Software for implementing trigger algorithms on the upgraded CMS Global Trigger System

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CMS Level-1 Trigger Upgrade

- LHC has resumed its operation in 2015
  - collision-energy will be increased from 8 TeV to 13 TeV
  - luminosity is expected to go up from 0.75×10^{34} cm^{-2}s^{-1} to 2×10^{34}cm^{-2}s^{-1}

  $\Rightarrow$ New challenges for the CMS Trigger system
- CMS Level-1 trigger system will be upgraded;
  - to improve its performance for selecting interesting physics collisions
  - to operate within the predefined data-acquisition rate
- Electronics for the calorimeter, muon and global trigger systems will be replaced
  - high bandwidth optical links for data communication
  - modern, large FPGAs and large memory resources for the trigger logic
- Upgraded system will be flexible for implementing further rate reduction and efficiency improvements as algorithms improve

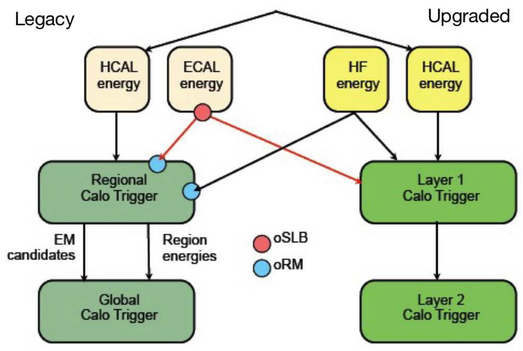

Fig. 1: Calorimeter Level-1 trigger transition

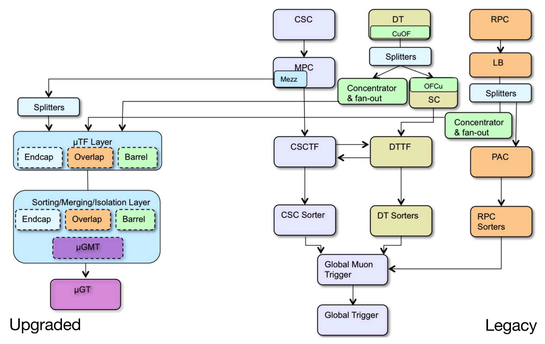

Fig. 2: Muon Level-1 trigger transition

Global Trigger (GT)

- GT is the final step of CMS Level-1 Trigger, processing a trigger *menu*
  - *menu* is a set of *algorithms* applied to trigger objects from calorimeter and muon
  - *algorithm* is formed by conditions for trigger object selection, with possible topological requirements on multi-object triggers, combined by simple combinatorial logic (AND-OR-NOT-XOR)
  - most basic algorithms consist of applying E_T or p_T threshold to single objects
- Present GT is comprised of several VME modules with FPGAs
- GT will be re-implemented on modern FPGA on an Advanced Mezzanine Card in MicroTCA crate
  - increased processing resources enabling more algorithms at a time than previously possible, allowing CMS to be more flexible in how it handles the trigger bandwidth
  - enabling CMS to match different objects, e.g. muons with jets, with higher resolution and efficiency
  - possible to calculate more sophisticated quantities, e.g. mass of a pair of objects

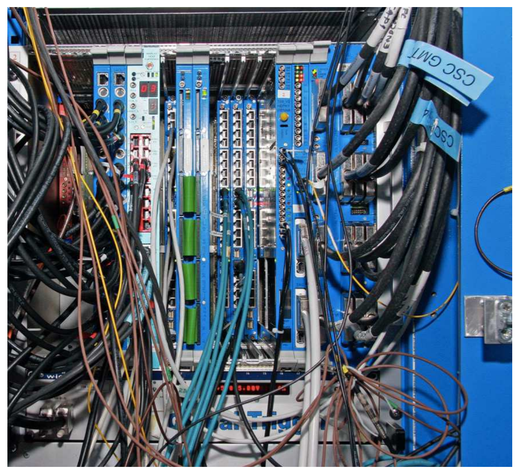

Fig. 3: Global Trigger system in 9U VME crate

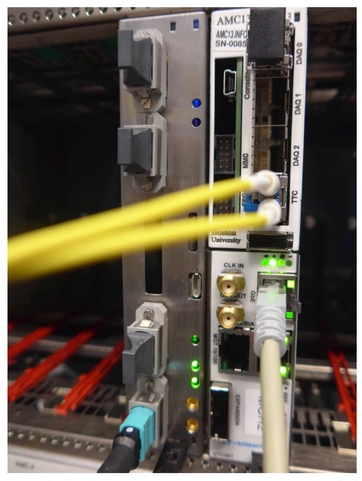

Fig. 4: Main components of Global Trigger system in MicroTCA crate

Trigger Menu Tools

- In order to handle the increased complexity of the trigger menu to be implemented on the upgraded GT, a set of new software has been developed
  - Trigger Menu Editor (TME) is an intuitive graphical user interface allowing a physicist to define a menu with analysis-like triggers
  - VHDL producer instantiates predefined firmware templates for implementing menu on FPGA
- The menu plays a central role in trigger selection, shared by;
  - a trigger emulating software in an offline software environment
  - the second level trigger, known as the High Level Trigger

Level-1 menu grammar

- For hiding the underlying hardware implementation as well as to make the data structure for a trigger menu to be flexible for a possible future evolution of the GT, a set of rules for describing an algorithm for the GT is introduced (Level-1 menu grammar)
  - Level-1 menu grammar is defined and parsed by `Boost.Spirit`.

Trigger Menu Editor

- TME provides a graphical user interface for a physicist to edit or to create a Level-1 trigger menu without exposing the complex hardware logic of the GT
- TME helps a user to express algorithms in the grammar for composing a menu
  - CMS online database (DB) and an XML file are used as a persistent storage and as a transient storage, respectively
  - An XML file will be used while developing a level-1 trigger menu without accessing the online DB which is located in a private network
  - DB interface of TME enables to access the database to upload and to download a trigger menu in an XML format
  - `Code Synthesis XSD` is used for creating XML data binding for `C++`
  - Database access is implemented by using `XDAQ/TS` framework developed for the CMS experiment

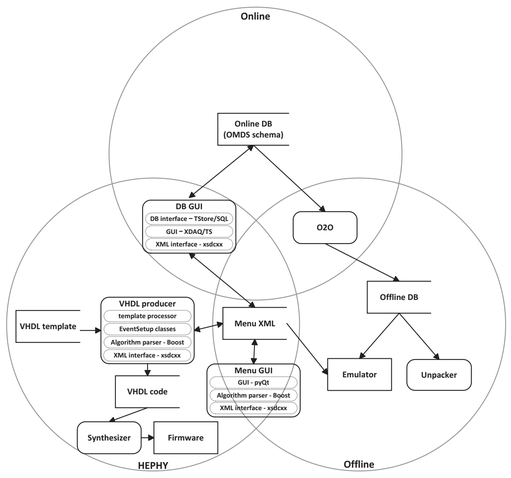

Fig. 5: Overview of Trigger Menu Tools

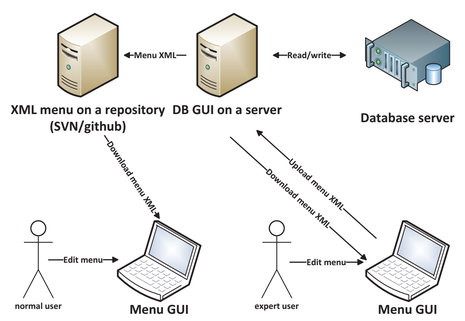

Fig. 6: Use case of Trigger Menu Editor

Algorithms in Level-1 menu grammar

- Algorithm is comprised of a combination of `object`, `function`, `cut`, and logical operators
  - `object`: a physical object created by calorimeter and muon trigger systems, with its p_T or E_T threshold applied at a certain bunch crossing offset.
  - `function`: a logical or mathematical computation based on `object`
  - `cut`: a condition applied on `object` or on the value computed by a `function`
- The simplest algorithm is an `object` with p_T or E_T threshold
  - A muon with $p_T \geq 20$ GeV is expressed as `MU20` or `MU20.ge.20+0`
- Selection condition can be applied to `object` by adding `cut` in square brackets
  - e.g. `MU20[MU_PHI_UPPER,MU_ETA_BARREL]`, here, `MU_PHI_UPPER` and `MU_ETA_BARREL` are defined by a user to specify ϕ and η ranges
- Di-muon trigger with $p_T \geq 20$ GeV and $p_T \geq 10$ GeV can be defined using a combination function as `comb{MU20,MU10}`. Selection condition can be applied to a `function` as well. For example, one can specify invariant mass range of di-muon as `mass{MU20,MU10}[MASS_JPSI]`. Topological requirements on multi-`object` can be applied with `delta` function.
- Due to its abstract nature, an algorithm expressed with the grammar is de-coupled from the details of the hardware implementation. VHDL producer is responsible for creating VHDL codes from the algorithm expressions. In this way, the flexibility in the software layer has been newly introduced.

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