ATLAS Offline Data Quality Monitoring

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Abstract. The ATLAS experiment at the Large Hadron Collider reads out 100 Million electronic channels at a rate of 200 Hz. Before the data are shipped to storage and analysis centres across the world, they have to be checked to be free from irregularities which render them scientifically useless. Data quality offline monitoring provides prompt feedback from full first-pass event reconstruction at the Tier-0 computing centre and can unveil problems in the detector hardware and in the data processing chain. Detector information and reconstructed proton-proton collision event characteristics are distilled into a few key histograms and numbers which are automatically compared with a reference. The results of the comparisons are saved as status flags in a database and are published together with the histograms on a web server. They are inspected by a 24/7 shift crew who can notify on-call experts in case of problems and in extreme cases signal data taking abort.

1. Introduction
Monitoring of all aspects of an experiment’s operation is important for success. Examination of the data taken by the detector can detect irregularities which may need to be corrected later or which may require immediate action by the experimentalists. Such monitoring should be comprehensive, while providing feedback as early as possible.

This paper describes the offline data quality monitoring system of the ATLAS experiment. This provides feedback from fully reconstructed events processed at the Tier-0 farm, with
Figure 1. The flow of monitoring and data quality information in ATLAS. Here we are concerned with the offline component.

histograms becoming available generally less than an hour after the start of an experimental run. A sophisticated suite of automatic checks is run on a subset of histograms produced from the data and identifies problematic distributions. The histograms and the results of the automatic checks are stored for future access. Summary flags are stored in a database and are used in physics analyses to determine the detector status.

It should be noted that ATLAS has additional data quality monitoring systems which are described in other contributions to these proceedings and are depicted in Figure 1. The online monitoring system provides near-real-time feedback on quantities that are available given the limited computing power in the online cluster. An additional system checks the records of the detector configuration system to determine if the parameters are acceptable for good quality data (fraction of active channels, high voltage, etc.). Beyond these, various ATLAS subdetectors have specific monitoring systems that are outside the present scope.

The flow of information in the offline data quality monitoring system is depicted in Figure 2.

2. Data Processing and Histogram Production at Tier-0

The primary application of the offline data quality monitoring is to give quick feedback on the prompt reconstruction of ATLAS data at the Tier-0 computer farm at CERN. The ATLAS computing model [1] foresees the first full reconstruction of all data occurring at Tier-0. This should be done before the relevant data are staged to tape due to incoming files, which is a period on the order of several days. In this time calibrations and alignment have to be verified by rapidly reconstructing a smaller “express” subset of the data. The first express reconstruction occurs as soon as data for a run are available and the necessary detector conditions information has been replicated to the Tier-0, generally within an hour of the start of a run. Additional reconstruction iterations will occur as necessary until the calibrations are signed off for full reconstruction. Data quality monitoring is run during each of these passes to ensure that the initial data is satisfactory (first pass) or that the calibrations are valid (second and higher passes). Every 15 minutes, and at the end of reconstruction, the available files from different computing nodes are merged to sum up the statistics. During the merging process additional post-processing code can be run on the produced histograms. The histogram files produced by the end-of-run merging are registered as a Grid dataset for world-wide access.

Automatic data quality checks at ATLAS are based primarily on histograms. The size and
memory requirements of histograms scale well with the number of events. In production, the histograms are produced by tools that run in the ATLAS software framework Athena. These tools are active during prompt reconstruction and can also be used on already-reconstructed files, although transient information available during reconstruction cannot be monitored in the latter case. Various tools are implemented that monitor information ranging from readout errors to reconstructed physics quantities such as dimuon masses for \(J/\psi\) and \(Z\) reconstruction.

User monitoring code is controlled by a manager class. Histograms are registered with the manager which handles proper placement into an output ROOT file and metadata such as the algorithm to use when merging histograms across files. Histograms can be declared with time granularities shorter than a run, and the manager takes care of the necessary bookkeeping. The manager also implements the trigger awareness facility, which specifies that user code should only be invoked when certain triggers or sets of triggers have been fired.

### 3. Data Quality Monitoring Framework

Both ATLAS offline and online automatic data quality monitoring use a common core software infrastructure, the Data Quality Monitoring Framework (DQMF) [2]. The concept is of a data quality “tree,” where the leaf nodes are specific histogram checks, and the interior nodes combine the results of their daughter nodes; the data quality results propagate up towards the root of the tree. The four currently implemented data quality flags are green, yellow, red, and undetermined (the last is used if, for example, statistics are too poor for a check to be performed). In the future an additional “detector disabled” flag is foreseen.

For the leaf nodes, input histograms are specified, along with check algorithms, thresholds, and reference histograms. Check algorithms can range in complexity from simple tests that histograms are empty (e.g. for readout errors) to \(\chi^2\) tests and shape comparisons. Check algorithms can also publish extra information on the histograms in addition to the overall flags. Interior nodes combine the information of their daughters using “summary” algorithms, which perform various logical combinations of the flags.

Reference [2] primarily discusses the online realization of the system. The offline variant differs in the input of histograms, output of results, and configuration format, driven by the different requirements for its environment. The offline latency and speed requirements are much more relaxed, where the checks are run at most once every few minutes instead of continuously as they are online. Therefore, instead of an always-on, distributed application as is used online, the offline implementation is a non-networked, standalone program (Histogram Analyzer or “\(\text{han}\)”) that runs as part of a Tier-0 job. The input to \(\text{han}\) is ROOT files, and the configurations are stored as single binary files that include all necessary information (such as reference histograms). Conversely, the offline environment places stricter requirements on provenance and preservation of the results. As a consequence, the output of the \(\text{han}\) application includes all information that would be necessary to reproduce the checks — the input histograms, the configuration, and any
references — in addition to the flags and additional algorithm results. This output is archived for future reference.

4. Presentation

4.1. Web Display

Once the results are available in the han output ROOT file, they must be made available to experimental shifters and other users. The primary means of visualizing the results is via the han Display (handi) application. This reads the ROOT files and produces a set of static HTML pages with the flags, algorithm results, and images of the histograms and associated references. The handi configuration — specifically the histogram display options and any additional information like histogram descriptions and actions to take if checks fail — are encoded as options in the han configuration file and propagated to handi via the han output file. A sample display from a mock data exercise is shown in Figure 3.

4.2. Conditions Database

Top-level summary information, on the level of subdetector units, is stored in the ATLAS conditions database [1], which is implemented using the LCG COOL technology [4]. COOL implements a versioned conditions database on top of various relational databases; related information is stored in “folders” which group related “channels,” and each channel has a sequence of data values, each valid for a specific interval. The data quality summary information is mapped to channels in dedicated COOL folders and flags are stored in these folders with intervals of validity set by the time granularity of the respective check. The versioning mechanism
makes it easy to distinguish different revisions of the flags. This information can then be accessed via standard ATLAS tools, including a web interface (shown in Figure 4).

4.3. Web Service
The information contained in the `han` output files is of general long-term interest — for example it contains run-by-run information on residual means and widths. This information should be made available without requiring scraping of the `handi` output HTML pages; in addition it should preferably be independent of the exact storage format, allowing internal changes to the `han` ROOT output format or backing by a different technology entirely such as a relational database. To address these concerns an XML-RPC web service is in the process of being deployed. This allows distributed, language-neutral use of the results of the DQMF checks. This system has been used to create plots of the history of any monitored quantity. Currently it is backed by SQLite databases which are updated when `han` output files are archived, which provides an order of magnitude speed improvement over direct access to the `han` files.

5. Additional Uses
The histogram comparison and display code is relatively lightweight and, in particular, is not tied to the Tier-0 reconstruction; it is available wherever the ATLAS codebase is deployed. This makes it useful for other purposes.

5.1. Grid Data Reprocessing
In the ATLAS computing model [1] reprocessing of data to take advantage of improved calibrations, alignment, and reconstruction algorithms takes place at Tier-1 sites. It is important to check the output of these reprocessing campaigns. The same monitoring code can be used here as in the Tier-0 processing, and the histogram file merging is handled by jobs scheduled by the ATLAS production system. In the setup used for the reprocessing of ATLAS 2008 cosmic ray data, the histogram datasets produced at various Tier-1 sites are replicated to storage at CERN, where `han` and `handi` are run.

5.2. Monte Carlo Production Validation
Standard monitoring code can be run on the files produced by ATLAS full Monte Carlo (MC) simulation. These files can then be compared with the results of previous MC runs, or even
with the corresponding histograms from data. The technical challenges of Grid operation are very similar to those for data reprocessing.

5.3. Code Validation
ATLAS runs many tests on its software on a nightly basis to catch problems introduced in development. These tests include a full test of the MC production chain and the full reconstruction of an amount of cosmic ray data. In principle any changes in the output of these checks from test to test should be fully understood in terms of code changes — in particular the monitoring histograms should be identical except where they were intended to change. They can be compared between nightly builds using the data quality monitoring tools, using a histogram comparison algorithm that flags as red any difference between input and reference histograms.

6. 2008 Production Experience
The offline data quality monitoring for Tier-0 operations was deployed in anticipation of 2008 data taking and was operational at LHC startup. After the September 19 LHC incident, ATLAS continued a combined cosmic data run which exercised many aspects of the data acquisition and monitoring infrastructure, including offline monitoring. Additional features were added at user request. The most rapidly evolving part of the system is the check configuration, which is changing as experience is gained with the ATLAS subdetectors and the parameters of normal operation are mapped out.

7. Summary
The ATLAS offline data quality monitoring infrastructure has been deployed and tested for monitoring of Tier-0 prompt reconstruction. It provides status flags and algorithm results for monitored histograms, which are provided to users through several interfaces. The core applications are available anywhere the ATLAS offline software framework is installed, and can be used in any validation task where histogram checks are needed.

References
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