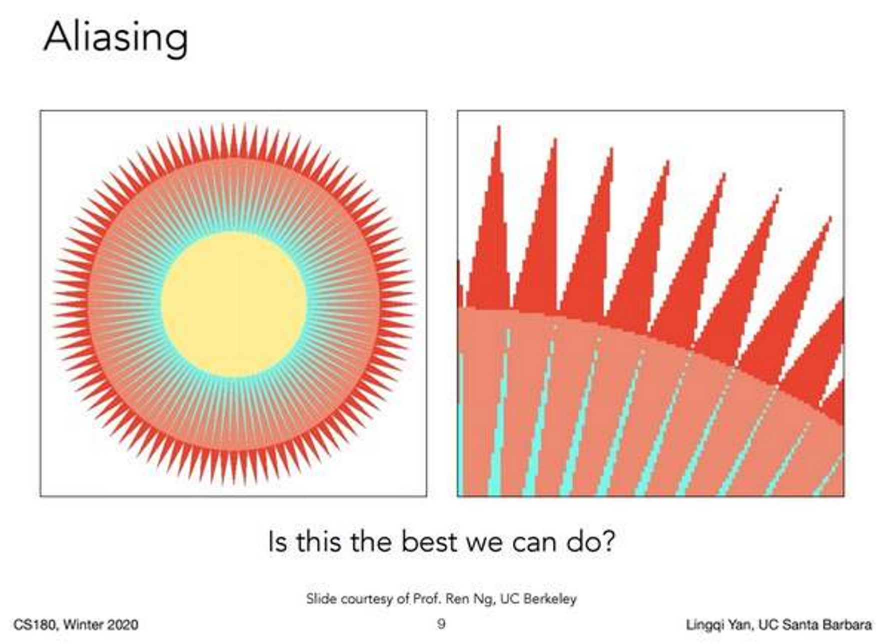
Lecture 06 Rasterization 2 (Antialiasing and Z-buffering)

2020年12月26日 17:27

走样与反走样



Wagon Wheel Illusion (False Motion)

采用上一讲的光栅化方法，会出现走样（Aliasing）现象
采样中出现的误差，错误，或不准确，称作Artifacts
例如：锯齿，摩尔纹，旋转车轮错觉等

Sampling Artifacts in Computer Graphics

Artifacts due to sampling - "Aliasing"

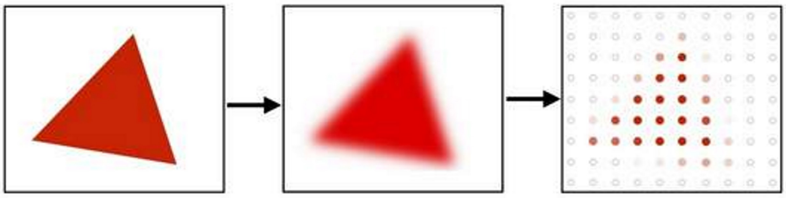
- Jaggies – sampling in space
- Moire – undersampling images
- Wagon wheel effect – sampling in time
- [Many more] …

Behind the Aliasing Artifacts

- Signals are changing too fast (high frequency), but sampled too slowly

这些artifacts背后的原因：
信号变化速度太快（高频率）
但采样速度相对太慢

Rasterization: Antialiased Sampling



Pre-Filter

(remove frequencies above Nyquist) (?)

Sample

Note antialiased edges in rasterized triangle where pixel values take intermediate values

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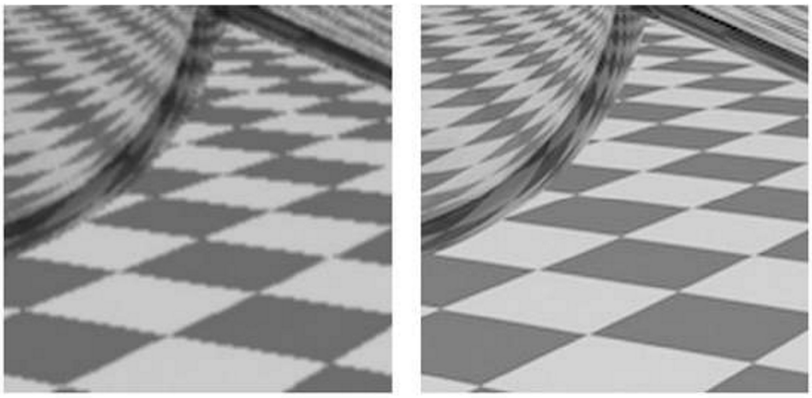
一种反走样的思想：先模糊，再采样

模糊的部分，可以看到光栅化以后像素颜色取了个中间值（intermediate values）

Antialiasing vs Blurred Aliasing



(Sample then filter, WRONG!) (Filter then sample)

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注意：如果先采样，再模糊，不能得到反走样的结果，而是得到blurred alias，模糊的锯齿

But why?

1. Why undersampling introduces aliasing?
2. Why pre-filtering then sampling can do antialiasing?

Let's dig into fundamental reasons

And look at how to implement antialiased rasterization

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思考背后原理：

（1）为何欠采样会导致走样？

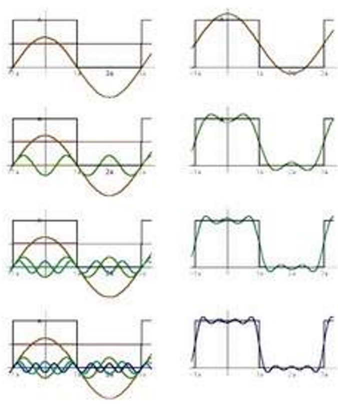
（2）为何pre-filtering（预滤波，前置滤波）可以反走样？

频域 frequency domain

Fourier Transform

Represent a function as a weighted sum of sines and cosines

Joseph Fourier 1768 - 1830



$$f(x) = \frac{A}{2} + \frac{2A\cos(t\omega)}{\pi} - \frac{2A\cos(3t\omega)}{3\pi} + \frac{2A\cos(5t\omega)}{5\pi} - \frac{2A\cos(7t\omega)}{7\pi} + \cdots$$

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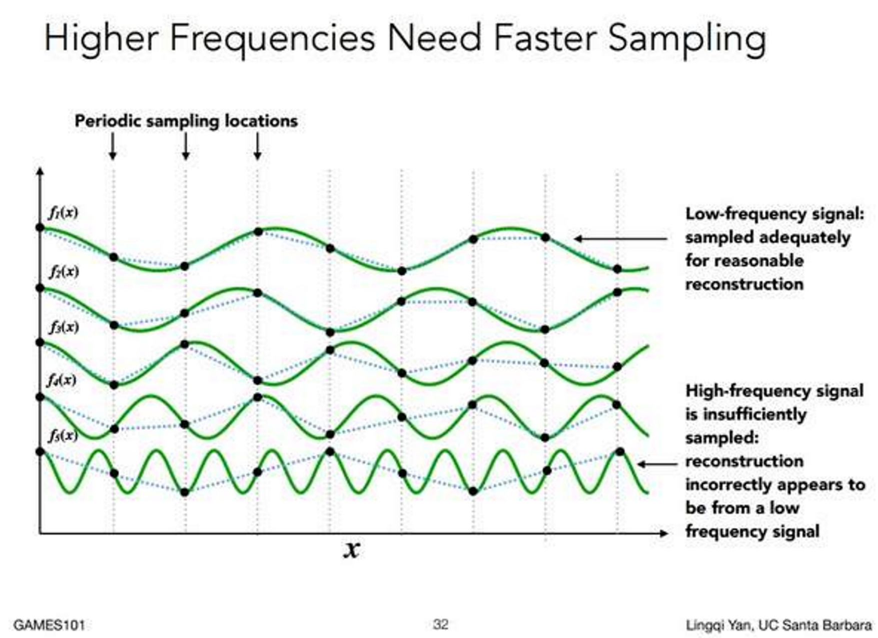
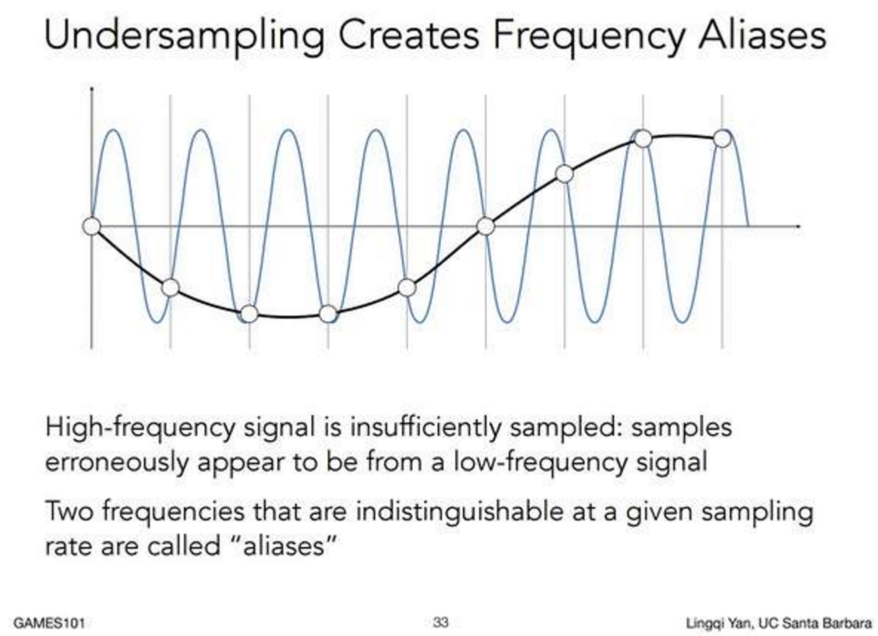
傅立叶变换：任何一个周期函数，都能用sin， cos及常数项表示



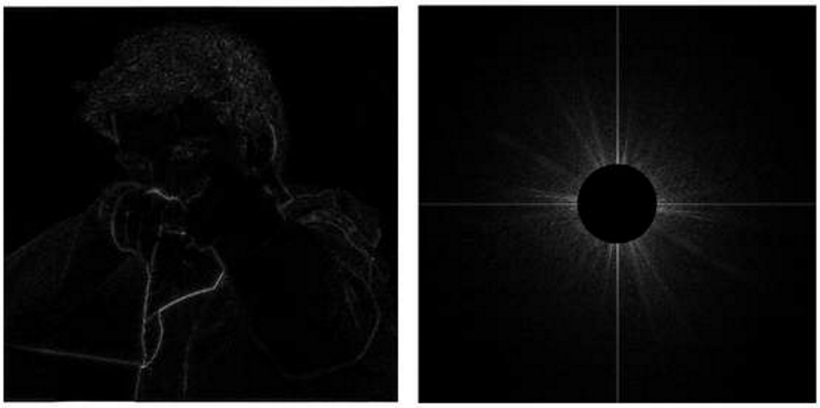
一个三角函数它有一定的频率，采样也需要有一个相应的频率，否则就容易失真。



走样：假设有两个完全不同的函数（蓝色线和黑色线），都在空心点采样，采样出来的结果都是黑色线，也就是两个不同的函数采样出来的结果是一样的，这就是“走样”。

傅里叶变换：可以把函数从时域变换到频域。时域的卷积等于频域的乘积

Filter Out Low Frequencies Only (Edges)



High-pass filter

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高通滤波：保留图像边界；

Filter Out High Frequencies (Blur)

Low-pass filter

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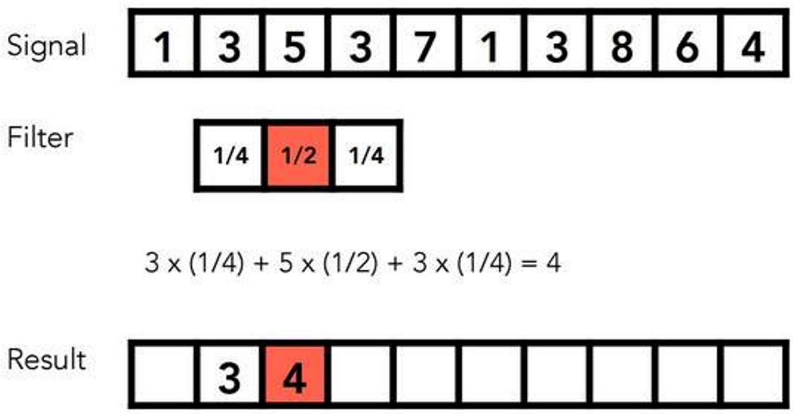
低通滤波：模糊图像边界。（边界：指图像中颜色发生剧烈变化的地方）

Filtering = Convolution
(= Averaging)

滤波=卷积（=求平均）

Convolution



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卷积
（不严谨的说法）按照一定的卷积核（权重）求某个点位周围带权的均值

Convolution Theorem

Convolution in the spatial domain is equal to multiplication in the frequency domain, and vice versa

Option 1:

- Filter by convolution in the spatial domain

Option 2:

- Transform to frequency domain (Fourier transform)
- Multiply by Fourier transform of convolution kernel
- Transform back to spatial domain (inverse Fourier)

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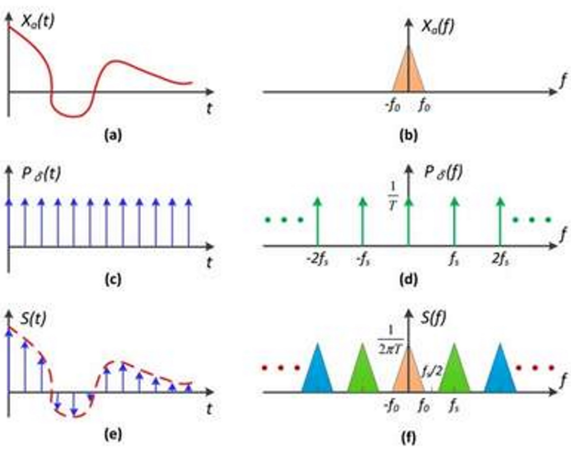
空间域的卷积相当于频域的乘积，反之亦然

Sampling = Repeating Frequency Contents



https://www.researchgate.net/figure/The-evolution-of-sampling-theorem-a-The-time-domain-of-the-band-limited-signal-and-b_fig5_301556095

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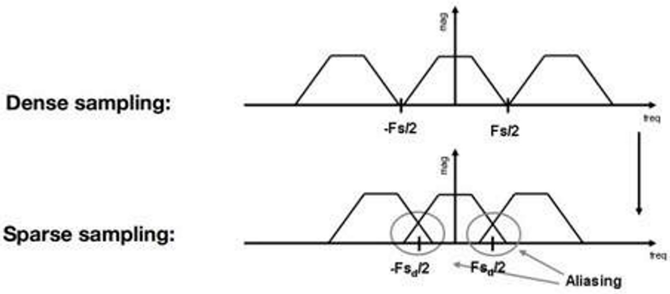
采样=重复频域的内容

Aliasing = Mixed Frequency Contents



走样=弄混了频率内容

How Can We Reduce Aliasing Error?

Option 1: Increase sampling rate

- Essentially increasing the distance between replicas in the Fourier domain
- Higher resolution displays, sensors, framebuffers…
- But: costly & may need very high resolution

Option 2: Antialiasing

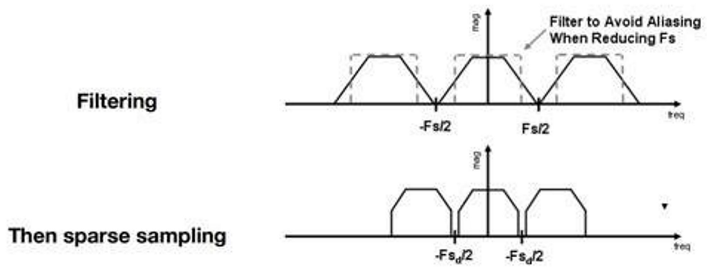
- Making Fourier contents "narrower" before repeating
- i.e. Filtering out high frequencies before sampling

如何减少走样误差?

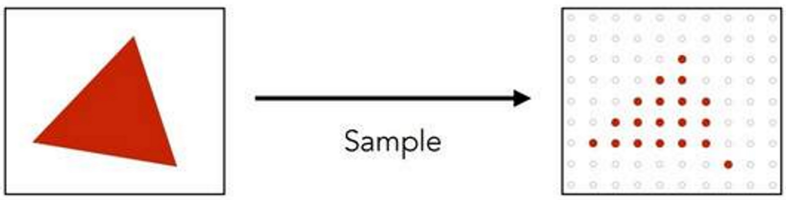
增加采样率：终极方法，但开销很大

反走样：先做模糊（低通滤波），再做采样

Antialiasing = Limiting, then repeating



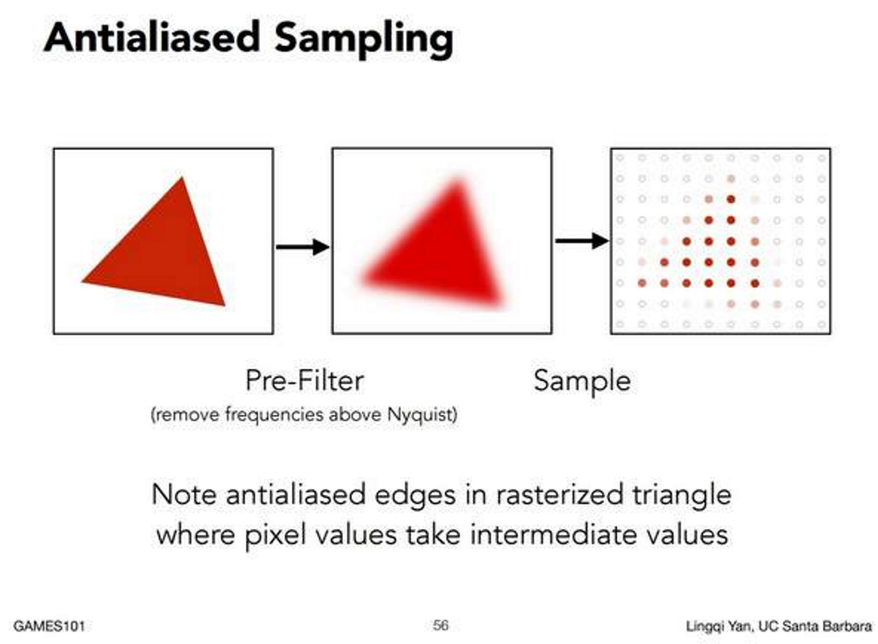
Regular Sampling



Note jaggies in rasterized triangle
where pixel values are pure red or white

普通采样：

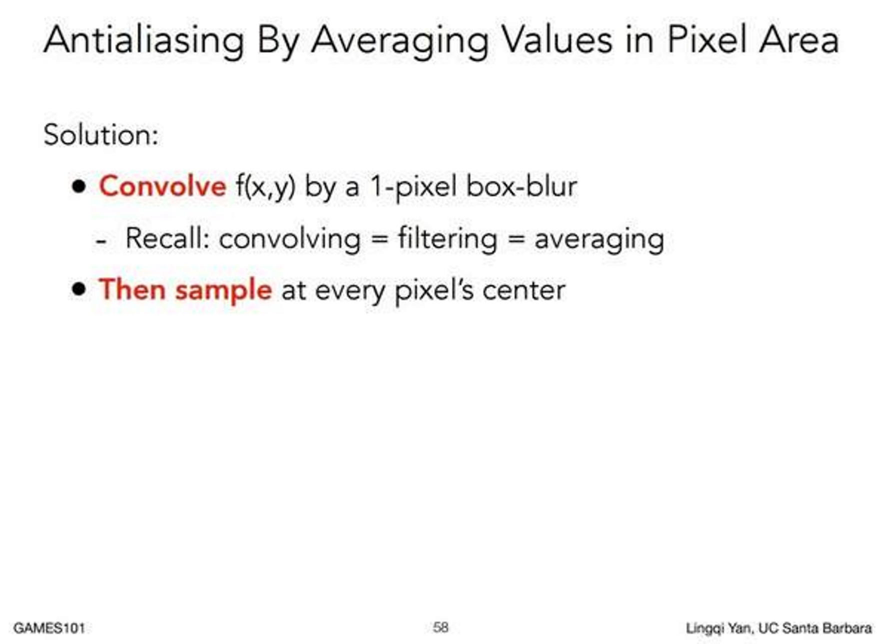
像素点非红即白，因此造成锯齿



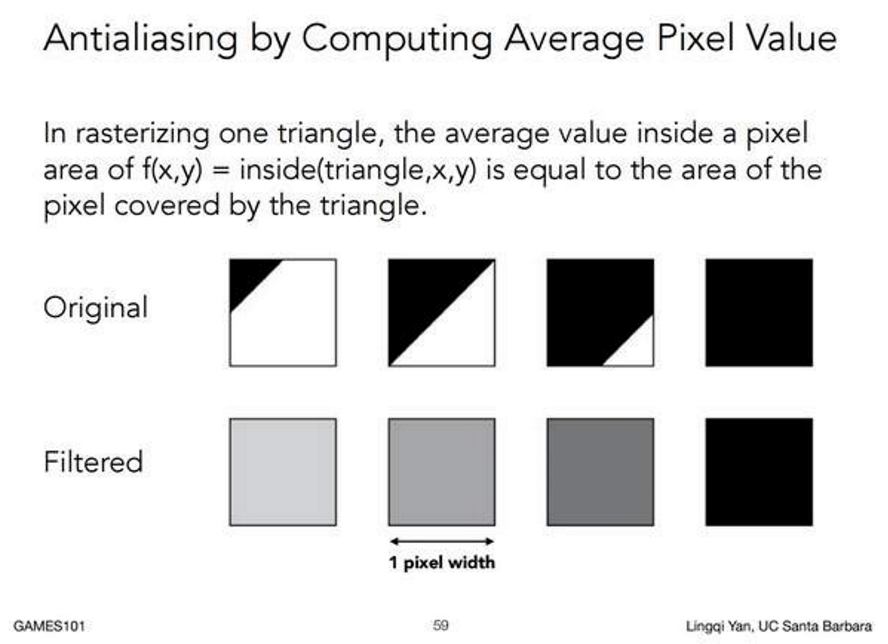
反走样后的采样：

先经过预过滤，再采样

边缘取了周围的像素点颜色的中间值（intermediate values）



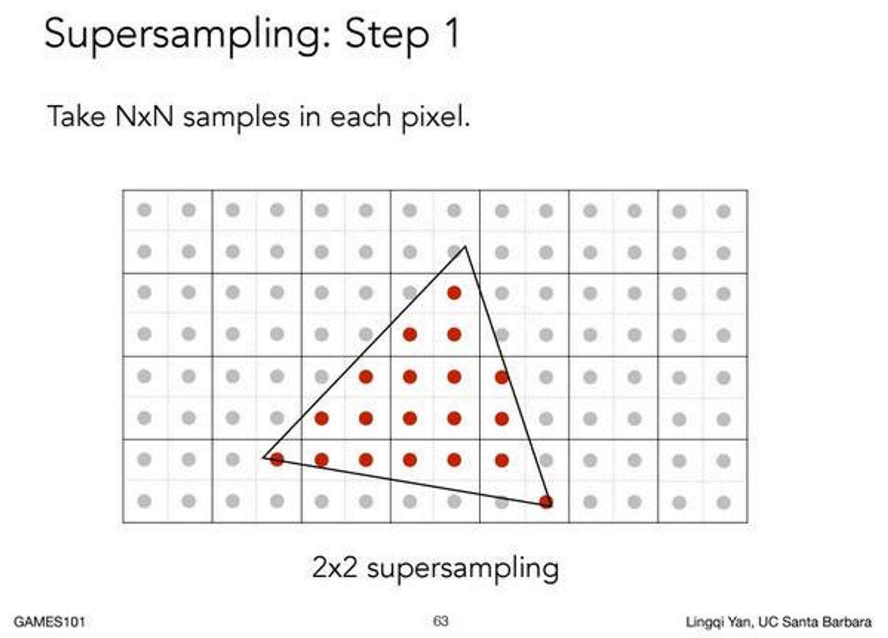
先做模糊操作（卷积），再在每个像素中心采样



通过计算平均像素点值的方法实现反走样

在对三角形光栅化时，像素点区域内部的颜色平均值等于该像素点被三角形覆盖的面积

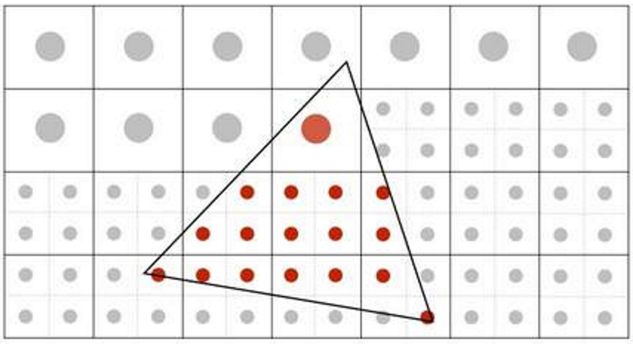
通过多重采样进行反走样（MSAA）



首先，在每个像素点内，取N*N个小的“像素”（采样点），对每个小采样点判断它们是不是在图形内

Supersampling: Step 2

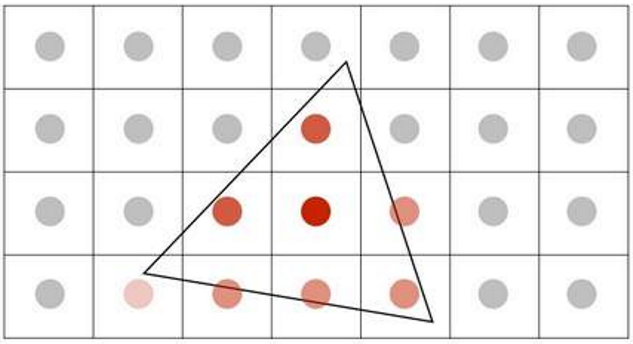
Average the NxN samples "inside" each pixel.

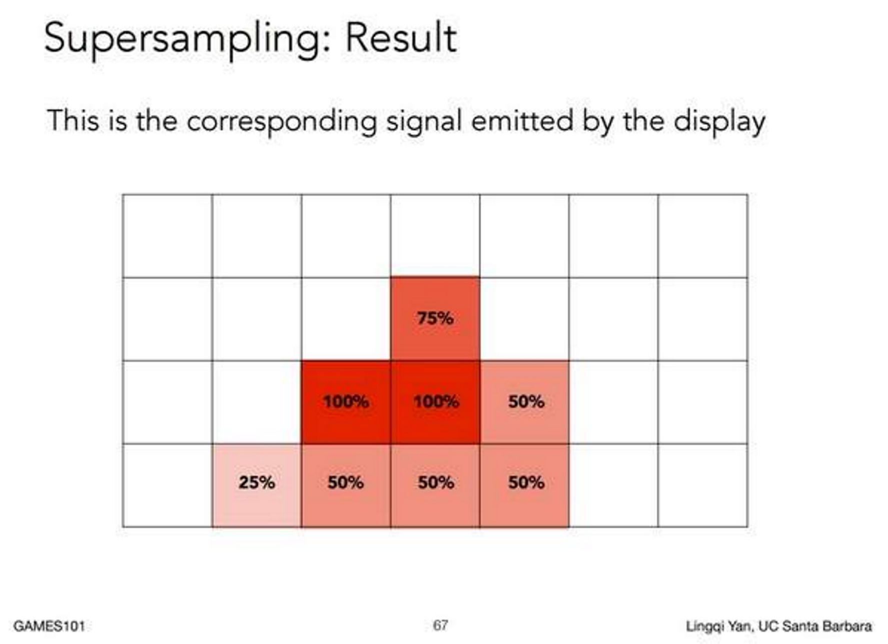


Averaging down

Supersampling: Step 2

Average the NxN samples "inside" each pixel.





求每个小像素判断结果的平均值，在图形内的小像素越多，则颜色越深，否则越浅。

MSAA并不是提升了屏幕分辨率解决了锯齿问题，而是增加采样点而得到近似的三角形覆盖
开销：增加了计算量

其他AA方法

FXAA（Fast Approximate AA）（配置要求低，效果一般）
后期做图像处理，把有锯齿的边界找到，换成没有锯齿的边界

TAA（Temporal AA）（配置要求高，效果好）
找上一帧的信息。对相邻两帧，找某个像素内不同位置的点，判断像素是否在三角形内

超采样（DLSS）:Deep Learning Super Sampling
小图拉大，用深度学习“猜”出缺失的细节