Towards an Interpretable Data-driven Trigger System for High-throughput Physics Facilities
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Motivations
- The volume of data available at contemporary experiments for high-energy physics is enormous and complex
- Sophisticated trigger systems for selecting relevant physics processes
- A trigger menu defines the selection criteria
- Trigger design relies heavily on prior knowledge of the feature-space being probed and modularized approaches to optimization are used
- Redundant labeling schemes and cost-ineffective algorithm execution

Data-driven Interpretable Trigger
- Replace the hand-designed trigger menu with an optimized data-driven trigger system with minimal run-time cost, without compromising physics coverage
- Interpretable predictive model: for any given event, provides explanation for the trigger decision; allows for pruning costly ineffective individual algorithm labels

Dataset
Simulated MC dataset (CMS Collaboration [1]) of top quark pair events generated in a p-p collision with a centre-of-mass energy of 8 TeV. Includes features of the event and the different trigger selections (defined by specific trigger labels) that each event may or may not have passed.

Cost-Efficient Interpretable Model
Given a set of candidate trigger labels from the existing trigger menu and a latency cost for each trigger label, we seek an optimal subset of labels that make the correct filtering decision with the minimal latency cost. The solution is used as the explanation of our predictive model, which is used to optimize the latency of the existing trigger system, by pruning the costly labels.

A novel cost-effective elastic net is used to construct local interpretable model-agnostic explanations: CE-LIME. The algorithm returns a weight vector \( \beta \) describing the importance of each feature \( f_i \), accounting for the cost \( c(f_i) \)

\[
\hat{\beta} = \arg \min_{\beta} \left( |y - X\beta|^2 + (1 - \alpha)\lambda \sum_{i=1}^{p} |\beta_i| \cdot c(f_i) + \alpha \lambda \sum_{i=1}^{p} |\beta_i|^2 \cdot c(f_i) \right)
\]

Automated Trigger Menu Refinement via Active Learning
- Using the cost-effective interpretable model, we construct an active learning model that continuously updates itself with incoming data, and provides explanations for those updates
- Properly quantify the uncertainty of the decisions of the data-driven trigger system

We seek the optimal active learning model that learns from data and decides which trigger label to query in a sequential manner. Only through interpretation of what is learned, we can understand why and how the trigger menu should be updated. We construct an autoencoder to capture the density estimate for each event.

Biggest challenge: simulating the selection of events via this mechanism, and correctly modeling and understanding the efficiencies of this evolving self-driving trigger system.

Ongoing Work
- We are exploring novel algorithms that account for the objective (anomaly detection) and the budget constraint on the label cost
- Demonstration of the approach is being prototyped using a Xilinx Versal Adaptive Compute Acceleration Platform (ACAP) board [3]
- Xilinx Versal ACAPs contain programmable AI engines, dedicated processors for high-speed, real-time data processing that support dynamic reconfiguration

References
[3] Xilinx AI Engine Technology