Unsupervised Learning: A Jet-level Approach

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ATLAS EXPERIMENT

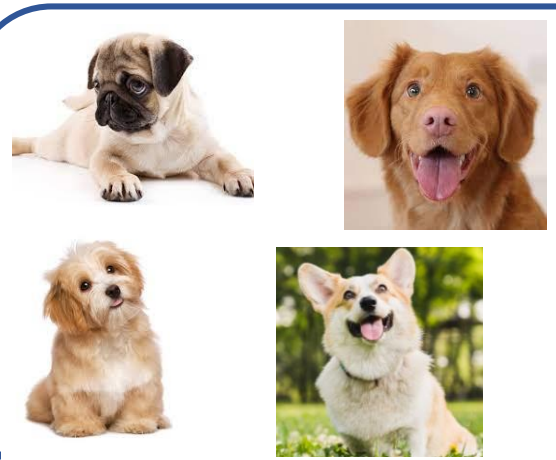
What is Anomaly Detection?

- **Anomaly detection** identifies features in the data that are inconsistent with a background only model
  - Requires the assumption that objects of interest are rare within the data set
  - AD algorithms work by uncovering the underlying structure of the data

Supervised Learning - Classification

Cats

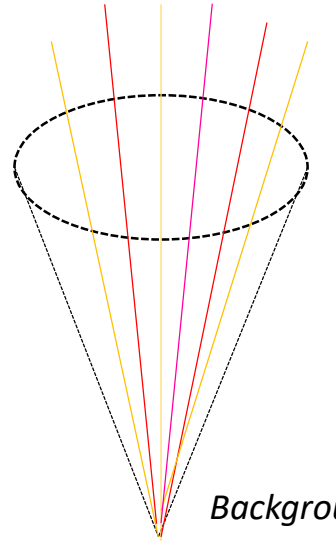
Dogs



Unsupervised Learning - Anomaly Detection

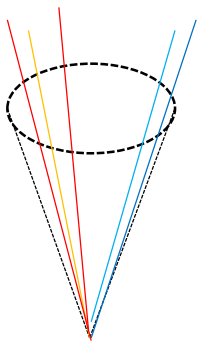
Which one is not like the others?

Why Anomaly Detection for Physics?

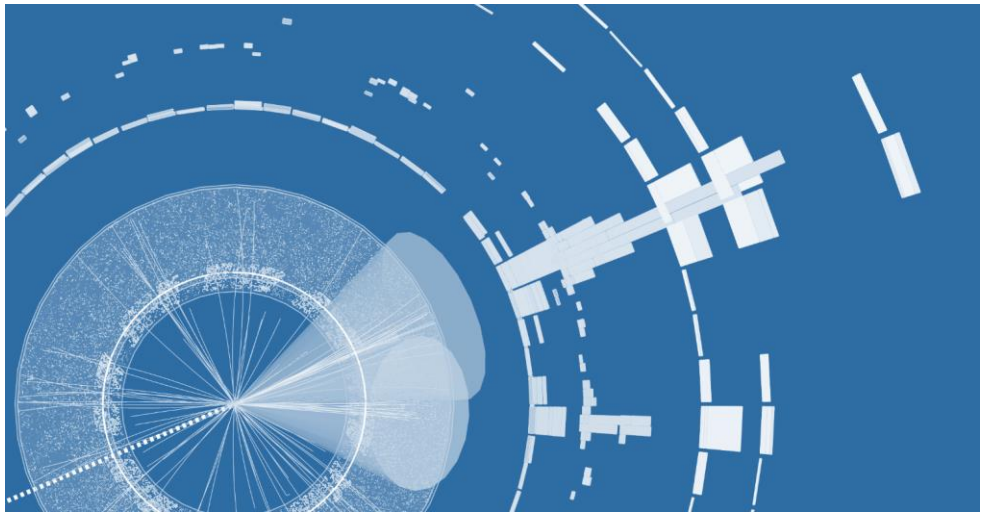


Background jet

- Lack of recent new physics + many exclusion results –> incentive to develop a **strong model independent search program**
  - Don’t guess what the signal looks like; look in the data to see what doesn’t fit the background
- Application: **hadronic jets**
  - A jet is a narrow cone of hadrons created by the showering of a quark or gluon
  - Background jets are plentiful in data, but have a complex substructure
  - An AD algorithm can uncover this structure, and tag jets with unusual substructure

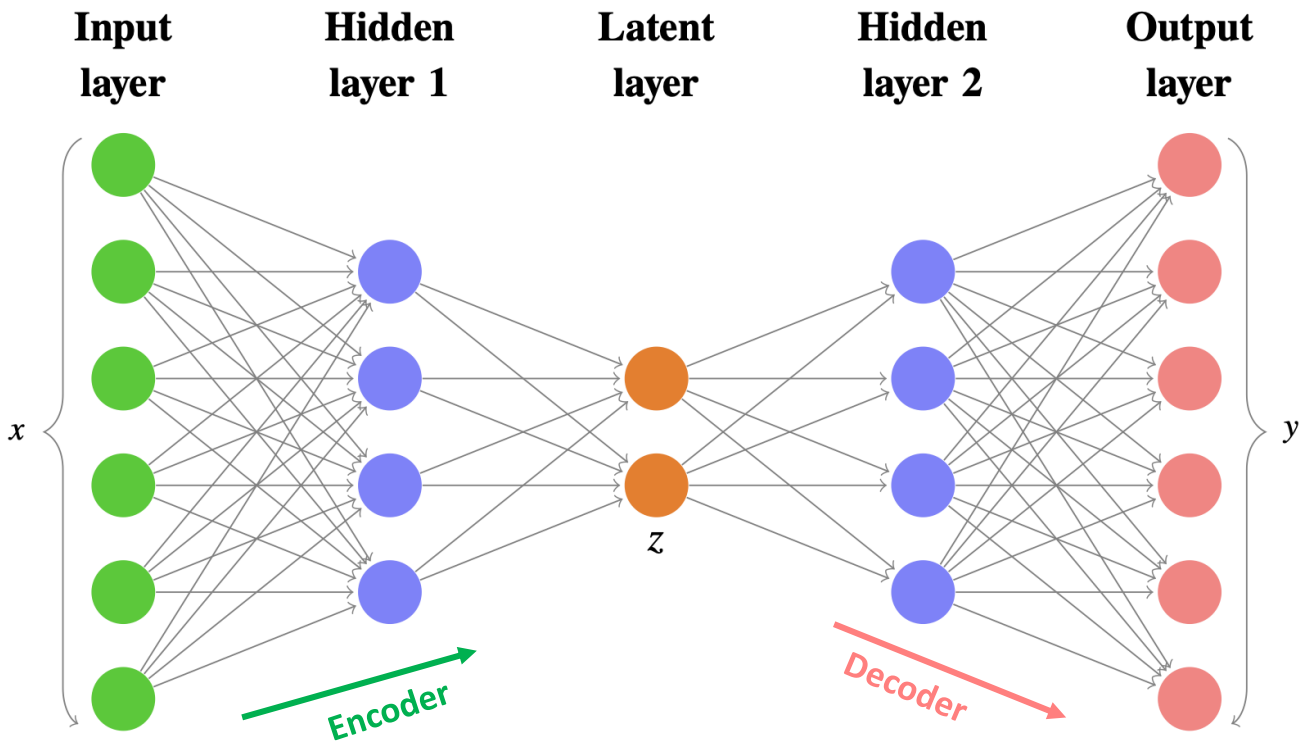


Unusual jet



Autoencoders

- An autoencoder is a model which **encodes** input into lower dimensional latent space to pick out it's most salient features, and then **decodes** from latent space while checking for reconstruction errors
  - If an object is more unusual within the data set, we expect it to have a larger reconstruction error



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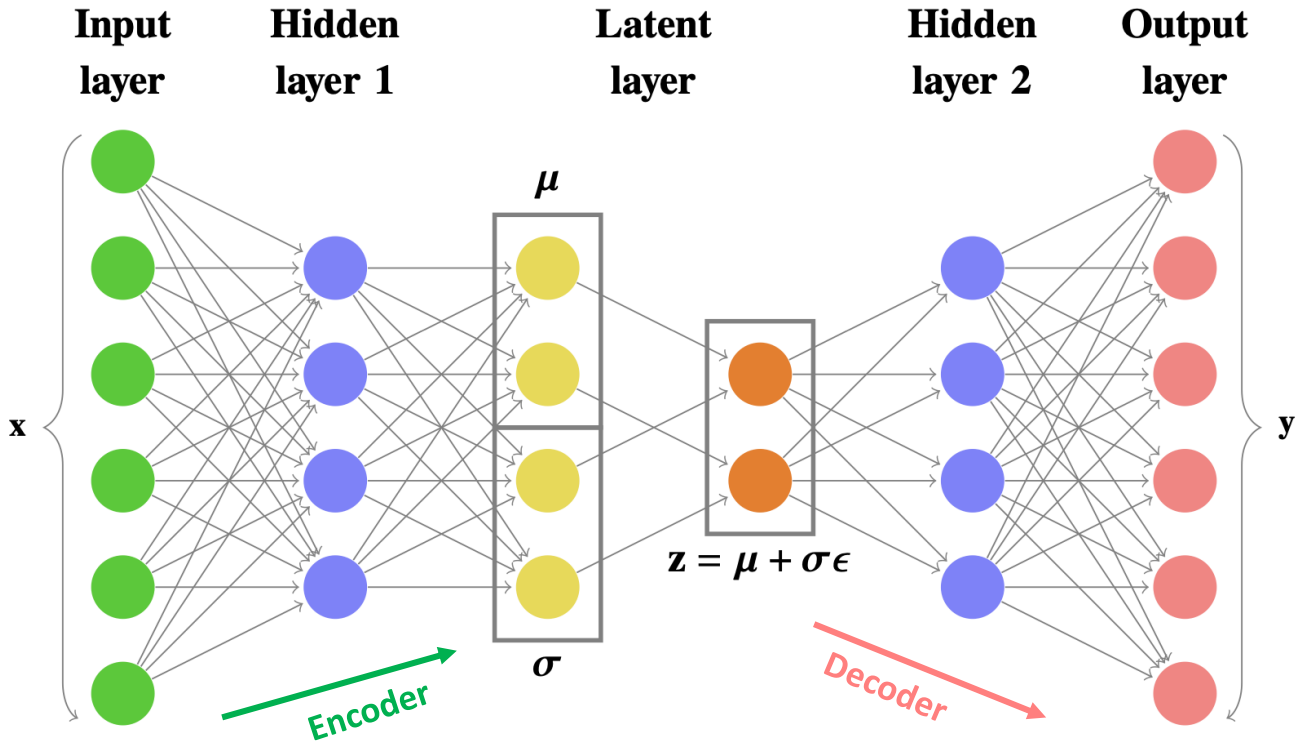
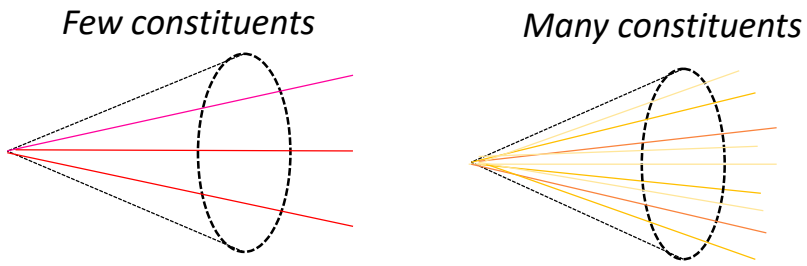
- A **variational autoencoder** encodes to a probability distribution in the latent space, which allows for Bayesian interference by sampling from this space

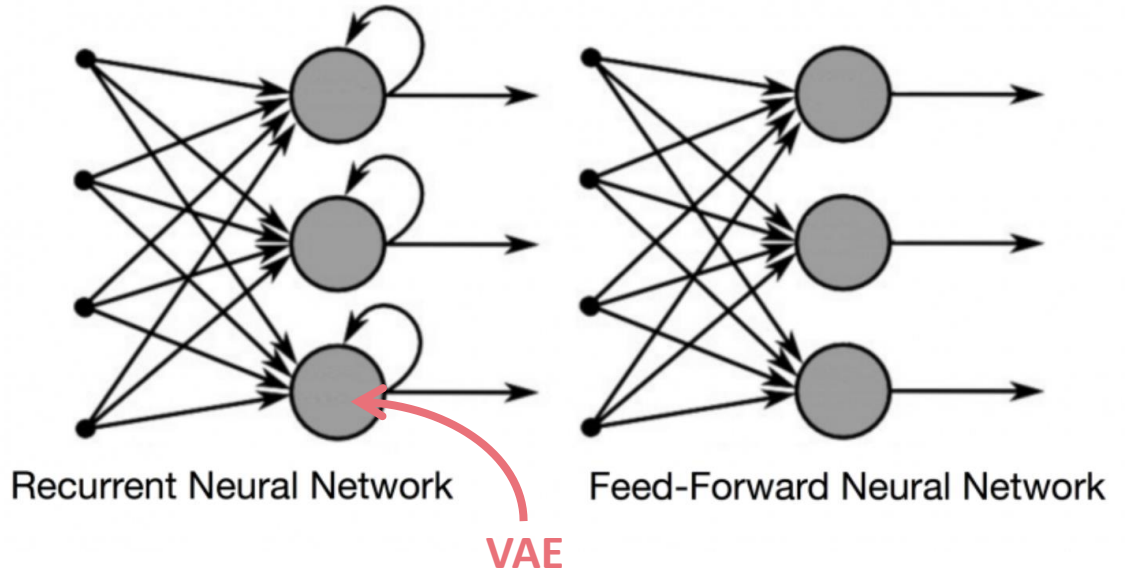


Variational Recurrent Neural Network

- Variational autoencoders are a **fixed length architecture**
  - To understand jet substructure, we want to look at jet constituents; **variable length sequences**

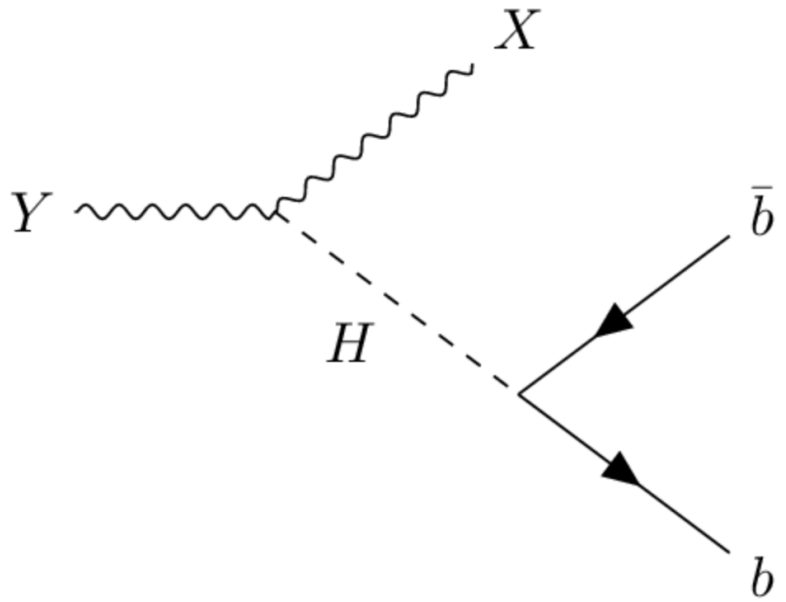


- A recurrent architecture addresses this problem
  - Recurrent networks break data into a sequence of features (*time steps*)
  - The input to each cell is a fixed length feature
  - The hidden state is updated at each time step. This allowed the hidden state to store the long term representation of the data in the sequence
- Variational autoencoder + recurrent architecture = **V**ariational **R**ecurrent **N**eural **N**etwork (VRNN)



Y->XH: The First Use of Unsupervised Learning on ATLAS Data

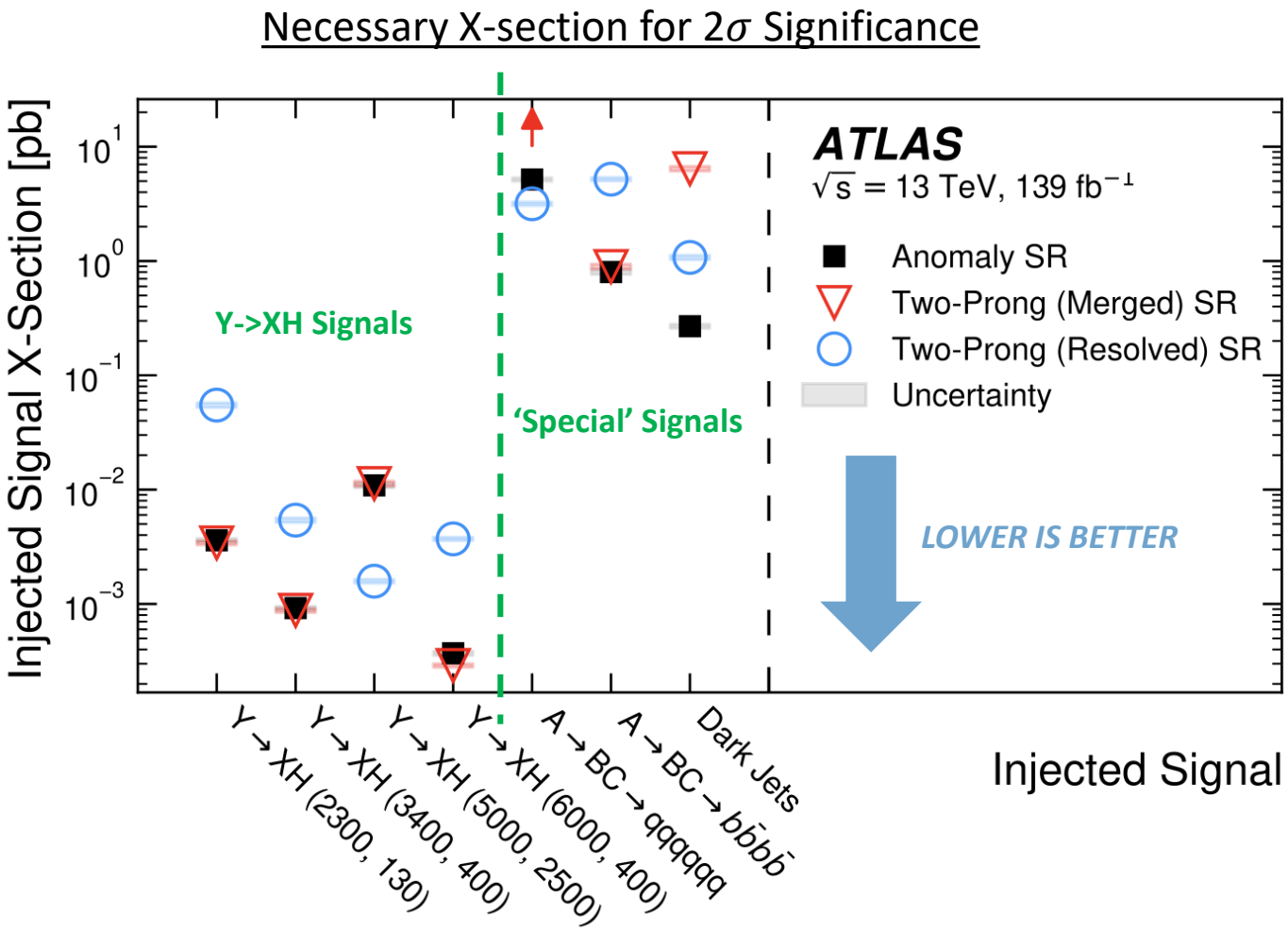
- The $Y \rightarrow XH$ analysis searches for heavy resonances decaying into a Higgs boson and new particle X in a fully hadronic final state [CONF - ICHEP 2022]
  - X and H are highly boosted and their decay products collimated
  - Reconstructed as 2 large jets in the final state
  - Fully data driven
- $Y \rightarrow XH$ analysis developed an unsupervised **Variational Recurrent Neural Network** as part of the search strategy, to tag unusual jets
  - VRNN produces an *anomaly score* (larger reconstruction error ⇔higher anomaly score); selects unusual jets
- The VRNN trained over the full Run-2 dataset



Results: Sensitivity to Many Signal Models!

- The ▽ and ○ symbols represent analysis approaches which are optimized for the Y->XH signals (information about signal model assumed)
- The ■ represents the VRNN approach (no information about signal models known)
- The VRNN does just as well as specialized approaches for Y->XH signals, and offers an order of magnitude improvement for a highly unusual signals such as dark jets!

→ **Model Independence** ←



Questions?