GNU Radio ile Uygulamalı Haberleşme Sistemleri

Linux Kış Kampı
Eskişehir, 10-13 Şubat 2025

Outline

Quick Recap

Digital Comms

QPSK

ADS-B

Recap - Analog Communications

- Amplitude/Frequency/Phase
- AM/SSB/NBFM/WBFM/CW
- Of the all above which one has the smallest bandwidth?

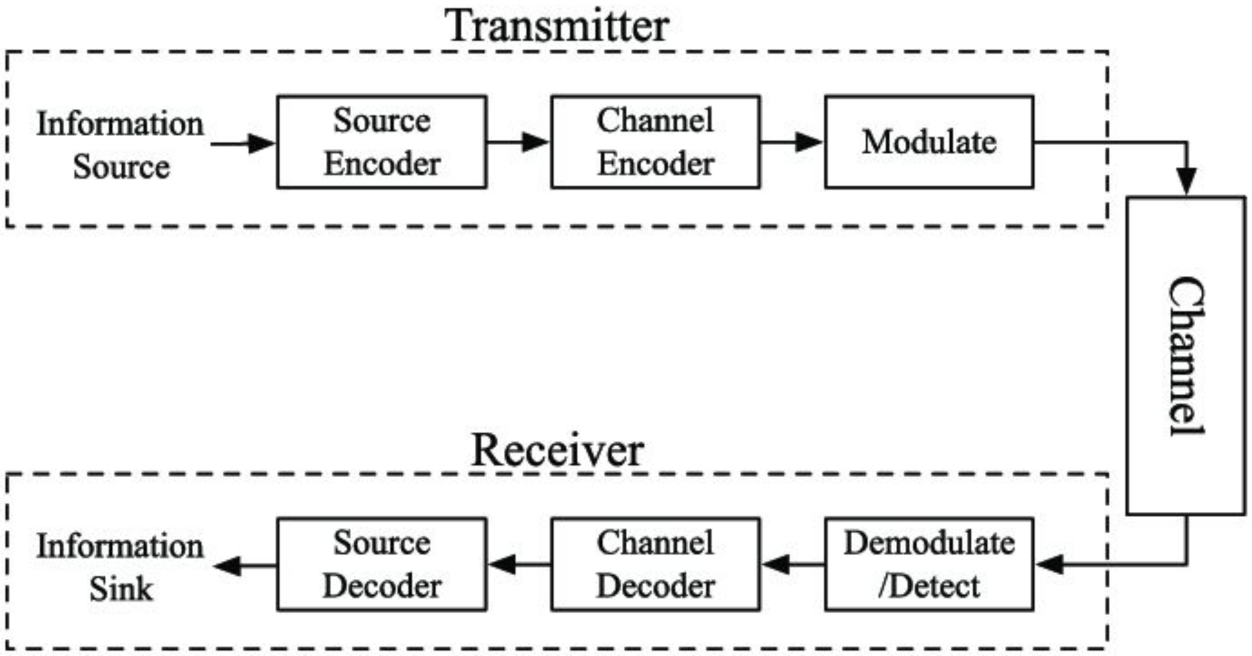
Schedule

- First Day: GNU Radio Introduction, DSP, GR Simulation Mode
- Second Day: SDR Introduction, RTL-SDR, GR Real-Time Mode
- Third Day: Analog Communications
- **Fourth Day: Digital Communications**

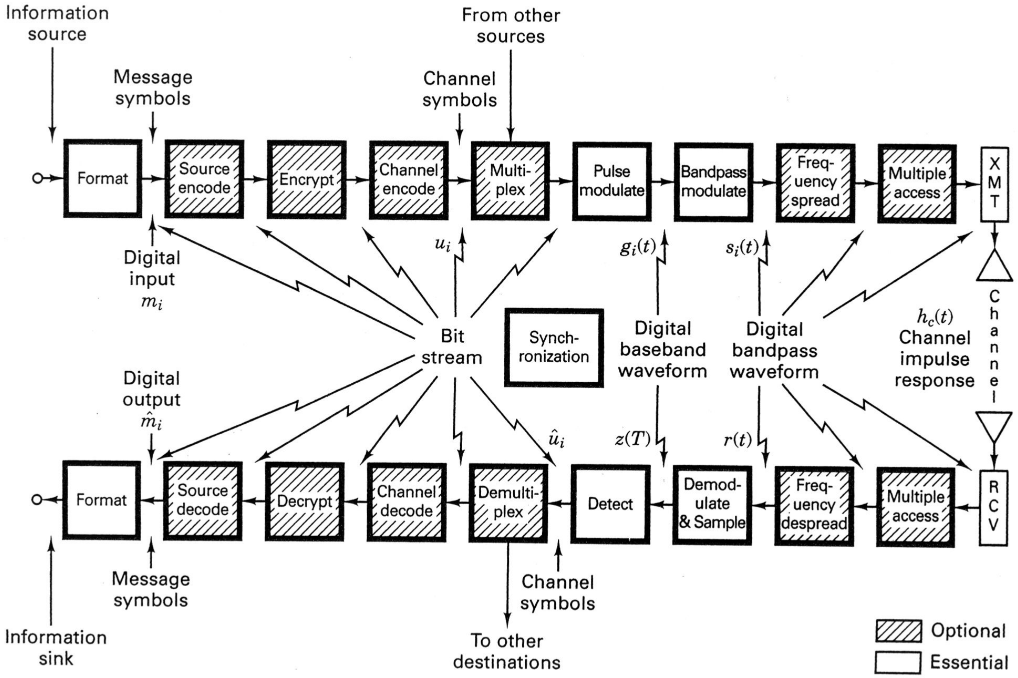
Digital vs Analog

- Source data
- Continuity
- Noise
- Error

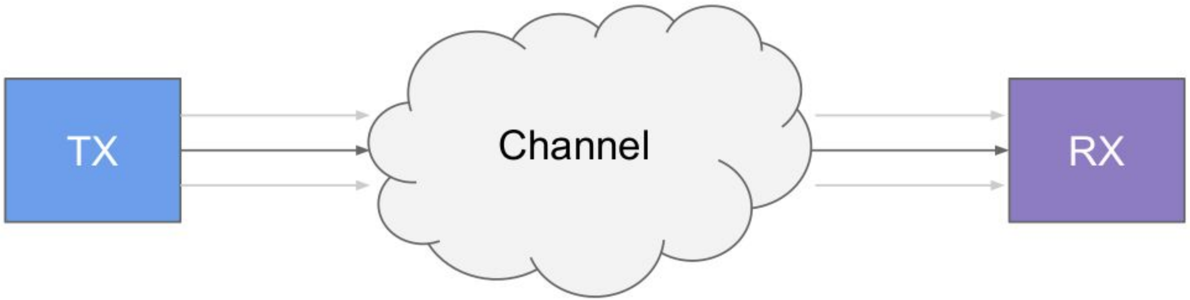
Communication Systems Block Diagram



Digital Communications - Detailed

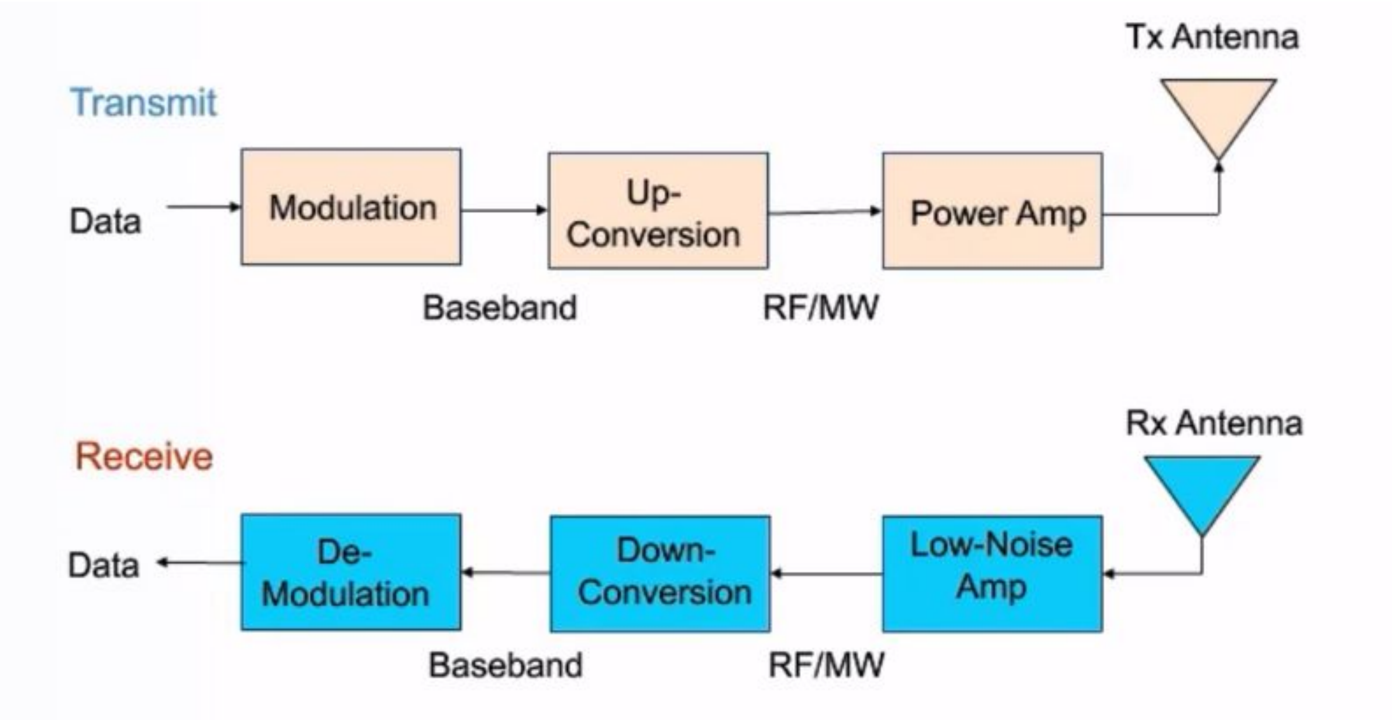


Wireless system: big picture



A transmitter, a receiver and a channel between them

Elements of Transmit/Receive



Transmitter

- Bits → Waveforms
  - Encoding
    - Add redundancy (intelligently) to help the receiver to recover the information despite errors.
- Modulation
  - Group/map bits into symbols.
  - “Mount” symbols on an analog waveform to be sent over the air.

Modulation Waveform

- Generate a basic analog signal and modify it according to the incoming bits and symbols:
  - Modify various aspects: amplitude, frequency or phase
    - AM, FM, Phase modulation

Modulation Order

- Defines the number of bits that are mapped to a symbol/signal.
  - With each Mod. order M, we can have up to M different symbols.
    - Mod. order M = 16: every log2(16) = 4 bits are mapped to a symbol.

      0000 → S1 0001 → S2 … 1111 → S16

Modulation Symbols

- Groups of bits:
  - Can be represented as an integer
    - E.g., 0010 → 2
  - Or, in a different plane as we will see next

IQ Representation

- A sinusoid signal can be represented by two other orthogonal sinusoids:
  - Inphase: $a \cos(2\pi ft)$
  - Quadrature: $b \sin(2\pi ft)$
    - Create an "orthonormal basis".
      - A complex 2D plane where any point can be reached through a linear combination of I & Q:

$$v = aI + jbQ$$

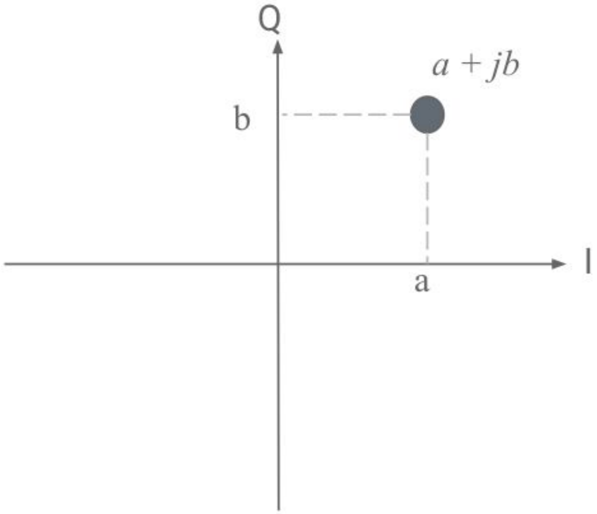
Web Resources for IQ Data

I/Q Data for Dummies

What’s Your IQ – About Quadrature Signals… | Tektronix

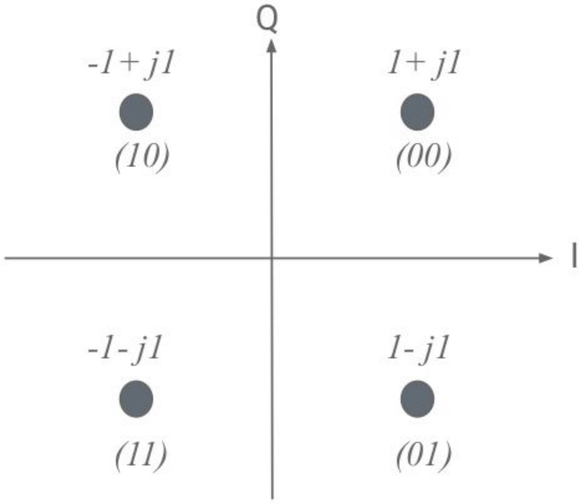
Constellation Diagram

- A 2D representation of symbols along I and Q:
  - Now, we define the symbols as complex numbers in the form of a+jb.
    - I and Q implied.
  - We don't normally choose any a & b.
    - Choose such that the points on the constellation have regular distances.
      - E.g., ±1, ±1j



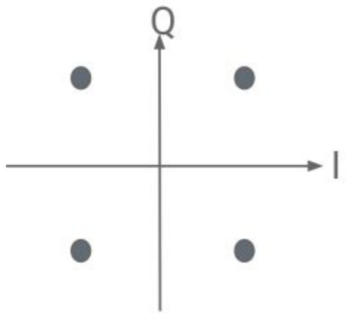
QAM

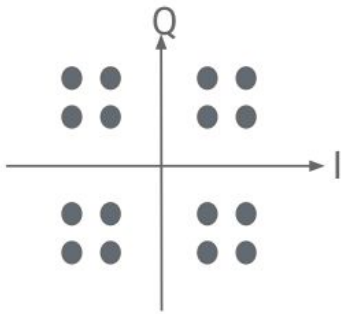
- What we saw was Quadrature Amplitude Modulation (QAM).
  - Generate signals through modifying the amplitude of two fundamental signals
  - Map each group of bits to these amplitudes.
  - Most used modulation scheme in modern wireless systems.
  - Bit values are assigned to QAM points in a particular order such that the hamming distance between neighboring points is always 1.
  - With this bit assignment, we probably see a 1-bit error even if we misdetect the symbol due to channel noise.



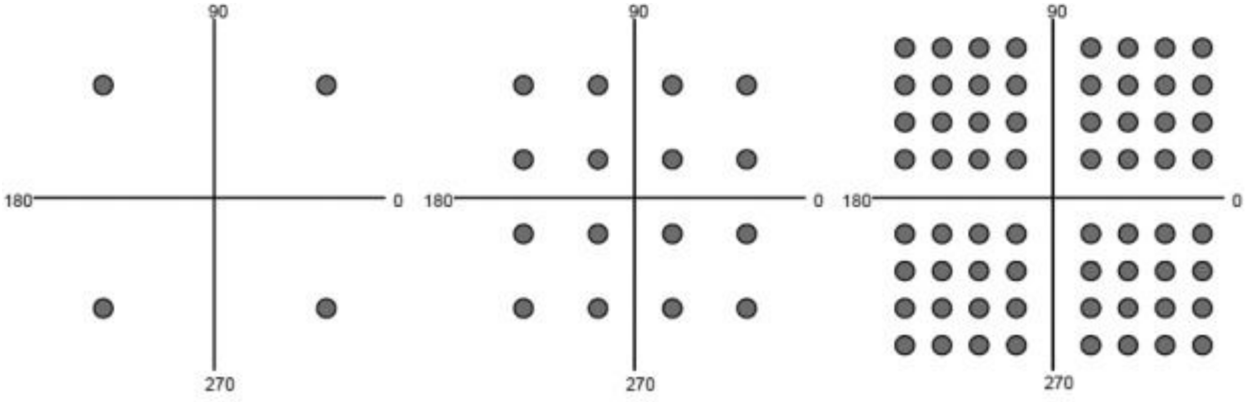
More QAM

- Can send more bits per symbol:
  - Higher modulation orders: 16-QAM, 64-QAM, 256-QAM
- Restricted by transmit power
  - For the same power budget, symbols get packed closer
    - Harder to sort out on the receiver side.





Higher modulations

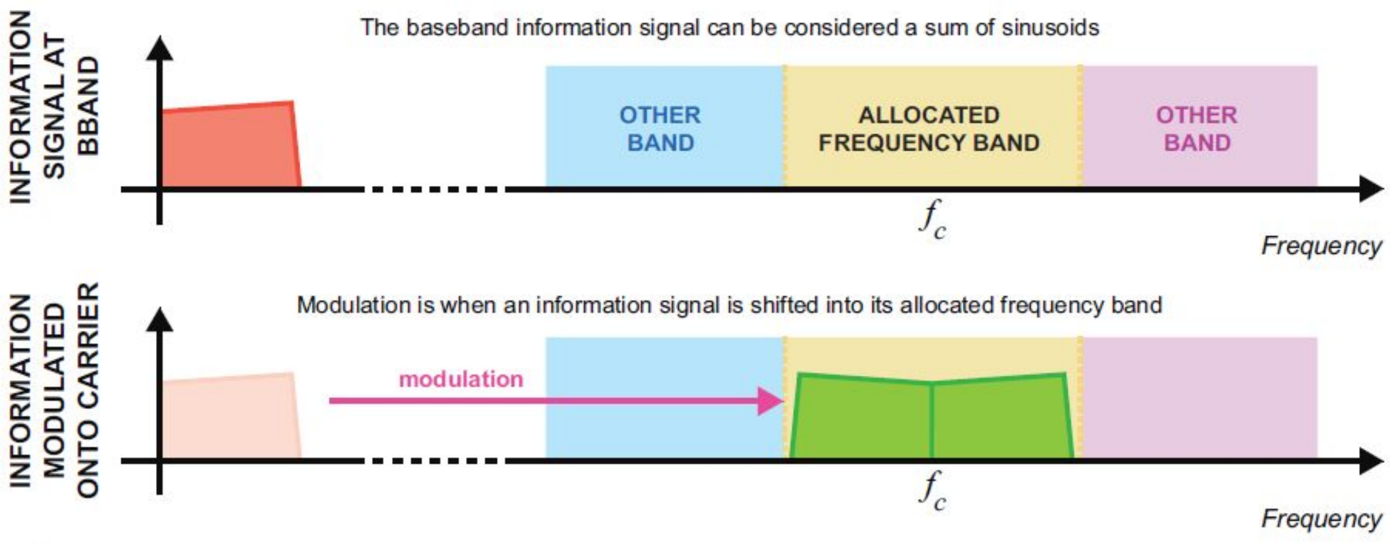


QPSK 16-QAM 64-QAM

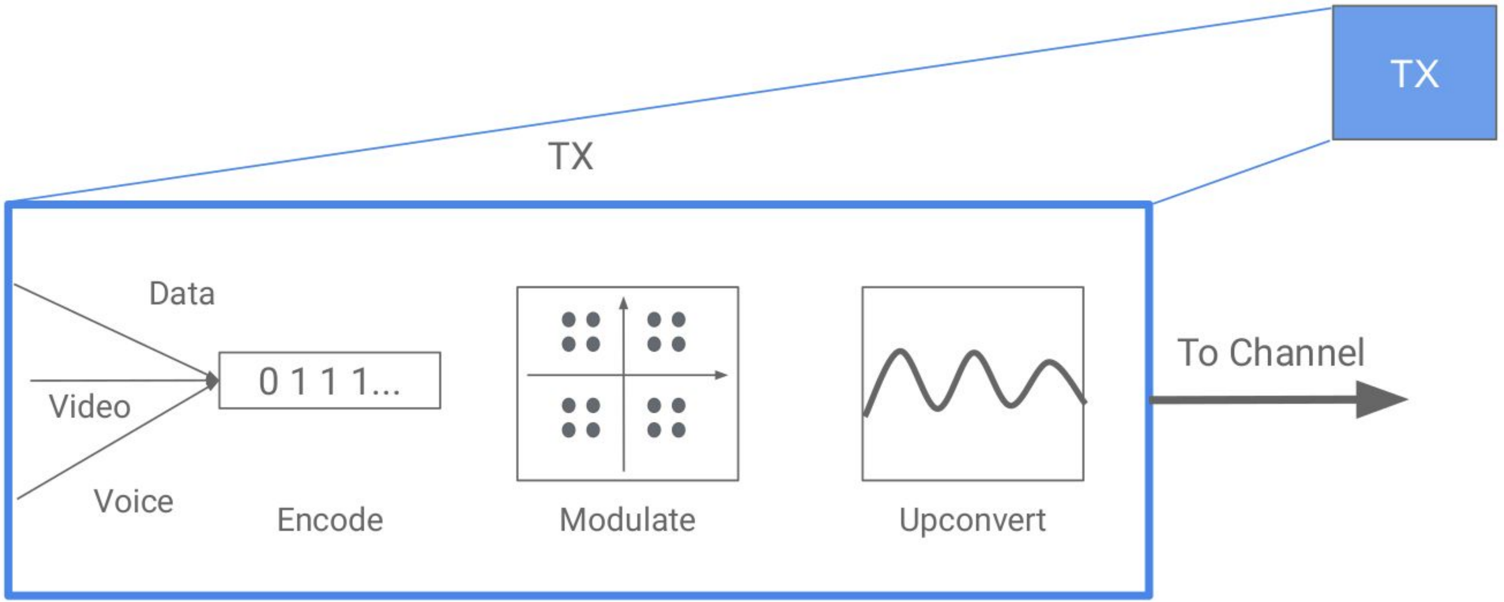
Upconversion (Carrier Modulation)

- Suppose we want to transmit a signal, s(t).
- We can’t just go ahead and transmit it!
  - Regulations on spectrum usage
- We need to move it to where we’re allowed to transmit.
  - Upconversion:
    - Multiply signal with a carrier sinusoid.
      - Sinusoid with carrier frequency fc

Shift the Signal

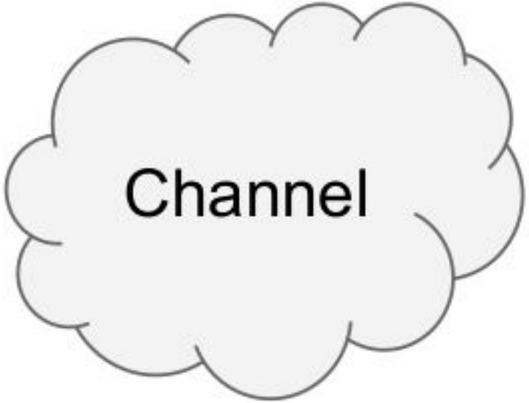


Transmitter: Putting all together



Channel

- Source of all difficulties in wireless.
  - Effect of the environment on the transmitted signal
    - Pathloss
    - Fading
      - Multipath
        - signal arriving through different paths
      - Doppler shift



Channel Modeling

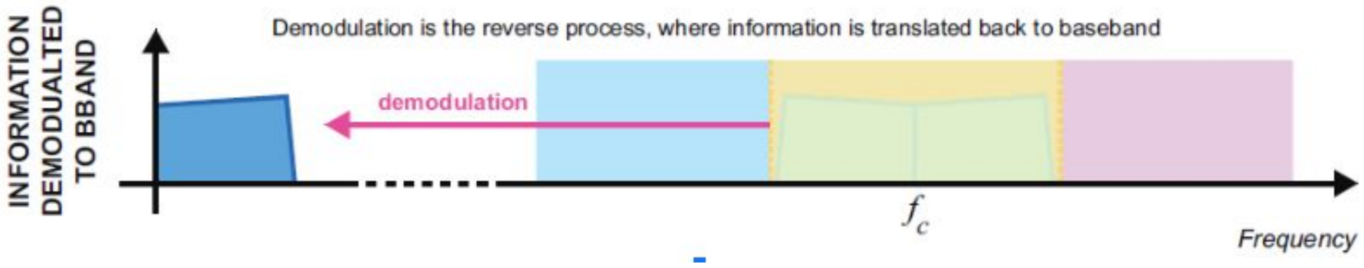
- It’s a random process.
- Modeled by random distributions. Most popular:
  - AWGN
  - Rayleigh
  - Rice

Receiver

- Waveforms → Bits
  - Downconversion
  - Synchronization
  - Equalization
  - Demodulation

Downconverison (Carrier Demodulation)

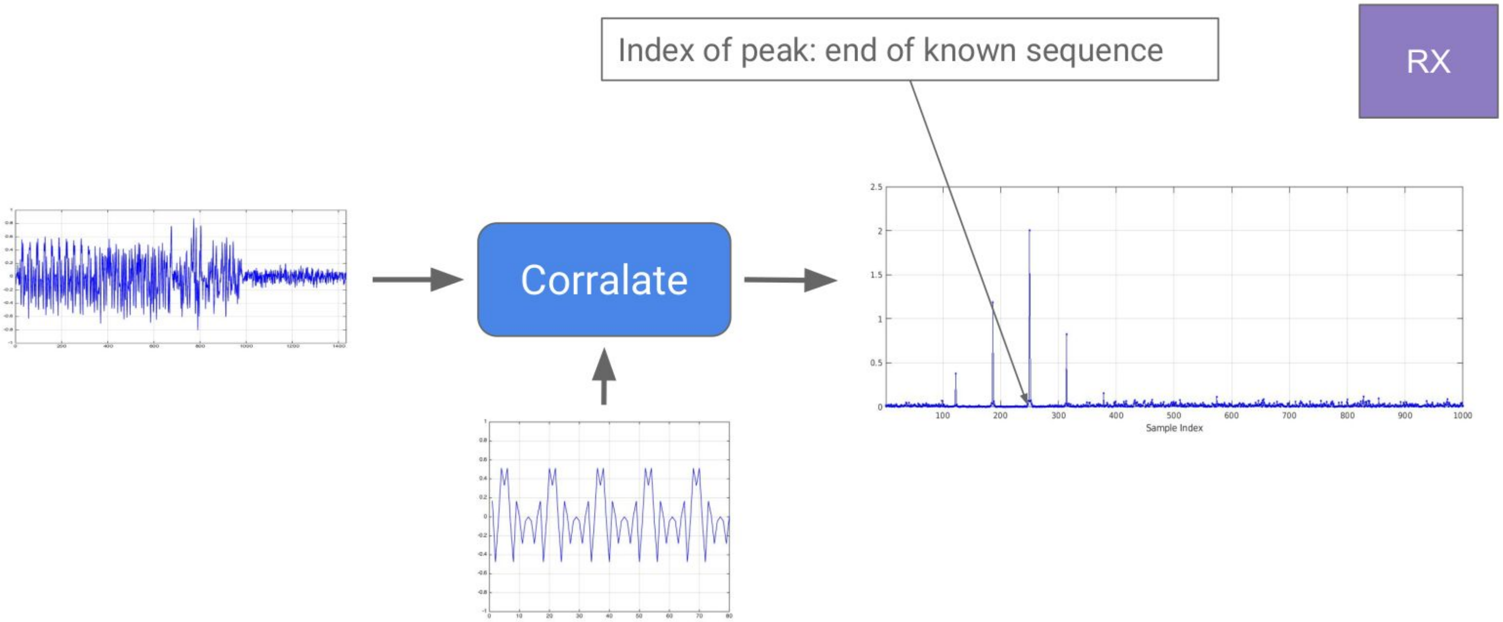
- Mirroring upconversion at the TX
    - Just multiply the received waveform with a sinusoid at the carrier frequency



Synchronization

- Before doing anything the receiver needs to first detect the start of a stream/packet/frame of incoming data.
- Correlate with a known sequence (sync. Signal)
    - Make out the start of the data stream relative to the correlation peak
    - Receiver knows where and how long the known sequence is

Synchronization



Equalization

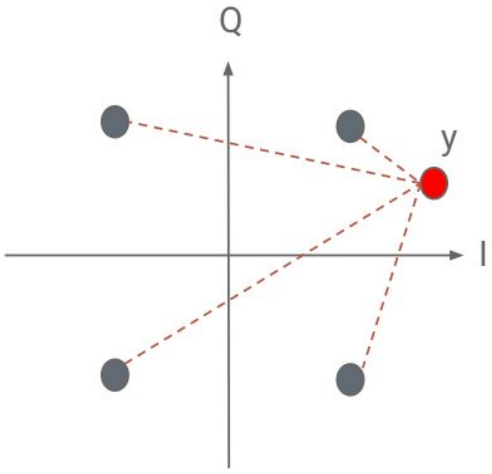
- Channel introduces errors.
- Need to offset these errors.
  - Reverse channel effect.
- Use the/a known sequence, called pilot, to estimate the channel
  - Remove the pilot. What’s left is channel + noise.
  - Get better estimates by averaging over more sequences.

Demodulation

- Decide which symbol, consecutively which bits, were sent.
- Need criteria to decide based on received signal
  - Maximum likelihood
    - Assume xi was sent (given), what is the probability of observing yj? → Choose xi with max. probability.
- Maximum a posteriori
  - Given observation yj what is the probability that xi was sent? → Choose xi with max. probability.

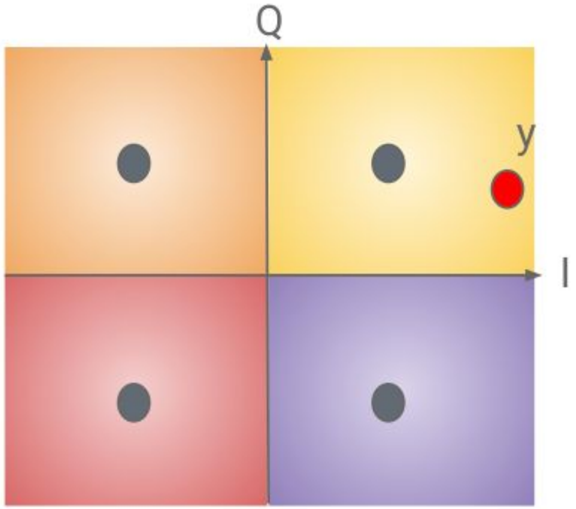
Smallest Distance

- If every symbol has the same probability of being sent, both criteria are the same.
- Smallest distance.
  - Choose the constellation point closer to where the received symbol has landed



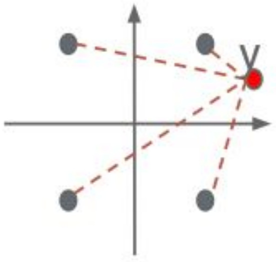
Decision Regions

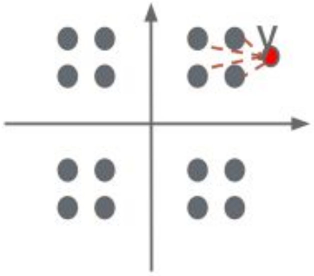
- These criteria define decision regions
  - Areas around each constellation point xi, where each point is closer to xi than any other constellation point xj.
  - Very regular for QAM
  - Decide based on which region y lands on



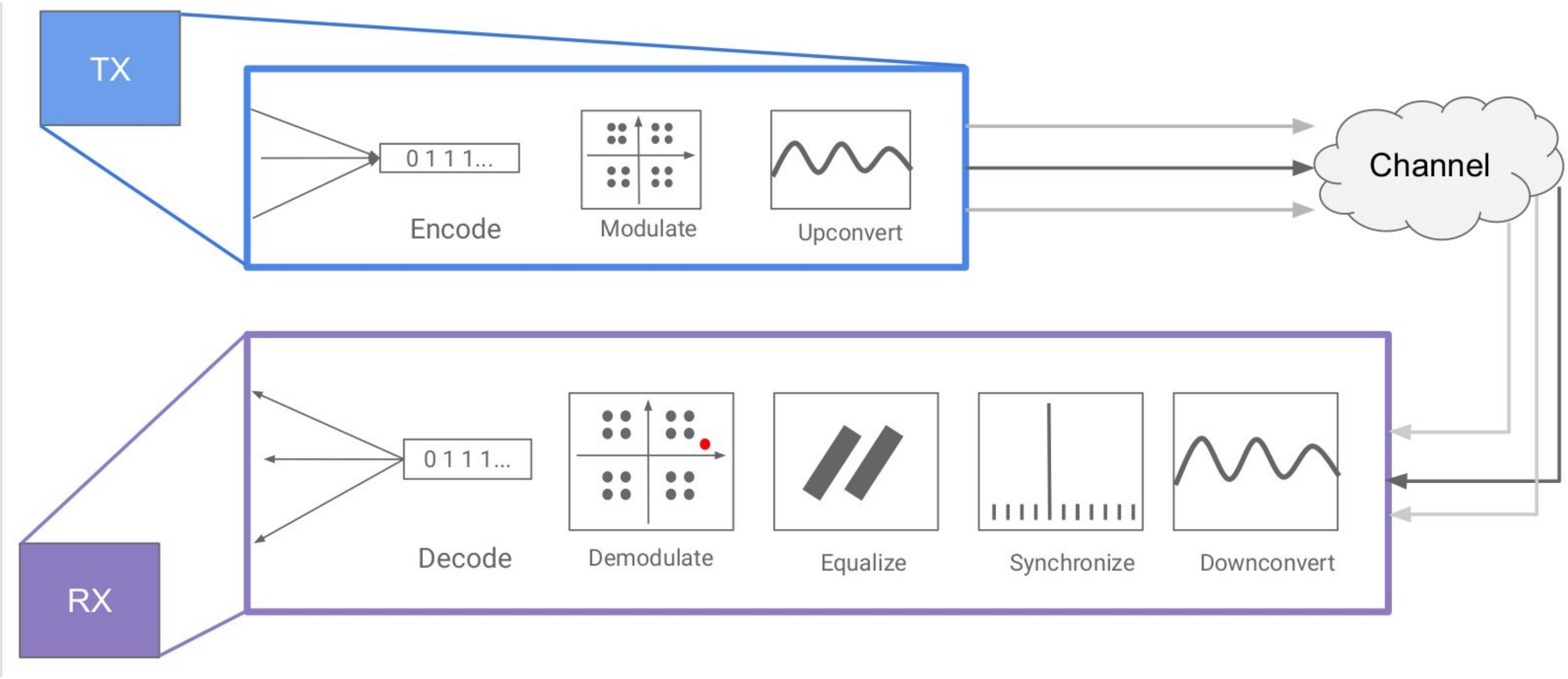
Errors

- Packing more symbols on the constellation increases rate.
    - More bits/channel use.
- Leads to more errors
    - Smaller distances/decision regions for same power
- Higher constellation orders need higher SNR
    - Makes the received symbol to land closer to the correct point.

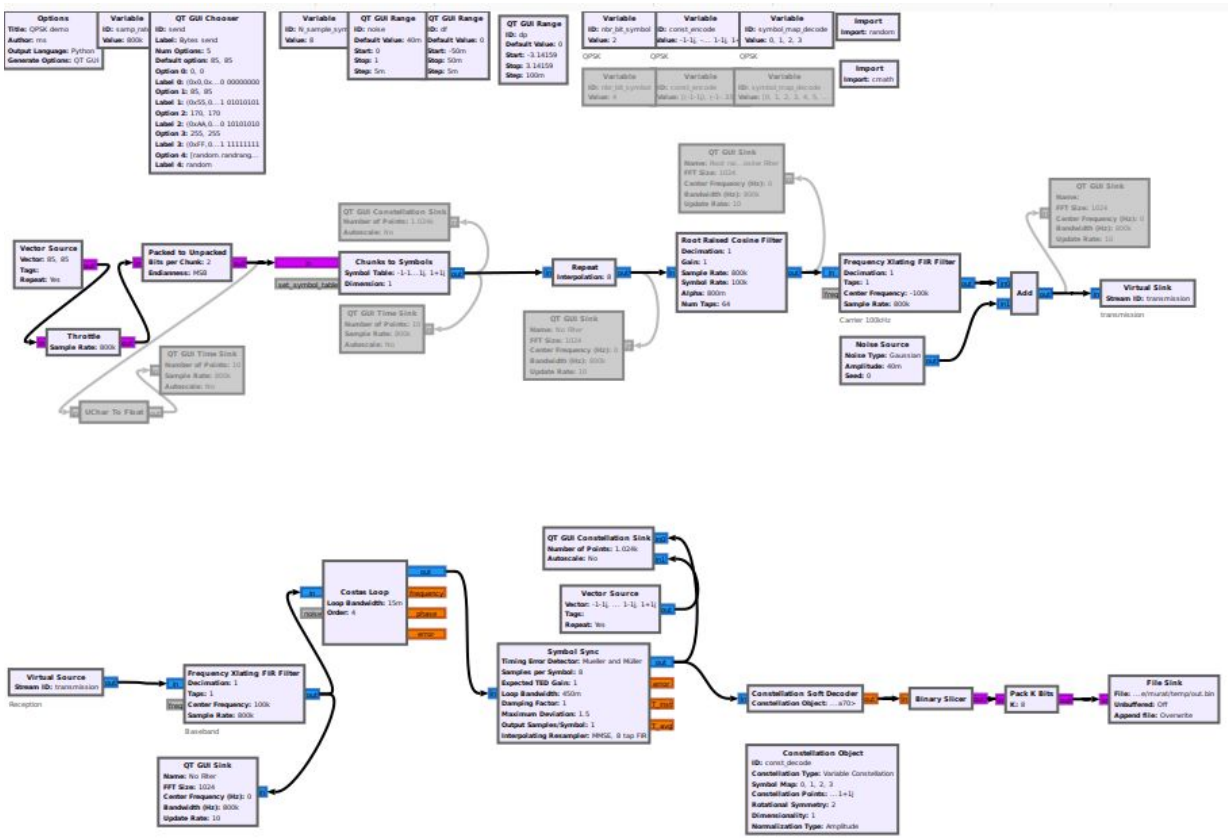




Wireless System: Putting all together



End-to-End Digital Communication System Simulation

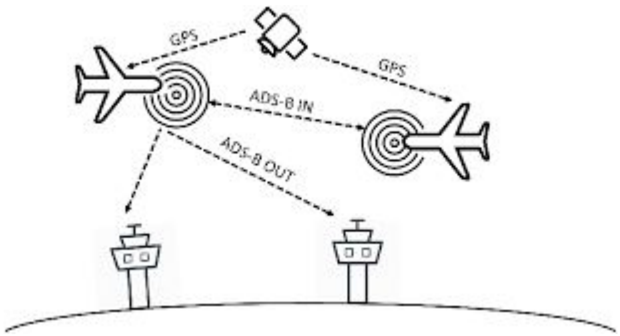


RADAR

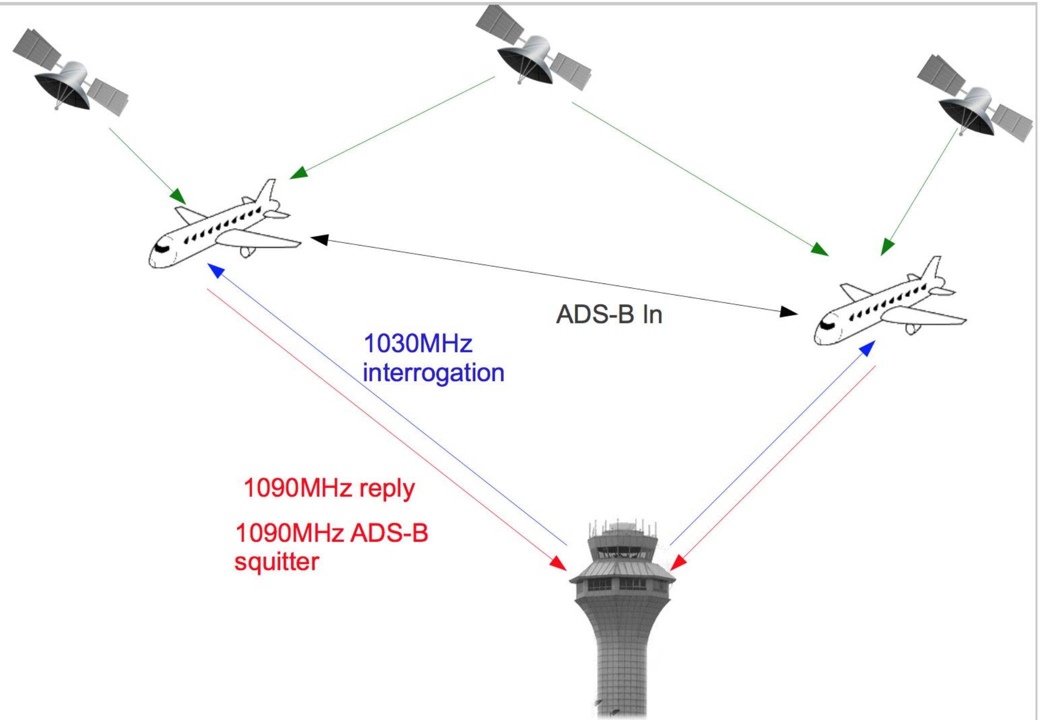
- Large areas of airspace are not covered by radar
- Radar installations are expensive!

Automatic Dependent Surveillance–Broadcast (ADS-B)

- Replacement for active RADAR
- Location, velocity, …
- 5-10 Messages/second
- You can receive
  - 1200 messages/second
  - from 133 different airplanes



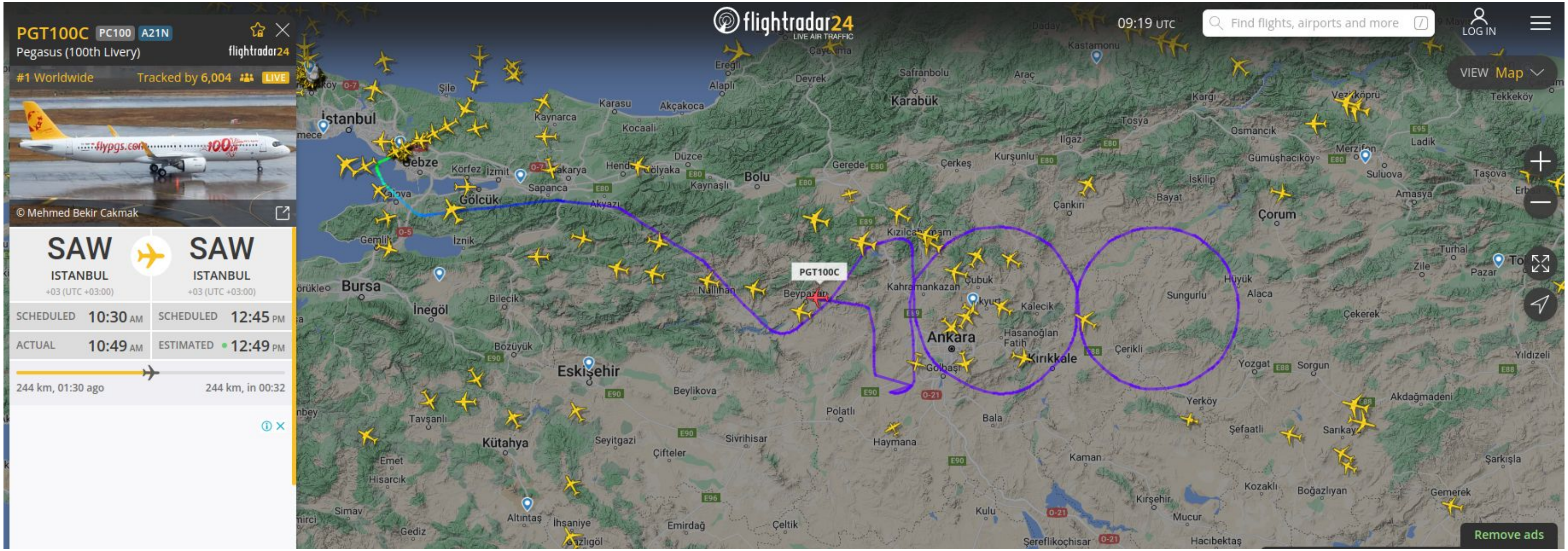
ADS-B



ADS-B In
1030MHz interrogation
1090MHz reply
1090MHz ADS-B squitter

ADS-B Aggregators

Pegasus 100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ACTUAL 10:49 AM
ESTIMATED 12:49 PM
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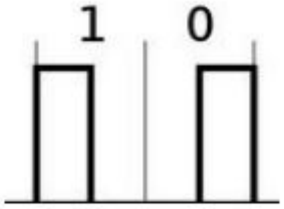
Drawing Hearts

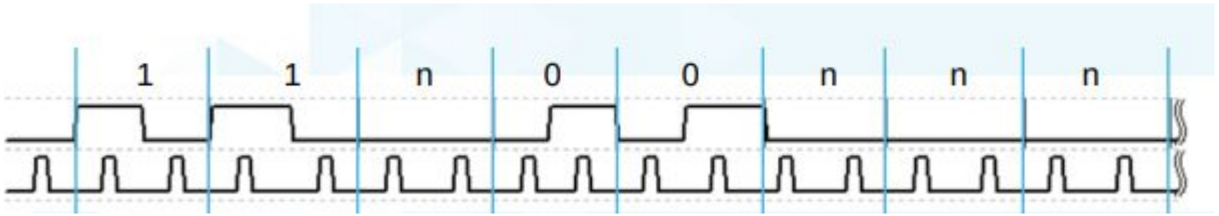
Check out for more on drawing hearts!

- https://www.flightradar24.com/blog/a-brief-history-of-drawing-hearts-with-an-airliner/

ADS-B Data Format

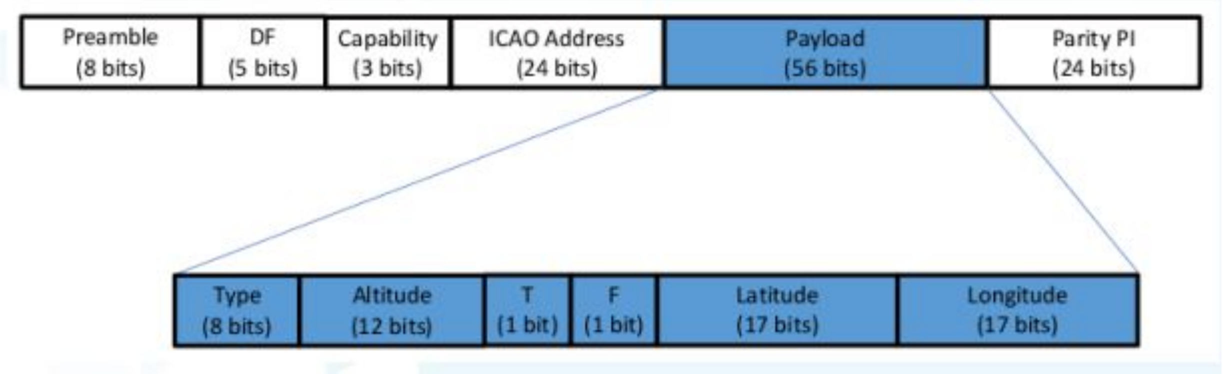


- Pulse Position Modulation (PPM)
- There are 2 bits, (1 and 0), and therefore two positions
- Manchester encoding used
- Each “bit” is 1μs long, the pulse is 0.5 μs.
- 8-bit preamble of “11n00nnn”
- Sample each bit twice (every 0.5 μs), or 2 MSPS



ADS-B Packets

- Short squitters are 56bits (8bits Control, 24bits address, 24bits parity check)
- Long squitters are 112bits (8 bits preamble + 8bits control, 24bits address, 56bits ADS-B message, 24bits parity)



ADS-B Hunting

- Use RTL-SDR to catch ADS-B signal

Schedule

- First Day: GNU Radio Introduction, DSP, GR Simulation Mode
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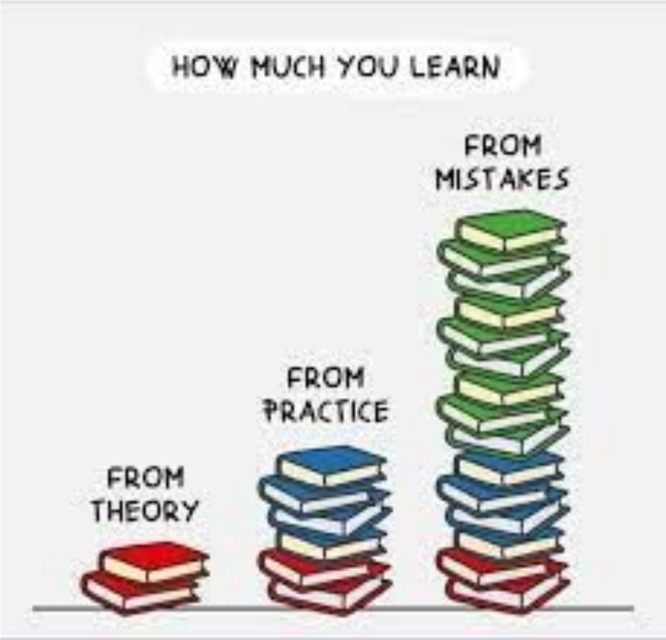
Do you agree?



Survey

- Have your say before leaving!

Nice to ***communicate*** with you all!

- Reach out to me at ytregitim@gmail.com
- Find me on LinkedIn
- Contact me for educational/academic deliveries