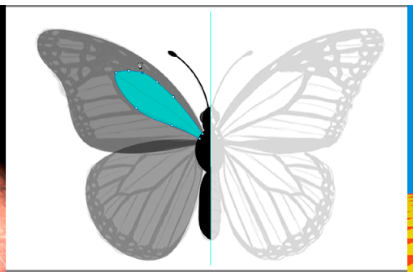
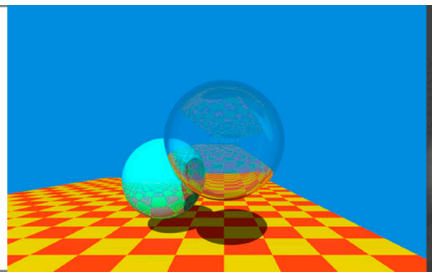
Introduction to Computer Graphics

GAMES101, Lingqi Yan, UC Santa Barbara

Lecture 5:
Rasterization 1 (Triangles)

光栅化.


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

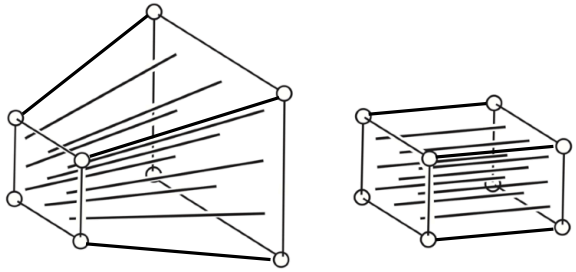
- Viewing (观测) transformation
  - View (视图) / Camera transformation
  - Projection (投影) transformation
    - Orthographic (正交) projection
    - Perspective (透视) projection

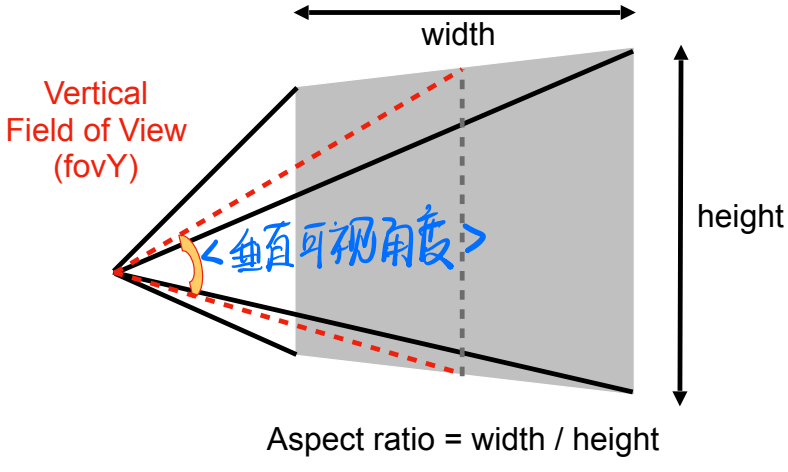
Today

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

Perspective Projection

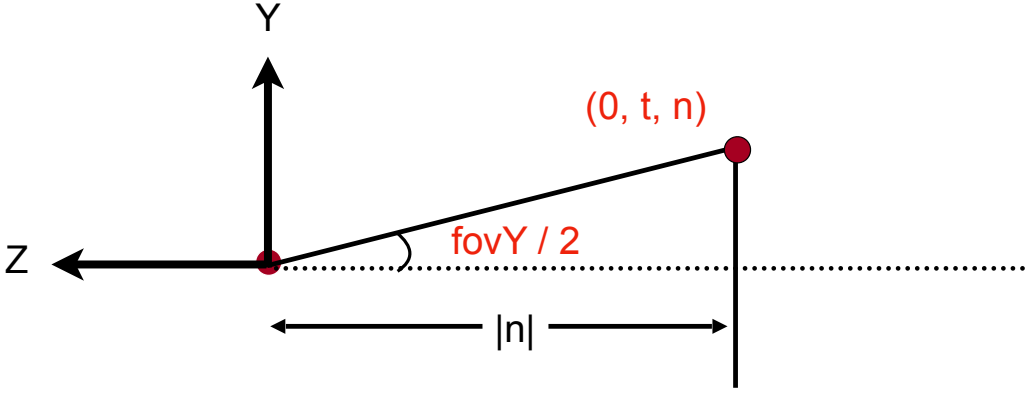
- What's near plane's l, r, b, t then?
  - If explicitly specified, good
  - Sometimes people prefer: vertical **field-of-view** (fovY) and **aspect ratio** <长宽比>
    (assume symmetry i.e. l = -r, b = -t)





Perspective Projection

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



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

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

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 ?

标准立方体到屏幕

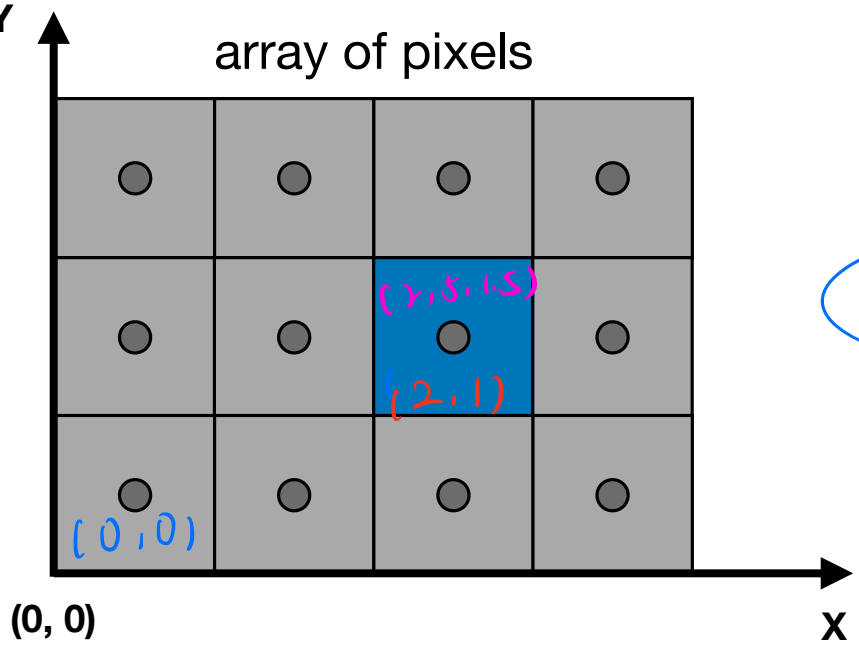
Canonical Cube to Screen

- What is a screen?
  - An array of pixels
  - Size of the array: resolution
  - A typical kind of raster display 典型光栅显示器(屏幕)
- 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

定义屏幕空间

- 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

像素坐标.

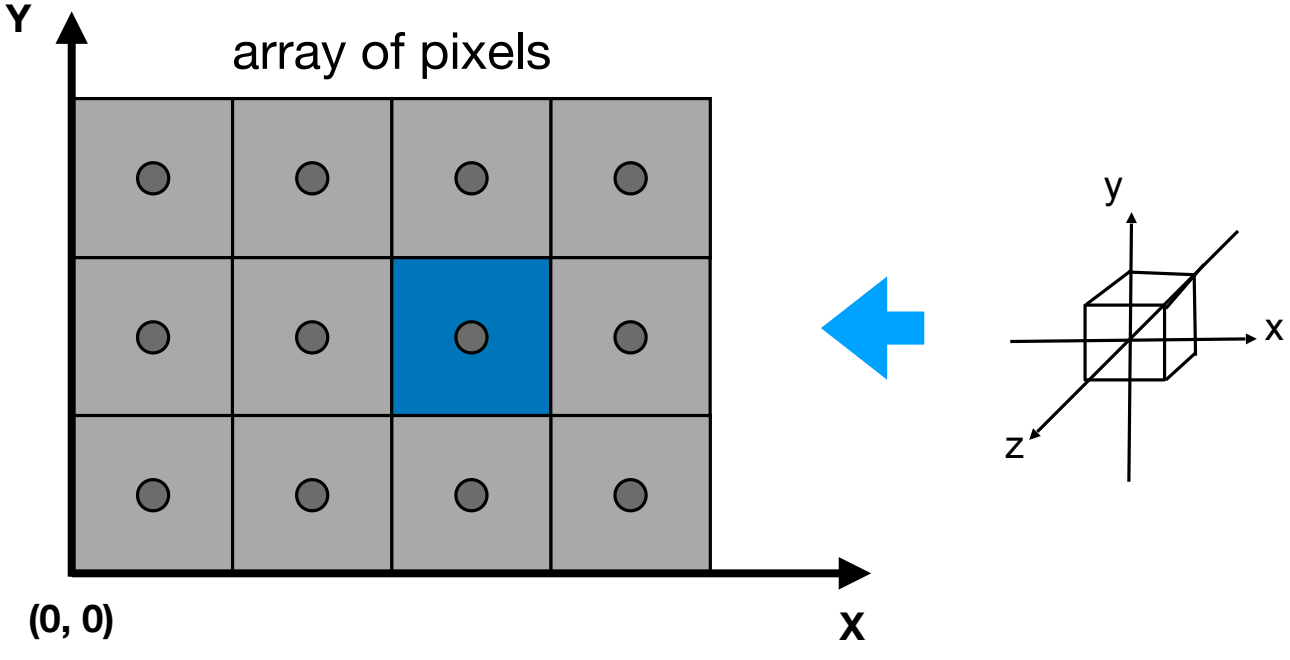
Pixels’ indices are from
(0, 0) to (width - 1, height - 1)

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

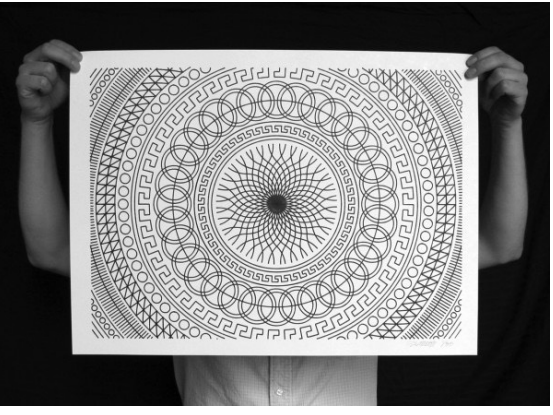
- Irrelevant to z
- Transform in xy plane: [-1, 1]^2 to [0, width] x [0, height]
- Viewport transform matrix:

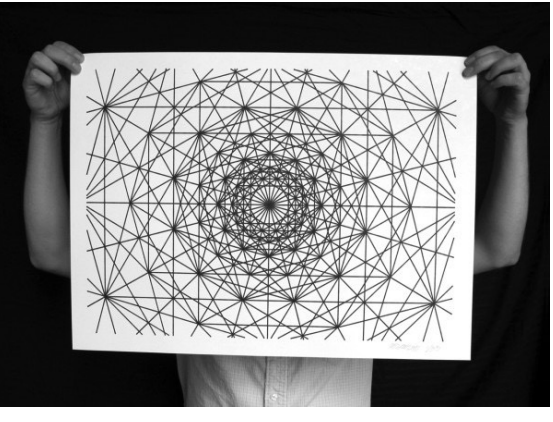
$$M_{viewport} = \begin{pmatrix} \frac{width}{2} & 0 & 0 & \frac{width}{2} \\ 0 & \frac{height}{2} & 0 & \frac{height}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Next: Rasterizing Triangles into Pixels

Drawing Machines

CNC Sharpie Drawing Machine





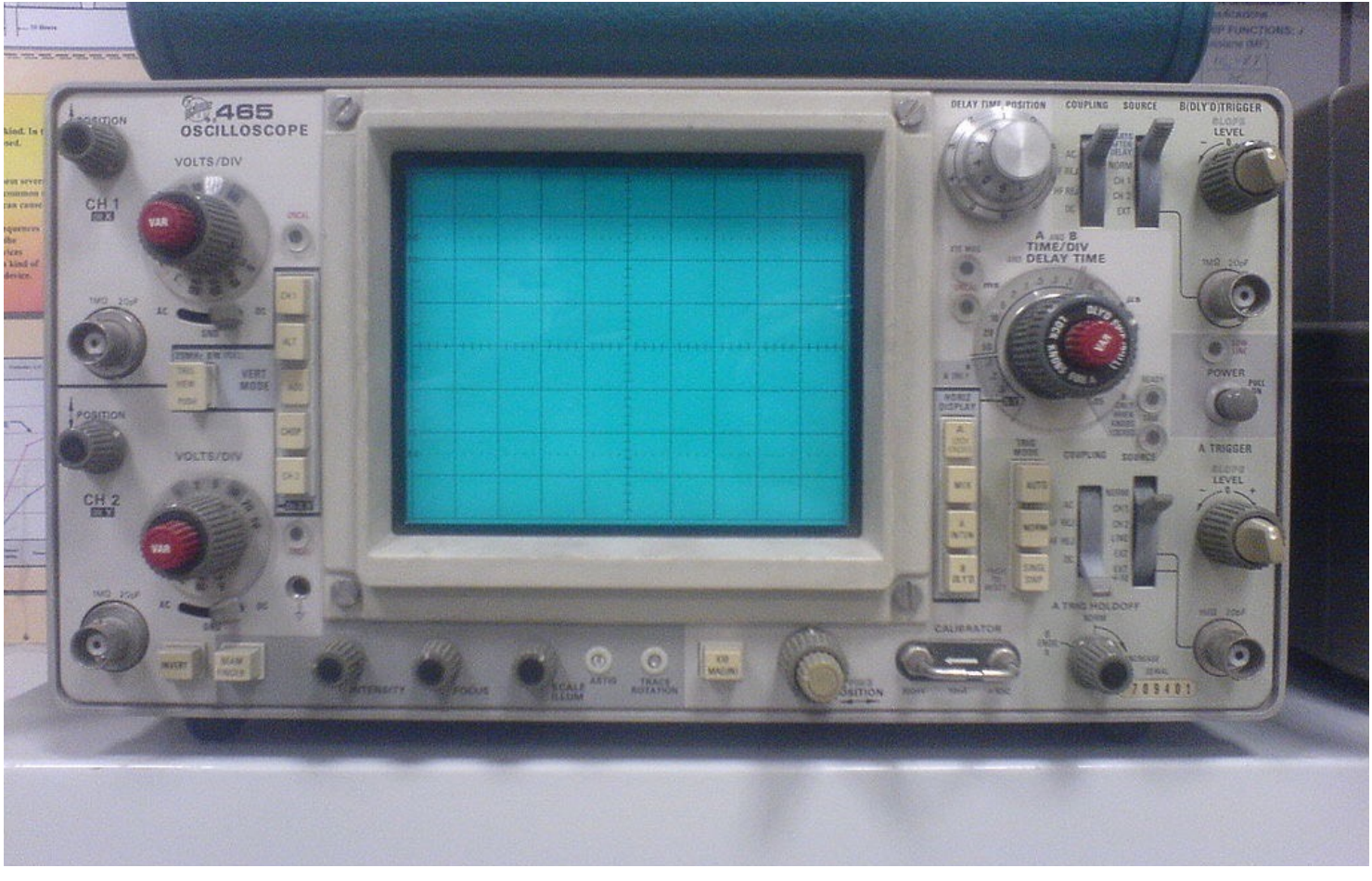
Aaron Panone with Matt W. Moore

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

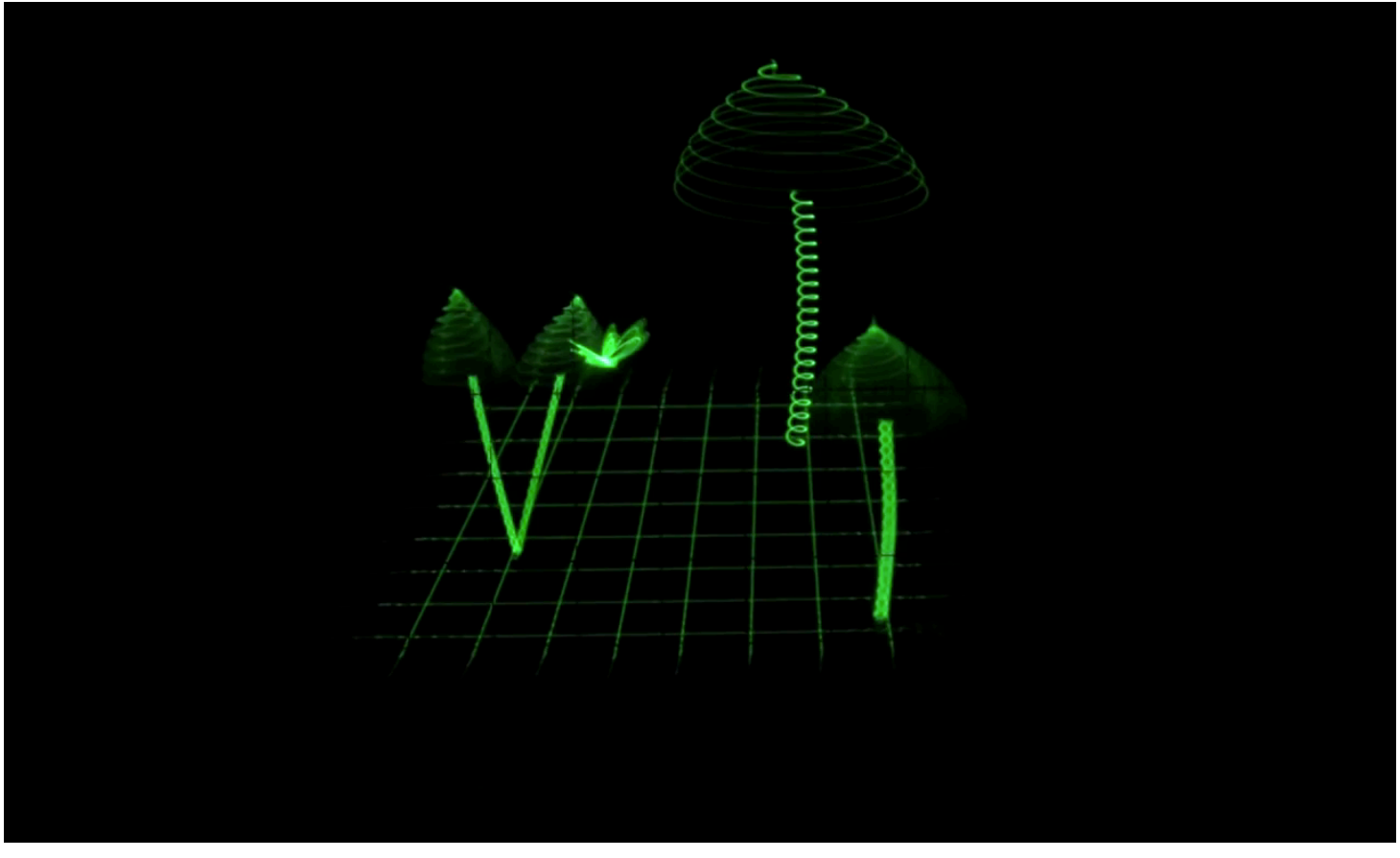
Laser Cutters

Different Raster Displays

Oscilloscope



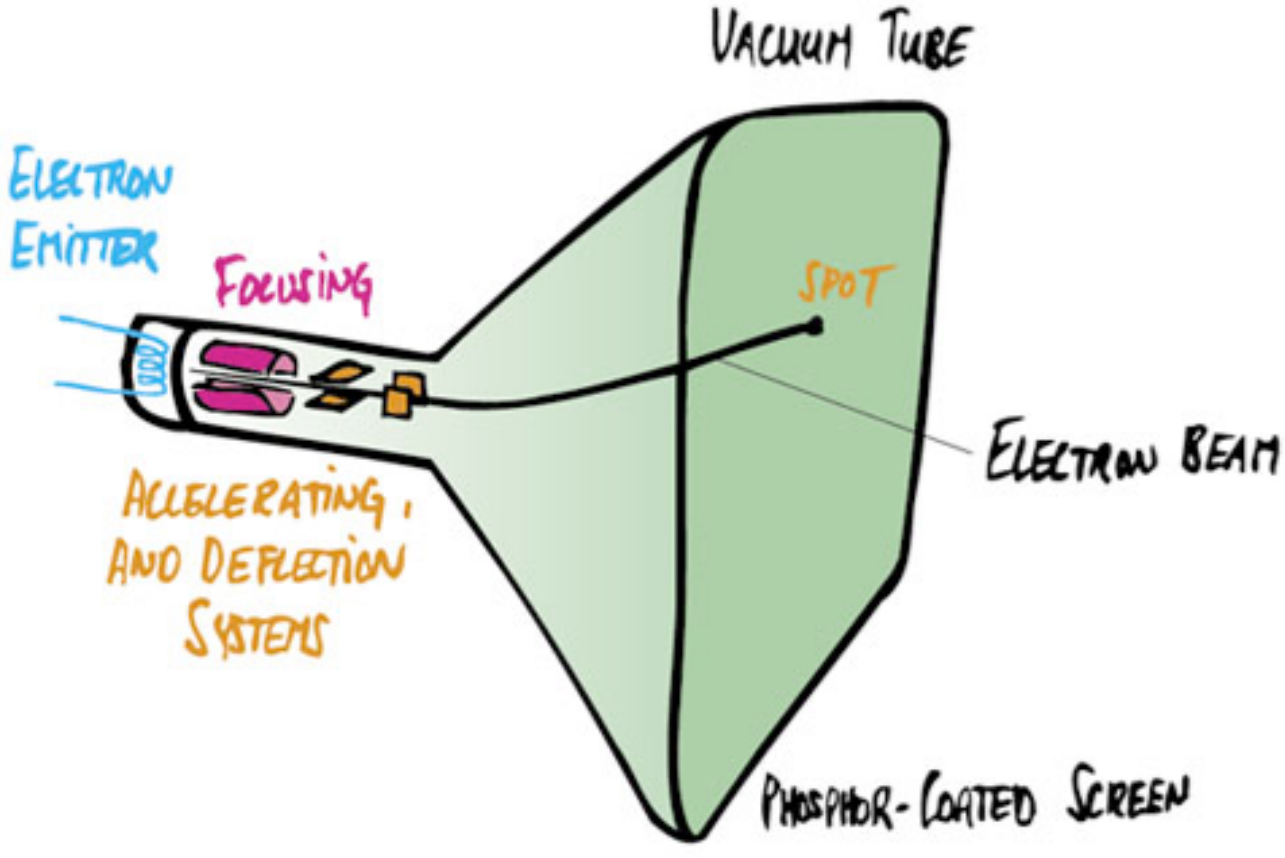
Oscilloscope Art



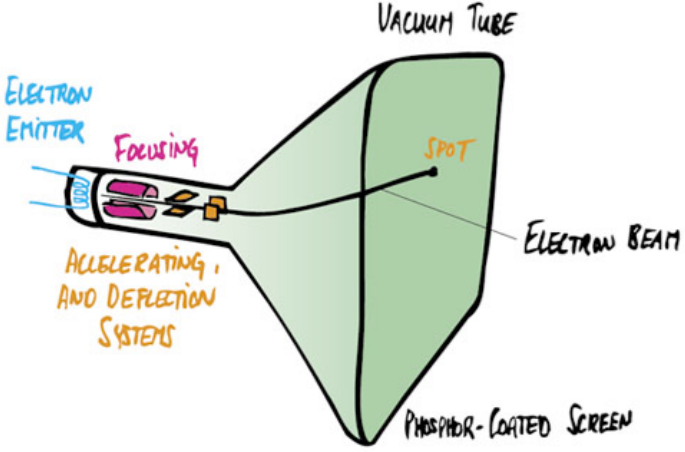
Jerobeam Fenderson

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

Cathode Ray Tube

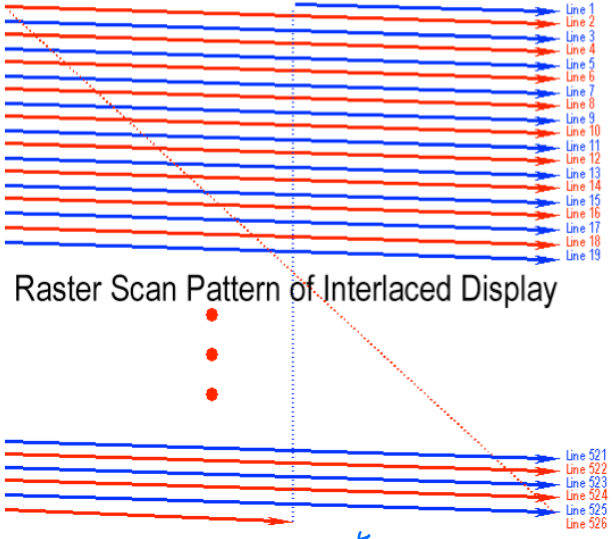


Television - Raster Display CRT



阴极射线管

Cathode Ray Tube

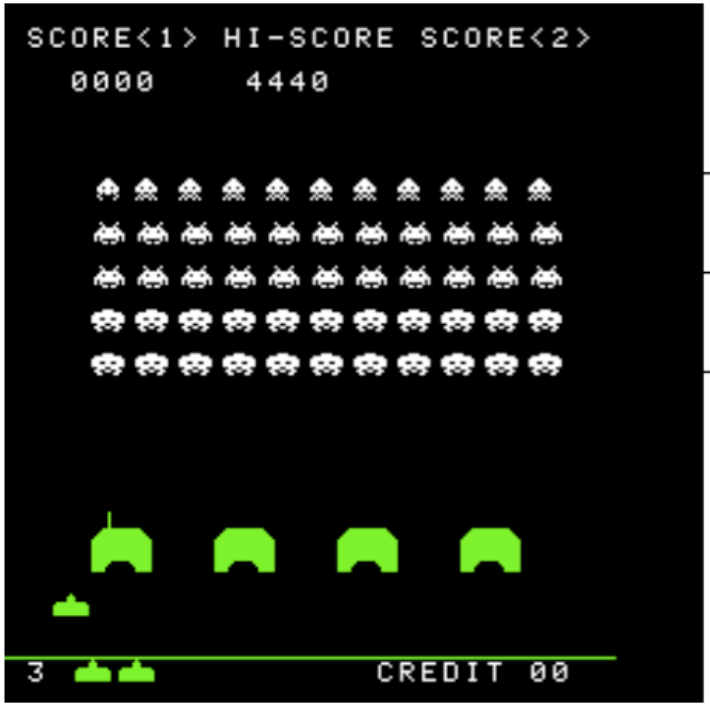


光栅扫描

Raster Scan

(modulate intensity)

Frame Buffer: Memory for a Raster Display



DAC =
Digital to Analog Convertors

Analog

Digital

Image = 2D array of colors

Flat Panel Displays

Low-Res LCD Display

Color LCD, OLED, …

LCD (Liquid Crystal Display) Pixel

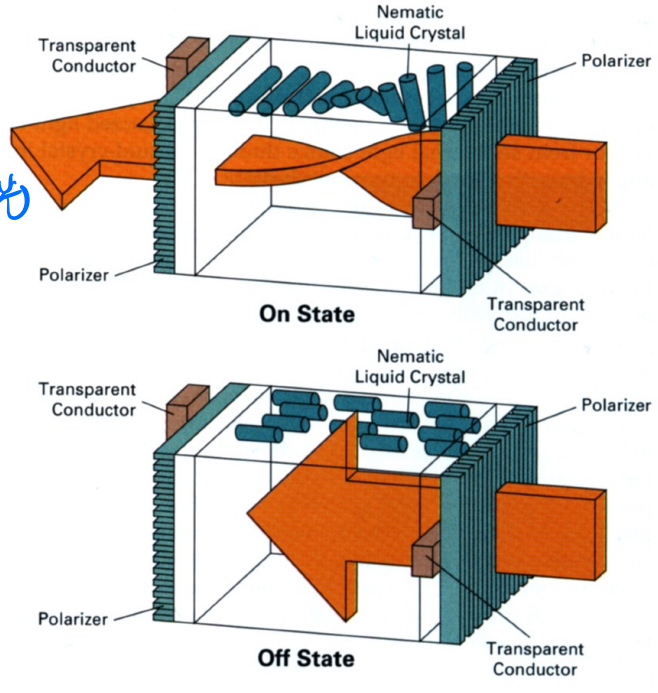
液晶显示

Principle: block or transmit light by twisting polarization

扭曲偏振光

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

Intermediate intensity levels by partial twist



[H&B fig. 2-16]

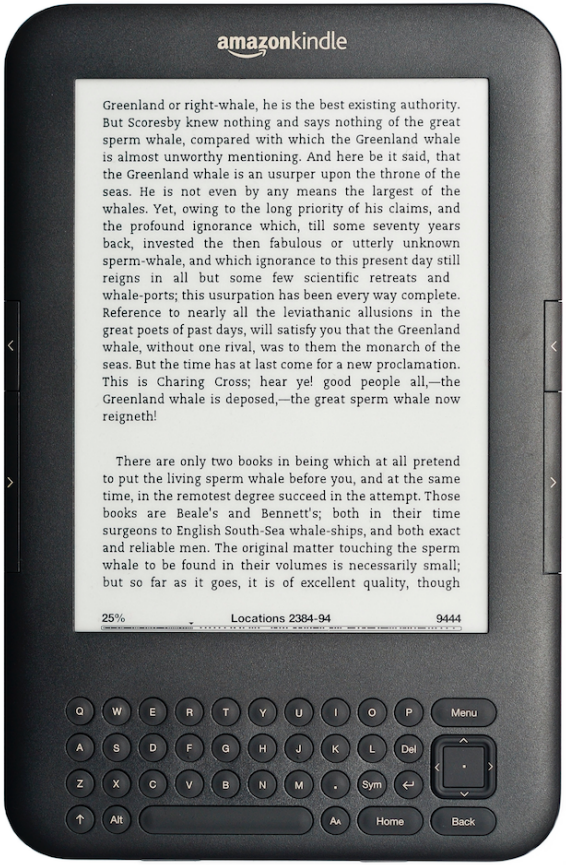
LED Array Display

Light emitting diode array

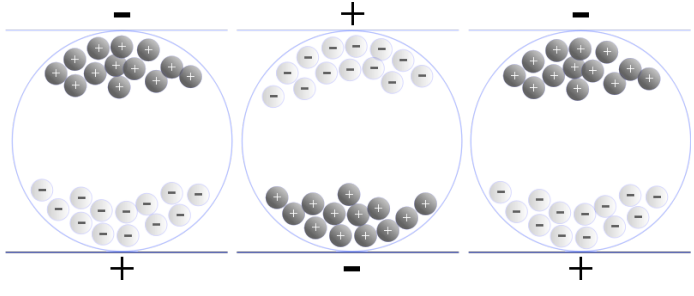
发光二极管阵列

Electrophoretic (Electronic Ink) Display

电泳(电子墨水)显示.



缺点：刷新率很低.



[Wikimedia Commons —Senarclens]

光栅化

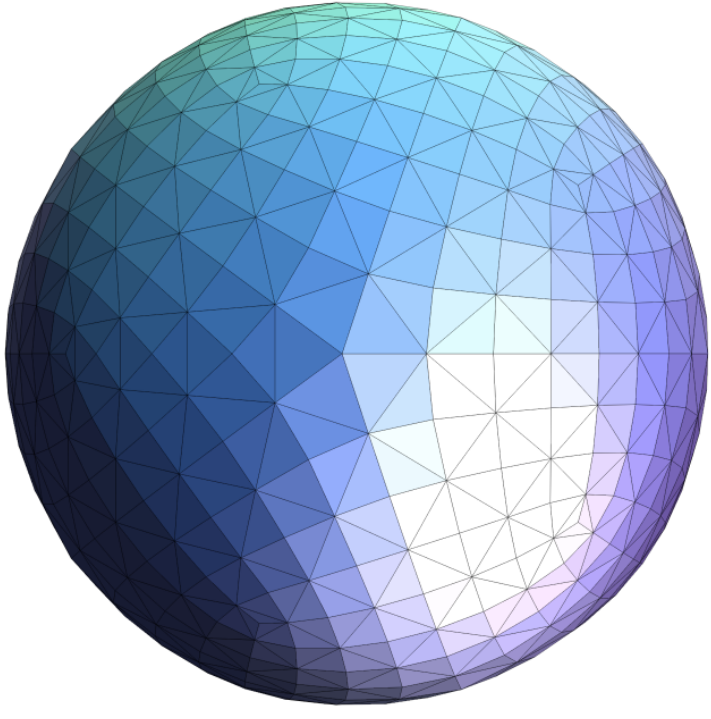
Rasterization:

Drawing to Raster Displays

绘制到光栅显示

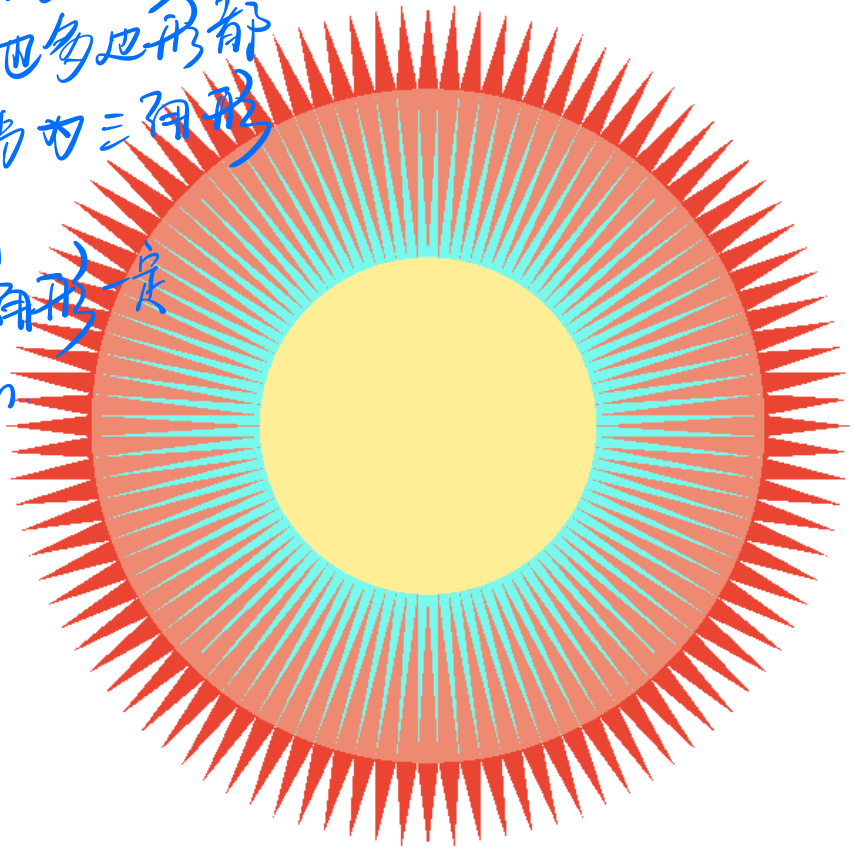
Polygon Meshes 多边形网格

Triangle Meshes 三角形网格.



Triangle Meshes

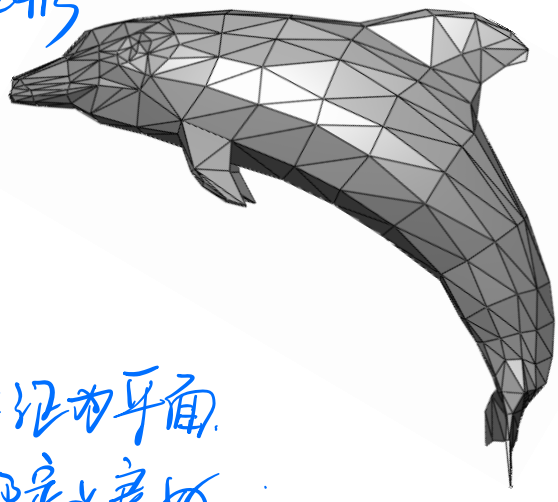
1. 最基础的多边形
2. 任何其他多边形都可以拆分为三角形
3. 给定3个点连成的三角形一定是平面的



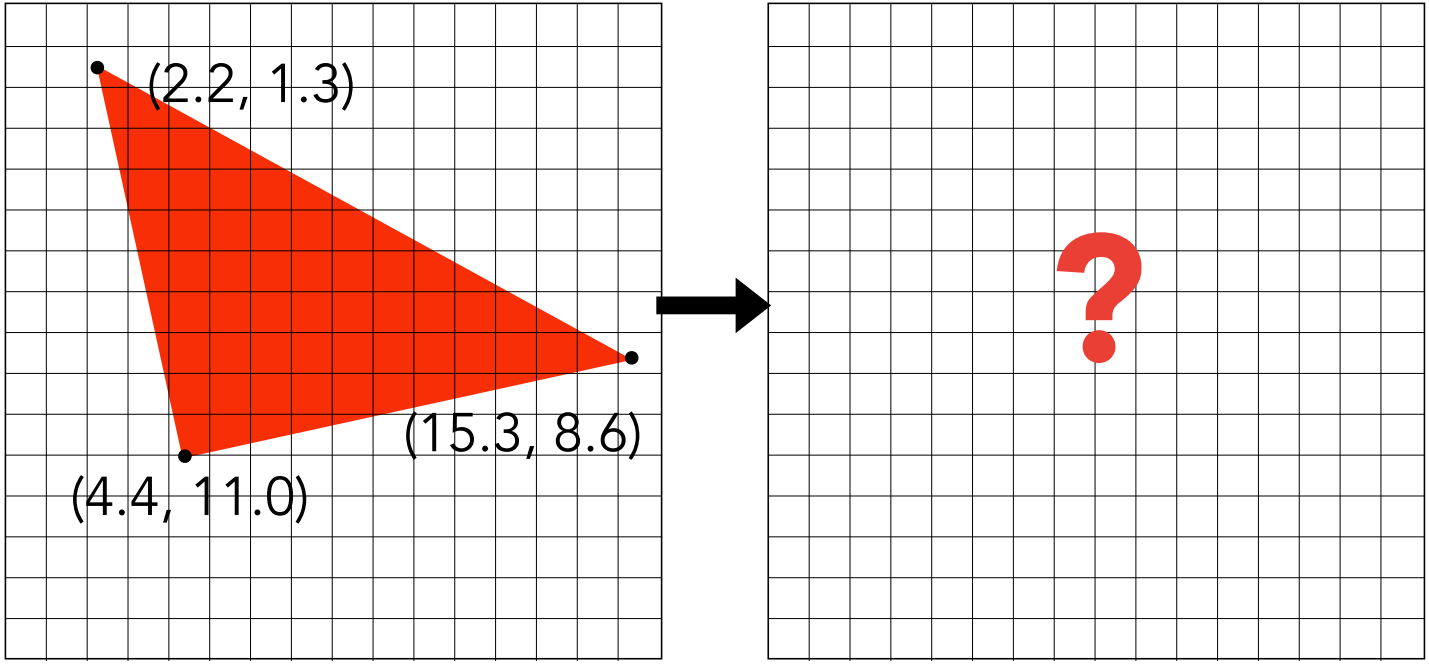
Triangles - Fundamental Shape Primitives

Why triangles?

- Most basic polygon 最基本多边形
  - Break up other polygons 分解其他多边形
- Unique properties
  - Guaranteed to be planar 保证为平面
  - Well-defined interior 内/外部定义良好
  - Well-defined method for interpolating values at vertices over triangle (barycentric interpolation) 重心插值



What Pixel Values Approximate a Triangle?



Input: position of triangle vertices projected on screen

Output: set of pixel values approximating triangle

投影在屏幕上的三角形顶点位置.

近似的三角形的像素值集

A Simple Approach: Sampling

Sampling a Function

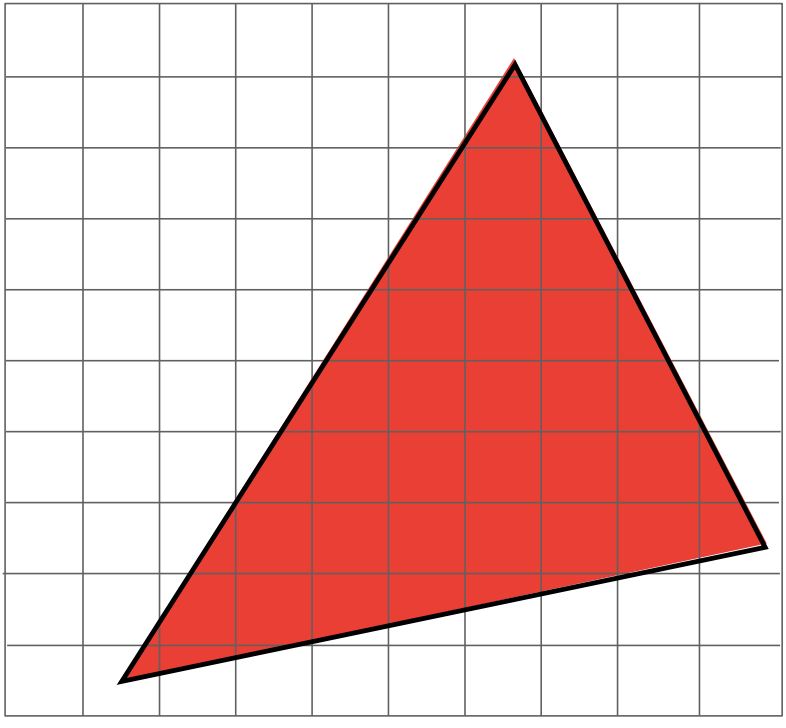
Evaluating a function at a point is sampling.

We can discretize a function by sampling.

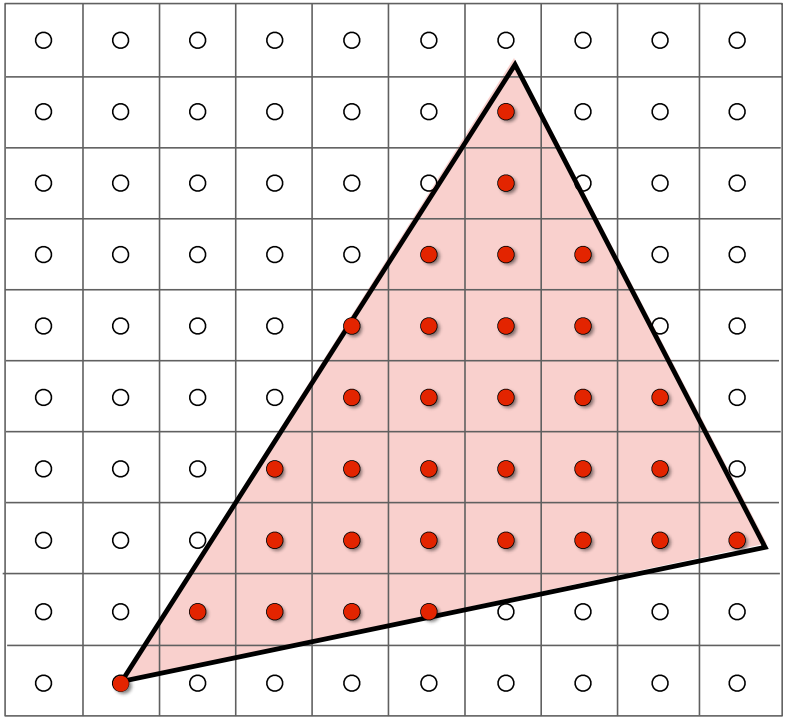
```
for (int x = 0; x < xmax; ++x)
    output[x] = f(x);
```

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

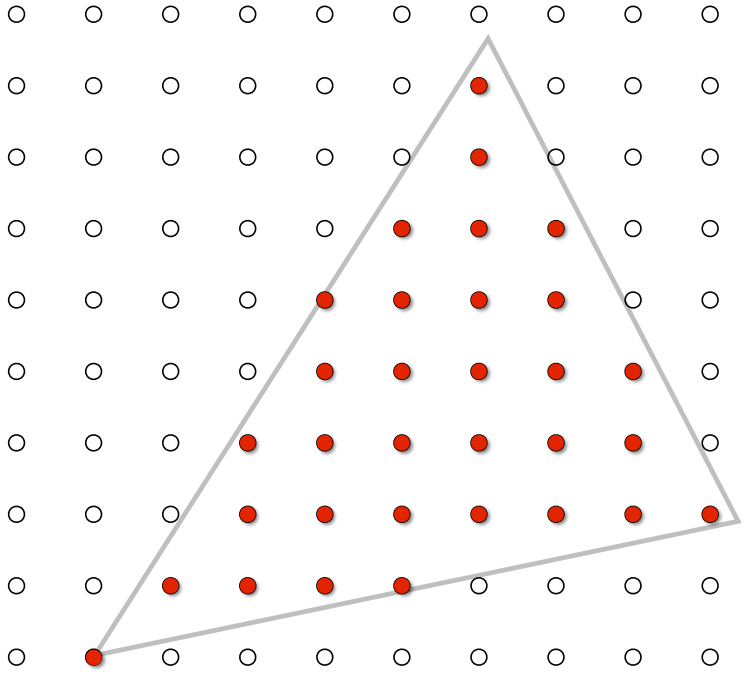
Rasterization As 2D Sampling



Sample If Each Pixel Center Is Inside Triangle

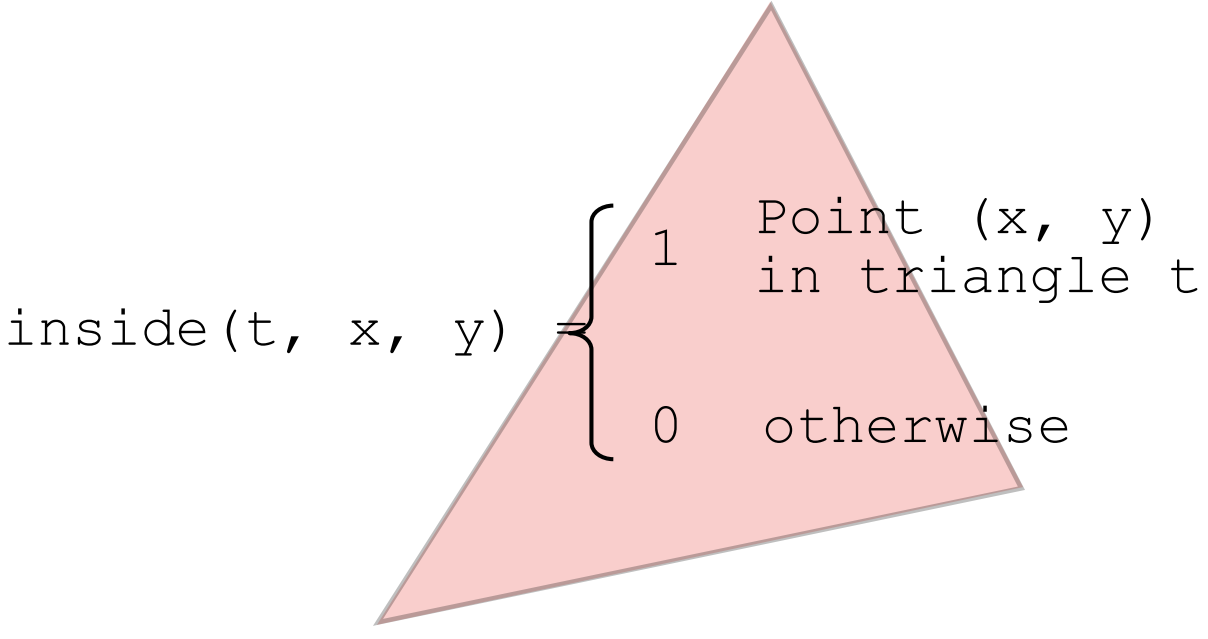


Sample If Each Pixel Center Is Inside Triangle



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

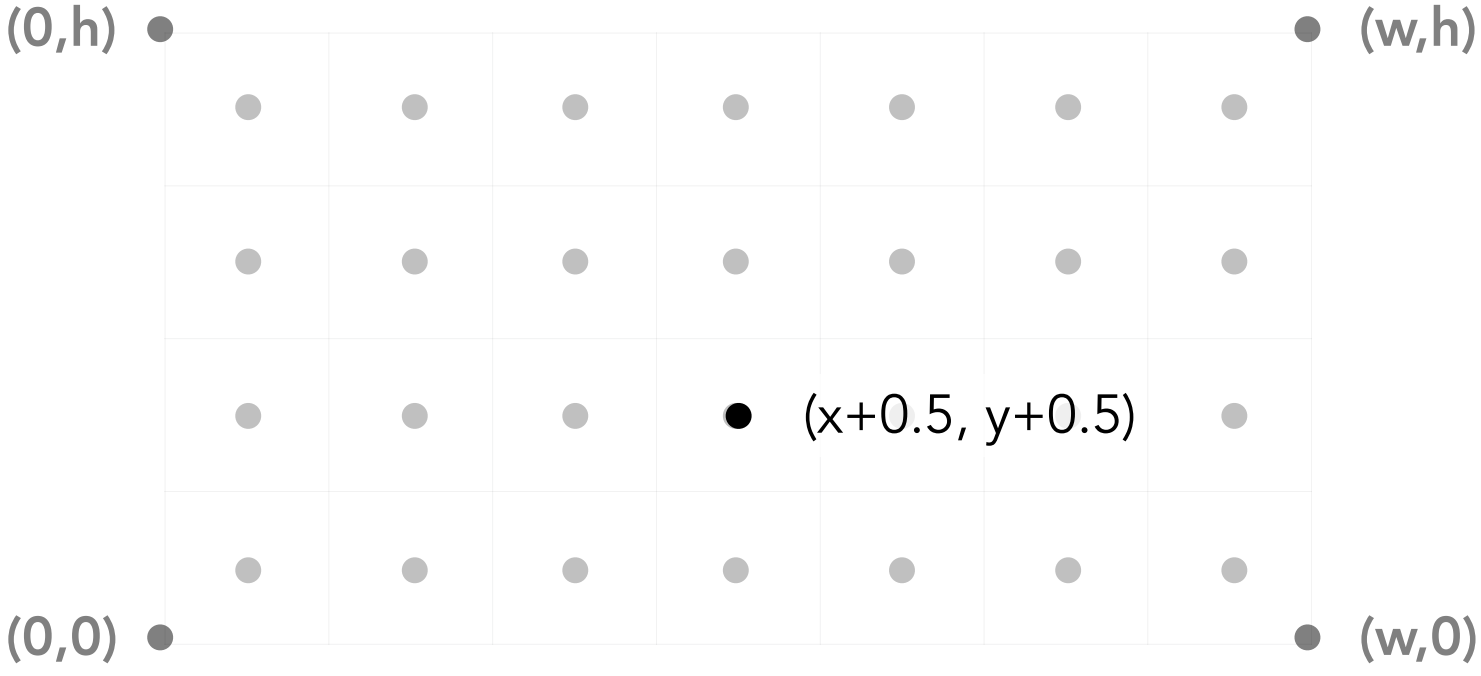
x, y: not necessarily integers



Rasterization = Sampling A 2D Indicator Function

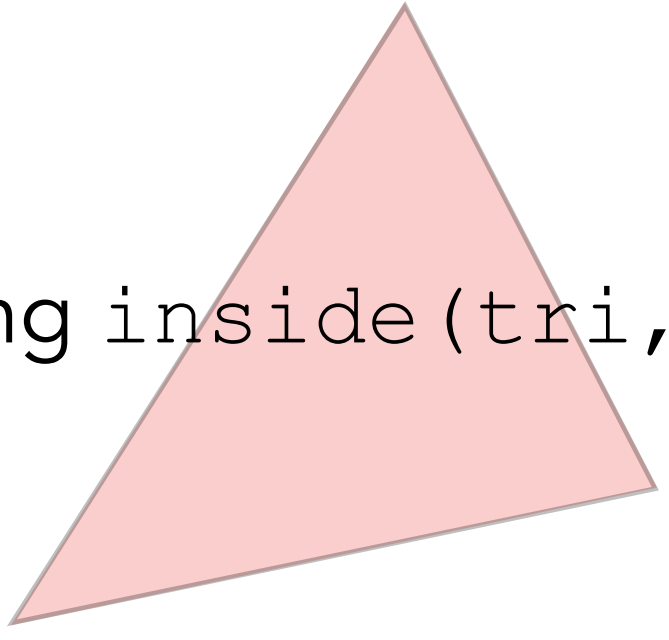
```
for (int x = 0; x < xmax; ++x)
  for (int y = 0; y < ymax; ++y)
    image[x][y] = inside(tri,
                         x + 0.5,
                         y + 0.5);
```

Recall: Sample Locations

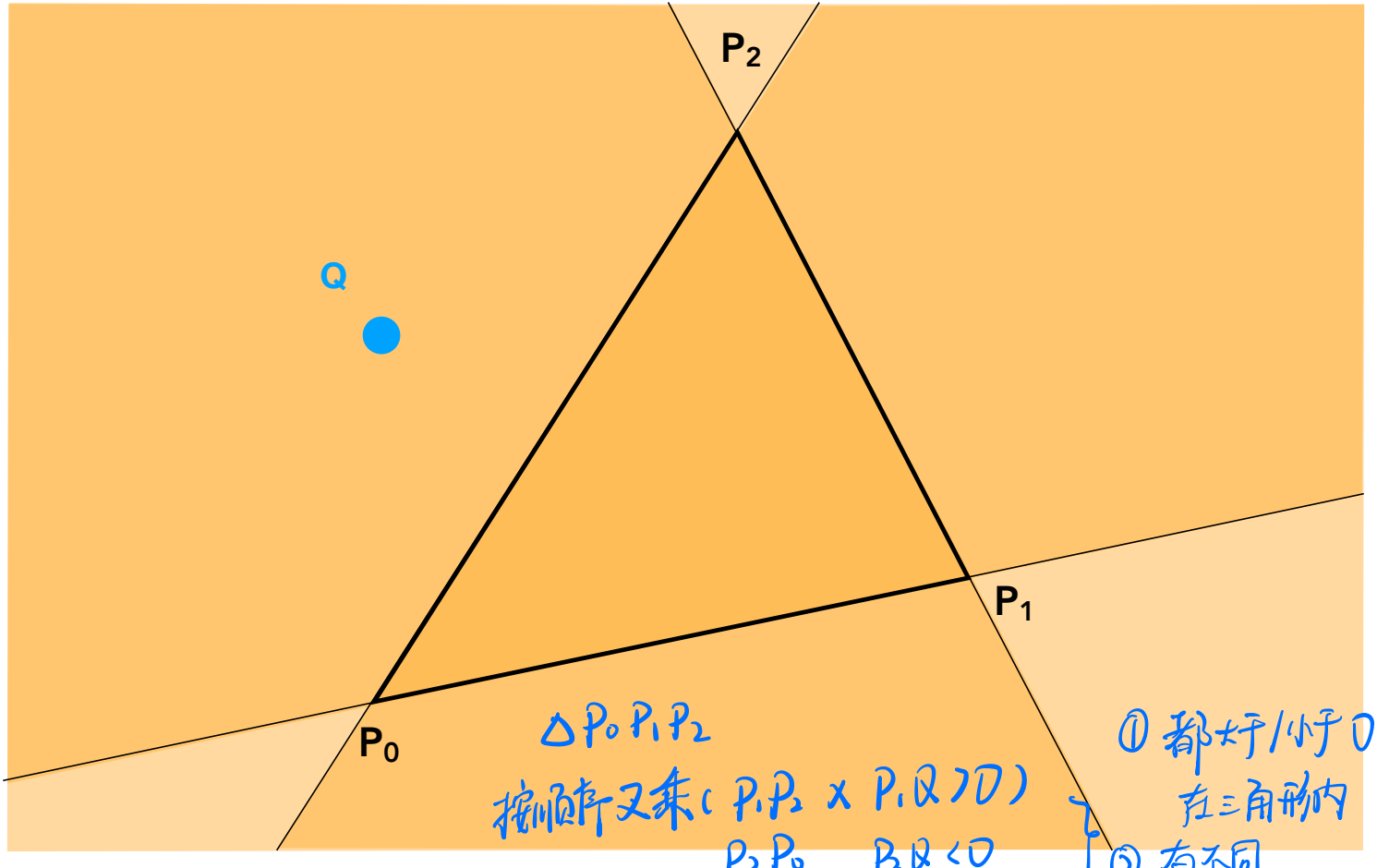


Sample location for pixel (x, y)

Evaluating `inside(tri, x, y)`



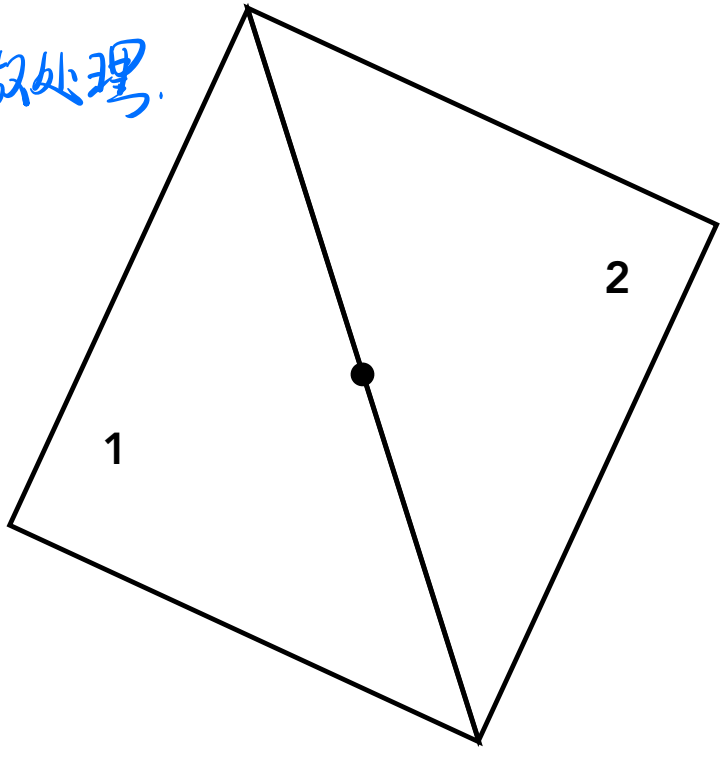
Inside? Recall: Three Cross Products!



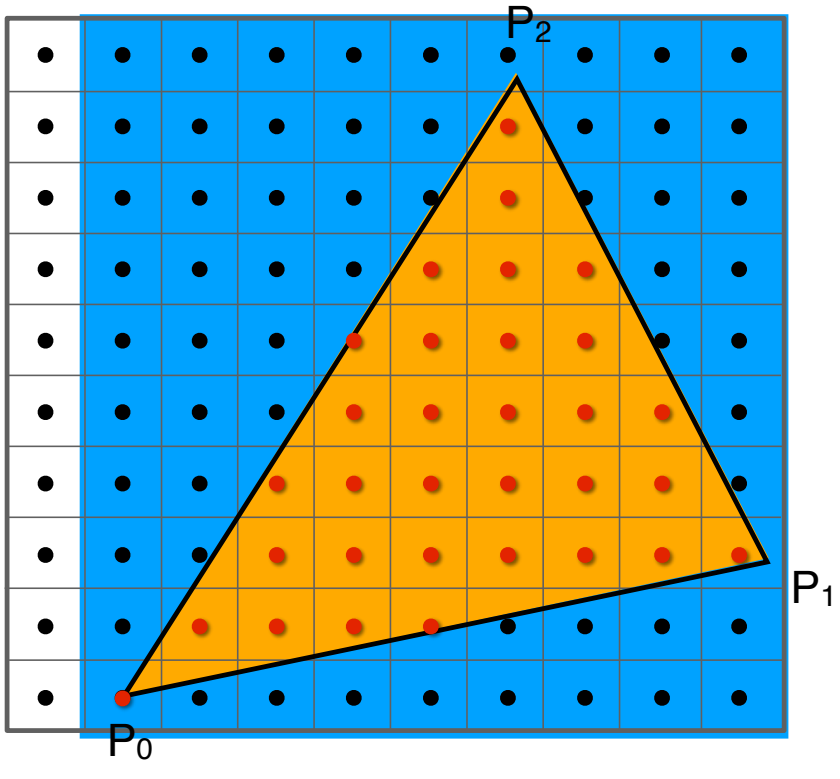
Edge Cases (Literally)

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

※ 边界点我们不做处理.



Checking All Pixels on the Screen?

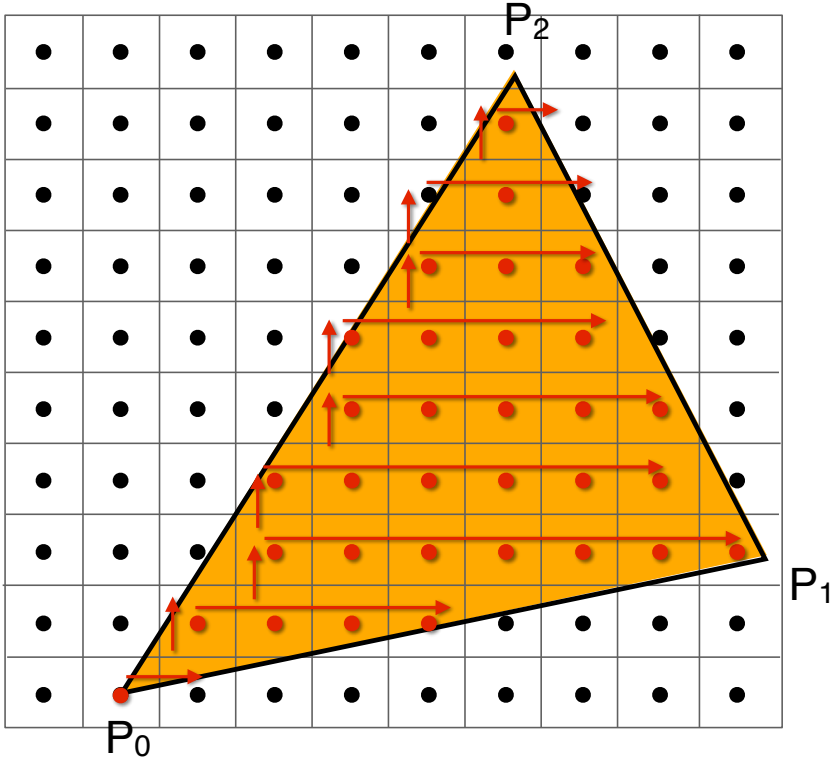


Use a **Bounding Box!**

包围盒(轴向) AABB.

增量三角形遍历

Incremental Triangle Traversal (Faster?)



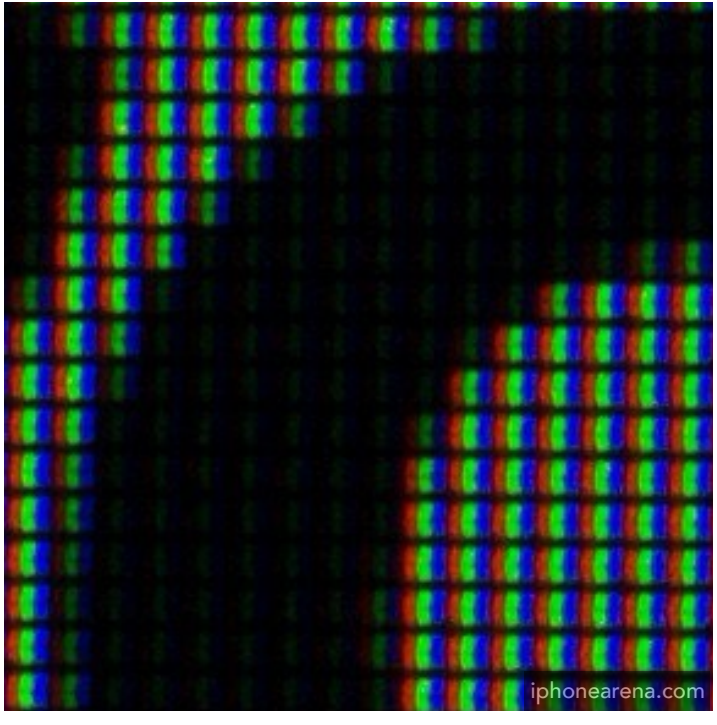
suitable for thin and rotated triangles

适用于薄且旋转的三角形

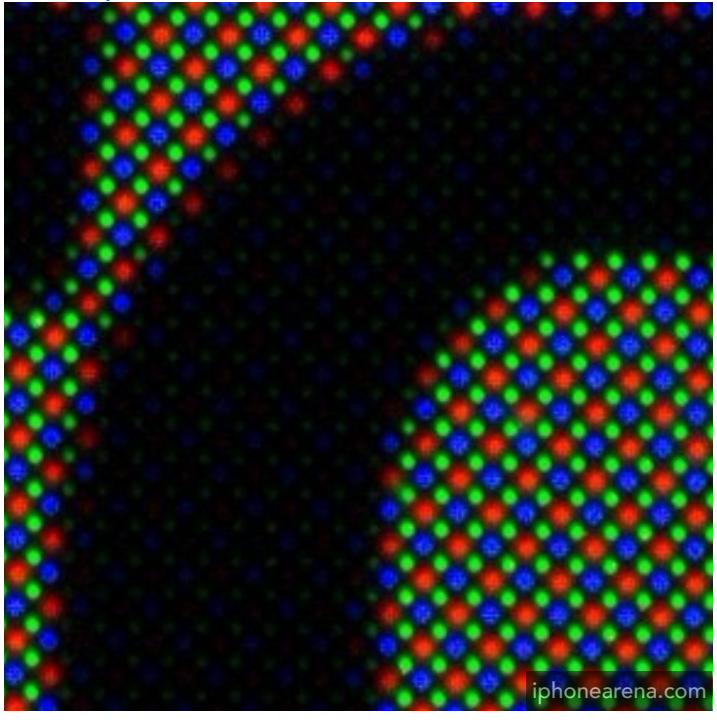
Rasterization on Real Displays

Real LCD Screen Pixels (Closeup)

Bayer pattern



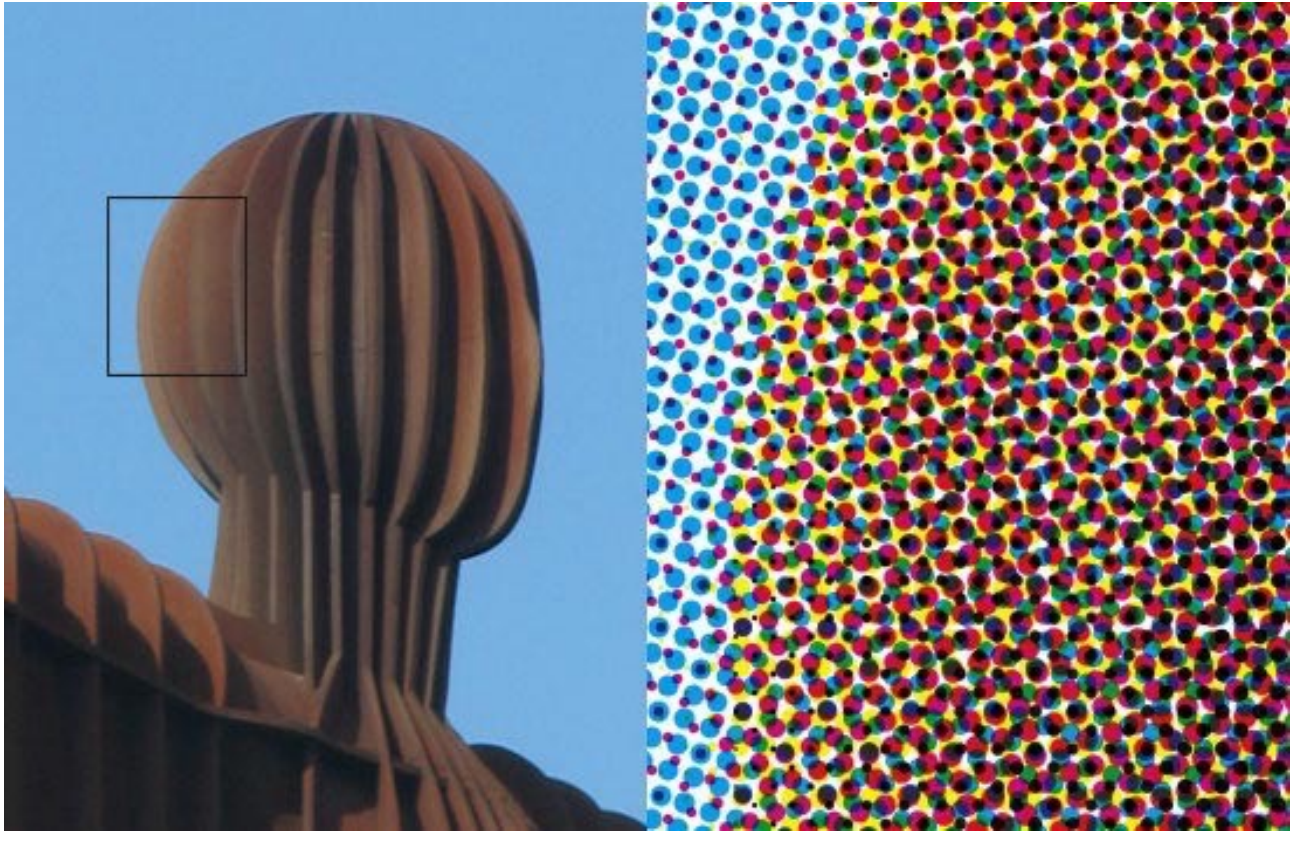
iPhone 6S



Galaxy S5

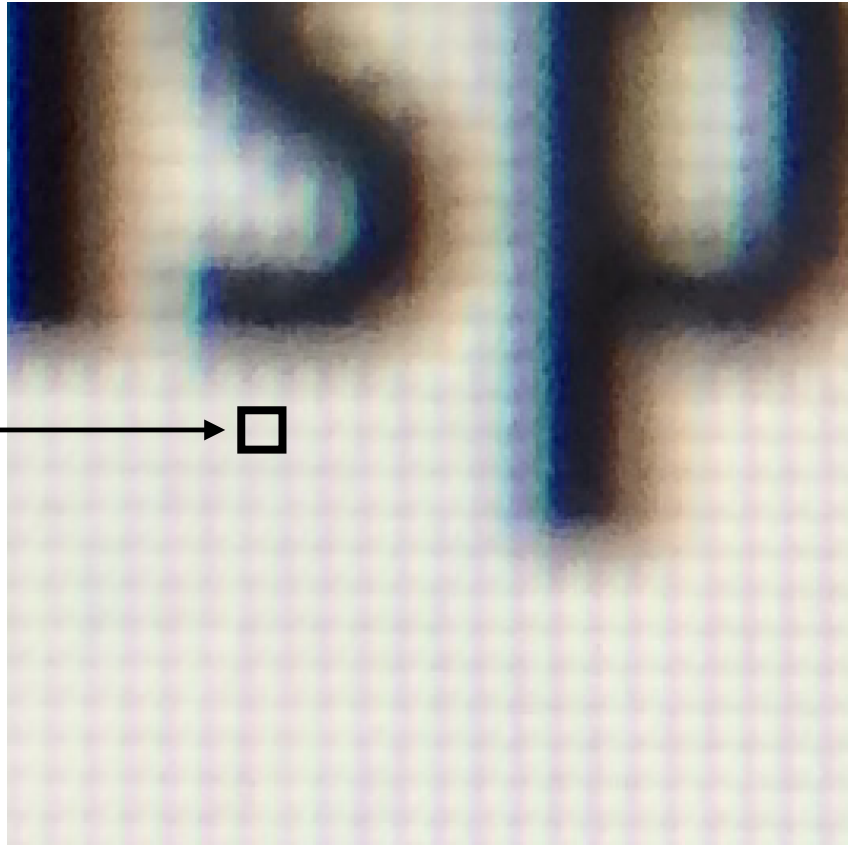
Notice R,G,B pixel geometry! But in this class, we will assume a colored square full-color pixel.

Aside: What About Other Display Methods?



Color print: observe half-tone pattern

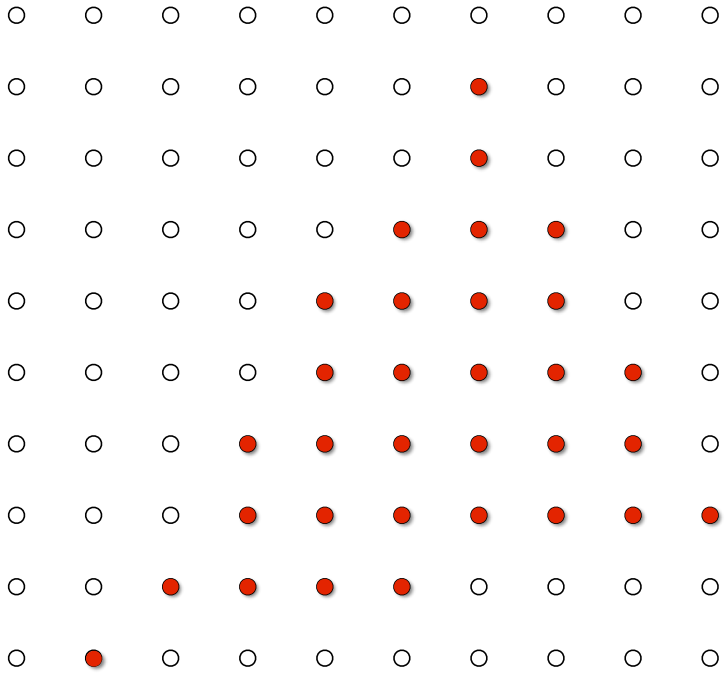
Assume Display Pixels Emit Square of Light



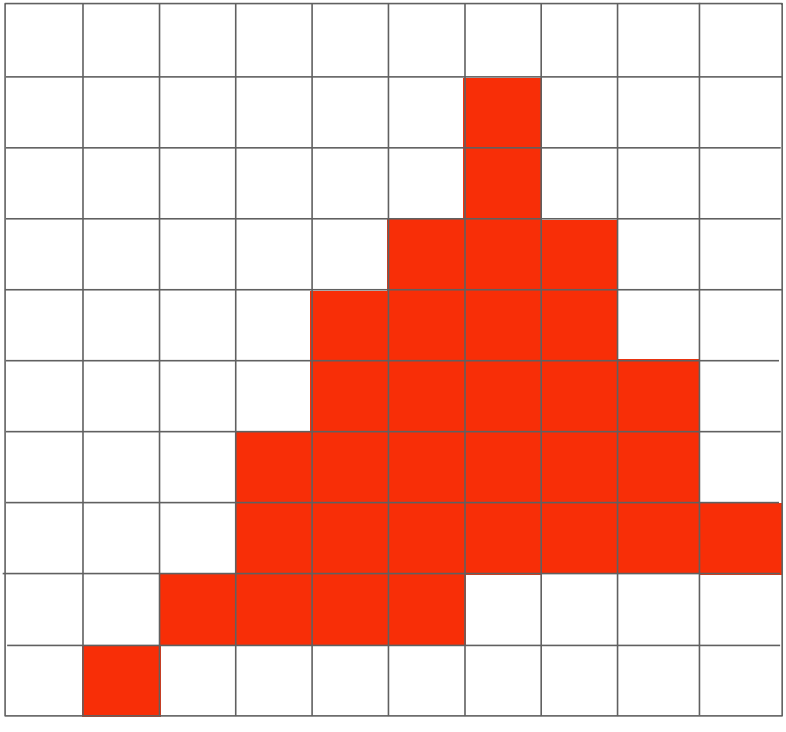
LCD pixel
on laptop

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

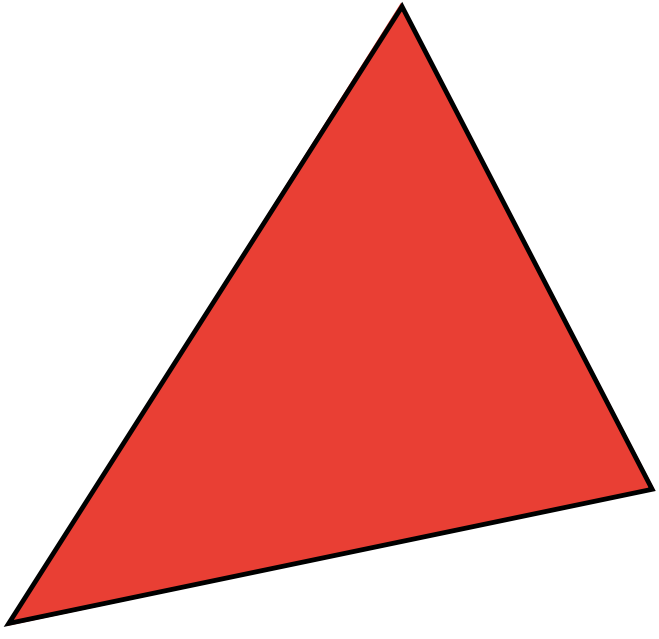
So, If We Send the Display the Sampled Signal



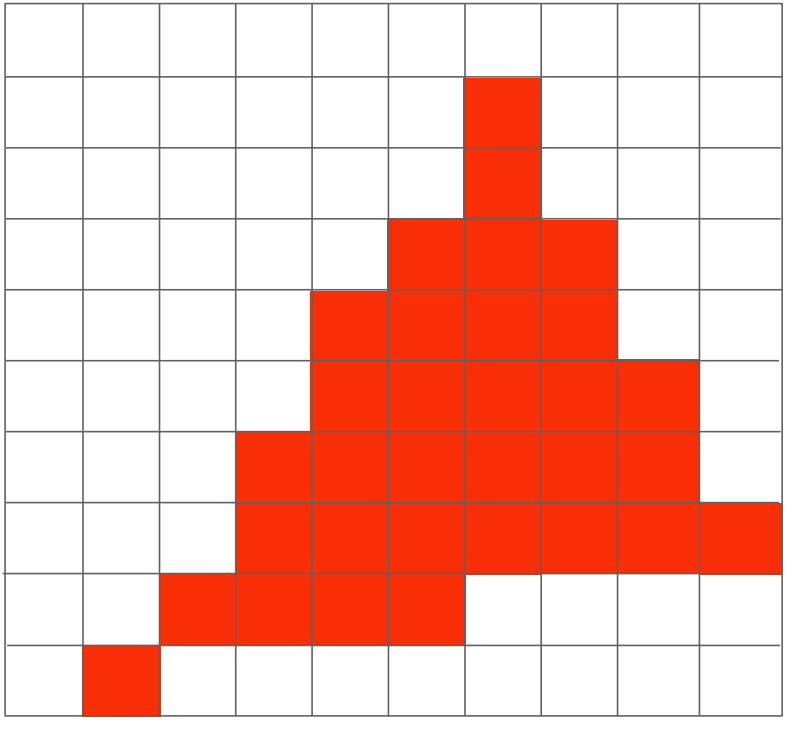
The Display Physically Emits This Signal



Compare: The Continuous Triangle Function

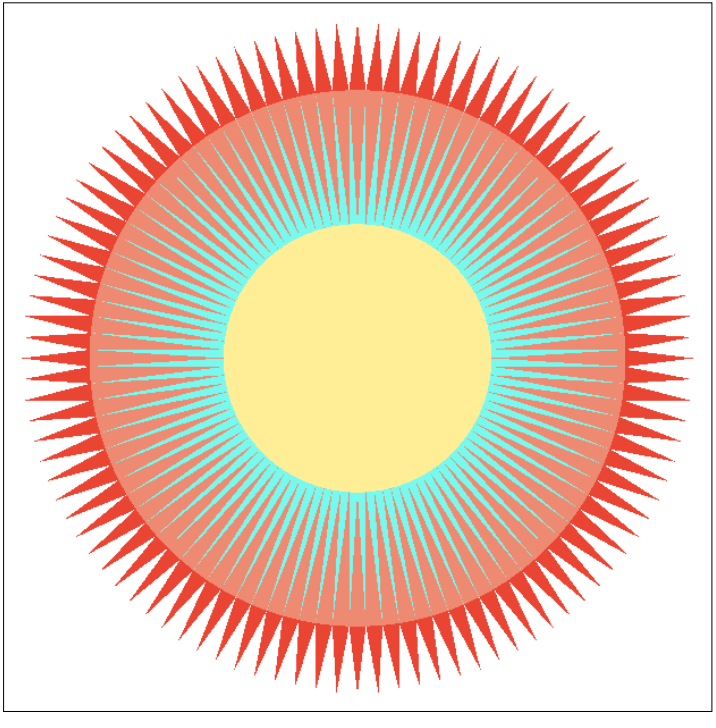


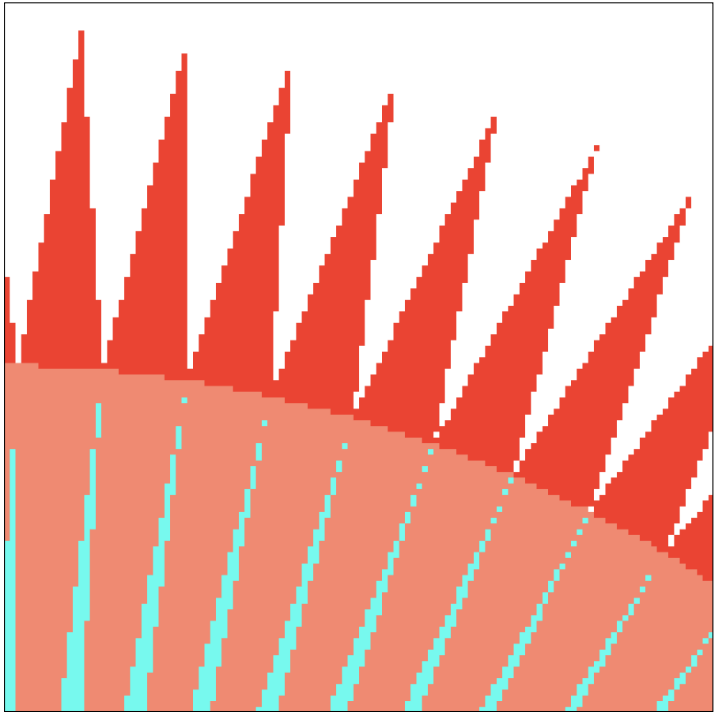
What's Wrong With This Picture?



锯齿. 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!)