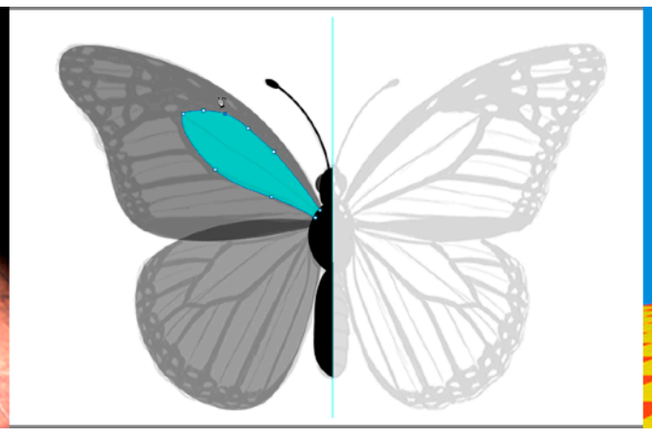
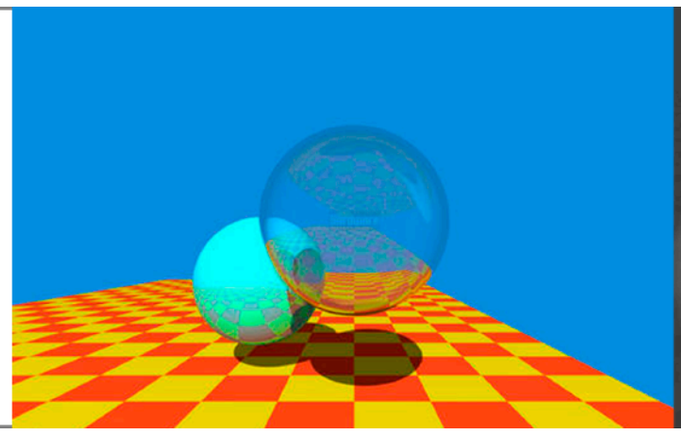
Introduction to Computer Graphics

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

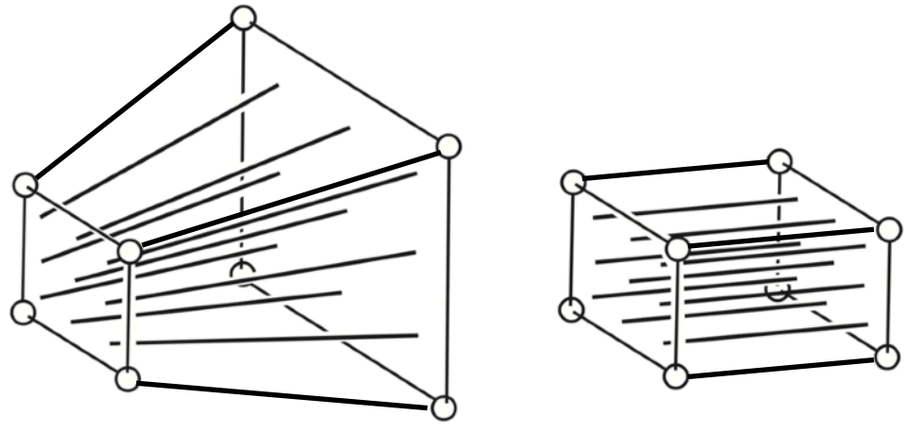
Today

- Finishing up Viewing
  - Viewport transformation
- Rasterization
  - Different raster displays
  - Rasterizing a triangle
- Occlusions and Visibility **遮挡和可见性**

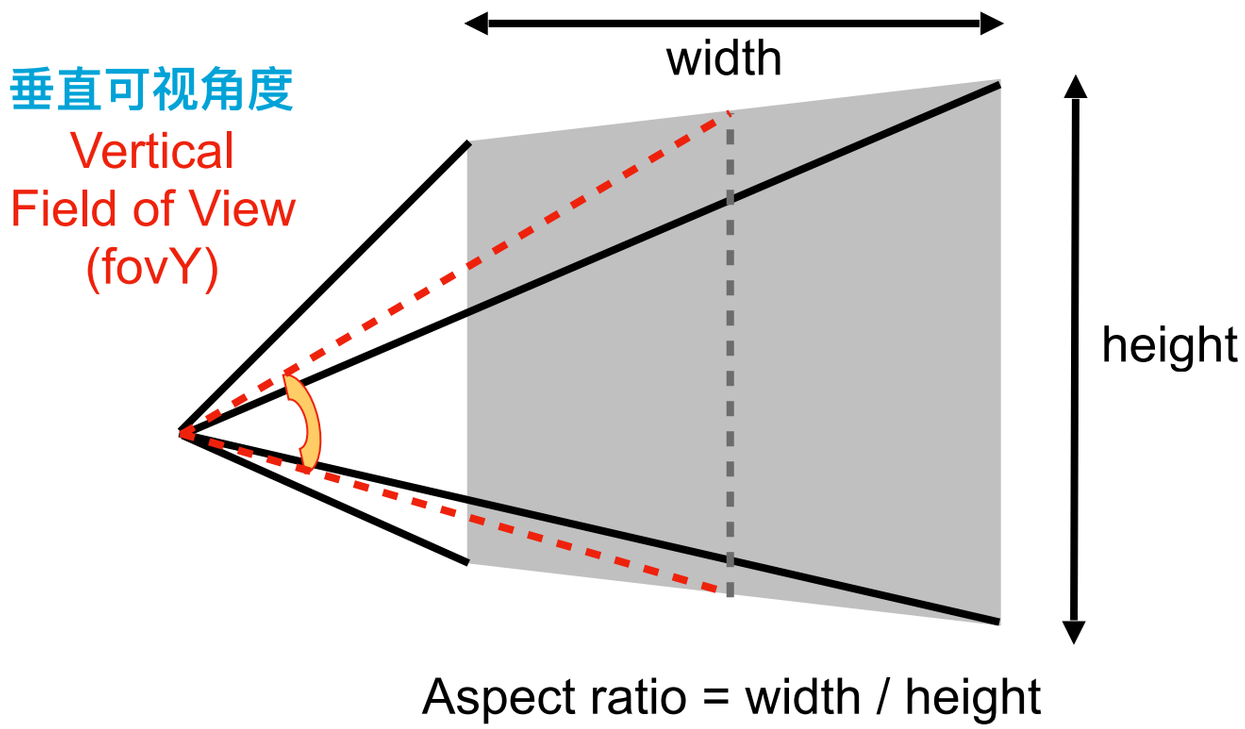
Perspective Projection

如何定义Frustum?

- 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** 长宽比



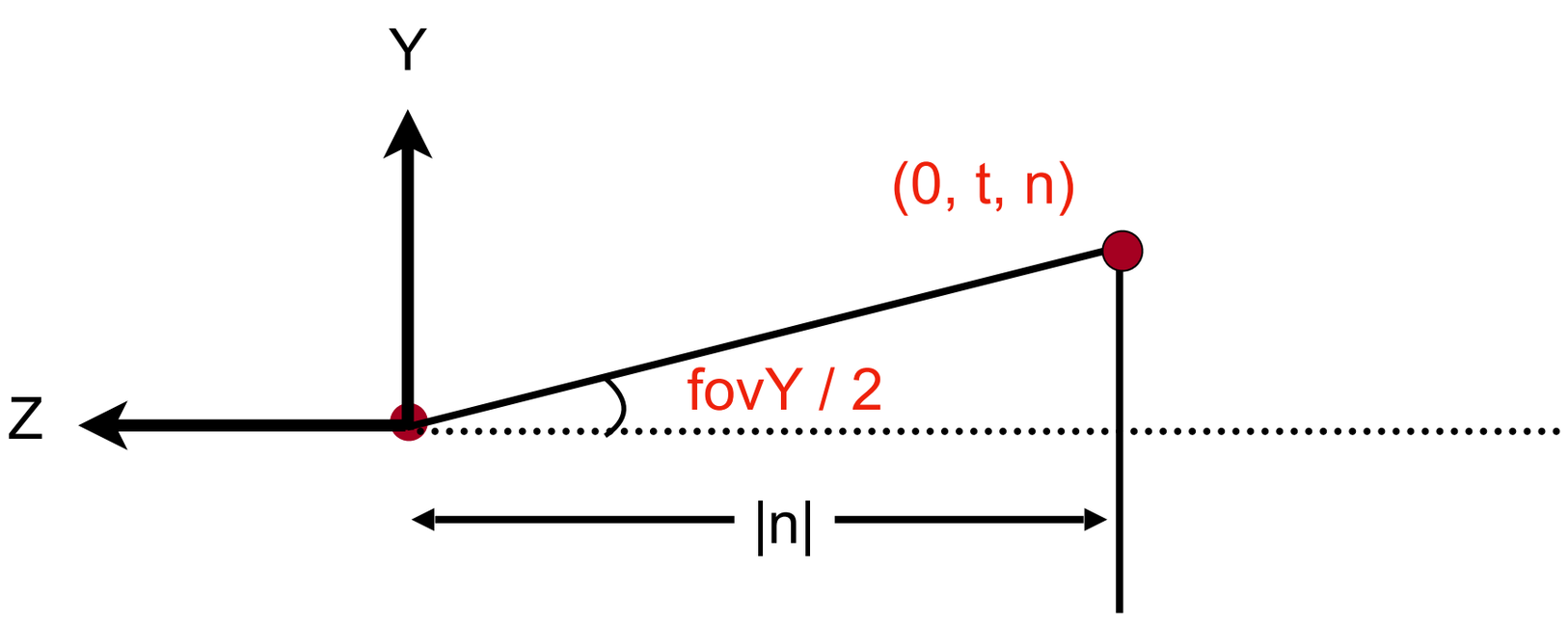
(assume symmetry i.e. l = -r, b = -t)



Perspective Projection

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

给定fovY，aspect，可以确定一个Frustum



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

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

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 ?

得到了在canonical cube的投影，那么这个cube应该画在哪里?

Canonical Cube to Screen

- What is a screen? 定义屏幕为二维数组
  - An array of pixels 像素组成的矩阵
  - Size of the array: resolution 屏幕的大小（实际是像素的多少）：分辨率
  - A typical kind of raster display 屏幕是典型的光栅成像设备

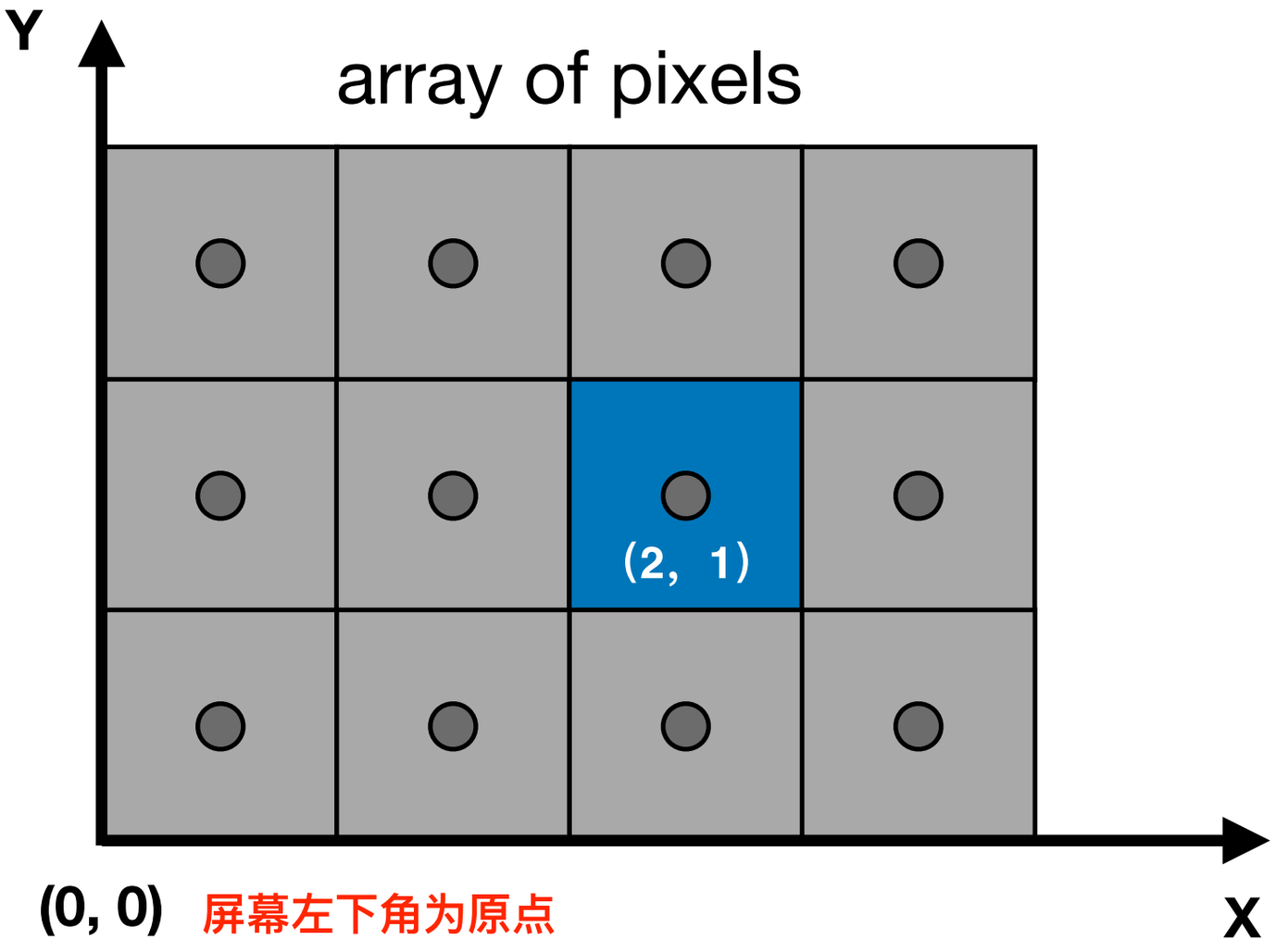
- Raster == screen in German
  - Rasterize == drawing onto the screen

- Pixel (FYI, short for “picture element”)
  - For now: A pixel is a little square with uniform color
    本课：像素是小方块，每个小方块只有一个颜色
  - Color is a mixture of (red, green, blue)

Canonical Cube to Screen

屏幕空间：在屏幕建立坐标系

- 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

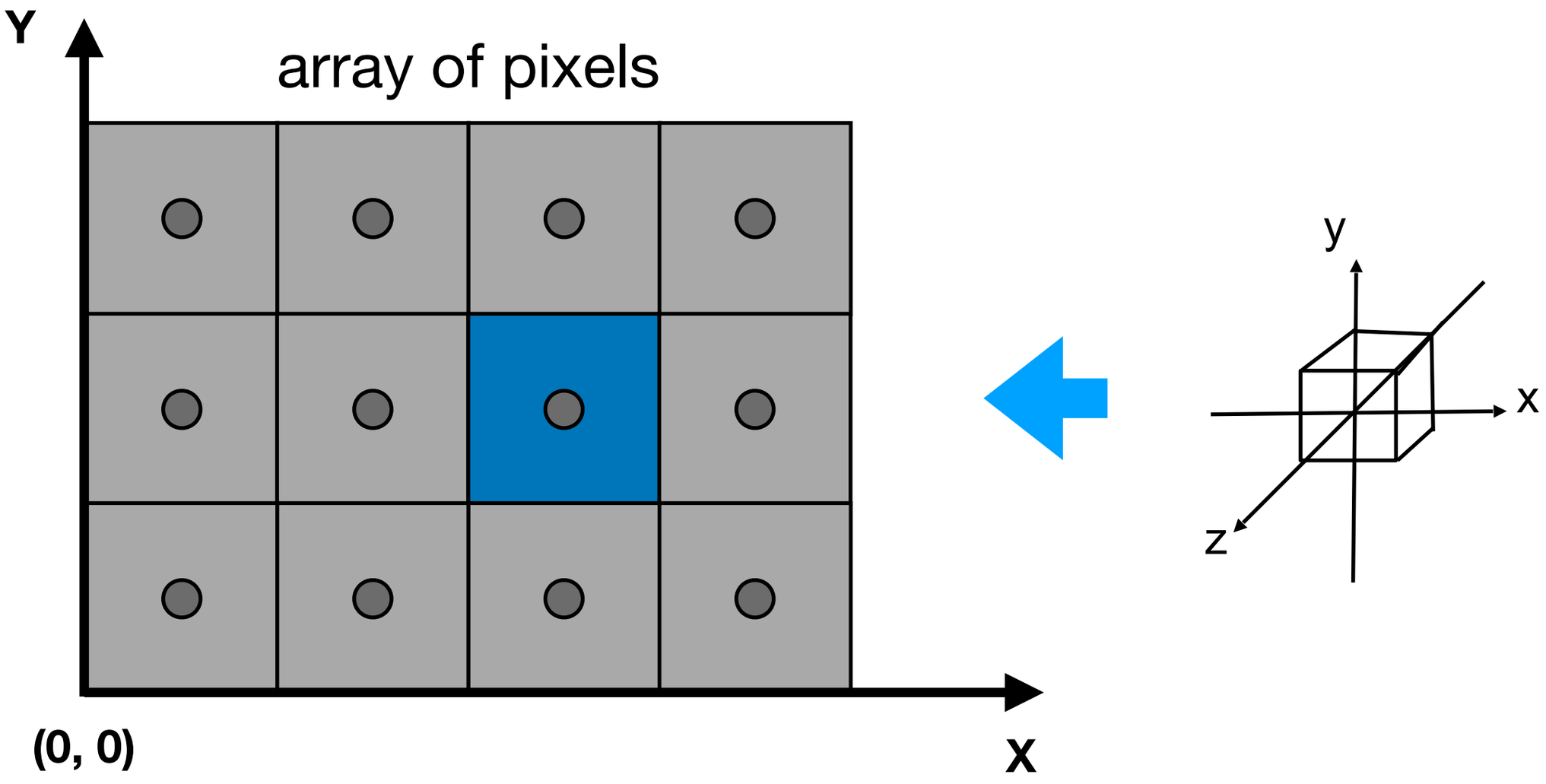
Pixels’ indices are from
(0, 0) to (width - 1, height - 1)

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:

视口变换

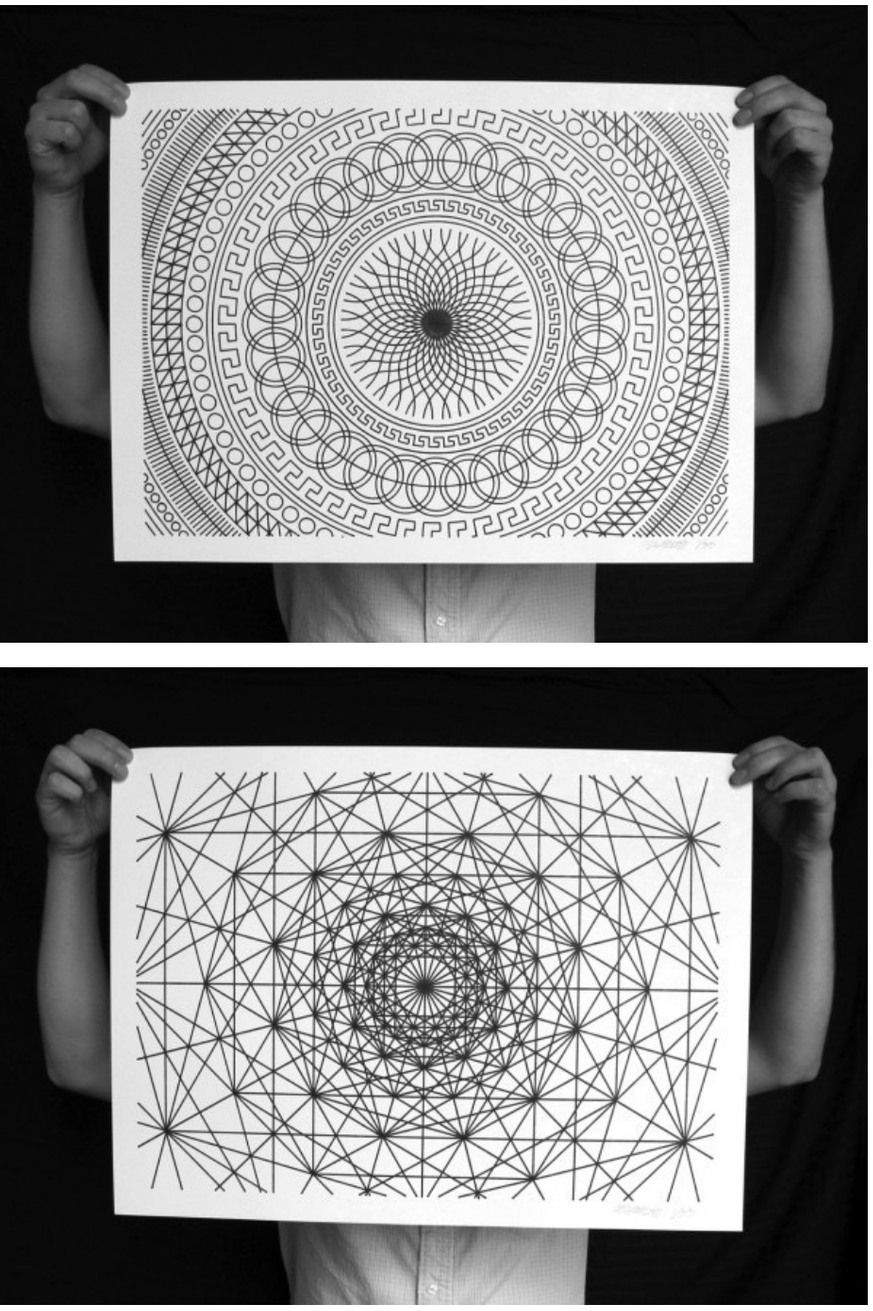
现在屏幕的左下角是原点，所以有平移量

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

Next: Rasterizing Triangles into Pixels

Drawing Machines

CNC Sharpie Drawing Machine



Aaron Panone with Matt W. Moore

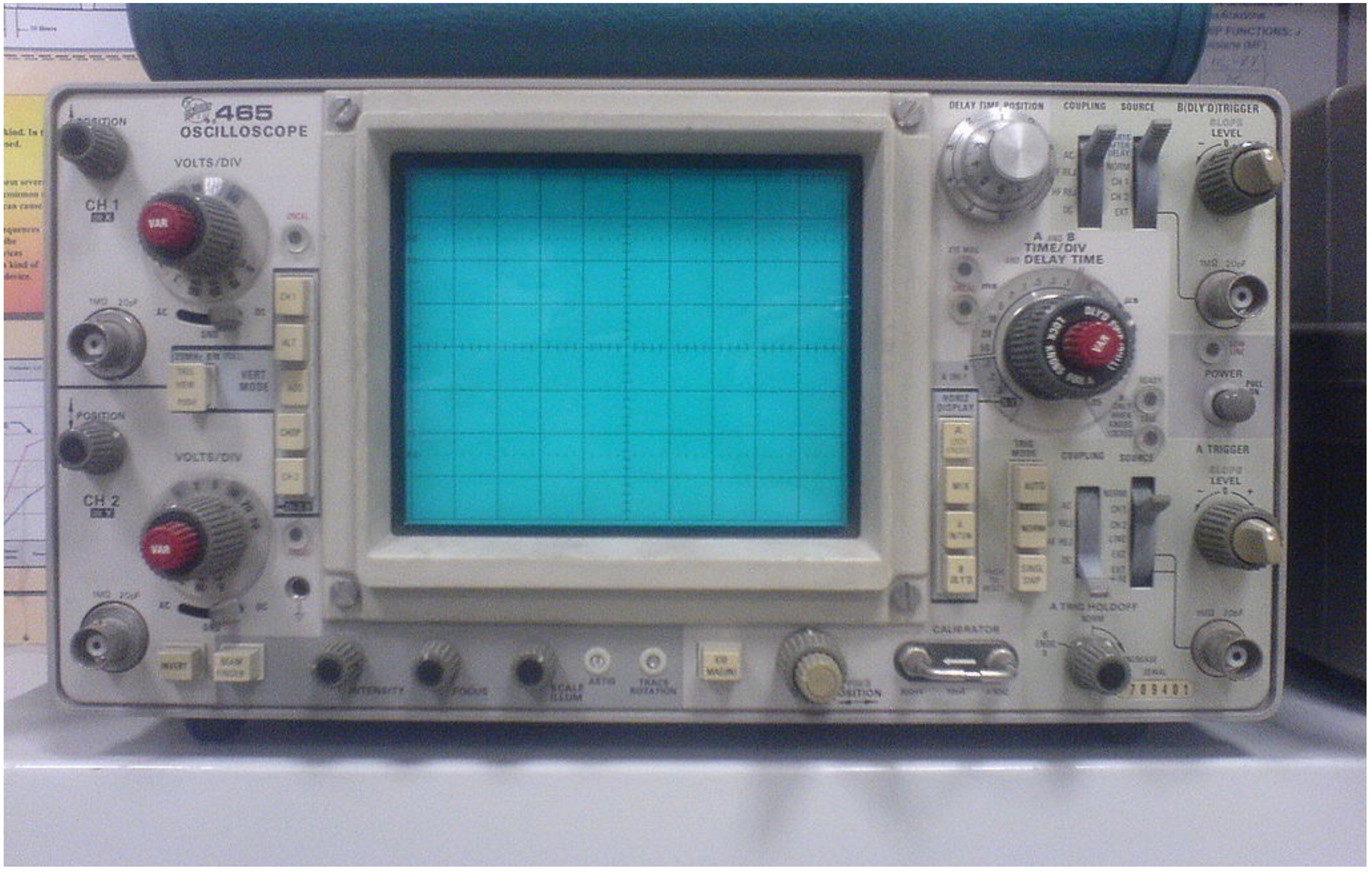
http://44rn.com/projects/numerically-controlled-poster-series-with-matt-w-moore/

Laser Cutters

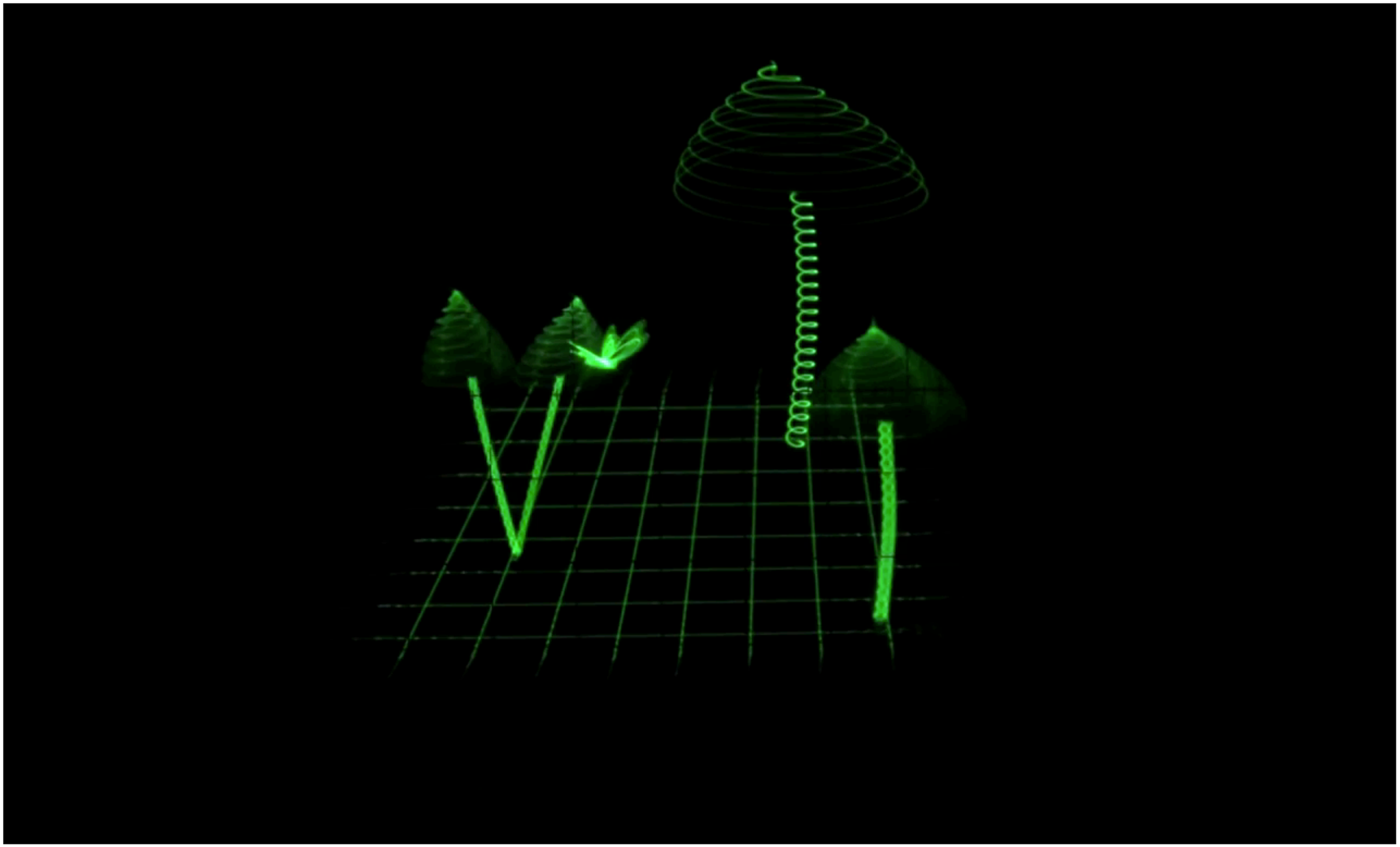
Different Raster Displays

一些成像设备简介

Oscilloscope



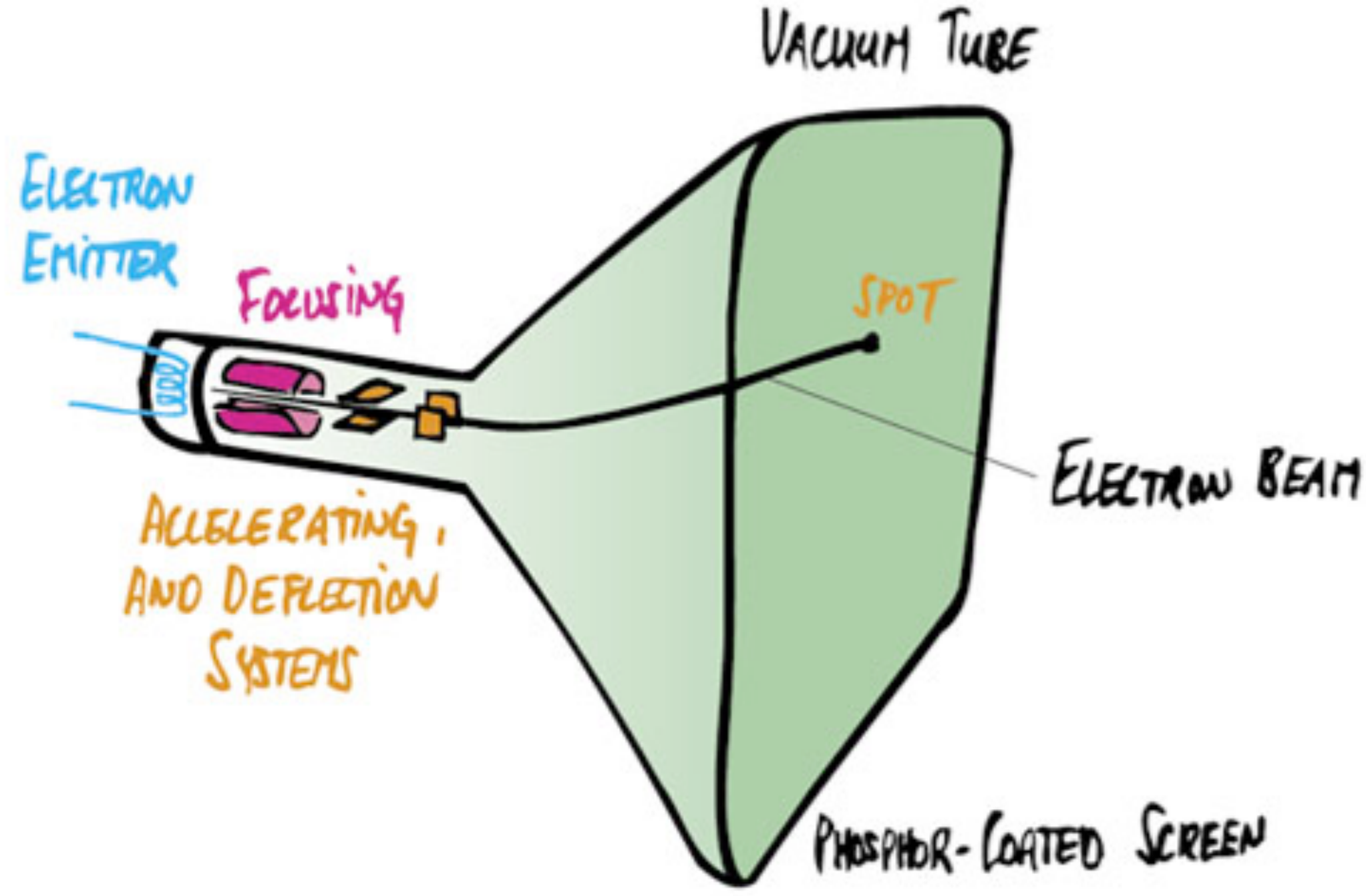
Oscilloscope Art



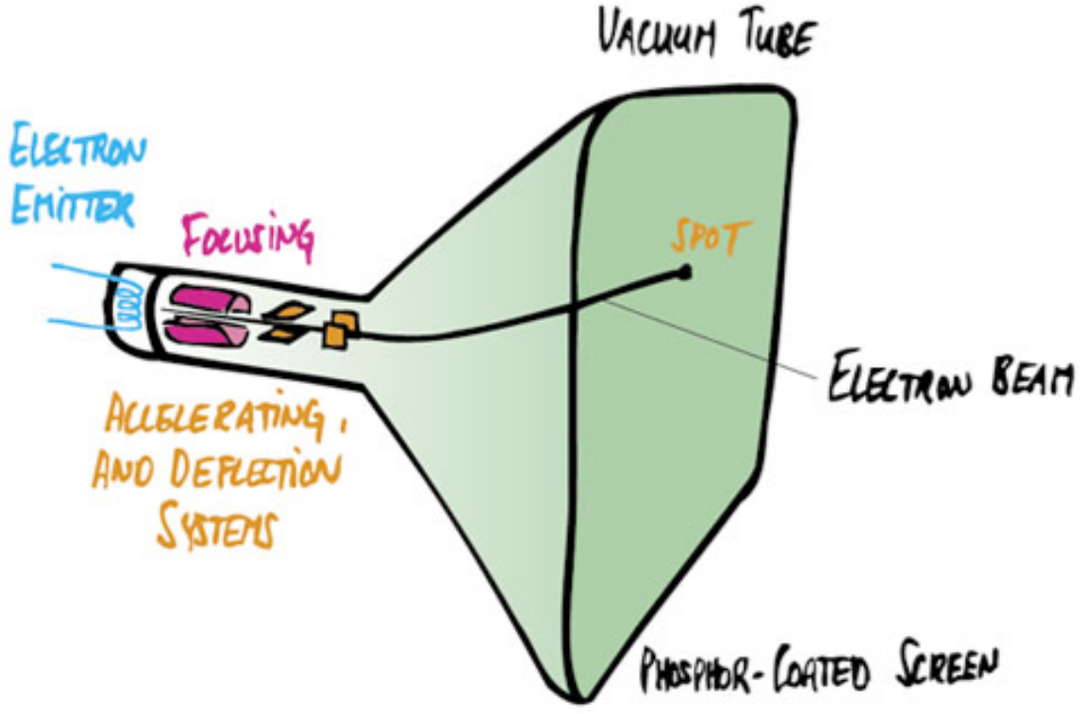
Jerobeam Fenderson

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

Cathode Ray Tube

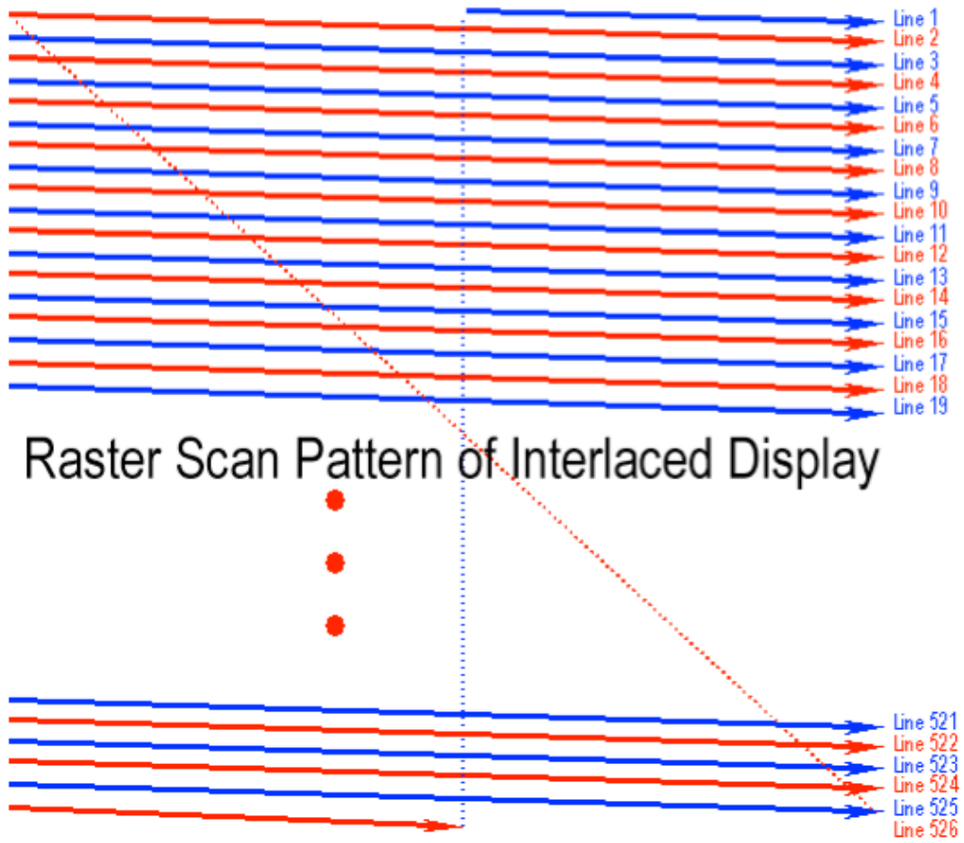


Television - Raster Display CRT



Cathode Ray Tube

隔行扫描技术： 单数行+双数行



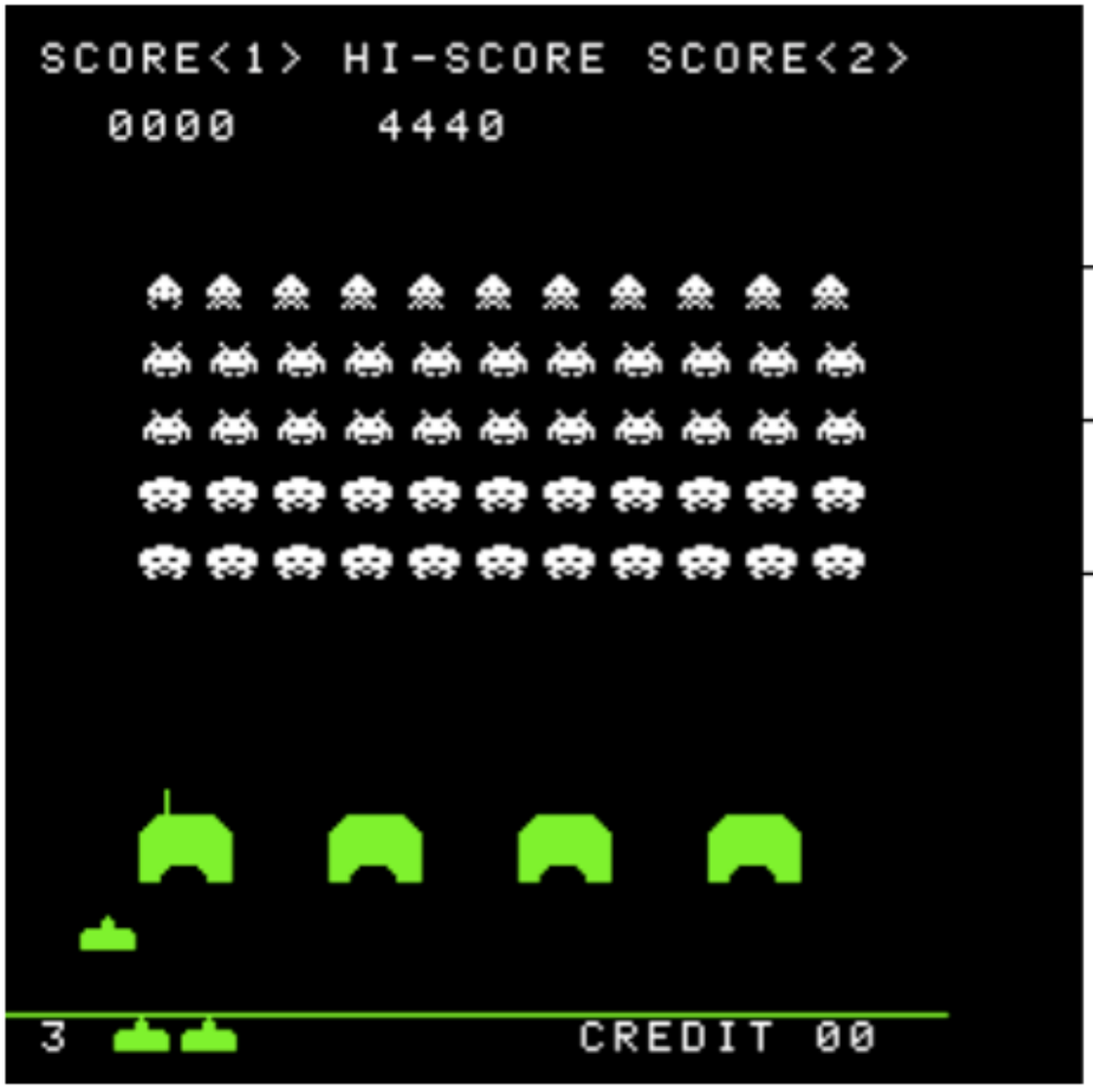
画面撕裂（高速画面）

Raster Scan

(modulate intensity)

Frame Buffer: Memory for a Raster Display

显示的图像是（显卡）内存中的一块区域



DAC =
Digital to Analog Convertors

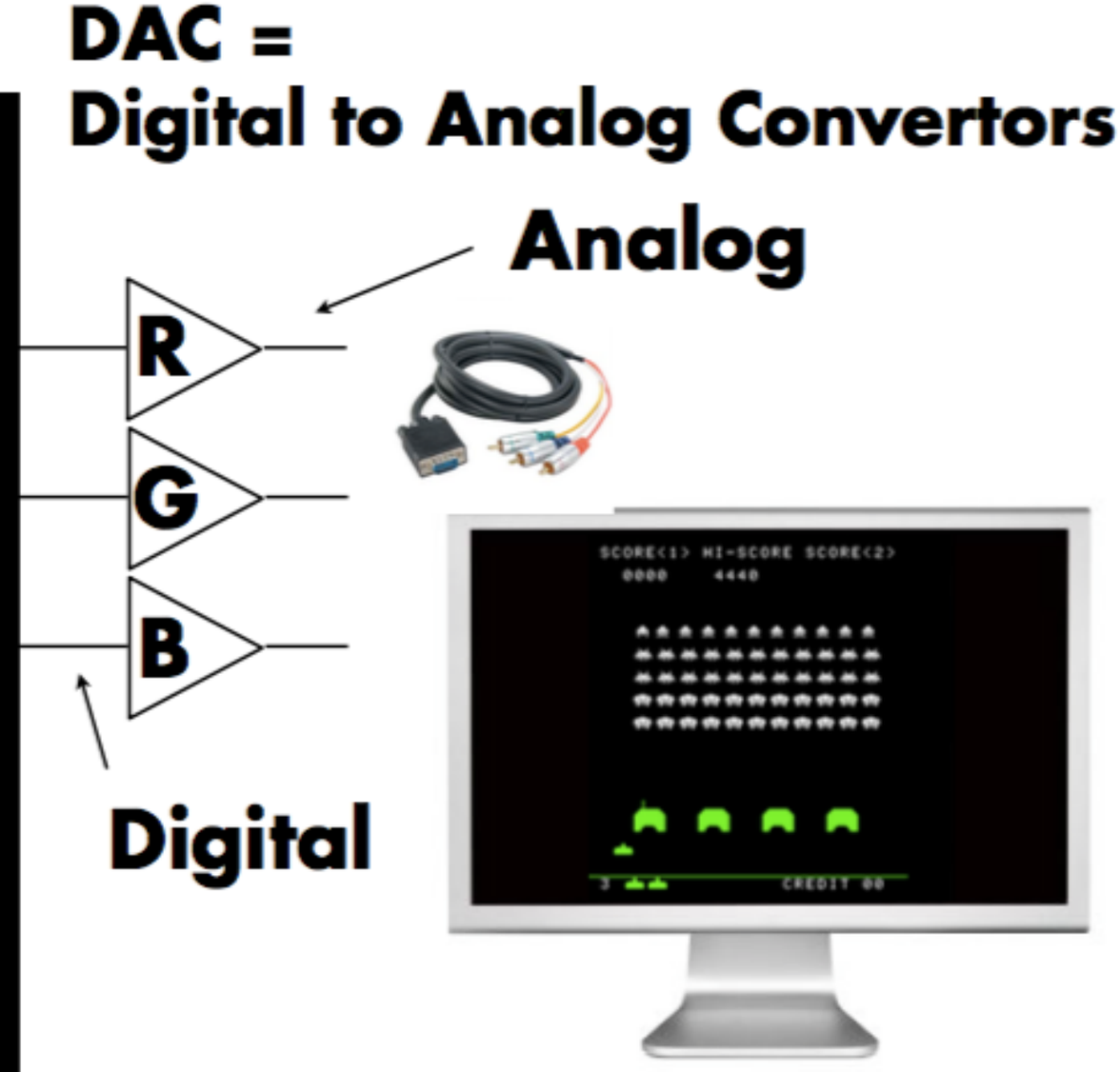


Image = 2D array of colors

Flat Panel Displays 平板显示设备

Low-Res LCD Display

Color LCD, OLED, …

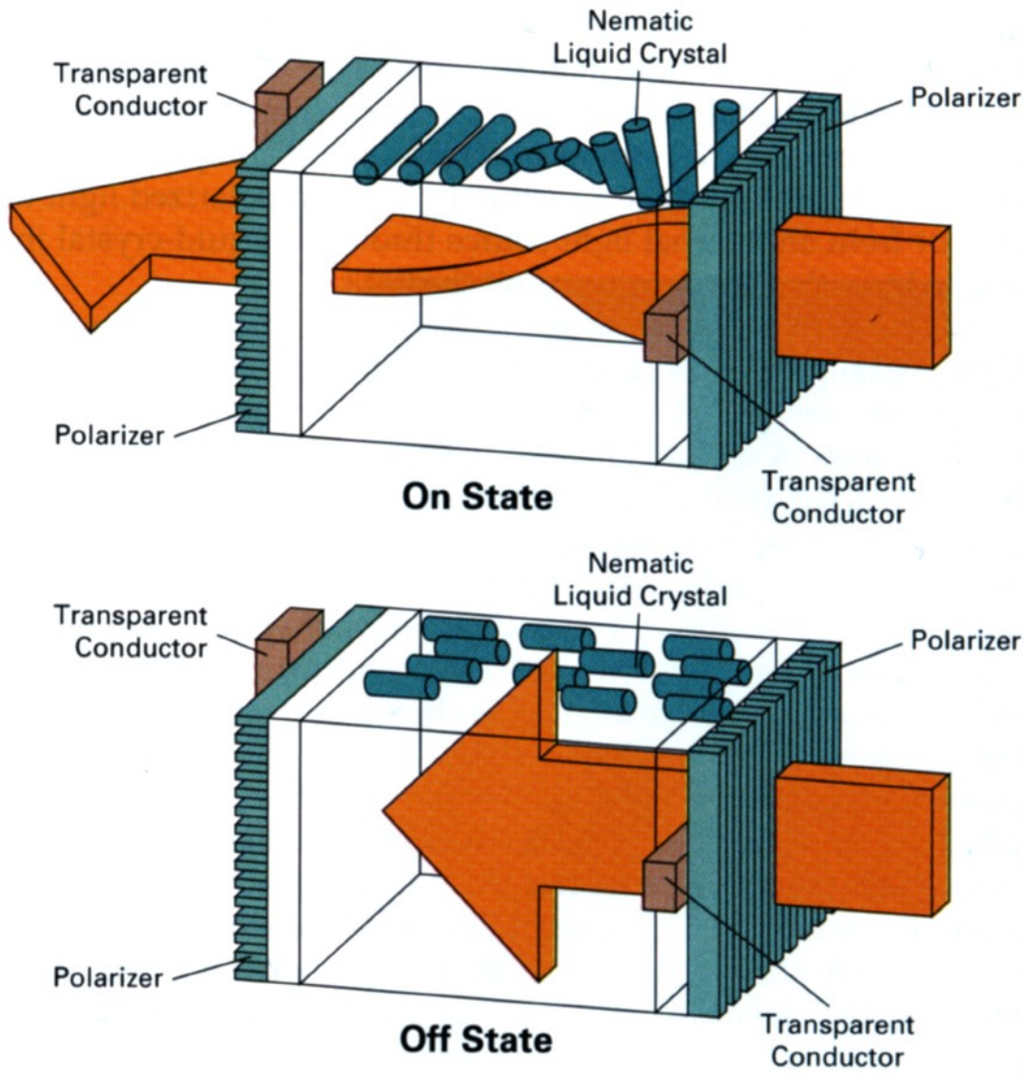
LCD (Liquid Crystal Display) Pixel

液晶显示器

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]

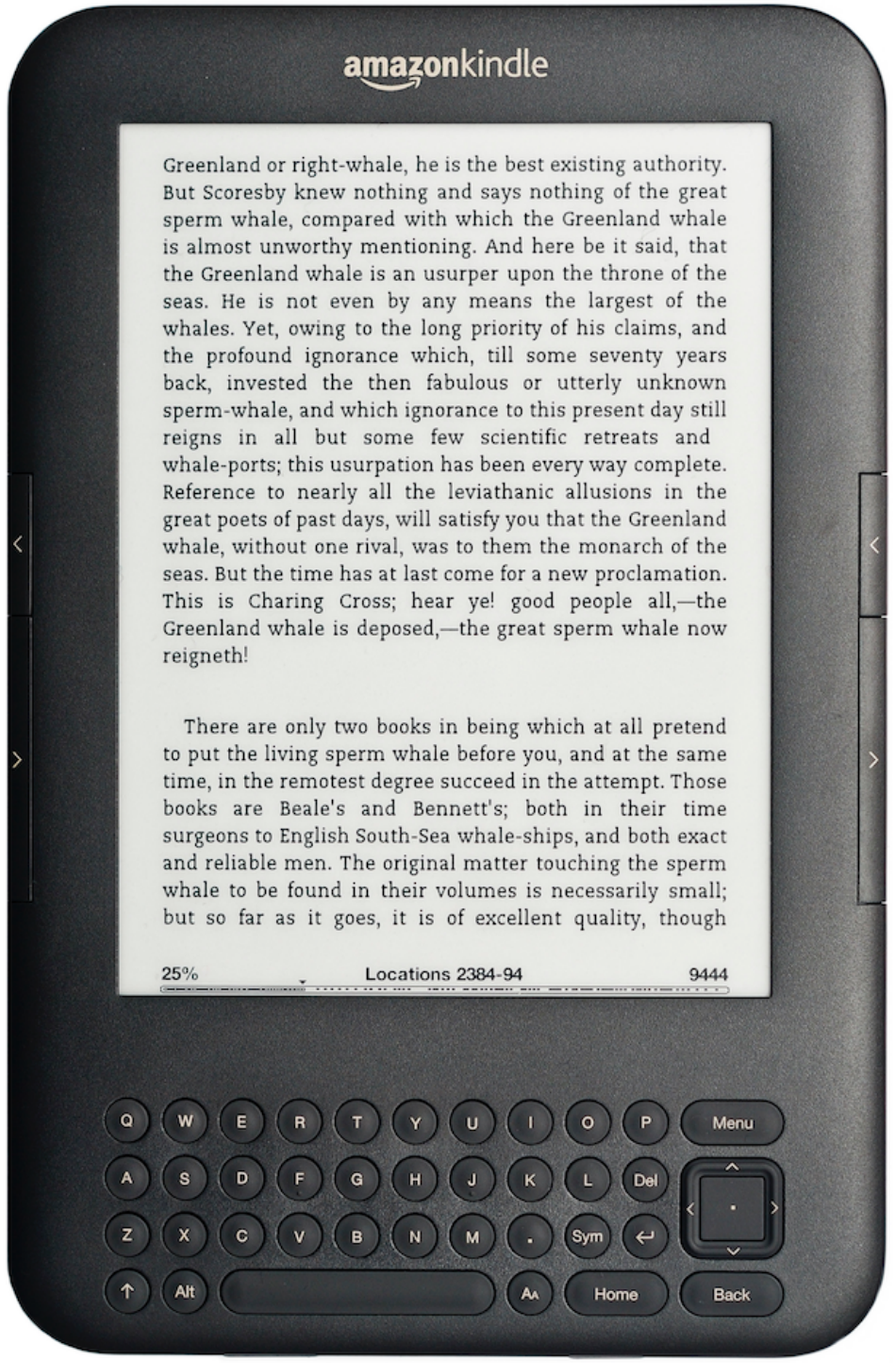
LED Array Display

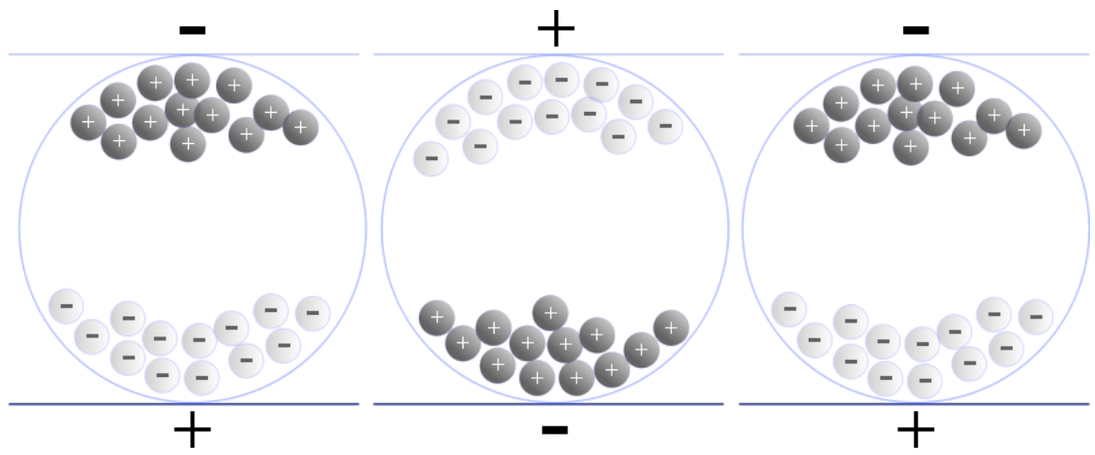
Light emitting diode array

Electrophoretic (Electronic Ink) Display

电子墨水屏

问题：刷新率很低





[Wikimedia Commons —Senarclens]

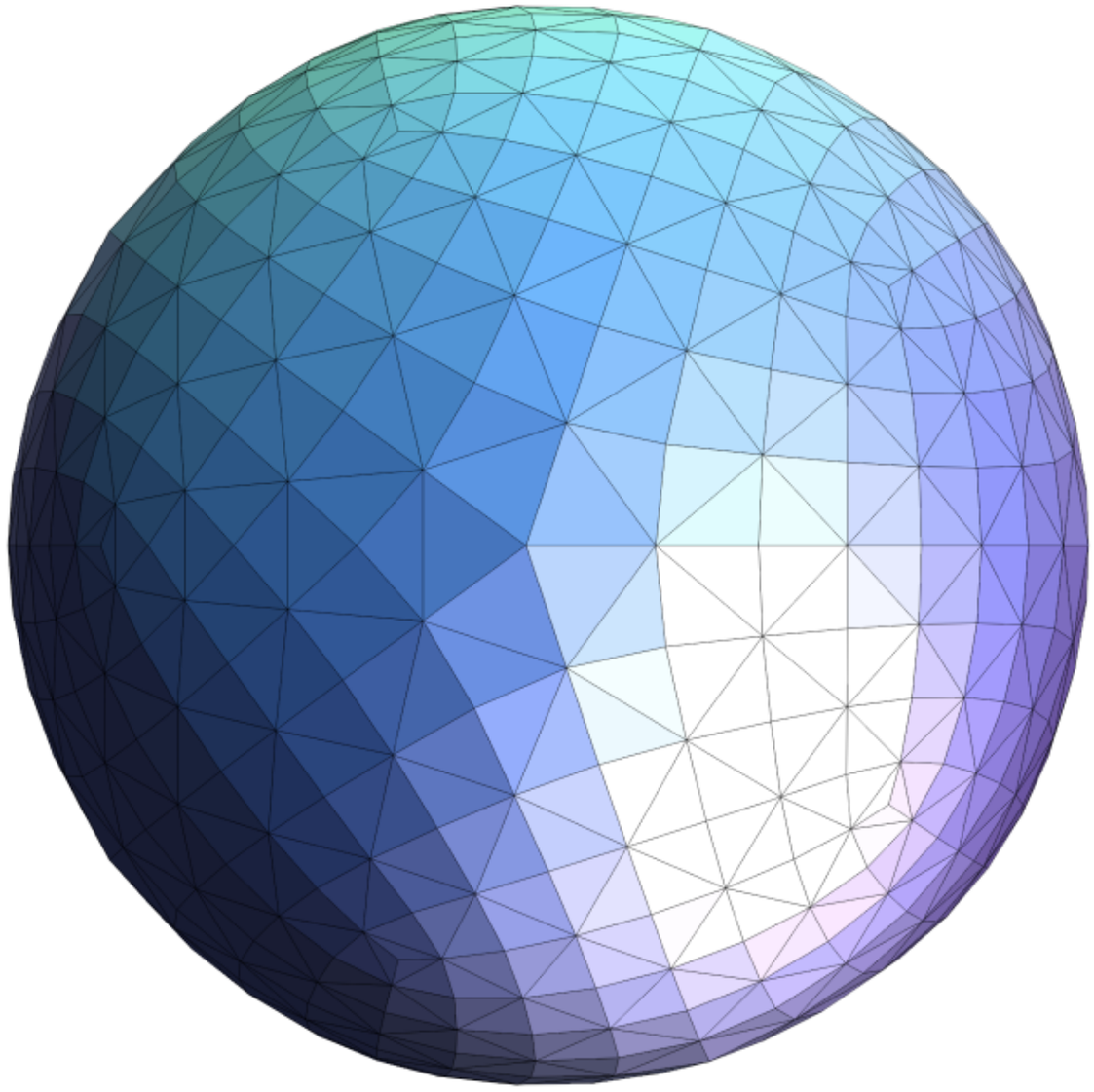
Rasterization:

Drawing to Raster Displays

Polygon Meshes

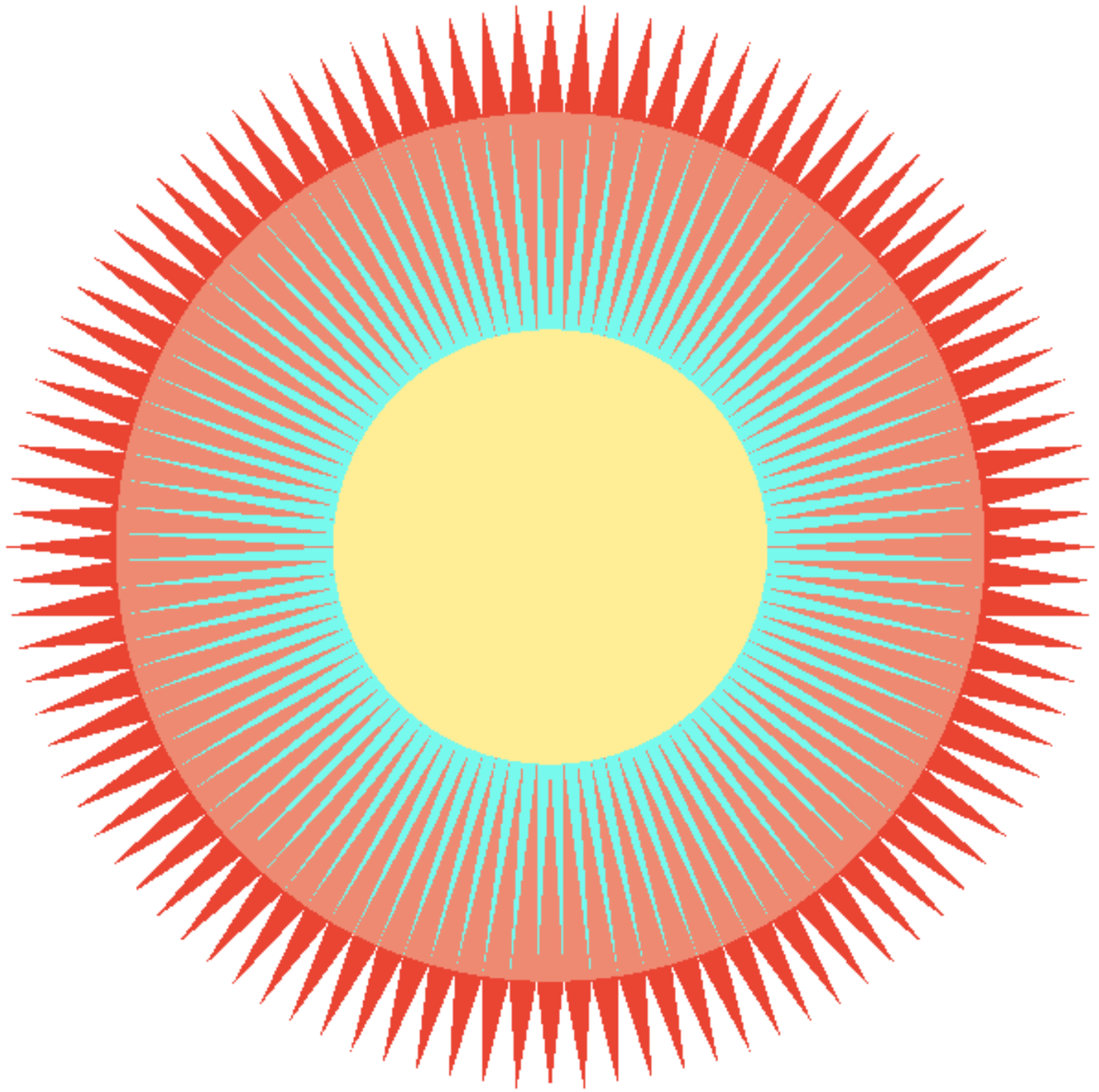
Triangle Meshes

三角形表示三维空间的图形



Triangle Meshes

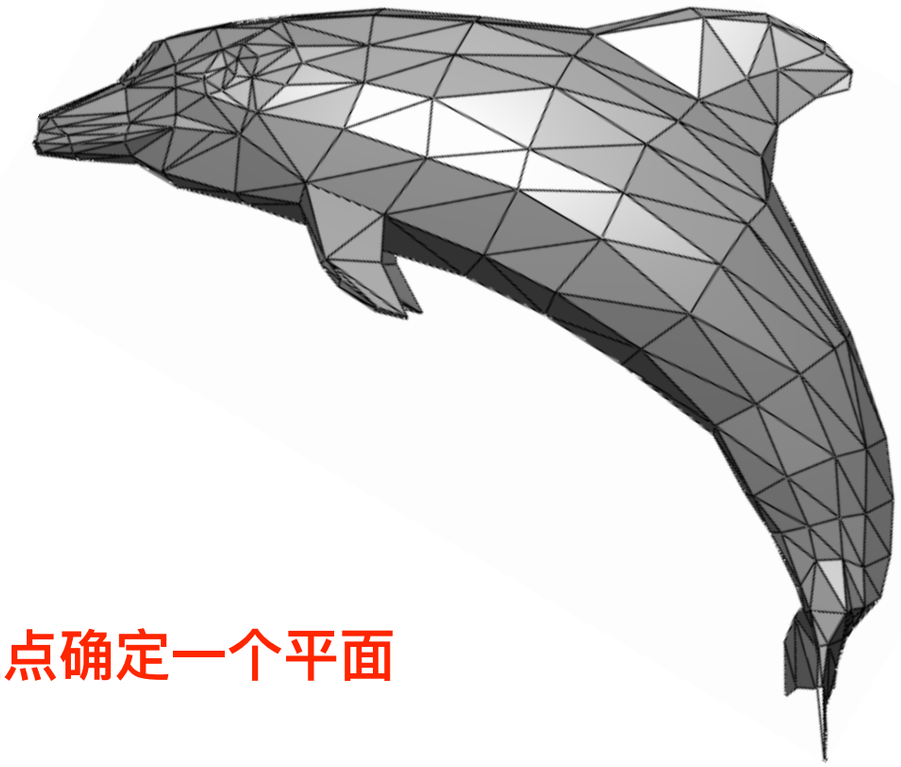
三角形也可以表示二维空间的图形



Triangles - Fundamental Shape Primitives

Why triangles?

- Most basic polygon
  - Break up other polygons

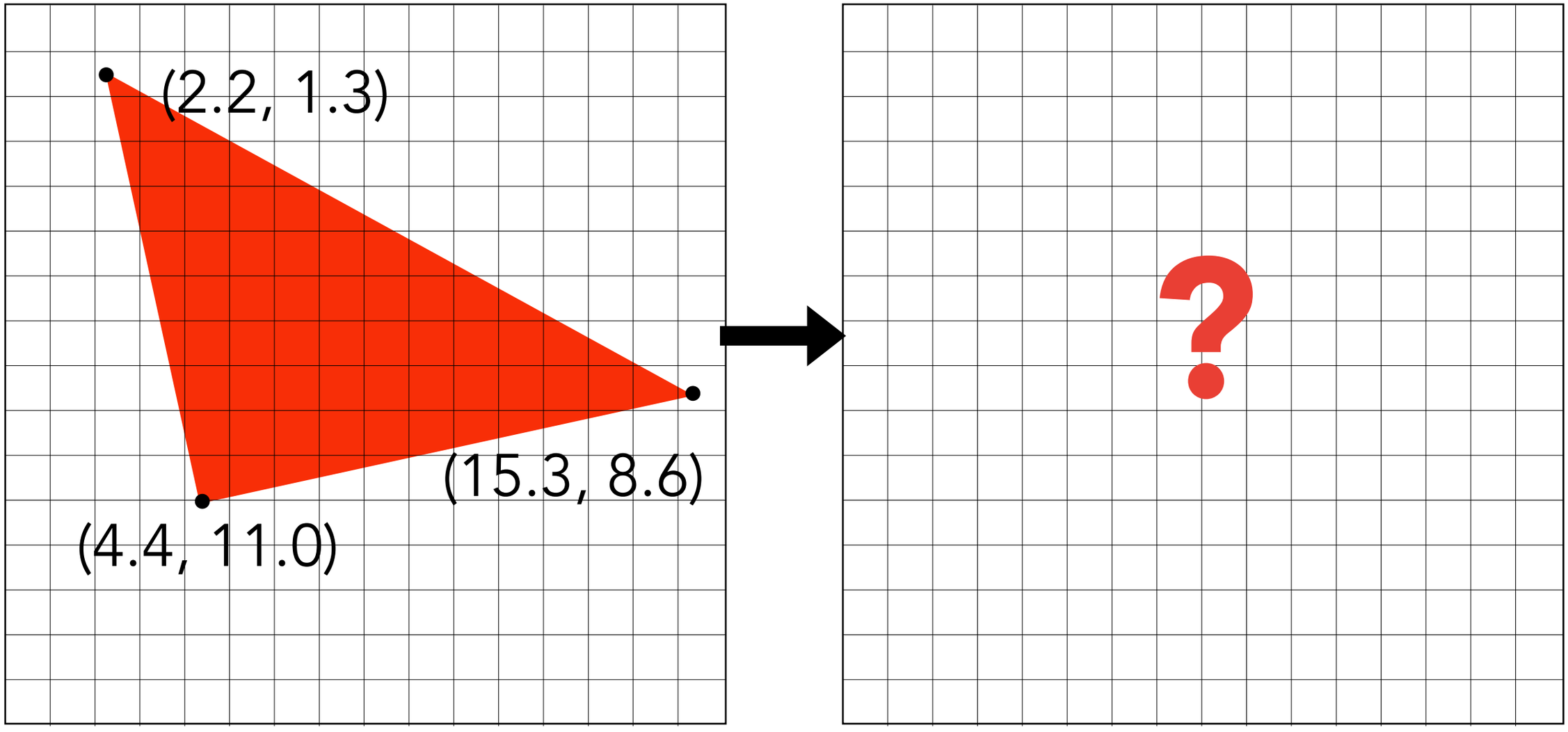


- Unique properties
  - Guaranteed to be planar 三点确定一个平面
  - Well-defined interior 内外定义明确
  - Well-defined method for interpolating values at vertices over triangle (barycentric interpolation)

方便进行插值，
填充三角形内部

What Pixel Values Approximate a Triangle?

判断像素（中心点）与三角形的位置关系



Input: position of triangle vertices projected on screen

Output: set of pixel values approximating triangle

A Simple Approach: Sampling

Sampling a Function

采样：给定一个连续函数，在不同离散点取函数值（函数的离散化过程）

Evaluating a function at a point is sampling.

We can discretize a function by sampling.

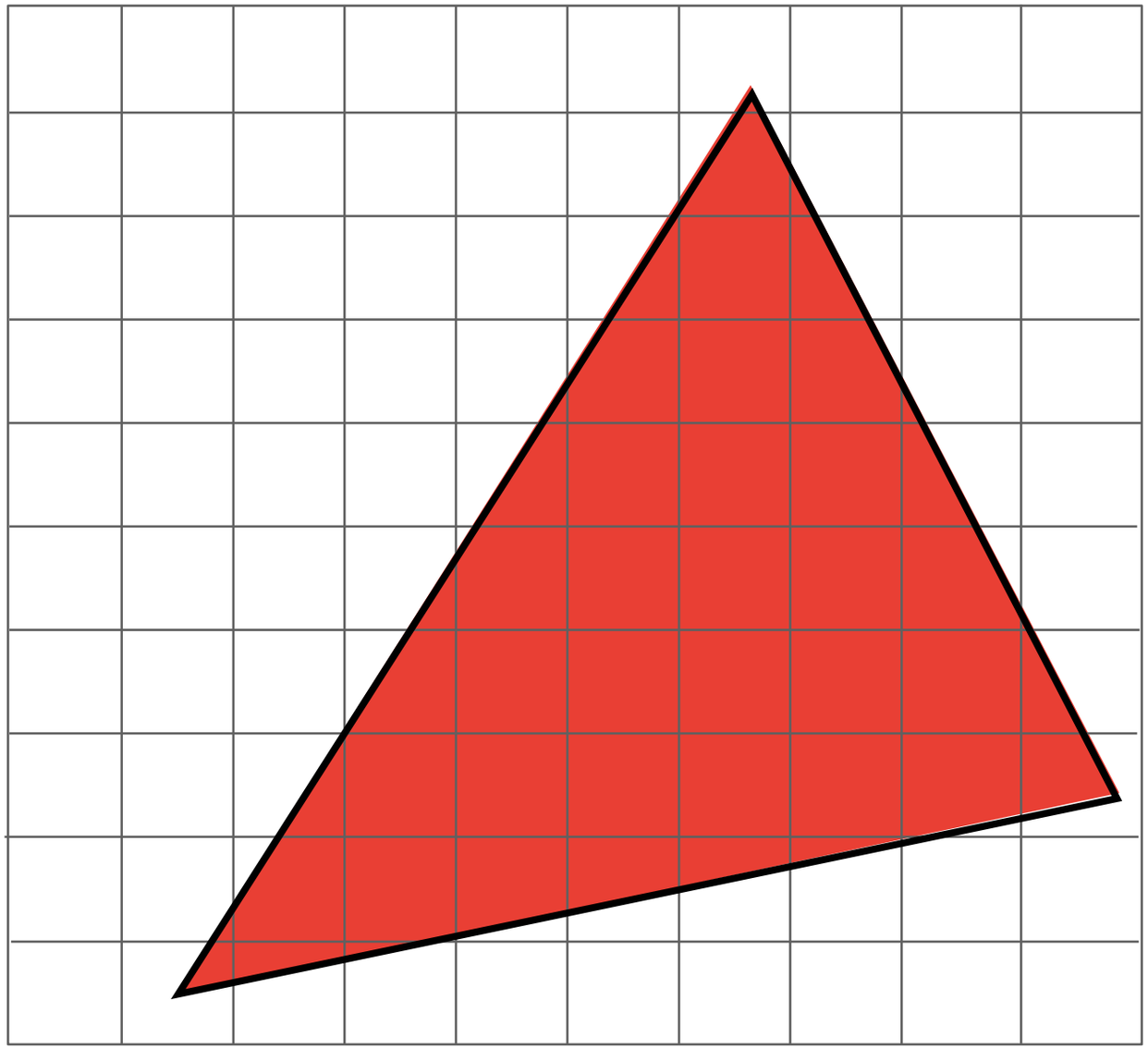
```
for (int x = 0; x < xmax; ++x)
    output[x] = f(x);
```

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

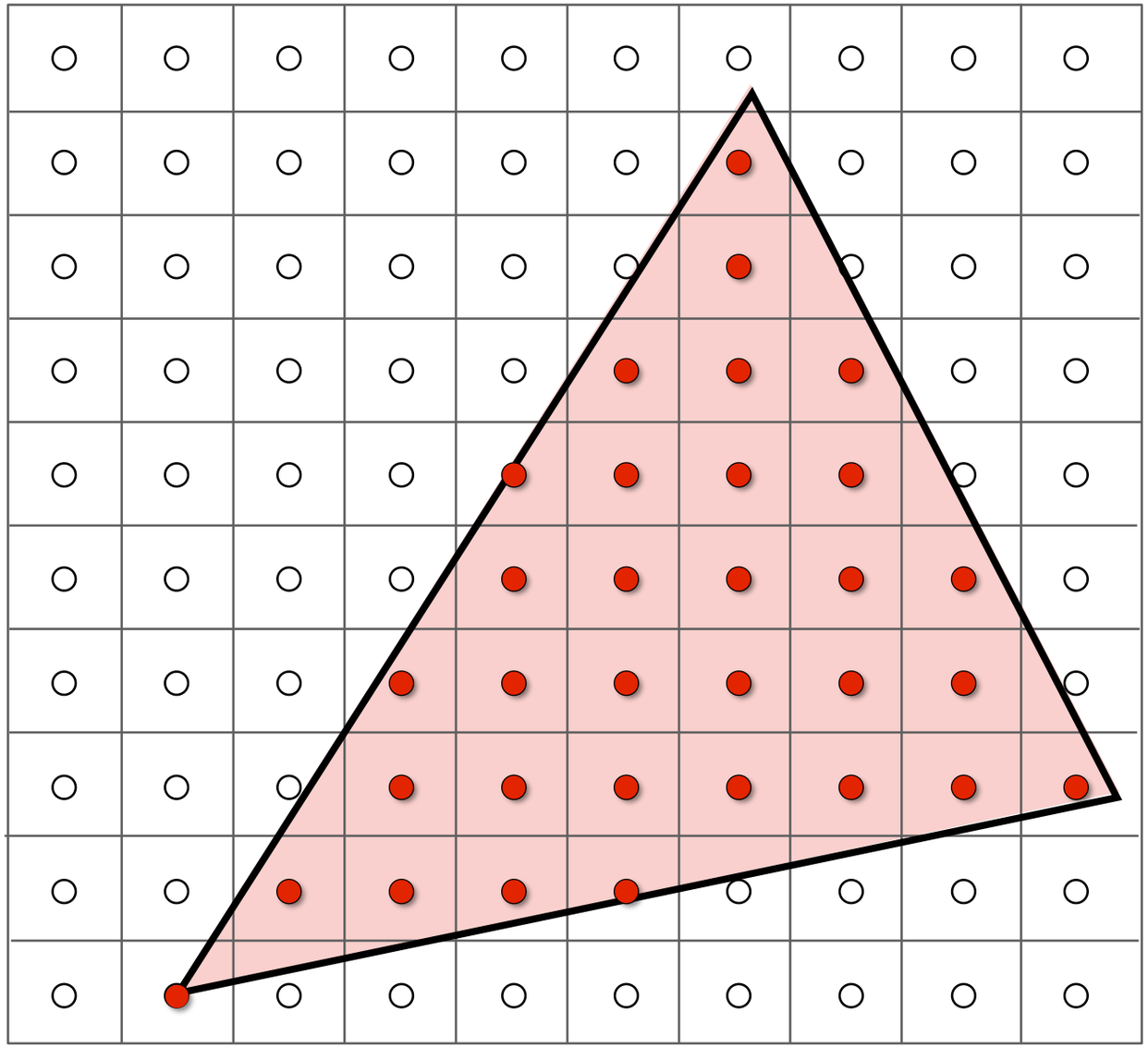
利用像素中心进行采样

Rasterization As 2D Sampling

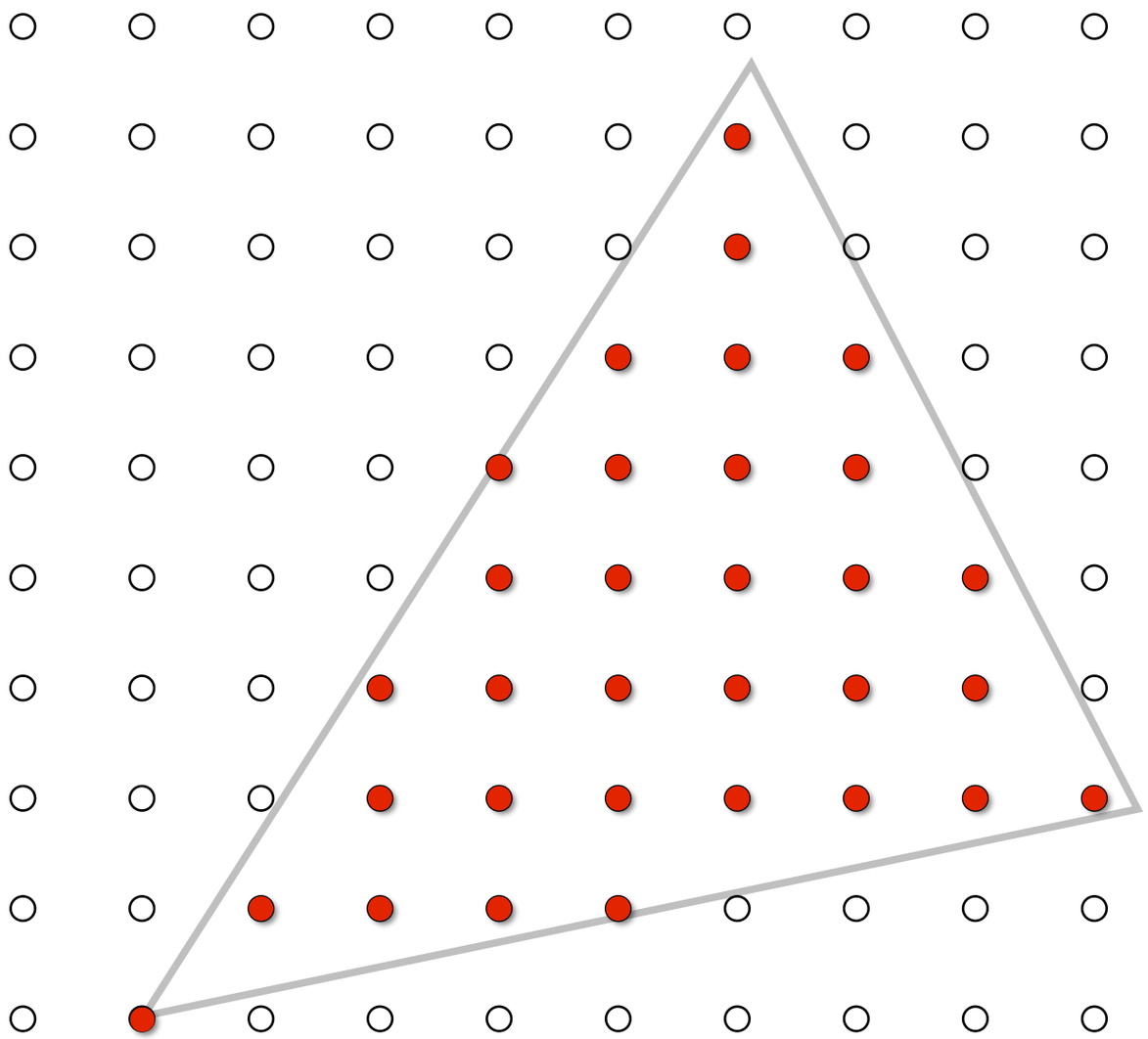
判断某点是否在三角形内部



Sample If Each Pixel Center Is Inside Triangle



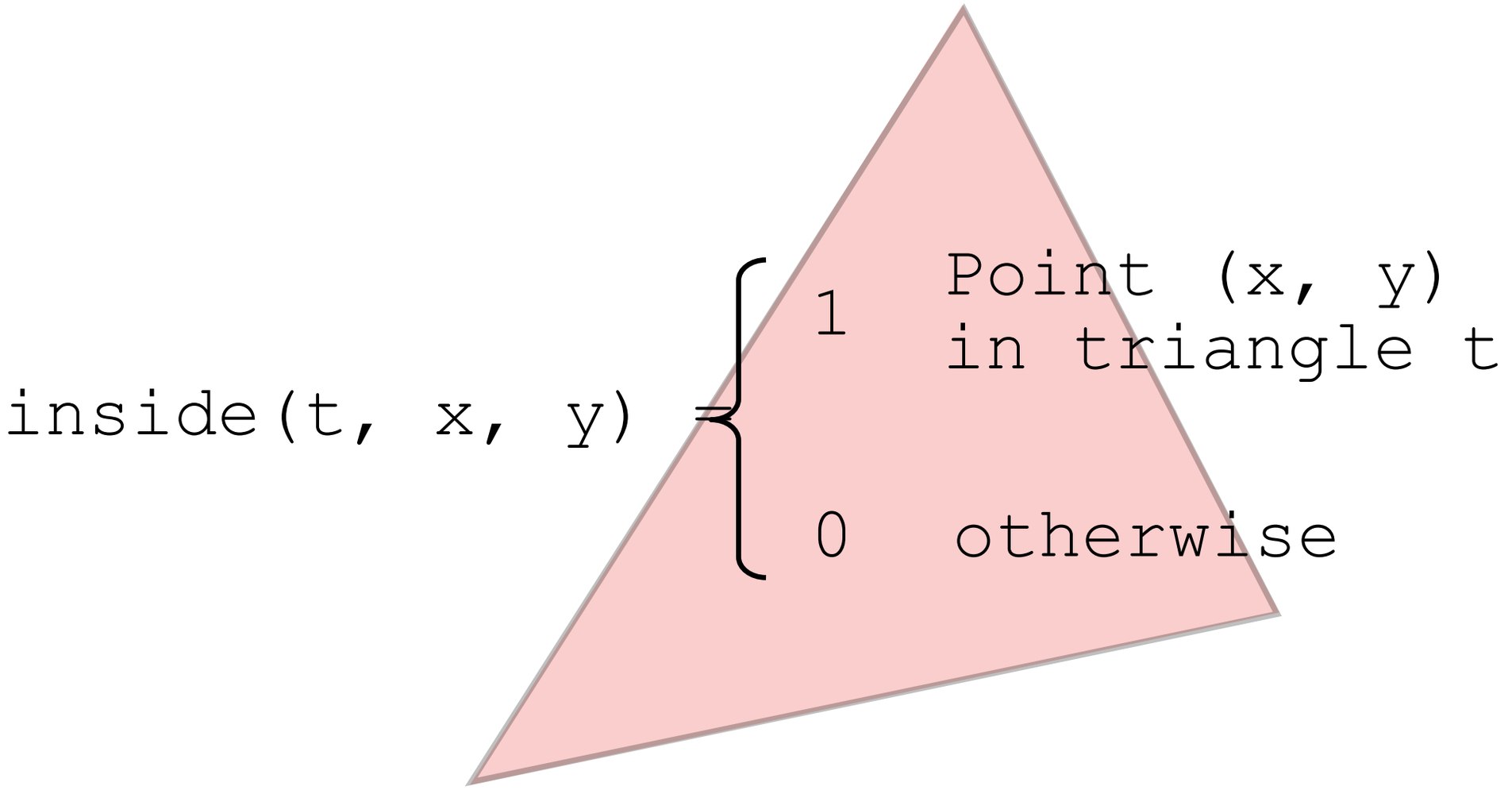
Sample If Each Pixel Center Is Inside Triangle



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

x, y: not necessarily integers

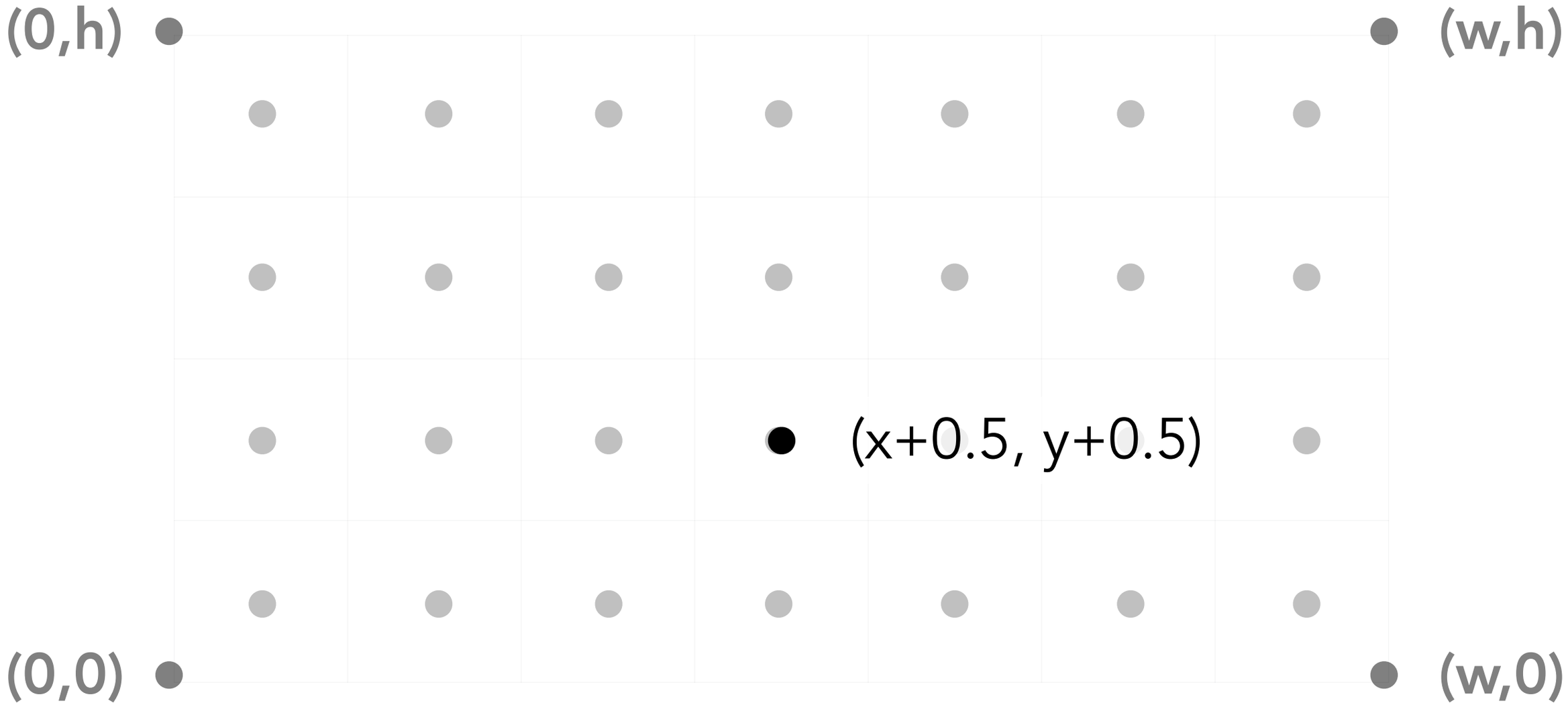
在像素的中心，确定函数值是1or0



Rasterization = Sampling A 2D Indicator Function

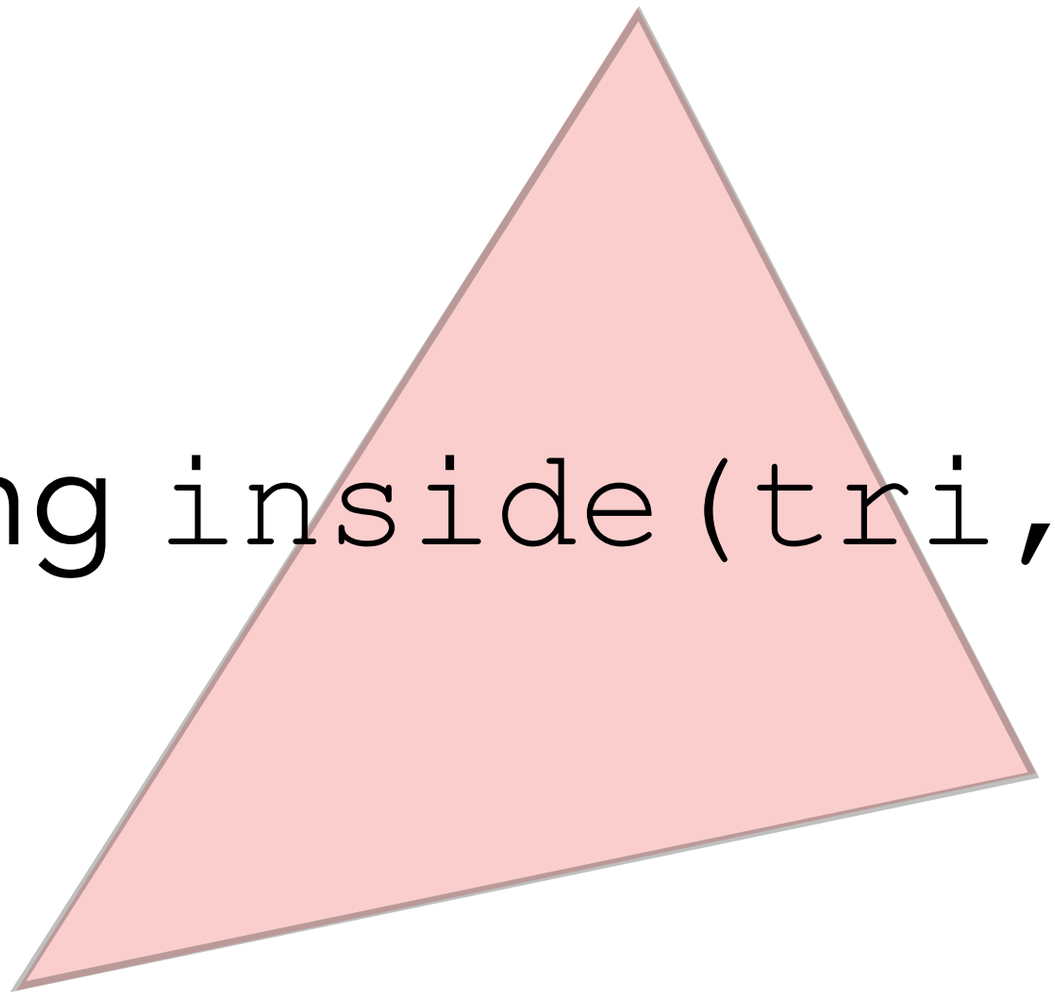
```
for (int x = 0; x < xmax; ++x)
  for (int y = 0; y < ymax; ++y)
    image[x][y] = inside(tri,
                         x + 0.5,
                         y + 0.5);
```

Recall: Sample Locations

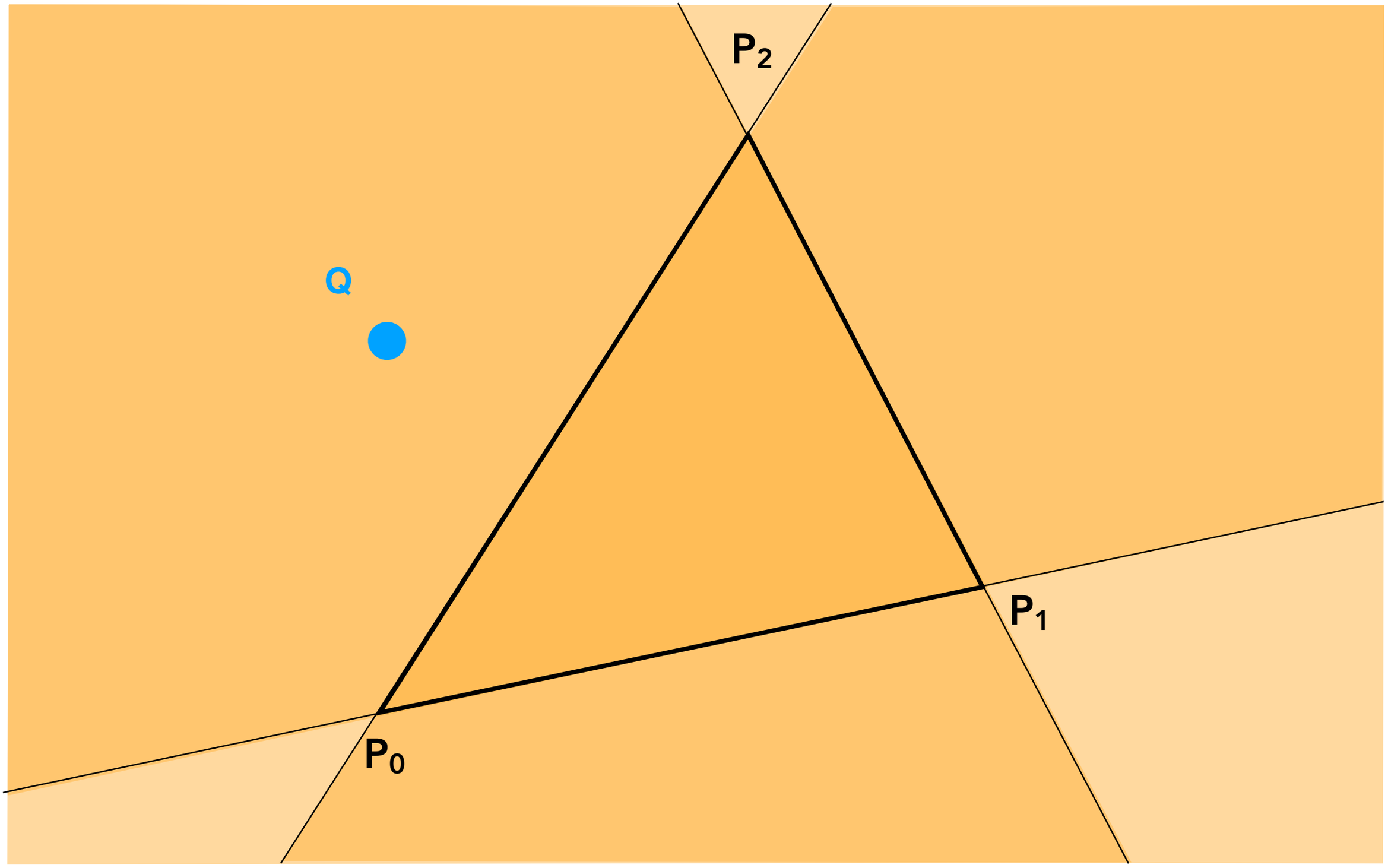


Sample location for pixel (x, y)

Evaluating `inside(tri, x, y)`



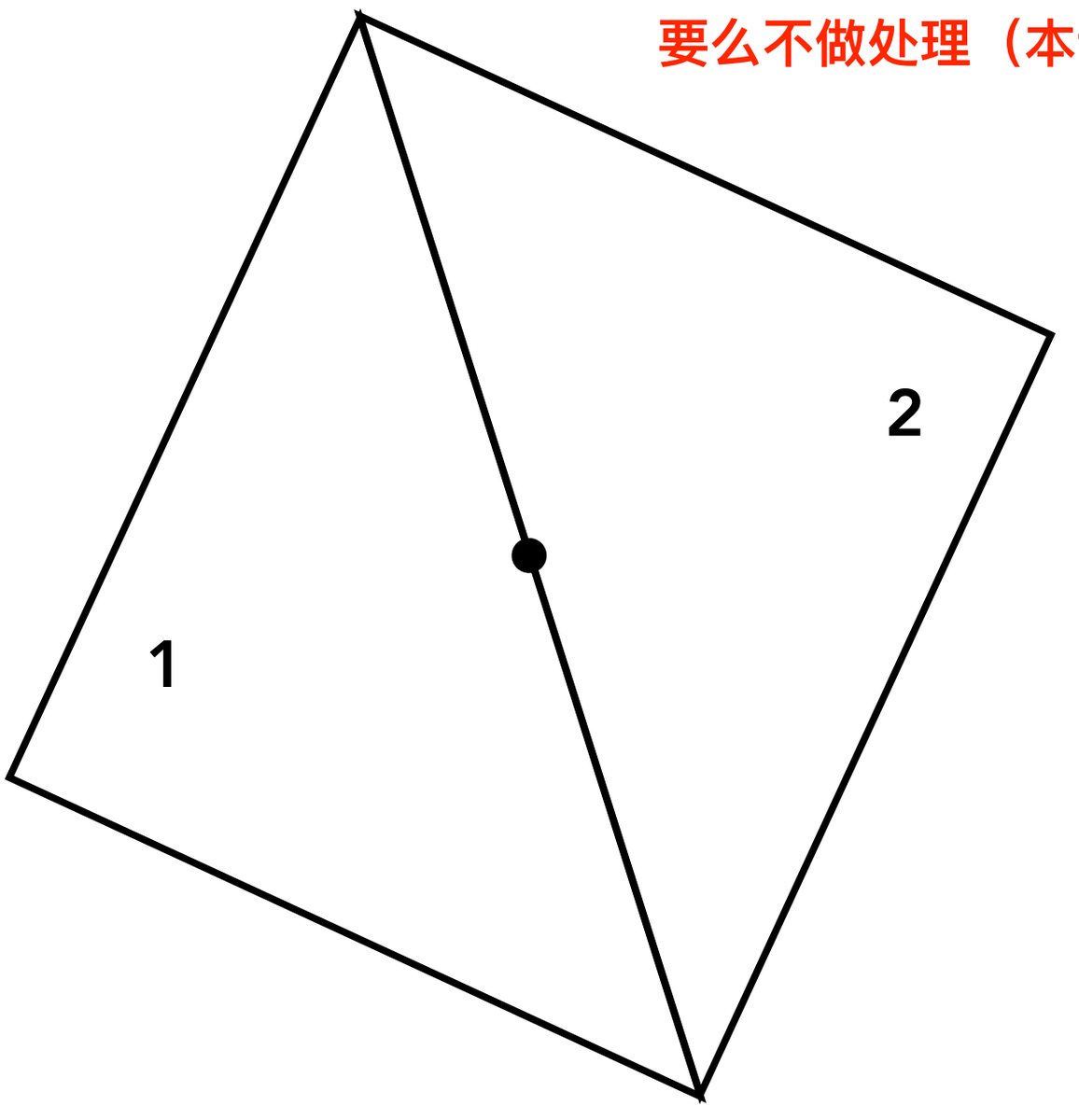
Inside? Recall: Three Cross Products!



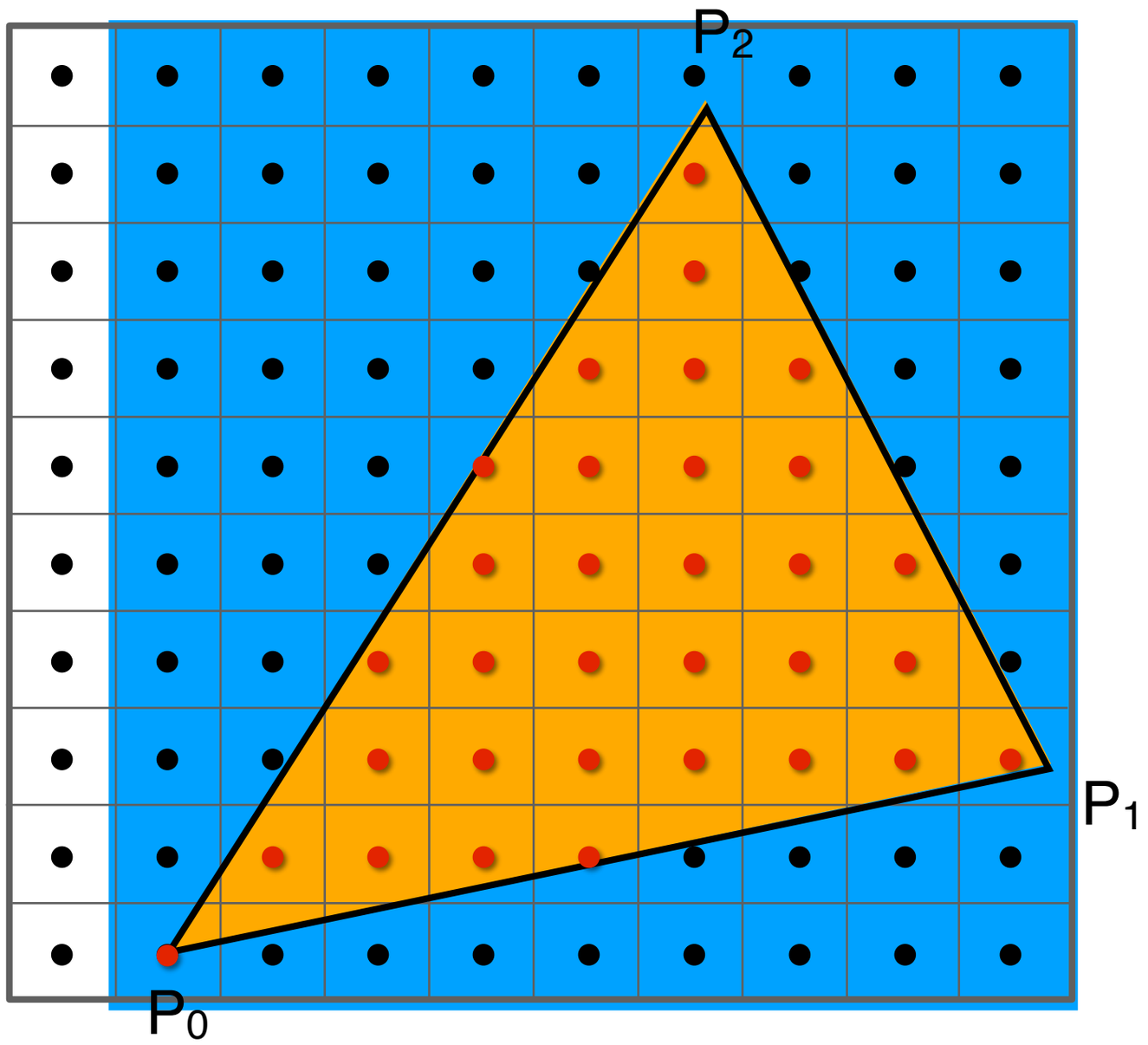
Edge Cases (Literally)

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

要么不做处理（本课），要么特殊处理



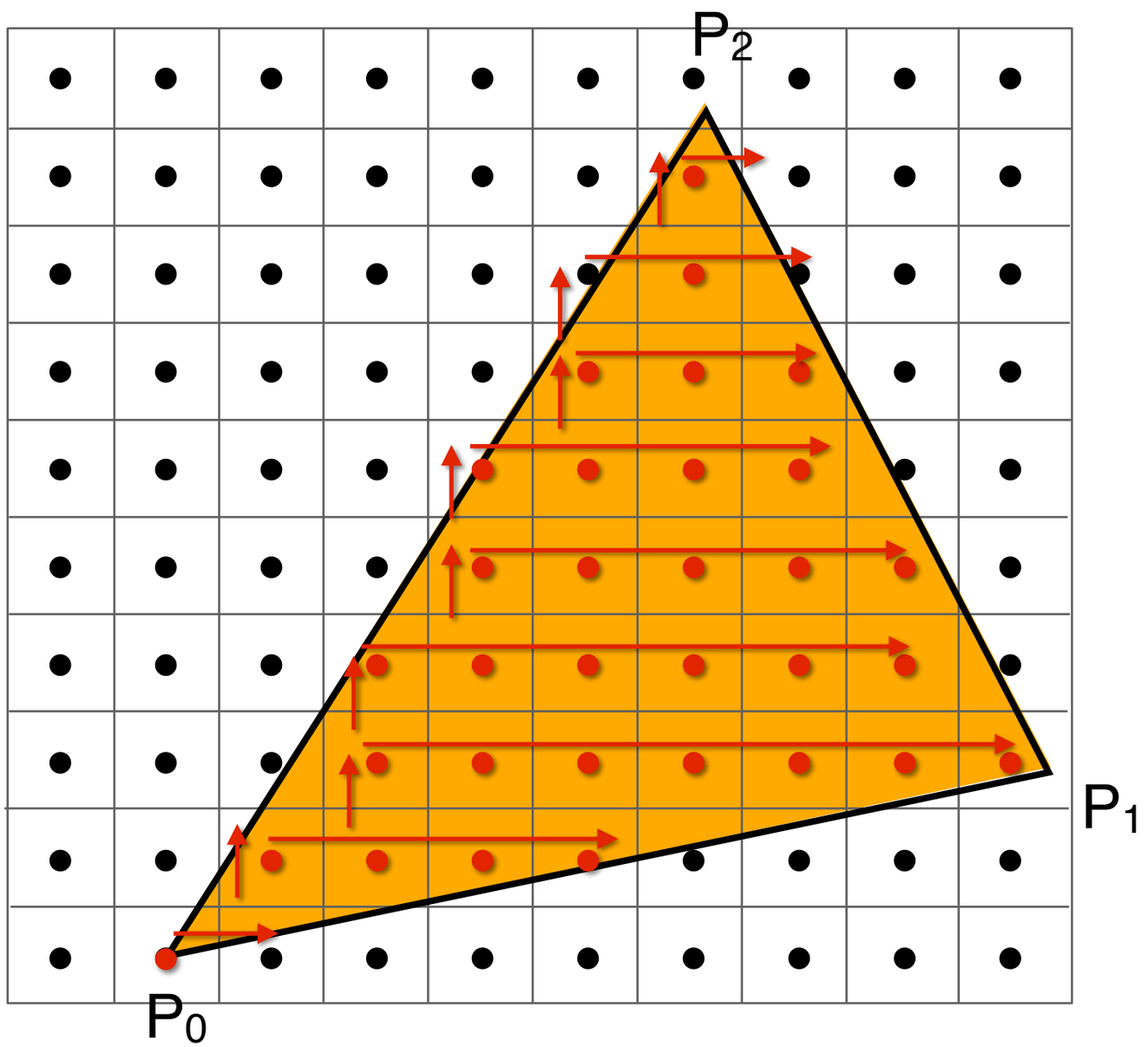
Checking All Pixels on the Screen?



Use a **Bounding Box!**

（轴向）包围盒

Incremental Triangle Traversal (Faster?)

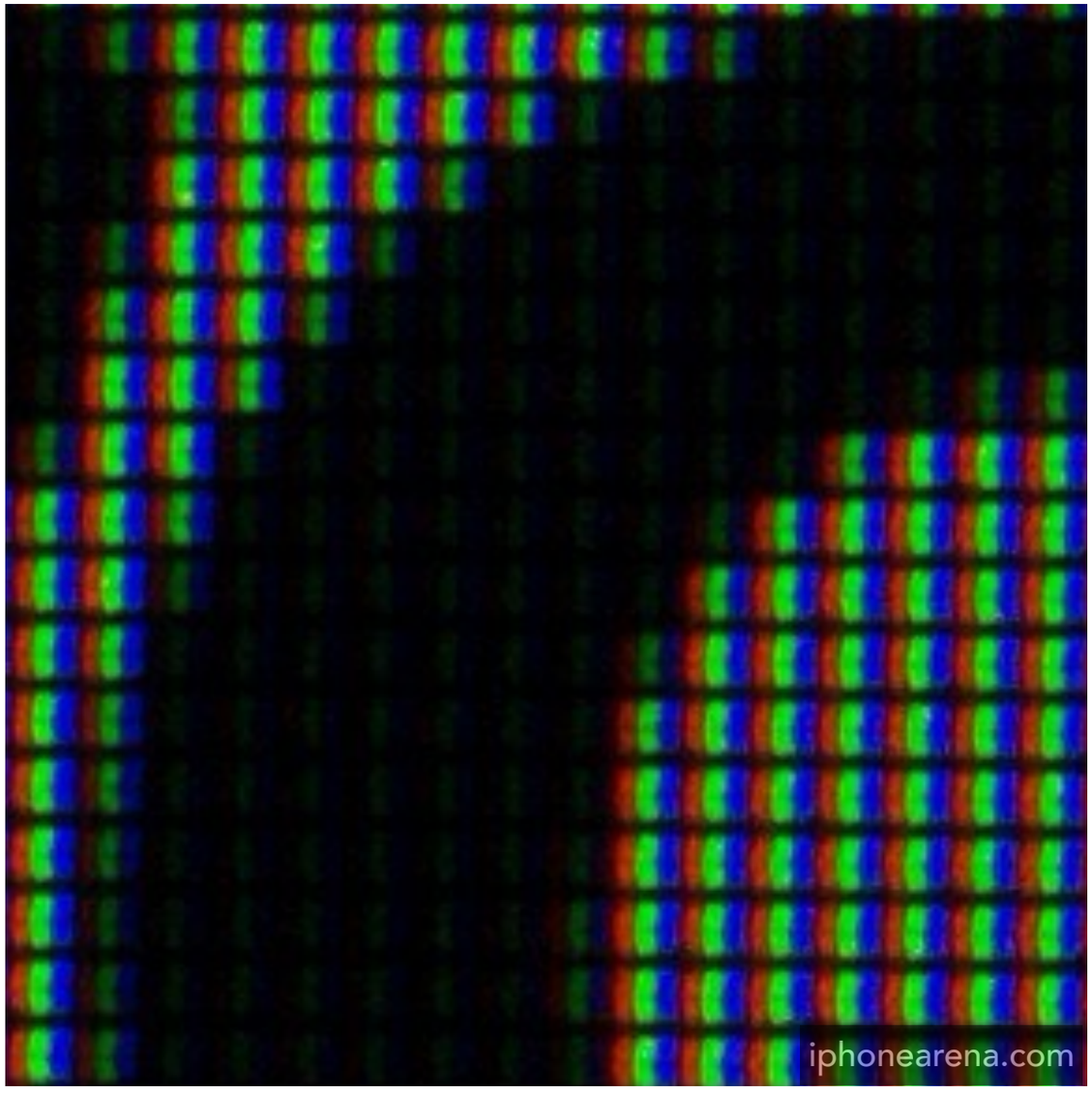


suitable for thin and rotated triangles

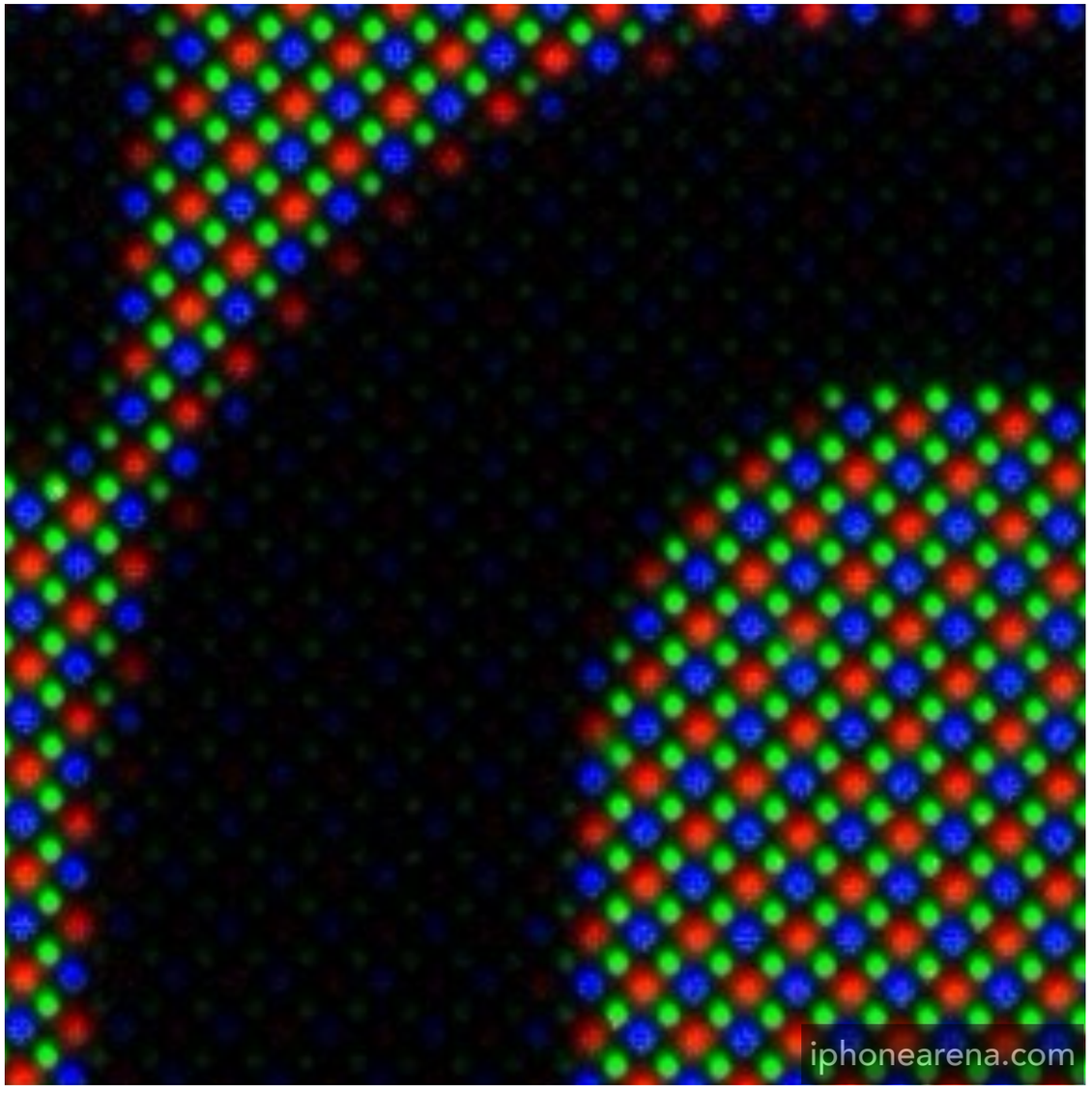
以上：光栅化的简单做法，通过采样和inside函数实现

Rasterization on Real Displays

Real LCD Screen Pixels (Closeup)



iPhone 6S

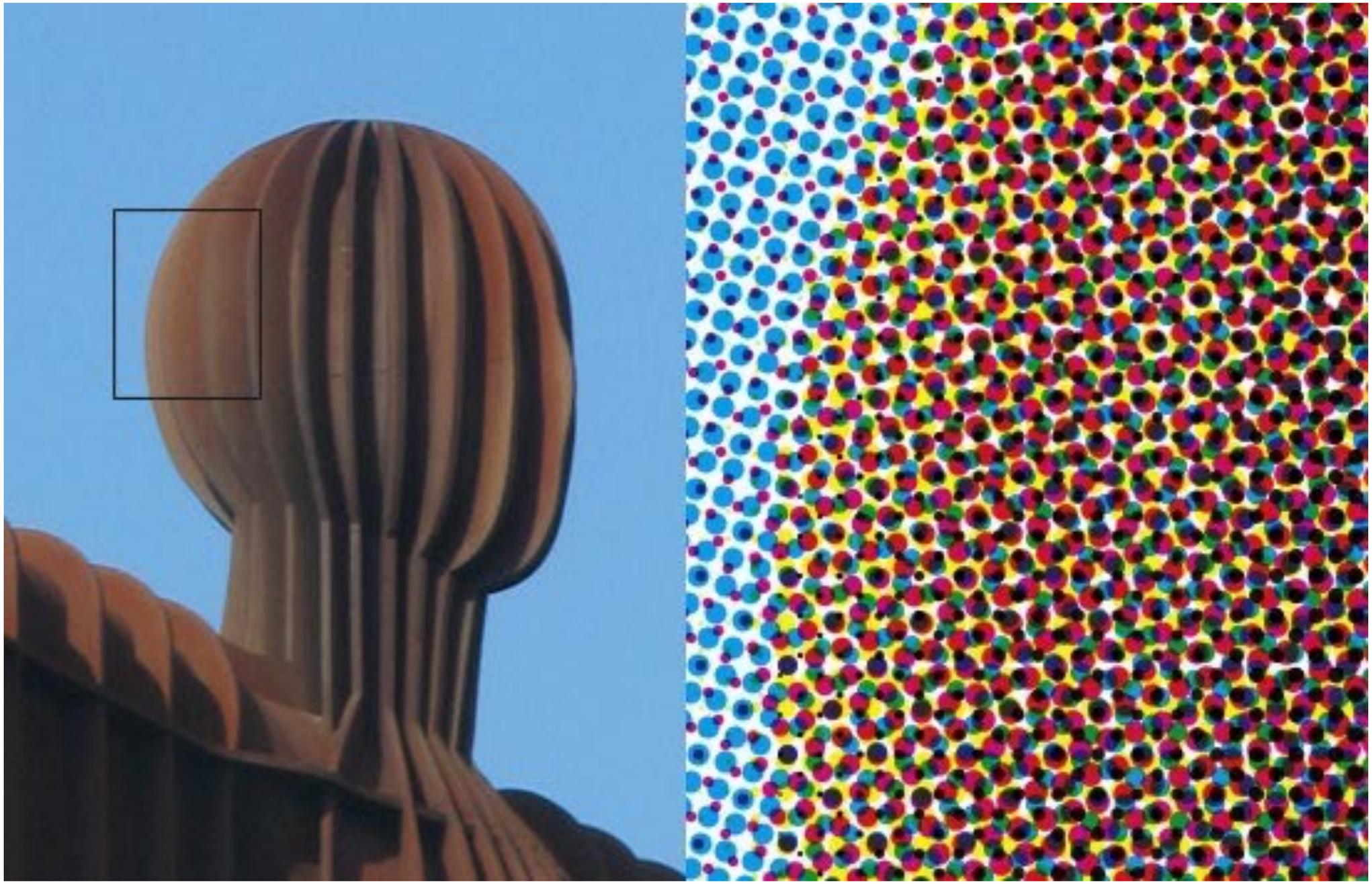


绿色密度更高 Galaxy S5

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

Bayer-Pattern

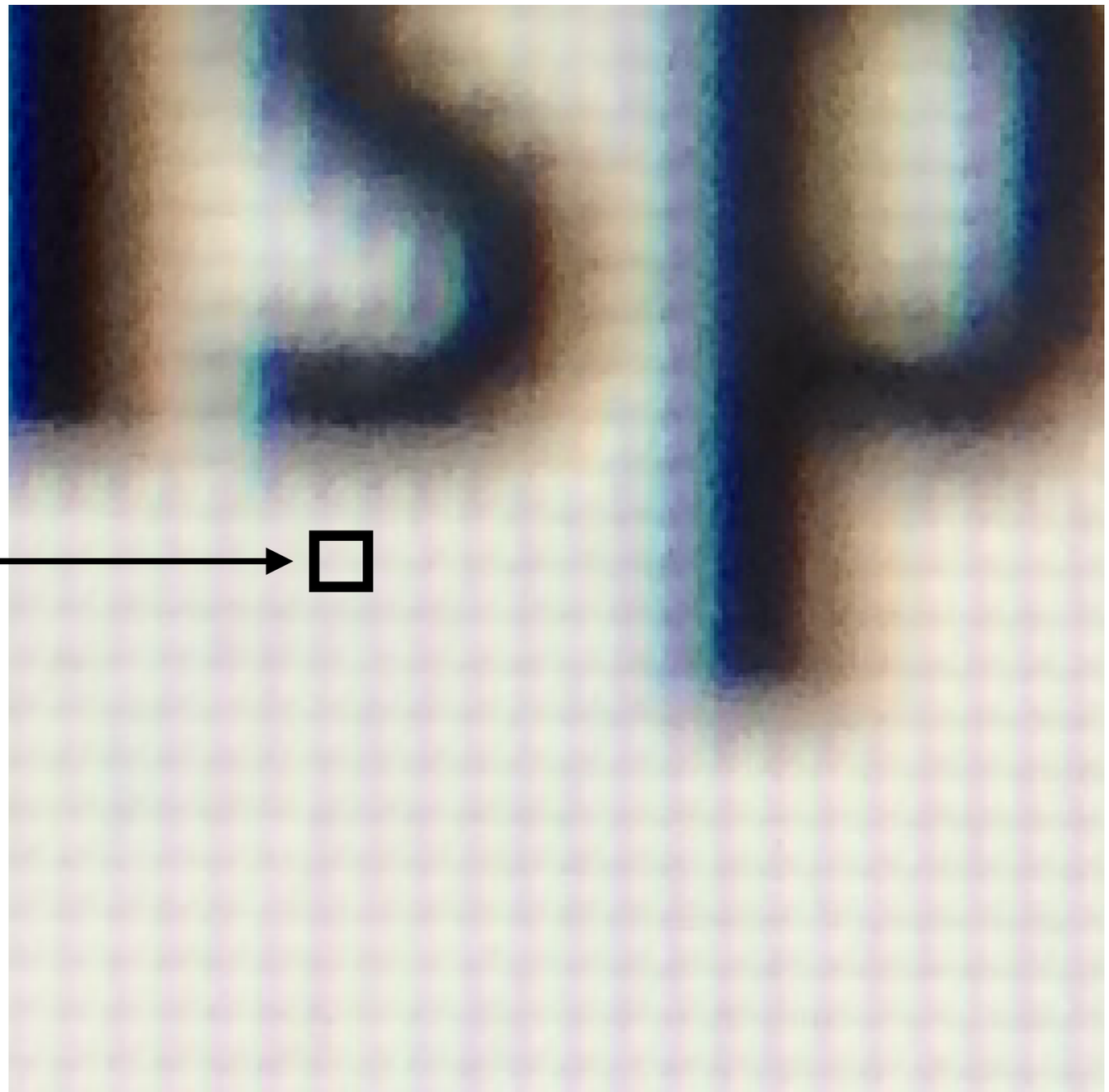
Aside: What About Other Display Methods?



Color print: observe half-tone pattern

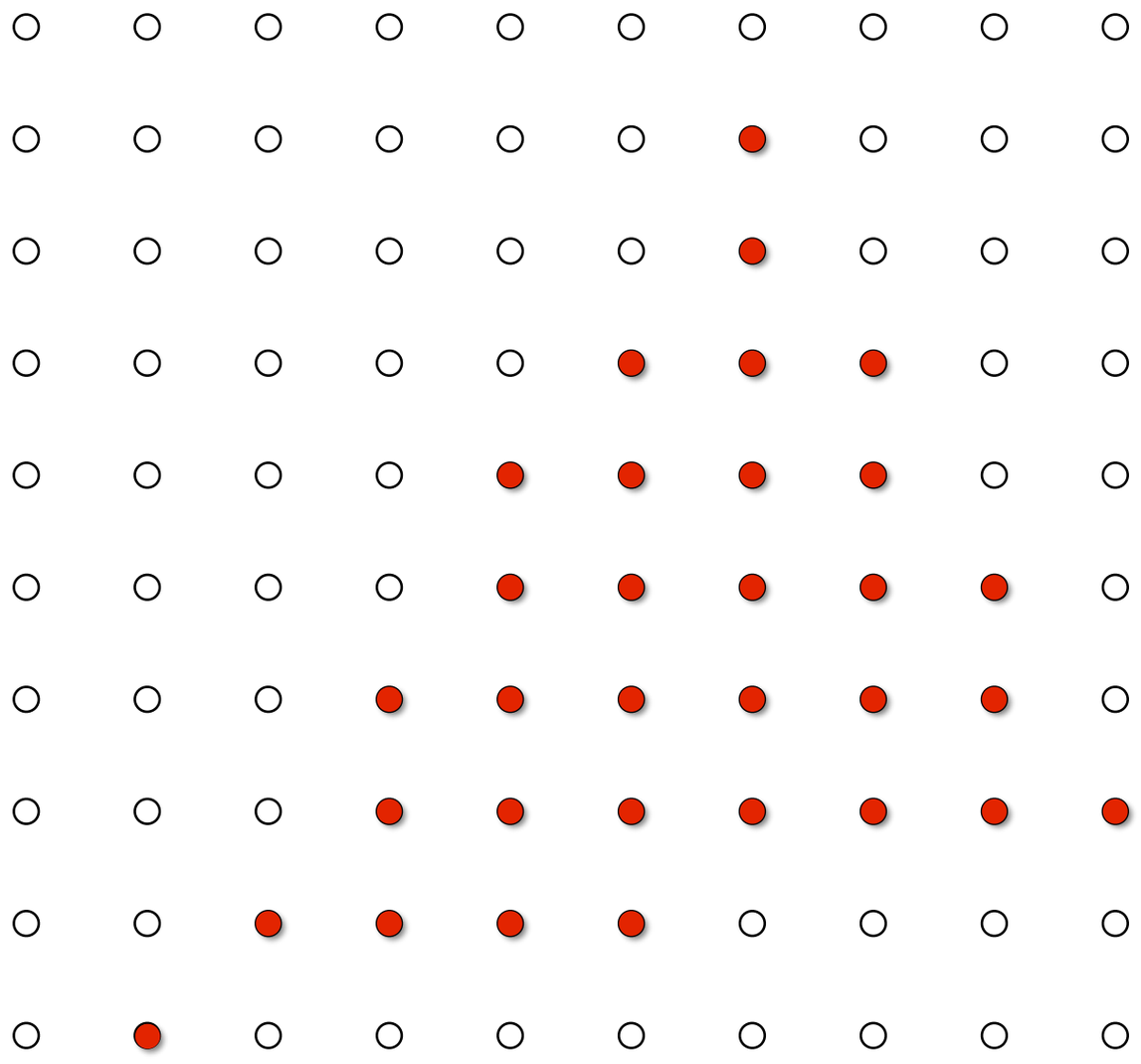
Assume Display Pixels Emit Square of Light

LCD pixel
on laptop

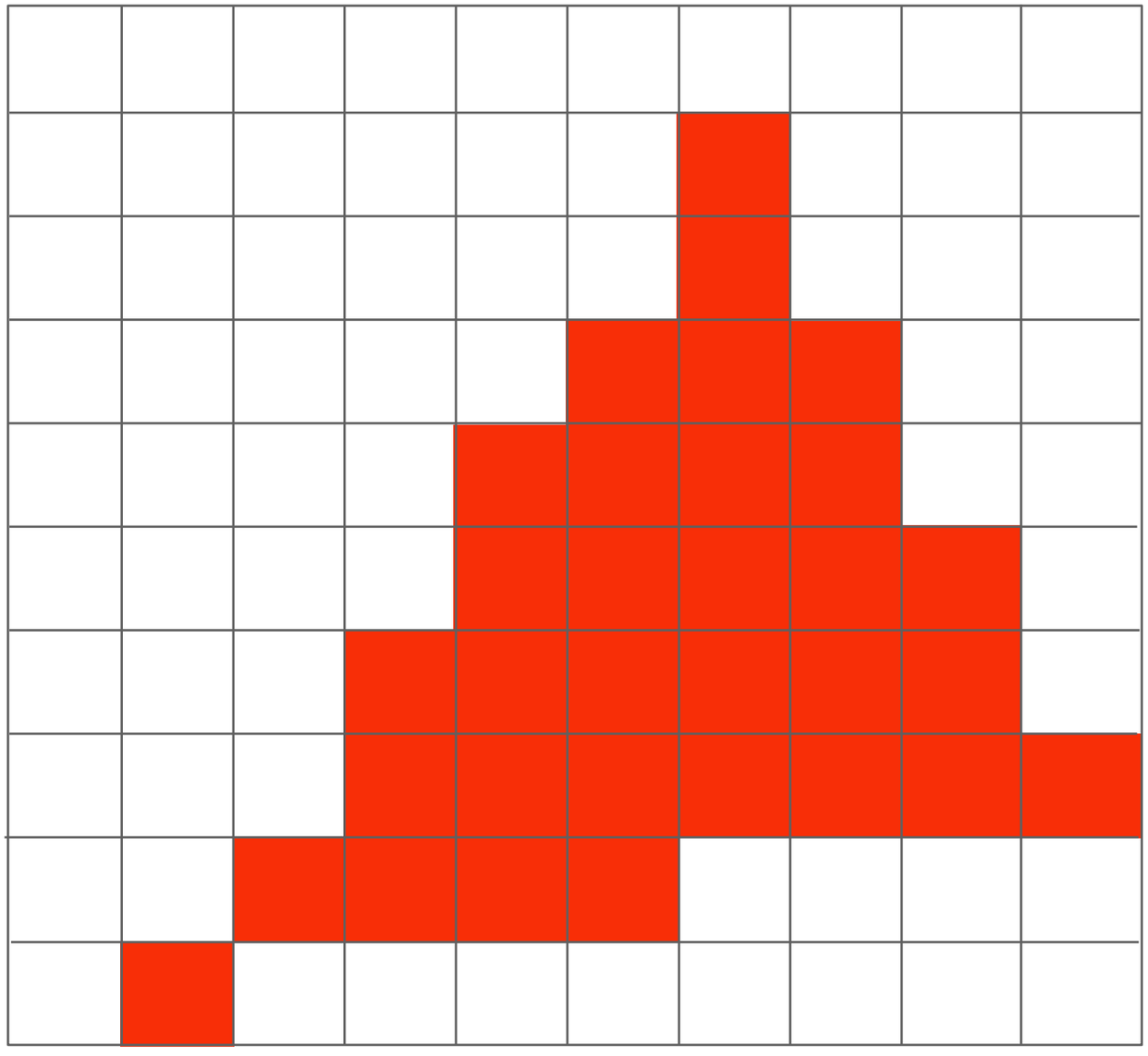


* LCD pixels do not actually emit light in a square of uniform color, but this approximation suffices for our current discussion

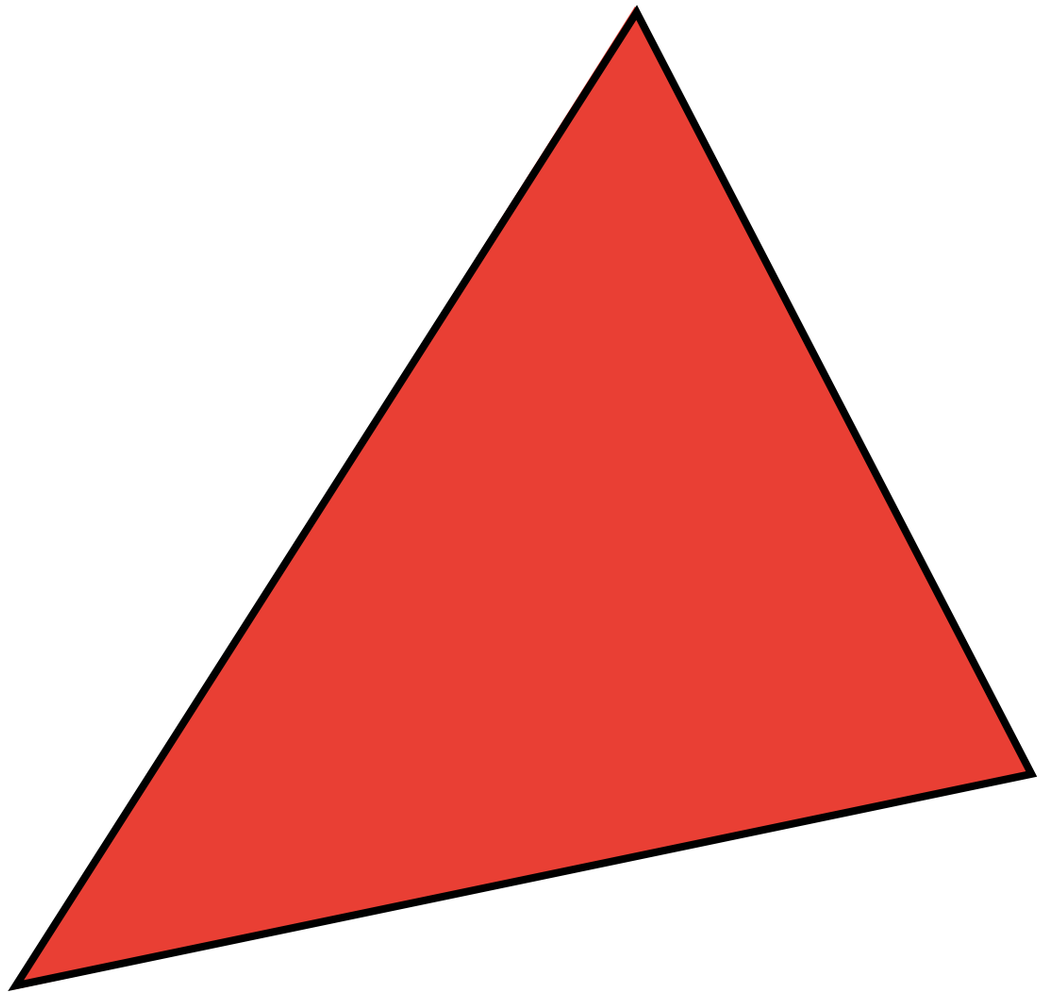
So, If We Send the Display the Sampled Signal



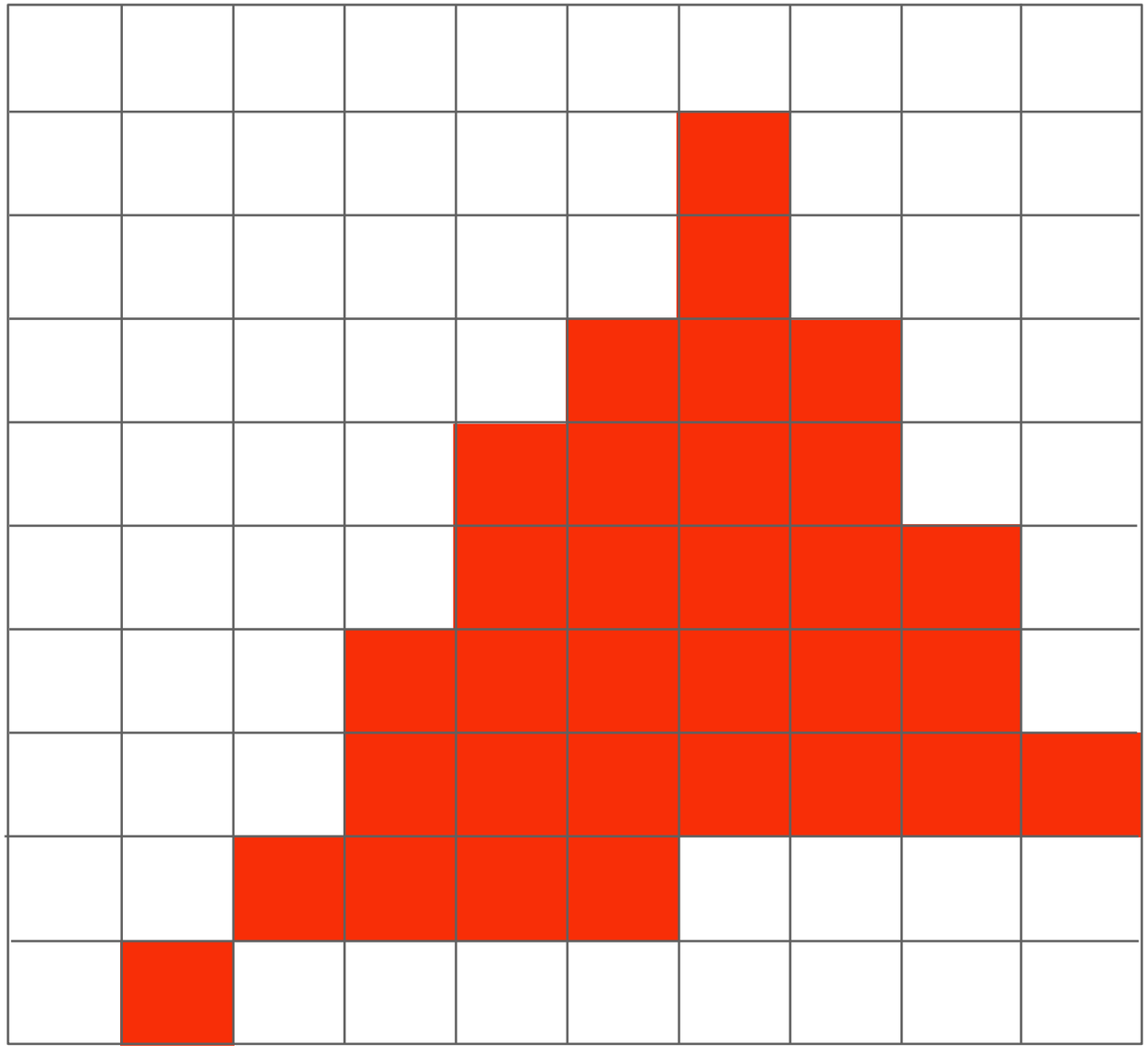
The Display Physically Emits This Signal



Compare: The Continuous Triangle Function



What's Wrong With This Picture?



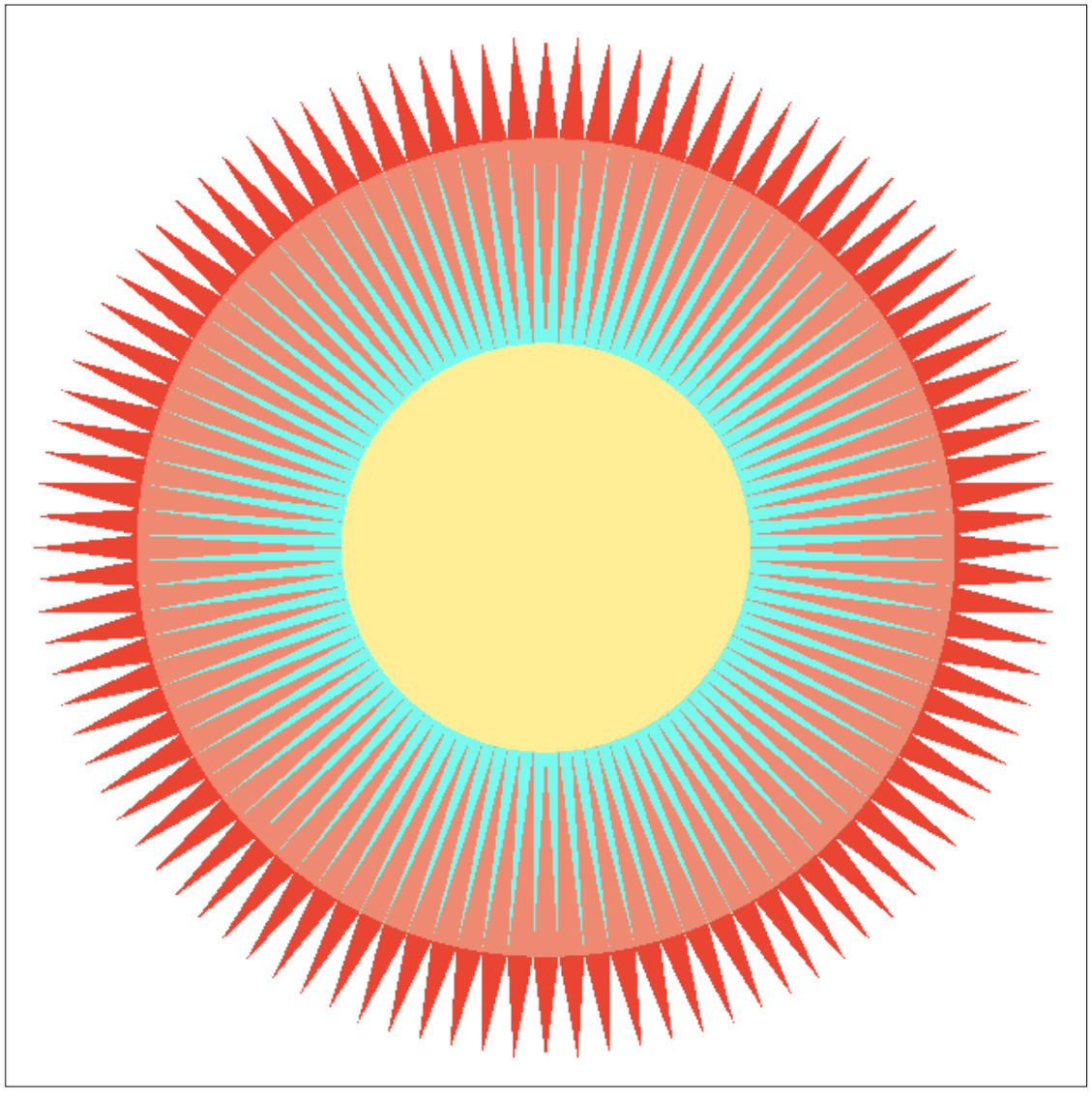
Jaggies!

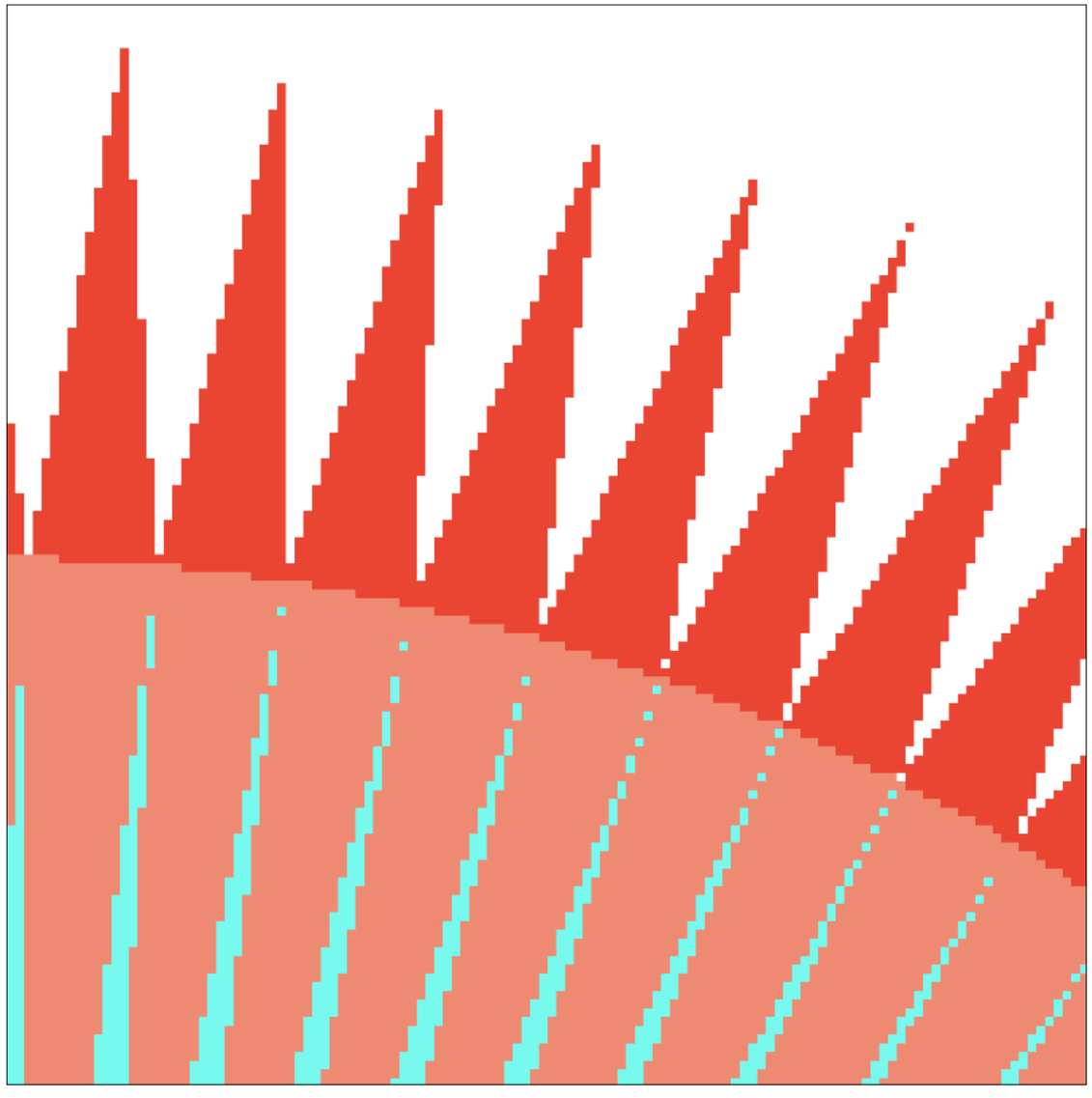
锯齿

Aliasing (Jaggies)

=> 抗锯齿，反走样！！！

信号的走样





Is this the best we can do?

Thank you!

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