

The digital world – precise, flexible

Atoms -> Bits

Analog signals -> Digital samples

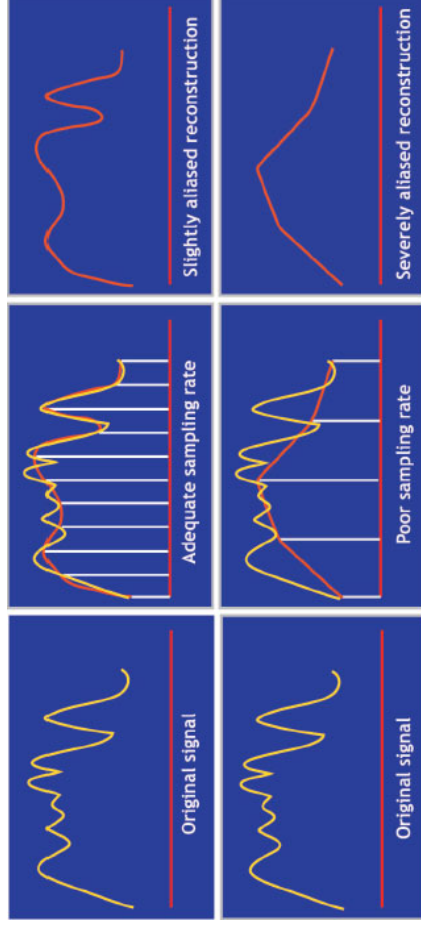
Q: What can't be digitized, why?

Once digitized, we can store, reproduce, transmit, sort, search, edit.. (eg. film, audio)

Lecture 19

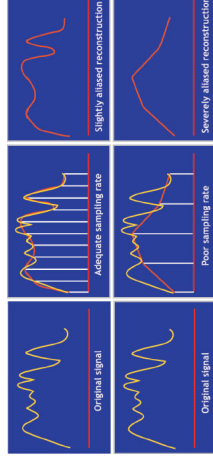
Digitization
(sampling, reconstruction)

Aliasing PROBLEM with digital signals



Lesson: need LOTS of samples!

The Nyquist sampling theorem



The sampling theorem states that for a limited bandwidth (band-limited) signal with **maximum frequency f_{max}** , the equally spaced **sampling frequency f_s** must be greater than twice of the maximum frequency f_{max} , i.e., **$f_s > 2 \cdot f_{max}$** in order to have the signal be uniquely reconstructed without aliasing.

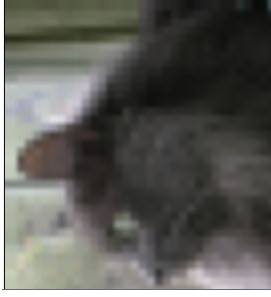
The frequency $2 \cdot f_{max}$ is called the **Nyquist sampling rate**. Half of this value, f_{max} , is sometimes called the **Nyquist frequency**.

[source: eFunda.com]

Inadequate sampling – digital image



717x658 pixels



36x33 pixels,
magnified ~10 times

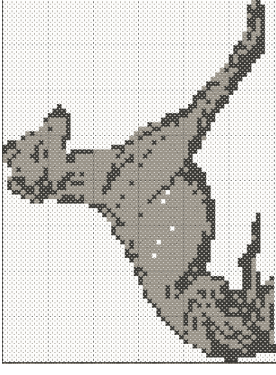
Inadequate sampling

* paint a sunset scene on a 2"x1" canvas, using just four colors and a fat brush?

* counted cross stitch

* LED signage

* cellphone screens



HUGE 50" SIGN

LOTS of detail, INADEQUATE samples

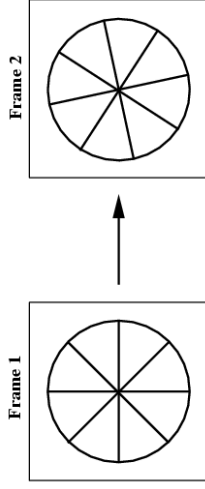
Temporal sampling

A wagon wheel's spokes appear to rotate fast, film records the action at 24 fps.

Eg. (3 rev/sec * 8 spokes/rev)/24 fps = 1 spoke/frame
At 2.5 rev/sec, 83% forward movement for each spoke.

Result? A wheel that appears to spin SLOWLY backwards..

more: http://www.tvtechnology.com/features/Tech-Corner/f-RH-artifacts_of_motion.shtml



Audio sampling

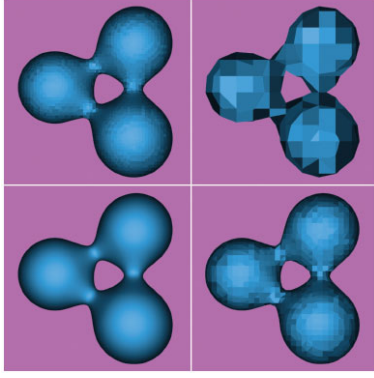
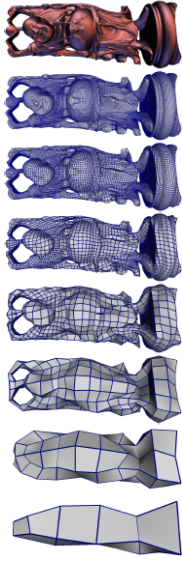
Whitebook Audio CD format:

Human hearing limit is ~ 22KHz (ultrasound limit).

So adequate sampling rate is ~ twice 22KHz, which is **44.1KHz** (at 16 bits/sample, by the way).

Inadequate sampling: violin sounds like a cello, and human voices spooky!

3D models and geometry



Sampling - resolution

In addition to rate, there is also resolution (detail in EACH sample).

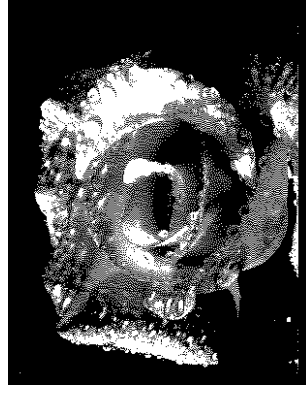
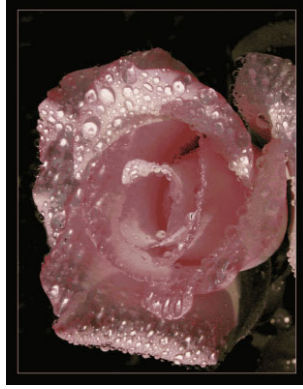
Eg. CD audio specifies 16 bits/sample

Images: 8 bits/channel, 16 bits/channel, etc.

8 bpc leads to ~16.7 million possible colors for a single RGB pixel.

In art, 'flat' (poster) versus 'smooth' (airbrush) coloring.

Sampling - resolution



Reconstruction, filters

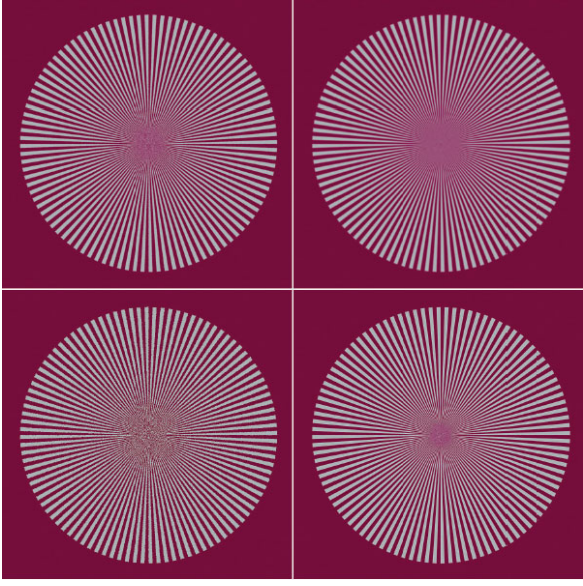
Given a set of digitized samples, how to approximate the original signal?

WEIGHTED AVERAGE of discrete samples - use current sample and neighbors.

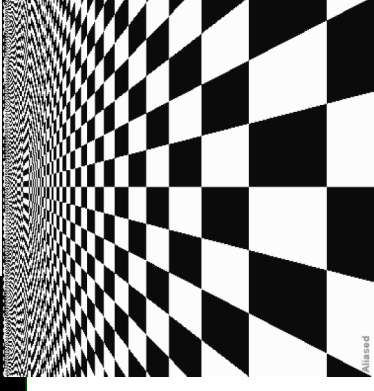
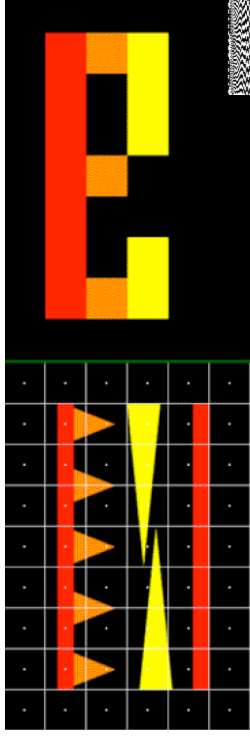
Reconstruction, filters

Box, triangle, Catmull-Rom, Gaussian...

Various ways to reconstruct. Look up literature on digital signal processing.



Aliasing in images, antialiasing



Antialiasing in general

Low pass filter (clamp, or precondition) input to eliminate problematic details (high frequencies)

Blend high frequencies (beyond Nyquist limit) with NOISE.

Analytically antialias if possible, eg. in shaders

Antialiasing in rendering

SUPERSAMPLING – Poisson disk, jittering.. Calculate MORE than necessary, then use to reconstruct.

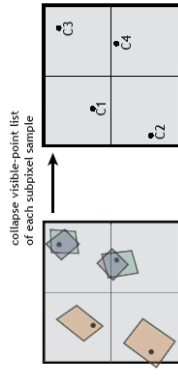
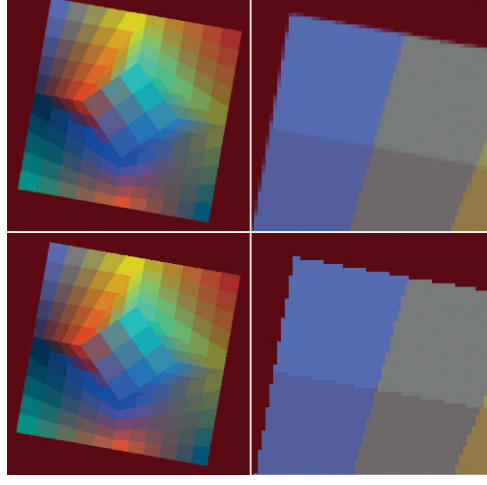
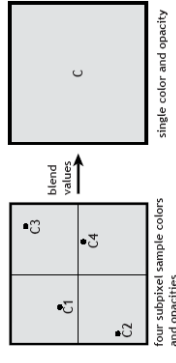


Figure 2.11 Collapsing visible-point sample lists



four subpixel sample colors and opacities

single color and opacity