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Analog Neural Networks in an Upgraded Muon Trigger for the DZero Detector

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ABSTRACT

The use of analog neural networks as part of the DZero muon detector is considered. A study was made of tracking through a single muon chamber using neural network techniques. A hardware application based on Intel's ETANN chip was designed and used in a test beam at Fermi National Accelerator Laboratory. Plans to implement a neural network trigger in DZero are also discussed.

1. The DZero Muon System

The DZero detector is a large general purpose detector for proton-antiproton collisions at Fermilab's Tevatron. With no central magnetic field, muons are identified by passage through a magnetized iron toroid as measured by a four-layer chamber inside the toroid and two three-layer chambers outside the iron. The momentum of the muon is determined by measuring the angular change in the track through the toroid.

The muon chambers consist of three or four layers of 24 parallel drift tubes[1] (figure 1). The layers of the tubes are offset in the drift direction to help resolve left-right ambiguities. Pairs of tubes are jumpered together to form a single wire. In addition to the drift time, the time difference of the pulse along the wire is measured to give the position of the particle in three dimensions. Each cell has a cathode pad cut in a repeating diamond pattern, and the ratio of the charge on the inner and outer parts of the pattern provides a vernier for the measurement along the wire. These pad signals are also passed through a discriminator and latched to be used for zero-suppression during readout.

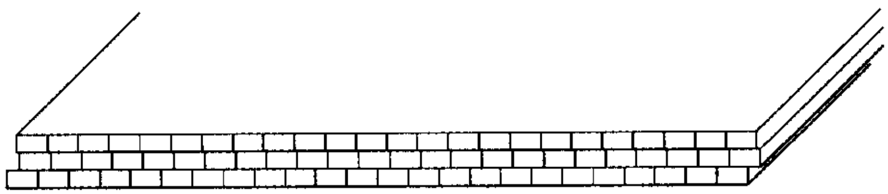

Figure 1. Cross sectional view of a three layer muon chamber with 24 columns of drift cells. The drift direction is horizontal in this view.

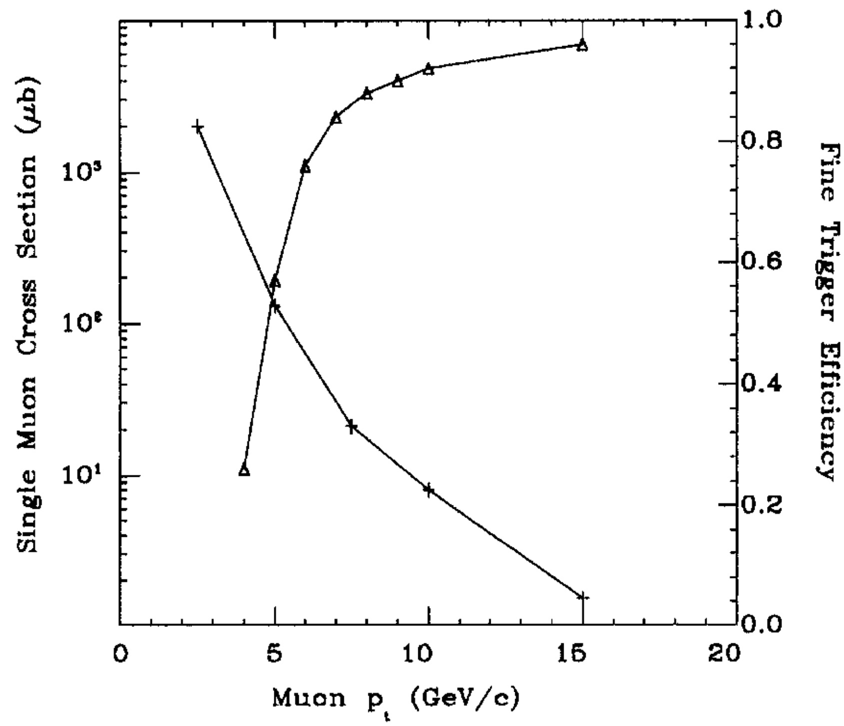

Figure 2. Efficiency of the muon fine trigger as a function of transverse momentum for a threshold set at 5 GeV/*c* (triangles). The background cross section of single muons is shown for comparison.

The fast muon trigger is based on the pad latches[2]. These latch bits are first passed through single chamber logic chips that generate a bit map consistent with positions of particle passage through the chamber. The fine granularity trigger bits, corresponding to a 5 cm half cell width, are logically "or"ed together to form coarse trigger bits of 60 cm span. The coarse trigger links bits from chambers in each of the three layers using logic chips within the space of one 3.5 μsec period between bunch crossings. The fine trigger uses look-up memories to compare the addresses of combinations with patterns of a particular momentum and then makes a cut on that momentum. When required, the fine trigger takes from 3 μsec to 30 μsec to form, during which time the experiment is dead to crossings. With only half cell resolution, the trigger is a weak measure of momentum (figure 2).

2. Neural Net Tracking in a Muon Chamber

In 1989 an extensive set of data was recorded with a set of three three-layer chambers as part of the testing of the muon electronics. These chambers were stacked on either side of a magnetized toroid with two layers of scintillator as a trigger to simulate the actual geometry of the DZero muon detector. The data was filtered to select those events that passed through all three chambers and had a reconstructed momentum greater than 5 GeV/*c*. In this set there were no tracks with an angle greater than 45 degrees from normal to the chambers. From this set of data 4000 events for training were selected that had good hits as defined by offline tracking in each of the three layers of a particular chamber.

Figure 3. Partial coverage of a muon chamber by three neural networks.

The initial network design covered 16 of the 24 columns of drift tubes with three overlapping nets of six columns each (figure 3). Each of the three networks had 18 input drift times, 20 hidden neurons, and 20 output neurons. The training used 2000 events from the sample for standard back-propagation described elsewhere[3]. The 20 outputs were divided into 10 bins to measure the slope of the line and 10 bins for the intercept. Analysis of the remaining 2000 events gave a measurement of the intercept with $\sigma = 15$ mm.

A second network design increased the number of hidden neurons to 64 and increased the number of output neurons to 64. The output neurons were split 32 for slope and 32 for intercept. Trained and tested in the same manner as the first network, this network measured the intercept with $\sigma = 6.7$ mm. Comparison with the existing trigger cells of 5 cm width based on latches shows the strength of the neural network.

3. Online Muon Tracking

In 1991 a special muon chamber with only two columns was placed in the Fermilab test beam for study. A network was designed with 12 inputs, 64 hidden neurons and 64 ouputs[4]. The inputs were the three drift times and three pad latches used to break the abiguity between the two cells. The drift times were entered three times to overcome the maximum weights that would be encountered in the hardware neural network. The outputs were divided into 32 slope bins and 32 intercept bins. A monte Carlo simulation of this chamber was used to generate 10000 events with the expected drift resolution of 500 μm. These events were used to train a simulation of the Intel ETANN chip[5] which features 64 inputs and 64 neurons and can be clocked to give a three-layer network of 64 inputs, 64 hidden neurons and 64 output neurons. More precise training of the chip proceded with 2000 events in a slow emulator and 600 events using chip-in-the-loop techniques.

To use the network online, a new board was added to the usual front-end electronics. This board picked up the input signals from the analog buffers on the chamber and fed them to the trained ETANN chip. When a trigger consisting of two scintillators and three pad latches was satisfied, the output neurons were clocked, then digitized along with the regular front-end analog signals. Since the ETANN was able to process the data in 3 μsec, it was ready for digitization by the time the microprocessor controlling digitization had responded to an interrupt.

Offline the drift times from the chamber were fit using least squares to a straight line and compared to the output of the network. The difference between the intercepts had a $\sigma = 1.0$ mm. When events were selected with least squre fits giving a chi-square less than 1.0, the resolution improved to $\sigma = 0.7$ mm. When used to analyze Monte Carlo data the same chip gave a resolution of $\sigma = 0.6$ mm. This compares favorably with the best offline resolution of $\sigma = 0.4$ mm.

4. Application to the Muon Trigger

The major weaknesses in the current DZero muon trigger are the inaccuracy in momentum determination due to large trigger cell size and possible long caluclation times when one of the look up memories in the fine trigger has many inputs due to high multplicity in a small region of the detector. The analog neural networks may offer a solution to both problems. It is clear that by using the analog signals substansially better cell resolutions can be achieved. In addition, the purely parallel nature of the network should make it immune to bogging down if a section of the detector has many hits.

A possible architecture for the neural network might follow an architecture simlar to the current trigger (figure 4). In this design each of the 164 muon chambers would have three networks covering all columns in the chamber. Each network would cover 16 input wires and 16 latches, with a final filter stage reducuing the information to a few analog signals correponding to positions of tracks through the chamber.

The output from chambers that might share parts of a single track would be brought into one of 16 linking networks in the counting house. These networks would be required to report a momentum for the track as well as generate a data set for inclusion in the data stream. The outputs of the linking networks can be counted and categorized by type and used to generate a table of trigger quantities such as 1 muon, central region, $p_t > 5$ GeV/c.

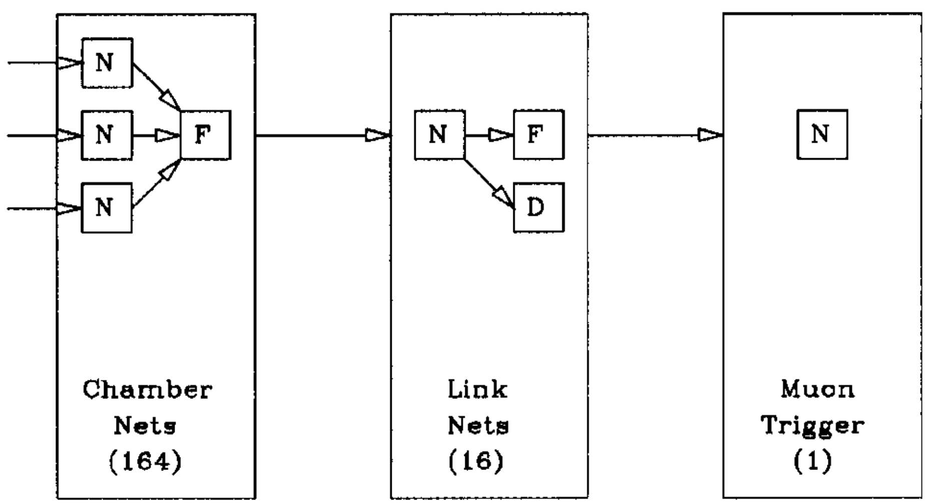

Figure 4. Block diagram of a trigger architecture using neural networks. N represents a neural network; F represents a filter to reduce the number of signals; D represents data to be included in the output stream.

Such an upgrade would be part of the planned upgrade to DZero for 1994[6]. Before this could be implemented a number of detailed designs and studies must be completed. For the current DZero run in 1992 a single board like that used in the test beam will be placed on a chamber with moderately high rates and its output will be digitized and included in the data stream for analysis. It is likely that the large number of outputs in the present network tests would give rise to too many signals cables to the next stage, so a scheme of filtering needs to be devised. Up to now, no special work has been done to take advantage of the repetitive pattern of the tubes, but this might simplify a local network design. The biggest concern is how to design a neural network for the DZero small angle muon system[1] which has a different tube geometry and high rates.

5. Acknowledgements

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6. References

1. C. Brown et al., "D0 Muon System with Proportional Drift Tubes", *Nucl. Inst. & Meth.*, A279 (1989) 331.

2. M. Fortner et al., "The VME-Based D0 Muon Trigger Eklectronics", *IEEE Tran. Nucl. Science*, 38:2 (1991) 480.

3. C. S. Lindsey, "Tracking and Vertex Finding in Drift Chambers with Neural Networks", *Proceedings of the Workshop on Neural Networks: From Biology to High Energy Physics*, Elba, Italy, June 1991.

4. C. S. Lindsey et al., "Real Time Track Finding in a Drift Chamber with a VLSI Neural Network", submitted to *NIM-A*.

5. Intel Corp., 2250 Mission College Boulevard, MS SC9-40, Santa Clara, CA 65052-8125.

6. D0 Upgrade, Fermilab P-823, April 1991.