EE334
Introduction to Digital Thinking

Many of you probably have heard the terms "digital audio" and "digital video", but don't realize what they mean. This lecture aims to clear up the confusion and to show you the magic behind digital media (audio, video, and just about anything else that can be converted and stored as bits).

1. What does "analog" mean?

In the old days, all of what we heard on the radio, watched on TV, and played on the record player was analog. That is, we received information in the raw. Sure, sometimes we'd change the format slightly to suit the medium (tape versus vinyl disc), but everything was analog.

The natural world is for the most part an analog world. That is, most everything we experience comes to us in an analog format. Colors are analog. Sound is analog. That's just the way it is.

2. What does "digital" mean?

Converting from Analog to Digital and Back
To convert from analog to digital, we sample the analog reality and convert each sample into a binary number (a digital number). The binary number represents the intensity of the analog reality. Since most things we want to convert to binary have a time component (music, video, etc.), we have to take many samples and many samples per unit of time.

The **analog-to-digital conversion (ADC)** process for sound is shown at a high level in Figure 1 below. To digitize an analog sound recording we sample the voltage levels (sound intensity levels) in the recording and turn each sample into a number. A sound recording may go on for several seconds, minutes or even hours. The recording may also have a wide range of intensity levels that need to be represented digitally. An intriguing thing is that **the digital version is always an approximation of the analog reality.**

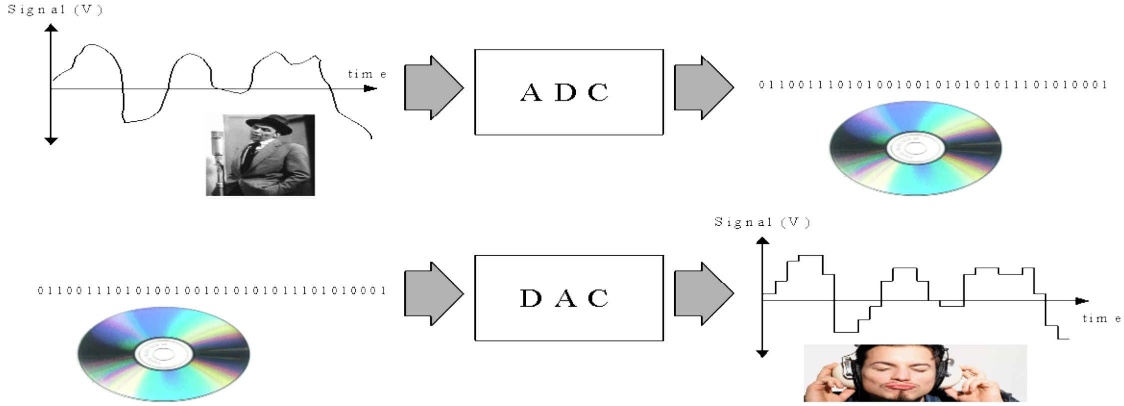


Figure 1. The analog to digital conversion process for audio.

3. Converting an analog sound recording to digital raises some serious questions.

   a. What happens if you don't sample fast enough? That is, what if the time between samples is too long?

   b. How fast do you have to sample to get good quality?

   c. What is the impact if your digital conversion doesn't do a good enough job of distinguishing between different sound intensity levels?

   d. How many sound intensity levels to you have to have to get good quality?

A digital recording is fine as far as it goes. It can be stored, manipulated easily (edited), transmitted, etc. However, a digital recording can't be understood directly by humans. To makes sense of a digital recording, the recording must be converted back to analog. Figure 2 shows, at a high level, the **digital-to-analog conversion (DAC)** process for audio.

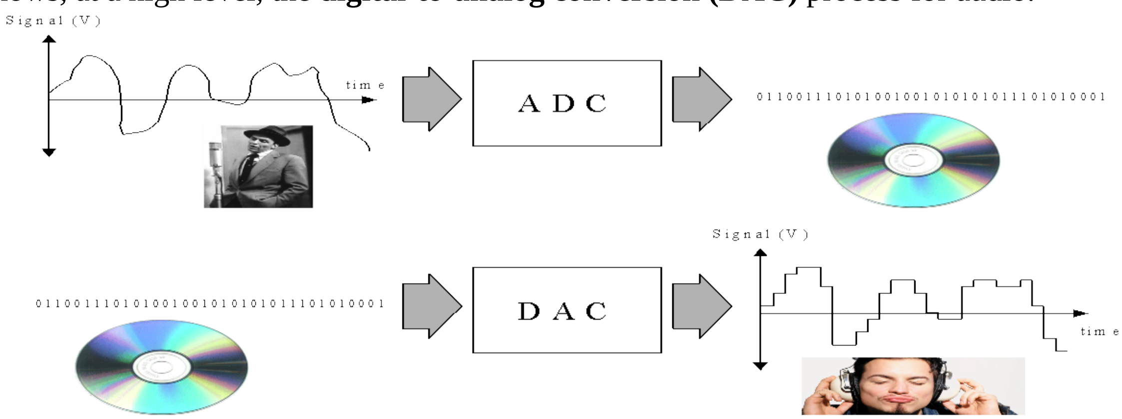
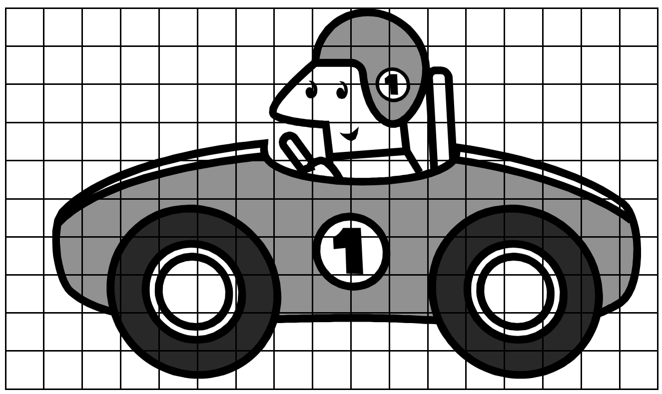


Figure 2. The digital-to-analog conversion process for audio.

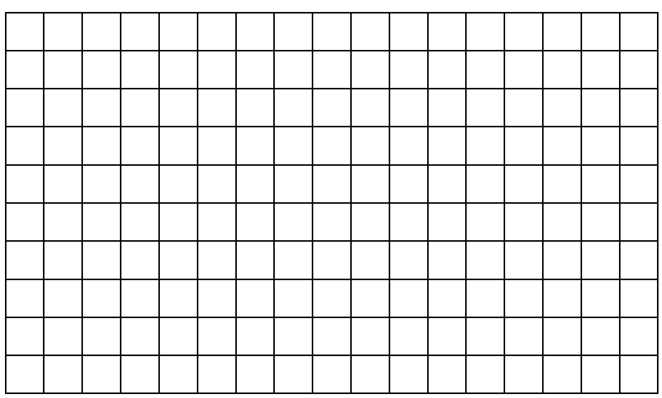
4. Is the gentleman in Figure 2 listening to the same piece of audio as the original Frank Sinatra analog signal in Figure 1? Yes, no, kind of? Explain.

5. Have you seen similar types of flaws in other kinds of digital media? If so, list and explain.

6. Let's do an analog to digital conversion of an image. See the picture below? A grid has been placed over the image. For each cell of the grid, write down a 0 if the cell is mostly white (empty) and a 1 if the cell is mostly black (filled in).



7. Reconstruct the image from your digital version. The cells are commonly called "pixels".



8. What were some of the difficulties you faced in doing the digitization?

9. How good is your reconstructed image? How could you make it better? What's the correlation between the quality of the reconstructed image and the number of bits?

10. Think about digitizing a color image. How does a color image affect the number of bits per pixel?

11. Video and movies are simply a series of still images played back at a rate that fools your eye into seeing motion. What does video do to the bit count?

12. Just about anything can be digitized. Brainstorm about things that can be digitized. For each thing, list how that thing would be represented digitally.

So we've seen how digital can be used to capture or represent things in our analogish real world. In a sense digital encodes the real world as numbers. The downside is that digital encodings of analog things are always an approximation of the real analog thing. However, there are things in the real world that at first seem analog, but are in fact discrete (come in independent chunks). When things are discrete, we can encode them digitally without loss of detail.

Put another way, digital is just a way of encoding (representing) things as numbers. Binary is a subset of digital in which everything is encoded as sequences of zeros and ones.

13. Below, list several discrete codes and briefly describe each. For instance, what are the symbols and what do the symbols represent?

Code	Symbol Types	Symbols Represent

You've already seen at least one kind of binary code, although you may not have realized it.

14. Now list any binary codes you can think of.

Code	Symbol Types	Symbols Represent

The American Standard Code of Information Interchange code **(ASCII)** is one of the most famous binary codes. In ASCII, 7-bit sequences are used to represent alphanumeric symbols (letters, numbers, punctuation, etc.).

15. How many possible characters can be represented by the ASCII code? I.e., how many things can you count with 7 bits?

16. Generally speaking, how many bits will you need to encode something that has n pieces/parts/things?

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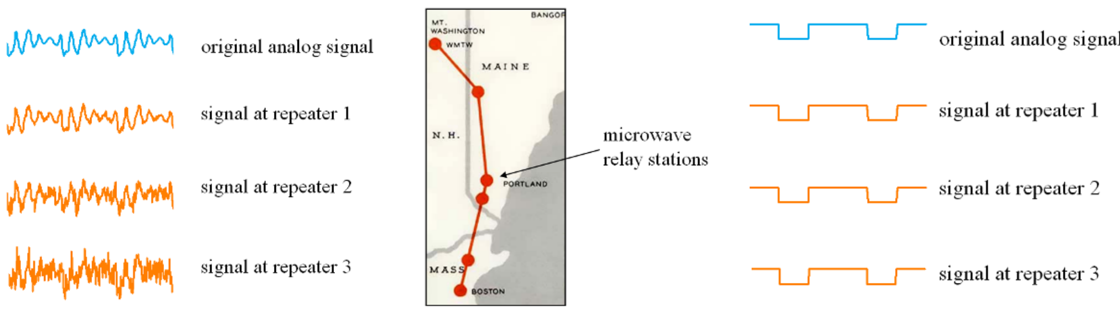
Advantages of Digital Signals

Look at the analog and digital versions of the same signal shown below. Both are traveling the same distance and suffer the same amount of noise and distortion. At each dot on the map, the signals are received and boosted by repeaters along the way.



Since the analog signal has an infinite number of voltages present, it's impossible to remove all the noise (stray voltages that attach themselves to the analog signal). The best we can do is remove some of the more glaring noise and then boost the signal (since it loses power along the way) before sending it to the next point along the route.

The situation is different for the binary version of the signal. The digital circuitry can distinguish between a binary 0 and 1 with a significant amount of noise because the digital signal consists of only two voltage levels (in this example) As long the noise doesn't cause a binary 0 (low voltage) to look like a binary 1 (high voltage) and vice-versa it's easy to tell a 0 from a 1. Digital signals can be stripped of any noise in a process called signal regeneration. That is, the digital signal can be completely reconstructed from the received version and transmitted afresh without much, if any, noise present. Even if a digital signal does contain bit errors, many of these errors can be fixed at the receiver through error correcting codes as we'll see in a future lecture.

Another advantage of digital over analog is that since digital is just numbers it's easy to manipulate digital data with computers. This is commonly called Digital Signal Processing (DSP). Here are some of the things DSP can do

- Filtering
- Equalization and mixing of signals
- Encryption and data compression
- Information storage and retrieval
- Signals can be multiplexed (multiple digital signals broadcast simultaneously)

17. Here's a chance for you to think of another advantage of digital over analog. Explain why making a copy of a copy of a copy (and so on) using analog systems leads to degraded quality, but repeated copying of digital data does not.