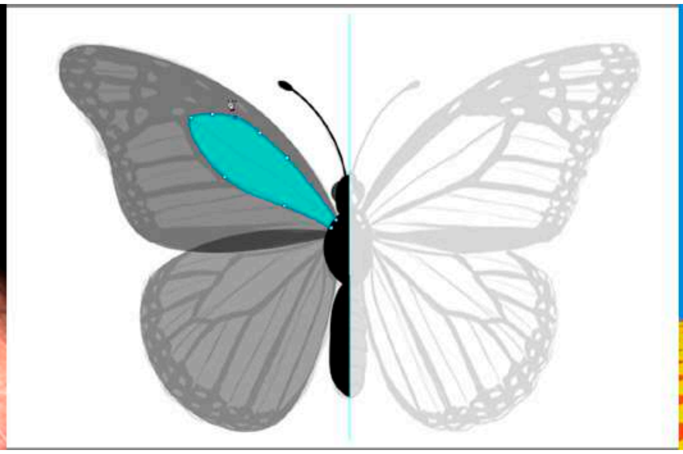
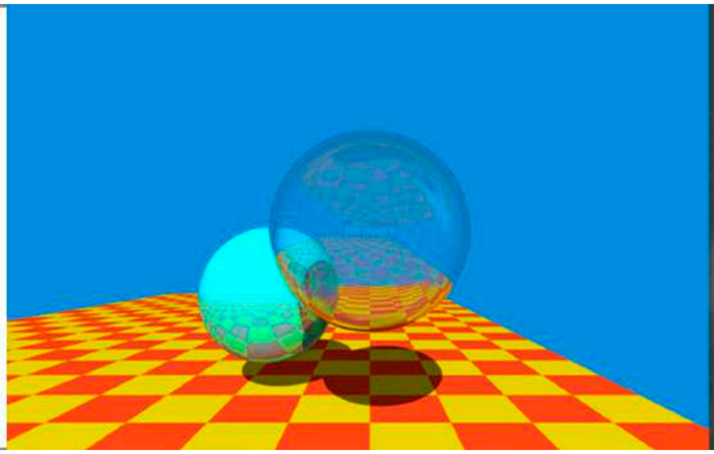
Introduction to Computer Graphics

GAMES101, Lingqi Yan, UC Santa Barbara

Lecture 5:
Rasterization 1 (Triangles)


http://www.cs.ucsb.edu/~lingqi/teaching/games101.html

Announcements

- Homework 0 — 188 submissions
  - No worries if you did not submit
- Homework 1 will be released today
  - Containing basic and advanced requirements (graded separately)
  - Pass or not pass depends on basic requirements only
- Asking on BBS
  - Please try to describe your question more clearly
- Today’s lecture is pretty easy

Last Lecture

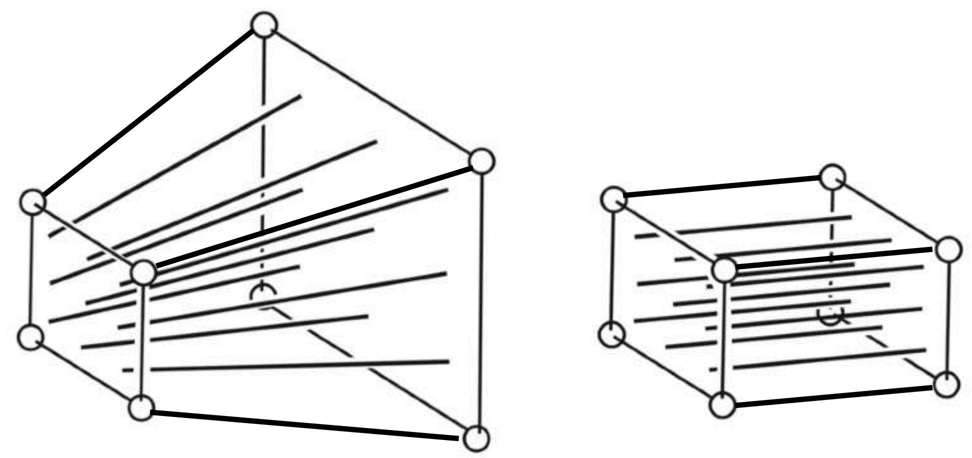
- Viewing (观测) transformation
  - View (视图) / Camera transformation
  - Projection (投影) transformation
    - Orthographic (正交) projection
    - Perspective (透视) projection

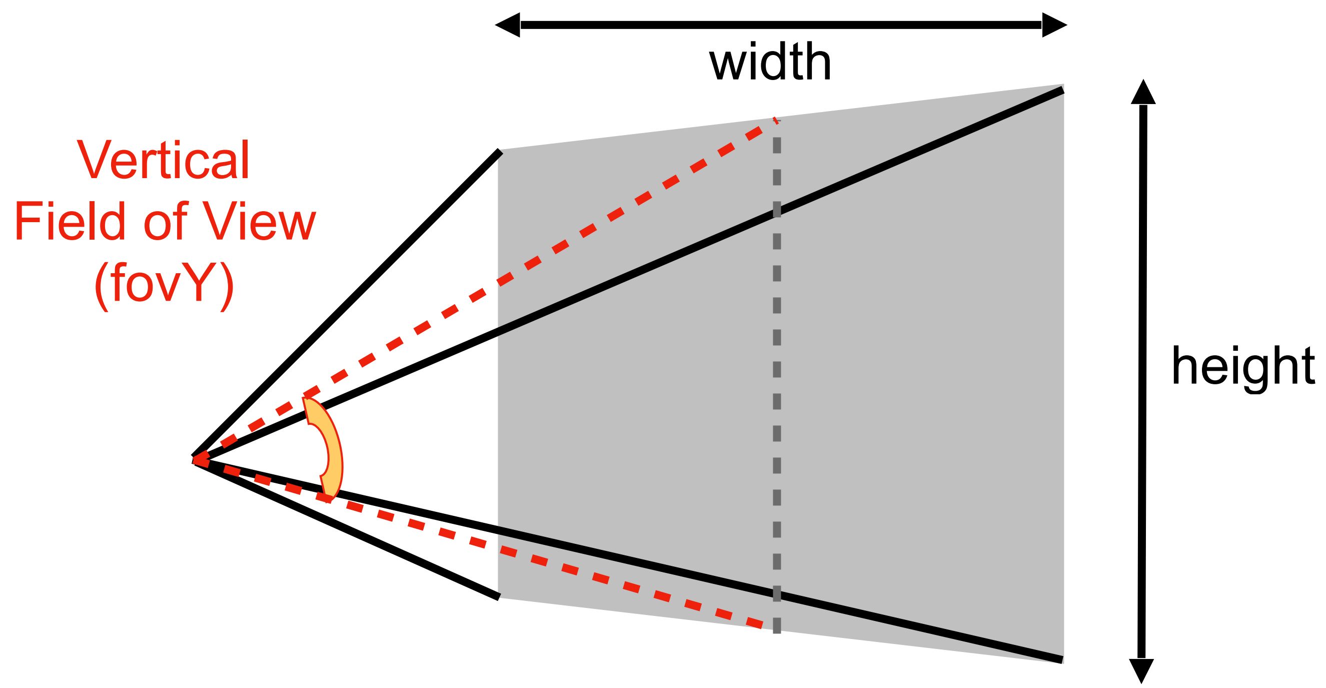
Today

- Finishing up Viewing
  - Viewport transformation
- Rasterization
  - Different raster displays
  - Rasterizing a triangle
- Occlusions and Visibility

Perspective Projection

- What's near plane's l, r, b, t then?
  - If explicitly specified, good
  - Sometimes people prefer:
    vertical **field-of-view** (fovY) and
    aspect ratio
    (assume symmetry i.e. l = -r, b = -t)

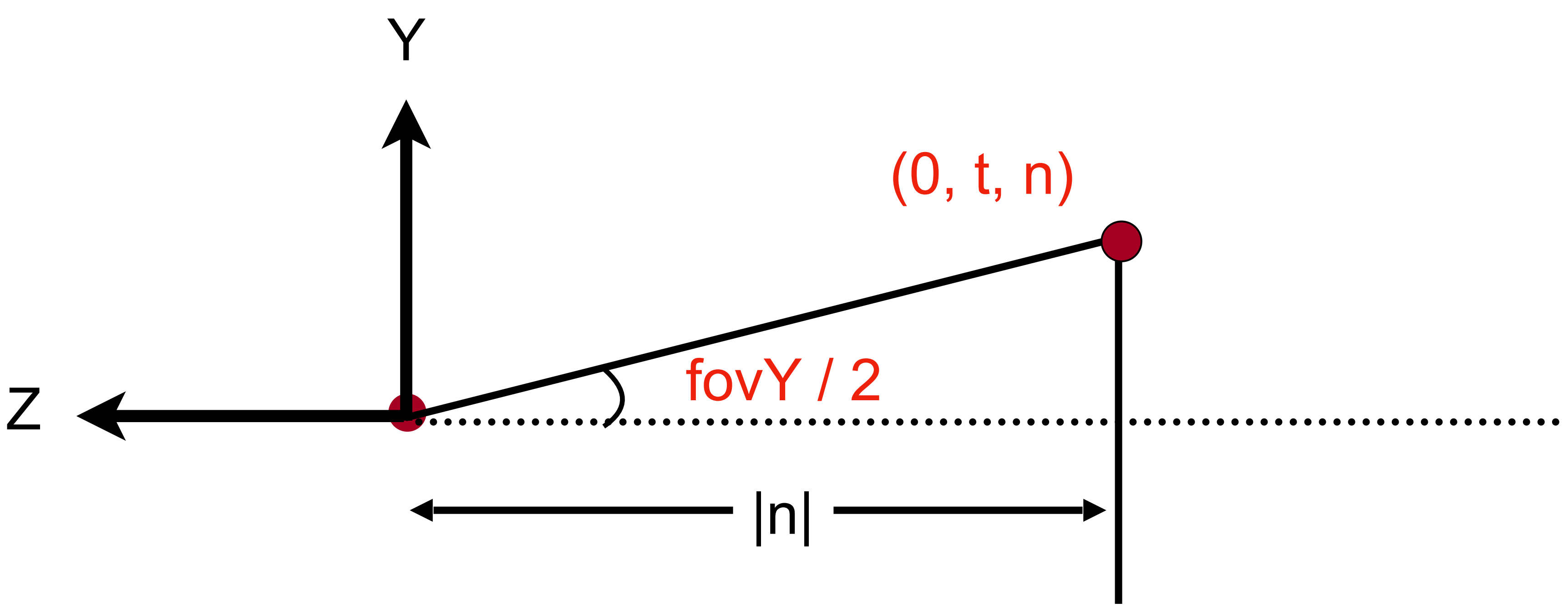




Aspect ratio = width / height

Perspective Projection

- How to convert from fovY and aspect to l, r, b, t?
  - Trivial



$$\tan \frac{fovY}{2} = \frac{t}{|n|}$$

$$aspect = \frac{r}{t}$$

What's after MVP?

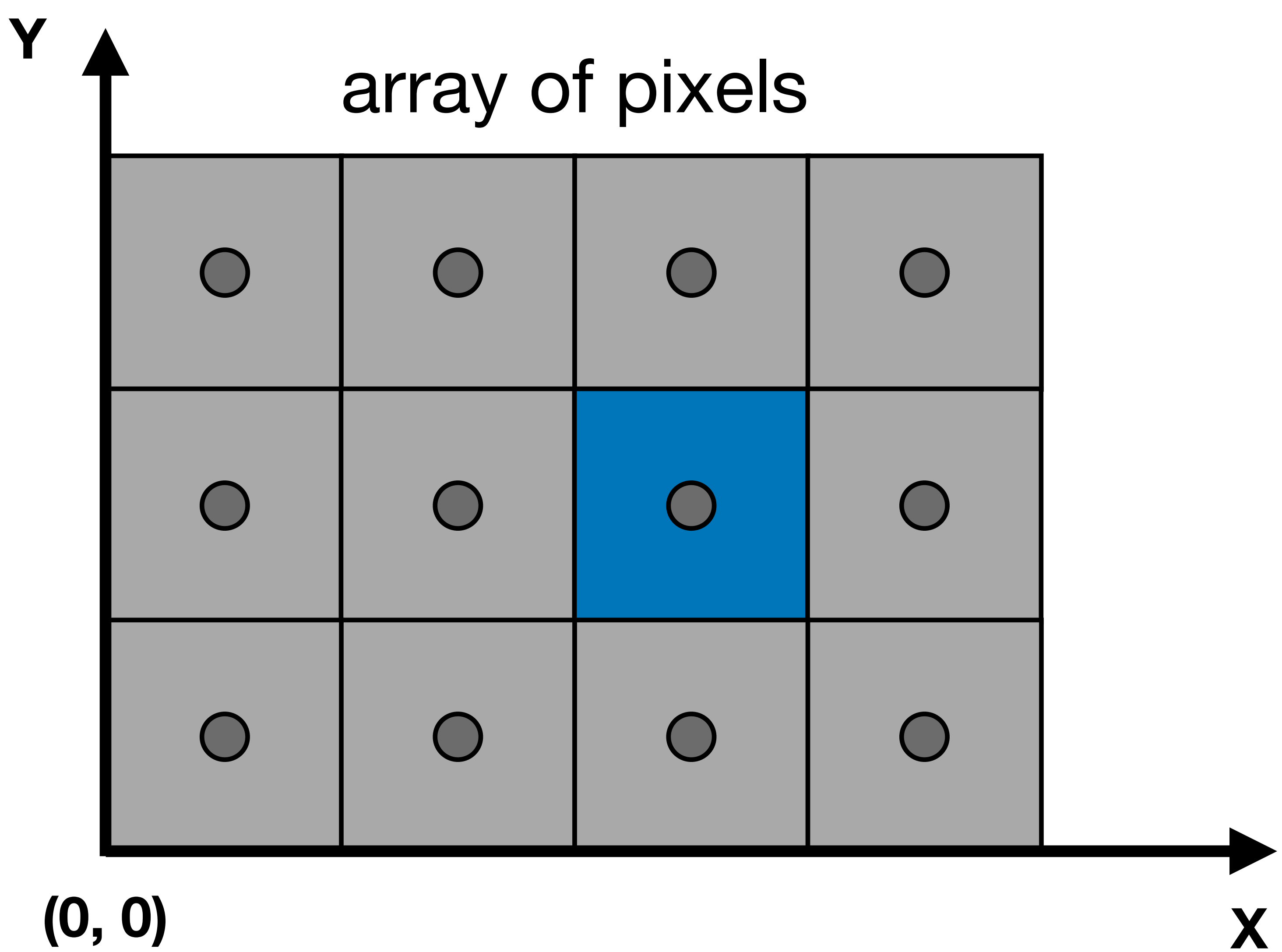
- **M**odel transformation (placing objects)
- **V**iew transformation (placing camera)
- **P**rojection transformation
  - Orthographic projection (cuboid to "canonical" cube $[-1, 1]^3$)
  - Perspective projection (frustum to "canonical" cube)
- Canonical cube to ?

Canonical Cube to Screen

- What is a screen?
  - An array of pixels
  - Size of the array: resolution
  - A typical kind of raster display
- Raster == screen in German
  - Rasterize == drawing onto the screen
- Pixel (FYI, short for “picture element”)
  - For now: A pixel is a little square with uniform color
  - Color is a mixture of (red, green, blue)

Canonical Cube to Screen

- Defining the screen space
  - Slightly different from the “tiger book”



Pixels’ indices are in the form of (x, y), where both x and y are integers

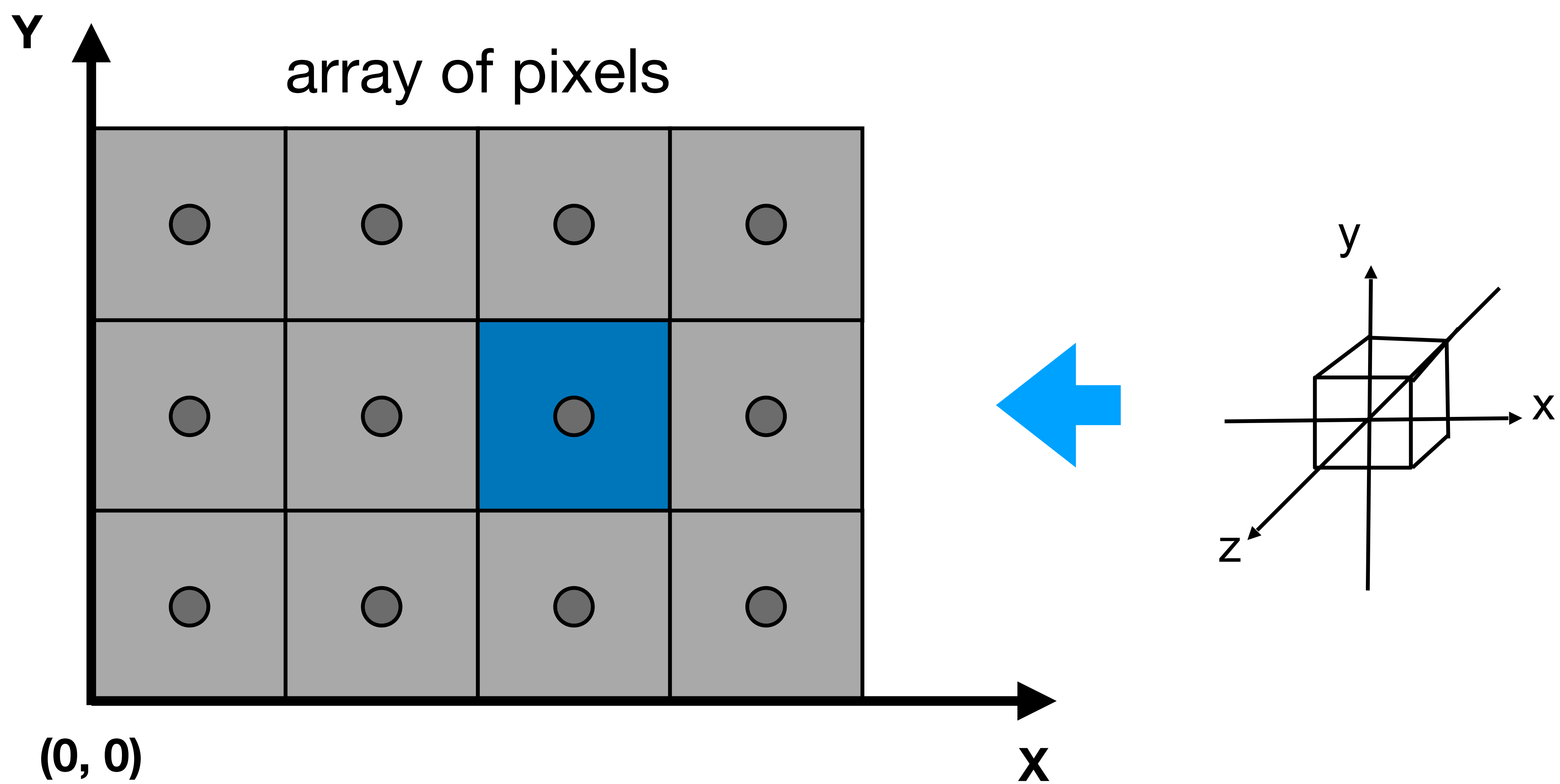
Pixels’ indices are from (0, 0) to (width - 1, height - 1)

Pixel (x, y) is centered at (x + 0.5, y + 0.5)

The screen covers range (0, 0) to (width, height)

Canonical Cube to Screen

- Irrelevant to z
- Transform in xy plane: $[-1, 1]^2$ to [0, width] x [0, height]



Canonical Cube to Screen

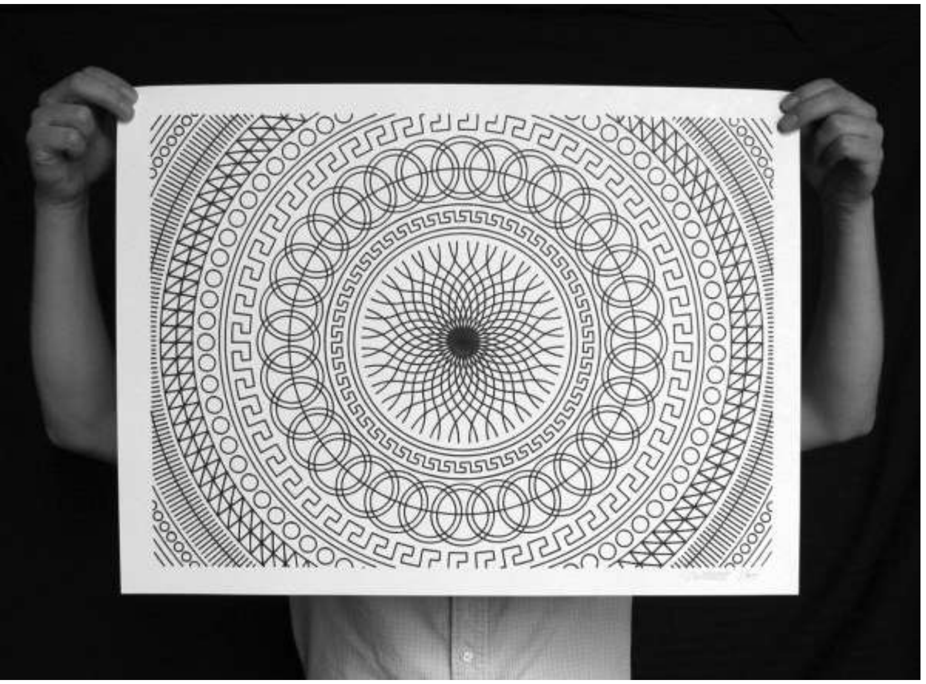
- Irrelevant to z
- Transform in xy plane: $[-1, 1]^2$ to [0, width] x [0, height]
- Viewport transform matrix:

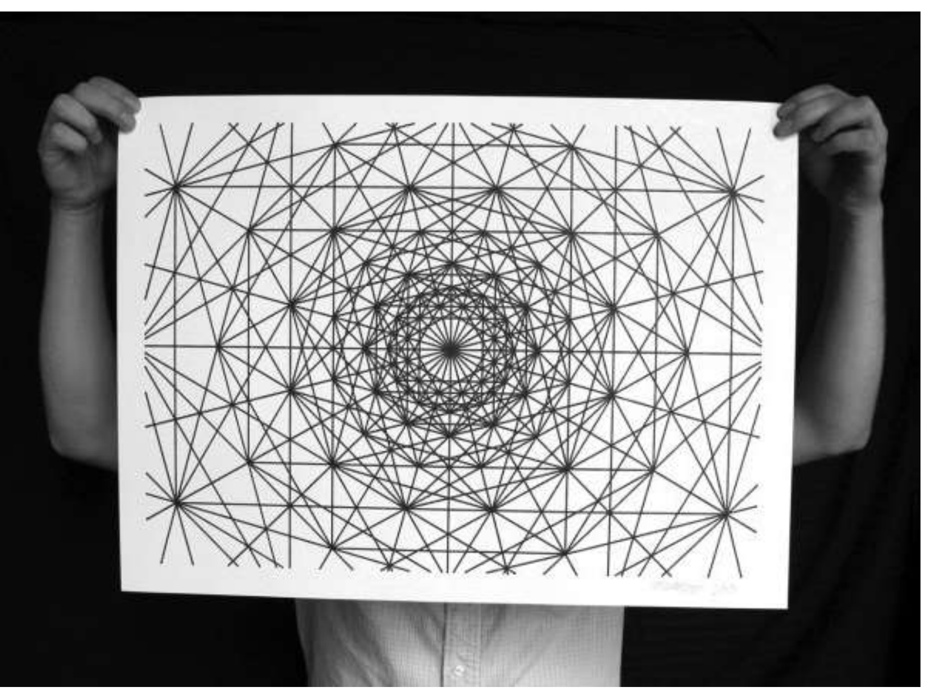
$$M_{viewport} = \begin{pmatrix} \frac{width}{2} & 0 & 0 & \frac{width}{2} \\ 0 & \frac{height}{2} & 0 & \frac{height}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Next: Rasterizing Triangles into Pixels

Drawing Machines

CNC Sharpie Drawing Machine





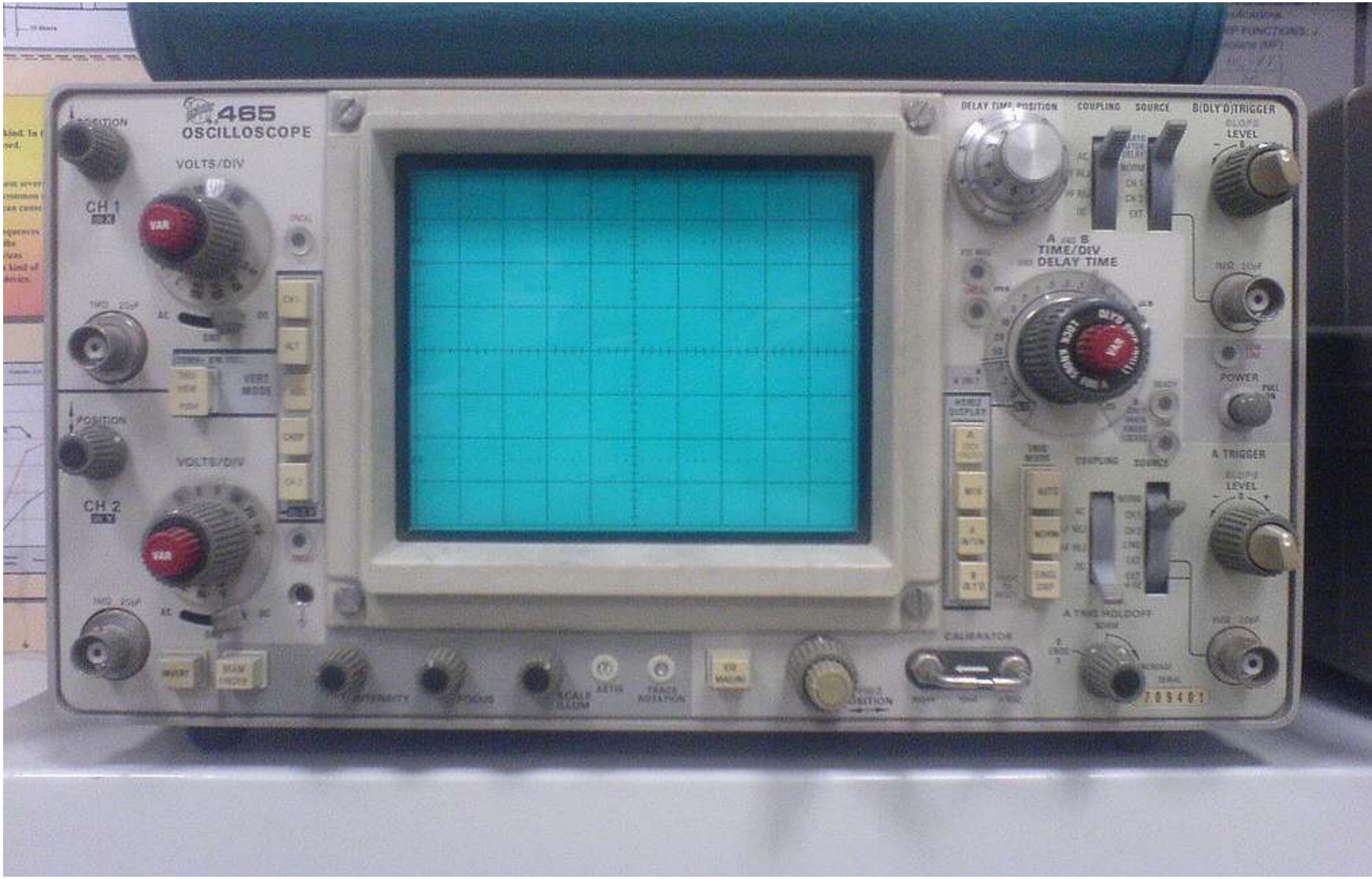
Aaron Panone with Matt W. Moore

http://44rn.com/projects/numerically-controlled-poster-series-with-matt-w-moore/

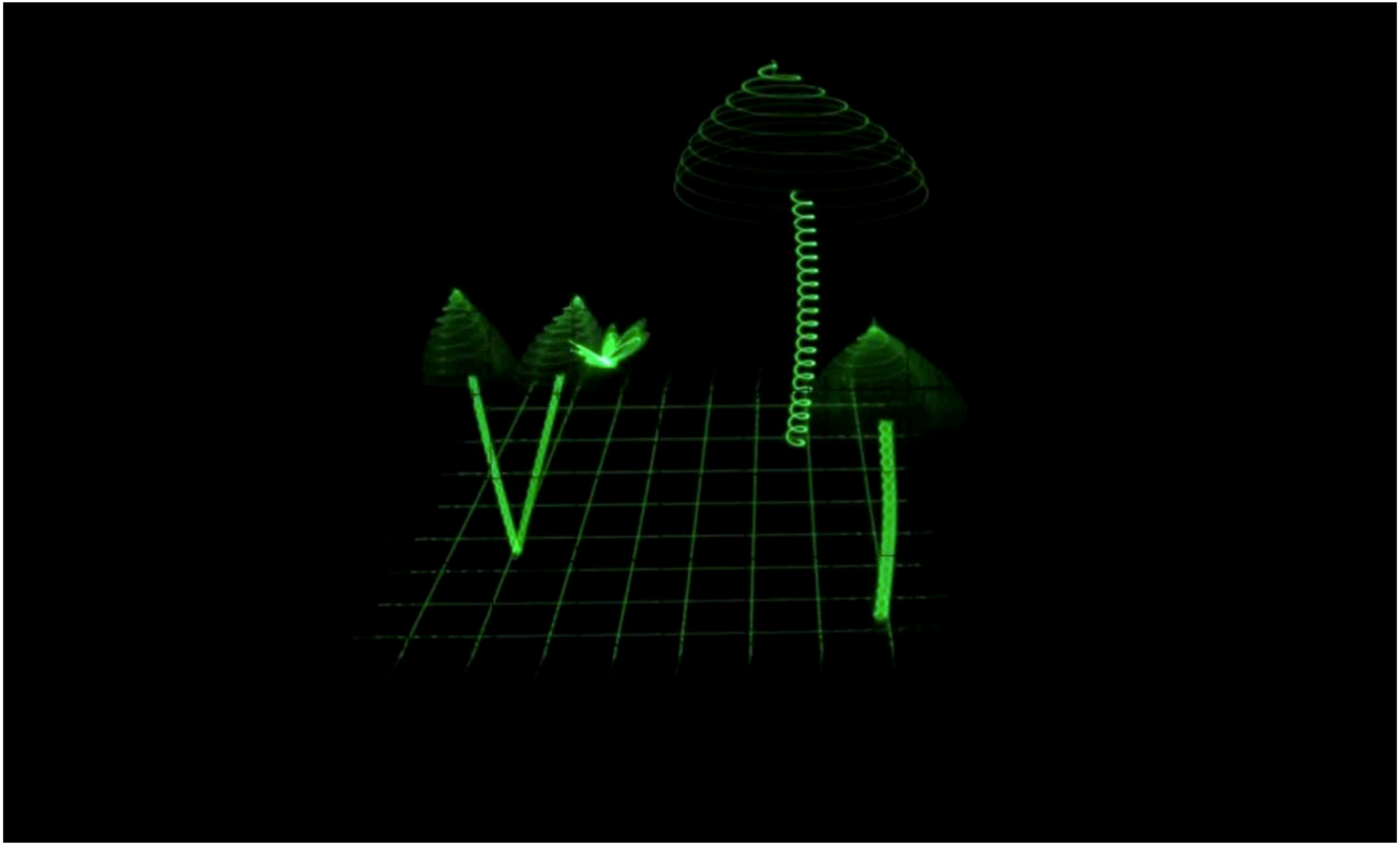
Laser Cutters

Different Raster Displays

Oscilloscope



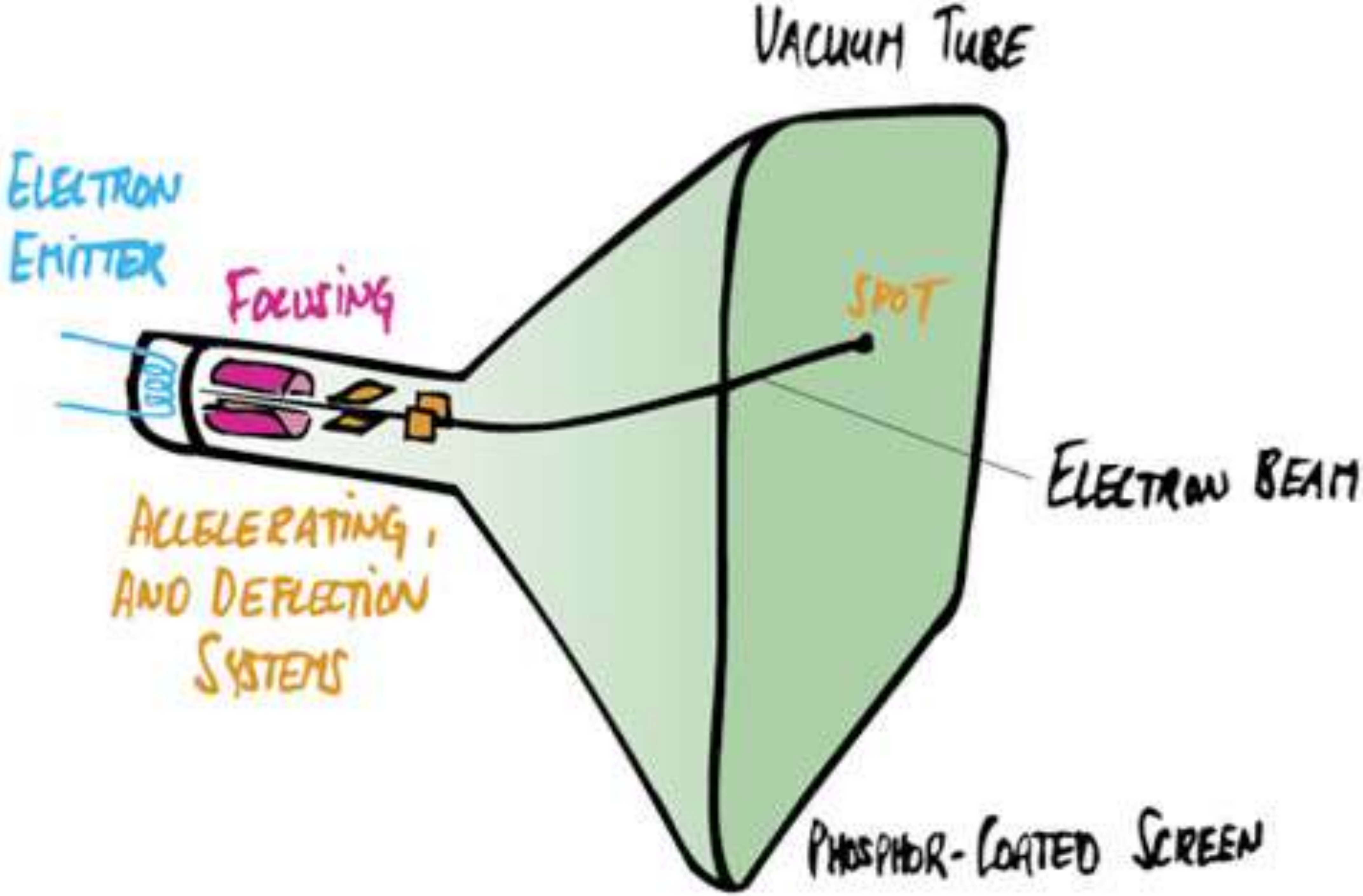
Oscilloscope Art



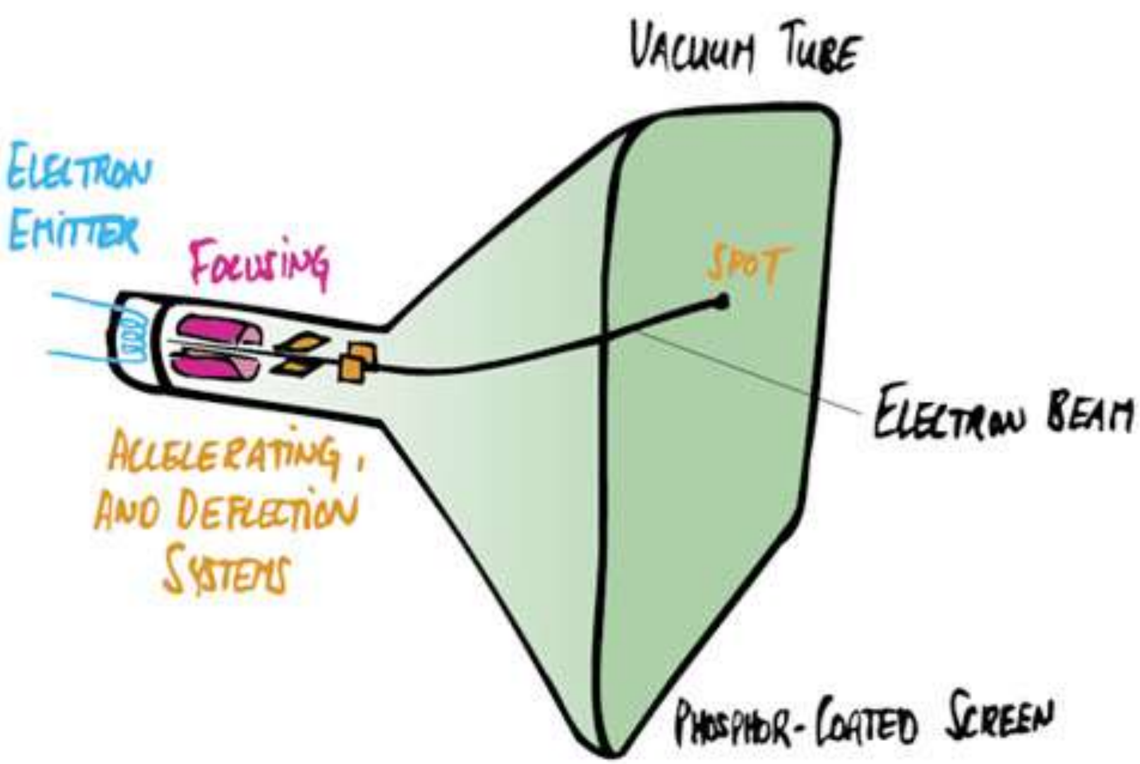
Jerobeam Fenderson

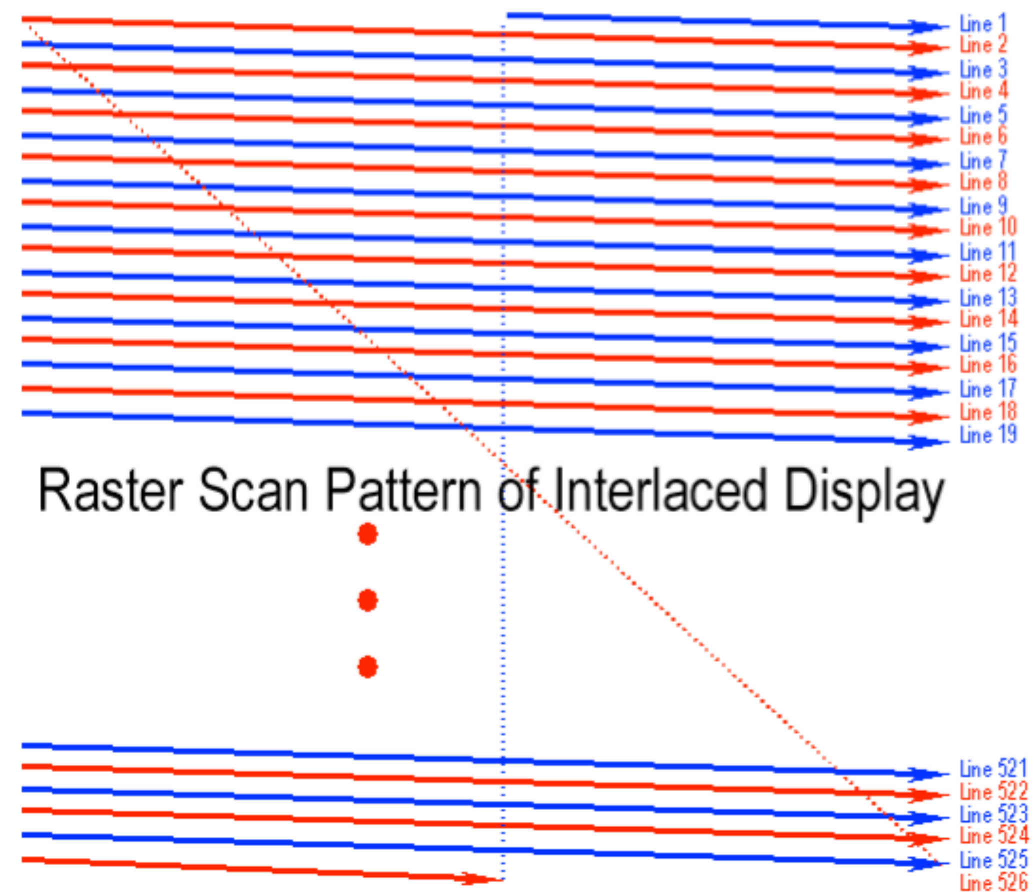
https://www.youtube.com/watch?v=rtR63-ecUNo

Cathode Ray Tube



Television - Raster Display CRT





Cathode Ray Tube

Raster Scan
(modulate intensity)

Frame Buffer: Memory for a Raster Display

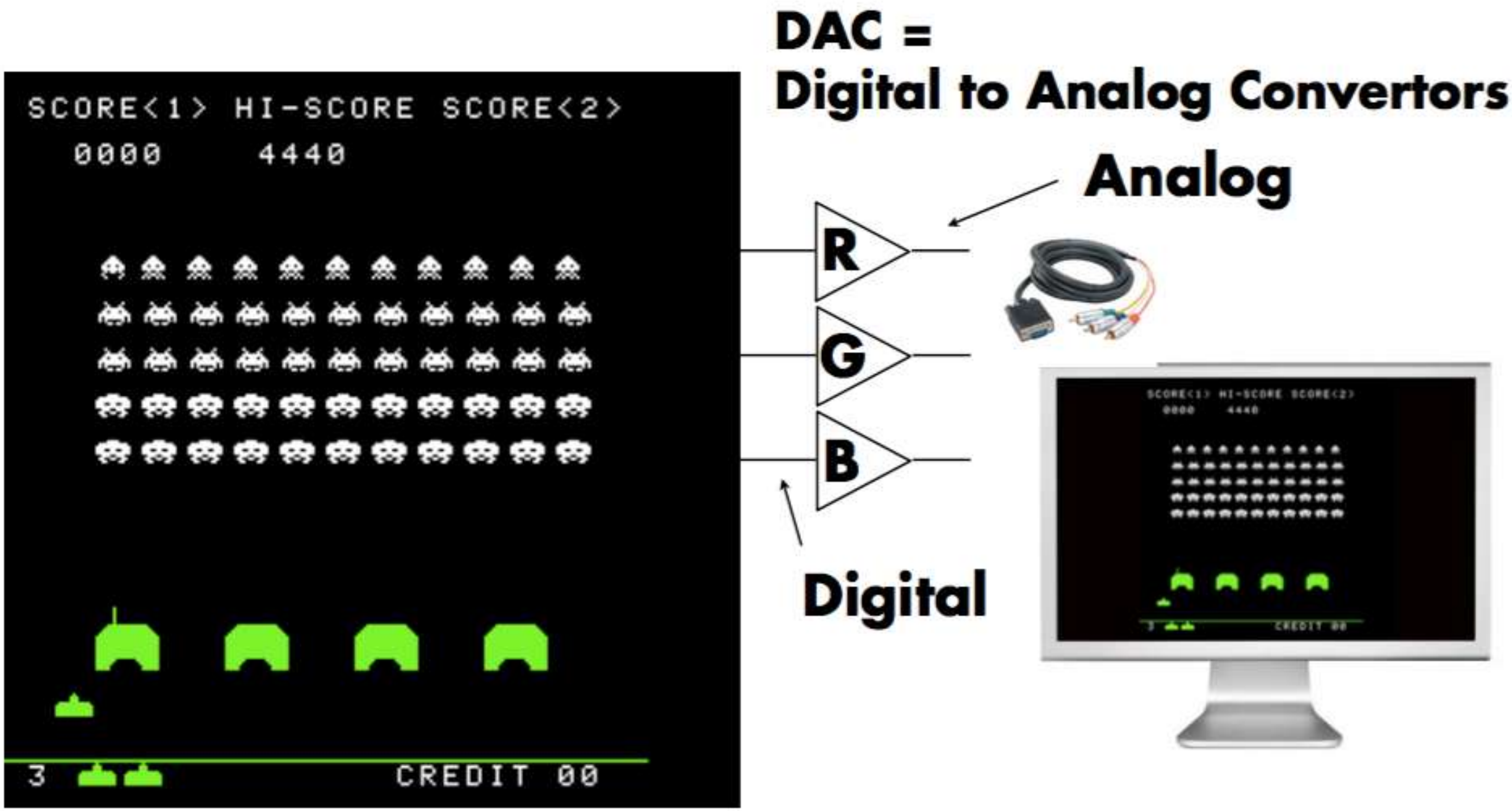


Image = 2D array of colors

Flat Panel Displays

Low-Res LCD Display

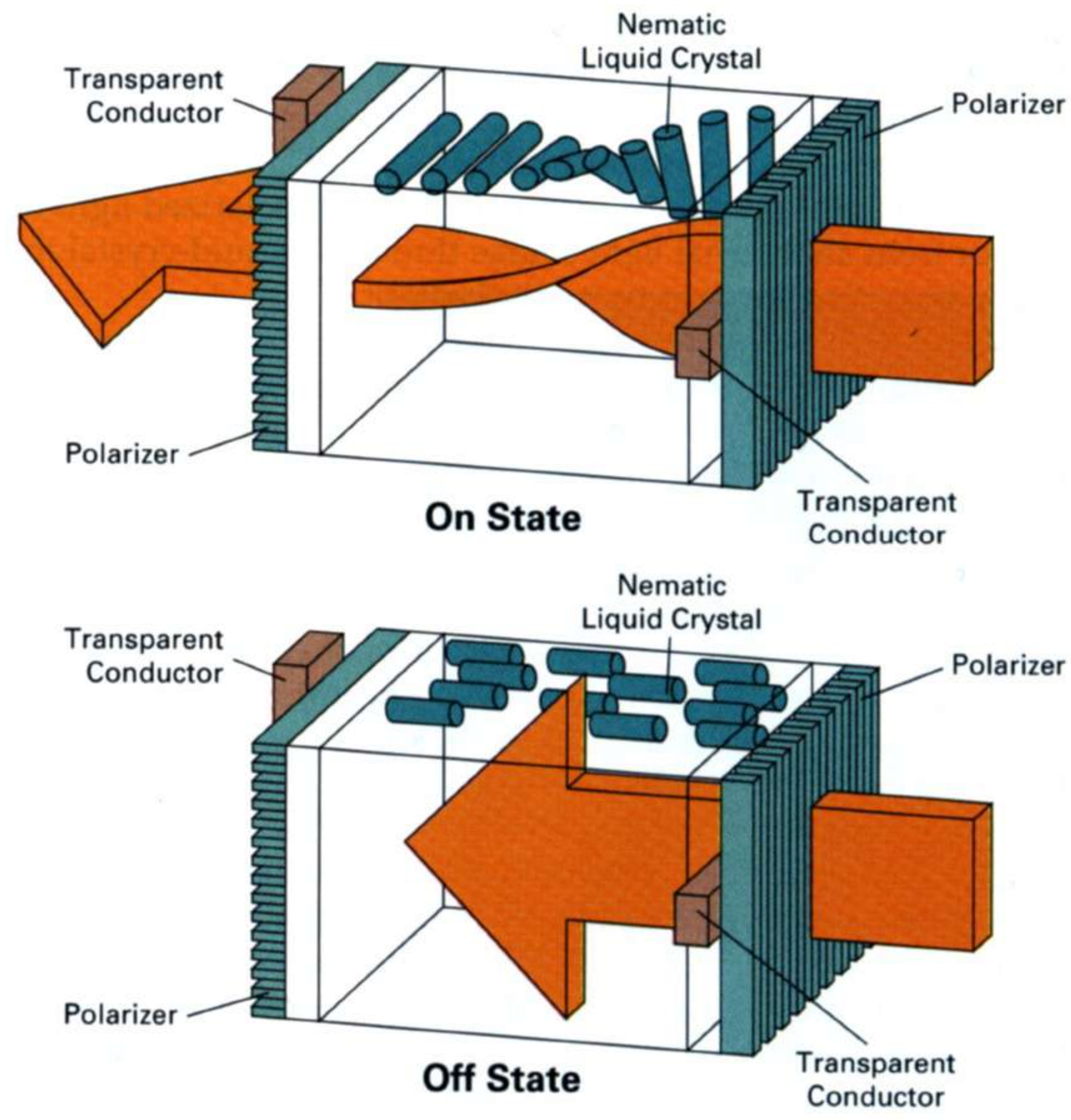
Color LCD, OLED, …

LCD (Liquid Crystal Display) Pixel

Principle: block or transmit light by twisting polarization

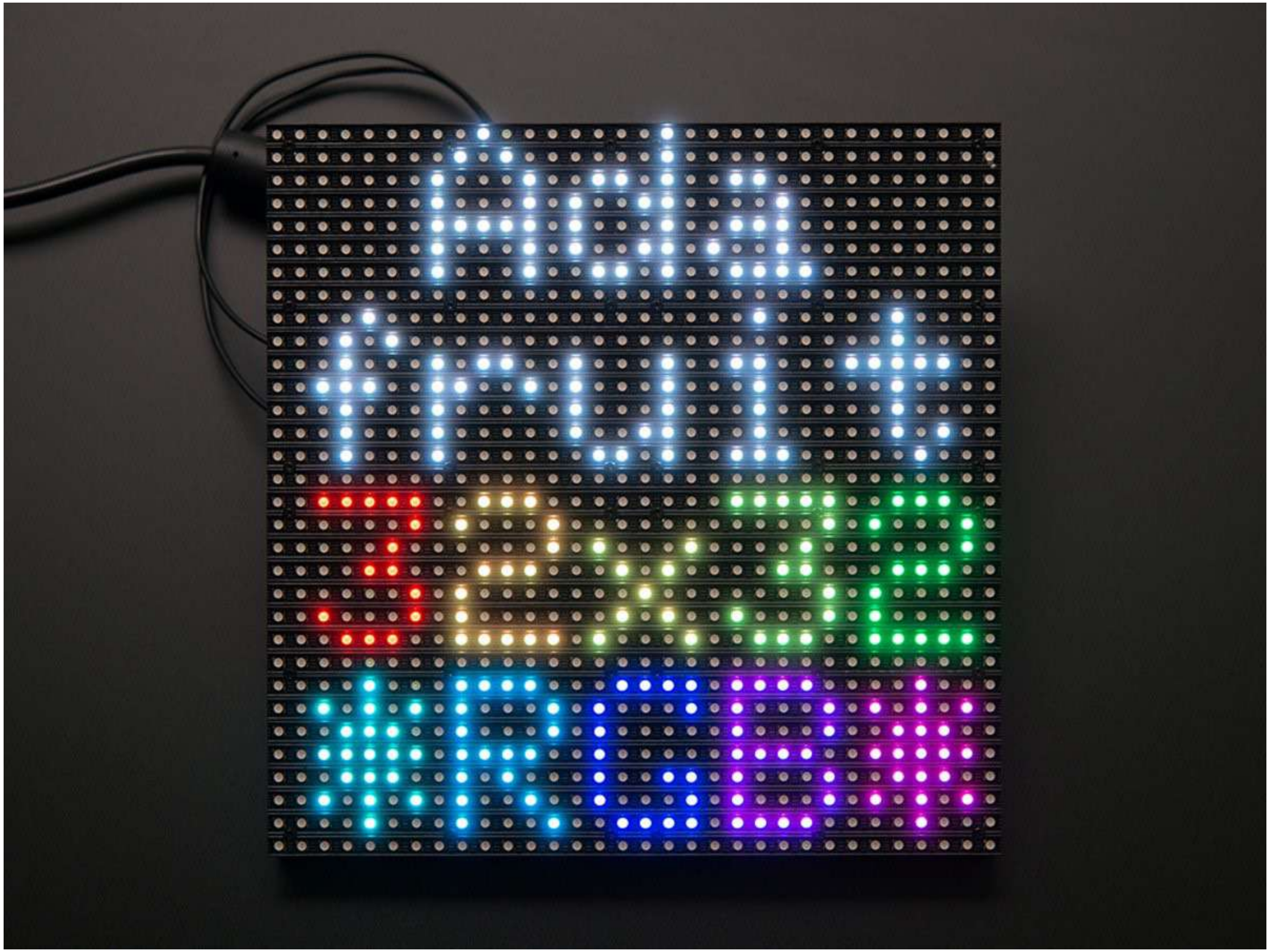
Illumination from backlight (e.g. fluorescent or LED)

Intermediate intensity levels by partial twist



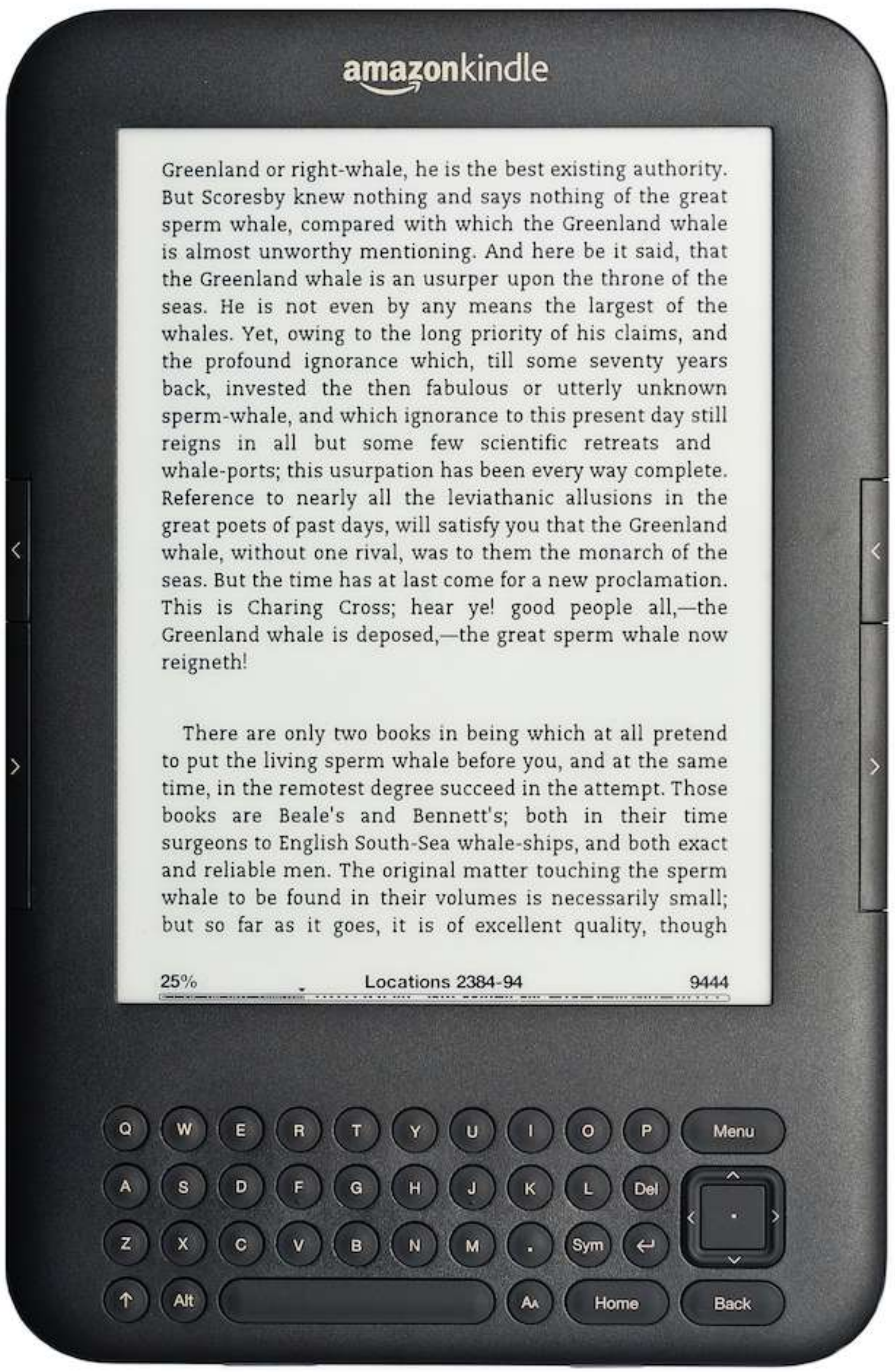
[H&B fig. 2-16]

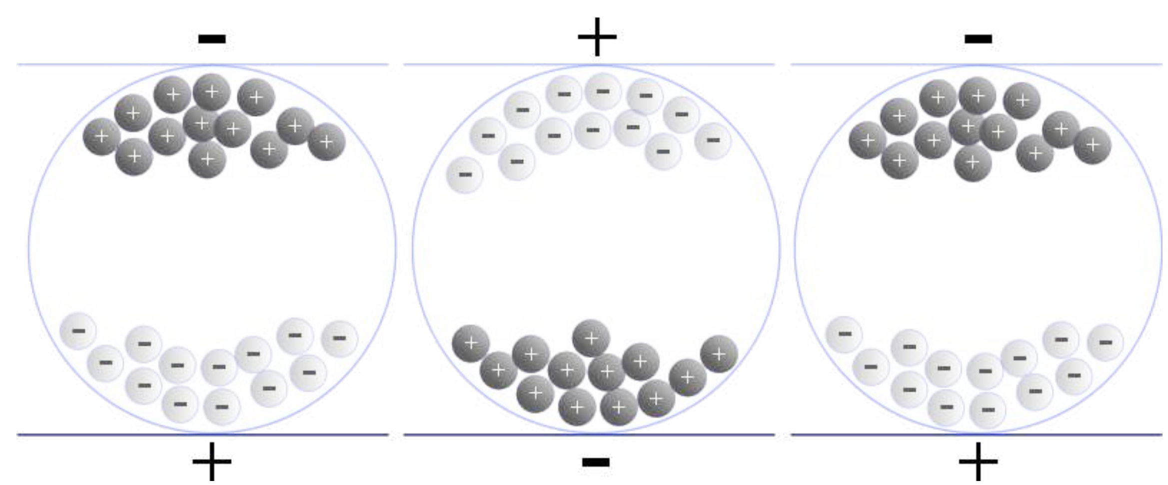
LED Array Display



Light emitting diode array

Electrophoretic (Electronic Ink) Display



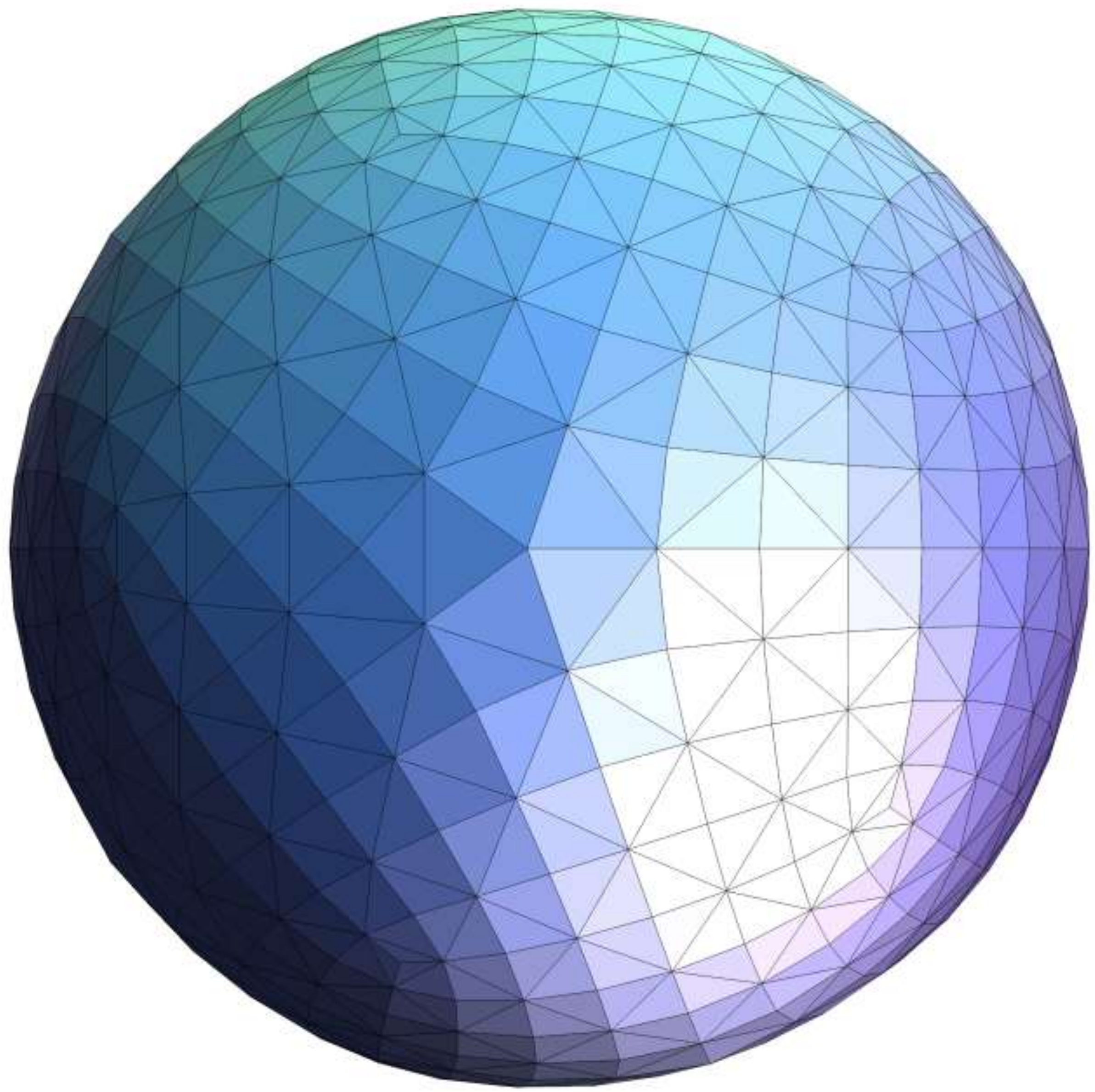


[Wikimedia Commons —Senarclens]

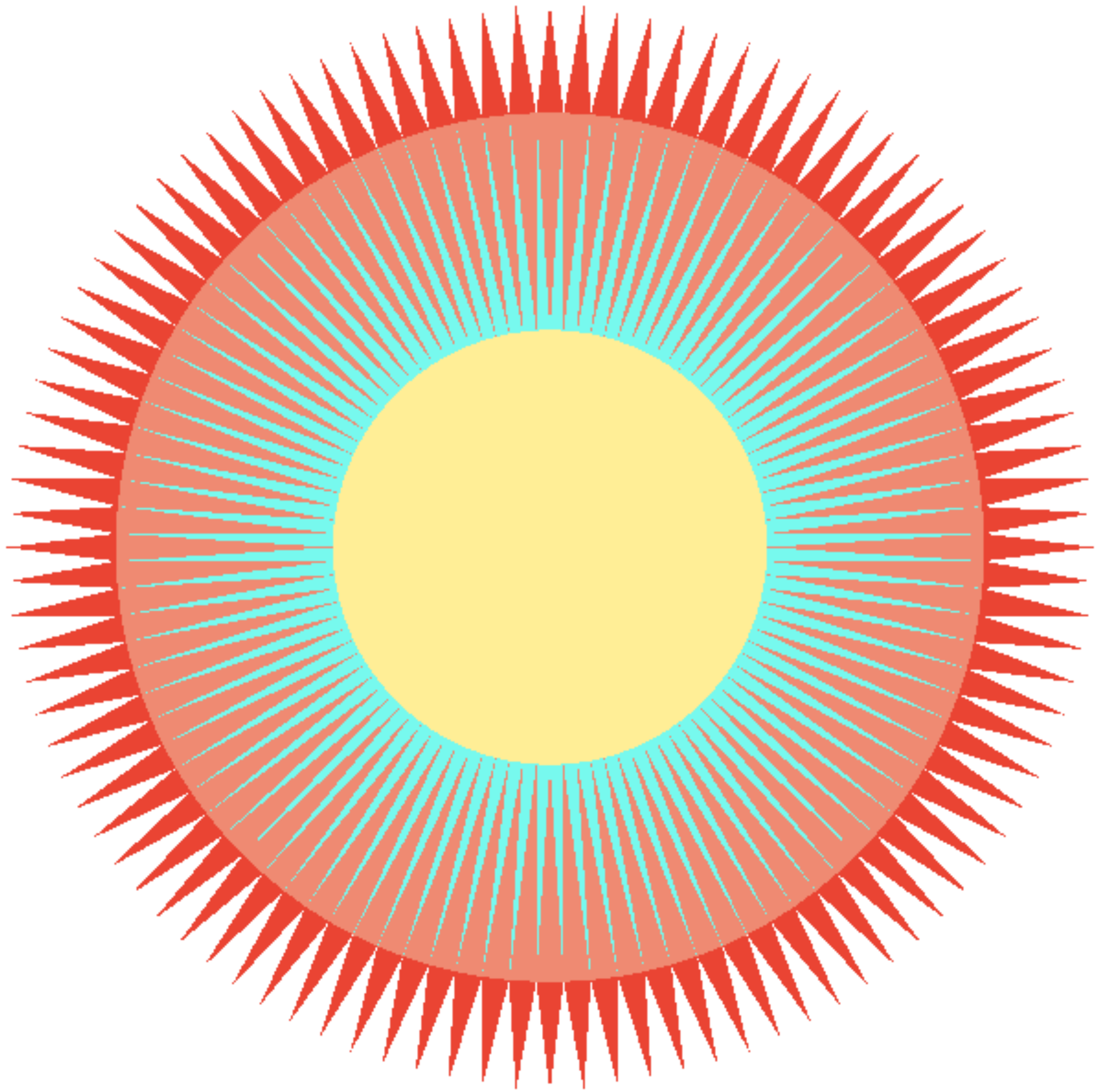
Rasterization:
Drawing to Raster Displays

Polygon Meshes

Triangle Meshes



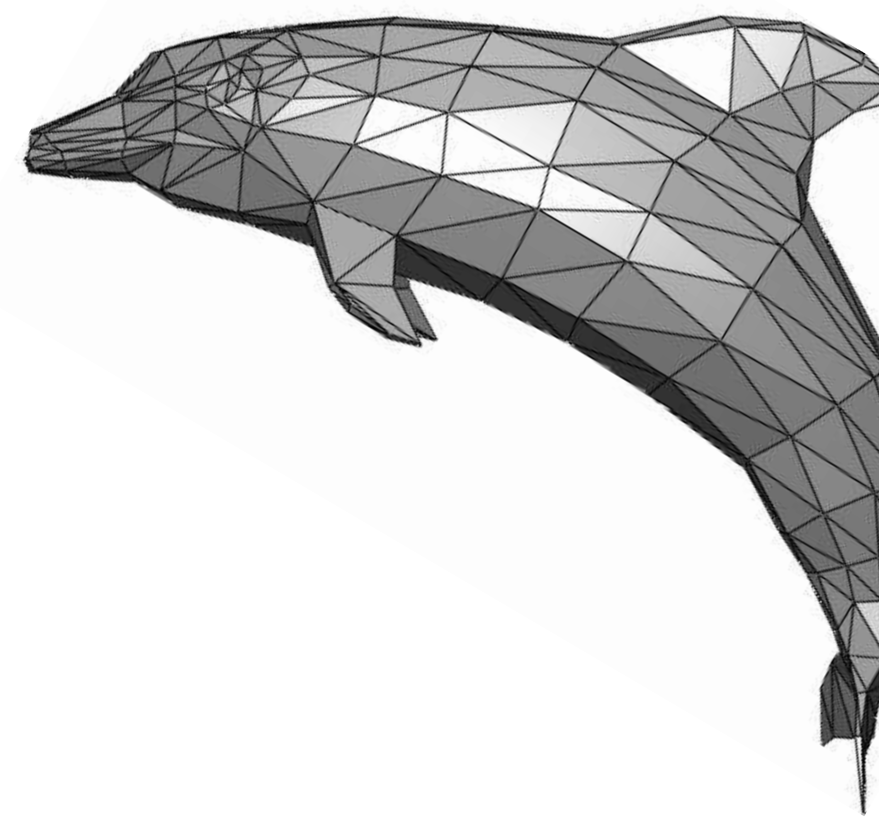
Triangle Meshes



Triangles - Fundamental Shape Primitives

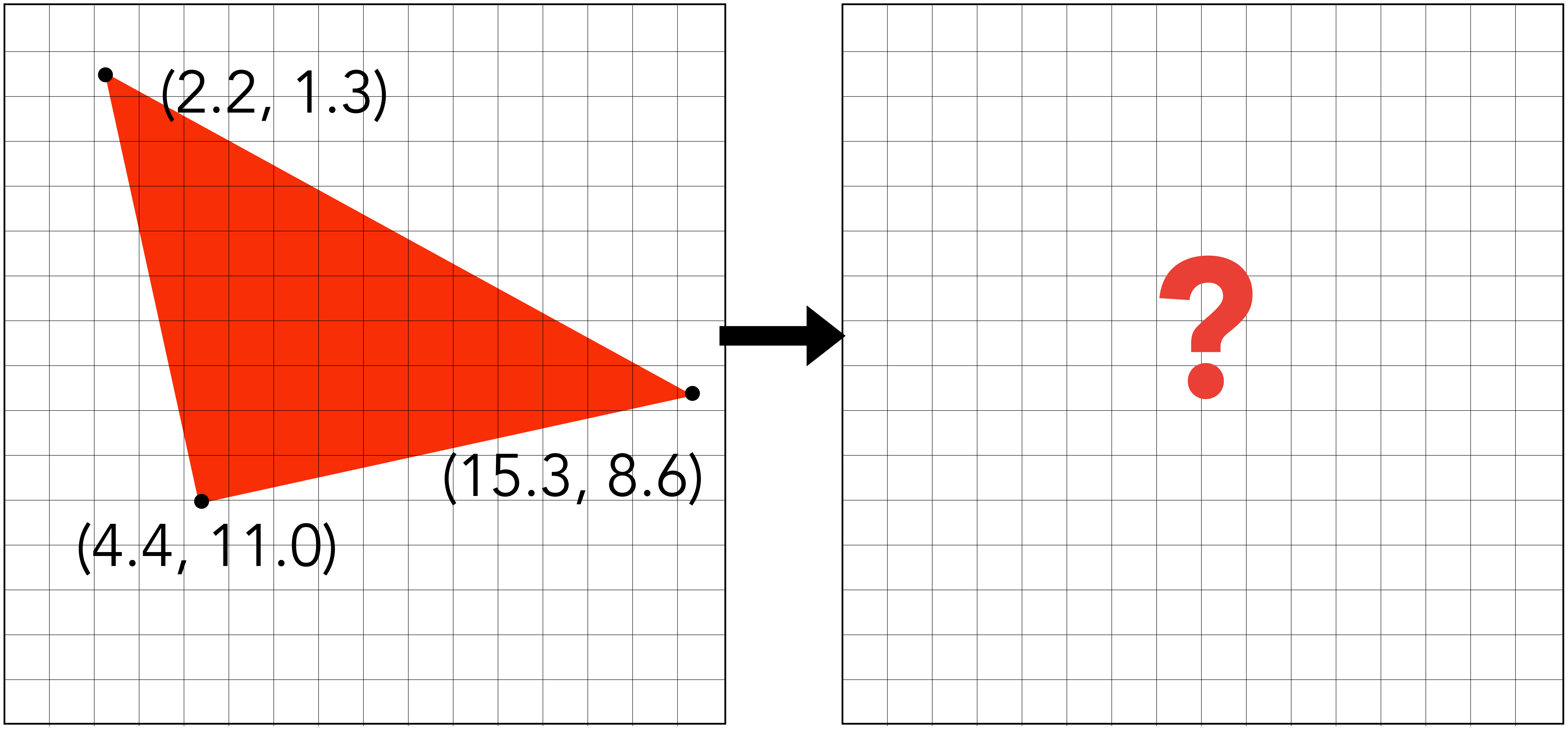
Why triangles?

- Most basic polygon
  - Break up other polygons



- Unique properties
  - Guaranteed to be planar
  - Well-defined interior
  - Well-defined method for interpolating values at vertices over triangle (barycentric interpolation)

What Pixel Values Approximate a Triangle?



Input: position of triangle vertices projected on screen

Output: set of pixel values approximating triangle

A Simple Approach: Sampling

Sampling a Function

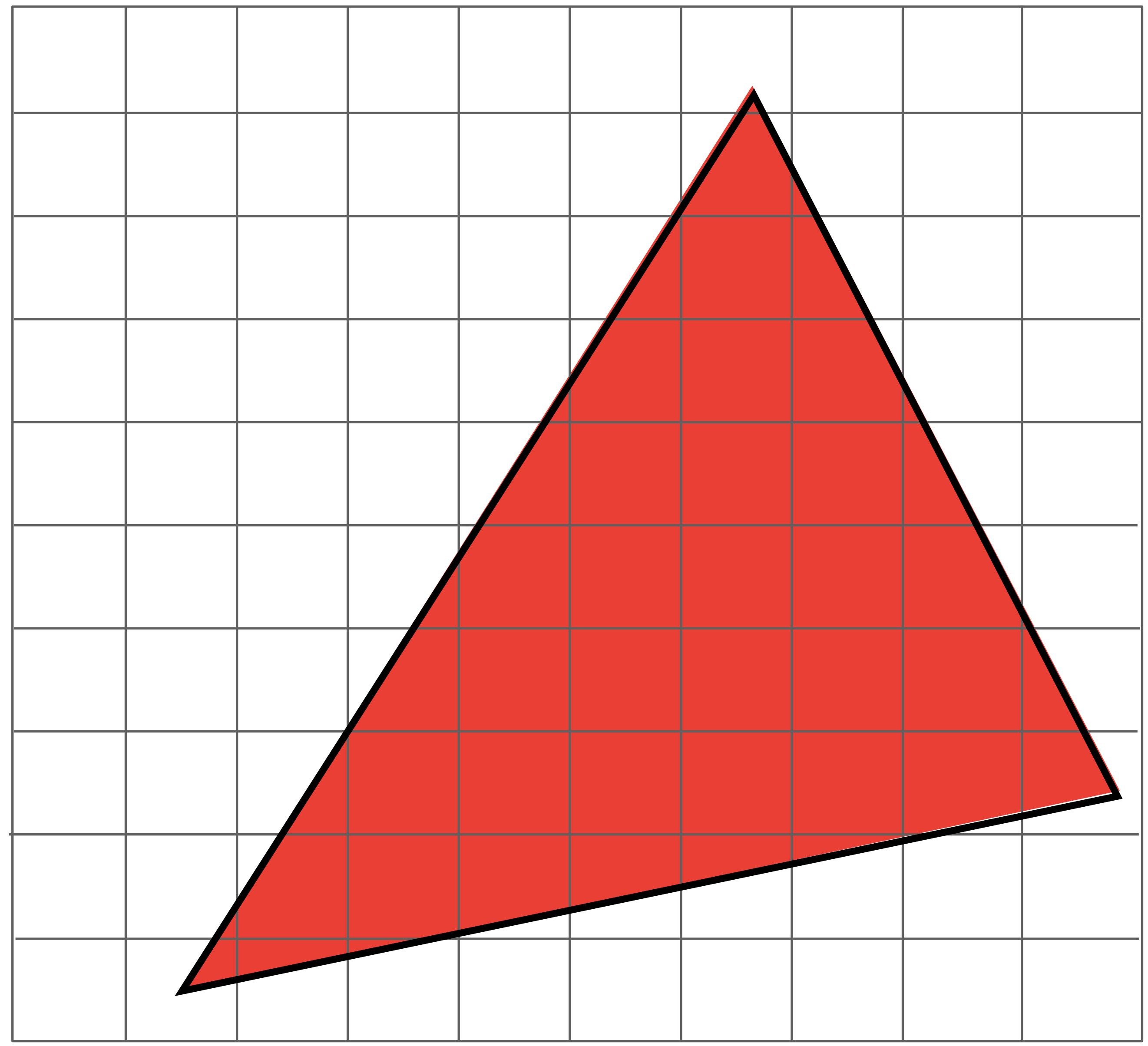
Evaluating a function at a point is sampling.

We can discretize a function by sampling.

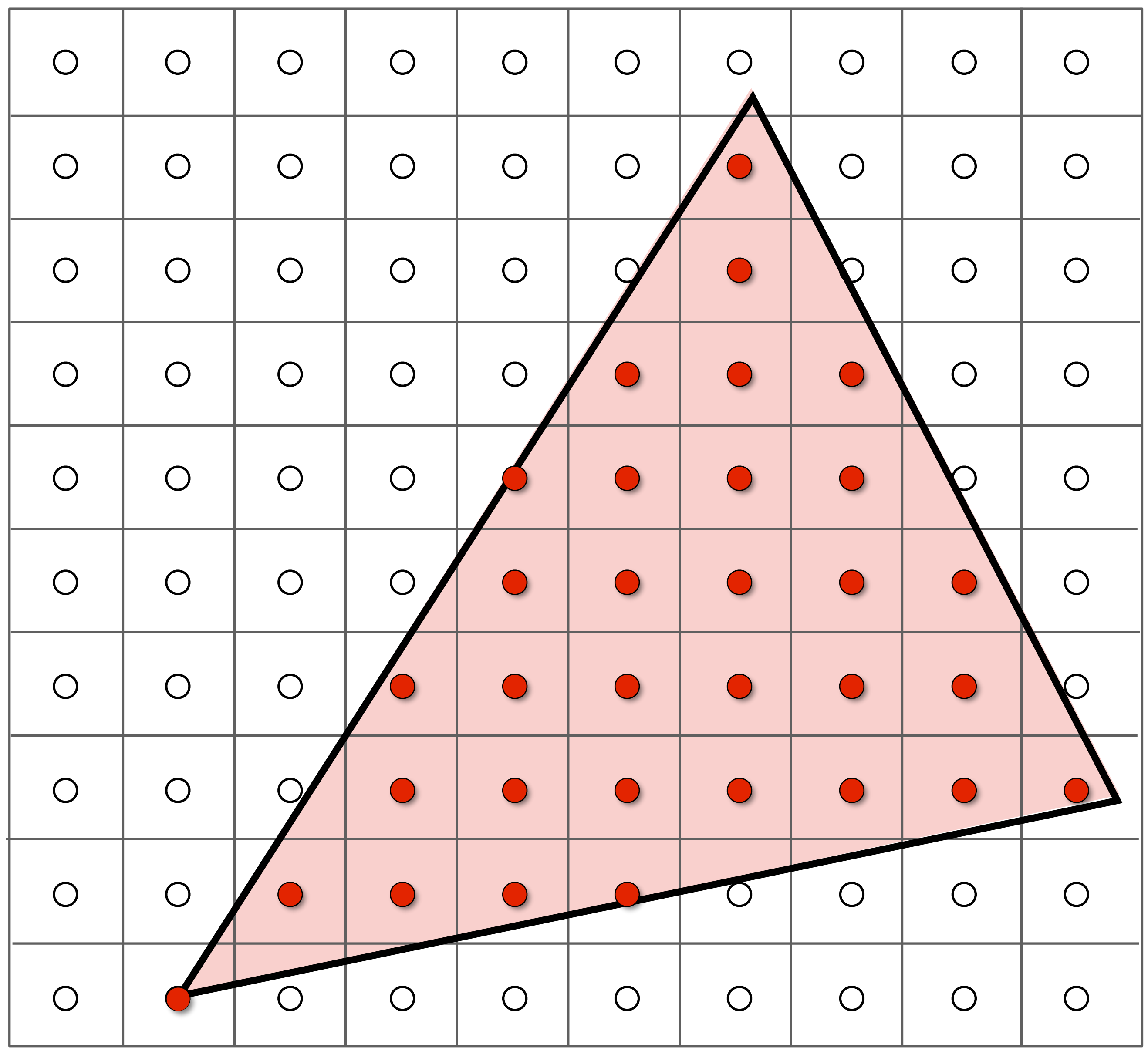
```
for (int x = 0; x < xmax; ++x)
    output[x] = f(x);
```

Sampling is a core idea in graphics.
We sample time (1D), area (2D), direction (2D), volume (3D) …

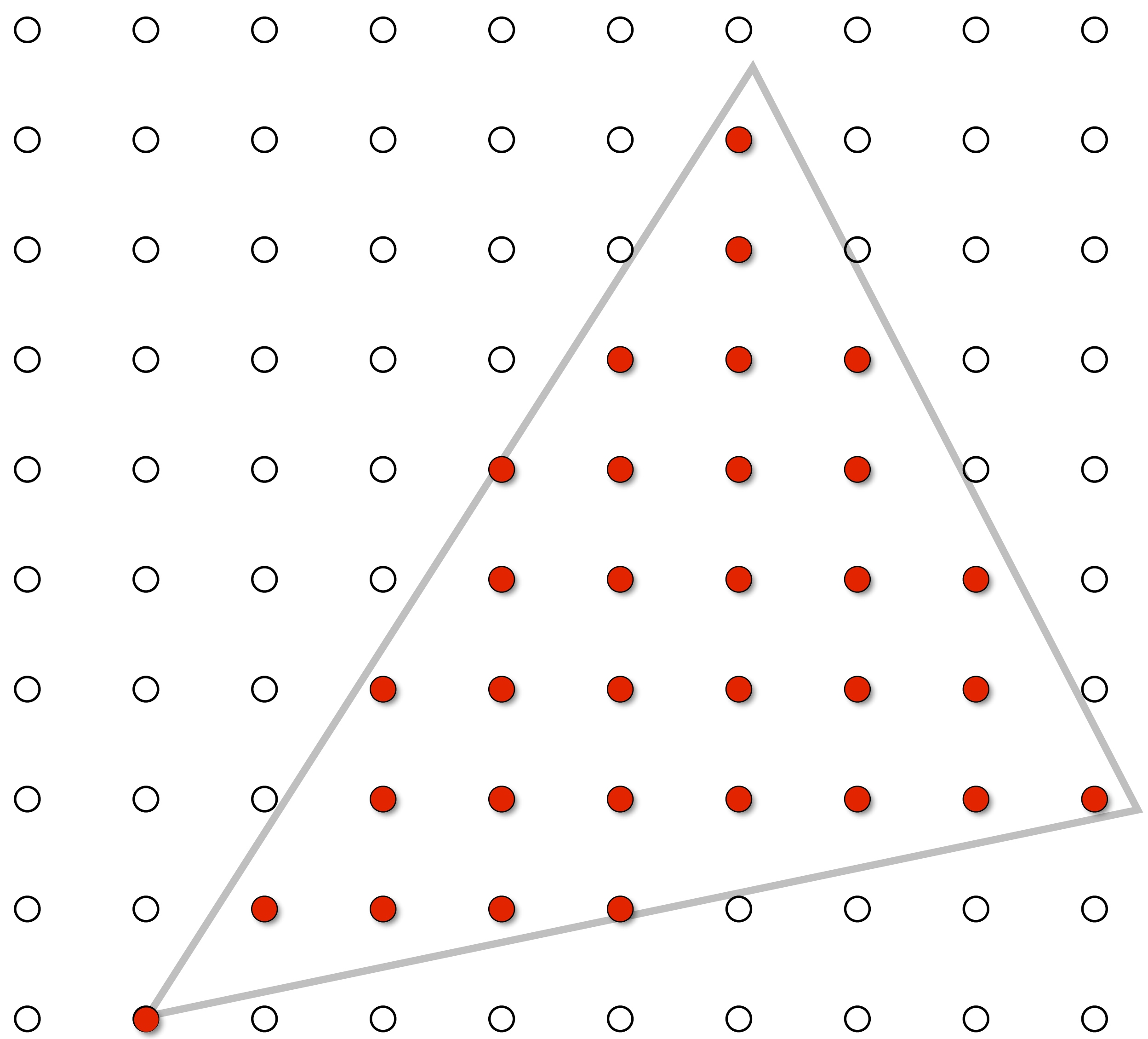
Rasterization As 2D Sampling



Sample If Each Pixel Center Is Inside Triangle

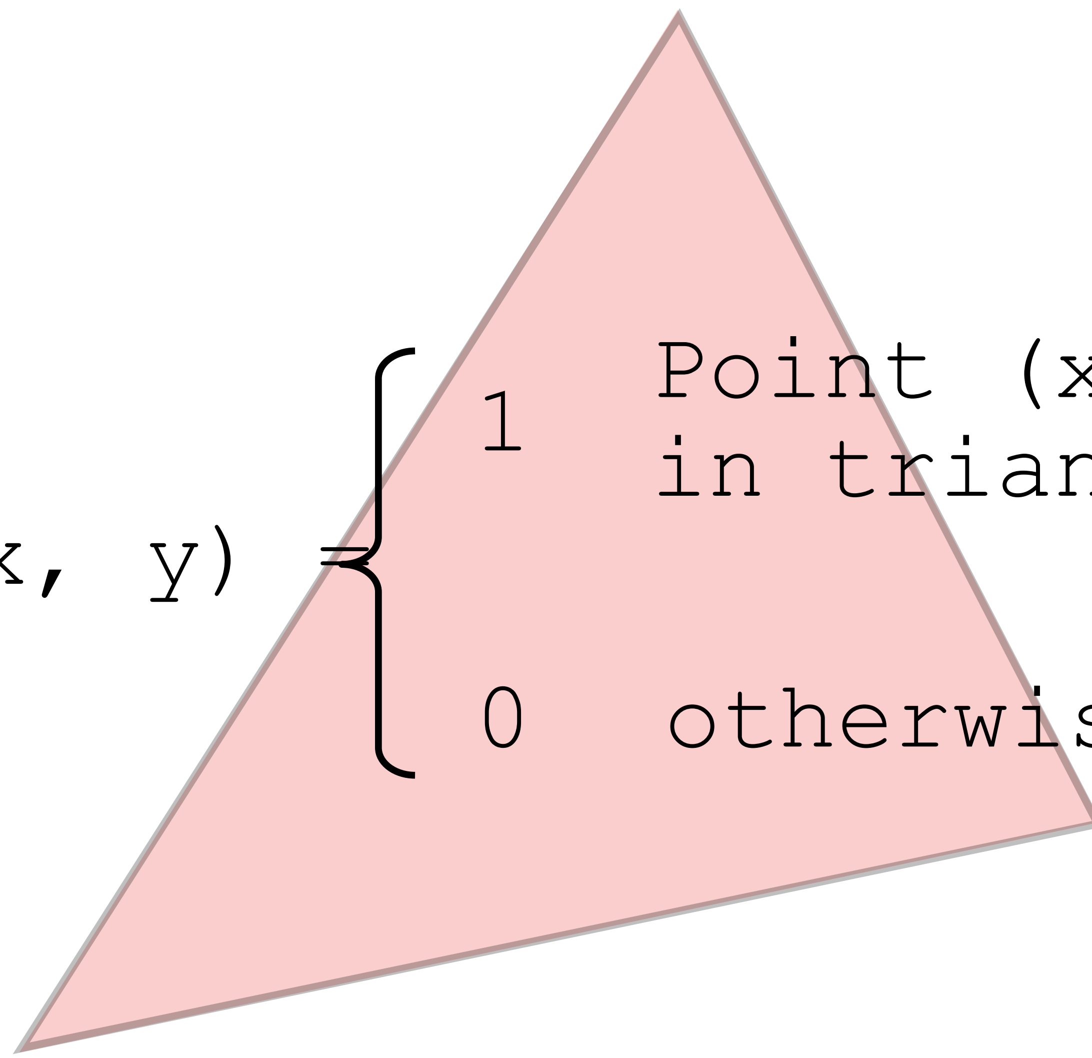


Sample If Each Pixel Center Is Inside Triangle



Define Binary Function: `inside(tri, x, y)`

x, y: not necessarily integers

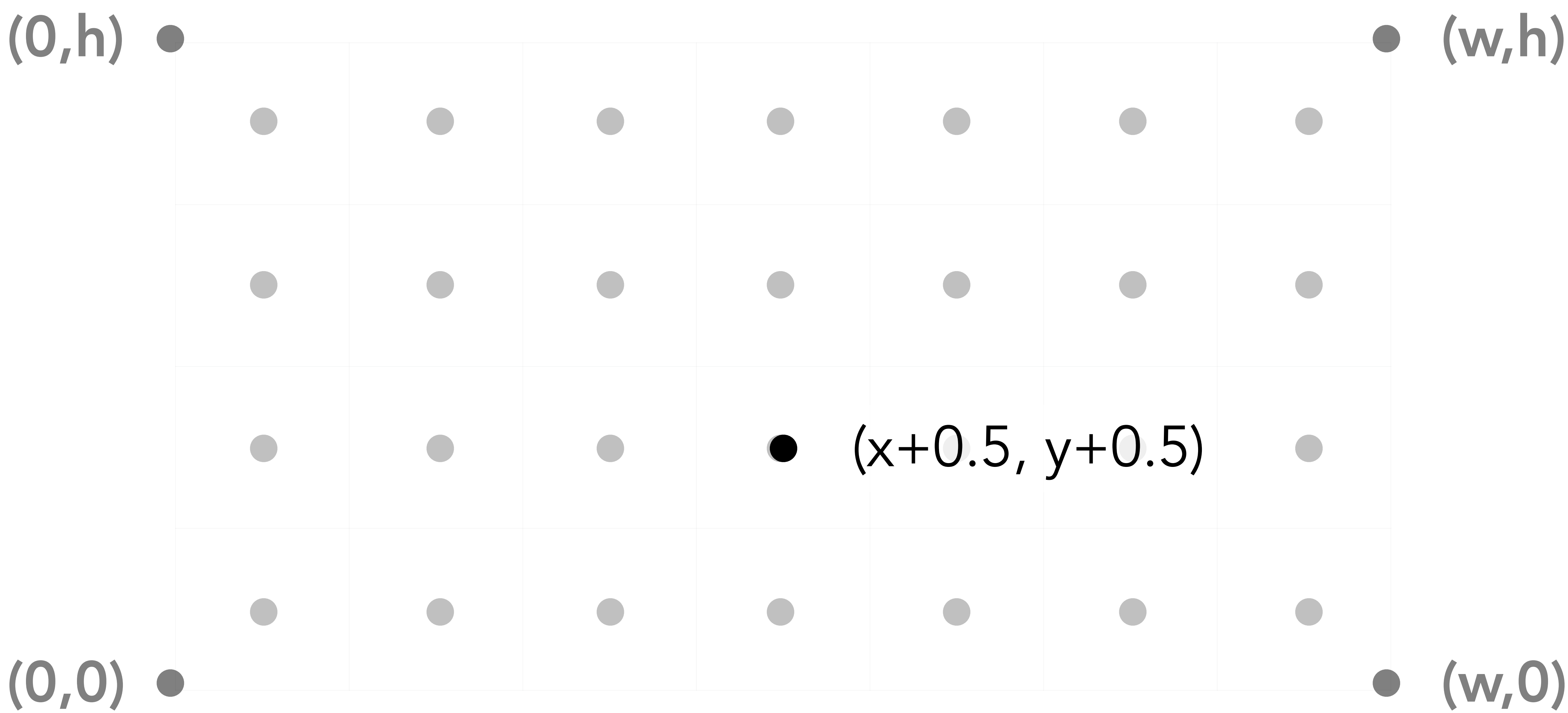


$$\texttt{inside(t, x, y)} = \begin{cases} 1 & \texttt{Point (x, y)} \\ & \texttt{in triangle t} \\ 0 & \texttt{otherwise} \end{cases}$$

Rasterization = Sampling A 2D Indicator Function

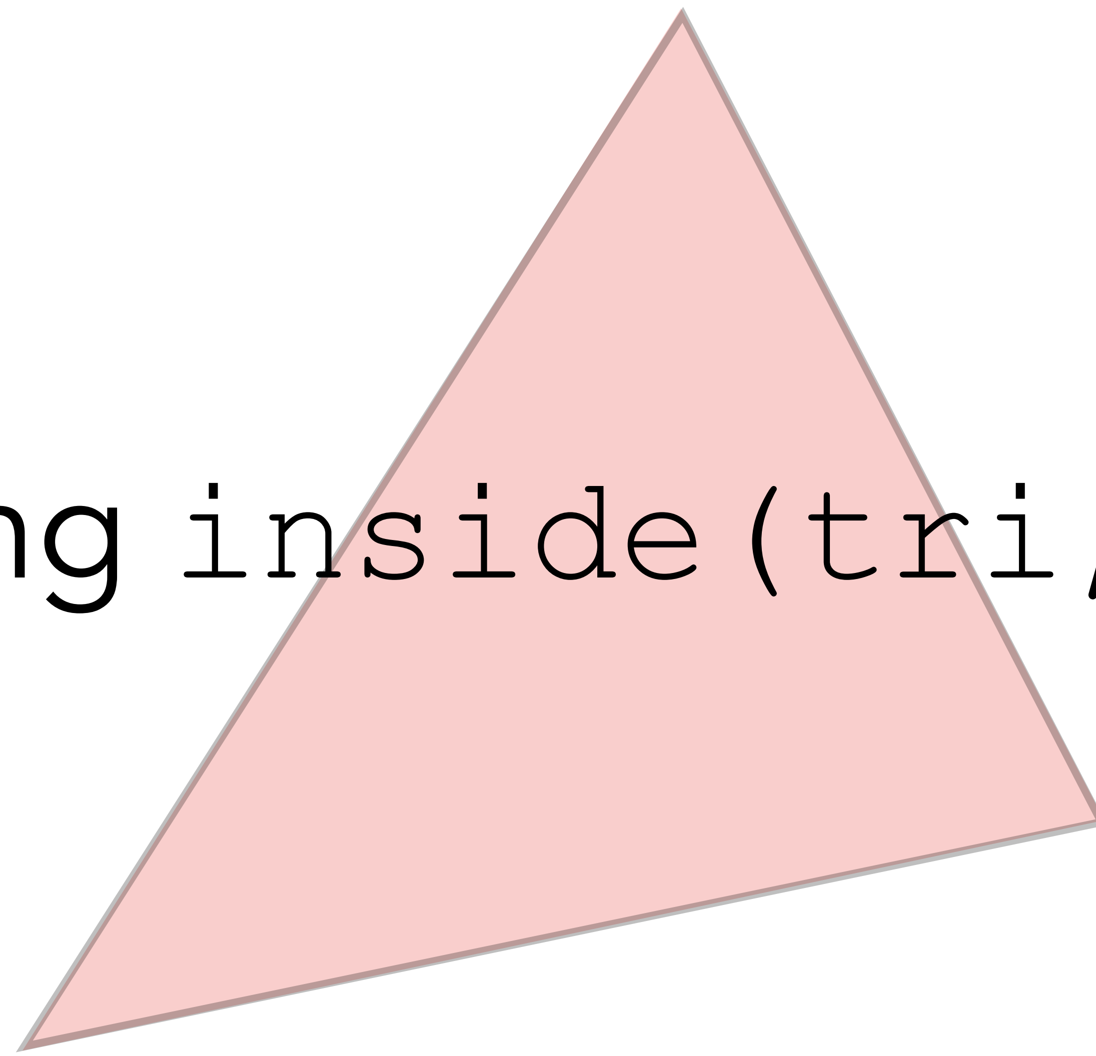
```
for (int x = 0; x < xmax; ++x)
  for (int y = 0; y < ymax; ++y)
    image[x][y] = inside(tri,
                         x + 0.5,
                         y + 0.5);
```

Recall: Sample Locations

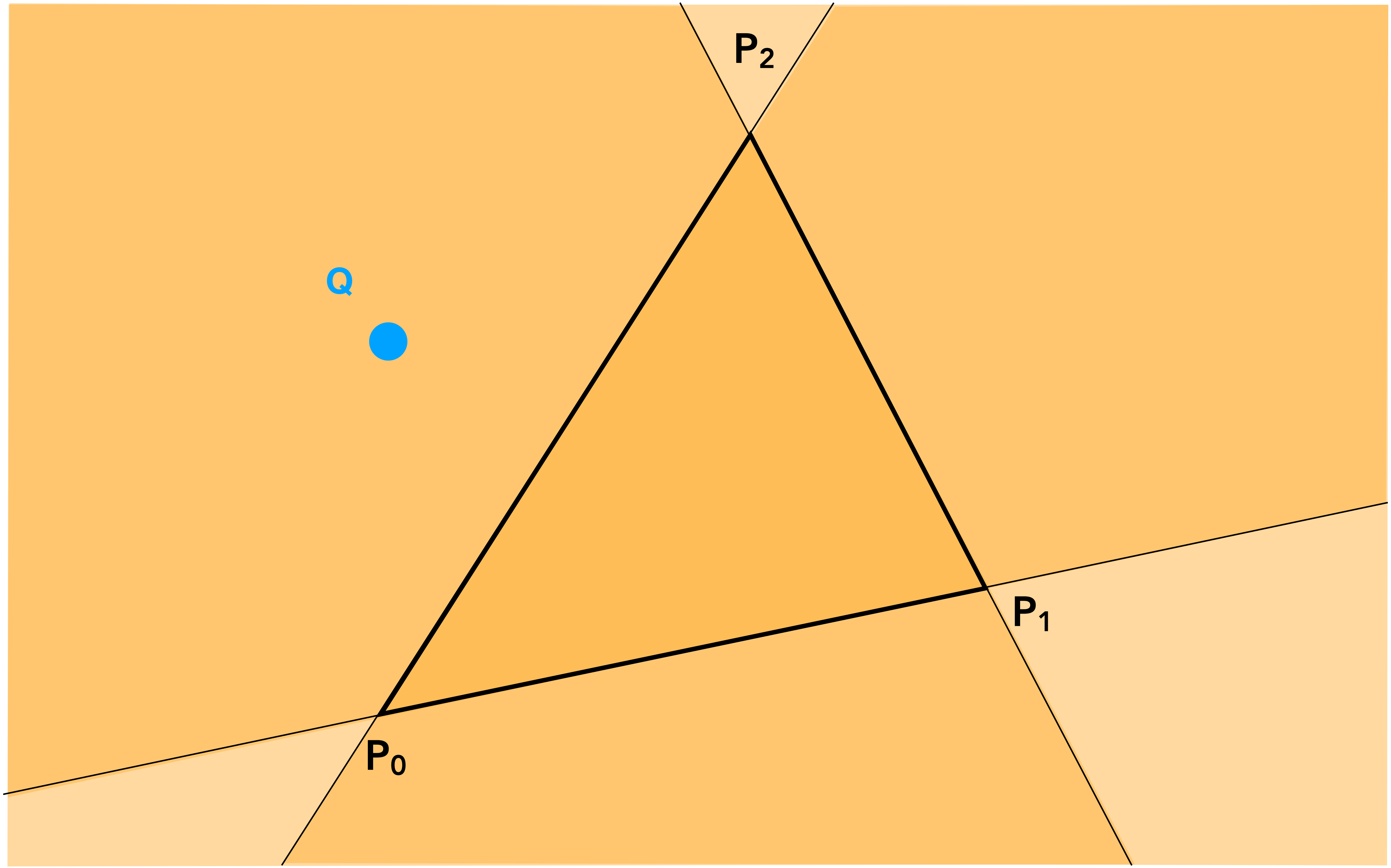


Sample location for pixel (x, y)

Evaluating `inside(tri, x, y)`

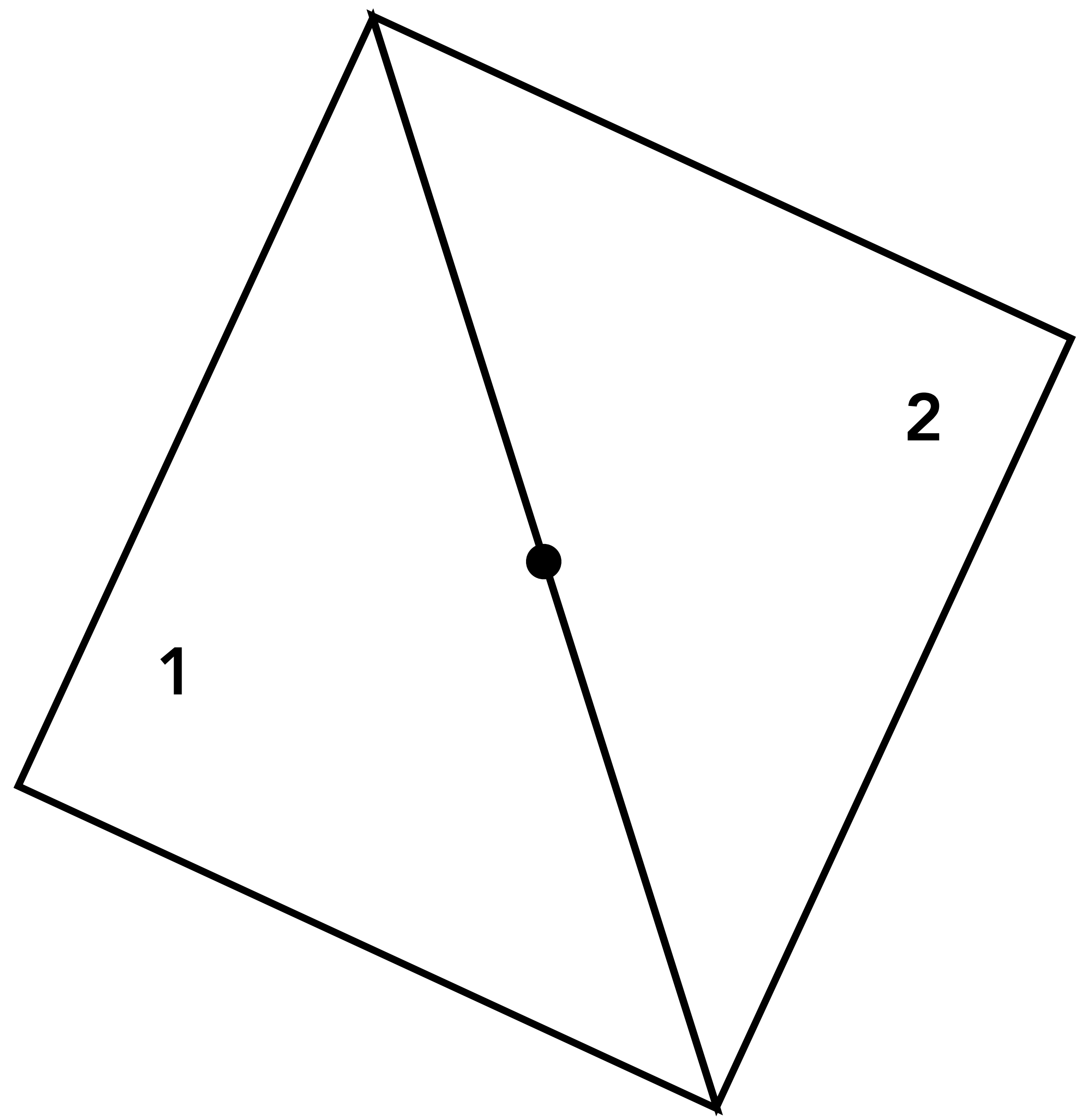


Inside? Recall: Three Cross Products!

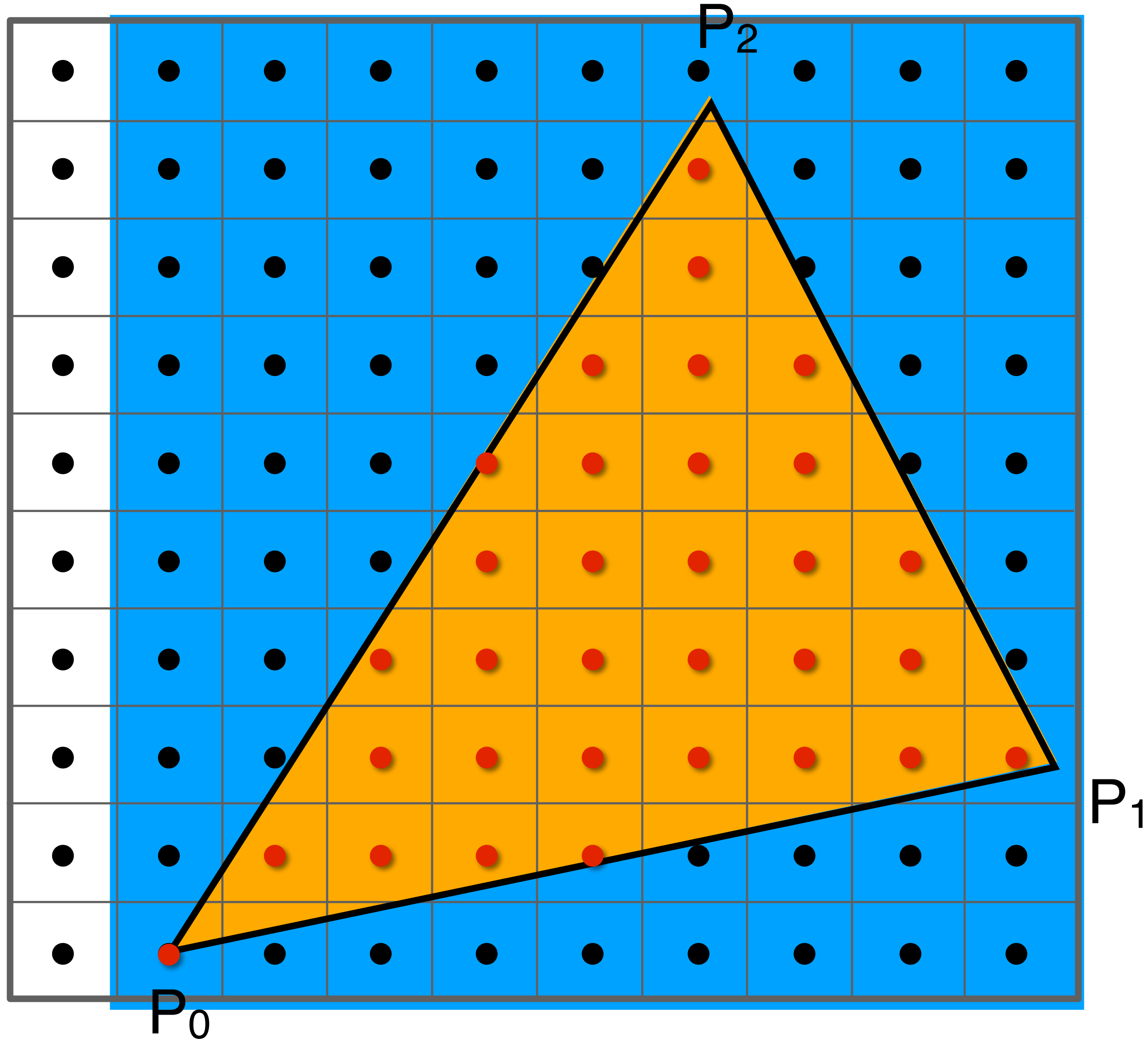


Edge Cases (Literally)

Is this sample point covered by triangle 1, triangle 2, or both?

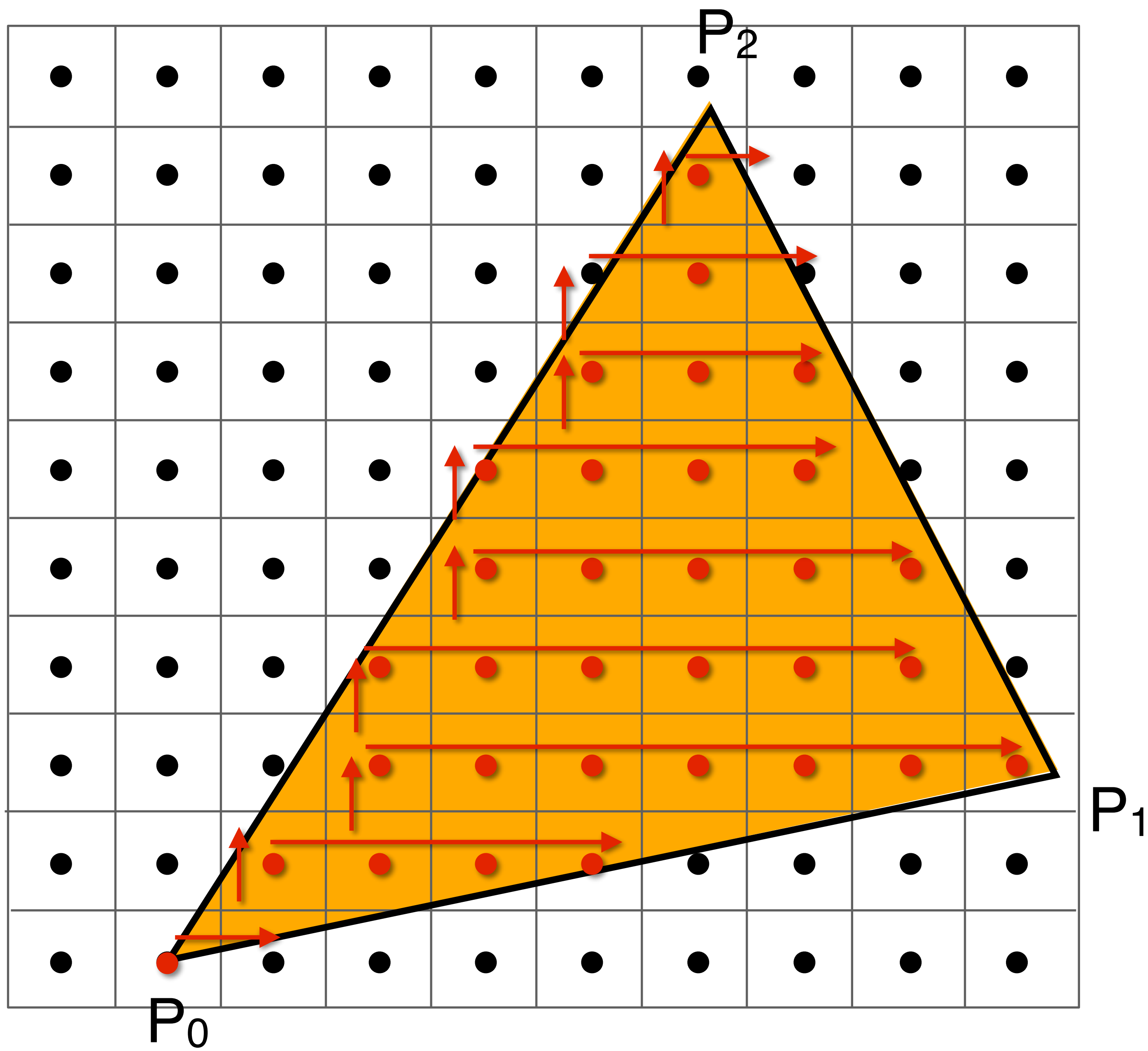


Checking All Pixels on the Screen?



Use a **Bounding Box!**

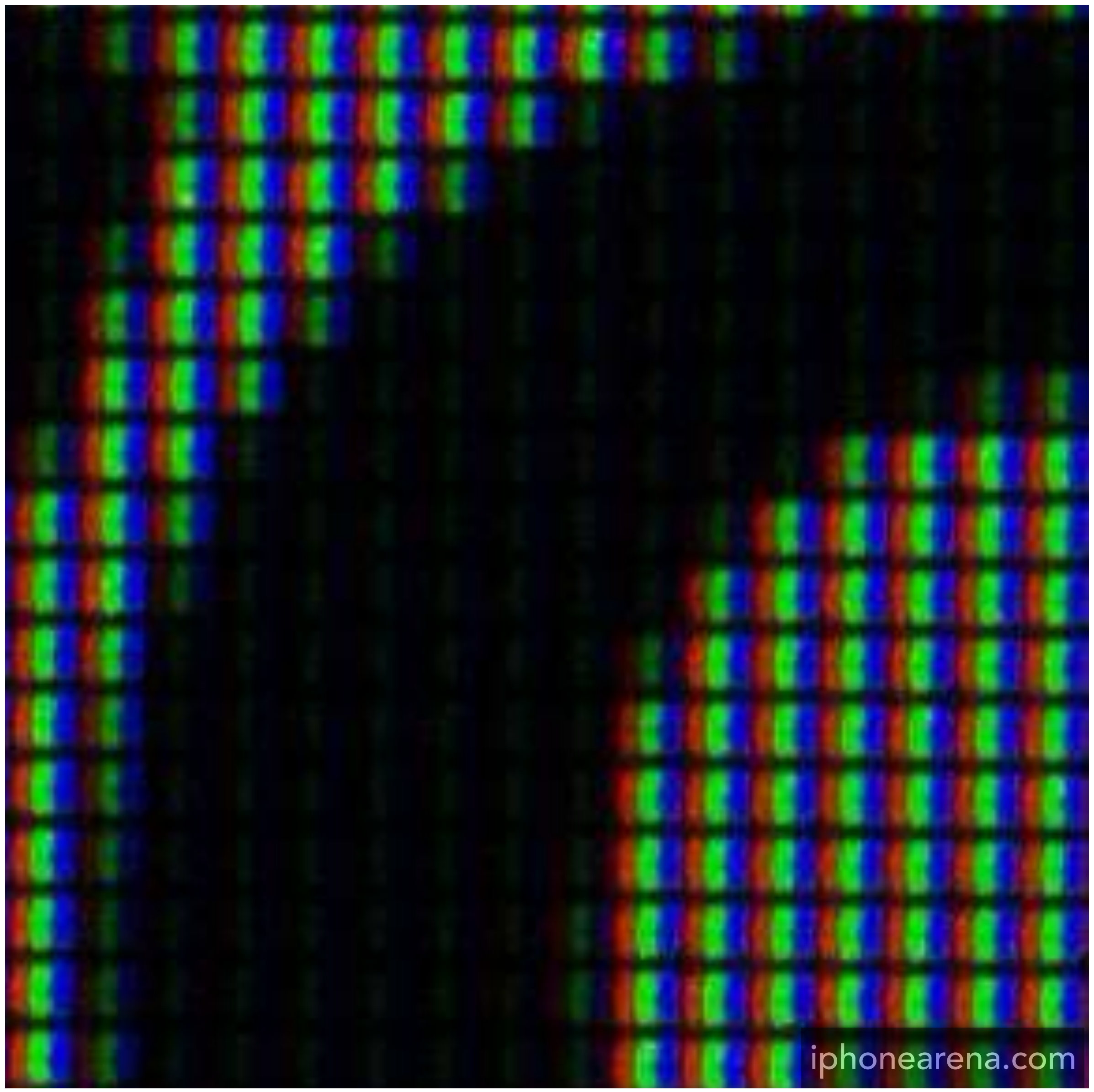
Incremental Triangle Traversal (Faster?)



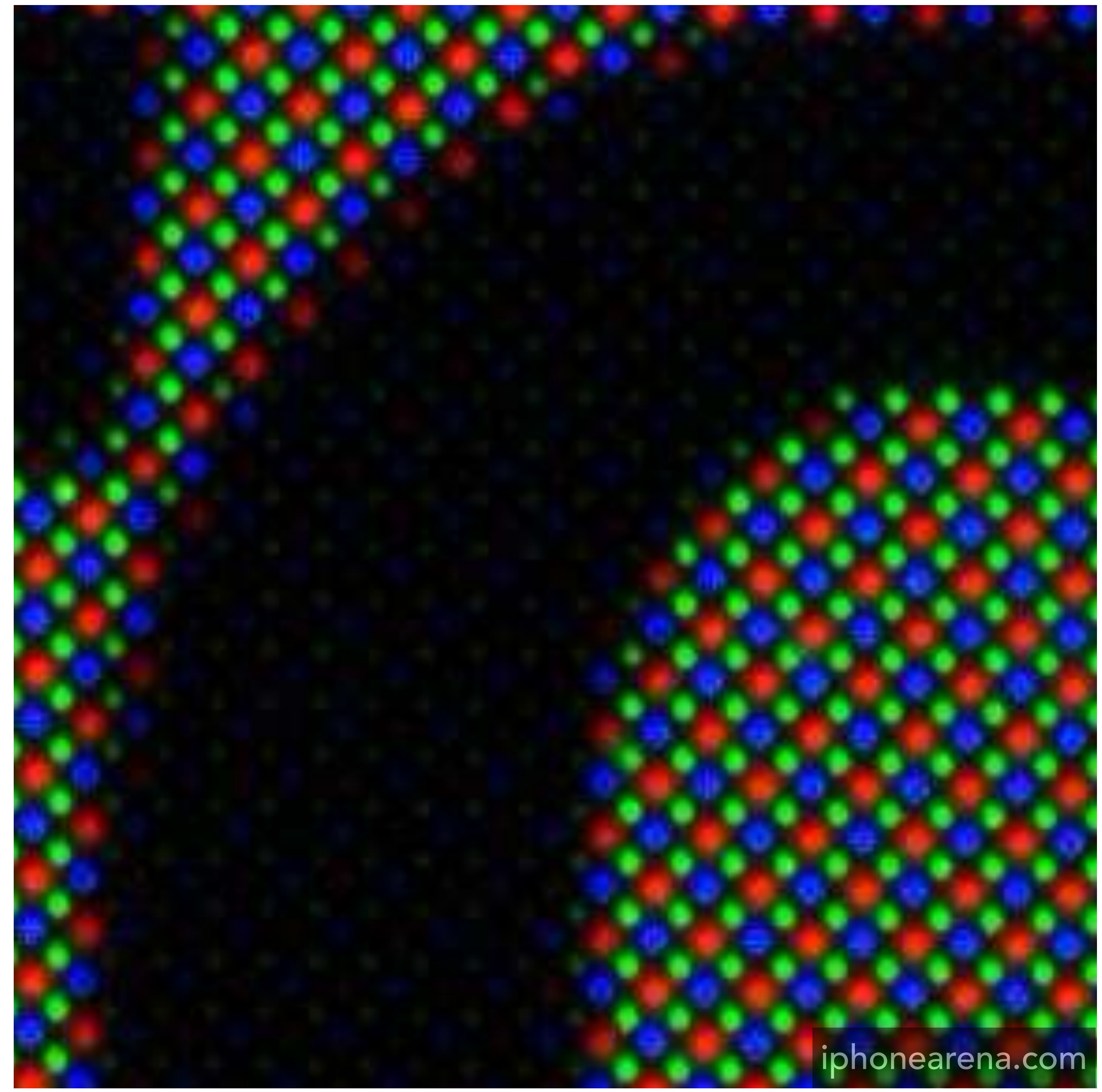
suitable for thin and rotated triangles

Rasterization on Real Displays

Real LCD Screen Pixels (Closeup)



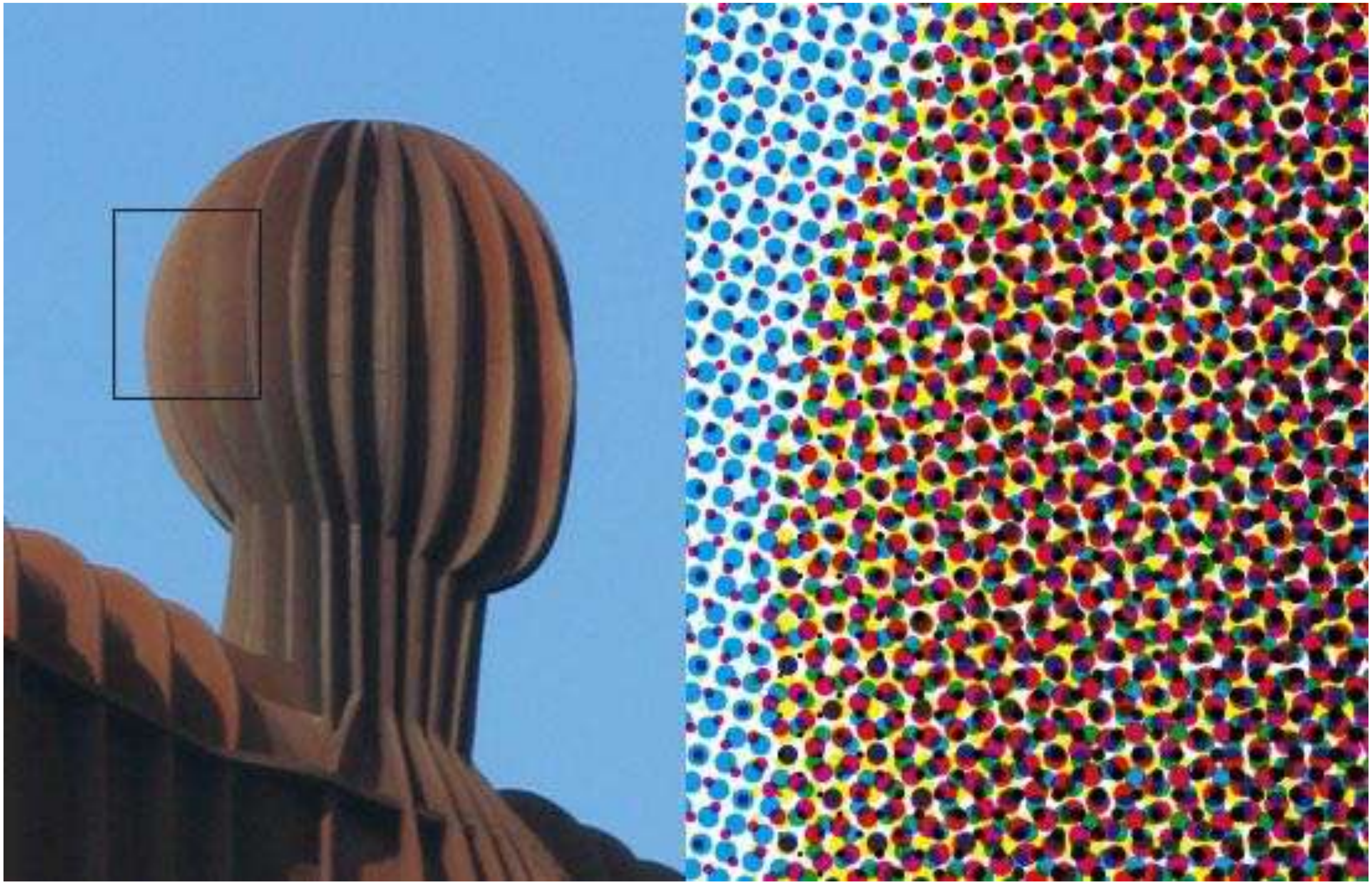
iPhone 6S



Galaxy S5

Notice R,G,B pixel geometry! But in this class, we will assume a colored square full-color pixel.

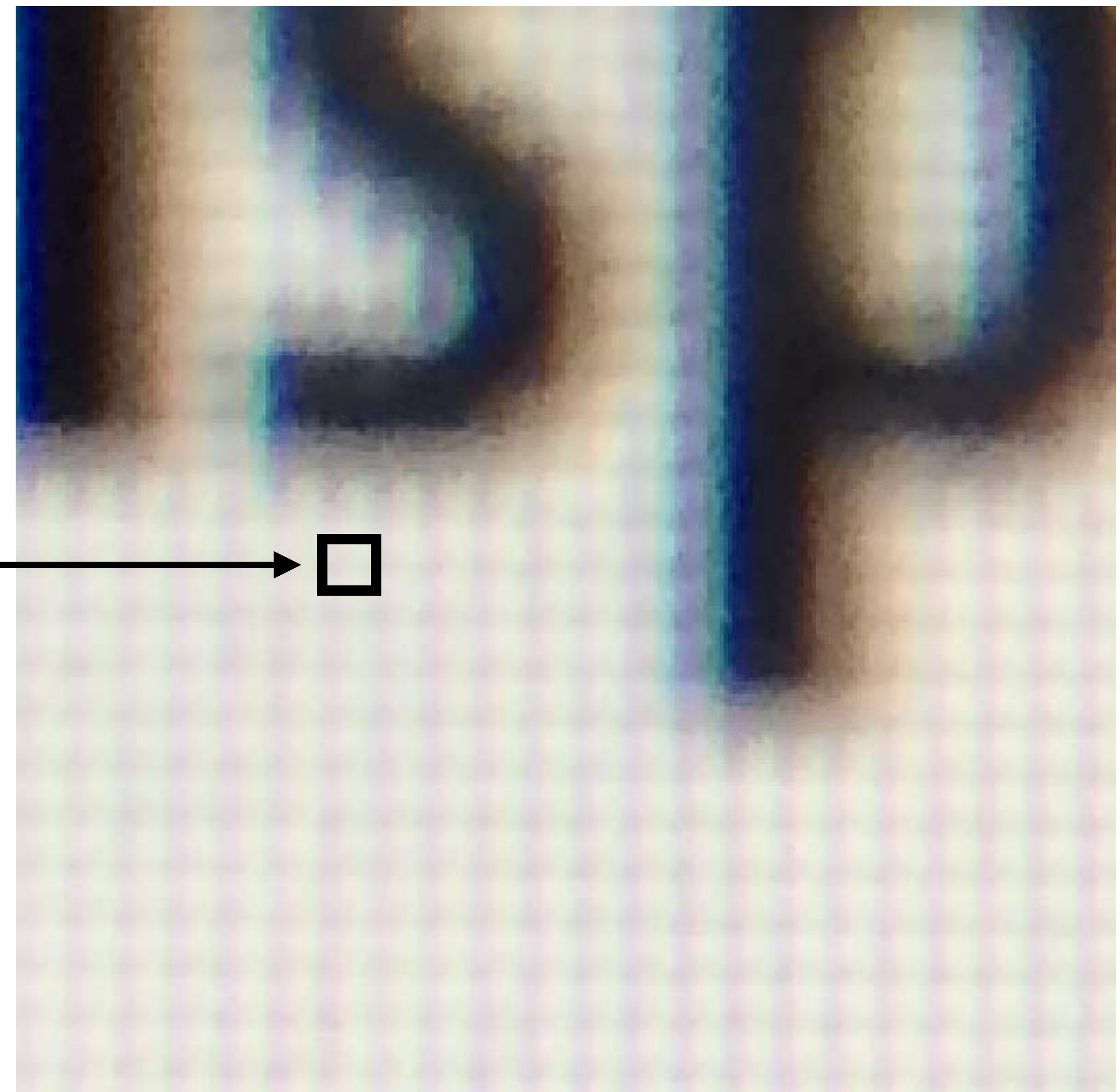
Aside: What About Other Display Methods?



Color print: observe half-tone pattern

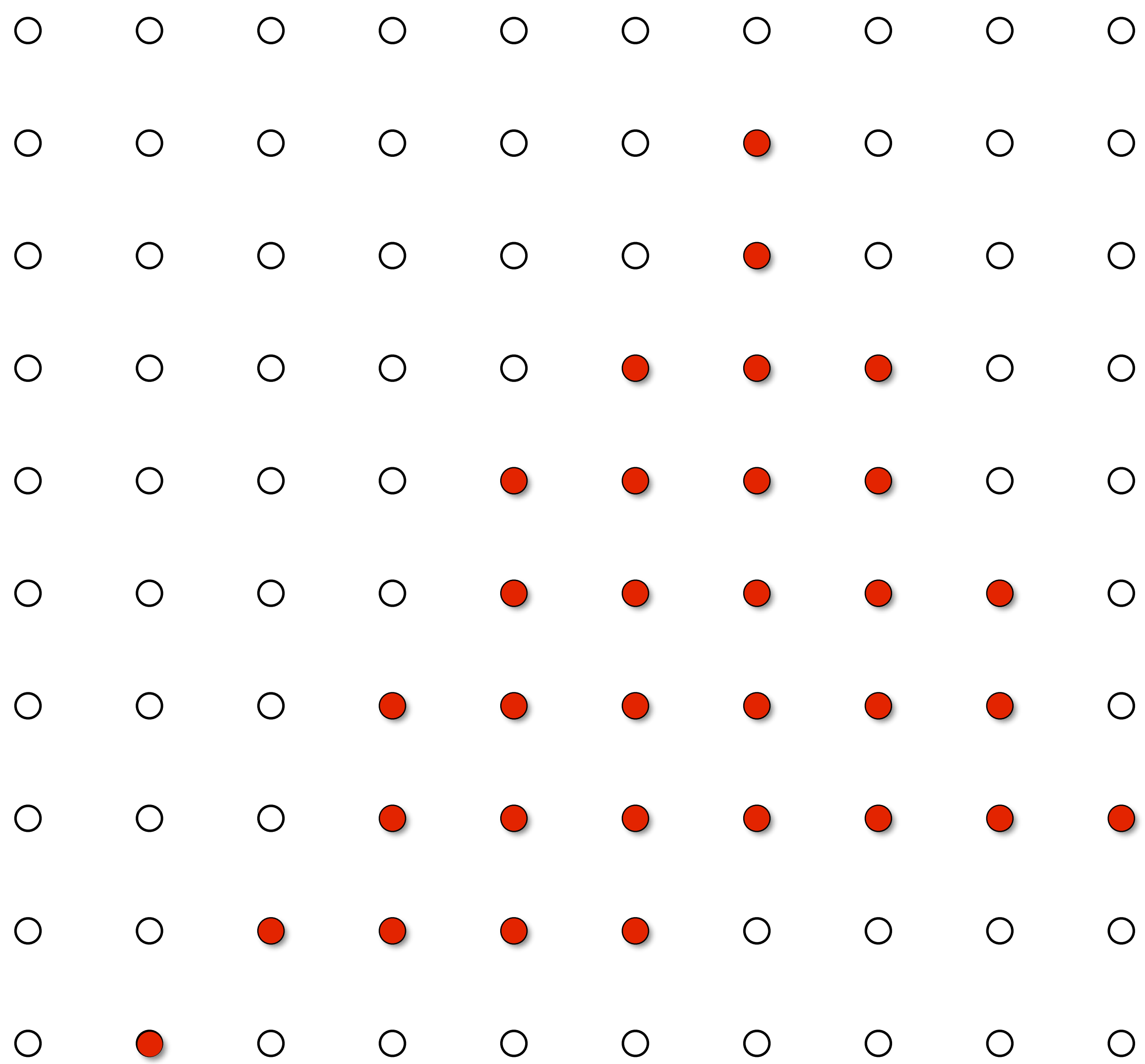
Assume Display Pixels Emit Square of Light

LCD pixel
on laptop

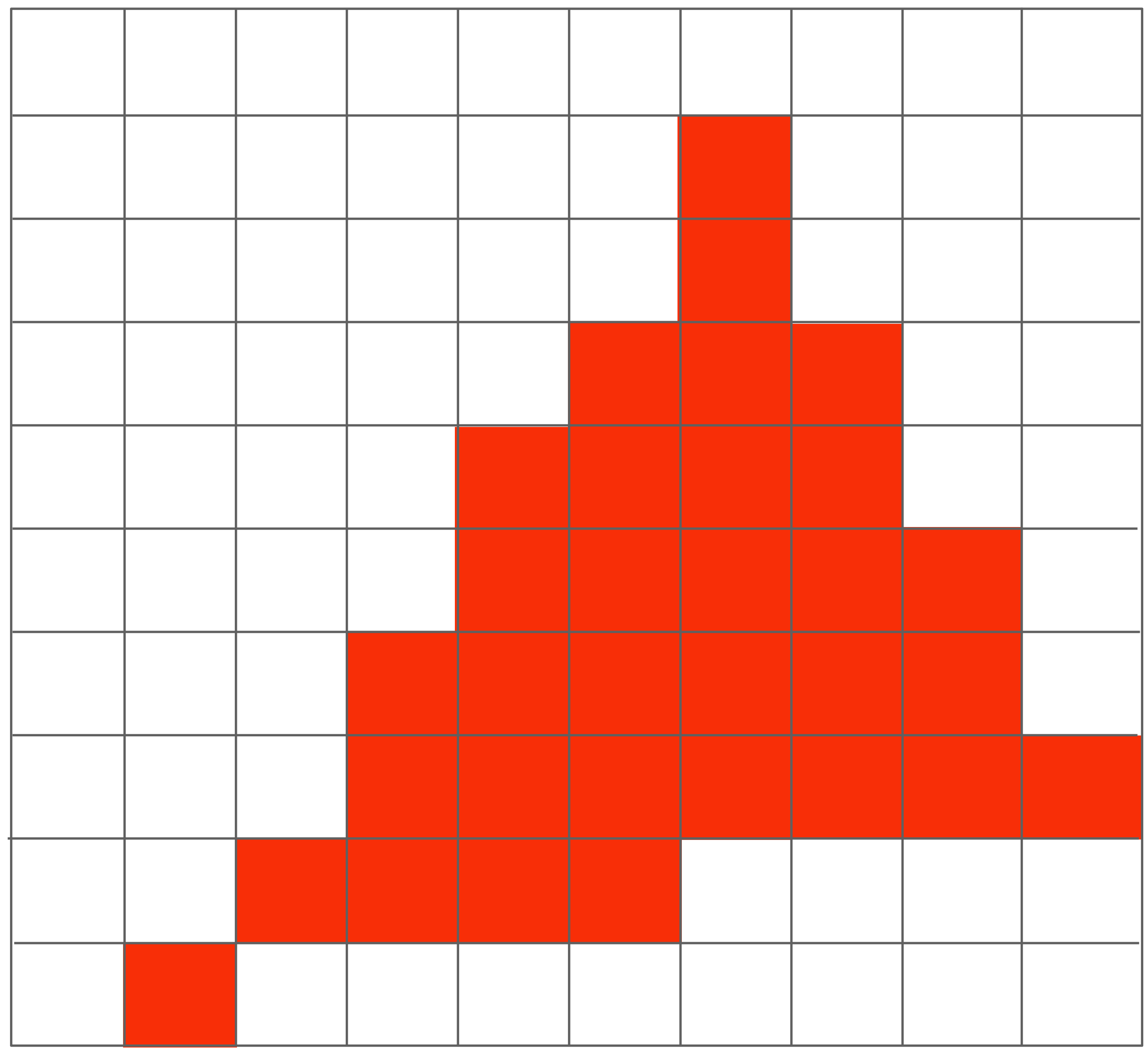


* LCD pixels do not actually emit light in a square of uniform color, but this approximation suffices for our current discussion

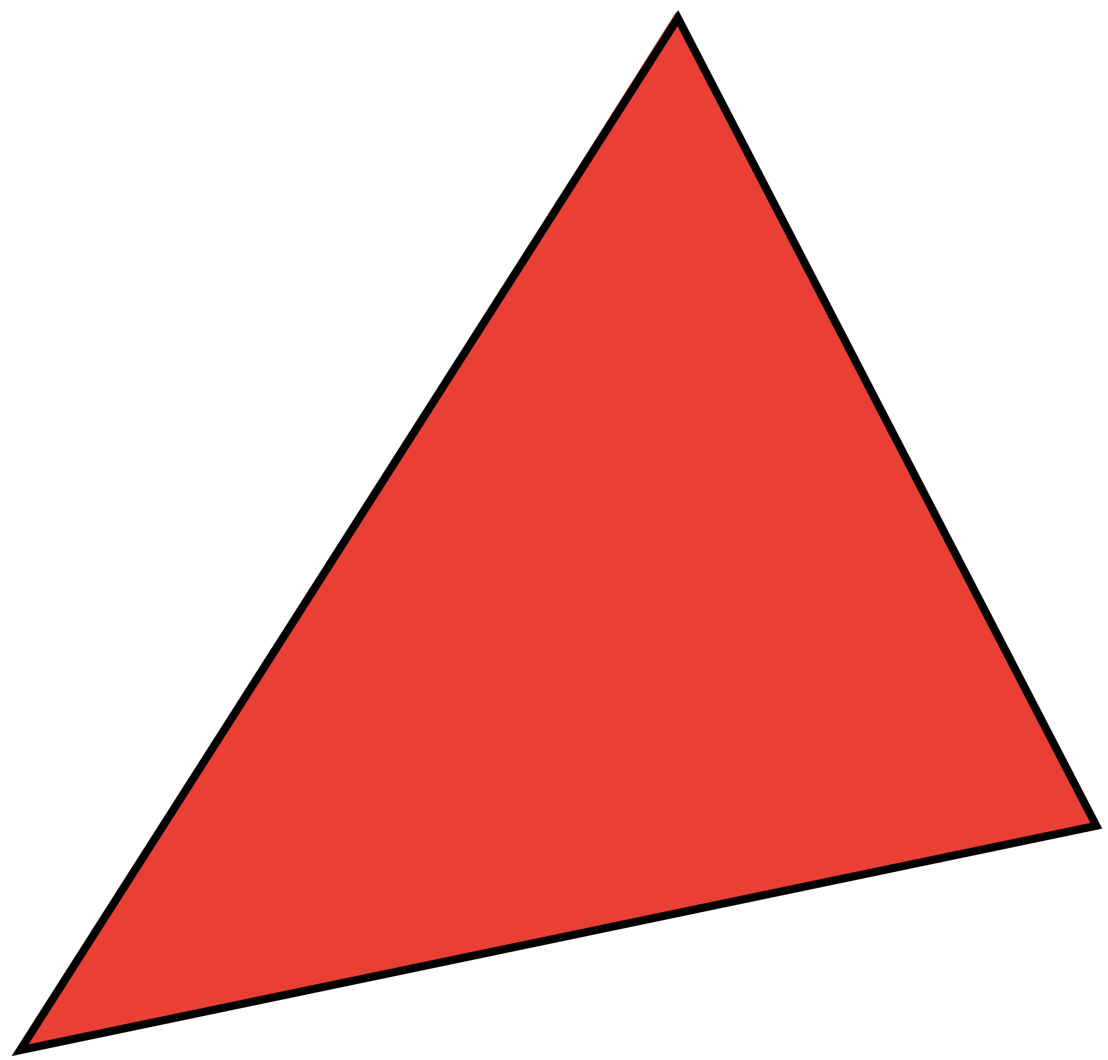
So, If We Send the Display the Sampled Signal



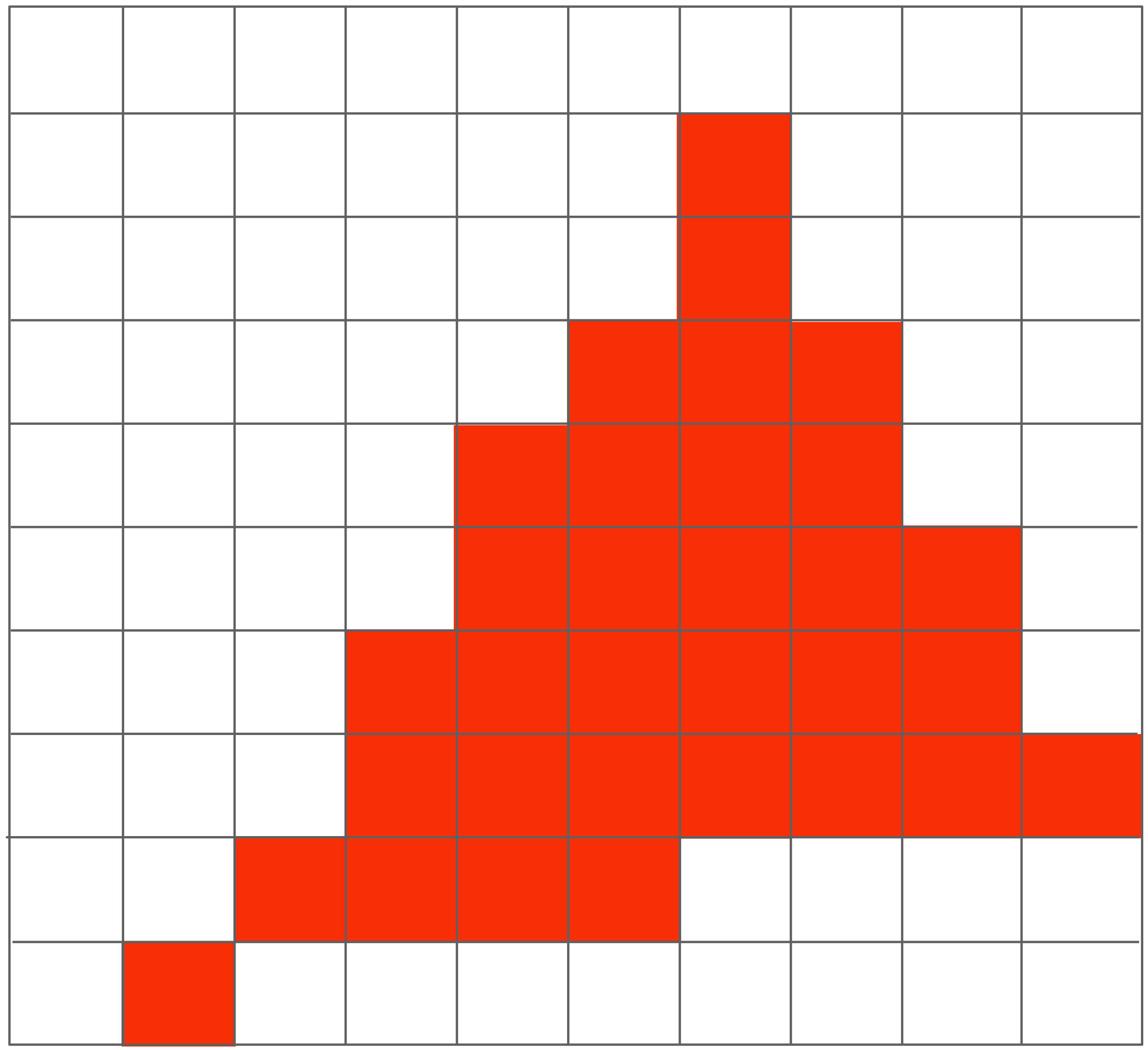
The Display Physically Emits This Signal



Compare: The Continuous Triangle Function

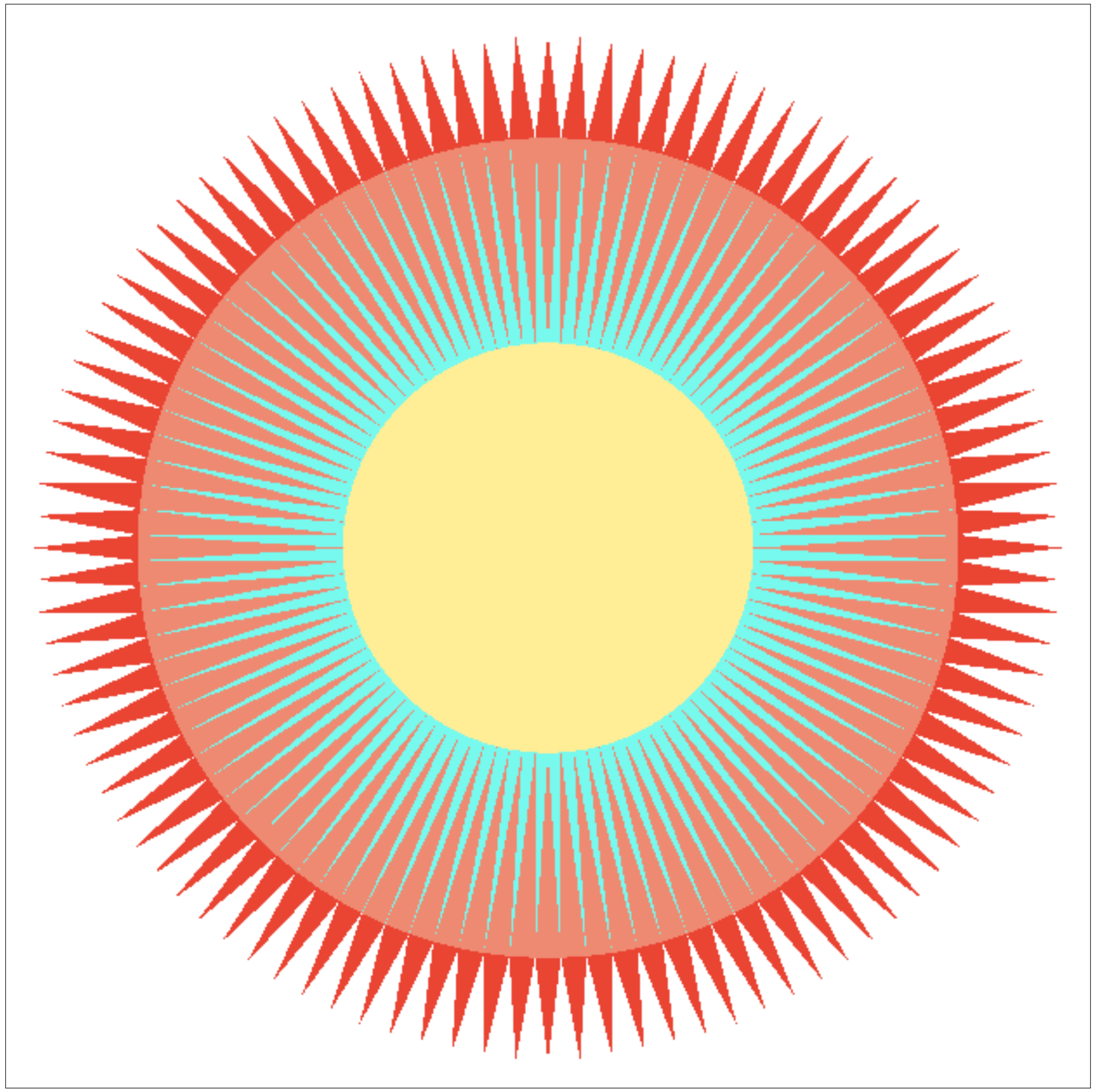


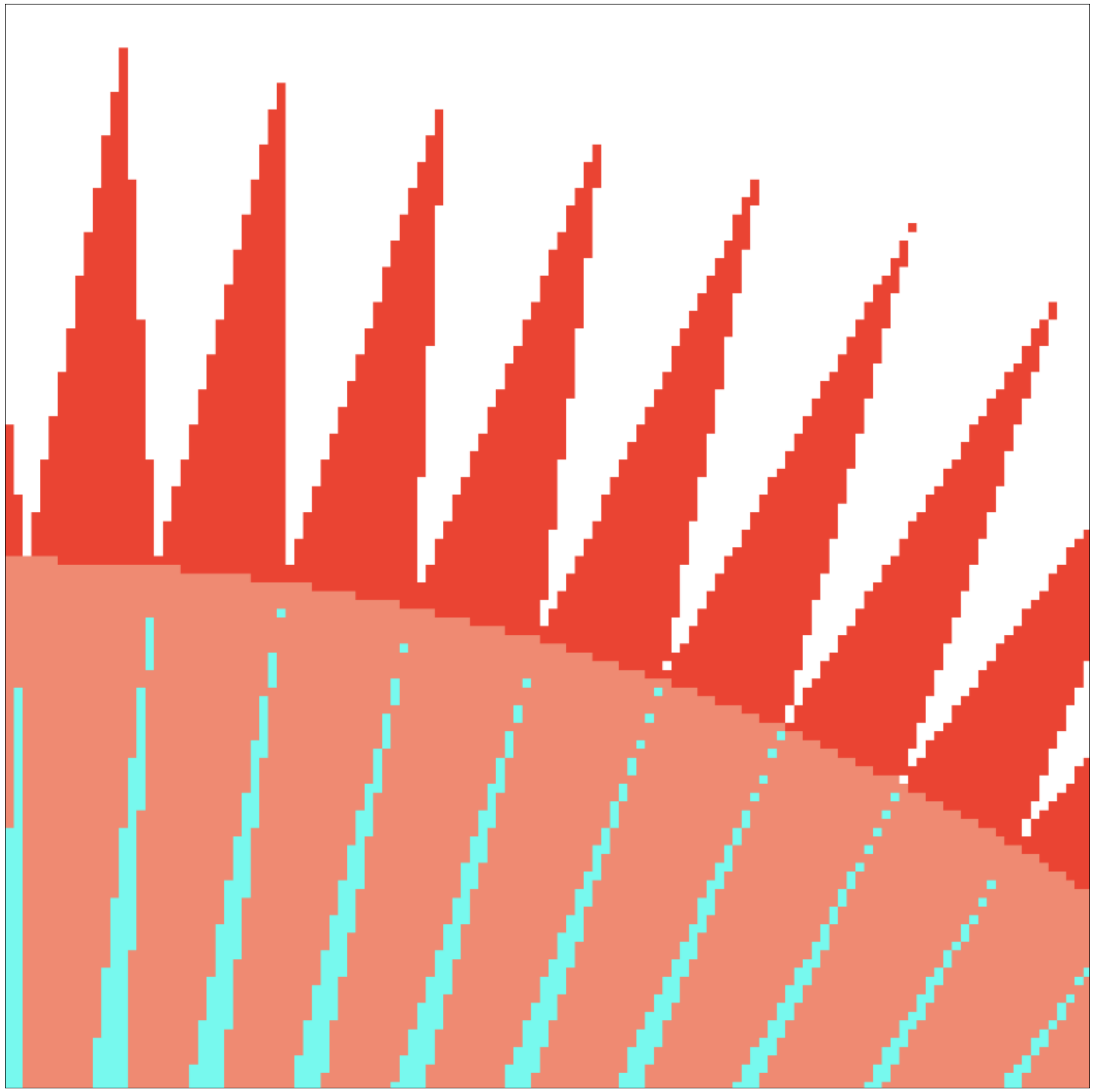
What's Wrong With This Picture?



Jaggies!

Aliasing (Jaggies)





Is this the best we can do?

Thank you!

(And thank Prof. Ravi Ramamoorthi and Prof. Ren Ng for many of the slides!)