Performance of the NOνA Data Acquisition and Data Driven Trigger Systems for the full 14 kT Far Detector

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NOvA Detectors

**Far Detector**
- Surface Detector
- 14 kt “Totally Active”, Low Z, Range Stack/Calorimeter
- Liquid Scintillator filled PVC
- 896 alternating X-Y planes
- Optimized for EM shower reconstruction & muon tracking, $X_0 \approx 40\text{cm}$, $R_m \approx 11\text{cm}$
- Dims: 53x53x180 ft
- “Largest Plastic Structure built by man”
- Started Operations May 2013
- First Beam Aug 2013
- Completed April 2014

**Near Detector**
- Underground Detector
- Identical to far detector
- Optimized for NuMI cavern rates
- -- 4x sampling rate electronics
- Completed April 2014
NO\text{\textnu}A is a unique challenge for Trigger & DAQ

At one level it’s very simple

There is only one detector technology

But…

That element is repeated 344064 times
All of these are precisely synchronized to each other and to their counter parts 810 km away
Elements are ALL in free running continuous waveform readout
180 kHz of cosmic rays are constantly lighting up the detector
Job of the trigger is to examine....

5ms data window at the NOvA Far Detector
Each pixel is one hit cell
Color shows charge digitized from the light

~Thousand cosmic rays cross the detector during readout frame (the many peaks in the timing distribution below)
Trigger

- To find ultra rare topologies like this:
Or this....
daq/trigger configuration 2014-2015

- fully instrumented/operational 14 kt far detector
  344,064 detection cells, 10,752 front end board,
  168 data concentrators, 45 data buffer/l3 trigger nodes, 5 data logging/
  arrays, 30 timing distributions units, 4 gps clock systems

Top view of completed NovA far detector
• Fully instrumented/operational 14 kt far detector
  344,064 detection cells, 10,752 front end board, 168 data concentrators, 45 data buffer/L3 trigger nodes, 5 data logging/arrays, 30 timing distributions units, 4 GPS clock systems
Continuous Flood of data into Trigger & Buffer Farm at peak of ~4.2 GB/s corresponding to 100% total live readout
Readout Data Structure

Data Readout is continuous series of 5ms readout frames

“Movie of the Detector”

Minimal data suppression (~6 MeV single hit threshold)

There are no gaps between frames

Each frame is routed to a separate buffer/trigger nodes for processing
EventBuilder/Buffer to Data Driven Trigger Interface

- Primary event builders assemble 5ms snapshots of full detector
  - 5 ms Data blocks need to be passed to software trigger chain
  - Desire for isolation between DAQ and Trigger
    - e.g. bad trigger algorithm should not affect event building

- Use Sys V IPC shared memory as isolation layer

- Single writer, multiple reader design
  - Implemented as circular buffer for writer
  - Presented as fixed length fifo with destructive read for readers
Buffer Node to Data Driven Trigger Interface

Buffer Node Event Builder Application

Input Buffer

Depth ~ 10 minutes

Ring Buffer

Global Trigger IN

DCM 1-01-01

DCM 1-14-12

To Datalogger

To Global Trigger

Shared Memory

Event Fifo

5ms

5ms

5ms

5ms

5ms

Average Wait Queue ~ 1 miliblock

Newest

Oldest

Write

Destructive Reads

Trigger Filter Application #1

Trigger Filter Application #2

... 

Trigger Filter Application #13

Out to Global Trigger

Average

Wait Queue

~ 1 miliblock
CPU Resource Mapping and Affinity

- 16 CPU cores on each buffer node are task assigned based on a shield/set model
- Three affinity sets: **System, DAQ, Trigger**
- Enforce resource allocations
- Impose subsystem separation
- Balances I/O, Proc and Comm. loads
- Operational Loads: [Idle, 6-8%, 99%]
Cascading Trigger Algorithms

- Trigger is designed to take advantage of modularity
  - Each trigger is a series of “paths” through different common algorithm modules
- Builds complex triggers from smaller units of work
- Paths are conditionally cascaded to run each module at most once
  - Entire branches can be aborted
- Each final decision is independent,
  - Out of order and minimized time to decision for each trigger path

Cascade of trigger/reconstruction modules for upward going muon, magnetic monopoles, calibration and high energy deposition triggers. Trigger decision points shown in blue.
Trigger Timing Resolution

- NOνA Front End boards now run in multi-point “waveform readout”
  - Spare sampling of APD input
- Fit for $t_0$ performed at data unpack for trigger over full dynamic range
  - Improves timing resolution by 7x over raw readout
  - Uses 12 bit (Int) $\rightarrow$ 9 bit (FP) encoding and lookup table scheme
  - Shared 44 MB lookup table covers > 68 B fit solutions at < 1.2% induced error on $t_0$
  - 15% impact on data unpack
- Single channel time resolution $\sim$10 ns
- Make possible high resolution timing on track fits $\rightarrow$ Upward going $\mu$ detection
Trigger Time to Decision

Time to decision for each 5 ms data block is driven by the total number of buffer nodes $N_{\text{Buff}}$ that are used in a round robin pattern and the number of filters per node $M_{\text{filt}}$ that are analyzing the data:

$$\langle \Delta t_{\text{dec}} \rangle = N_{\text{buf}} M_{\text{filt}} \times 5 \text{ ms}$$

Current configuration runs:
- 45 buffer nodes
- 13 filters per node

$$\langle \Delta t_{\text{dec}} \rangle = 2.925 \text{ s}$$

NO$\nu$A trigger execution time for leading trigger processes. Total average time to decision < 1 s.
Trigger Time to Decision

- Trigger is fully integrated with offline analysis framework
- Allows complete characterization of new triggers performance
- Use combination of Zero bias readout data & Monte Carlo simulation to determine scaling prior to new trigger deployment

Scaling of trigger decision time with detector readout mass. Triggers are characterized based on zero bias readout of current detector configuration.
Maximum Time to Decision

Maximum time to decision is based on the total data volume buffered across the DAQ farm.

Each buffer nodes is configured with a 5 GB memory segment dedicated to live data storage.

- Each buffer holds ≈ 5.5 s of full detector data
- Aggregated ≈ 4 min look back

Look back buffer is aggregated across buffer node pool. Gives a maximum 240 s of latency to trigger decisions.
Trigger Live Time

DAQ Readout is 100% live in streaming mode

Trigger operates on the stream with live time determined from the number of dropped 5 ms data frames which are NOT examined by the trigger

Total trigger live time is balanced against physics sensitivity for current trigger suite

Average live time > 0.9

NOνA trigger live time corresponds to the absolute wall time that the trigger was able to process to decision across all paths.
NO\nuA Global Trigger Design

• Global Trigger aggregations multiple trigger sources through prioritized queue structure

• Permits independent trigger and trigger group based
  – Prioritization
  – Prescaling
  – Throttling

• Allows for balancing
  – High Level software DDTs
  – External Beam triggers
  – Pulsers (hardware/software)
  – Readouts 50 \mu s – 60 s

NO\nuA Preliminary

NO\nuA trigger rate balancing and stability for select trigger groups
NOνA Global Trigger Design

Main Application Thread

Trigger Reception/Generation Pool
- Trigger Thread "Beam"
- Trigger Thread "Data Driven"
- Trigger Thread "Internal/Pulser"

External Sources
Beam

DDS Receivers

DDS Sender
Queue Servicing Agent (Sender)

Prioritized Queues
- Fifo High
- Fifo Medium
- Fifo Low

Prioritized/Balanced Servicing

Master Trigger
Data Logger
- Disk
- Disk

Buffer Farm
- Buffer Node 001
- Buffer Node 002
- Buffer Node 003
- Buffer Node 003
- Buffer Node 200

Data Copy

Master Trigger

Fifo Lower
DAQ Uptime

Acquired far detector neutrino exposure for first 12 months of physics running
NOβA Near Detector beam profile as a function of the time $\Delta t$ between the trigger time $t_0$ and the time of the observed hits in the detector. Beam crossing was computed to occur 217.6 $\mu$s after the trigger time $t_0$. The 6 batch structure of the extracted NuMI beam is evident.
Far Detector $\nu$ Observation

Observed time profile of candidate neutrino events observed at the NO$\nu$A Far detector from March 2014-March 2015. The excess seen in the spectrum corresponds to the time interval, corrected for $\nu$ flight times, electronic and signal propagation delays, of the predicted far detector beam crossing.
Summary

• The NOνA experiment has successfully created, commissioned and is operating, a continuous, free running, dead-timeless DAQ system that is able to scale to readout the full 14 kt NOνA far detector.

• The experiment has also successfully created a high level “data driven trigger” system that is capable of analyzing the full, unfiltered NOνA data stream and readout triggers windows from 50 μs to 1 minute in length.

• These combined systems have currently collected over 5.7 billion events which are currently under analysis.