Virginia Tech
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The Future of Radio
Learning Efficient Signal Processing Systems

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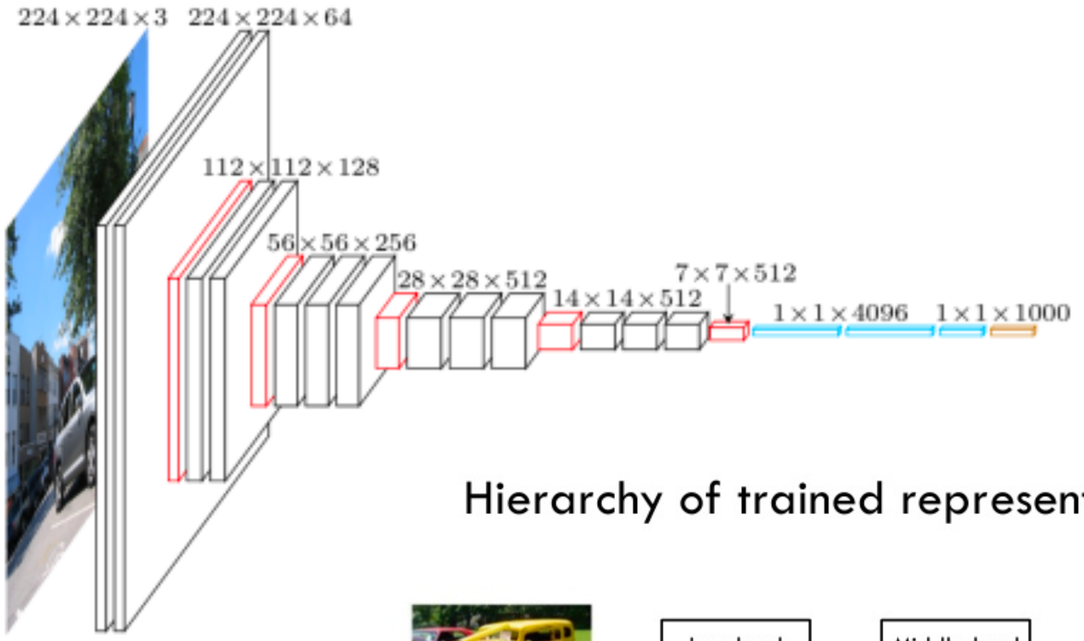
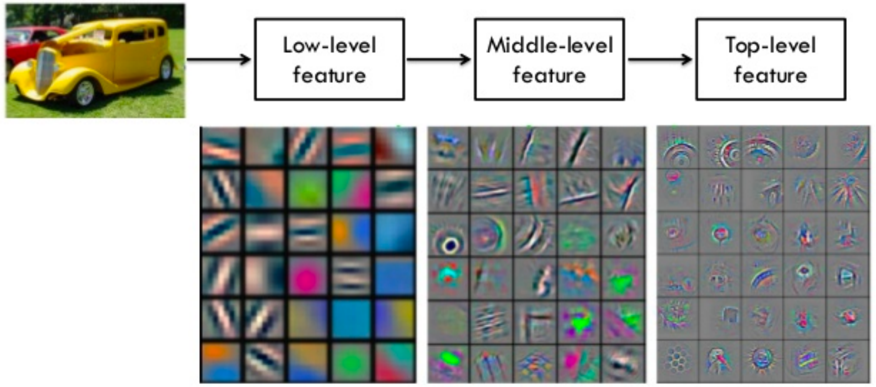
Deep Learning Trends

- Large Neural Networks are Disrupting Signal Processing
- Bigger change than most people realize
  - Feature Learning
  - End-to-end learning
  - Widely applicable to many domains
- Feature engineering is becoming irrelevant
  - Expert transforms unnecessary to achieve state of the art performance
  - Engineered features created barriers to learning anyway
  - Engineered algorithms created work in optimizing disparate algorithms
  - Just embrace everything as a dense multiply accumulate with some arbitrary set of weights



Hierarchy of trained representations



Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

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Deep Learning Trends

- Things that aren't that exciting anymore
  - Computer Vision (Object Recognition)
    - Self driving cars (Tesla, Comma.ai, etc)
  - Voice Recognition (Siri / Google Assistant)

- Its clear deep learning can (has) destroy the state of the art in these fields
  - Custom silicon can drastically bring down power costs of these networks
    - Apple "Bionic" processor, Google TPU, etc
  - These ships are already sailing wholesale

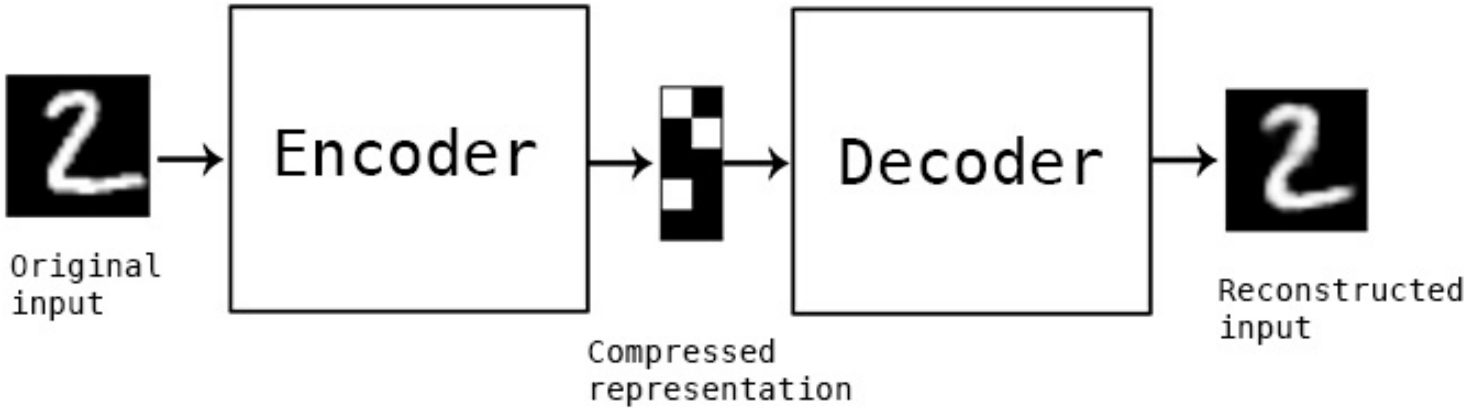
What is still brewing …

- Probably every signal processing algorithm on earth could be reconsidered/improved
  - Especially learned representations …

$$\phi : \mathcal{X} \rightarrow \mathcal{F} \qquad \psi : \mathcal{F} \rightarrow \mathcal{X}$$

- Simple construct of the autoencoder
  - Learns entirely new representations of information
  - Based on reconstruction loss or other loss functions

$$\phi, \psi = \arg\min_{\phi,\psi} \|X - (\psi \circ \phi)X\|^2$$

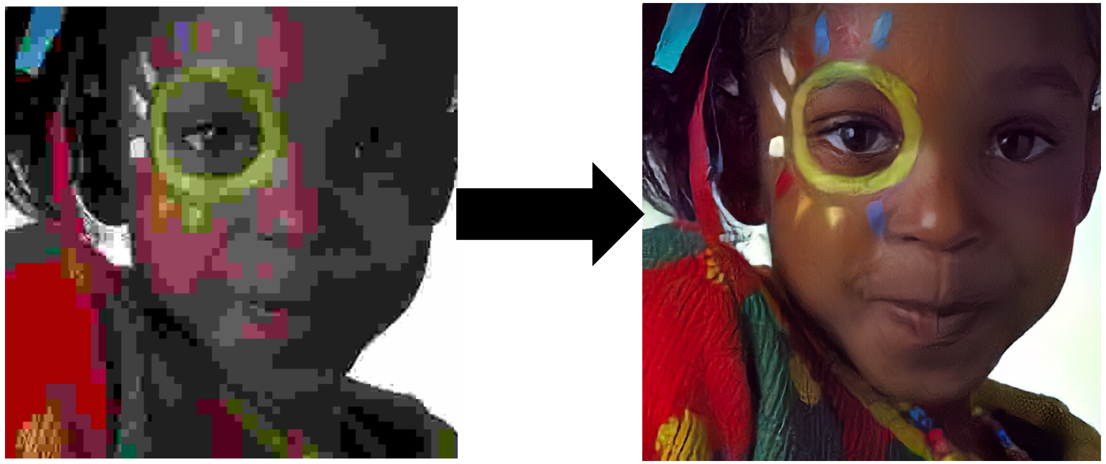


Minimize encoder and decoder loss

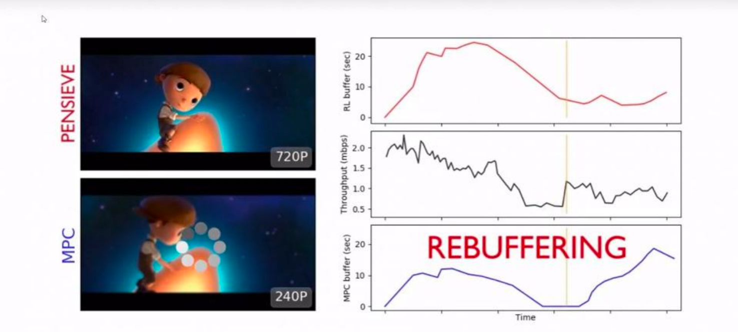
Only for relevant distribution of X!

What's interesting … and coming next…

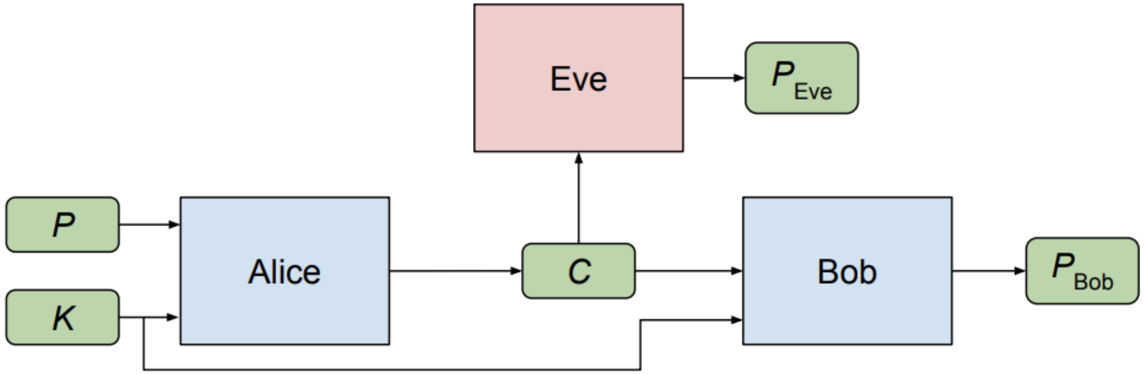
- **Image Compression Schemes**
  - Context aware compression: both 0.08 bits/pixel
  - New JPEG Standards

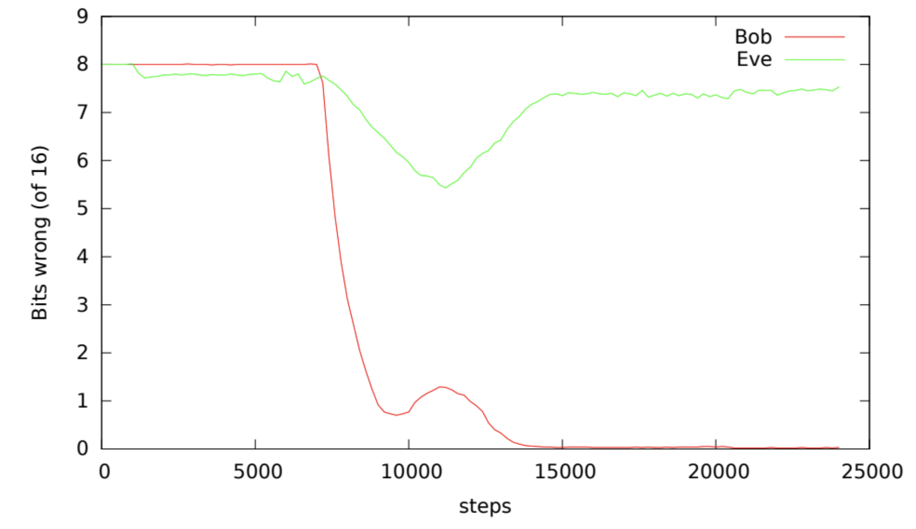


- Video Compression
  - Netflix / MIT adoption now



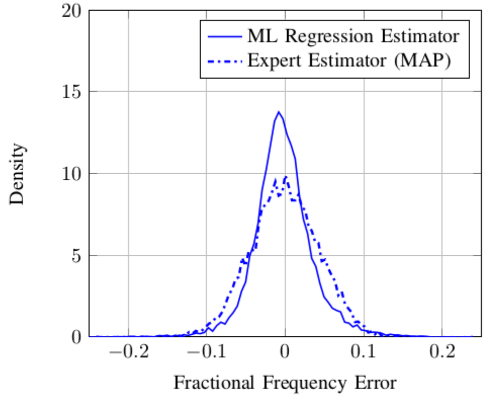
- Encryption
  - Simply a min/max reconstruction optimization

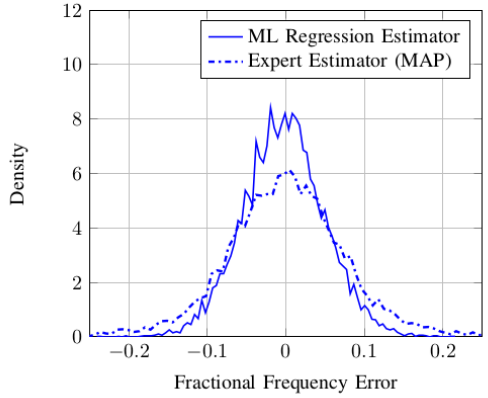


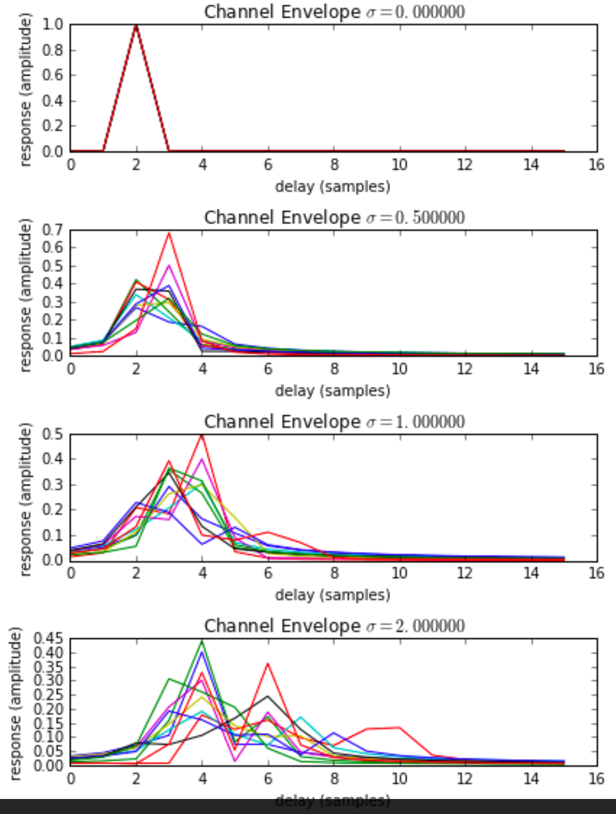


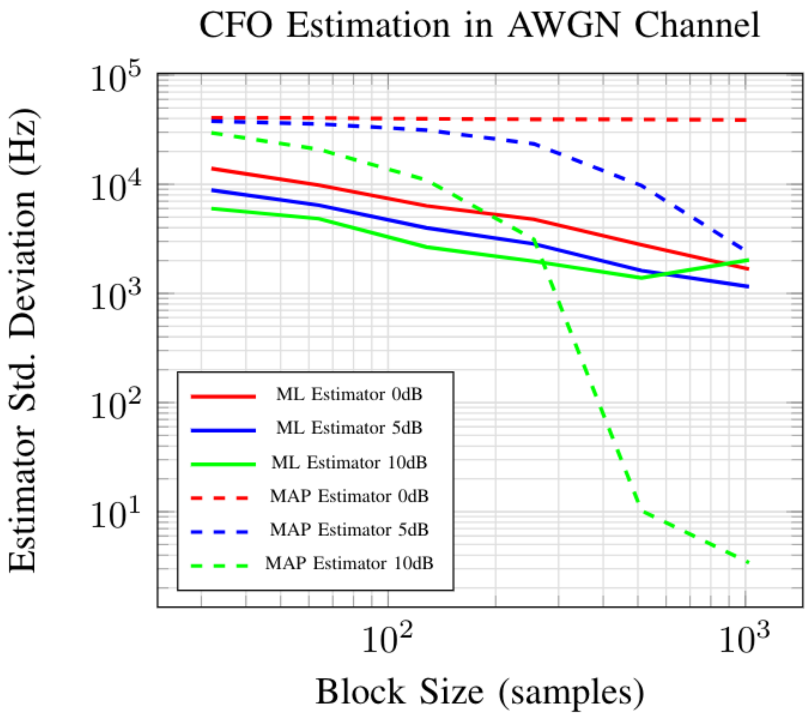
Better Estimators under impaired channels

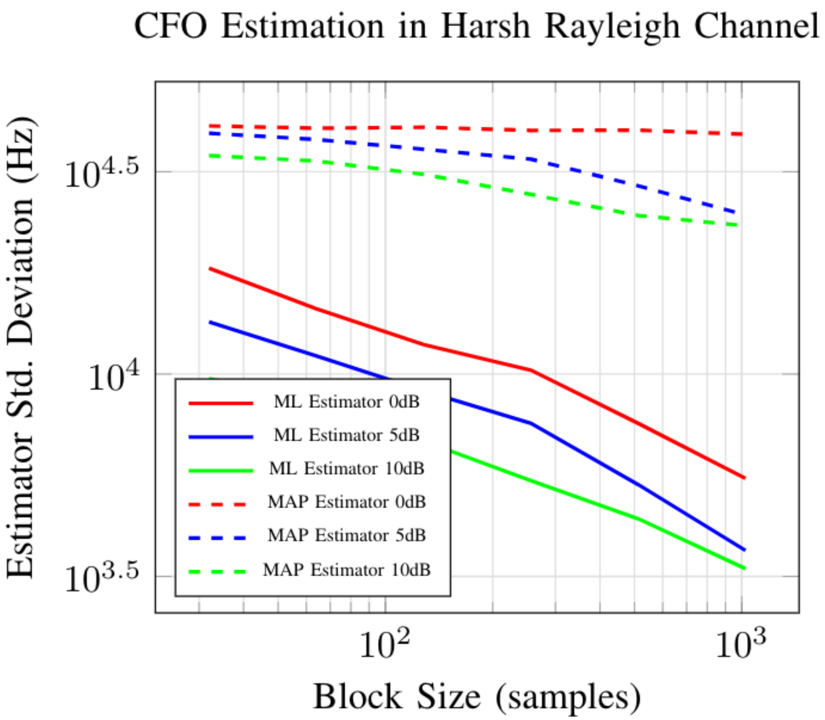
- Re-consider estimators and representations
  - In the context of actual distribution information
  - Better estimation under impairments!
  - Especially good for short-time windows





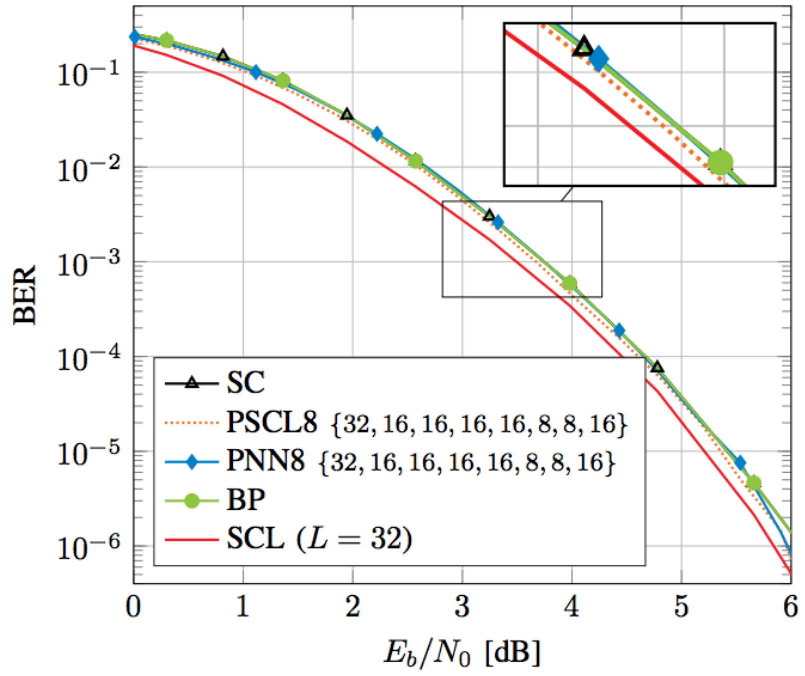


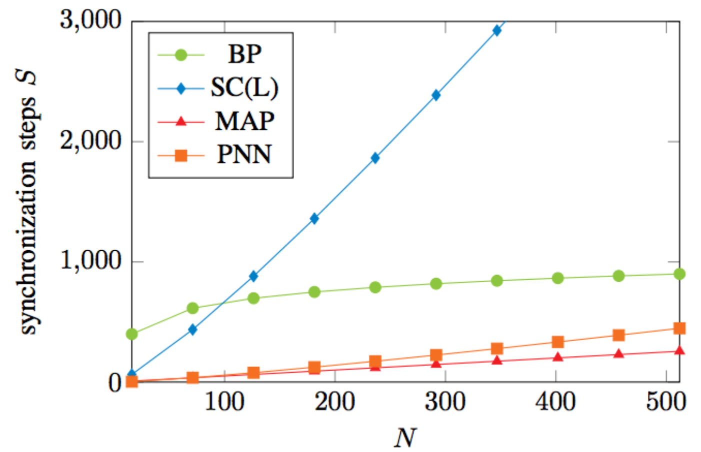




Efficient Approximate Decoders

- Learning decoders for 'near optimal' error correction codes! (Partitioning to scale)
  - FEC decoding / detection currently the #1 power consuming operation in radio baseband devices
  - Work from Cammerer, Gruber, Hoydis, ten Brink (University of Stuttgart / Nokia-Bell Labs)
  - Shows near-optimal polar code decoding performance with partitioned neural networks at lower complexity than successive cancellation or Belief Propagation!
- Potentially a major advance in error correction
  - Learn approximate decoders on code-word sets
  - Low latency one-shot decoding at higher efficiency
- **"Scaling Deep Learning-based Decoding of Polar Codes via Partitioning"** https://arxiv.org/abs/1702.06901

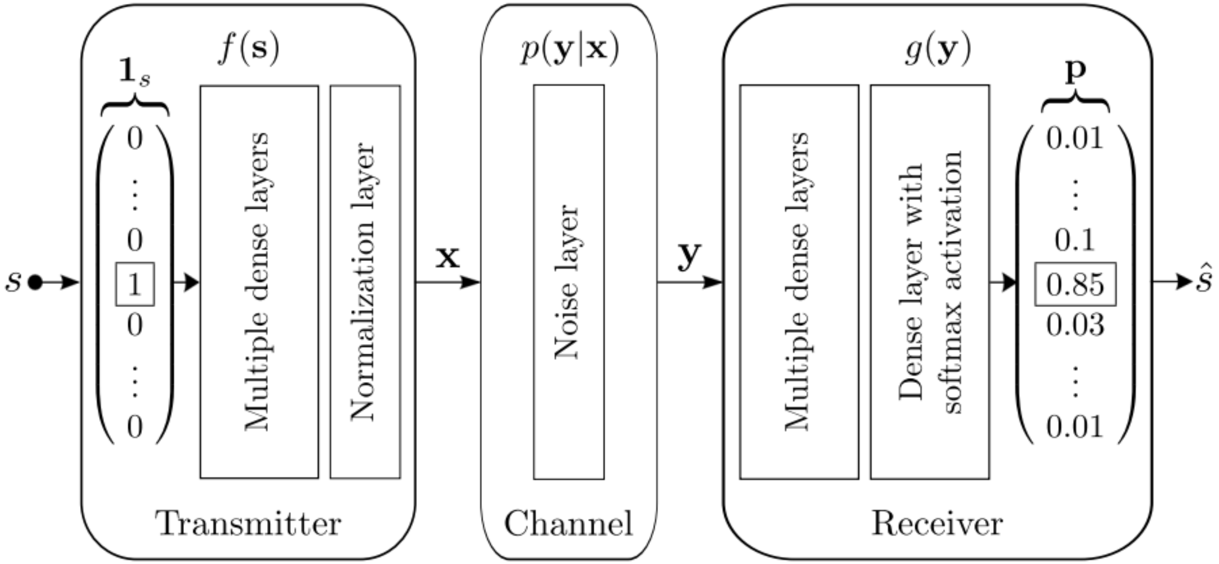




Rethink Approach to Communications

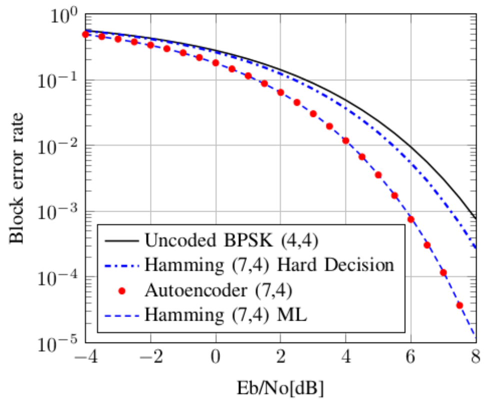
“Reproducing at one point either exactly or approximately a message selected at another point”

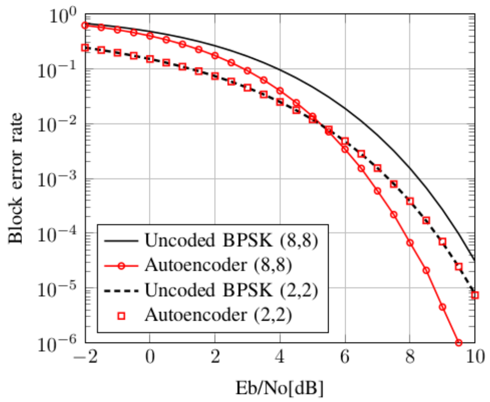
- C. E. Shannon, “A mathematical theory of communication,” 1948

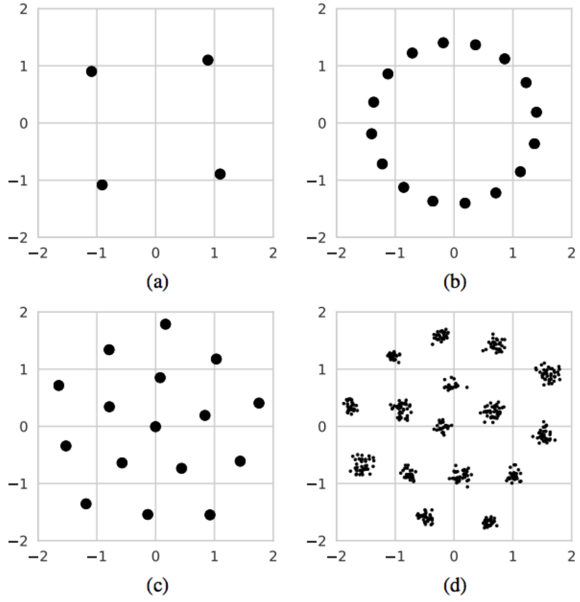


- All communication systems need to do is optimize for reconstruction loss
  - Everything else is a secondary sub-task
  - Lets not get hung up on minutia

- This actually works really well
  - Matches coded modulation baselines immediately

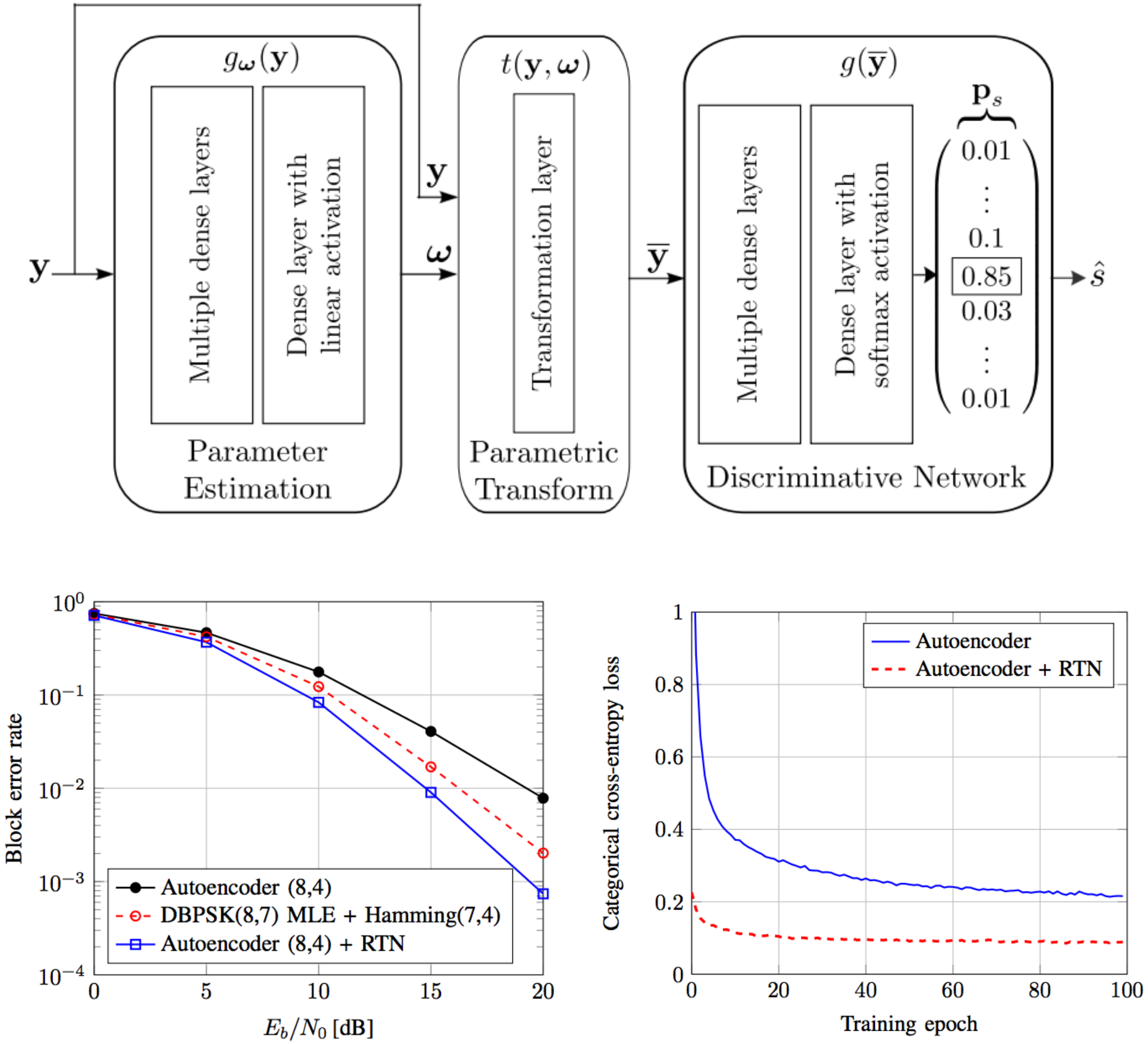






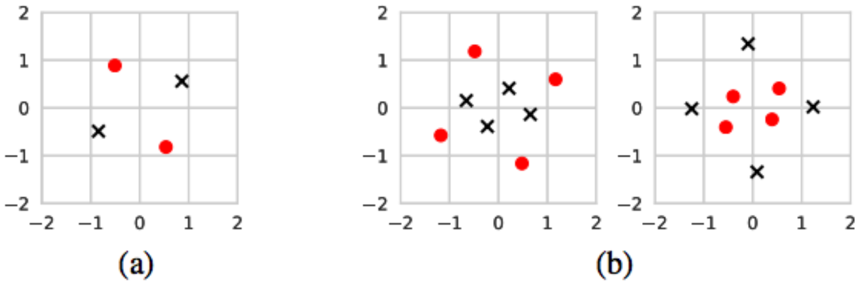
Radio Methods for Saliency

- How can we reduce the search space?
  - Leverage things we know about propagation physics?
- Introduce domain aware attention mechanisms in the right way –
  - Decomposition of receiver
    - Learned estimation modules (Attention model)
    - Expert transformation modules to match physical world propagation models/effects
    - Learned demapping/representation modules
  - Joint learning of encoder/modulator, synchronizer, decoder/demodulator, and over the air representation
    - Lower complexity learning problem
      - Converges faster, less overfitting
      - Only imparts propagation medium expert knowledge (things we can't change)
      - Learn everything else end-to-end

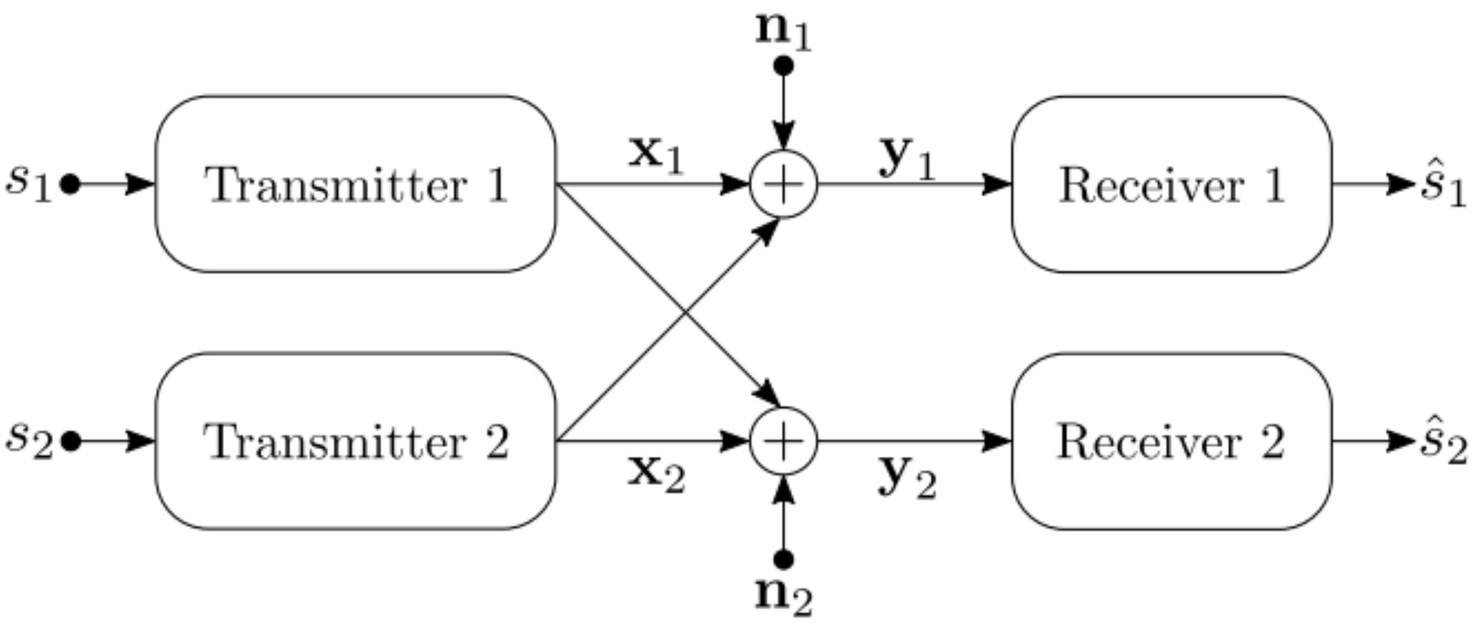


What if we have to share the channel?

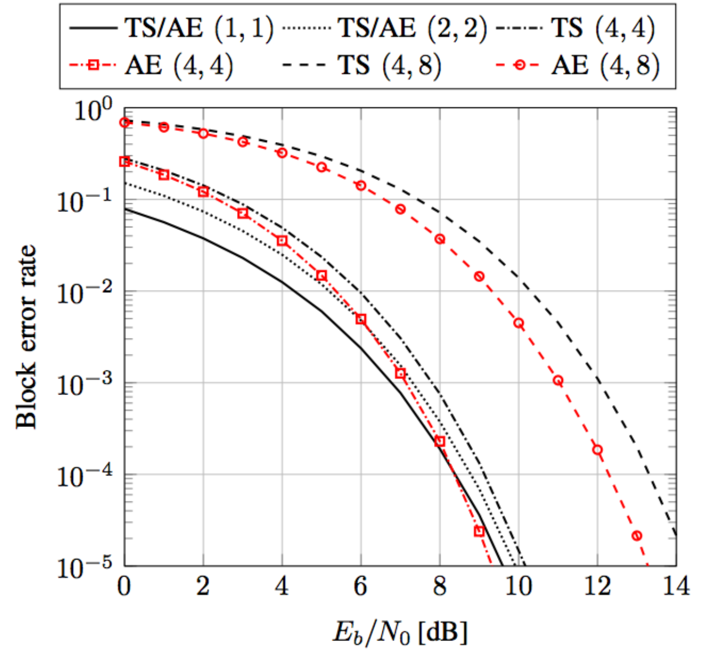
- Can easily extend this method to multi-access channel
  - Learn a better solution than orthogonality
  - Same basic principals
  - Comes up with immediately interpretable results



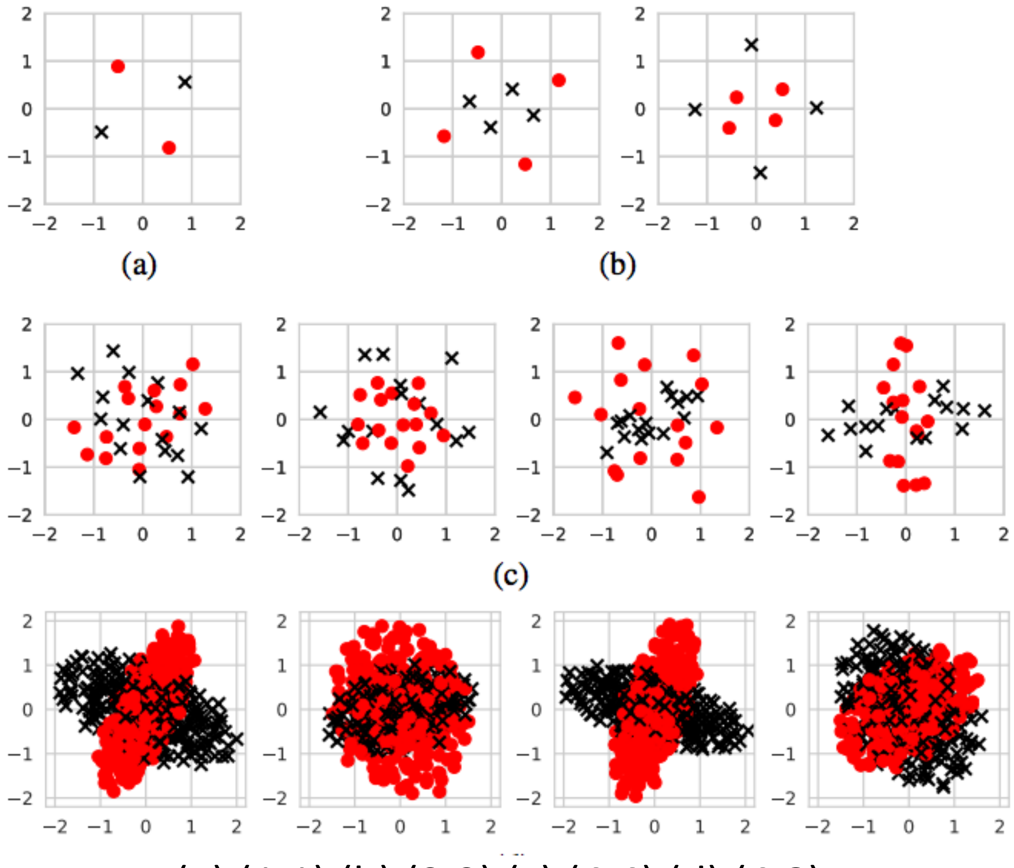
(a) (1,1) (b) (2,2)
(bits, symbols)



- Comparison with existing methods
  - Compare the multi-user access channel
  - Orthogonal (Time-slicing (TS)) vs learned method
  - Learns new never before seen PHY scheme
  - Infinite number of possible waveforms!
  - In this case pseudo-orthogonal superposition code



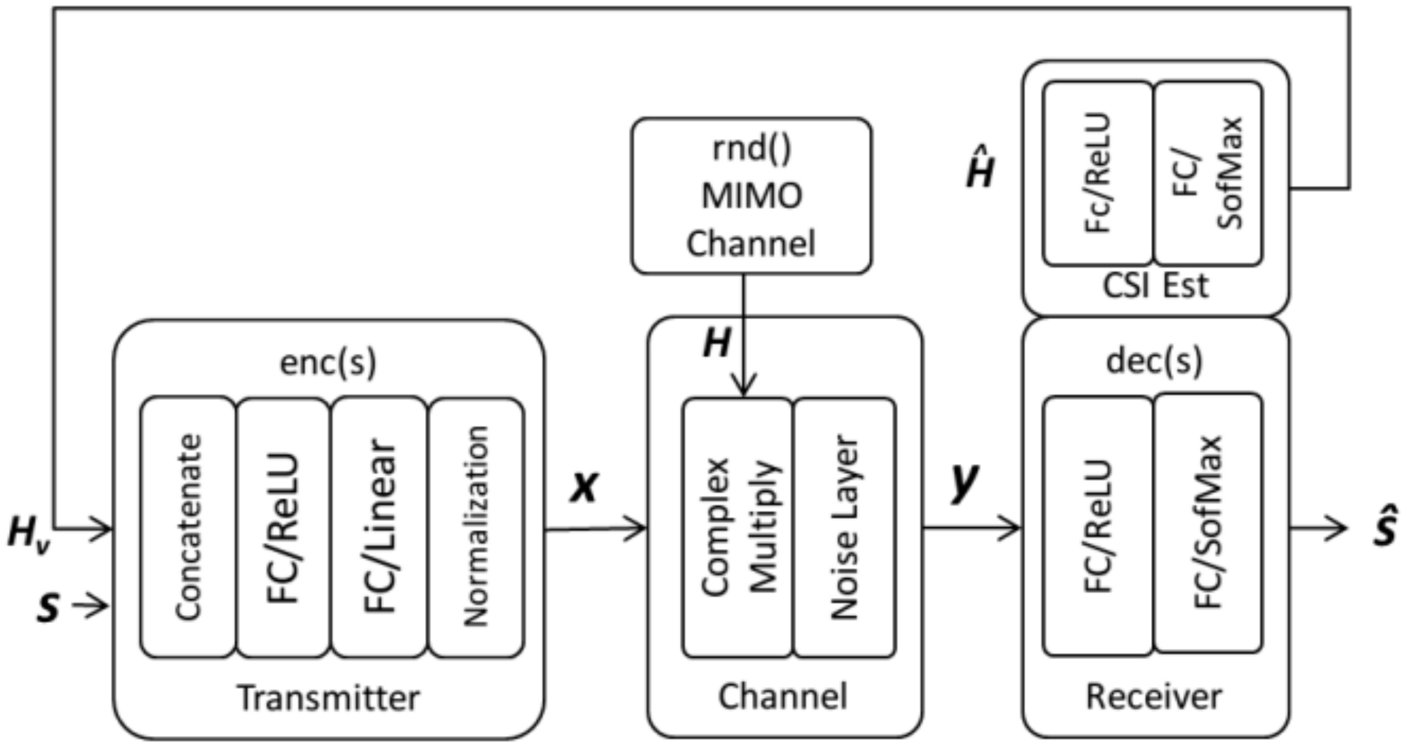
Complex PHY Learning



(a) (1,1) (b) (2,2) (c) (4,4) (d) (4,8)
(bits, symbols)

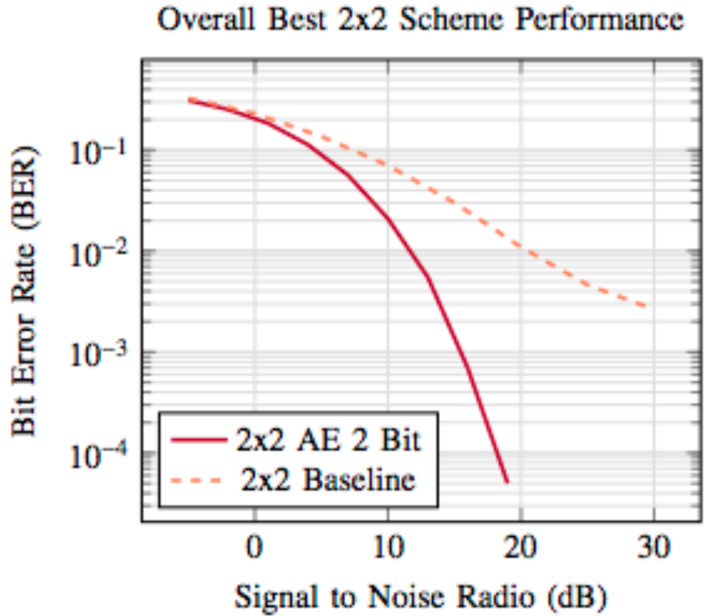
Synthesizing Complex Multi-Antenna PHYs

- Extend this technique to multi-antenna
  - Same basic principals
  - Complex MIMO channel effects
- Incorporate CSI feedback
- Entirely new MIMO scheme



Synthesizing Complex Multi-Antenna PHYs

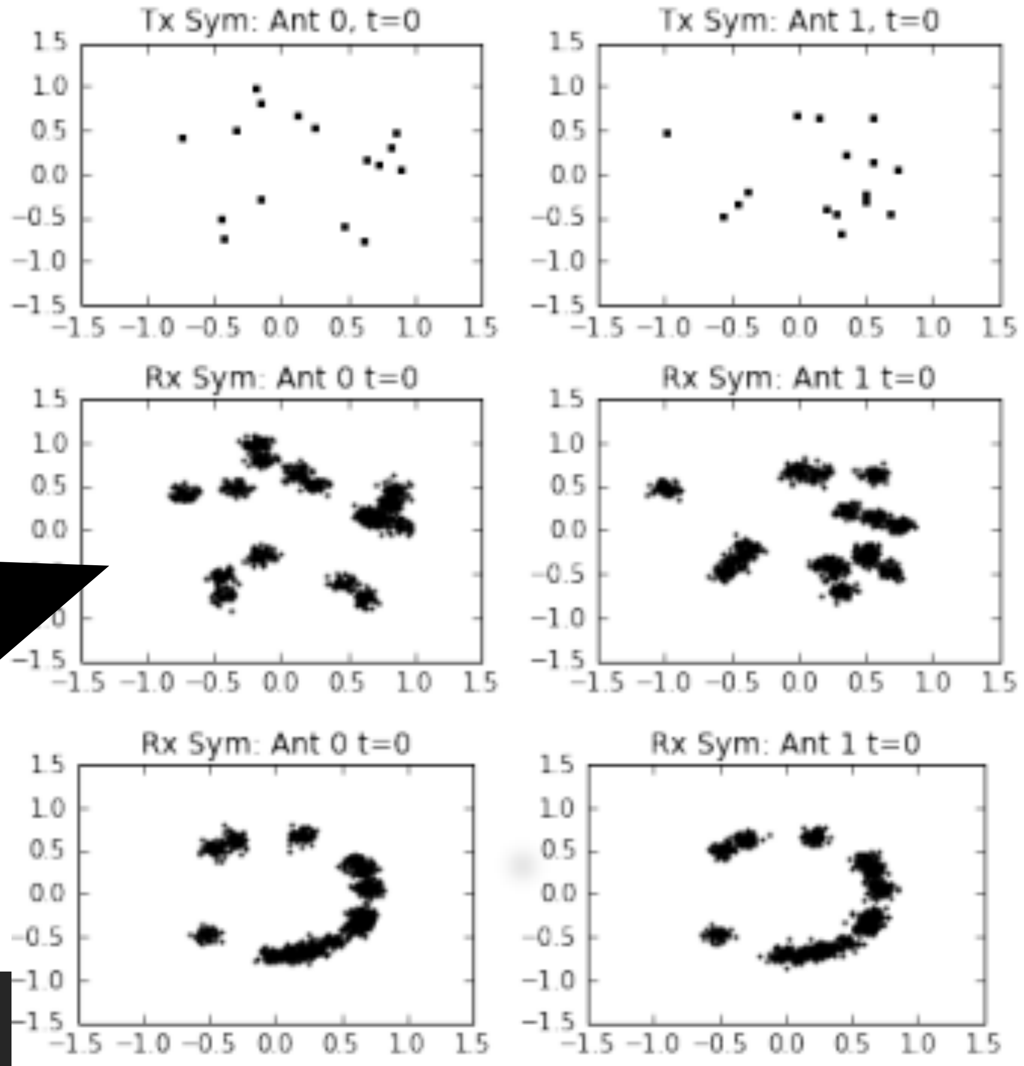
- Can learn incredibly complex joint solutions
  - Soft joint-modulation-coding schemes
  - Outperform current baselines (zero forcing MIMO)
- Enormous potential for distributed wireless
  - MIMO system performance
  - Secrecy and privacy



Learned 2x2 Constellations

1. Transmitted
2. Diag Rx
3. Uniform Rx

Complex MIMO PHY Learning
Non-standard MIMO QAM Modes



Thanks! Questions?

ML Driven RF Systems are coming FAST
Come and work with us / talk to us!

Next generation radio sensing and communications systems

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