

Detect New Physics with Deep Learning Trigger at the LHC

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The LHC Big Data Problem



L1 Trigger

- 40M bunch crossing per second
- Logging rate: ~100 kHz
- Non-zero suppressed RAW data rate ~1PB/s
- Zero suppressed data rate is ~20TB/s
- Coarse local reconstruction implemented on FPGA/hardware.



HLT Farm

- Logging rate ~1kHz
- Data rate ~1GB/s distributed over dozens of primary datasets
- Simplified global reconstructions implemented on CPUs.

Data Flow





Offline Computing

Data Analysis

- Roughly **1GB/s** data rate
- Global reconstruction fully optimized for accuracy with software implemented on CPUs.
- User-written code, plots, theses, talks, etc.
- ~100 papers of 10 MB each year, less than 1kB/s

Trigger at LHC



The interested physics productions are much smaller comparing to inelastic production
Trigger in LHC: finding a needle in a haystack scenario (anomaly)



• Event not trigger will be lost forever!

The LHC Big Data Problem



Could new physics have been discarded by the trigger already?

Model-Independent Searches in HEP

- specific alternative models.
- high-energy physics over the years.



Traditional new physics search relies on hypothesis testing with

Motivated multiple attempts for model-independent searches in

Anomaly Trigger Anomaly Triggers SM (background) **Trigger Threshold** New Physics +others

Standard Triggers



Maff.

- A Model-Agnostic Trigger for anomaly events with deep learning
- Deployment at Level-1 trigger to avoid bias from upstream
- Within the resource and latency requirement of the trigger system

ly events with deep learning old bias from upstream uirement of the trigger system

X

Autoencoders in a Nutshell

- Compression-decompression algorithm that learns to describe the a given dataset in terms of point in lower-dimension *latent space*, from which it reconstructs the original data.
- **Unsupervised learning**, used for data compression, generation, clustering, etc.
- Anomaly: any event whose decompressed output is "far" from the input, in some metric of the autoencoder loss.



CMS Phase 2 Level-1Trigger



- Sketch of upgraded CMS Phase
 2 Level-1 Trigger system
- Produce Particle Flow particles, combining Calo/Muon/Tracker information
- Produce PUPPI weight of each particles for pileup mitigation
 - Outputs of each trigger systems send to Global Trigger for Level-1 decision



Example AE Model

- Train with simulated ZeroBias event at 200 pileup
 Use simulated PUPPI Jet/MET/MHT inputs (18 inputs) with
- Use simulated PUPPI Jet/MET preprocessing
- Model to be implemented at Global Trigger
- Activation function: ReLU
- Loss function: L1Loss
- Number of layers: 8 layers
- Model is designed with simplic resource/latency requirement



Model is designed with simplicity for firmware implementation and

AE Performance



- Model was trained and validated with simulated Zerobias events, no knowledge of signal during training
- Use the reconstruction loss of AE inputs and outputs as discriminator
- Inference with signal samples show the separation power

AE Implementation

- Use the <u>hls4ml</u> package to implement the AE model into FPGA firmware
 - With additional logic for L1Loss function calculation
- Fully unroll AE with minimal latency, well within the Phase 2 Global Trigger latency budget
- With Xilinx Virtex UltraScale+ (VU9P) FPGA, the AE consumes ~10% of DSP resource, ~1% of Filp-Flops and LUTs
- AE is not sensitive to small variances of individual input features, can tolerate noisy online condition
- Trigger rate rising above a fixed budget can be prevented by additional logic in the firmware that would dynamically adapt the autoencoder threshold



Conclusions

- The LHC has an enormous potential of discovering physics beyond the Standard Model, given the unprecedented collision energy and the large variety of production mechanisms that proton-proton collisions can probe.
- We propose a model-independent anomaly detection technique, based on deep autoencoders, to identify new physics events
- Simple AE model can be implemented at the Level-1 trigger level
- More advanced AE model can be designed for HLT or 40MHz scouting system
- Stay tune for the <u>CMS Phase 2 Level-1 Trigger TDR</u>

