The ATLAS Hardware Trigger System

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1 Introduction

Within the ATLAS detector bunches of particles collide with a frequency of 40 MHz. A trigger system is needed to select interesting events and only record these to reduce the amount of data recorded overall. ATLAS has a 2-level trigger system, consisting of the hardware trigger system (L1T), reducing the rate from 40 MHz to 100 kHz, and the High-Level-Trigger (HLT), which is a software trigger reducing the rate further to a few kHz.

2 The hardware trigger system in Run-3

The hardware trigger receives information from the calorimeters and the muon detector. It provides the Level-1 trigger decision, the so-called Level-1 accept (L1A) 2.5 μs after the collision since the inner detector cannot buffer events longer than that. The calorimeter hardware trigger in Run-3 consists of 3 Feature EXtractors (FEXes) that receive calorimeter data in various granularities to identify various Trigger OBjects (TOBs) for each event: the electron FEX (eFEX) finds e/γ and τ TOBs using 24 modules receiving data at a very fine granularity. The jet FEX (jFEX) receives data with a more coarse granularity, which is spread over only 6 modules to find small radii (R $<$ 0.4) jet TOBs. It additionally provides τ TOBs, as well as E_t^{miss}, Sum(E_T) and e/γ TOBs outside of the eFEX coverage. Last but not least, the global FEX (gFEX) receives data with very coarse granularity on a single module to find large radii jet TOBs and exotic signatures, as well as various versions of E_t^{miss} TOBs. All FEXes and the L1Muon system send their TOBs to the topological processor (L1Topo). L1Topo consists of 3 modules and evaluates TOBs to send only individual trigger bits per algorithm to the Central-Trigger-Processor (CTP), which issues the L1A. It hosts a vast amount of multiplicity algorithms (i.e. count TOBs over threshold), many topological algorithms (i.e. calculating and cutting on topological quantities between 2 or more TOBs), and some more special algorithms, like a KalmanMET or Simple Cone.

3 The Sliding Window Algorithm and the jFEX

For jet TOB finding, the jFEX uses the so-called *Sliding Window Algorithm*. As preparation, the calorimeter data is decoded, problematic cells are masked, a noise cut is applied, and the electromagnetic and hadronic components are summed to 0.1x0.1 (in $\eta|\phi$) TriggerTowers (TTs). The *Sliding Window Algorithm* is composed of three steps:
For any TT position, all TTs in a 3x3 block are summed up to a so-called seed energy. In the next step, each seed energy is compared with the seed energies within a 0.5x0.5 search window around the seed to determine if the seed position is a local maximum (LM). To resolve the edge-case of seed energy equality, the LM demands in one direction of the detector strict-larger and the other direction larger-equal comparisons. To calculate the energy of a jet TOB that is built on an LM, all TTs within a $R < 0.4$ are summed up.
Since the *Sliding Window Algorithm* has a latency budget of only 25 ns, the calculations for all positions are done in parallel. Due to latency constraints, this parallel approach is used throughout most parts of the hardware trigger system. The system uses Field-Programmable-Gate-Arrays (FPGAs) to meet the required bandwidths and parallel, low-latency computations.
A jFEX module features 4 large processor FPGAs (Virtex US+ 9P). Each module is responsible for a slice in η, whereas each FPGA is responsible for a ϕ quadrant of an η slice. Dividing the workload by detector area allows the logic to fit into FPGAs. Each module can receive data from fibers at 11.2 Gbps per fiber. The up to 240 fibers per module allow for a total receiving bandwidth of just over 16 Tbps for the jFEX system.

4 The hardware trigger system in Run-4 and beyond

For Run-4, ATLAS will receive a new inner detector, allowing for a higher accept rate and the buffer latency will be increased to 10 μs. Since the pile-up is planned to increase from currently 60 to up to 200 collisions per event, the trigger system will also be upgraded. The calorimeter trigger system will be extended by the addition of the forward FEX (fFEX). It will consist of 4 modules and receive information at cell-level granularity. Its job will be to provide e/γ and τ TOBs from $\eta > 2.5$ onwards, as well as small and large radii jet TOBs from $\eta > 3.2$ onwards.
The L1Topo will be replaced by the Global trigger system. Since in addition to the TOBs from the FEXes Global will also receive cell-level granularity information from the calorimeter, it will be able to further refine the received TOBs. It will also absorb nearly all algorithms currently running on L1Topo. Global will use the increased latency budget to apply time-multiplexing to the individual modules: the global trigger system will send events to individual Global Event Processors (GEPs) in a round-robin scheme. Thus with 48 GEPs, a GEP will have 1.2 μs before it receives another event. This will allow for more complex, iterative trigger algorithms, which will improve the performance of the system to meet the challenges that come with increased pile-up.