Derived Physics Data Production in ATLAS: Experience with Run 1 and Looking Ahead

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Abstract. While a significant fraction of ATLAS physicists directly analyse the AOD (Analysis Object Data) produced at the CERN Tier 0, a much larger fraction have opted to analyse data in a flat ROOT format. The large scale production of this Derived Physics Data (DPD) format must cater for both detailed performance studies of the ATLAS detector and object reconstruction, as well as higher level and generally lighter-content physics analysis. The delay between data-taking and DPD production allows for software improvements, while the ease of arbitrarily defined skimming/slimming of this format results in an optimally performant format for end-user analysis.

Given the diversity of requirements, there are many flavours of DPDs, which can result in large peak computing resource demands. While the current model has proven to be very flexible for the individual groups and has successfully met the needs of the collaboration, the resource requirements at the end of Run 1 were much larger than planned. In the near future, ATLAS plans to consolidate DPD production, optimising resource usage vs flexibility such that the final analysis format will be more homogeneous across ATLAS while still keeping most of the advantages enjoyed during Run 1.

The ATLAS Run 1 DPD Production Model is presented along with an overview of the resource usage at the end of Run 1, followed by an outlook for future plans.

1. Introduction
The ATLAS Collaboration [1] has an extremely successful analysis model that resulted in some 270 publications at the time of writing (October 2013), a very similar number to the CMS collaboration. The analysis model [2, 3] itself was based on the philosophy that each individual group had its own specific and often unique requirements. Therefore the collaboration, through the Physics Analysis Tools (PAT) group, provided analysis tools rather than a one-size fits all framework. The Combined Performance (CP) groups, e.g. Egamma, Muon, etc. delivered analysis tools through PAT which could be used to calibrate and apply scale factors to the reconstructed objects. On top of this toolkit, many groups built their own group-specific analysis frameworks to make analyses in their group more uniform and efficient. These tools allowed users to analyse Petabytes of reconstructed and simulated data and apply the best knowledge to analysis-level objects using the CP tools, producing high quality physics results.
1.1. The reconstruction chain

During Run 1, the ATLAS data processing and reconstruction chain went through several steps. The RAW detector data is promptly processed using the Athena software framework [4], based on Gaudi [5], at the Tier0 into first an ESD (Event Summary Data) and then an AOD (Analysis Object Data) format. The AOD was designed and intended to be the analysis format for the collaboration, with the subsequent data processing step necessitating the use of Athena. In particular, ROOT [6] alone is not able to process the AOD, but the Event Data Model provided in the AOD and directly available in Athena provides a powerful analysis interface.

2. DPD Production and the Run 1 Analysis Model

The PAT group provided Athena-based software tools for end-user analysis. One key component in terms of the analysis model were the tools to perform data-derivations, allowing users to perform event selections and select the particular object and object containers from the AOD that they would keep in their output - Derived Physics Data (DPD). Both Athena (DAOD) and Root (NTUP) output formats are supported, with the latter being simple flat ROOT TTrees with additional physics metadata stored in-file\(^1\). The ROOT format proved to be very popular with the majority of the physics and CP groups.

Each of the physics and CP groups defined their own DPDs, mostly in the ROOT ntuple format and the production of these data formats became a significant workload. Therefore a DPD Production Team was made to coordinate the production of all of the DPDs, with each of the groups providing people for the maintenance of their software. All DPD productions used the same software release, and this release was based on but independent of that used at Tier0 to produce AODs. This allowed improvements, or fixes, to the object definitions available in AOD, and all groups could benefit from these improvements in their DPDs, in both the Athena and ROOT environments. Final CP performance recommendations including e.g. energy calibrations could be applied at any stage in the analysis chain. The overall analysis model can be seen in figure 1.

The result of this model, which provided optimal flexibility for the groups, was a resounding success with ATLAS producing around 270 papers to date (October 2013), similarly to CMS.

\(^1\) For historical reasons, the ROOT NTUP format is also referred to as a D3PD.
2.1. Problems with the run 1 analysis model

As the software producing the AOD was frozen, the number of fixes needed to improve the reconstructed objects in AOD built up over time, as seen in figure 2. As each of the DPDs were independent, this meant that the same object fixes were being applied over and over again in the production step of each DPD, which could eventually lead to large CPU consumption in the DPD-making jobs. In addition, groups could add new object collections (e.g. new jet collections) during the DPD-making step. The extent of the CPU requirements for these reconstruction operations had not been anticipated and, when integrated over all DPDs, amounted to a similar amount of CPU per event as the RAW to AOD object reconstruction.

As DPD productions were largely independent of one another and followed individual group schedules, the CPU usage was generally not a problem. However, after a large reprocessing campaign to create new AODs had finished in 2012, all groups wanted to create their DPDs based on these new AODs. As most of the CPU was performing operations that added information not available in AOD (rather than fixing the AOD, an operation equivalent to AOD reprocessing and therefore unnecessary post-reprocessing) then the CPU requirements were large. The resulting peak in the computing demands would have had negative impact on other critical resource-intensive work, primarily Monte Carlo production. The resources available for DPD production were therefore quickly limited to prevent this, resulting in significant delays for the end user.

In addition to the CPU usage, there was also a rapidly evolving problem in finding space to store all of the DPD outputs. Each of the groups had evolved separately and worked with their own DPDs. As time passed, each group requested to add more and more information to its
DPD until several groups produced DPDs of a similar size to the AOD. The result was that the total disk space usage of DPDs was similar to that needed for AOD, despite DPDs only being useful for individual groups.

3. The Analysis Model Review
An Analysis Model Study Group (AMSG) reviewed the ATLAS analysis model around the same time as the resource problems of DPD Production were becoming evident. In the meantime, and in order to provide a best-case scenario for the current analysis model, the DPD Production team embarked on the implementation of the simplest solution - the Common DPD.

3.1. The Common DPD
The concept of the Common DPD is very simple - it simply merges the content of the existing DPDs. In practice this was reduced to only cover the ROOT NTUP formats and in particular only those made from AOD. NTUPs made from the ESD are a special case as they need the more detailed information only available in the ESD (for example calorimeter cells) and are highly optimised for very specific tasks. Thus, the prototype of the Common DPD started from the merging the content of the largest of the AOD-based NTUPs.

After two months it became evident that this solution could accommodate all of the AOD to DPD use cases except for b-tagging (which requires a lot of detailed information per jet in order to understand b-tagging performance). The Common DPD was then fully implemented and validated by all of the physics and CP groups and production launched after a further four months. The CPU and disk usage compared to the previous scenario are a factor of three smaller, allowing for a much more efficient analysis format production. In addition, cross-group studies that were previously made difficult because of the inhomogeneity of the various DPD formats is now much simpler.

The size of the Common DPD is similar to the AOD, but includes all of the additional object collections that existed in previous DPD incarnations and more besides. Further optimisation is planned to provide an optimal format for the legacy run 1 dataset.

4. The Run 2 Analysis Model
The AMSG had identified several areas for future improvement in the analysis model, targeting run 2 for implementation during LS1. One area was related to the observation that the majority of the collaboration preferred to analyse their data in ROOT rather than Athena. The first recommendation from the AMSG was that the AOD should be made to be directly readable in ROOT, such that analysis could be performed directly on the new AOD, called xAOD. Note that not all analyses can benefit from this change as some require architecture and services that can only exist in the reconstruction world of Athena, but such analyses already live happily in the Athena environment and this doesn’t need to change.

A second recommendation was to implement the train model for DPD production, where a train model here means one input file is used to produce several output files. Thus in the train model, the large file I/O is minimised and all of the DPD outputs are made in one job, i.e. the train. Such train models have been successfully used by many other collaborations. The outputs of the train are the same format as xAOD, i.e. they can be analysed in both Athena and ROOT. The train model also allows CPU-intensive tasks to be organised more efficiently. The run 2 analysis model is sketched in figure 3.

A final recommendation from the AMSG relates to the build-up of fixes to AOD objects. In the future, the analysis model will allow for the AOD version to be updated so that these fixes can be applied once, as shown in figure 4.
5. Conclusions

The ATLAS analysis model used in run 1 provided optimal flexibility for the many physics and CP groups to work both independently and benefit from common improvements in reconstructed physics objects. The impressive publication rate, equal to that of CMS, is testament to the success of the model.

The complete independence of the analysis format production for each of the groups had consequences in terms of computing resource usage. Over time, these resources became very significant, both in CPU and disk usage, showing signs that the analysis model would not scale further. A study group was set up to review the situation, while the DPD production group in charge of producing the analysis formats attempted to consolidate the formats being produced into one common format. This Common DPD reduced the resource usage by a factor of three for both CPU and disk, despite having greater useful content than the total of the individual DPDs. Meanwhile, the study group recommendations pave a way for a different analysis model in run 2. The principle components of this model are that the output of the reconstruction should be directly readable in ROOT as well as Athena, the train model should be used in DPD production and that it should be possible to update the AOD software to prevent a large build-up of reconstruction fixes.

References

[1] ATLAS Collaboration (Aad G et al.), 2008, “The ATLAS Experiment at the CERN Large Hadron Collider,” JINST 3 S08003
[2] Adams D, Barberis D, Bee C, Hawking R, Jarp S, Jones R, Malon D, Poggio L, Poulard G, Quarrie D and Wenaus T, 2005, “The ATLAS Computing Model,” CERN-LHCC-2004-037/G-085
[3] Amir Farbin for the ATLAS Collaboration, 2008, “ATLAS Analysis Model,” CHEP 2007, Journal of Physics: Conference Series 119 042012
[4] Calafiura P, Lavrijsen W, Leggett C, Marino M and Quarrie D, 2004, “The athena control framework in production, new developments and lessons learned,” In *Interlaken 2004, Computing in high energy physics and nuclear physics* 456-458
[5] Cattaneo M et al., 2001, “Status of the GAUDI event-processing framework,” Proc. of CHEP 2001
[6] Rene Brun and Fons Rademakers, 1996, “ROOT - An Object Oriented Data Analysis Framework,” Proceedings AIHENP’96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A 389 (1997) 81-86
Figure 4. The AOD can be updated at Tier0, alleviating the buildup of object reconstruction fixes. The key is the same as in figure 1.