Computer Graphics
- Introduction of OpenGL

Junjie Cao @ DLUT

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http://jjcao.github.io/ComputerGraphics/

Last Time

Last Time

Story → **Computer Graphics** → **Image**

What is computer graphics?

- The use of computers to synthesize and manipulate **visual information**.

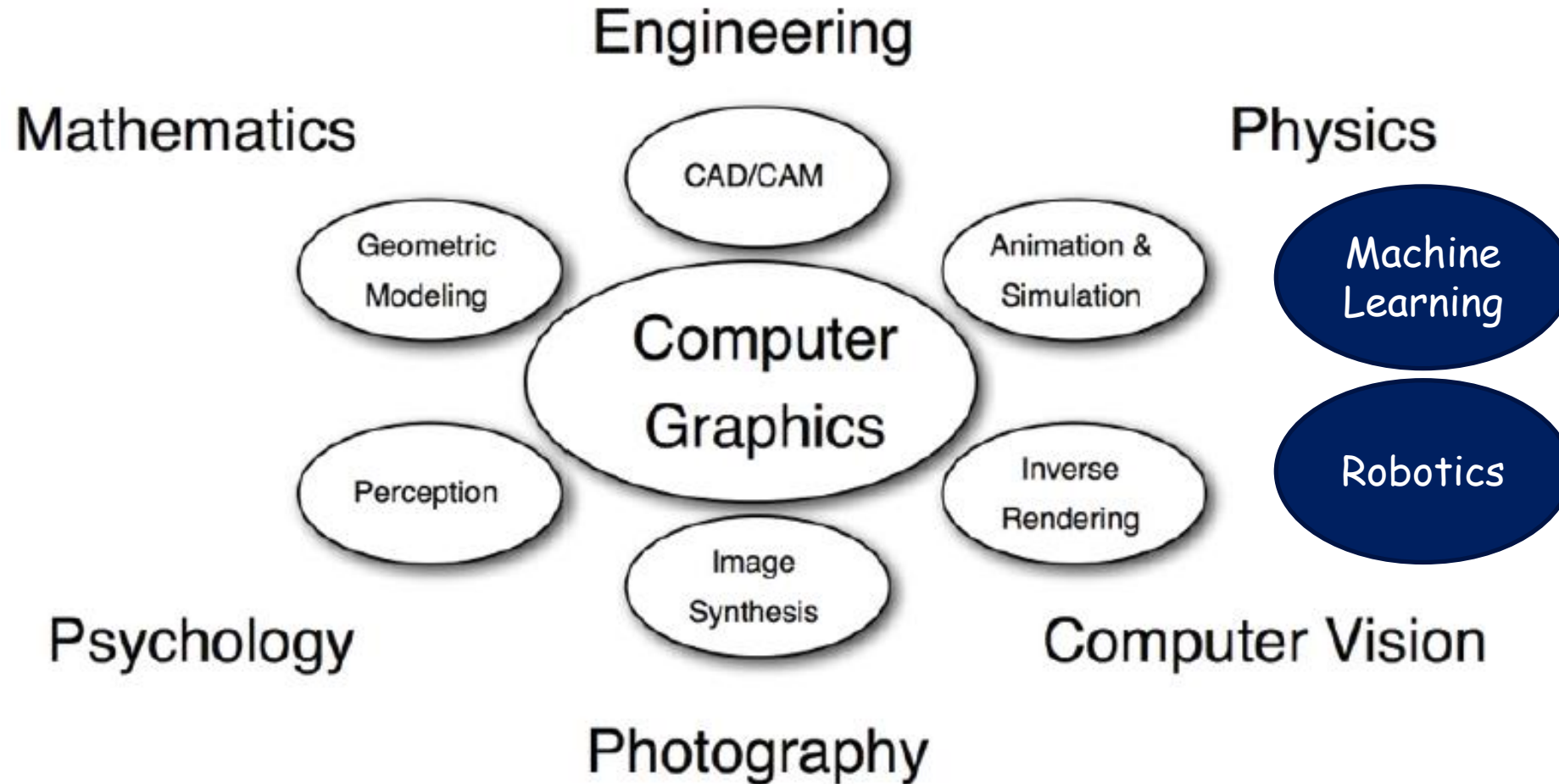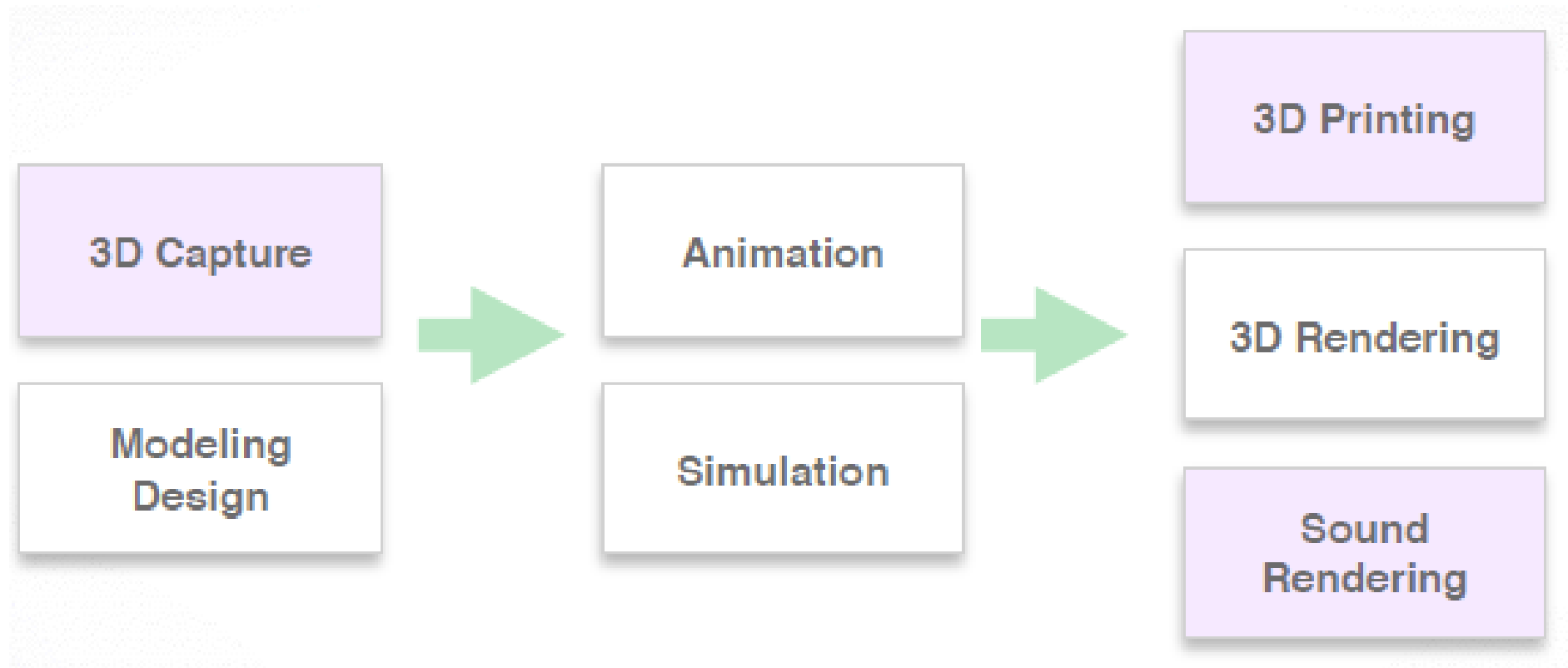- The use of computers to synthesize and manipulate **sen**

(sound)

(touch)

Related to many Disciplines

3D Computer Graphics Pipeline

3D Capture

Modeling Design

Animation

Simulation

3D Printing

3D Rendering

Sound Rendering

Emerging Fields

Render [ren-der]

- OpenGL's primary function – Rendering

- Rendering?
  - converting geometric/mathematical object descriptions into frame buffer values, i.e. pixel array

- OpenGL can render:
  - Geometric primitives
 - Bitmaps and Images (Raster primitives)
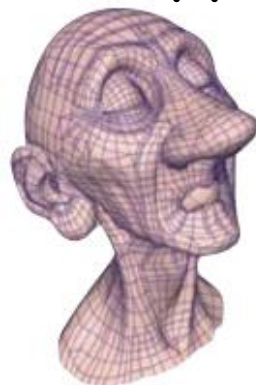
input data

output rendering

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

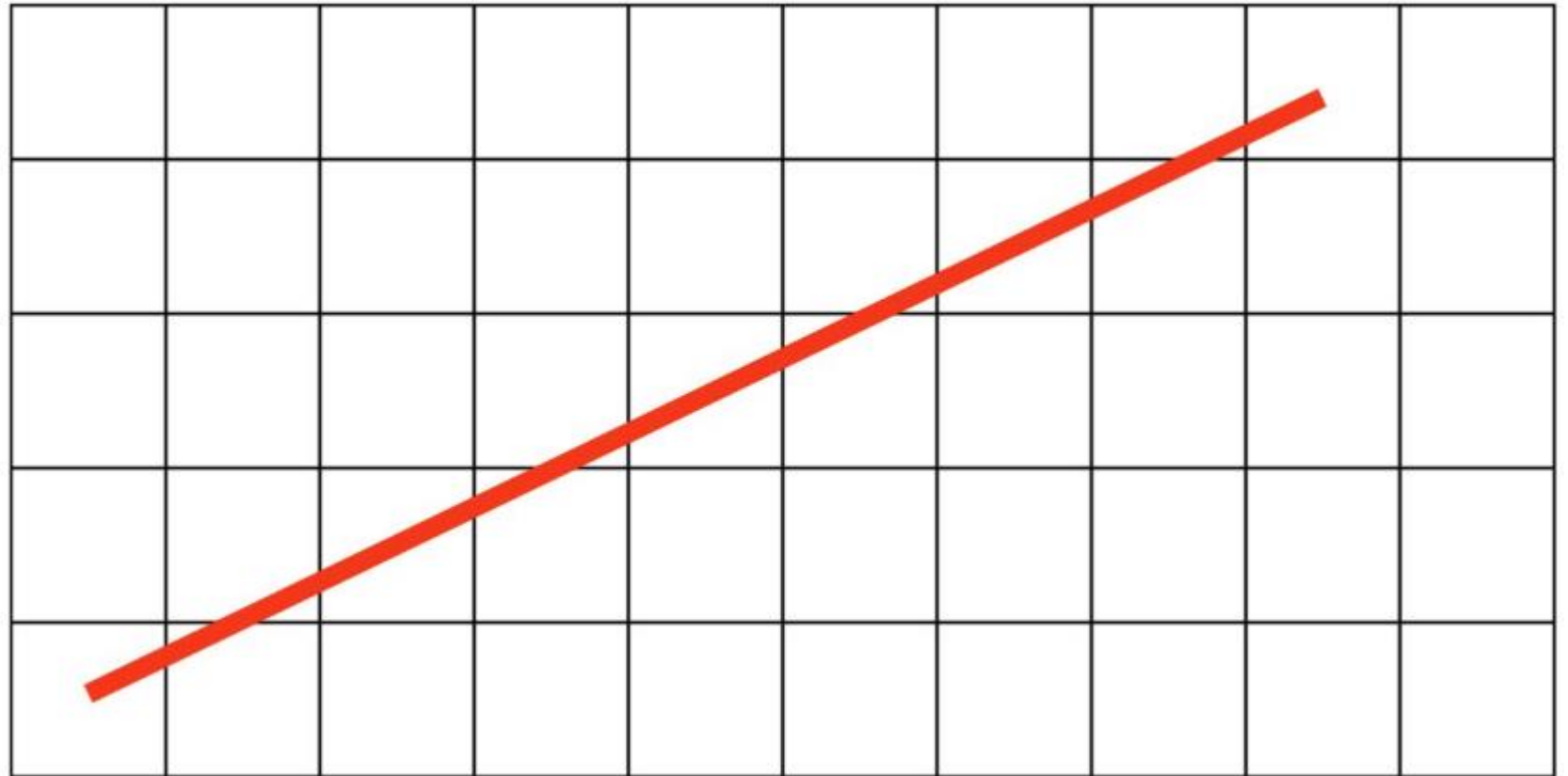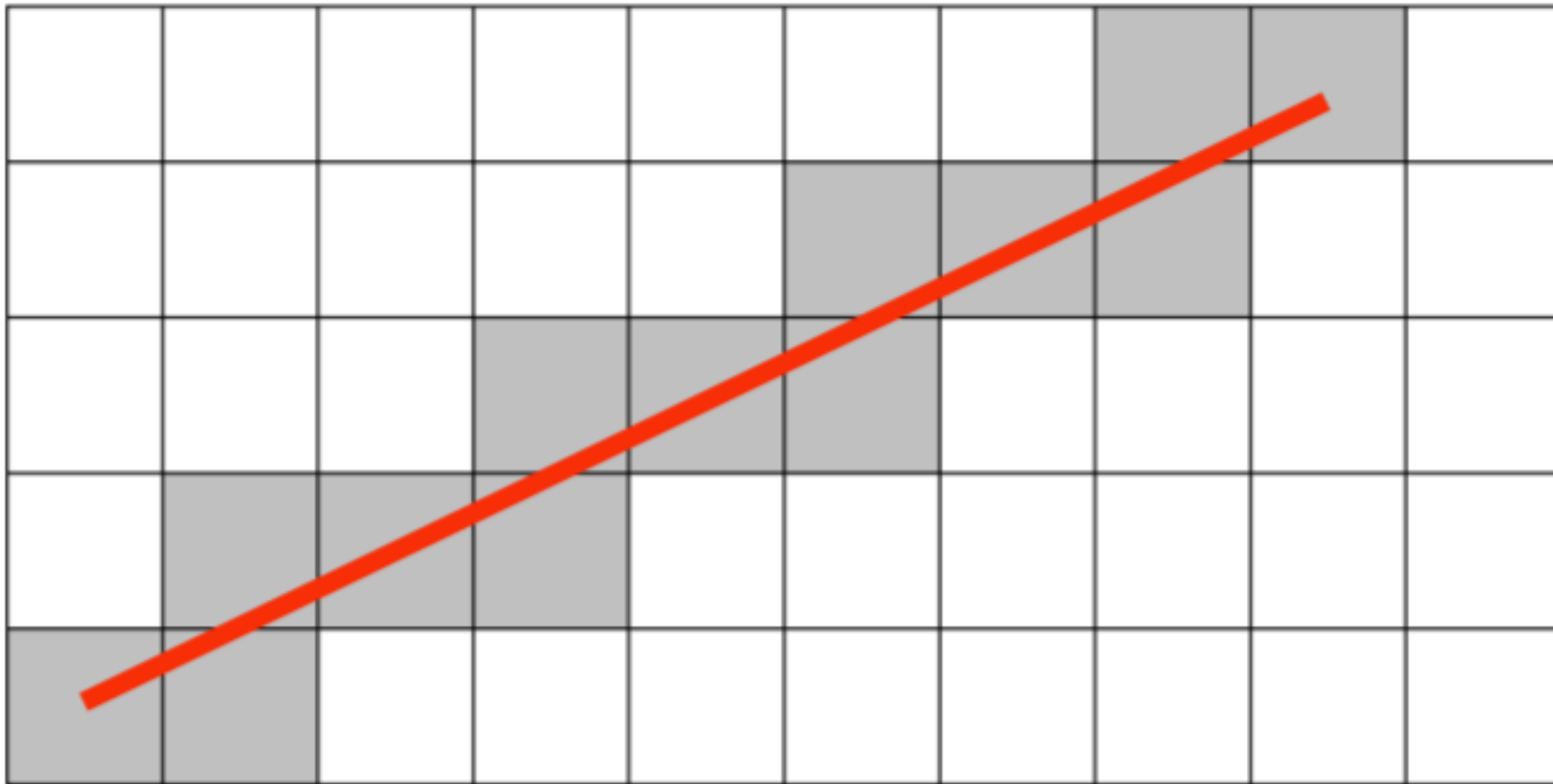| R 93% | R 35% | R 90% |
| G 93% | G 35% | G 90% |
| B 93% | B 16% | B 0% |
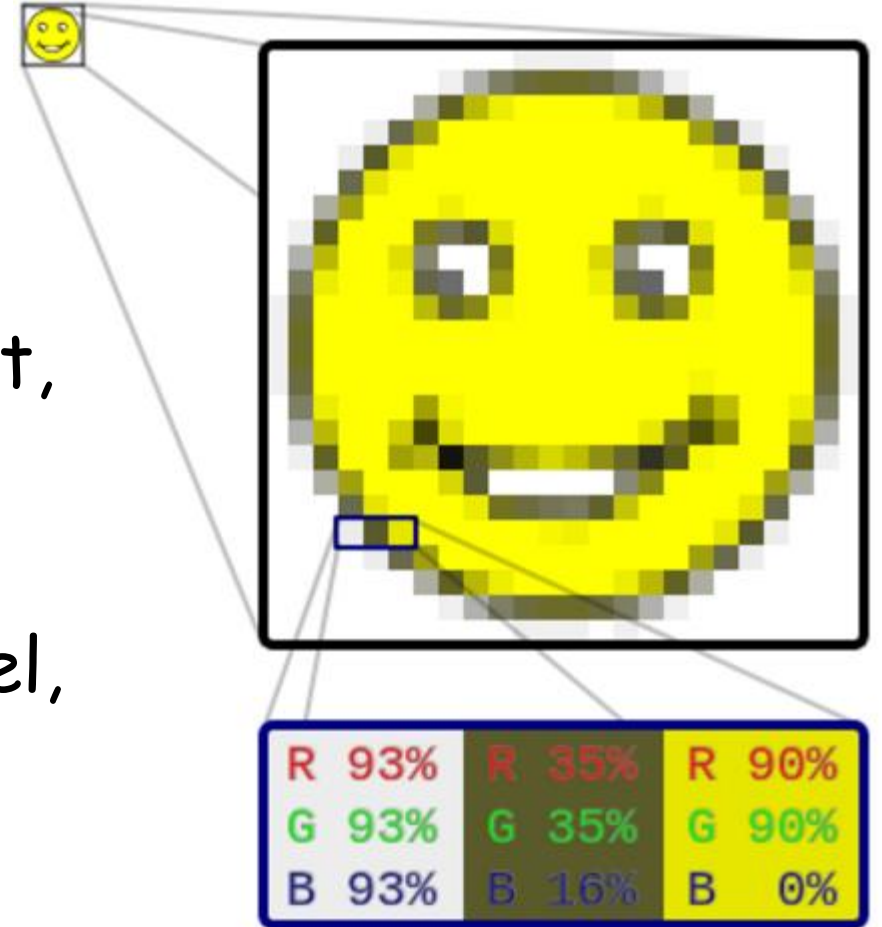
How to make an image?

photography

drawing

What pixels should we color in to depict a line?

- "Rasterization": process of converting a continuous object to a discrete representation on a raster grid (pixel grid)
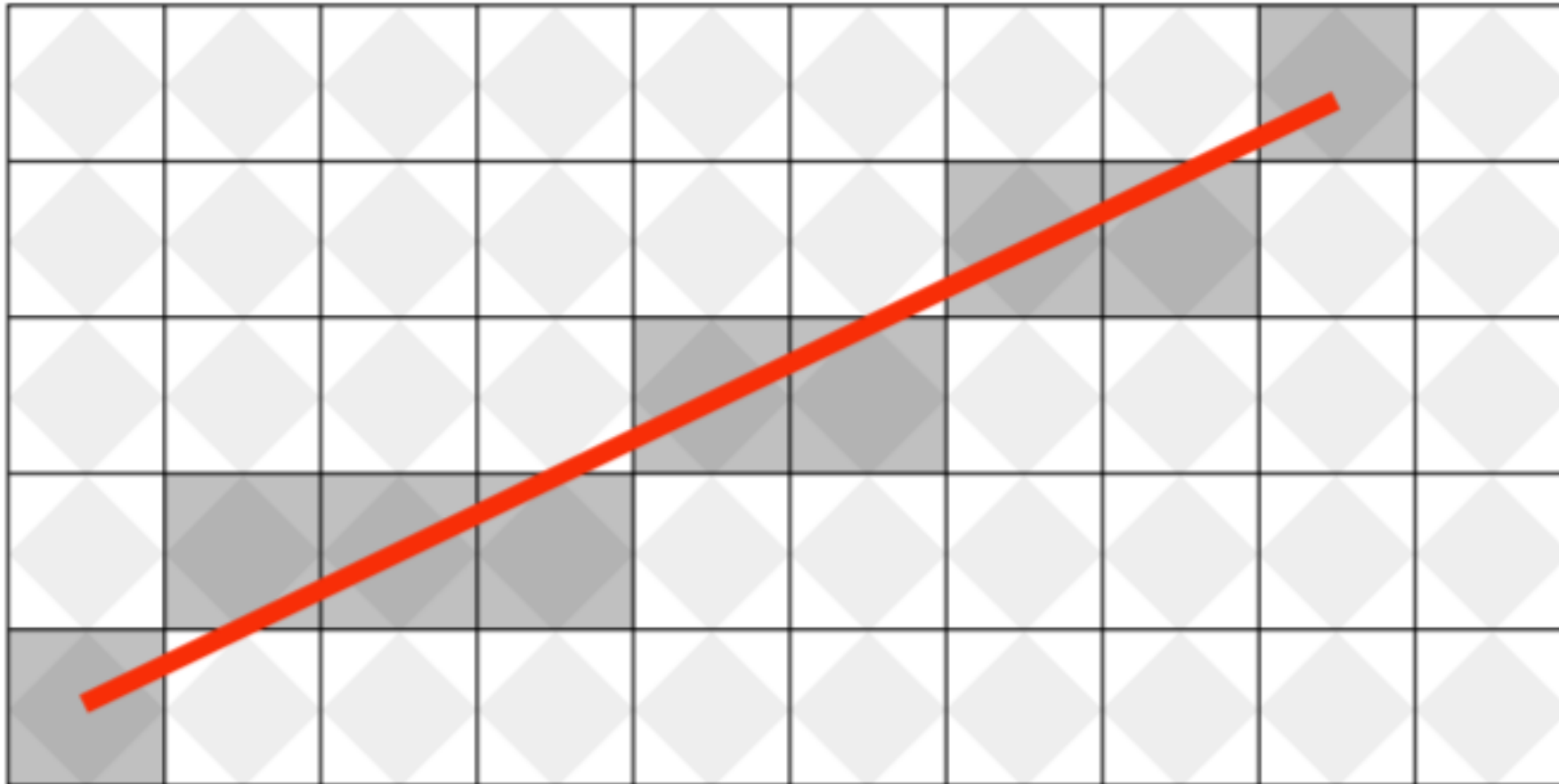
What pixels should we color in to depict a line?

- Light up all pixels intersected by the line?

What pixels should we color in to depict a line?

Diamond rule (used by modern GPUs):
light up pixel if line passes through associated diamond

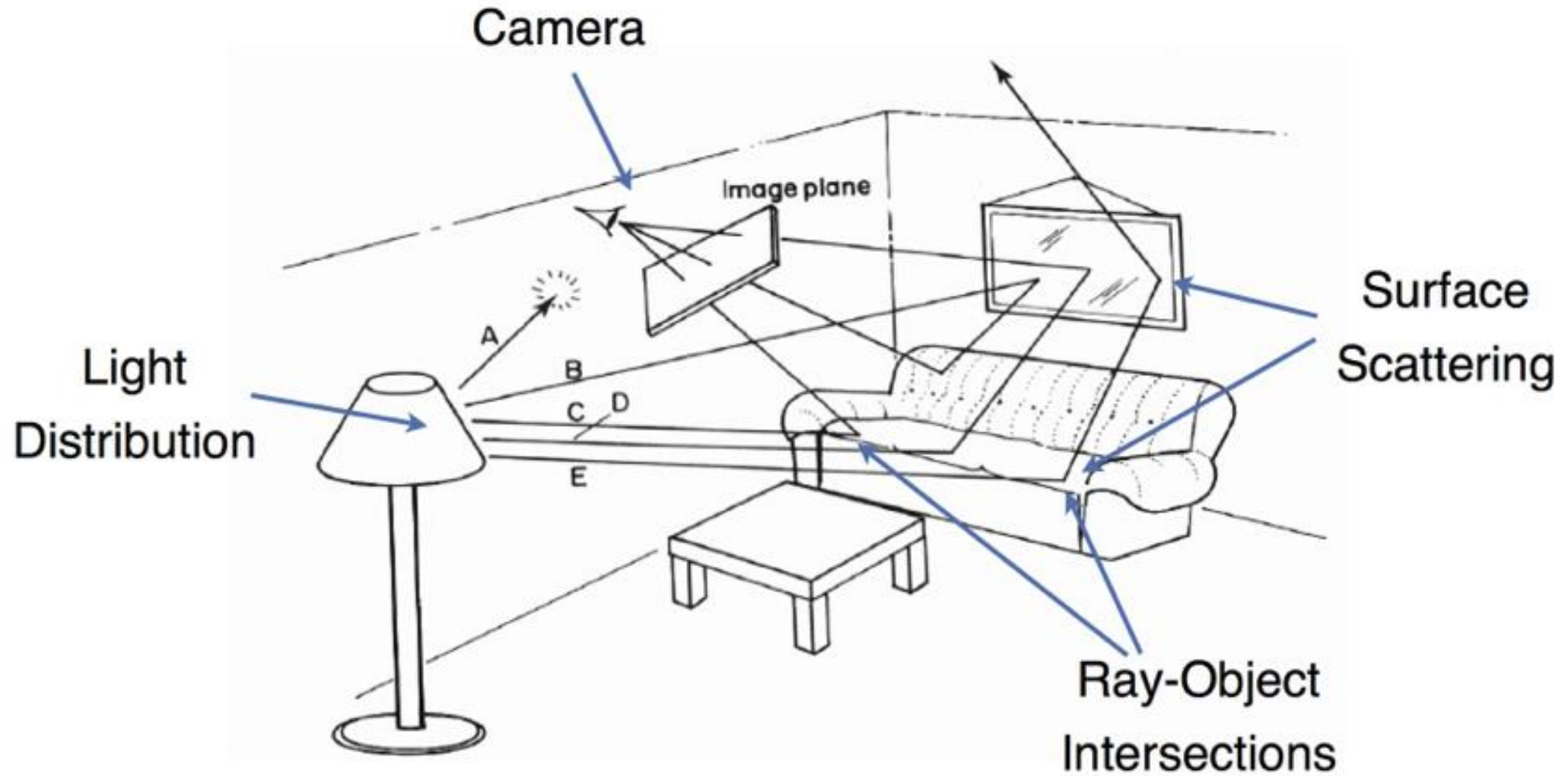# How do we find the pixels satisfying a chosen rasterization rule?

- Could check every single pixel in the image to see if it meets the condition...
  - $O(n2)$ pixels in image vs. at most $O(n)$ "lit up" pixels
  - must be able to do better! (e.g., work proportional to number of pixels in the drawing of the line)

  - Back to this later

Okay… let's take a step back

2d Vector image => Bitmap / raster image
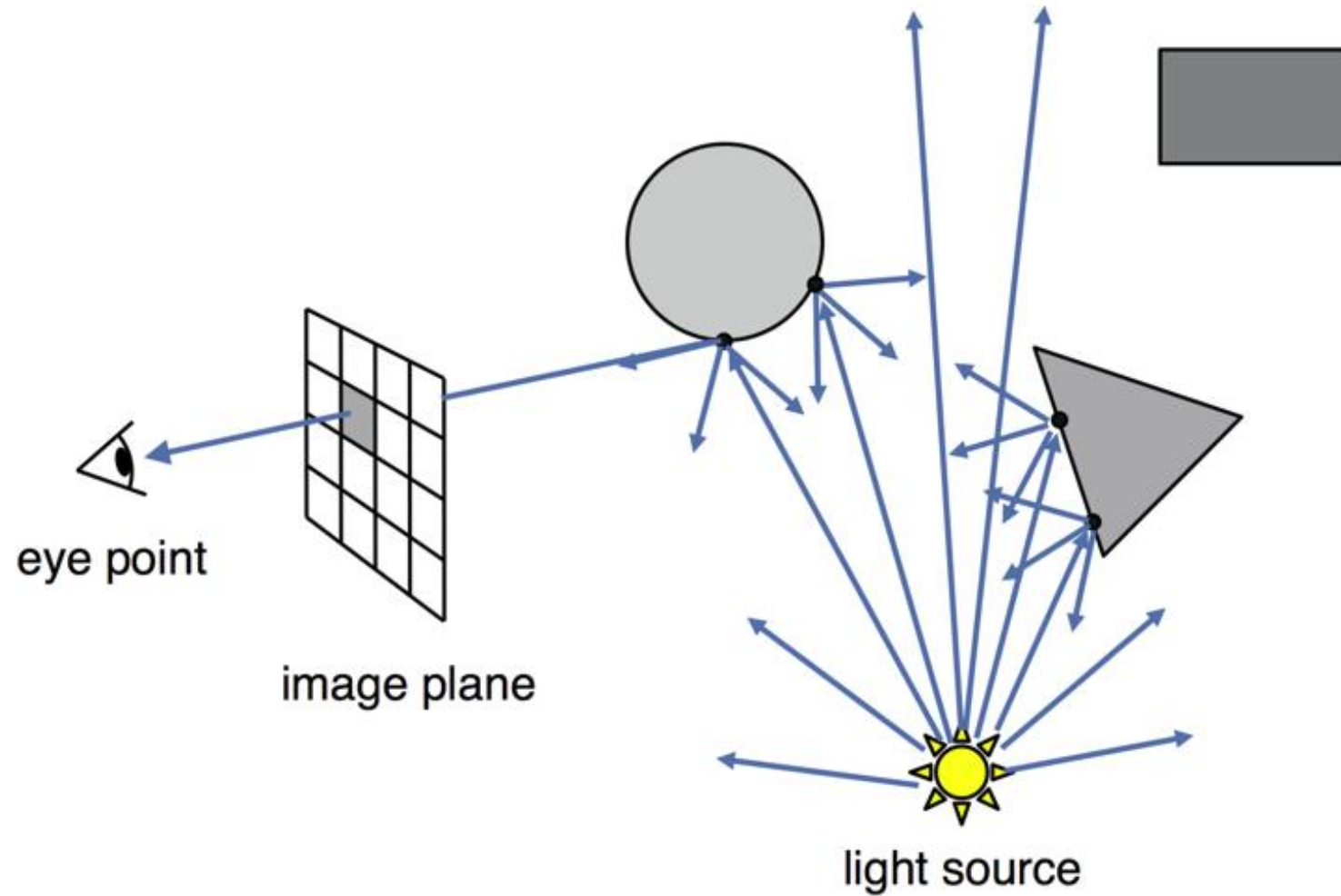? => vector image

In the physical world

Camera

Image plane

Light Distribution

A
B
C D
E

Surface Scattering

Ray-Object Intersections
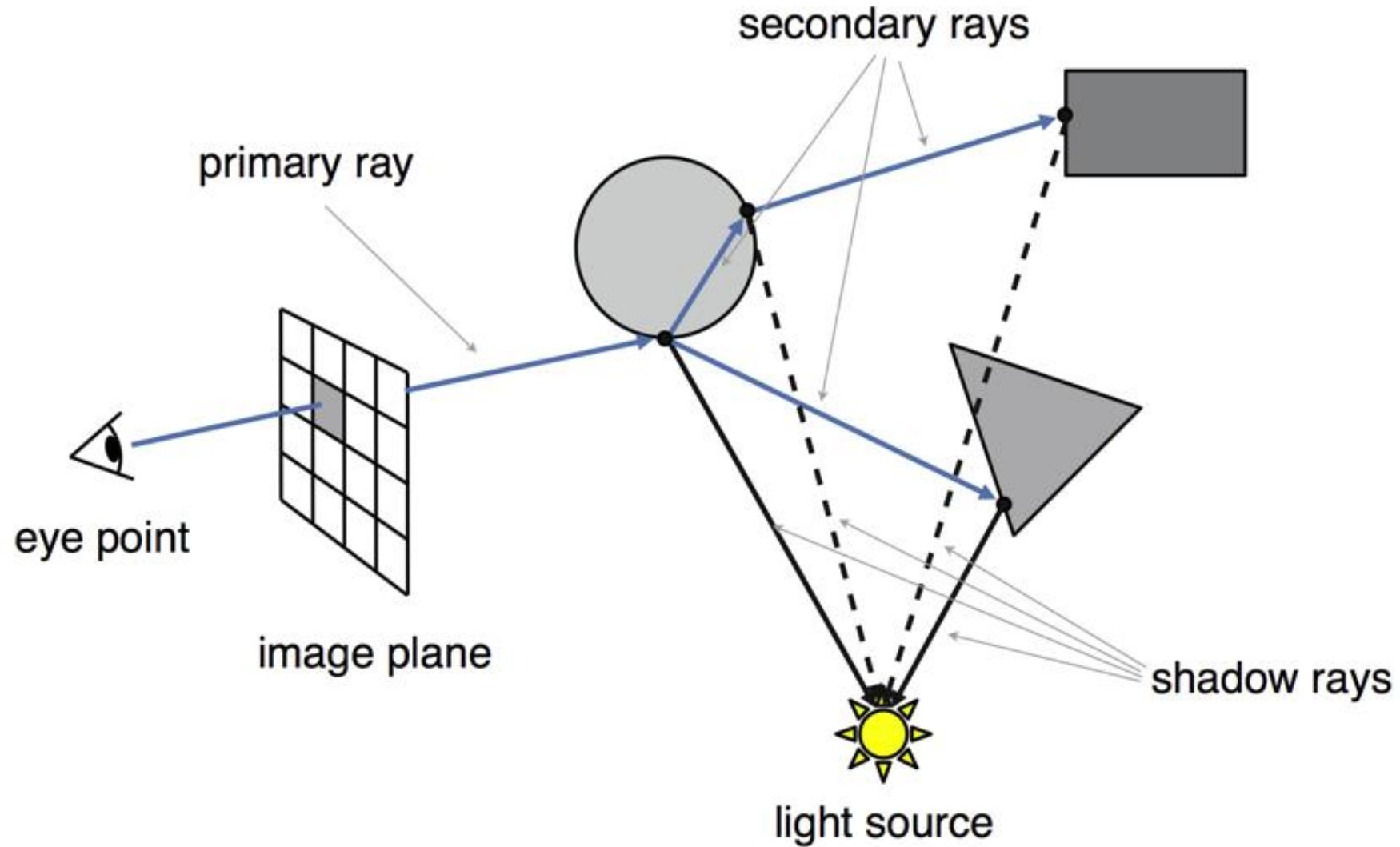
Light Transport

- 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**

Light-Oriented (Forward Raytracing)

eye point

image plane

light source

Only a `fraction` of light rays reach the image

Eye-Oriented (Backward Raytracing)

secondary rays

primary ray

eye point

image plane

shadow rays

light source

or simply "Raytracing"

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):** Back to this later
  - walk through objects, transforming and then drawing each one unless the z-buffer says that it's not in front
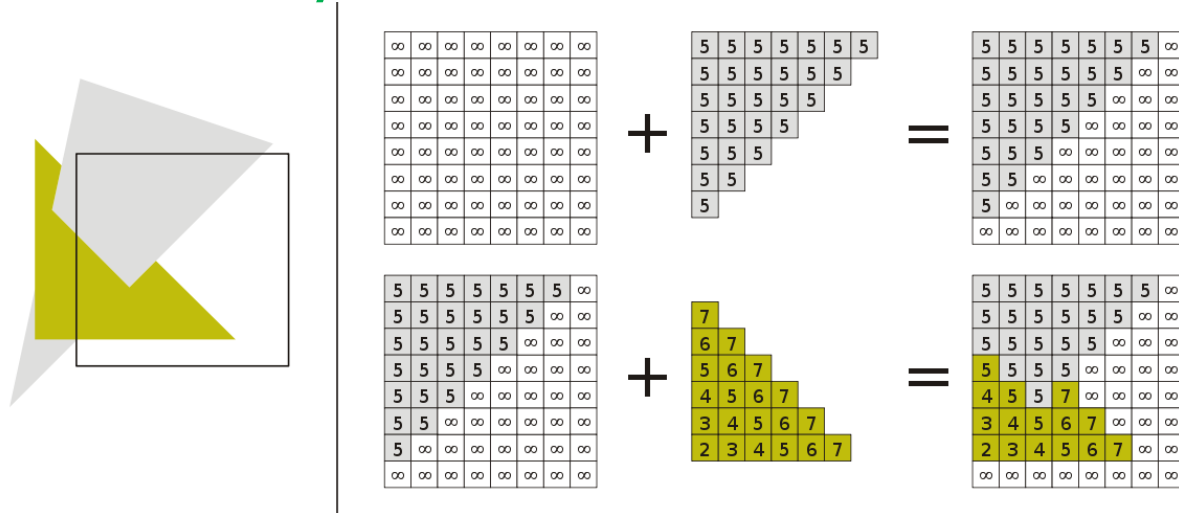
Let's leave rasterization to the GPU

OpenGL Programming Main Steps

- Initialize OpenGL (using GLUT, discussed later)
- Define the geometry (points lines Define the geometry (points, lines, triangles/polygons)
- Define the vertex attributes (color normal etc)
- Transform the geometry (translate, rotate, scale)
- Set up the camera (position direction angle etc)
- Set up lighting (light position/color etc)
- Set up textures
- Draw
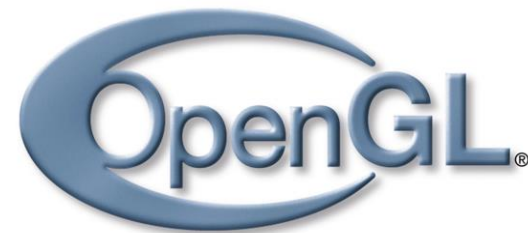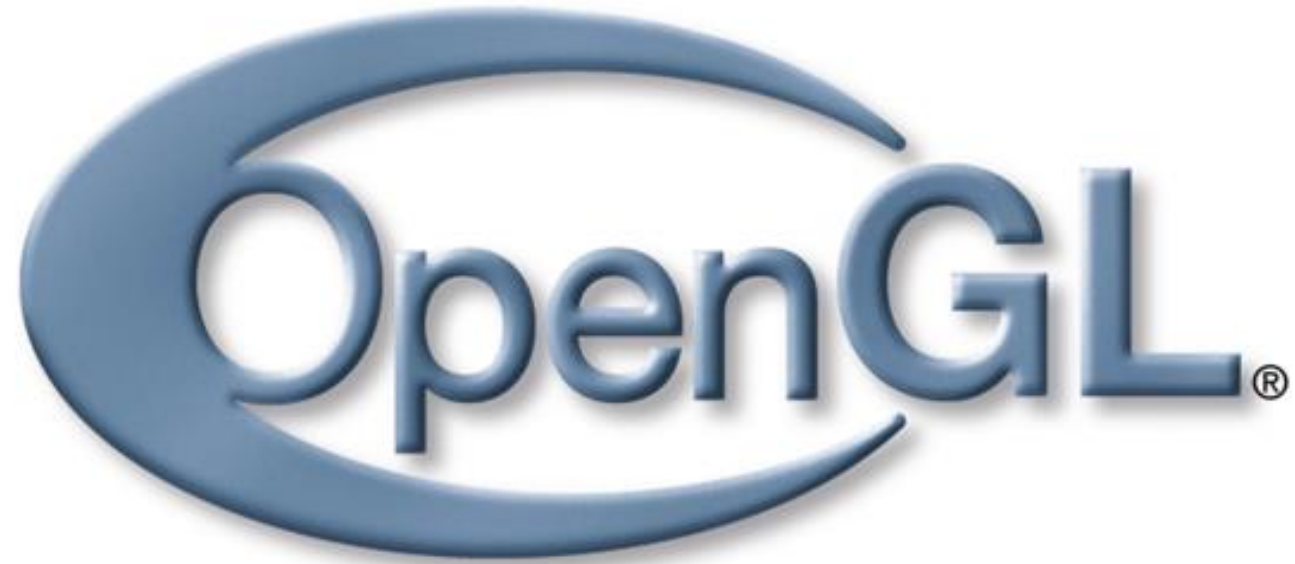
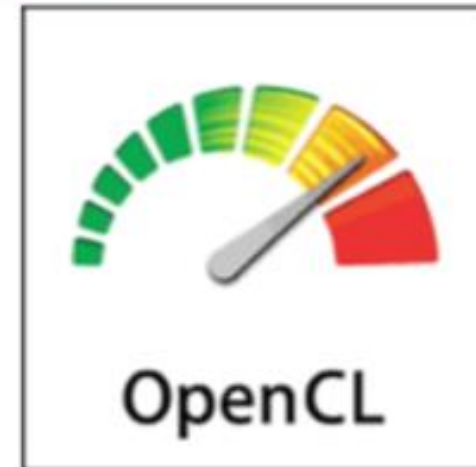- **Industry Standard API for Computer Graphics**
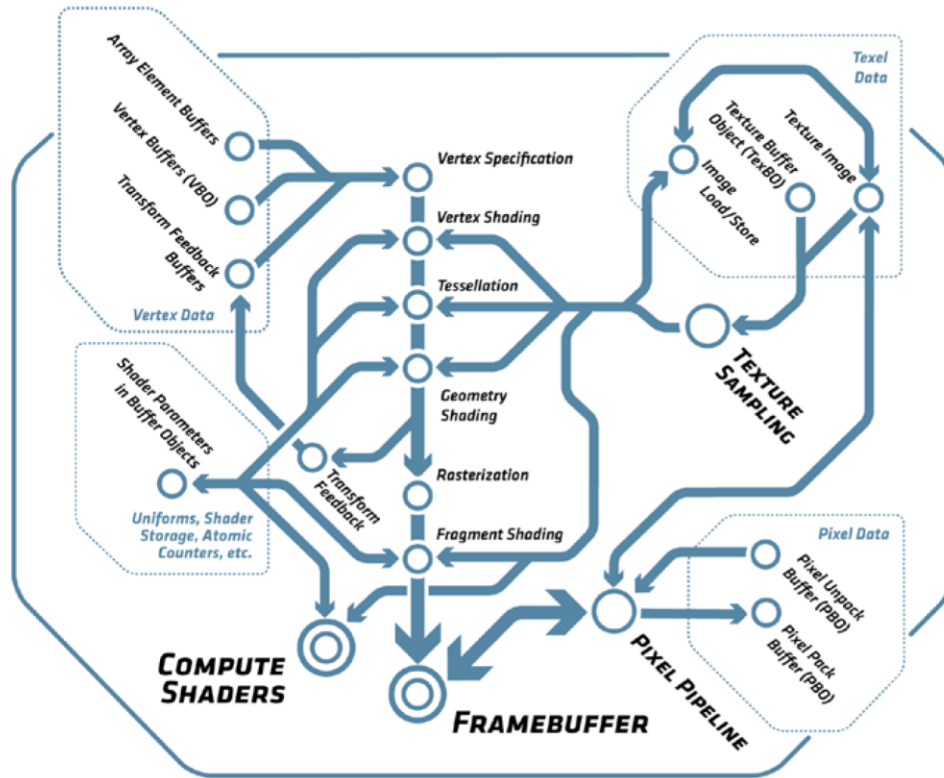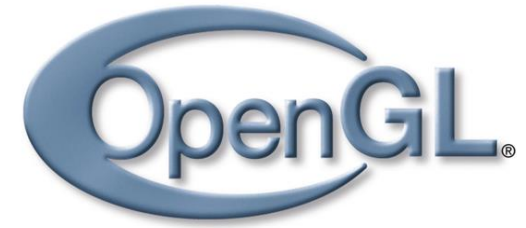
Alternatives

interactive, but not cross-platform

OpenGL Family

Continuing OpenGL Innovation

Bringing state-of-the-art functionality to cross-platform graphics

OpenGL 4.5

OpenGL 4.4

OpenGL 4.3

OpenGL 4.2

OpenGL 4.1

OpenGL 3.3/4.0

OpenGL 3.2

OpenGL 3.1

OpenGL 2.0   OpenGL 2.1   OpenGL 3.0

| 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
DirectX 9.0c		DirectX 10.0		DirectX 10.1		DirectX 11		DirectX 11.1		DirectX 11.2

Descendent of GL (from SGI) since 1992

What is OpenGL

- **Low-level**
  - A software interface to graphics hardware that consists of about 250 distinct functions

- **System-independent**
  - Designed as a streamlined, hardware-independent interface to be implemented on many different hardware platforms

- Client-Server abstraction
  - Client is the program which sends commands to the server
  - Server (graphics card) produces pixels on the screen
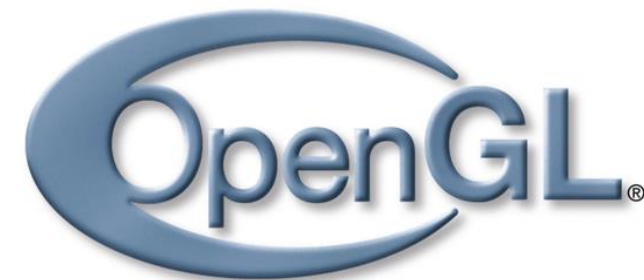
Where is OpenGL used?

- CAD

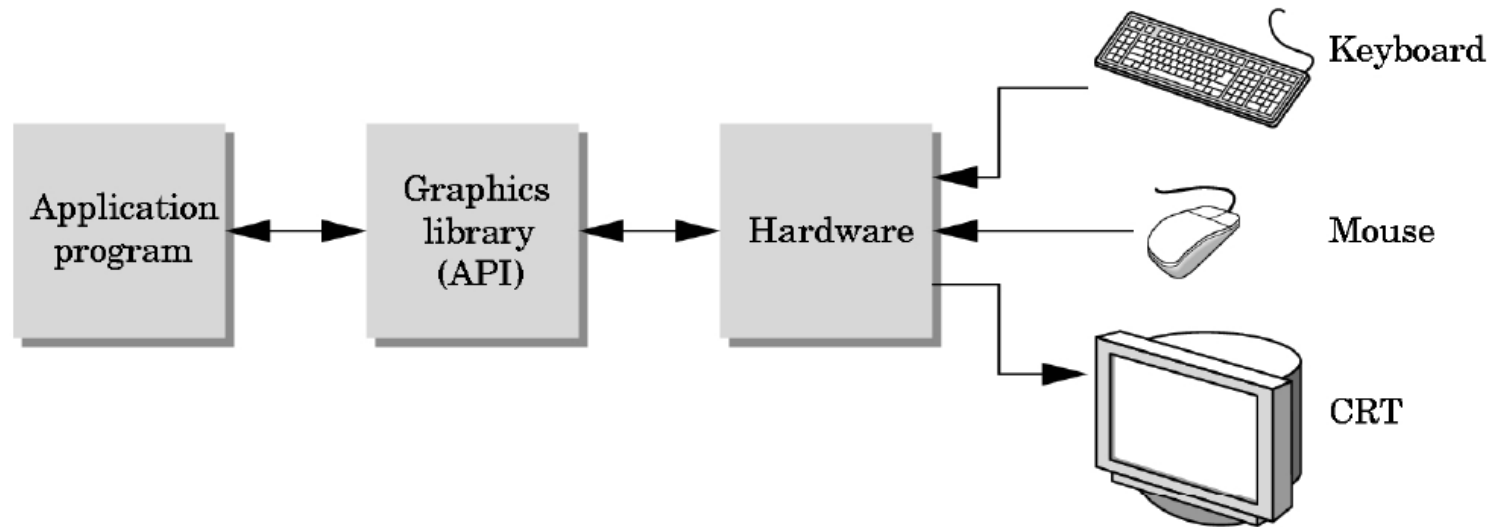- VR

- Scientific Visualization

- Simulators

- Video games
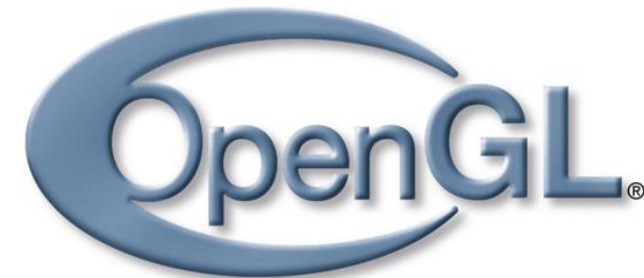
Realtime Graphics Demo

- Realtime rendering: Unreal Kite Demo
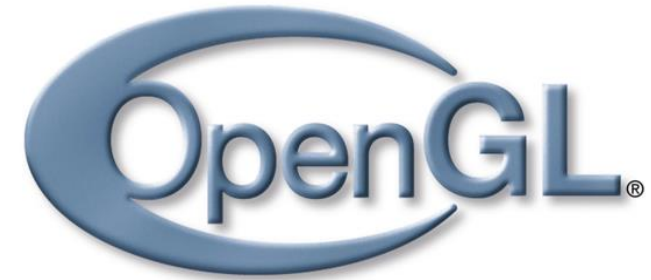- Smoke simulation: Efficient Smoke Simulation on Curvilinear Grids-HD

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
```
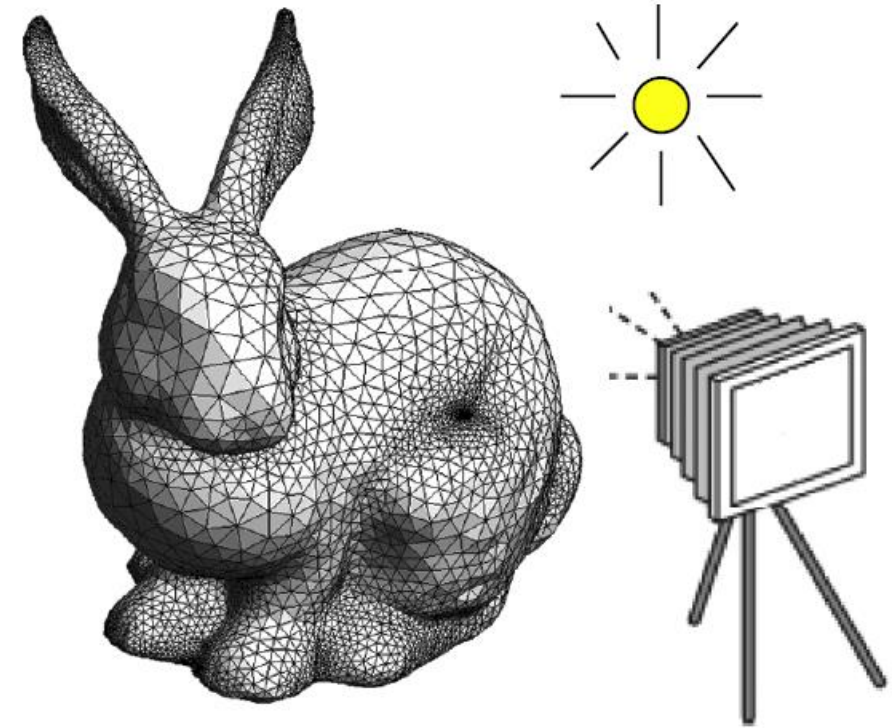
How does OpenGL work

- **From the programmer's point of view:**
  - Specify **geometric objects**
  - Describe **object properties**
    - Color
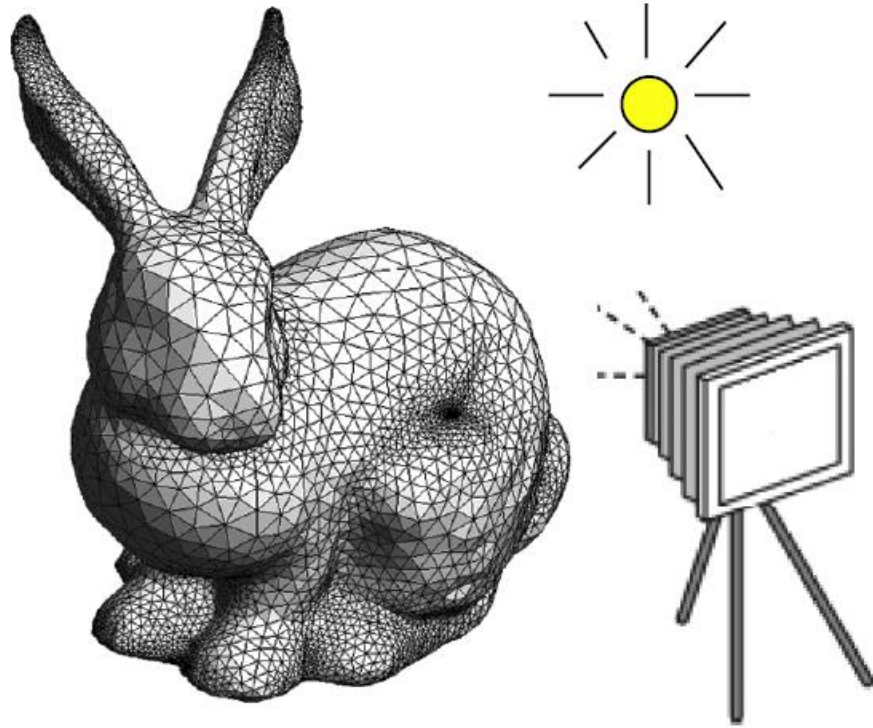   - How objects reflect light
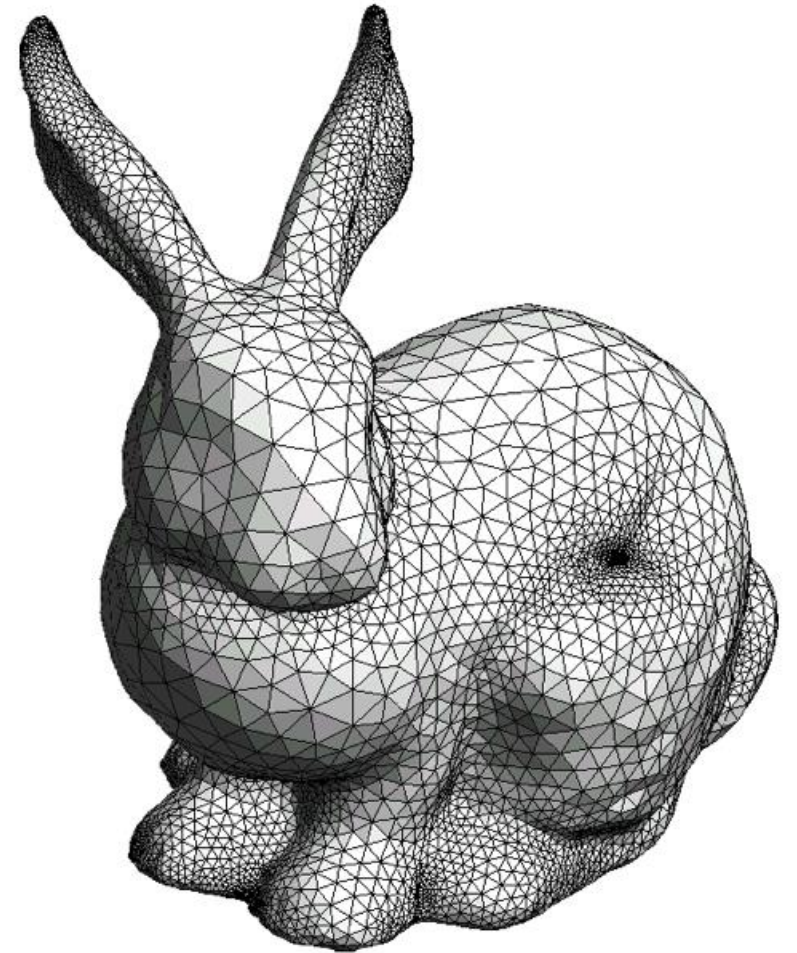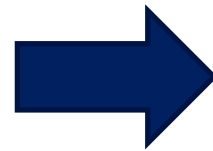
How does OpenGL work (continued)

- **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, model transformation, …

- These variables (state) then apply to every subsequent drawing command

- Function calls
  - No data structures

- They persist until set to new values by the programmer
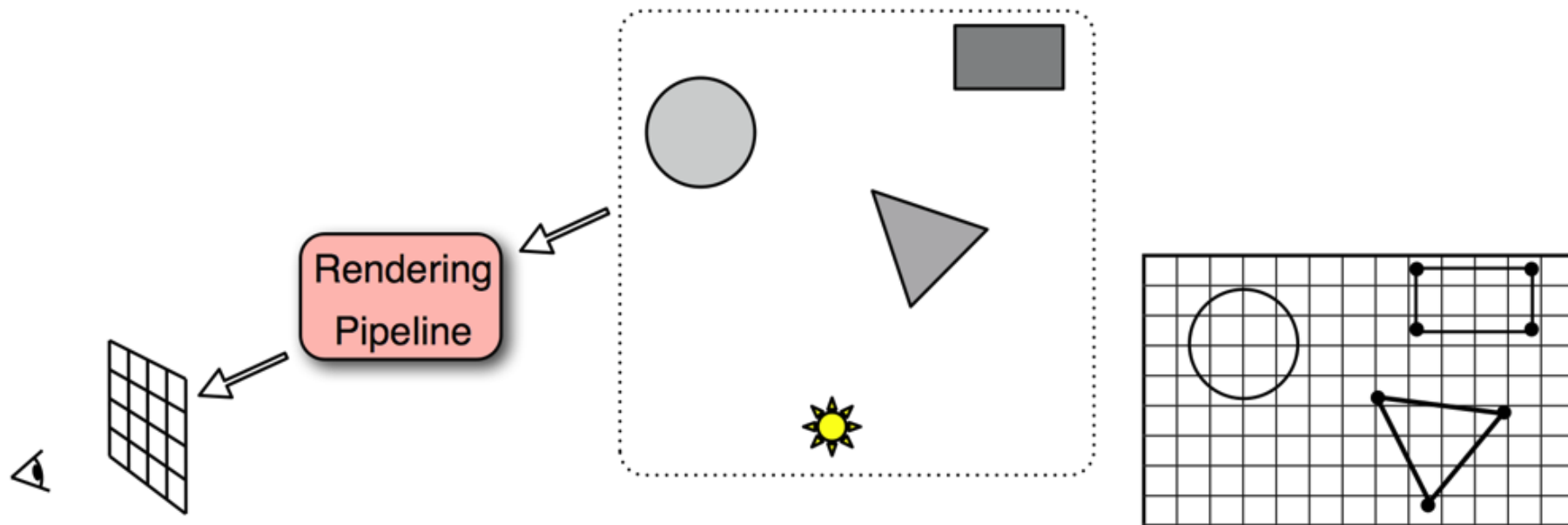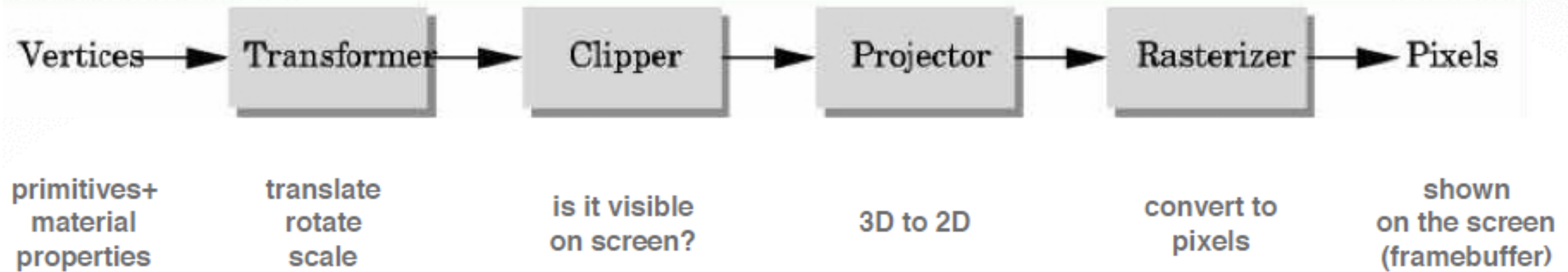
OpenGL Library Organization

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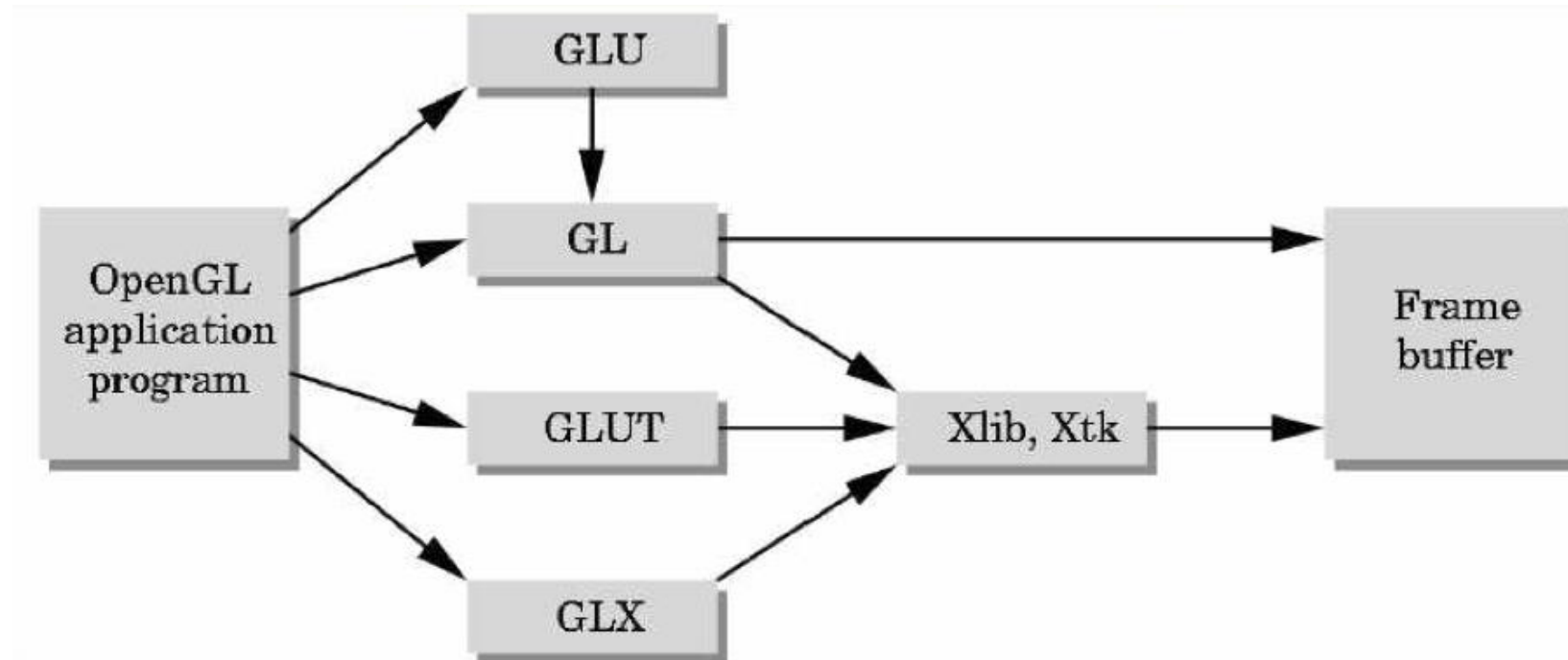
OpenGL Command Syntax

- Constants begin with GL_ and are in capital letters
  - GL_LIGHTING,
  - GL_SMOOTH, etc

- Commands have prefix gl and initial capital letters for each word
  - glEnable(),
  - glDisable(), etc

- Some commands contain extra letters which indicate the number and type of variables
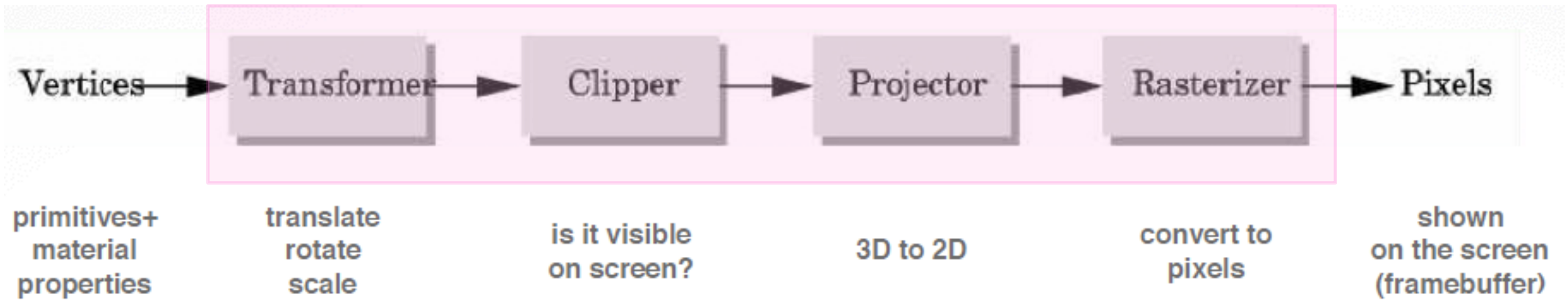 - glColor3b(), glColor3i(), glColor3f(), etc

OpenGL Graphics Pipeline

Vertices → Transformer → Clipper → Projector → Rasterizer → Pixels

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

Rendering Pipeline

OpenGL uses immediate-mode rendering

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

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

- Entire scene is **redrawn** for every frame

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

OpenGL Graphics Pipeline

Vertices → Transformer → Clipper → Projector → Rasterizer → Pixels

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

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

Vertices

Vertices → Transformer → Clipper → Projector → Rasterizer → Pixels
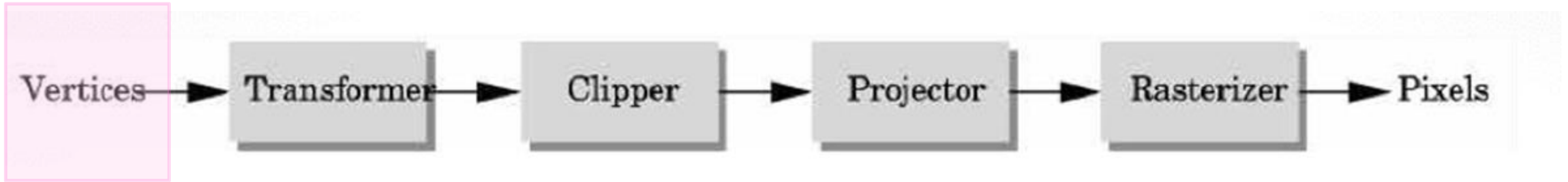
- Vertices in **world coordinates**

- **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

Vertices → Transformer → Clipper → Projector → Rasterizer → Pixels
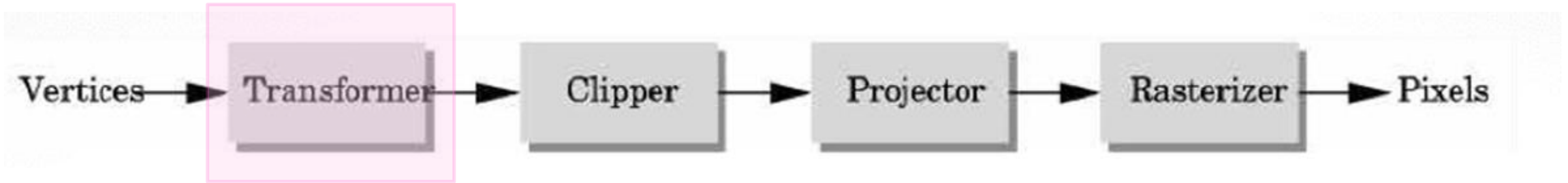
- Transformer in **world coordinates**

- **Must be set before object is drawn!**
  - glRotate (45.0, 0.0, 0.0, -1.0);
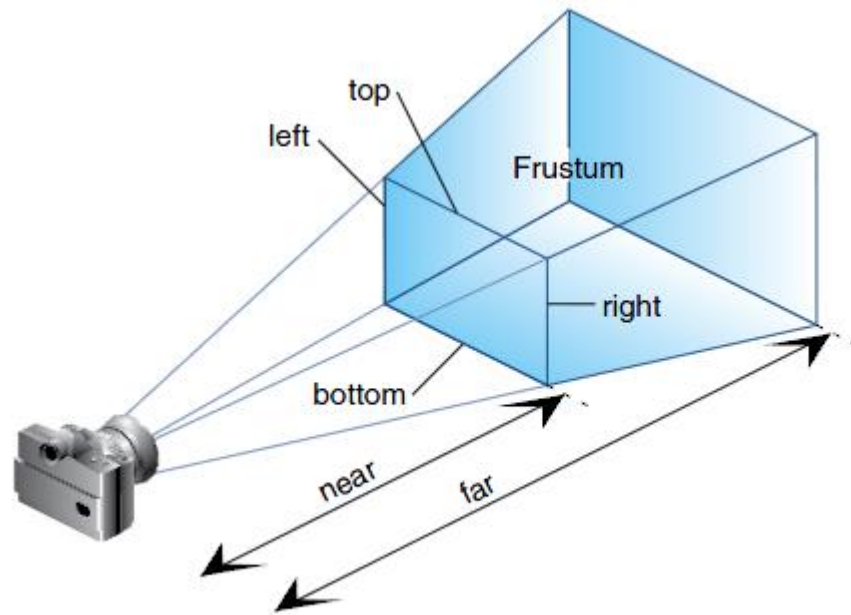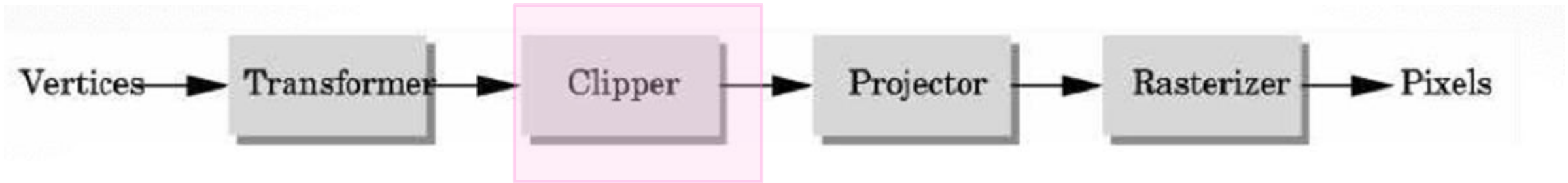 - glVertex2f(1.0, 0.0);

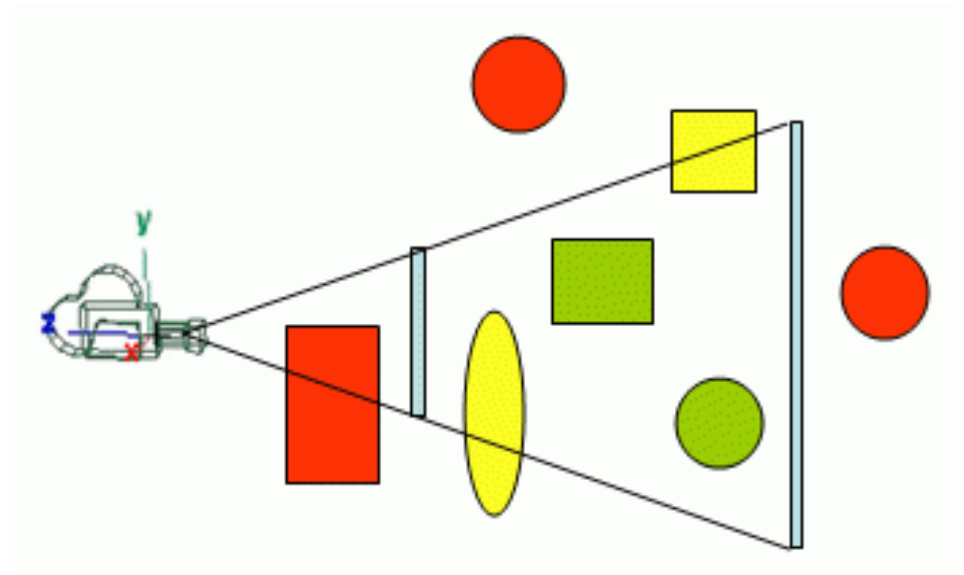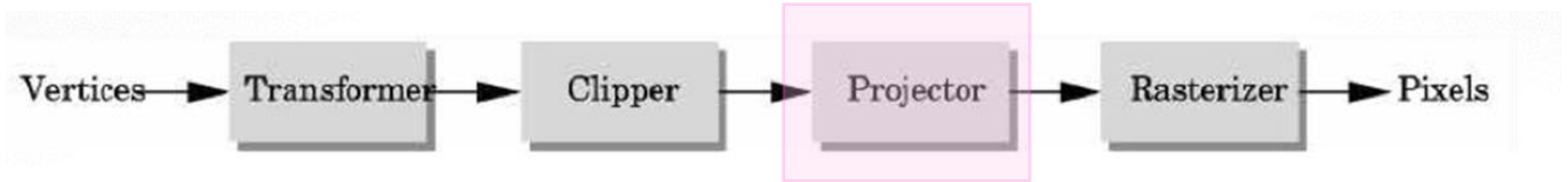- Complex [Angel Ch. 3]

Clipper

Vertices → Transformer → **Clipper** → Projector → Rasterizer → Pixels

top
left
Frustum
right
bottom
near
far

Figure 3-13   Perspective Viewing Volume Specified by glFrustum()

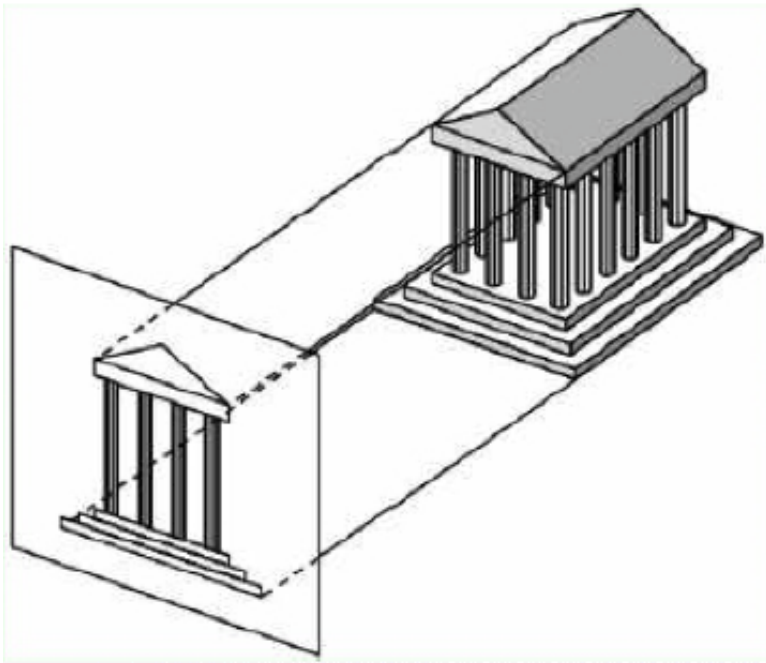# Projector
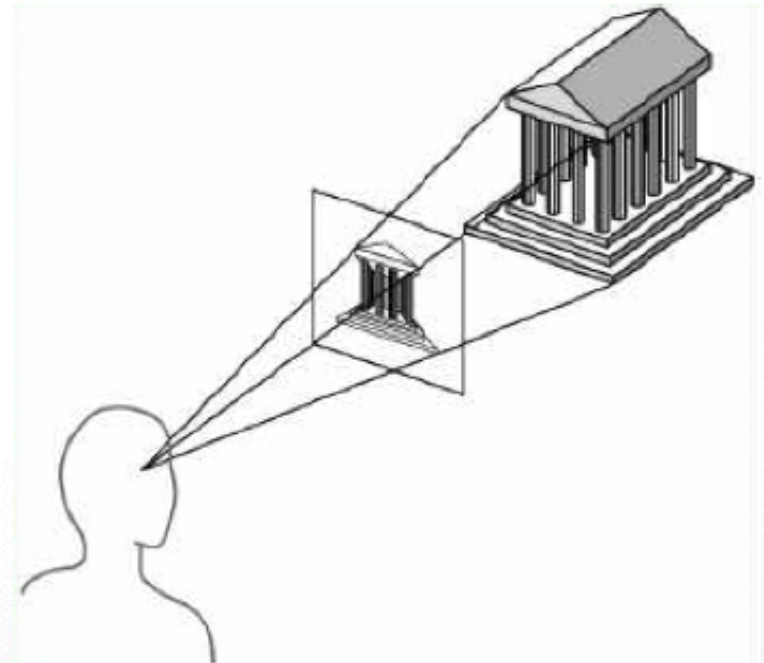

- Complex transformation [Angel Ch. 4]

orthographic   perspective

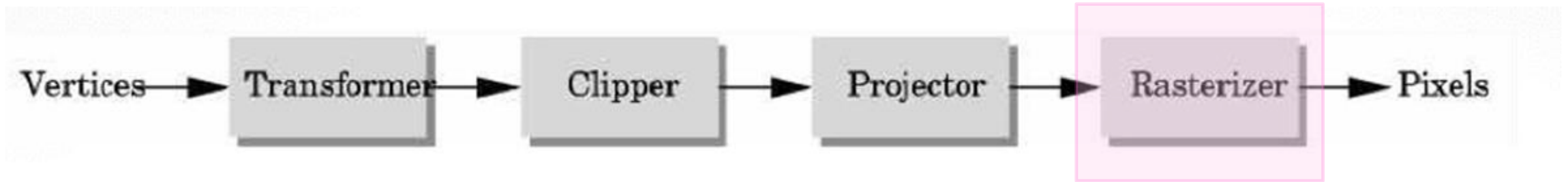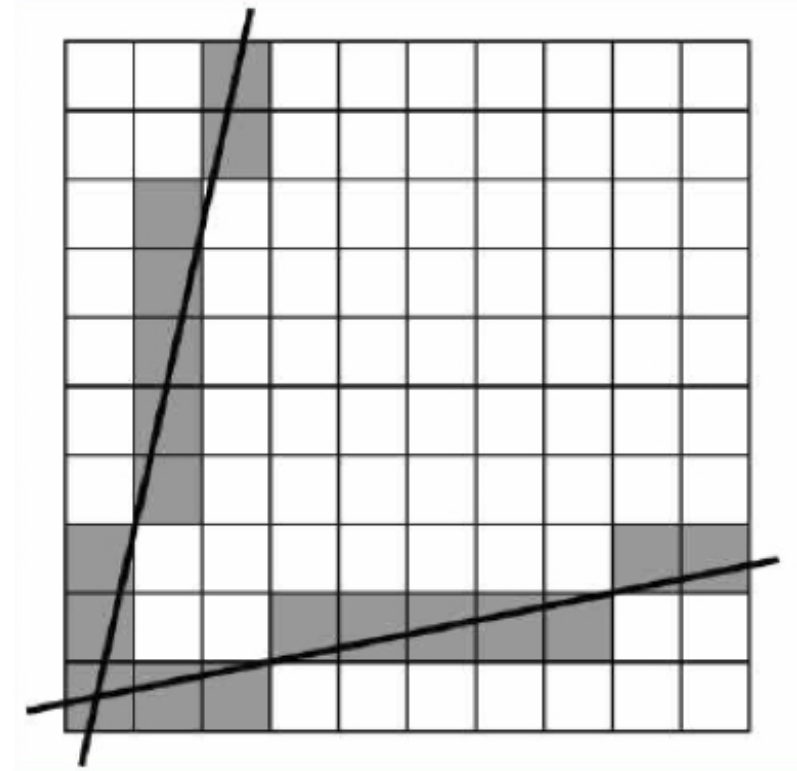# Rasterizer

Vertices ➤ Transformer ➤ Clipper ➤ Projector ➤ Rasterizer ➤ Pixels

- Interesting algorithms [Angel Ch. 6]

- **To window coordinates**

- Antialiasing

More Resources

- ## Official OpenGL Documentation
  – https://www.opengl.org/wiki/OpenGL_Reference
  – Or "man glVertex" on Linux/Mac

- ## Legacy OpenGL Tutorials
  – NeHe (http://nehe.gamedev.net/tutorial/lessons_01__05/22004/)
  – Programming Techniques GLUT Tutorial
    (http://www.programmingtechniques.com/2011/12/glut-tutorial-drawing-basic-shapes.html)

- ## Modern OpenGL Tutorials
  – OpenGL-Tutorial (http://www.opengl-tutorial.org/)
  – OpenGL-Introduction (https://open.gl/)

Thanks