A General Scheme for Optimization of Trigger Rates in an Experiment with Limited Bandwidth

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Introduction

Most modern colliders for particle physics experiments produce a large total interaction rate which greatly exceeds the readout and data storage capabilities of the detectors involved, necessitating the use of a sophisticated trigger system. Such a system must keep rare or hitherto unobserved processes with maximum possible efficiency, while recording only a fraction of those processes with high rates. A stable trigger rate and good background rejection often require complicated trigger conditions with moderate efficiencies, which are mostly biased towards certain topologies or kinematic regions and therefore difficult to control with sufficient precision. On the other hand, trigger conditions with high efficiencies and small bias are susceptible to varying backgrounds, resulting in large and often unstable output rates.

An algorithm for optimizing trigger rates is presented which is implemented into the H1 trigger system and allows the use of unbiased, variable rate trigger conditions without compromising overall data taking efficiency. The general scheme of this procedure is described and first results on its performance are reported.

Adjustment of Trigger Rates

The H1 experiment at the HERA electron proton collider operates a first-level trigger system where the global trigger decision is calculated as the logical OR of 128 programmable conditions called subtriggers. Each individual subtrigger can be downscaled by a presettable factor. This downscaling allows the storage of a sensible amount of high rate physics processes for analysis as well as monitoring and calibration purposes without exceeding overall bandwidth limitations.

During the first years of operating H1 the downscale factors were defined in advance. However, since collider operating conditions often differ from those assumed, this choice was not always optimal. Ad hoc manual corrections to the downscale factors often led to unsatisfactory results when the overlap between trigger conditions was not properly considered. Therefore an optimization procedure was developed which allows the definition of priorities for trigger conditions using a set of explicit rules, rather than by fixing the downscale factors directly. According to these rules the downscale factors are calculated online by an iterative analysis which assigns weights to triggered events. The procedure leads to an optimal output rate and allows a fast reaction to changing beam and background conditions. Subtriggers can be combined in a nested tree structure with groups and subgroups. For every group the maximum output rate can be either fixed or expressed in terms of relative fractions of the available total output rate. The flexibility of the scheme is illustrated in the following example:

```
Total rate: 50 Hz
{ Rare Process:          df 1                  { s1 }
  High Rate Process A:    0.5 { stable:   0.9  { s2 }
                                unbiased: 0.1  { s3 }
                              }
  High Rate Process B:    0.5                  { s4 }
}
```

Here three different processes are considered — generically called *Rare Process*, *High Rate Process A* and *High Rate Process B* — to be selected by the subtriggers `s1`, `s2` and `s3`, and `s4`, respectively.

It is assumed that the subtrigger condition `s1` produces a stable and sufficiently low output rate such that the corresponding downscale factor can be safely fixed to 1 by `df 1`. The remainder of the 50 Hz total rate is equally divided among the processes A and B. The weights within process A emphasize subtrigger `s2`, which takes 90% of the assigned rate of A while 10% remain for `s3`, enabling, for instance, unbiased cross checks of this analysis channel.
In case the allowed output rate for a subtrigger is not fully consumed, the remaining bandwidth is filled up by assigning additional rate to other subtriggers within the same group. The given strategy therefore allows the maximum proportion of events to be generated by high efficiency, unbiased subtriggers without compromising the stability of data taking.

Prediction of Rates using Event Weights

Central to the algorithm described here is the ability to predict trigger rates for any given set of downscale factors. For this, overlaps between subtriggers have to be considered when calculating cumulative rates. A weight is assigned to each event j according to the probability P_j of keeping the event after downscaling, expressed as

$$P_j = 1 - \prod_{i=1}^{N_s} \left(1 - \frac{r_{ij}}{d_i}\right)$$

where r_{ij} is the binary decision for subtrigger i in event j, d_i is the downscale factor of subtrigger i and the product runs over all subtriggers N_s. The weight of an event is defined as the ratio of this probability evaluated with a new set of downscale factors to the probability obtained with the downscale factors active when the events were sampled. The expected rate is then estimated by summing the weights for a sample of 1000 events. In this way, the optimization proceeds by iteratively adjusting the downscale factors and comparing the predicted rate with the defined rules. At each step in this procedure the overlaps between subtriggers are evaluated and taken into account.
For physics analyses based on data taken with this scheme, cross sections can be calculated in a similar manner using the event probabilities defined as above.

Performance

The algorithm described here for the optimization of trigger rates was used for the first time within the H1 experiment towards the end of the 1997 data taking period. The application of the new scheme during this time was very successful, as it allowed the acquisition of a large amount of unbiased data over a short time interval, giving rise to high precision measurements in several physics channels. Although individual subtriggers showed a large rate variation, the new scheme ensured smooth running with a stable total output rate. Consequently the dead-time remained small and the full sensitivity to rare or potentially unobserved processes was maintained throughout the whole period.
In summary, the concept of this new scheme for optimizing trigger rates has proven to be highly successful and the experience gained with this approach will be beneficial for the future running of H1 as well as the next generation of high rate experiments.