The 'ABC' of cognizant DAQs

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BROOKHAVEN NATIONAL LABORATORY
PROPOSAL INFORMATION QUESTIONNAIRE
LABORATORY DIRECTED RESEARCH AND DEVELOPMENT PROGRAM

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TITLE OF PROPOSAL:	**The 'ABC' of cognizant Data Acquisitions**		
TYPE A			
PROPOSAL TERM	From **October 2021**	Through	**September 2024**

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Intellectual Merit

What is the key research hypothesis that the PI aims to prove?

- address challenge of increasing data rates at LHC, EIC, and synchrotron facilities by integrating edge based AI/ML data reduction and signal processing techniques into data acquisition system (DAQ) front end electronics

How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields?

- if the LDRD is successful it will provide a way to enhance purity of recorded data would give a better use of the luminosity/ brilliance of these expensive to operate facilities and therefore
  - increase operational efficiency
  - reduce data storage space
  - simplify offline data calibration and reconstruction

What is the specific innovative claim?

- bring AI/ML as close as possible to the detector

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Heart of the LDRD Proposal

DAQ systems are heart of any detector at a collider or accelerator facility

A cognizant DAQ brings intelligence based on AI/ML from offline post processing into detector readout electronics

- enhance quality of signal events by detecting problems in detector performance by interfering and recalibrating the problematic section of the detector
- low power consumption and latency to classify and discriminate between real signal based hits/events from false positives

Advantages of a cognizant DAQ:

- improve effective use of the delivered luminosity
- reduce requisite storage space from exabyte scale by several orders of magnitude
- offline data calibration and reconstruction and such time to publication would be reduced

Goal

Provide modular building blocks (software and hardware) for a cognizant DAQ easily applicable at different experiments

- prototype electronic boards to integrate intelligence next to the detector and develop an autonomous calibration system
- software and algorithms to integrate the intelligence next to detector
- proof of concept based on the ATLAS HL-LHC Silicon Strip detector modules and staves to develop and qualify the building blocks of a cognizant and detector-aware DAQ
- proof of concept using existing readout electronics from STAR@RHIC to integrate AI/ML
  - full readout chain of Monolithic Active Pixel Sensors (MAPS) based μ-vertex tracker
  - a calorimeter system based on a silicon photomultiplier (SiPM) photosensor readout

Expected Results

Results will be combination of hardware, software, and Tensorflow or Torch models that provide data reduction, autonomous calibration, and improved signal-to-noise ratio

- DNN capable of classifying whether a signal in the readout electronics should be propagated downstream for further processing or if the event should be filtered
  - initially trained in a supervised fashion using manually labeled datasets
- unsupervised or self-supervised autoencoder trained to reconstruct signal in readout electronics
  - mean-squared error between reconstruction and input signal increases as detector loses calibration and a threshold tolerance on this error will trigger the recalibration routine
- DNN based classifier that can be used to localize from which part of the detector a signal was generated
  - for example, mitigate the effects of detector radiation damage on the pulse thresholding by allowing for spatially resolved calibration pedestals

Silicon Strips (ATLAS)

Align detector in real-time

- train and verify ML/AI algorithms to reconstruct in real time trajectories of particles crossing reference modules and apply corrections for dynamic misalignment and vibration
- concept consists of multiple staves or modules mechanically mounted on an optical table
    - modules and staves readout using a DAQ based on a FELIX card — all available at BNL!
- one Strip module acts as the device under test (DUT), attached to precise translation stages that can induce misalignments or vibrations
- data samples from assemblies can be obtained to train and verify the ML/AI algorithms using test beam facilities such as FNAL FTBF or CERN SPS H6/8 beamlines

Figure 1: a) ATLAS ITk Strip Stave and FELIX readout at BNL. (b) ATLAS ITk Strip Stave. (c) ITk Strip Sensor s-curve calibration obtained using FELIX card.

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Data Reduction

Learning Approach

- DNN architecture most suitable for FPGA deployment are convolutional based
  - Finite Impulse Response (FIR) IP cores make efficient use of multiply-accumulate resources to implement AXI streaming with deterministic latency
- fully convolutional Centernet approach as starting point
  - Centernet is object detection algorithm that analyzes images to generate bounding boxes, labels, and pose
  - open source repository with Torch implementation available for quick proof of concept
- bounding box extents regressed by DNN can trigger readout electronics to store or filter signal

Triggering autonomous recalibration

- autoencoder-based outlier detection
  - uncalibrated state considered outlier state
  - autoencoder trained to reconstruct signals collected when system is calibrated
  - threshold on the error automatically triggers a calibration run
- training run can be executed after each calibration procedure without manually labeling data

Roman Pots (STAR)

Adjust noise voltage thresholds in real time

- Roman Pot detectors based on pixelated Silicon detectors
- single scalar voltage threshold set to discriminate between dark counts and signals of interest
  - doesn’t account for distribution of responses of individual pads
- defects from radiation damage accumulated in Si broaden distribution of quantum efficiency
  - effect becomes more detrimental with integrated dose

Improve spatial resolution and provide pad-resolved calibration thresholds

- train a DNN to identify pad of origin
  - initial network architecture an object detector similar to Centernet
  - convert to heat map to avoid overwhelming FPGA with pixelated detector channels
- **could allow pad pitch in Roman Pot detector to be decreased from 500 μm to 3 mm**
  → provides a factor 30 power reduction
- more specific classifications such as photon type (e.g. optical, dark count, x-ray, gamma) can further classify signal and whether to filter it for data reduction

Milestones

Year 1

- demonstrate real-time detector configuration change in response to conditions through ML/AI tool
- use simulated data to select and tune AI/ML algorithm and test its application on the data

Year 2

- demonstrate real-time data calibration in response to detector conditions through ML/AI tools
- implement the algorithm into FPGA

Year 3

- full chain of ML/AI tools in firmware & software to optimize data taking in response to detector conditions through ML/AI tools

Success Criteria:

- set of modular building blocks (software and hardware) for a cognizant DAQ easily applicable at different experiments