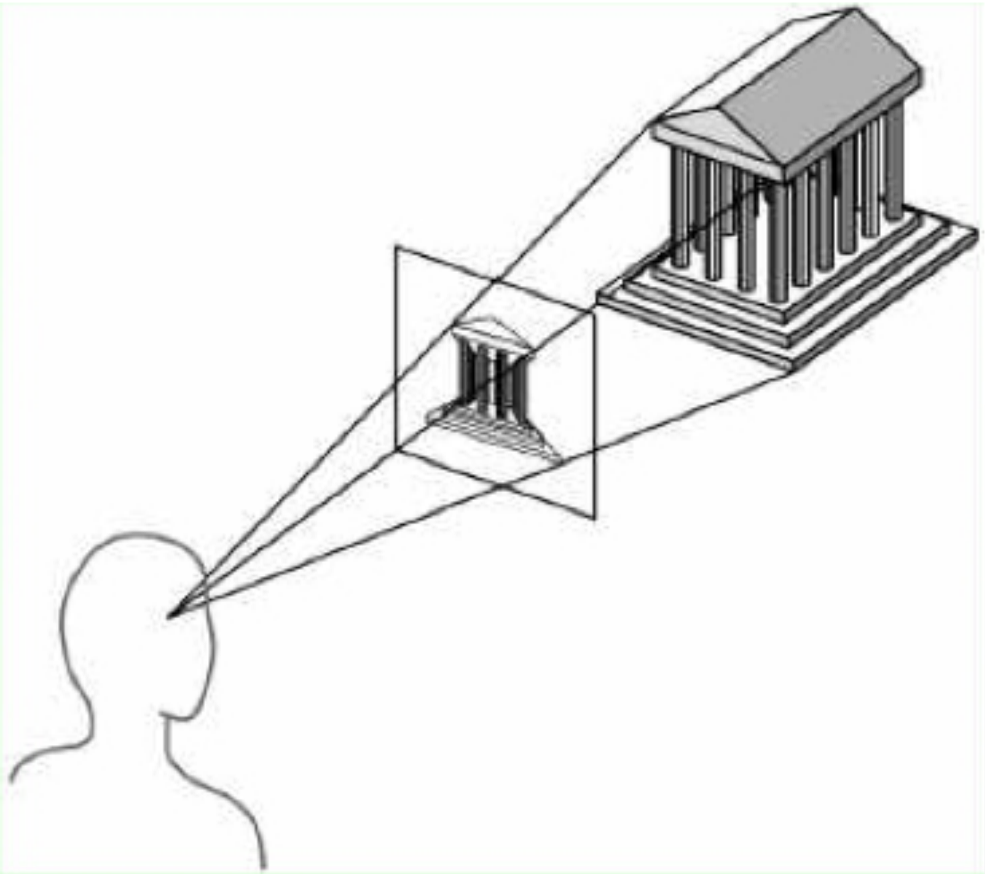


- Complex transformation [Angel Ch. 5]

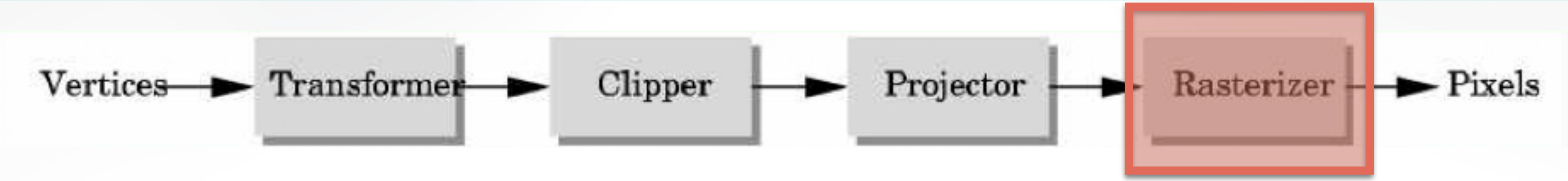
orthographic



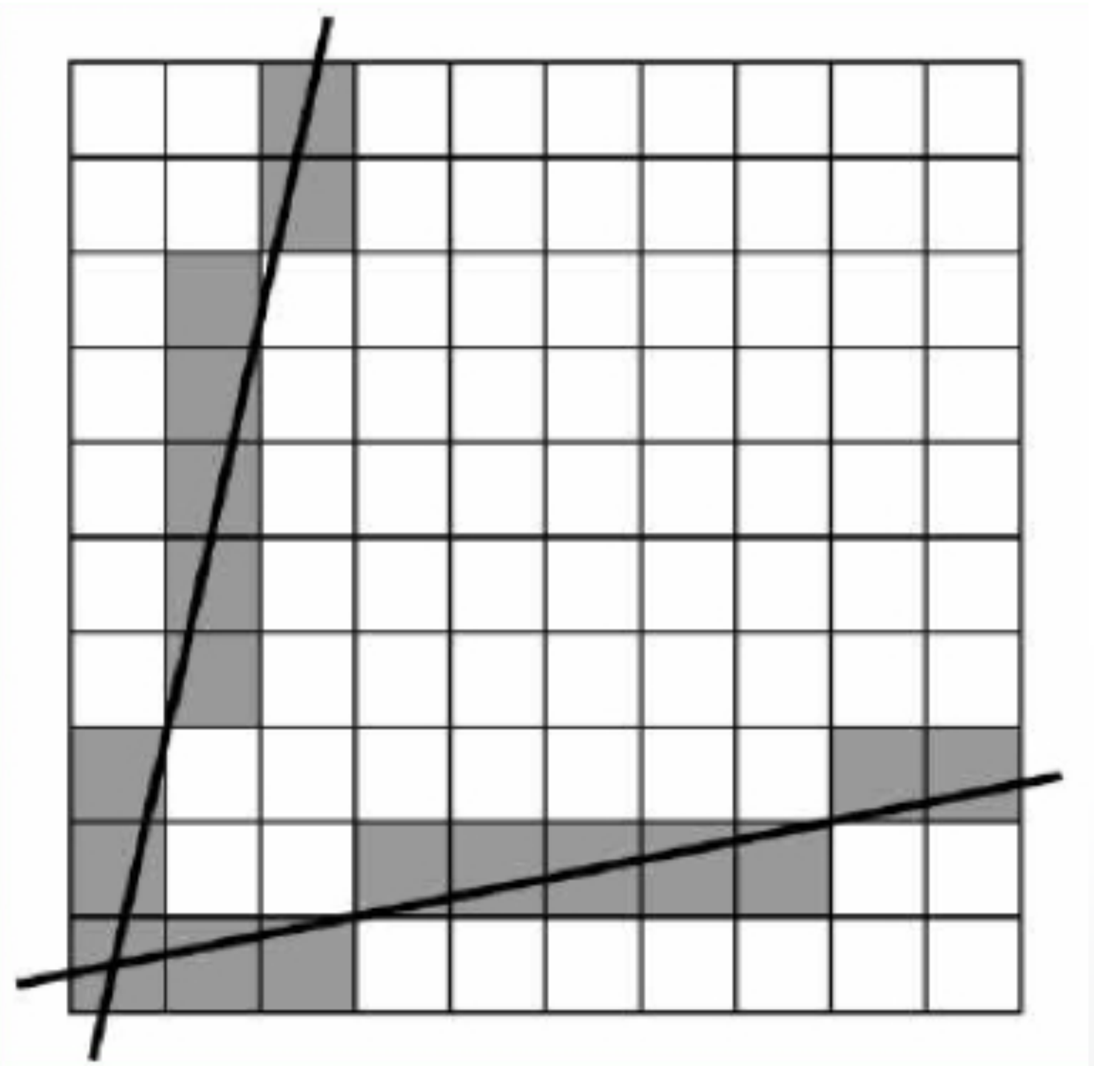
perspective



Rasterizer



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

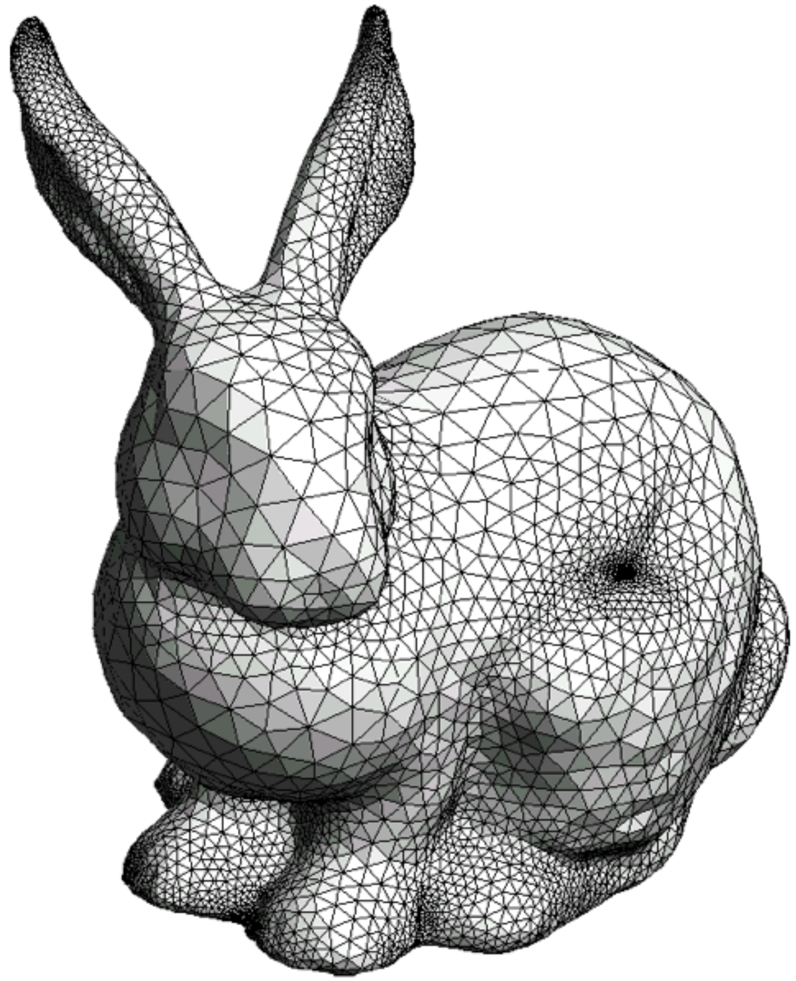


Primitives

- Specified via vertices

- General scheme

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



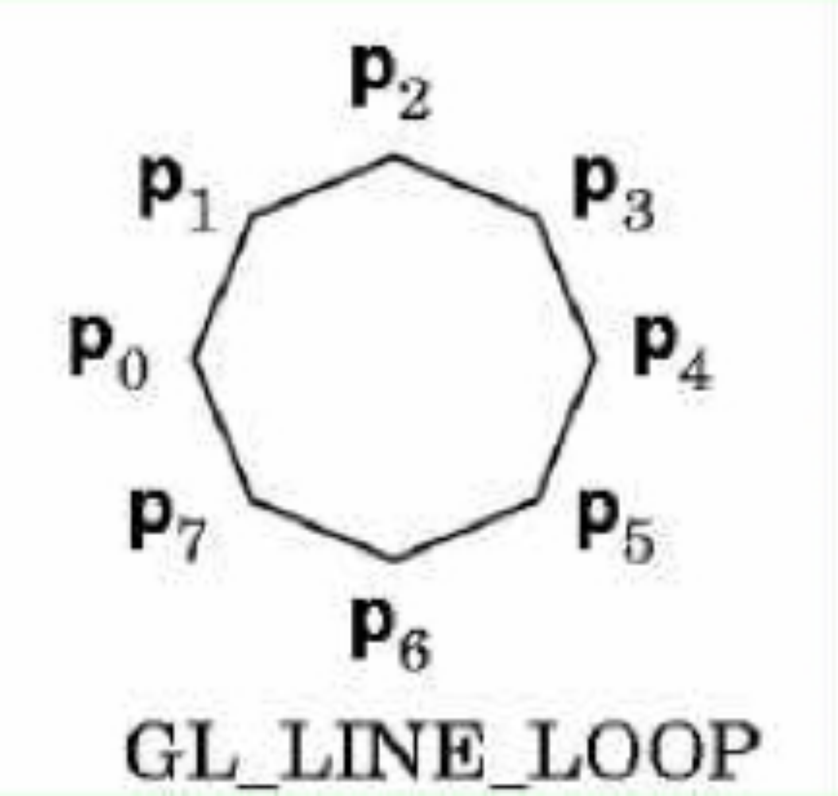
- **type** determines interpretation of vertices

- Can use glVertex2f(x,y) in 2D

Example: Draw Square Outline

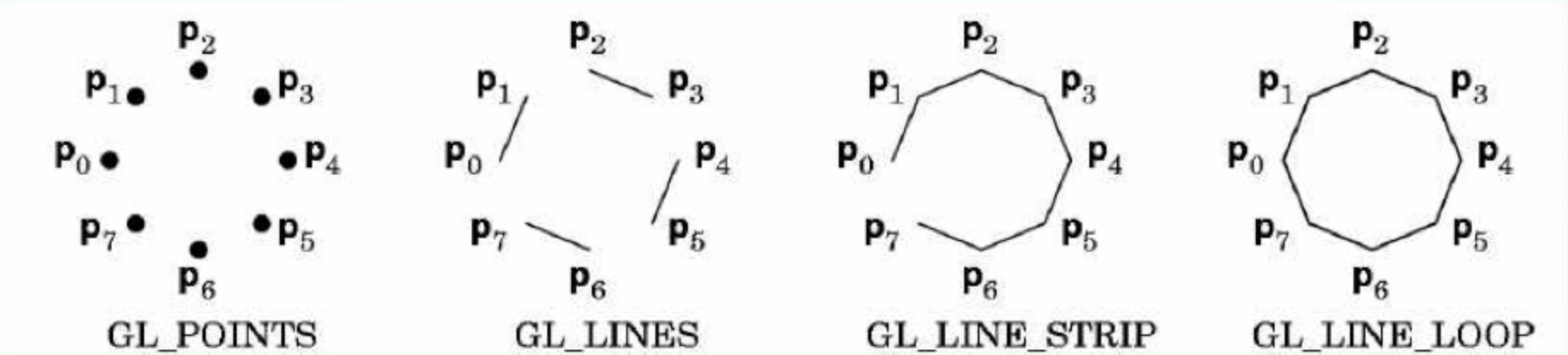
- **Type = GL_LINE_LOOP**

```
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 between glBegin(Type) and glEnd()

Points and Line Segments

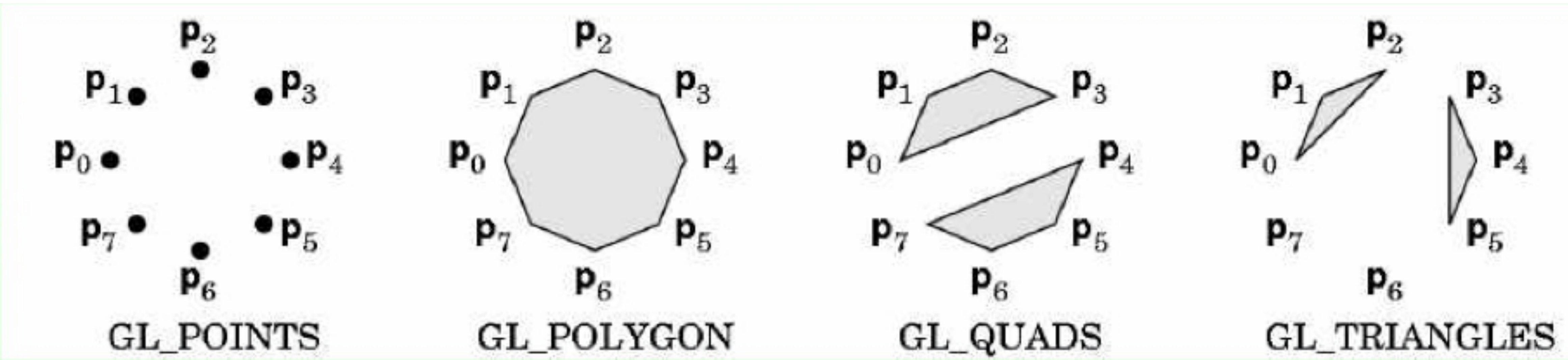



```
glBegin(GL_POINTS);
    glVertex3f(…);
    …
    glVertex3f(…);
glEnd()
```

draw points

Polygons

- **Polygons enclose an area**

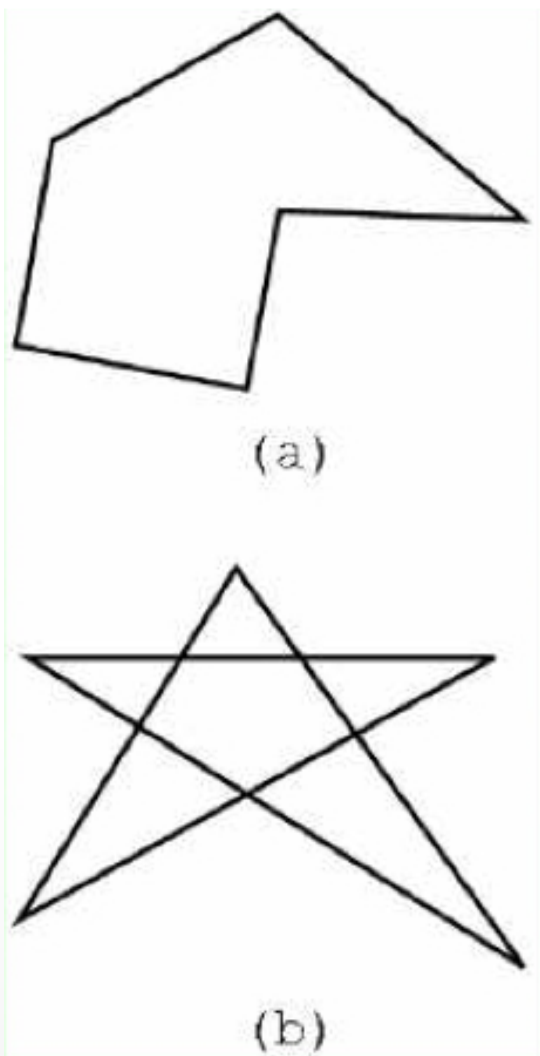


- Rendering of area (fill) depends on attributes

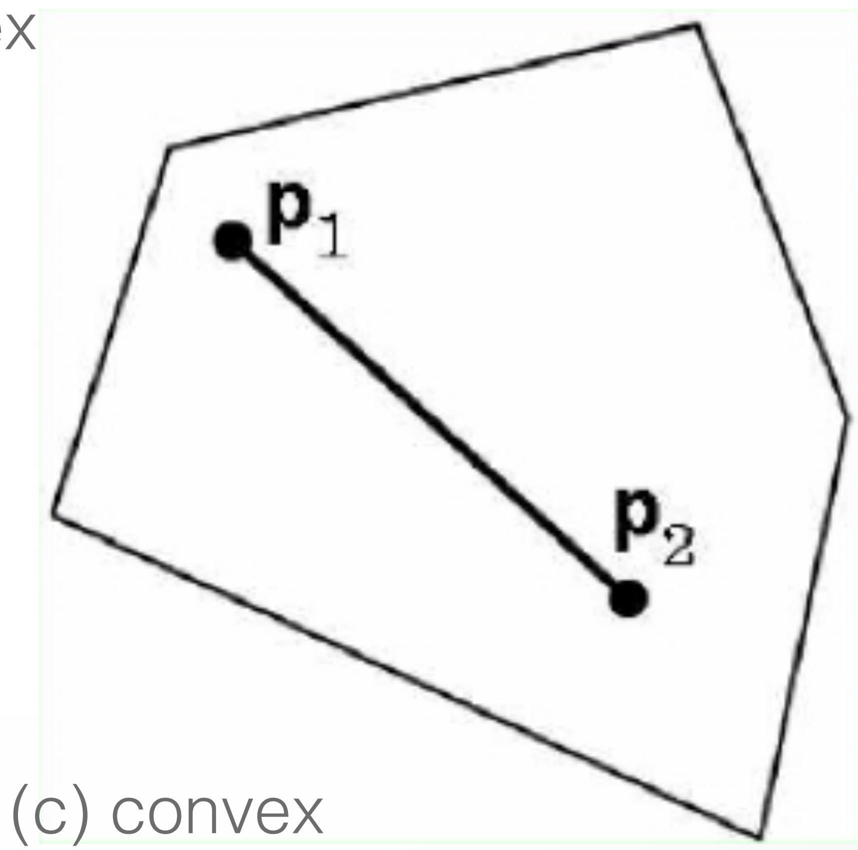
- **All vertices must be in one plane in 3D**

Polygons Restrictions

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



(a) simple, but not convex



(b) non-simple

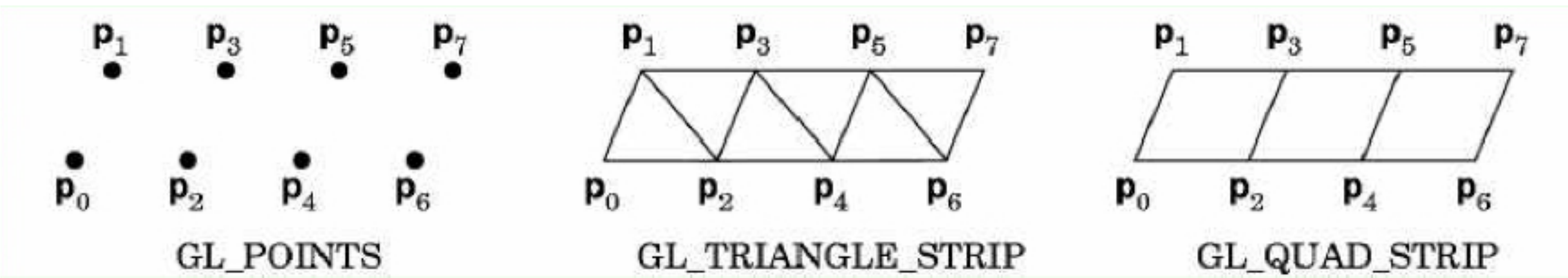
(c) convex

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 (**tessellation**)
- **Triangles are most efficient**

Polygons Strips

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



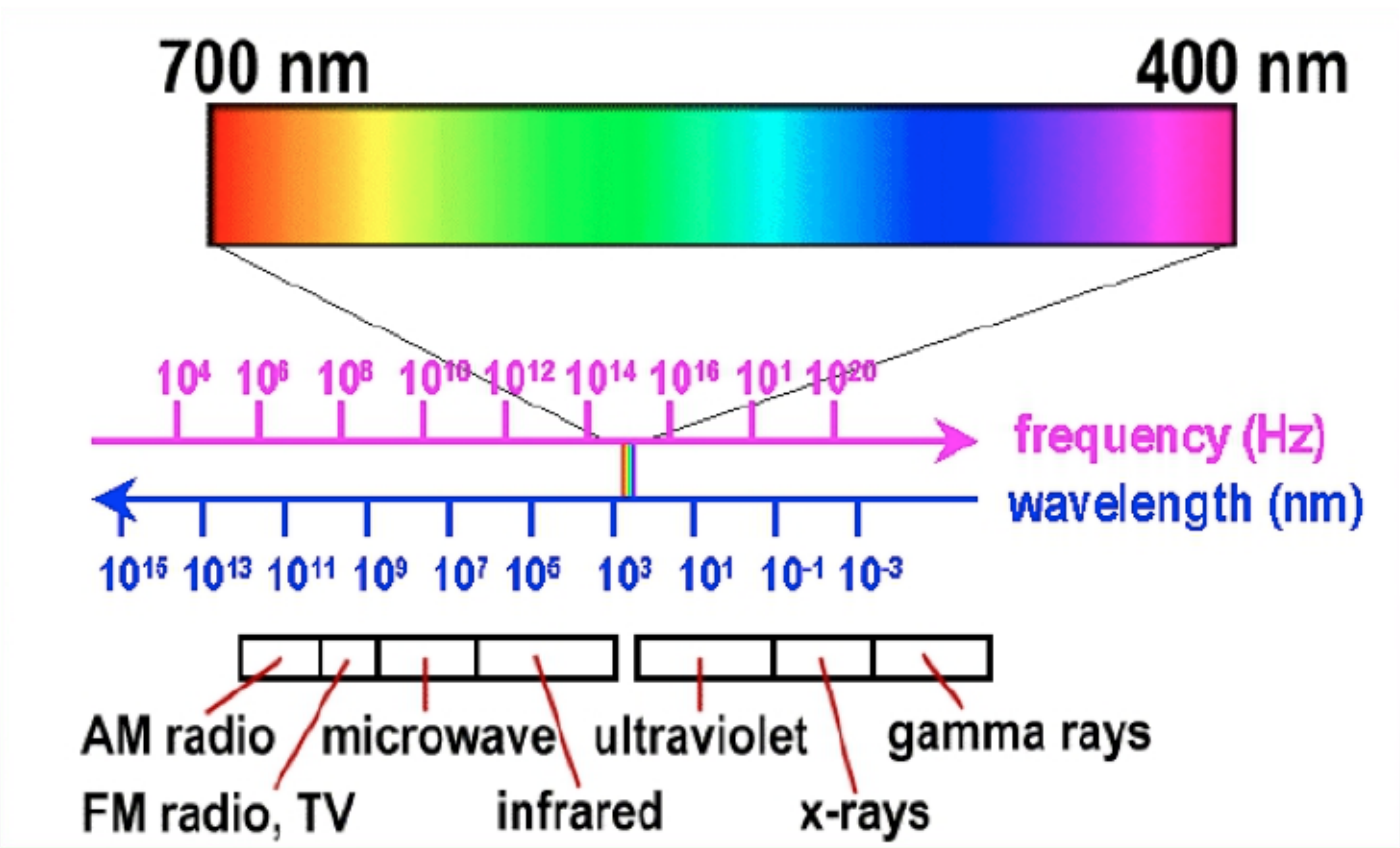
- Polygons have a **front and a back**, possibly with different attributes!

Attributes: Color, Shading, Reflections

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

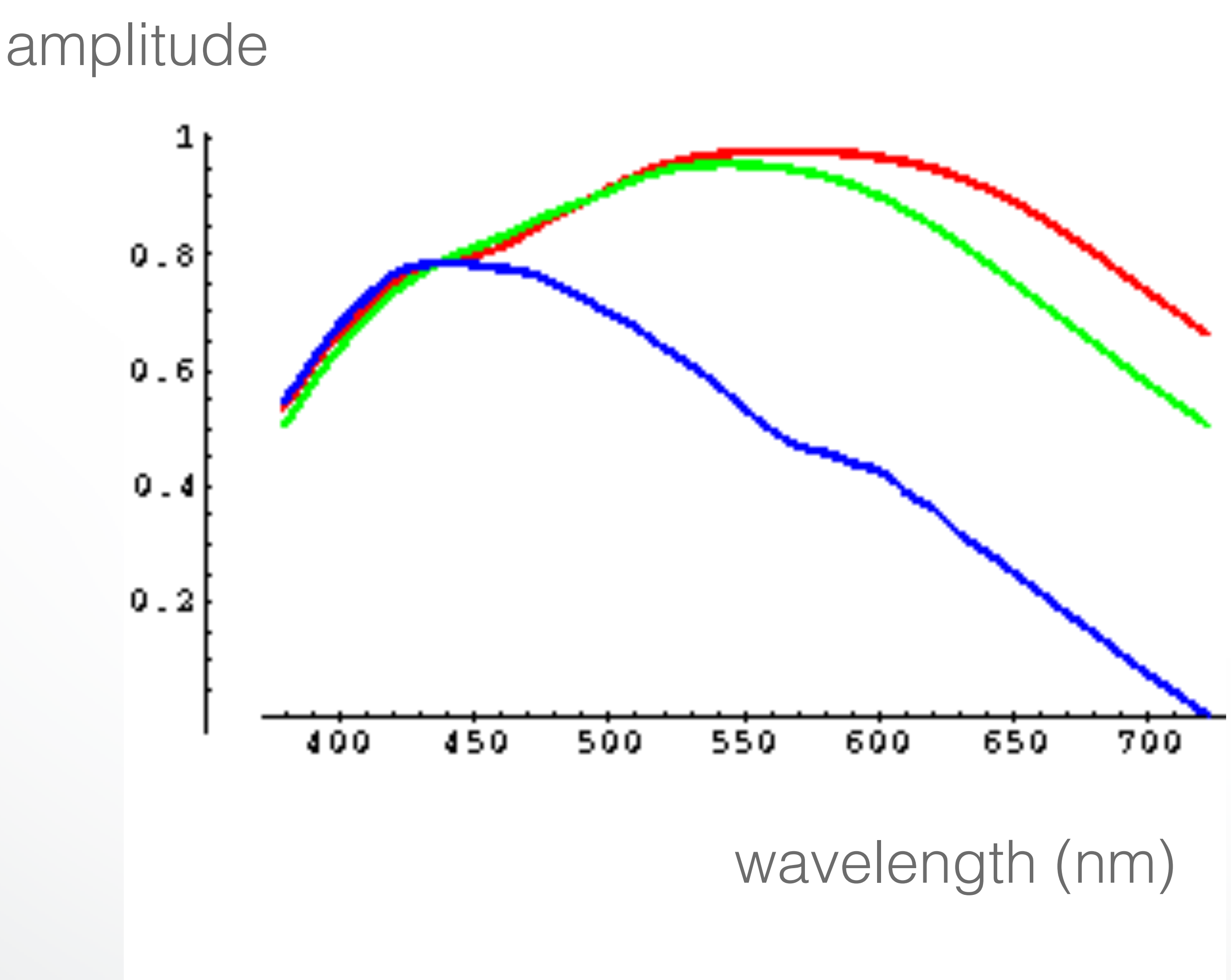
Physics of Color

- 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)**

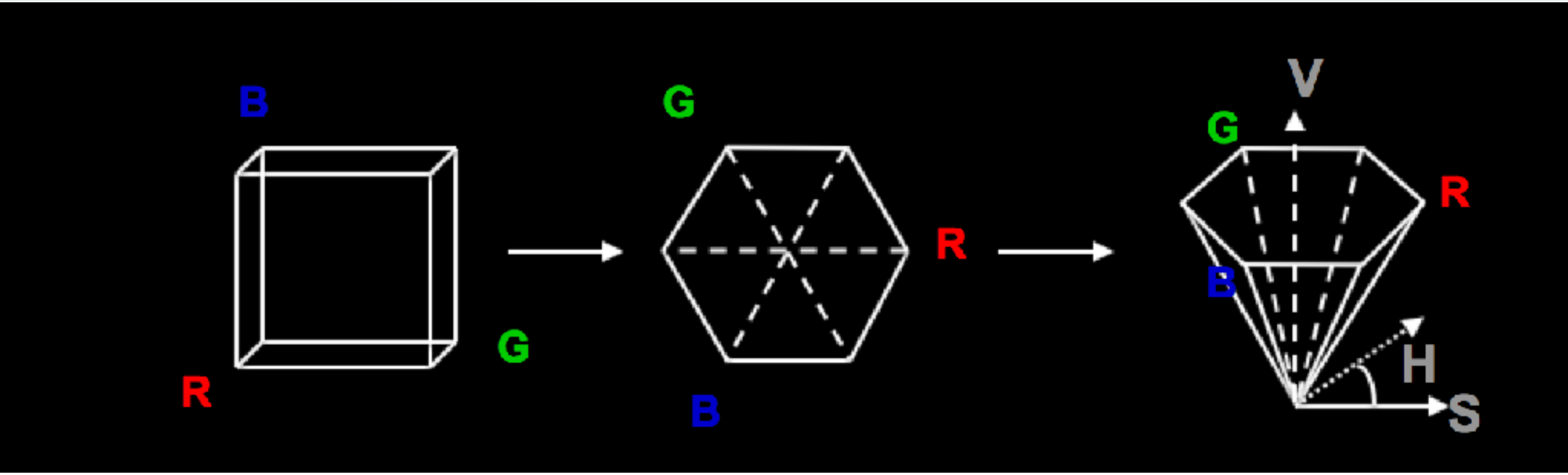
  Hue: what color?

  Saturation: how far away from gray?

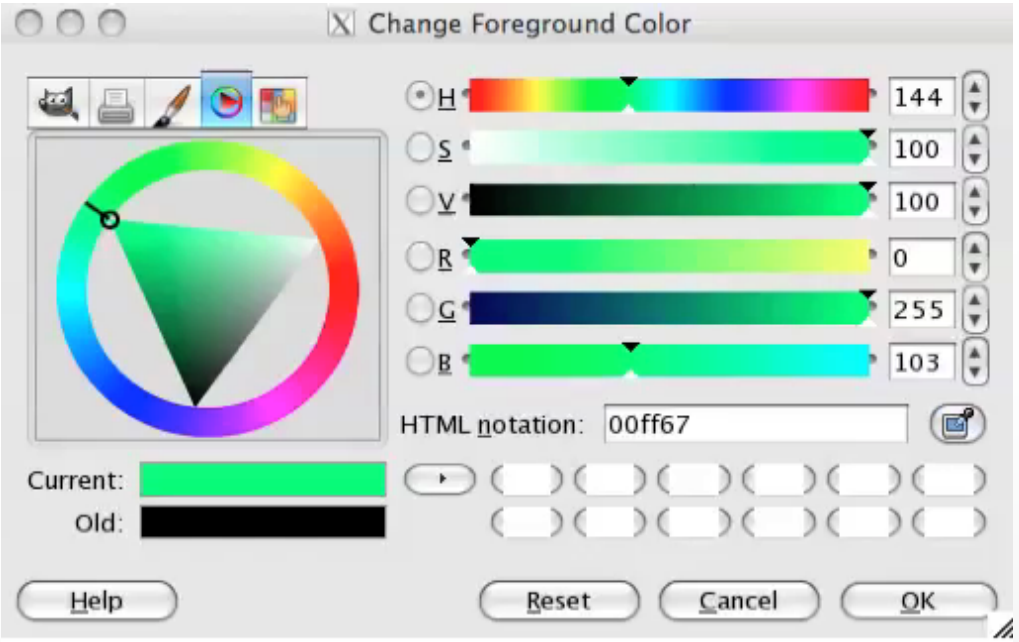
  Value: how bright?

- 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

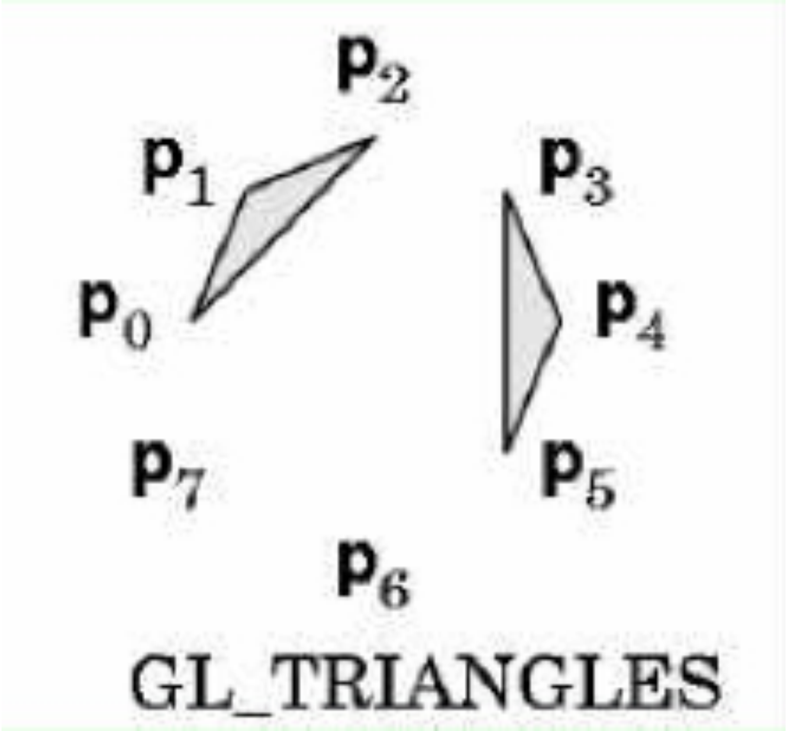
- The routine where you render the object
- Install with glutDisplayFunc(display)

```
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!

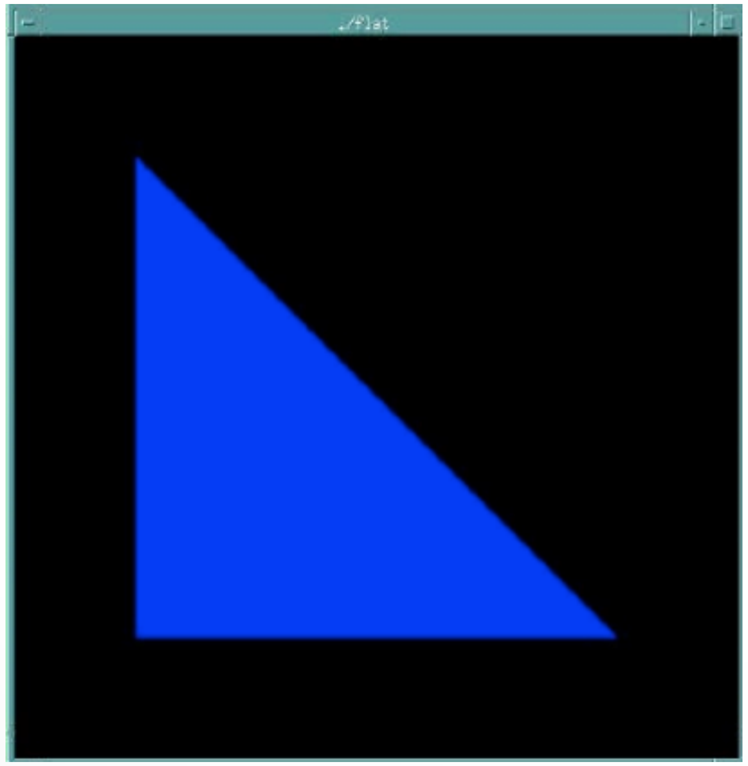
```
void triangle()
{
   glBegin(GL_TRIANGLES);
      glColor3f(1.0,0.0,0.0); // red
      glVertex2f(5.0,5.0);
      glColor3f(0.0,1.0,0.0); // green
      glVertex2f(25.0,5.0);
      glColor3f(0.0,0.0,1.0); // blue
      glVertex2f(5.0,25.0);
   glEnd();
}
```



The Image

glShadeModel(GL_FLAT)

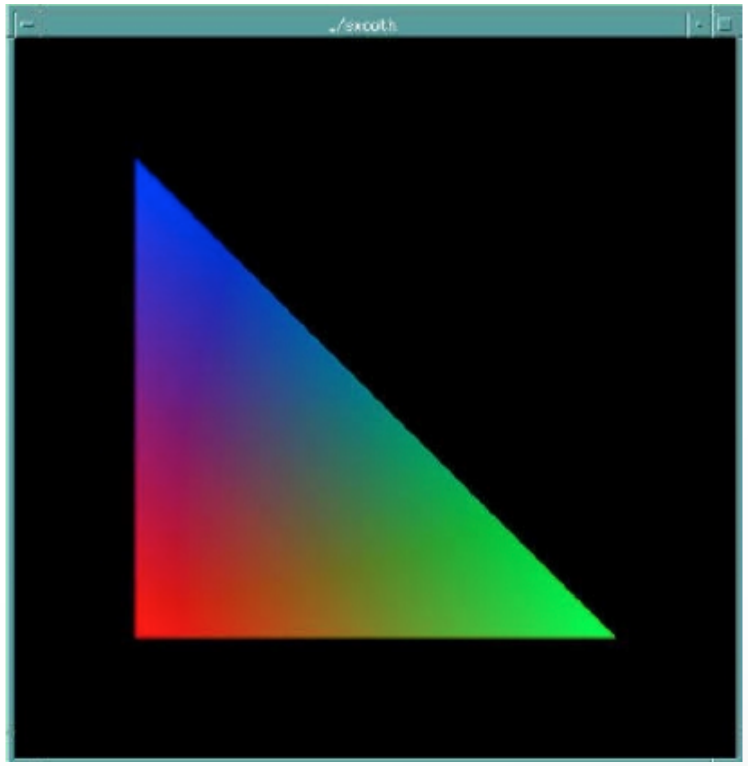
color of last vertex



glShadeModel(GL_SMOOTH)

each vertex separate color

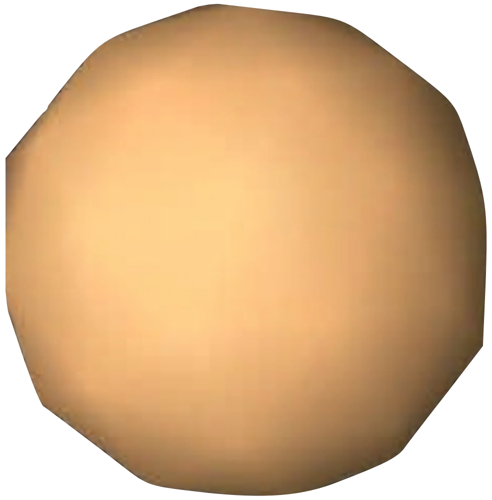
smoothly interpolated



Flat vs Smooth Shading

Flat Shading

Smooth Shading



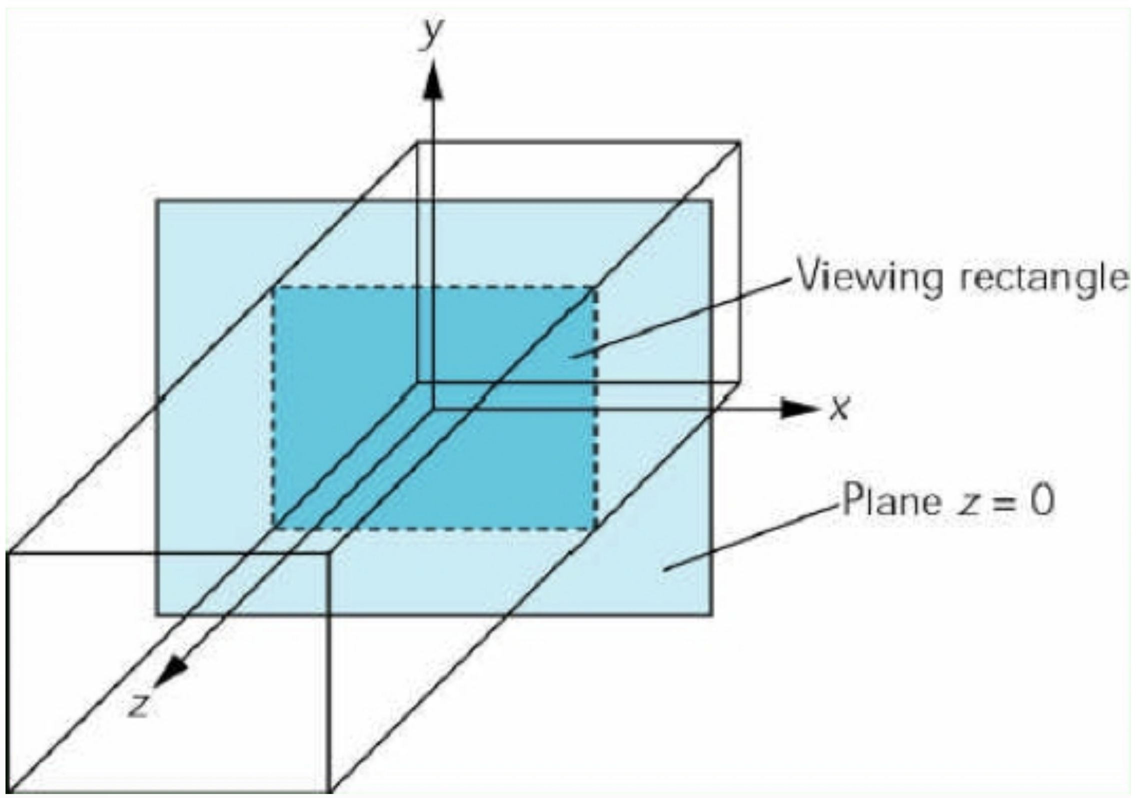
Projection

- 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);
}
```

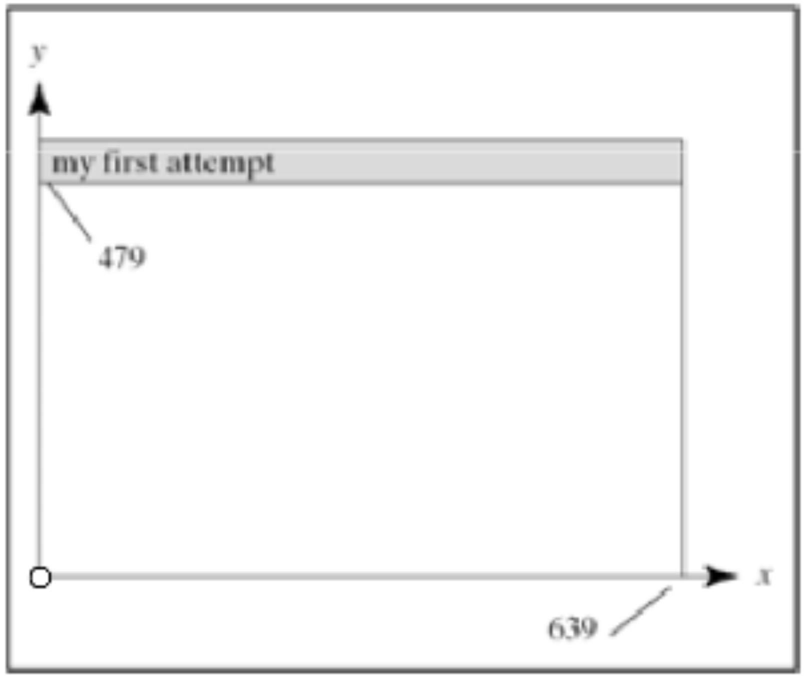
Orthographic Projection

- glOrtho2D(left, right, bottom, top)
- In world coordinates!



Screen coordinates

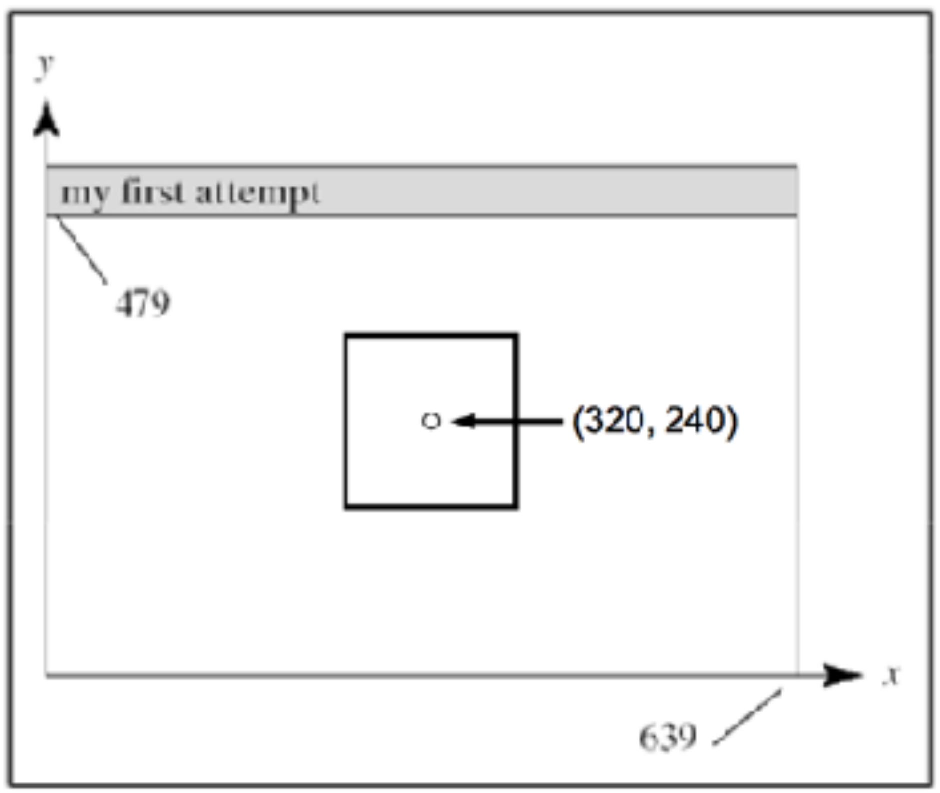
- Bottom left corner is origin
- **`gluOrtho2D()`** sets the units of the screen coordinate system
    - **`gluOrtho2D(0, w, 0, h)`** means the coordinates are in units of pixels
    - **`gluOrtho2D(0, 1, 0, 1)`** means the coordinates are in units of “fractions of window size” (regardless of actual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



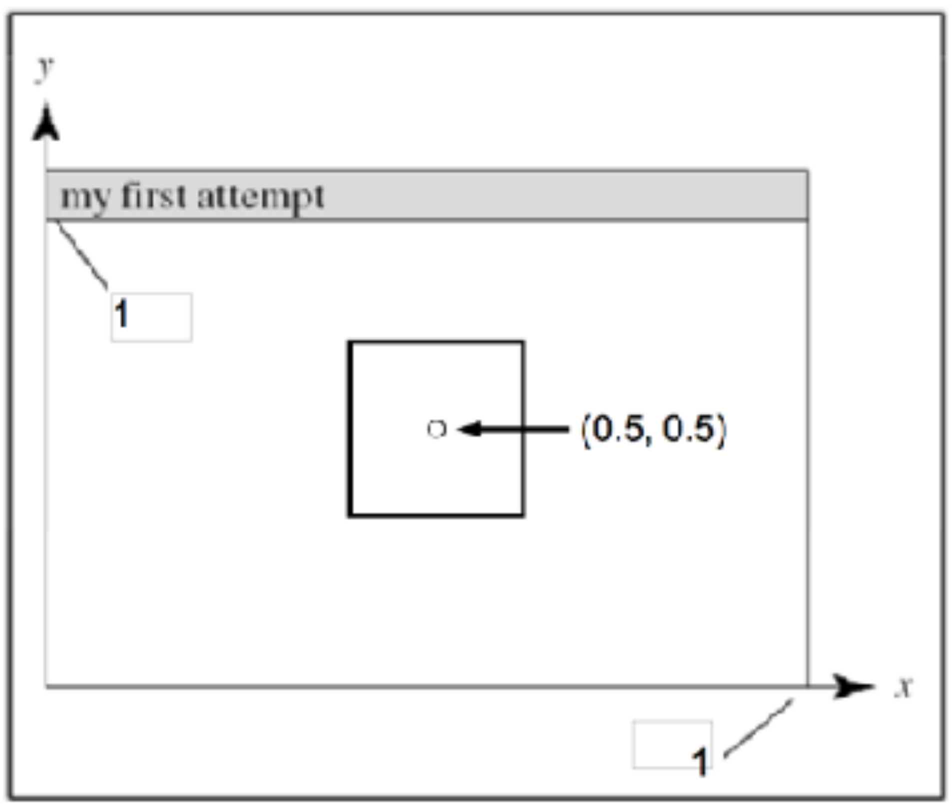
from Hill

Screen coordinates

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

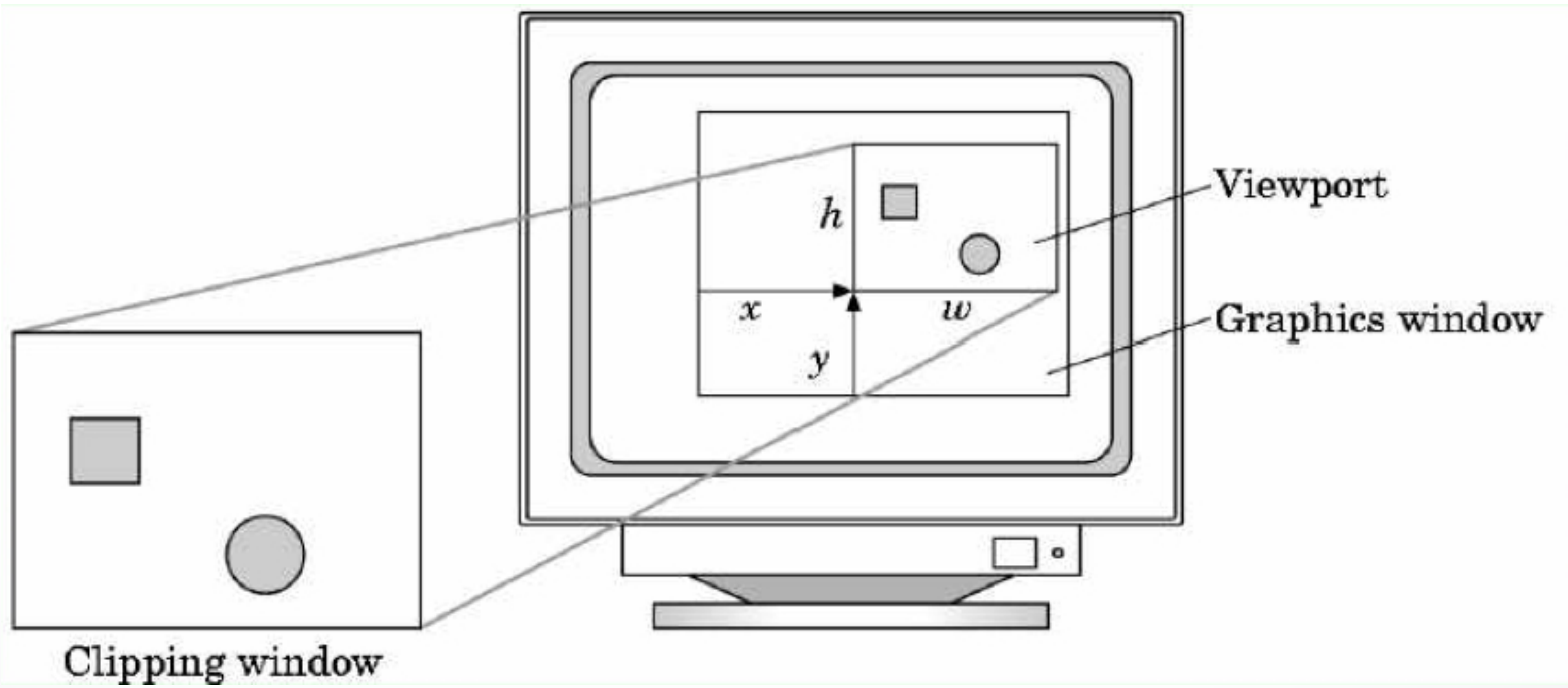


`gluOrtho2D(0, 1, 0, 1)`



Viewport

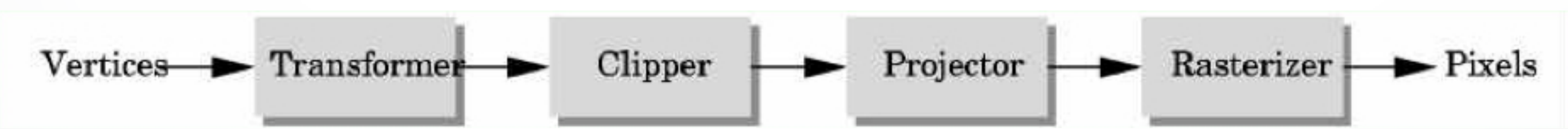
- Determines clipping in window coordinates
- glViewPort(x,y,w,h)



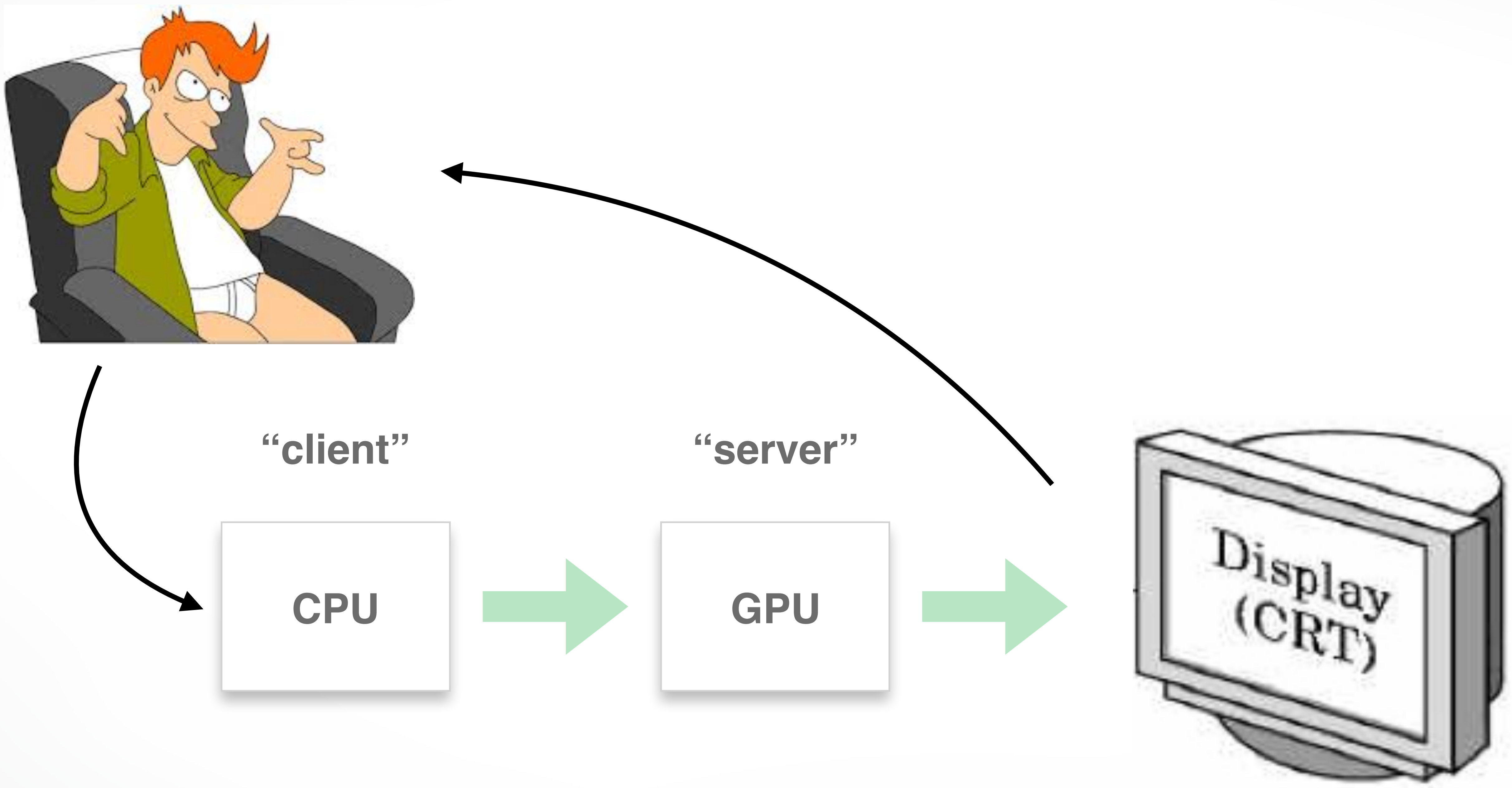
Let’s code a triangle!

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!