Using a neural network approach for muon reconstruction and triggering

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Outline:

- The Triggering problem
- The ATLAS First level Muon Trigger
- Using ANN for classification and triggering
- Comparison between our net and LVL1 trigger
- Running the net in later stages of the trigger
- Using ANN to tune a HW trigger
LHC & ATLAS

14 TeV proton-proton beams
Design luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
Physics goals: Understanding of fundamental symmetry breaking; Higgs search, Supersymmetry search, B-Physics ...
“Typical” ATLAS collision

- $4 \times 10^7$ bunch crossing per second
- 23 events per bunch crossing
- 1Mbyte per event
- Data rate $\sim 10^{15}$ Byte/s
- Trigger and reconstruction play a key role
Trigger DAQ System

Event rate and decision stages

Rate (Hz)

Jets: $b \rightarrow \mu$
$\pi/K \rightarrow \mu$

W, Z
Top

H $\rightarrow \gamma\gamma$

Interaction rate
~1 GHz
Bunch crossing rate 40 MHz
LEVEL 1 TRIGGER
< 75 (100) kHz
Regions of Interest
LEVEL 2 TRIGGER
~ 1 kHz
EVENT FILTER
~ 100 Hz

Data recording

Available processing time

$25 \text{ ns}$ $\mu\text{s}$ $\text{ms}$ $\text{sec}$ $10^3 \text{ sec}$

LVL1 40 MHz
$LVL2$ 75 kHz (100 kHz)
Event Filter ~1 kHz
average ~10 ms
class $< 2.5 \mu\text{s}$
few sec

Trigger with ANN
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Muon Trigger Chambers

TGC octant

R = 11.9m
η = 1.03

3,600 TGC chambers produced in Israel, China and KEK

R = 2.6m
η = 2.42

Trigger with ANN

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Physics and muon trigger

Muon trigger plays vital role in
Higgs Search
H→ZZ*→ 4 leptons
B-Physics
B_s →phi (J/ψ) →μ^+μ^-X

![Graph showing muon trigger efficiency](image)

Trigger with ANN

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**Muon trigger**  
*(based on the $P_t$ at... the interaction point)*

Or:

- selecting a hundred interesting events out of billion others in one second
On the muon way... Material...
inhomogeneous magnetic field

Toroid bending power of the azimuthal field components

Magnetic field map in the transition region

-> tracks are bent by highly inhomogeneous magnetic fields

Atlas detectors absorption shielding the muon system

Trigger with ANN

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Low Pt High Pt trigger

- Require a coincidence of hits in the different layers within a road. The width of the road is related to the $p_T$ threshold to be applied.

- Low Pt $\frac{3}{4}$ doublets

- High Pt $+=\frac{1}{2}$ triplet
Current implementation in electronics - Coincidence matrix

Output:

\[ A = R \]
\[ B = \delta R \]

Or

\[ A = \phi \]
\[ B = \delta \phi \]
Feed forward
ANN architecture
first schemes

Preprocessed parameters of straight track of muon

linear output

sigmoid hidden layers

input
Network performance

Training set 2500 events.
In one octant.

Test set of 1829 events.

Distribution of network errors - approximately Gaussian.
compatible with stochasticity of the data (IP width, EM scattering, mag field..)

charge is discrete - 95.8% correct sign.

dPt/Pt vs η at small η larger widths.
The effect is due to smaller Magnetic field and larger inhomogeneities

dQ vs Pt: Larger errors in charge at high momentum
Electronics implementation

• An implementation multi-layer perceptron simulated similar network:
  – 4 input neurons dx/dz, x, dz/dy, y
  – Two 8 neurons hidden layer
  – Output: pt, phi, theta and q.

• Chorti, Granado, Denby, Garda ACAT00.
Selection Network

• Preprocessing
  – Fit hits to Line

• Inputs
  – \( x = A_x z + B_x \)
  – \( y = A_y z + B_y \)

• Outputs
  – Trigger (Pt th.)

hidden layers: 2x10 neurons
Training

- Generate ATLAS simulated muons dist. in $\eta, \phi$ for one octant ($p>1$ GeV, $\eta>1.05$)
- Study with 80,000 events.
- Divide into sub regions by position of the first hit
- Train ANN on 30,000
- Use Levenberg-Marquardt algorithm Early stopping methods are used (validation set / bayesian regularization).
- Train for $P_{th}=5$GeV
- Training stage 1000 epochs
- Preprocessing hits $\rightarrow x, y, dx/dz, dz/dy$ with Hough transform and simple straight line LMS fitting.
- Vary the number of neurons in the architectures.
ANN Study regions:
ATLAS Trig Sim vs ANN
in red ATRIG, in blue ANN (trained for threshold at 5 GeV)
Combined comparison

red ATRIG, in blue NN
New comparison – ANN trained and implemented **AFTER** level1 trigger simulation (cut at 6 GeV)

NN set at $\text{Pt}=5.5$

NN set at $\text{Pt}=5$

$\frac{1}{N} \frac{dN}{d\text{Pt}}$

$\frac{1}{N} \frac{dN}{d\text{Pt}}$
NN (after LVL1)/ LVL1 ratio

NN/LVL1

Pt (GeV)

21 Pt (GeV)
Atrig and NN Efficiency and purity

\[ \text{Genration: Pt dist.} \]

\[ \text{Genration: } \eta \text{ dist.} \]

\[ \text{efficiency} \]

\[ \text{purity} \]

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High Pt ANN Training

1/N dN/dPt

Trigger with ANN

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GeV/C
Use ANN for electronics configuration (very Preliminary)

- Start with normal slopes and origins of events input in the x-z and y-z planes.
- Create from it virtual hits in 2 adjacent planes. These are hits a real event might have produced.
- Take the new points on the first plane and shift them randomly in R and $\phi$.
- For each shift create a new origin/slope in x-z and y-z planes and test it with the ANN.
- Plot the results. $\rightarrow \smile$
- This is like asking "What should the shape of the coincidence matrix in the electronics be to create a behavior similar to the NN?"
Summary & some future plans

• A relatively simple feed-forward architecture was used to solve a complicated inverse problem.
• The simplicity of the network enables very fast hardware realization.
• Due to its simplicity a similar ANN can very efficiently be used in a classification problem necessary for triggering purposes.
• A comparison with a realistic example of first level trigger simulation is in favor of the ANN.
• A similar architecture trained after simulation of a first stage of electronics trigger shows a further very clean background rejection.
• Plans:
  – Continue studies of tuning the first level trigger with the ANN output.
  – Compare with ATLAS revised simulation environment.
  – Try to add additional information available in the next stage of the triggering.
  – Implementation?
Meanwhile life goes on .. continue constructing chambers... testing...

Thank you