EE603A Notes

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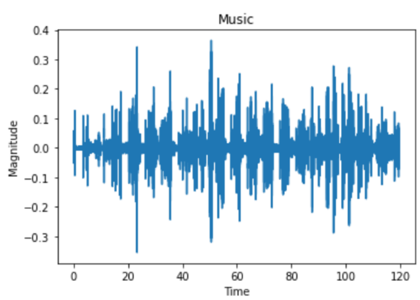
1 Signal Processing and Machine Learning

1.1 Signal Processing

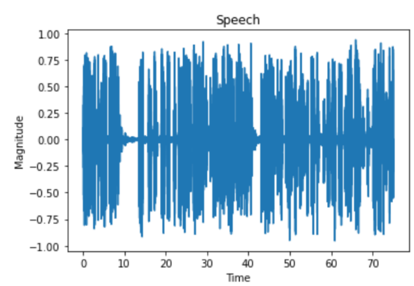
Signal - Any function or measurement that conveys information is known as a **Signal**
Examples of Signals -

Audio

An audio signal is a representation of sound, typically using either a changing level of electrical voltage for analog signals, or a series of binary numbers for digital signals.



(a) Music Signal

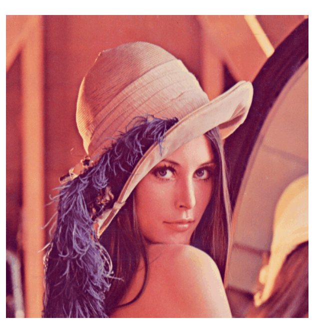


(b) Speech Signal

Representation of Music and Speech signals

Image

Image signal is a representation of 3-Dimensional world onto a 2-Dimensional which are usually in the form of pixels.



(a) Color Image

(b) Grey scale Image

Representation of Image signals

Fun Fact: The name of the woman in the above Image is Lenna (or Lena). This image is considered one of the most studied female face of all time. For further references see 2001 IEEE Newsletter.

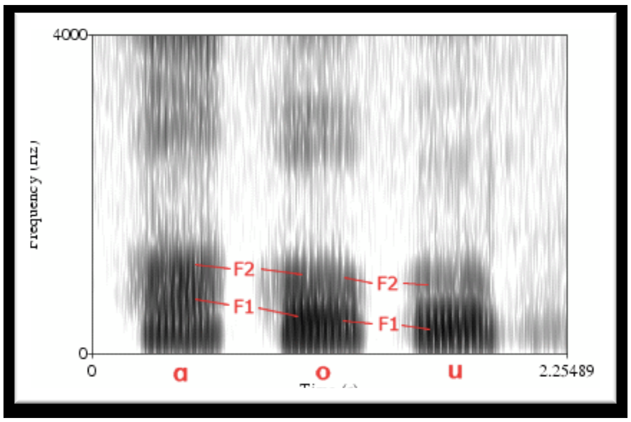
Video

A video signal is simply a sequence of still images, acquired typically at a rate of 24, 25, 30, 50, or 60 frames per second which can also have audio as well. For an example of video see one of the video from You tube.

Signal Processing - Analyzing, modifying, and synthesizing of any **signal** is known as **Signal Processing**
Examples of Signal Processing -

Speech Recognition

Speech recognition with linguistic rules is one of many examples of signal processing on audio signals.
Ken Stevens' "Acoustic Phonetics is a famous book which presents the theory of speech-sound generation in the human vocal system .

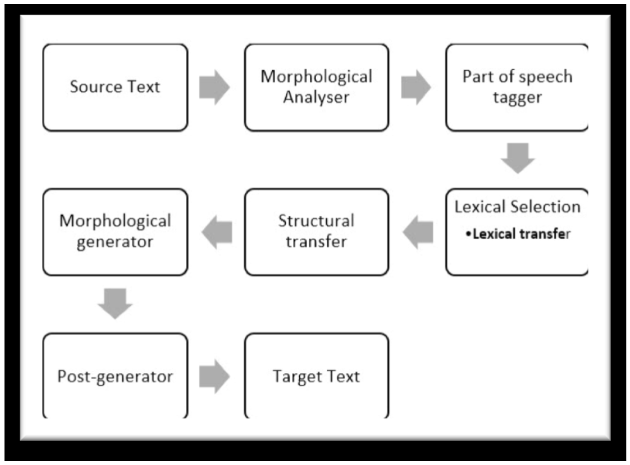


Frequency representation of 'a' 'o' 'u' vowels

Image segmentation/recognition algorithms

Image after processing which recognizes various parts of the image.

Machine translation of text



Machine translation of text

1.2 Machine Learning

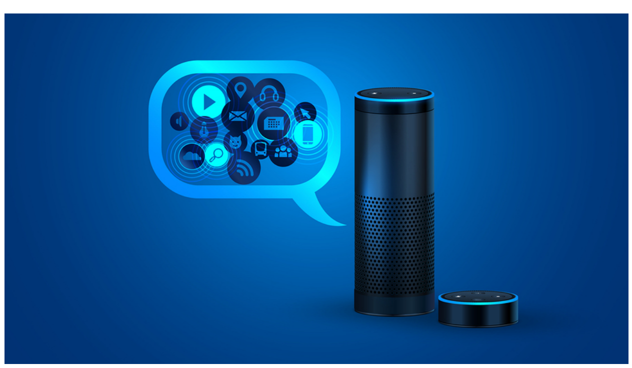
Machine Learning - Is the study of algorithms to make a computer do specific tasks without hand-made explicit rules. It does these specific tasks by learning from the data provided by us.

We might think we play a small role in Machine Learning but still to make our model work properly we need to

- feature engineer when we have a small set to data sets
- hand-tune learning algorithm a lot
- keep in mind the costs and reliability issues with out Machine Learning model

Few real world examples where Machine Learning is used -

Alexa



Alexa is one of the famous cloud-based voice service

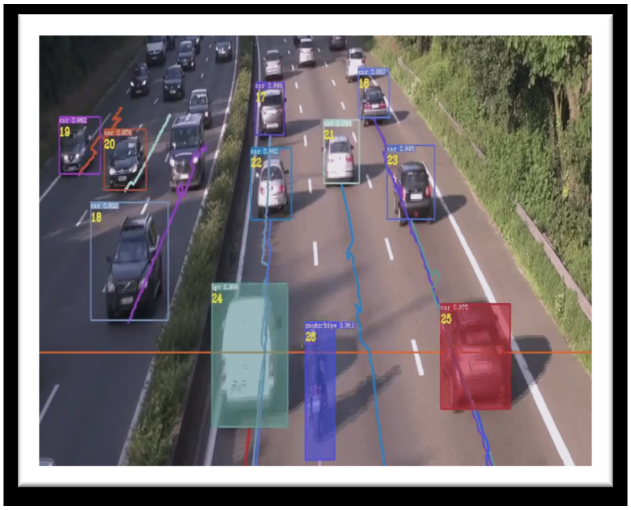
Alexa is Amazon's cloud-based voice service available on hundreds of millions of devices from Amazon and third-party device manufacturers. With Alexa, you can build natural voice experiences that offer customers a more intuitive way to interact with the technology they use every day.
Link to the Video showed in the lecture.

IBM Watson Health Cloud

IBM Watson Health Cloud

IBM Watson Health is a digital tool that helps clients facilitate medical research, clinical research, and healthcare solutions, through the use of Machine Learning, data-analytics, cloud computing, and other advanced information technology.

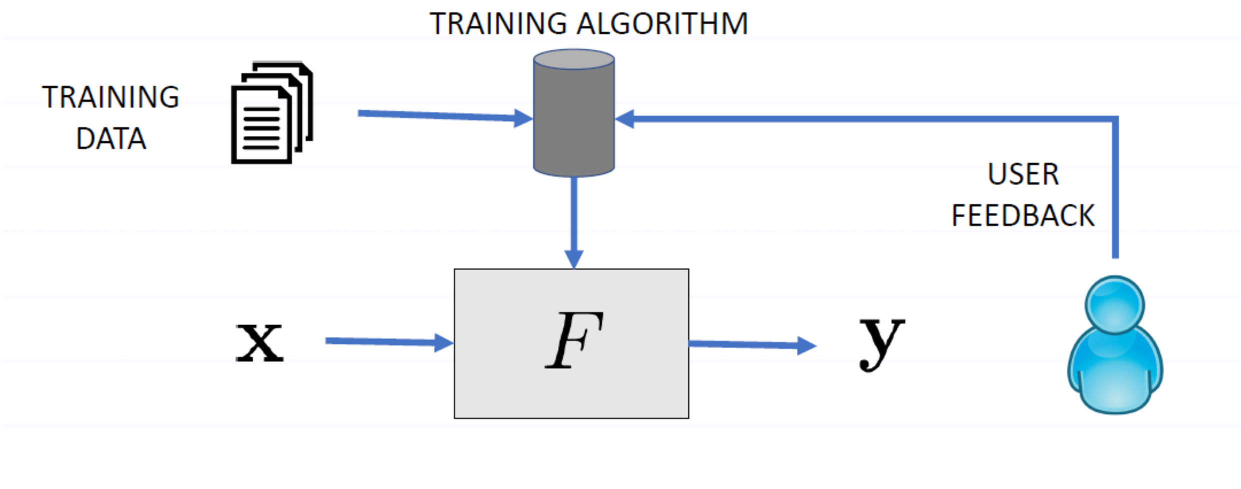
Video Surveillance



Surveillance of vehicles in traffic

Video surveillance uses Machine Learning and Deep Learning methods to identify objects, classify them, and determine their properties. For our example of video surveillance used in traffic, we can classify different vehicle and even the model of the vehicle, we can determine some properties such as vehicle speed, registration number etc.

1.3 Machine Learning Model



Example of a typical Machine Learning model

1.4 Machine Learning and Signal Processing

- Machine Learning is opaque to the structure in the signal.
- Signal Processing is opaque to the tasks we are interested in.

1.5 Machine Learning for Signal Processing

Signal Processing	**Machine Learning**
Studies a wide variety of phenomena	A model is specific to a particular problem
Relies on lesser data	Needs huge amounts of data
Provides explanation, so easy to debug and correct	Mostly opaque to explanation, difficult to debug
Less accurate for tasks in the wild	High accuracy for tasks in the wild
Needs a lot of manual effort by experts	Need less manual effort by experts
Large number of manually tunable parameters	Small number of manually tunable parameters

Table 1

By using Machine Learning for Signal Processing we try to bring the best of both worlds together and try to make use of advantages of both.

2 Wave-forms

In this lecture, we will learn and explore wave-forms. The guide deals with audio waves. The following images are taken from the website Pudding.

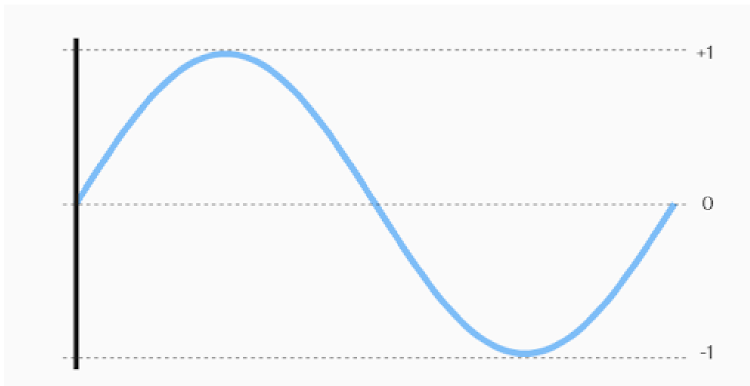


Figure 1: Sine Wave

Let's start with how to read waveforms-:
Take a look at the waveform diagram given here, the blue line gives the data we are graphing and the X-axis depicts time, therefore, this shows how the wave's displacement changes over time.

2.1 Displacement

When the guitar string vibrates, chain reaction occurs around the air molecules and they all start vibrating. The waveform above shows a single oscillation of a sound wave. It starts by displacing the air molecule in the positive direction by '1', and then in the negative direction by '-1'.

2.2 Amplitude

Waveforms are abstract representation of sound waves. Amplitudes basically measures how much a molecules is displaced from its resting position. In this case(mentioned above) we are measuring it from 0 to 1. Amplitude can be thought of as loudness, the more molecules are displaced the louder sound seem to us.

*** Summary until now is -:** A waveform is a graph that shows a wave's change in displacement over time. A waveform's amplitude controls the wave's maximum displacement.

2.3 Frequency

The waveform above we are looking at is periodic, this means that the waveform can be repeated to produce a constant sound. Frequency is a measure of how many times the waveform repeats in a given amount of time. The common unit of measurement for frequency is the Hertz, which

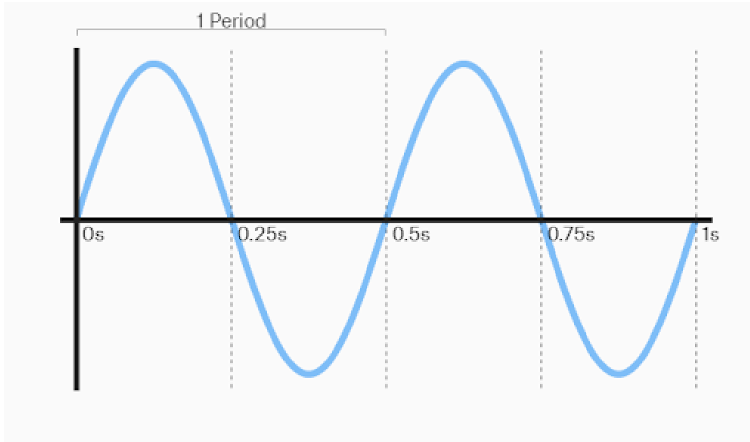


Figure 2: Waveform with freq 2Hz

represents the number of repetitions per second. Through this definition, we can deduce that the above waveform has a frequency of 2 Hz.
We can think of frequency as pitch, the faster a wave repeats itself the higher the pitch of the note.

2.4 How Sound Works

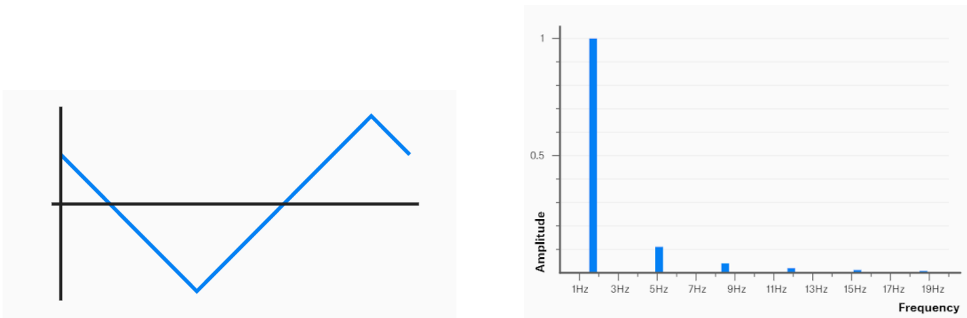
Let's unravel this bit more. The air around us is filled with molecules. When we play speaker it vibrates really quick and that vibration moves through air molecules like a chain reaction until it reaches our ear and is processed by our brain.
Note that the air molecules themselves aren't flying across the space, they're just vibrating. But that vibration moves through the field.

2.5 Harmonics

So far we have been using the same shape of the waveform, shape of waveform refers to the curve of the waveform line. We've been looking at a sine waveform. Its origins come from trigonometry, and it's known as the fundamental waveform. We call it fundamental because there are no "side effects".When a wave has "side effect" frequencies, we call them harmonics.

2.6 Triangle Waveform

It looks quite a bit like a sine wave, but curviness is removed. Instead, straight-line connected in a triangle-like shape. Notice that the sound is a little brighter. This is because of harmonics. Harmonics are the additional frequencies that are created by certain waveforms.
Harmonics are always a multiple of the root frequency. Triangle waveforms only have odd harmonics.

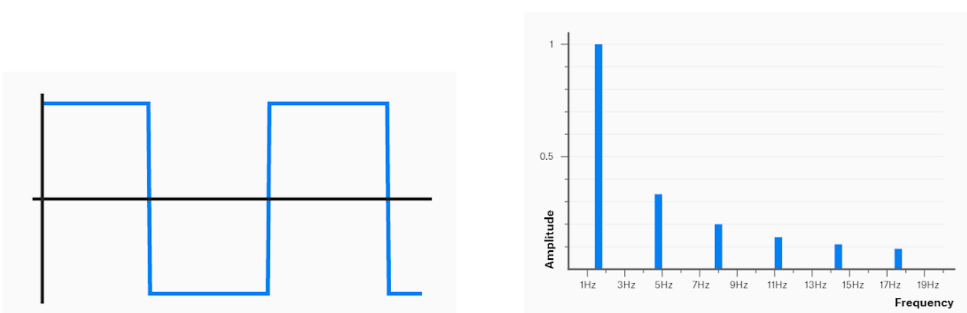


(a) Triangular wave (b) Harmonics of the waveform

Figure 3

2.7 Square Waveform

A common periodic waveform jumping between highest and lowest possible values; it's a binary wave. Square waves also have odd harmonics. The difference is that the square wave harmonics don't "fall off" as much the further you get from the root.

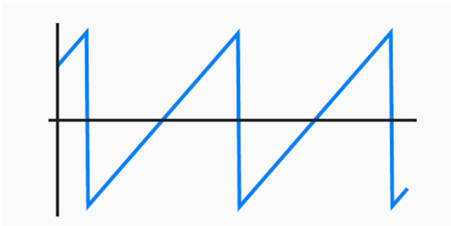


(a) Square Wave (b) Harmonics of the waveform

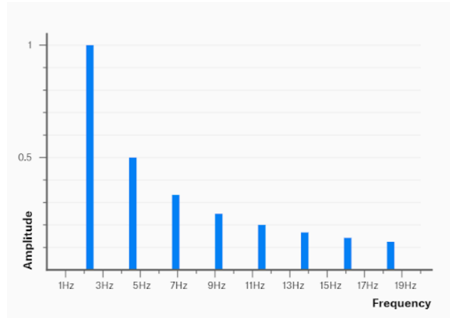
Figure 4

2.8 Saw-tooth Waveform

This waveform exhibits the linear rise of the triangle waveform with the hard drop of the square waveform. When we run the bow over the violin's string it causes the string to vibrate in the



(a) Saw-tooth Wave



(b) Harmonics of the waveform

Figure 5

sawtooth-like pattern. In terms of harmonics, sawtooth waveforms have additional frequencies at every multiple of root frequency.