Nanosecond AI for anomaly detection with decision trees on FPGA using fwXmachina

ATLAS EXPERIMENT

SMARTHEP Edge Machine Learning School

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fwX – an efficient BDT implementation on FPGAs

FW X Machina

Framework for generating nanosecond-scale inference BDTs for use in FPGAs

Anticipated areas of use: event analysis in hardware triggers in HEP experiments

Work on

- Fast event classification with BDT (Hong et al., JINST 16, P08016 (2021))
- Fast regression with deep BDT's (*) (Carlson et al., JINST 17, P09039 (2022))
- Fast anomaly detection with BDT-based auto-encoders (*) (Roche et al., accepted for publication)

* Currently being implemented in ATLAS L1 trigger

BDTs for auto-encoders

Typically constructed using neural networks

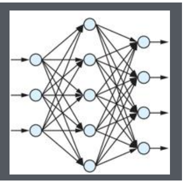
- Challenge to implement in pure digital logic on FPGA

See: Govorkova et al., *Autoencoders on field-programmable gate arrays for real-time, unsupervised new physics detection at 40 MHz at the Large Hadron Collider*, Nature Mach. Intell. **4** (2022) 154–161
https://doi.org/10.1038/s42256-022-00441-3

Neural Network

Popular	Been around HEP since the 80s[1]
Depth	Challenging, so ~3 on FPGA[2]
Score	$y = \Theta(\mathbb{M} \cdot x + b)$

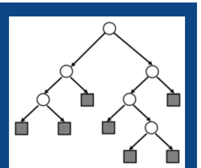
Activation (Θ) *Multiplication* ($\cdot$)



Decision Tree

Popular	Discovered the Higgs![3]
Depth	Challenging, so 4 to 8 on FPGA[4,5,6]
Score	$y = \Theta(x < \text{threshold})$

Step fn (Θ) *Comparison* ($<$)



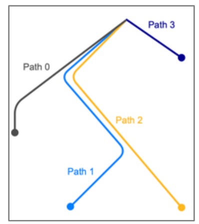
Classification performance of BDTs is often comparable

Advantages of BDT

- Technical (no multiplication)
- Philosophical (interpretable)

FWX approach:

- Goal: make evaluation of the BDT in FPGA faster while using less resources
- Achieved by parallelizing node evaluation

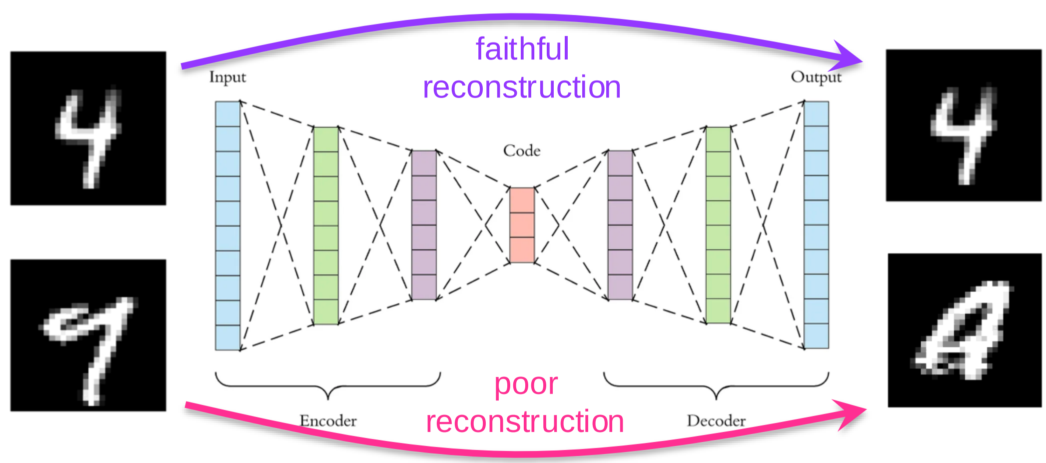


Auto-encoders for anomaly detection

Auto-encoders rely on data-compression algorithm (usually NN, fwX: BDT), trained on known, expected data (background)

Encoding input into latent ("code"-) space and decoding back into input space preserves objects which are similar to training sample (known data), but fails to faithfully re-construct anomalies (unknown data)

Training sample: 0..4



Poor reconstruction

large discrepancy between input and output => high anomaly score

Our approach to using BDTs for auto-encoders

Novel algorithm for using decision trees in auto-encoders for anomaly detection

- Anomaly score from comparison of input with latent space, no decoding step

Method: (a glimpse)

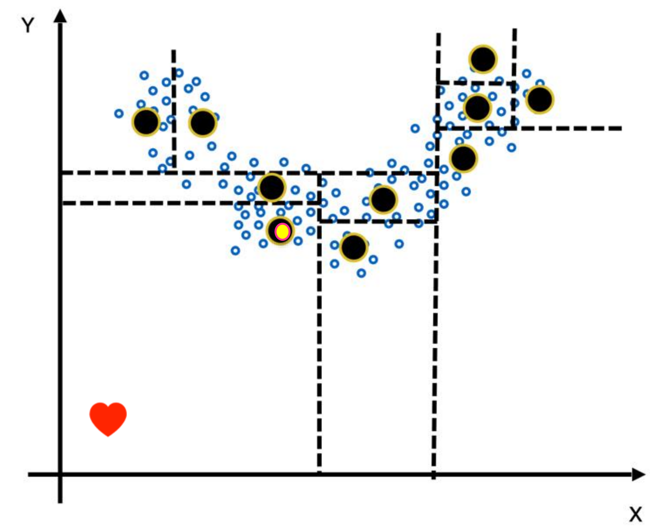
Place small boxes around locations of high event density

Encoding an event ❤:

- Return *index b* of the box the event ❤ falls into

Decoding a box index *b*:

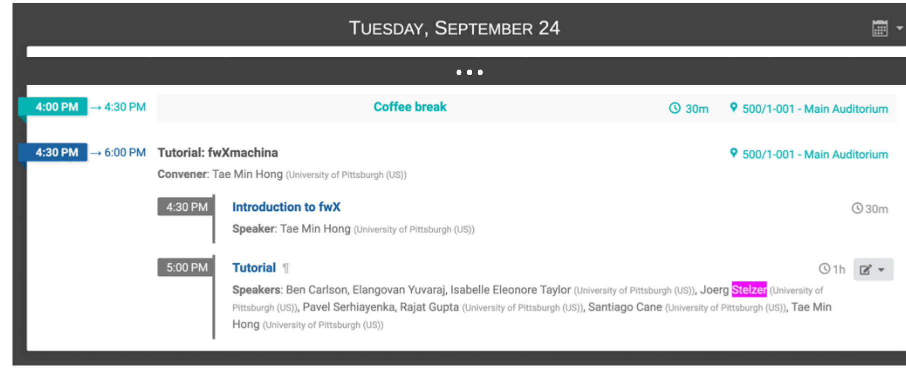
- Return the median ● of the training data in box *b*



Want to learn more – join us tomorrow

In-depth introduction to anomaly detection with FWX by Tae tomorrow afternoon @16:30.

Followed by a hands-on tutorial



Tutorial with three parts

- Training and fwX-BDT code generation (with TMVA and FWX)
- Synthesis (with Vivado)
- FPGA evaluation (simulation with Vivado)

Each part has a 10’ video (where you can work along), followed by a Q&A session

- If you like to follow the tutorial on your laptop, please make sure you have root, fwX (part 1) and vivado (parts 2+3) installed