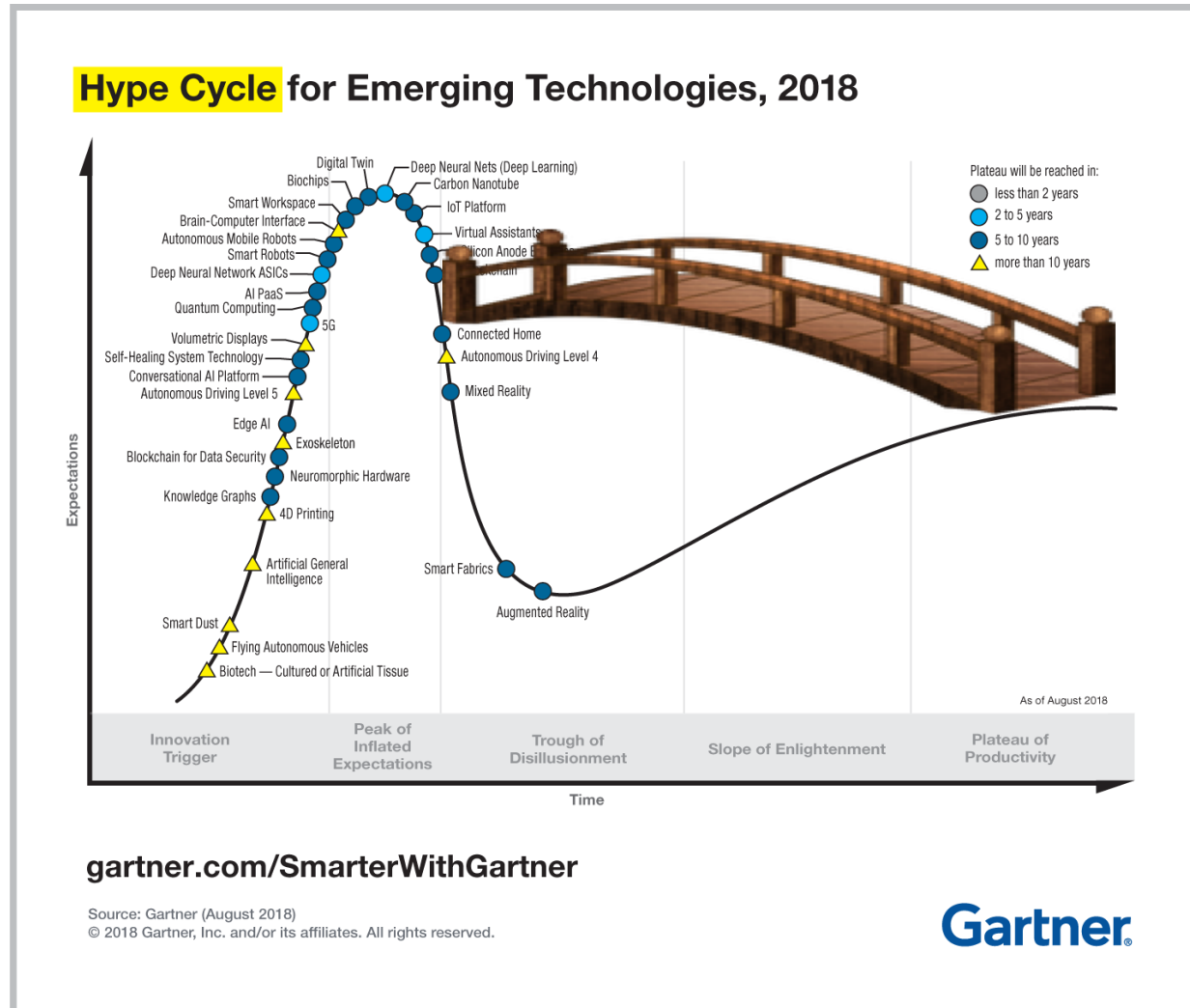


Deepmod: Self-Taught Waveform Synthesis and Analysis in the Amplify-and-Forward Relay Channel

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Tennessee Tech University

CCAAW '19

Technology Hype Cycle



- Deep learning will play a key role in 5G, tactical, and space networks
- Deep learning is also a key actor in the hype cycle...
- How to bridge the gap to avoid disillusionment?

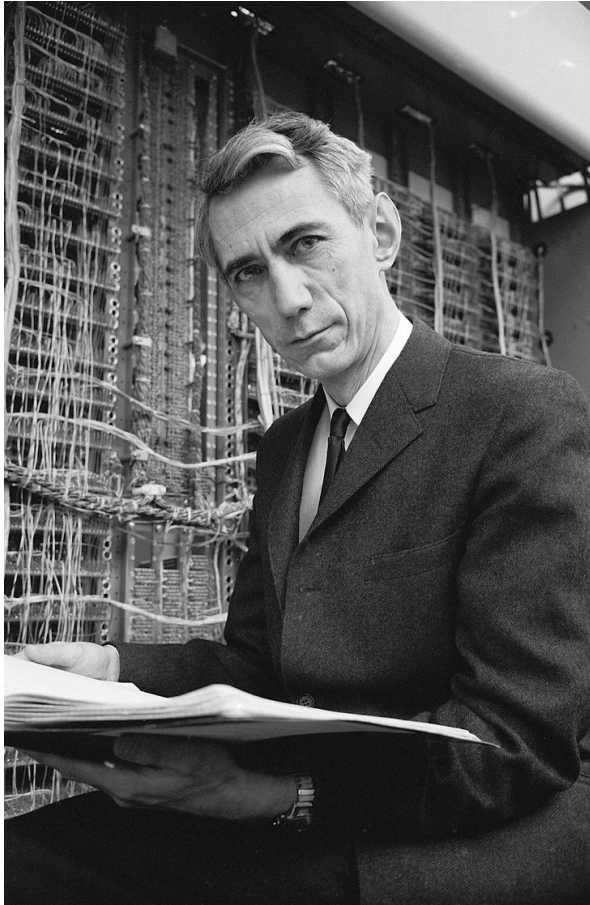
The Problem with Humans

- Humans are intelligent and very good at solving problems
- Many ground-breaking discoveries are single-agent single-discipline situations
 1. Give me a function
 2. I'll solve it
 3. Give me a constraint
 4. I'll optimize it
- New problem? Go back to 1)

* Technology only advances as quickly as the appropriate humans are presented with appropriate problems (a source of disillusionment).

Not very efficient, for example... the Bit, the Current, and the Channel: A Love Story

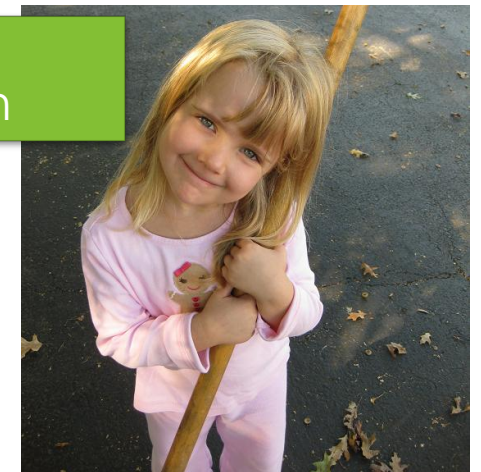
The **Bit**, the Current, and the Channel: A Love Story



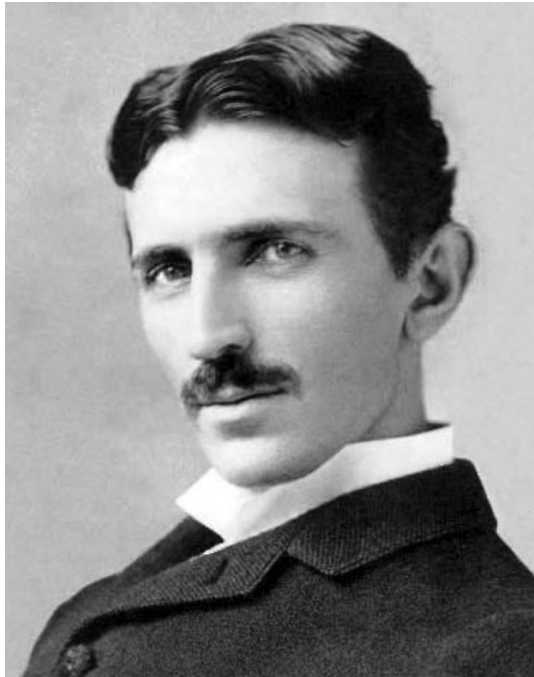
Claude Shannon: The Father of Information Theory. Developed the fundamental unit of information – “the bit”.

“It would be cheesy to compare him to Einstein. Einstein looms large, and rightly so. But we’re not living in the relativity age, we’re living in the information age. It’s Shannon whose fingerprints are on every electronic device we own, every computer screen we gaze into, every means of digital communication.”

Shannon
Anderson



The Bit, the **Current**, and the Channel: A Love Story



Nikola Tesla: The Champion of Alternating Current (AC). AC gives us the power to deliver energy AND information.

“The scientists from Franklin to Morse were clear thinkers and did not produce erroneous theories. The scientists of today think deeply instead of clearly. One must be sane to think clearly, but one can think deeply and be quite insane.”

Tesla
Anderson



The Bit, the Current, and the **Channel**: A Love Story



James Maxwell: The Father of Electromagnetics (EM). “Maxwell’s Equations” describe how we can transmit AC over wireless channels.

“According to modern physicists, the greatest physicists of all time: 1. Albert Einstein 2. Isaac Newton 3. James Clerk Maxwell 4. Niels Bohr 5. Werner Heisenberg 6. Galileo Galilei 7. Richard Feynman 8. Paul Dirac 9. Erwin Schrödinger 10. Ernest Rutherford”

James & Maxwell
Anderson



Collage of Human Discovery

The bit is represented by the current and transmitted over the channel.

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t}$$

$$C = B \log_2 (1 + S/N)$$

bandwidth of the channel

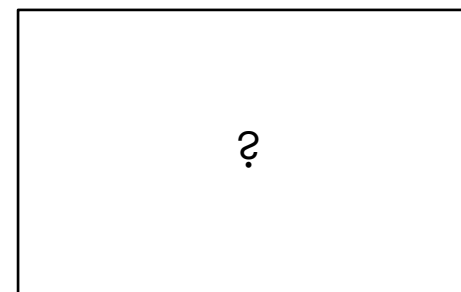
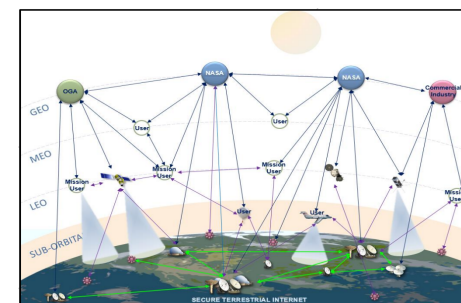
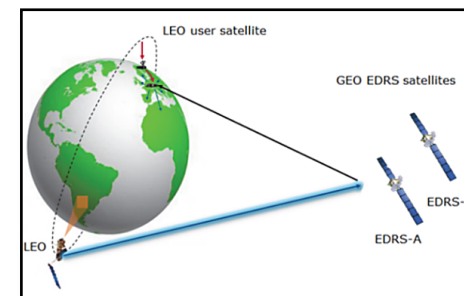
Channel capacity in bits/s

signal-to-noise ratio

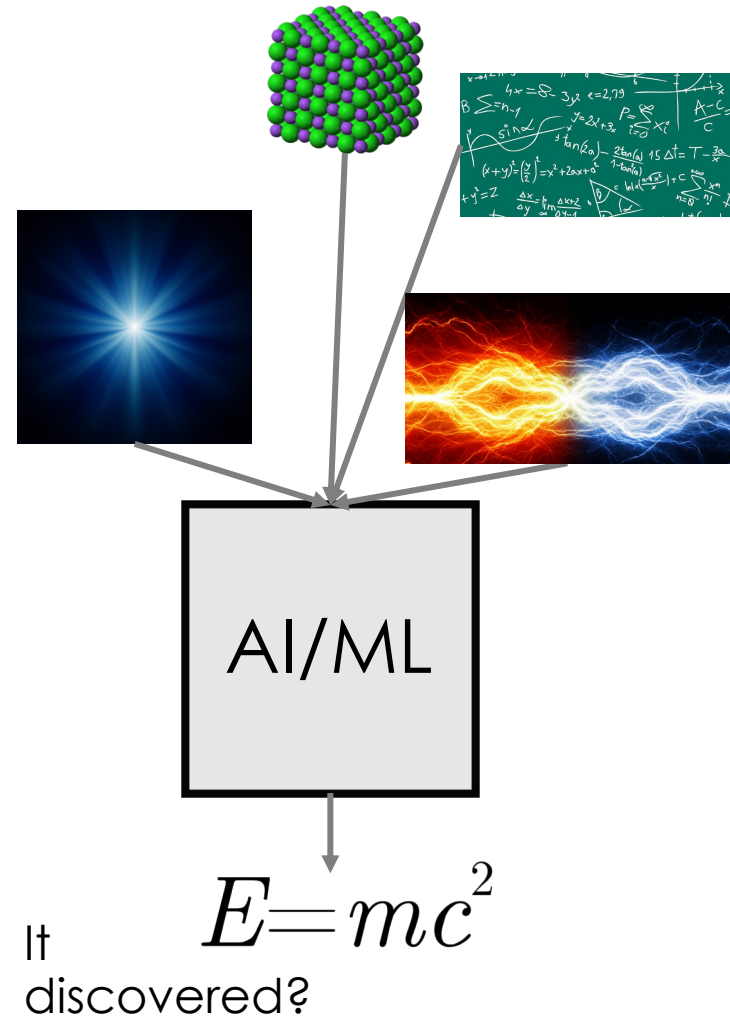
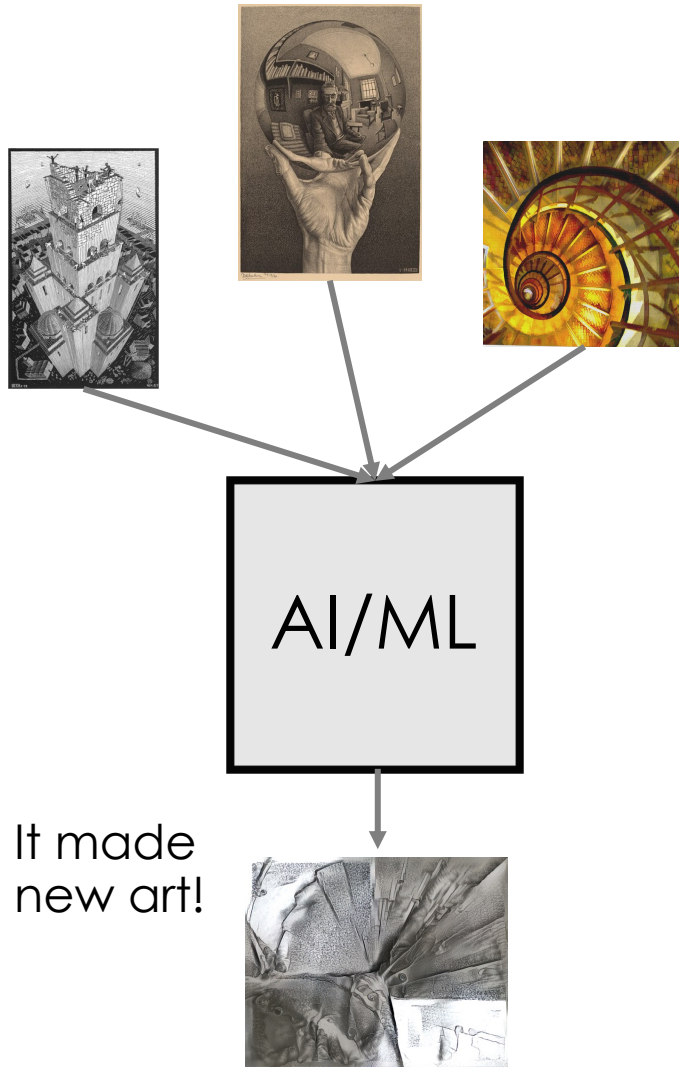
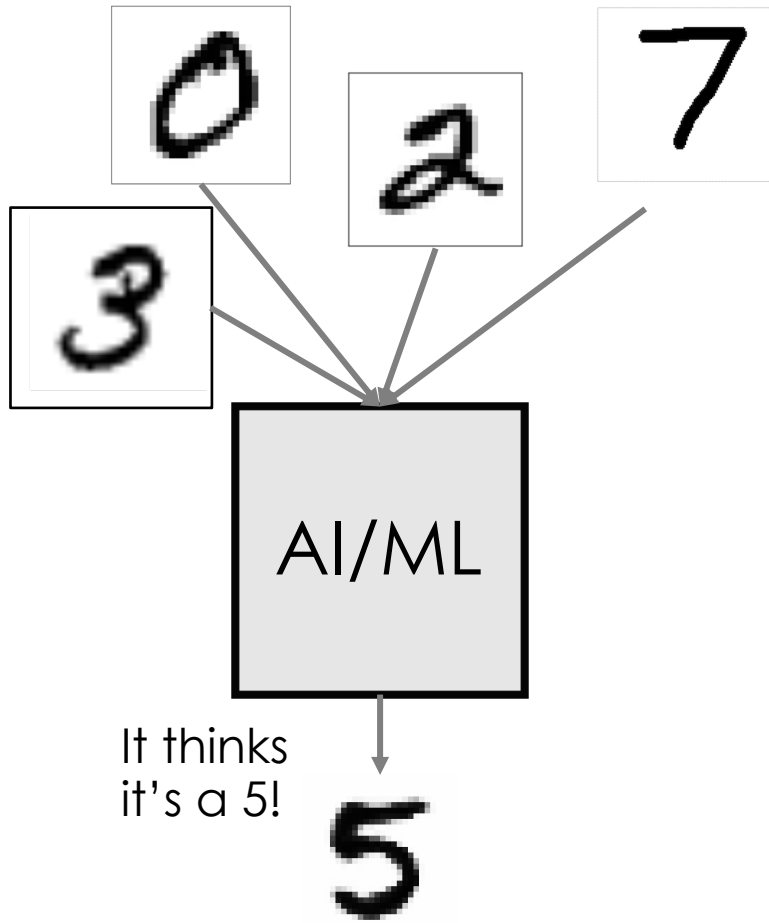
$$\frac{\partial^2 \varphi}{\partial t^2}(x, t) = c^2 \frac{\partial^2 \varphi}{\partial x^2}(x, t)$$

$$\varphi = \sum_n [A_n \cos(k_n x + \omega_n t) + B_n \sin(k_n x + \omega_n t)]$$

And **100,000,000's man-hours** later...





The Problem with Artificial Intelligence / Machine Learning (AI/ML)



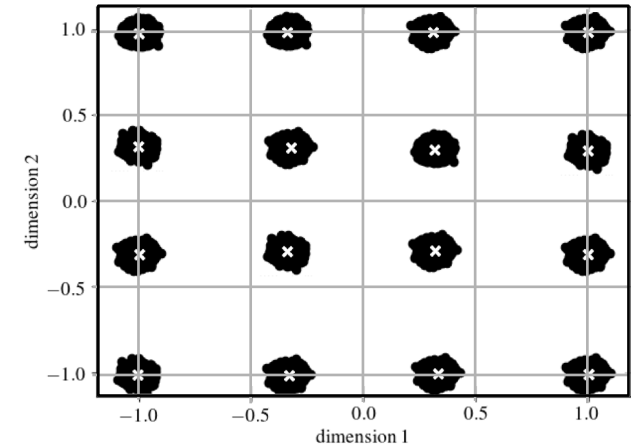
Human labor-saving machines

Human discovery machines

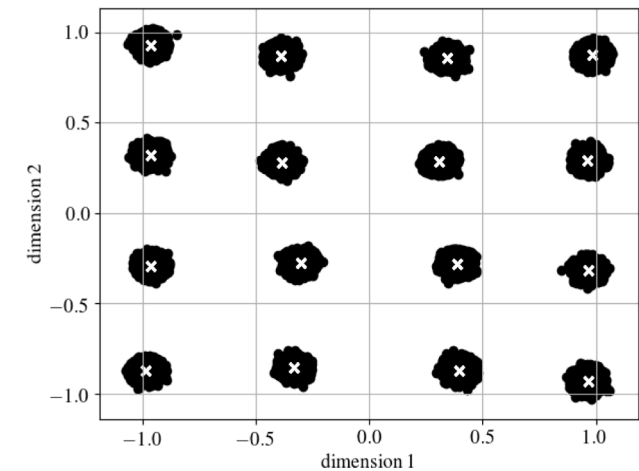
Machine Learning in Communications

- This is a noisy symbol  representing four bits (e.g. 1101)
 - We want to place 16 of these on a fenced, flat space so that no two clusters overlap (overlap means bit errors!)
 - Minimize the bit-error rate
-
- This is a noisy symbol  representing four bits (e.g. 1101)
 - Give a machine a convolutional neural network with two dimensional fully-connected inner layer


Human Invented 16-QAM



Machine Invented 16-QAM

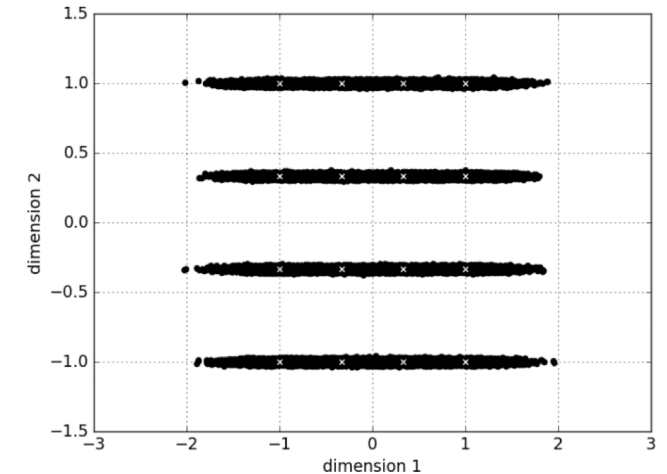


16-QAM New Problem

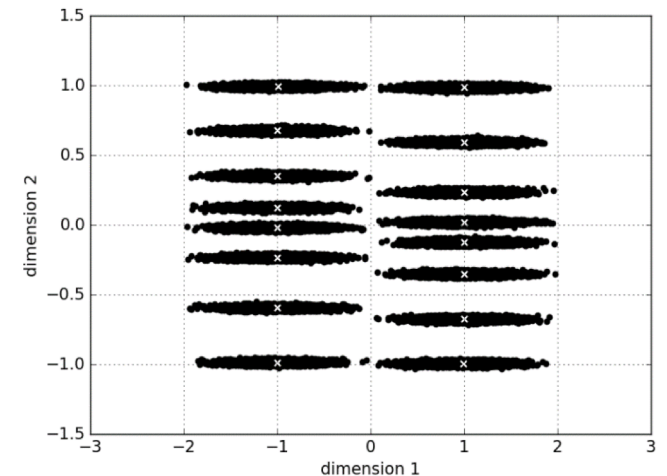
- Most channels don't have "nice" noise...
- This is now a noisy symbol  representing four bits (e.g. 1101)
- The human-invented 16-QAM is terrible with massive cluster overlaps (bit errors)
- What can we do?

- Same machine. New discovery.

Human Invented 16-QAM

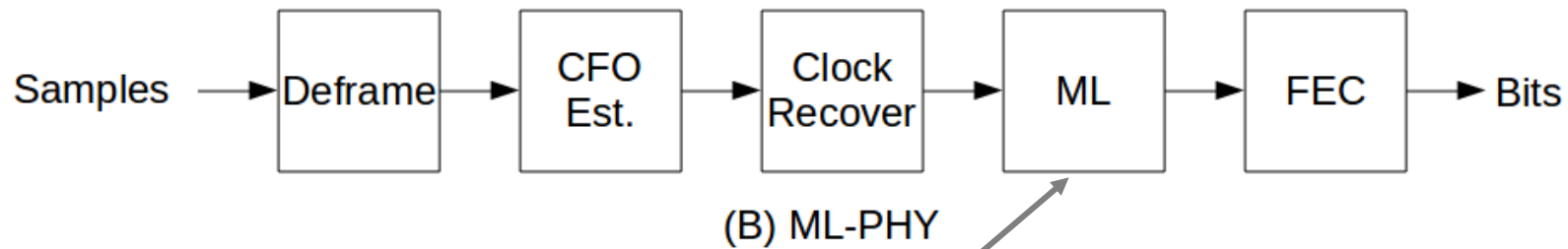
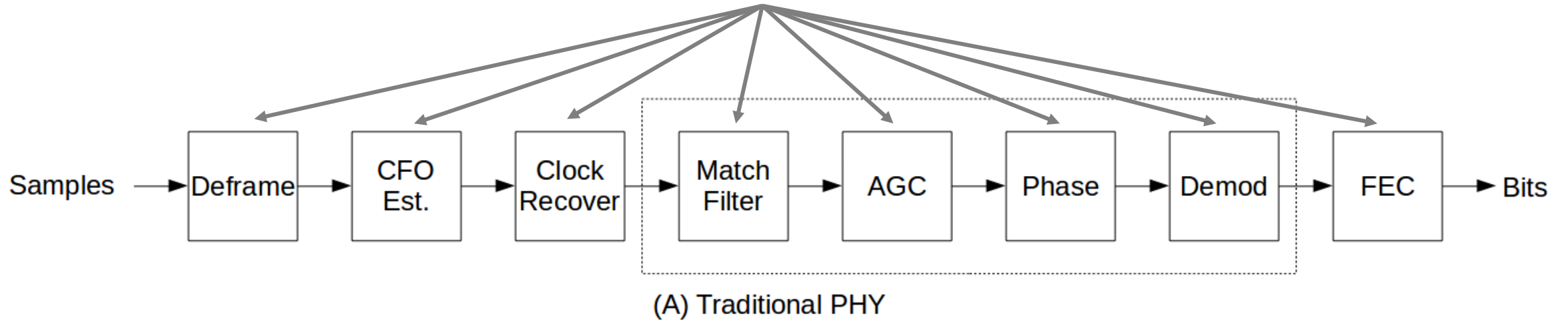


Machine Discovered 8x2-QAM

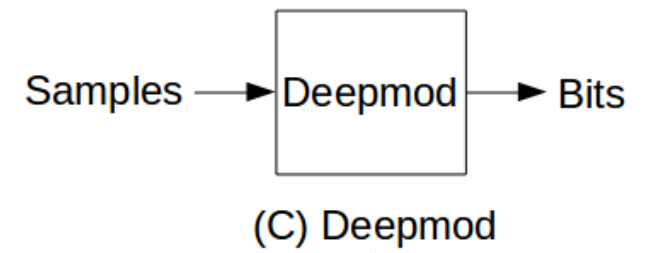


Deepmod: Deep Learning Modulator/Demodulator

Lots of human invented signal processing blocks



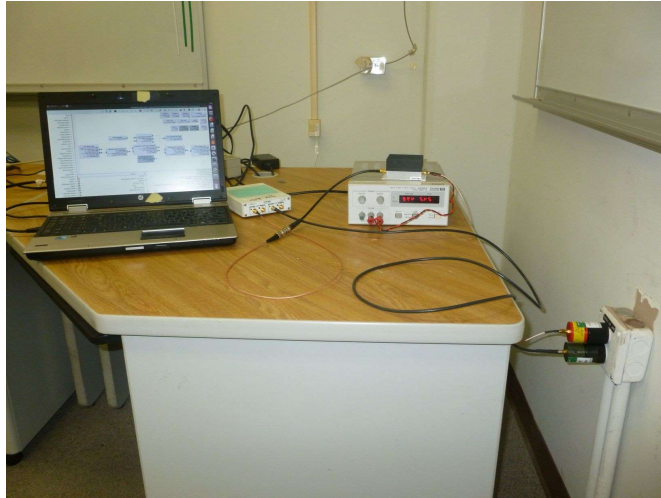
Straightforward to replace some with ML blocks



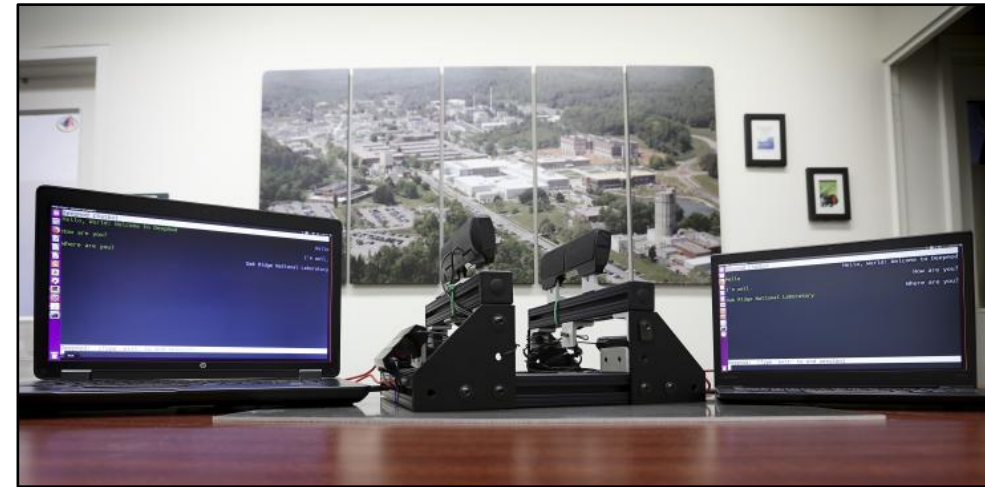
We want to *discover* communications

Deepmod: Letting the Machine Discover In the Wild

Powerline Channel



Acoustic Channel

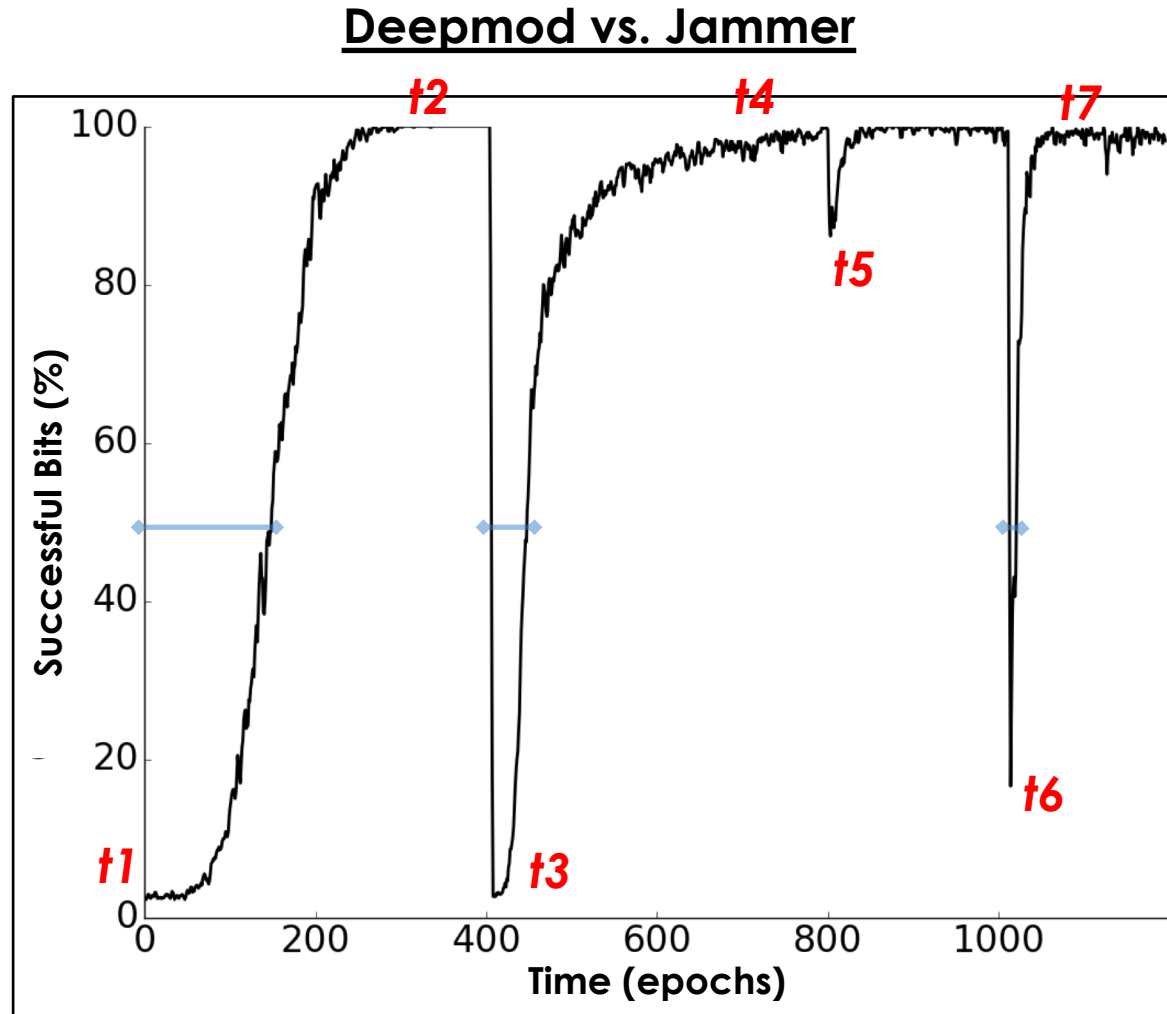


RF Channel



- **3** different channels
- **1** machine learner (deepmod)
- **0** phase-locked loops (PLL), frequency-locked loops (FLL), channel equalizers, (de)modulators, constellations, carrier frequency offset (CFO) estimators, automatic gain controllers (AGC), filters, forward-error correction (FEC) codes, etc.

Deepmod: Contested Channel

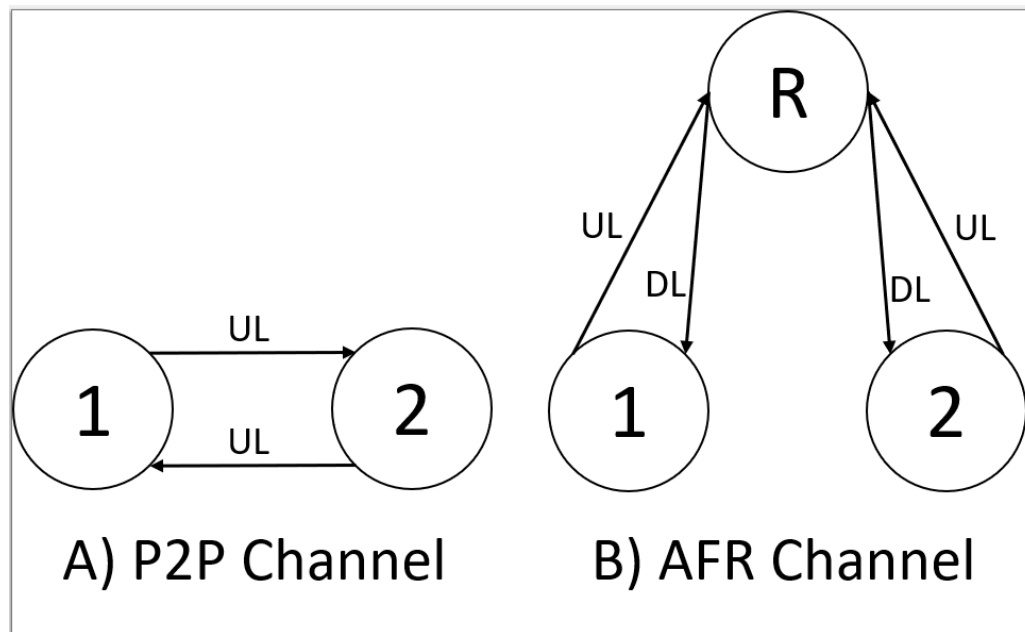


- t1**: Two Deepmod enabled radios are powered on
- t2**: Radios converge to a viable communications protocol
- t3**: Narrowband jammer is engaged; performance bottoms out
- t4**: Deepmod recovers by “learning” new jammed channel
- t5**: Jammer is turned off confusing Deepmod temporarily
- t6**: Jammer is turned back on
- t7**: Deepmod recovers quickly; retained knowledge of both “on” and “off” jammer states

Deepmod learns to communicate.

Deepmod: Amplify and Forward Relay (AFR) Channel

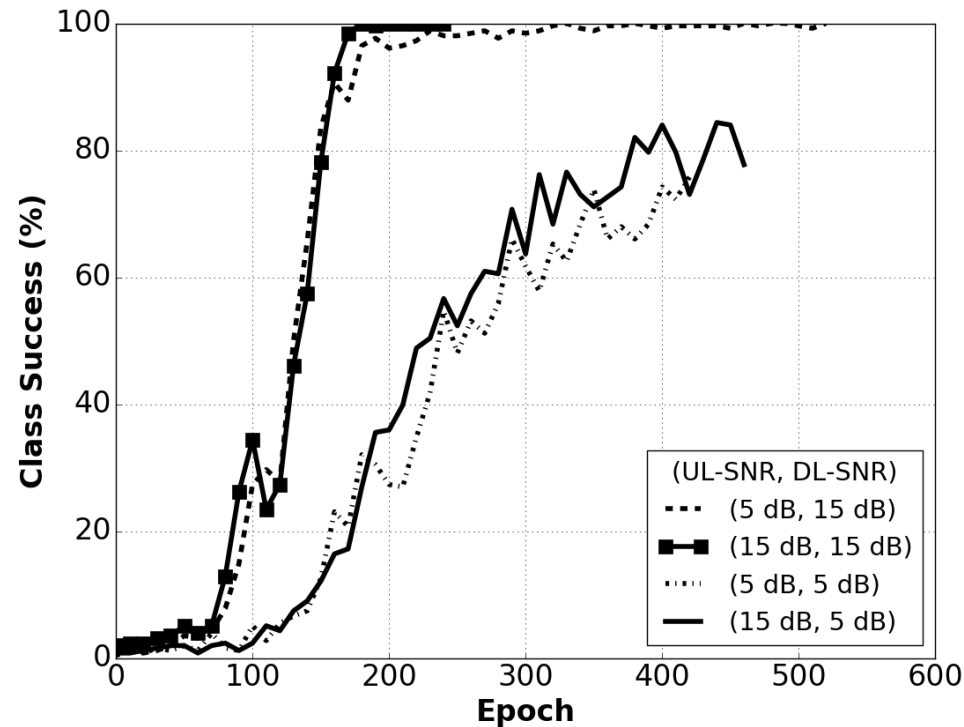
AFR channel: Important for non-LOS communications such as in satellite or tactical networks.



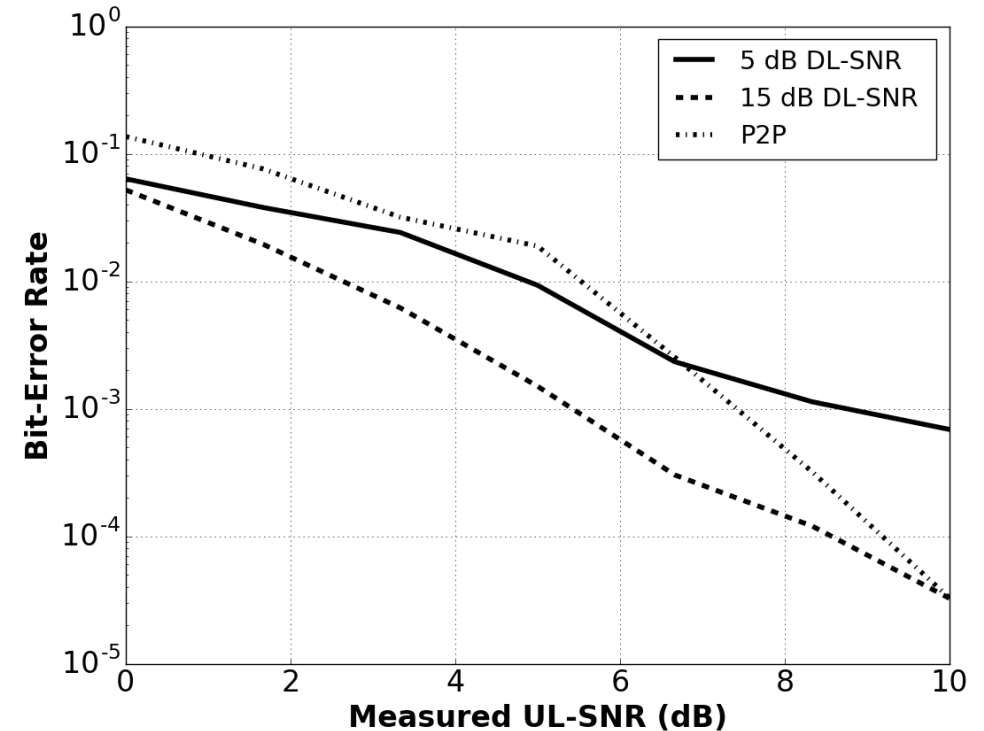
- In deepmod, a third “dumb” node is added to act as an amplify-and-forward relay channel
- All waveforms are transmitted through relay (no LOS connection between users)

Deepmod learns to communicate.

Performance of Deepmod in AFR Channel

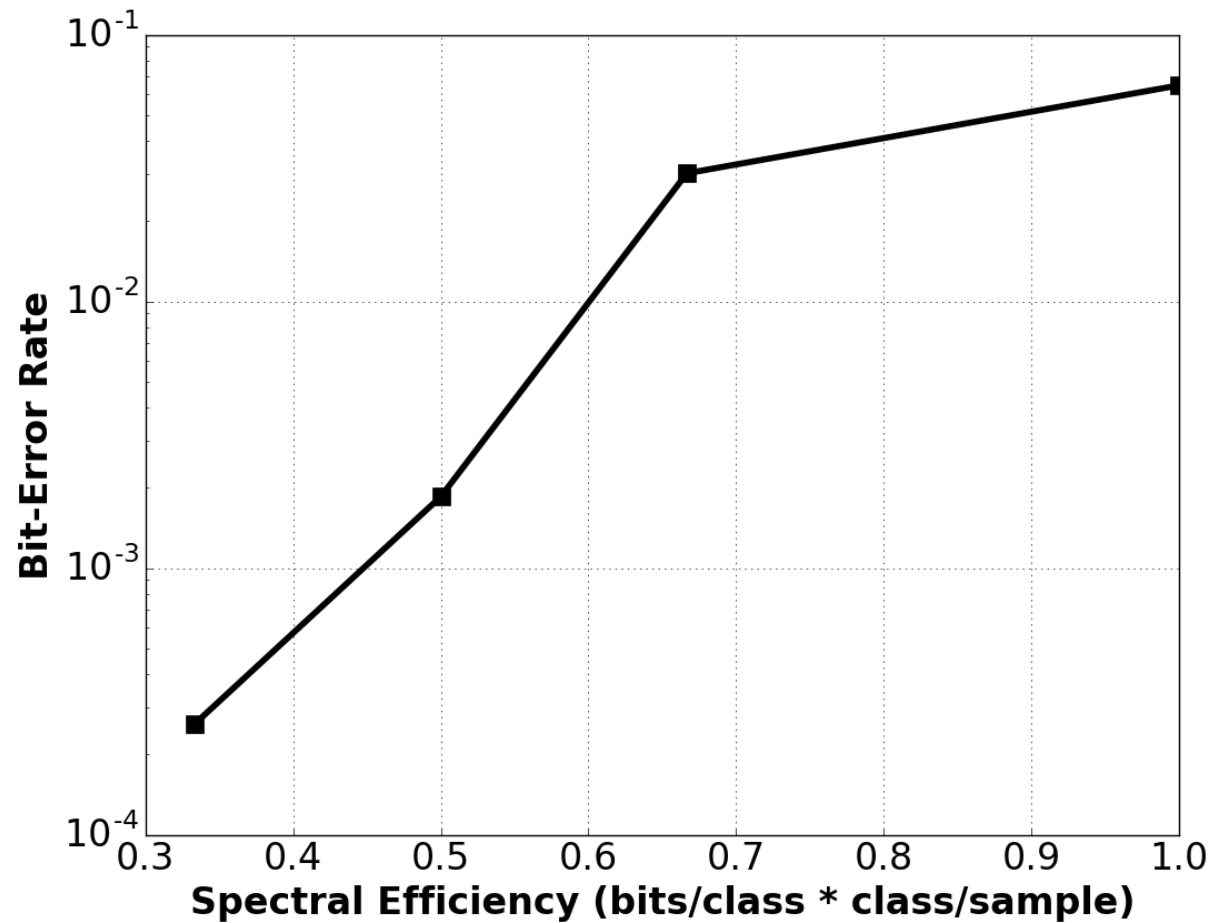


- One epoch is the time to transmit, and receive, a single batch
- DL-SNR appears to dominate training time
- May be hardware artifact of USRP relays



- BER performance passes litmus test
- Comparable to P2P when UL-SNR is sufficiently high
- Direct comparison with traditional comms in experimental setup is difficult

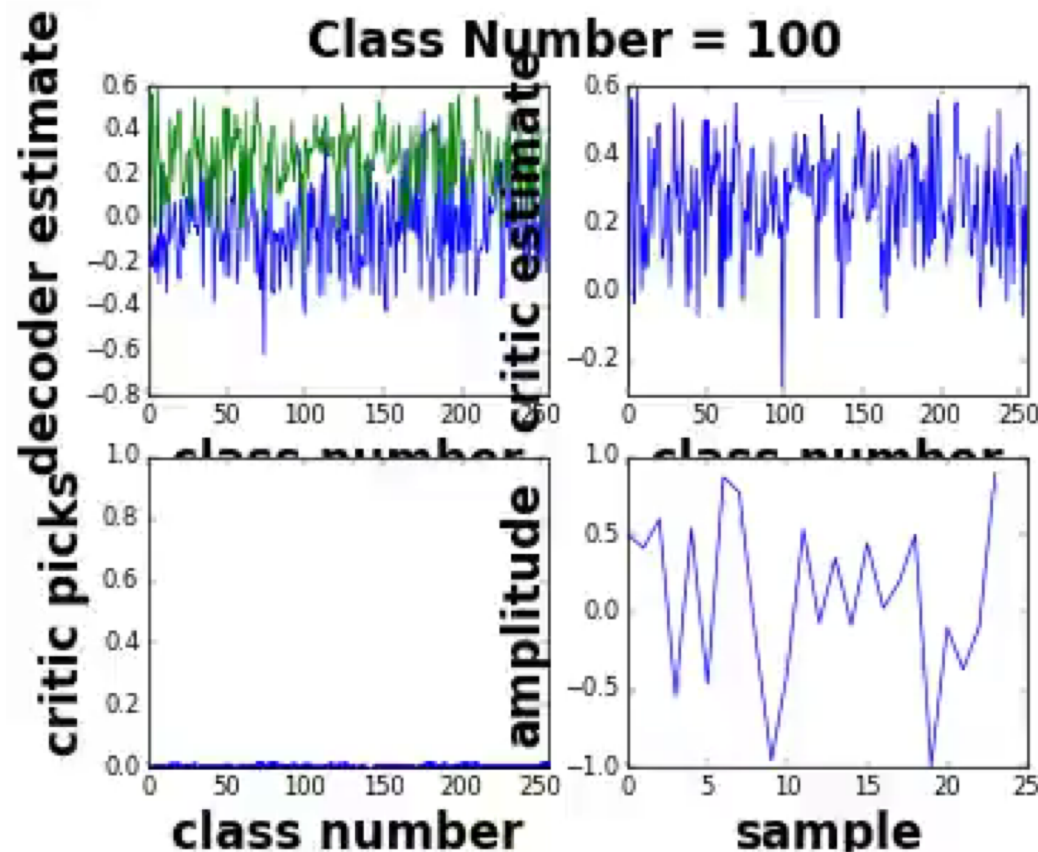
Improving Performance of Deepmod in AFR Channel



- 256 classes or 8 bits per class
- A waveform with 8 (complex) samples per class would have an efficiency of 1 bit per sample.
- Decreased efficiency improves performance
- Is it error correction or just more "EbN0"?
- Could we modify the loss functions to improve error correction?

Deepmod: A Look Under the Hood – Decoder, Encoder, and Critic

Decoder estimate of Class #100



Critic prediction of Class #100

Encoder performance of predicted class

Interleaved real/imag samples of Class #100

Conclusions

- Humans are intelligent but slow to respond
- Repeated research and development cycle even for marginal advances in technology
- Machine intelligence is often used as labor-saving devices: self-driving cars, zip code readers, facial recognition, etc.
- We need machines that can “discover” in order to break the cycle - **Eureka Machines**
- Deepmod discovers communications in a wide variety of channels including AFR channels
- **Can the machine discovery the next comms technology before the human?**
- Still not a holistic, or practical, solution (yet)



Questions?



Adam Lane
Anderson II