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HEP Software Foundation Community White Paper Working Group – Conditions Data

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Abstract: To produce the best physics results, high energy physics experiments require access to calibration and other non-event data during event data processing. These conditions data are typically stored in databases that provide versioning functionality, allowing physicists to make improvements while simultaneously guaranteeing the reproducibility of their results. With the increased complexity of modern experiments, and the evolution of computing models that demand large scale access to conditions data, the solutions for managing this access have evolved over time. In this white paper we give an overview of the conditions data access problem, present convergence on a common solution and present some considerations for the future.

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Contents

1 Introduction

Access to conditions data is critical to producing the best physics results from HEP experiments. It is somewhat surprising then that few people can accurately define what conditions data means. The challenges for conditions data access are many, notably the requirement to provide simultaneous read access to conditions data for distributed computing resources at kHz rates. This is a highly non-trivial problem that has brought difficulties, especially to the biggest experiments with the largest distributed computing resources; it is easy to get wrong. Equally those shared difficulties provoked collaboration on shared solutions, particularly between ATLAS and CMS [1–4], and this white paper benefits greatly from that work.

The purpose of this white paper then is to answer the following questions:

1. What is conditions data ?
2. What are the major use cases and challenges for conditions data access ?
3. What does best practice for conditions data access management look like ?
4. What challenges are posed by conditions data access in the future ?

The reader should note that this paper focuses primarily on conditions data access and therefore not all aspects of conditions data management are addressed[1].

The paper is organised as follows: section 2 answers the first two questions, thus defining the scope of the work presented here. Section 3 describes best practice in conditions data access management by means of a detailed prototype. The requirements for the future success of HEP in terms of managing conditions data access are discussed in section 4, attempting to answer the final question in the list above, before drawing conclusions in the final section.

2 Conditions data in HEP experiments

Although conditions data is a commonly used term in most HEP experiments, its definition remains ambiguous for many non-experts. Such ambiguity is not helpful and has caused considerable problems in the past, some examples of which will be given later. Conditions data is distinct from the particle collision event data collected from the experimental detectors, hereafter simply referred to as event data. However, conditions data is not all non-event data but rather a particular subset.

From the detector expert perspective, conditions data can be broadly defined as the non-event data required by event data-processing software to correctly reconstruct the raw detector event data. In the case of simulated event data, the scope

[1]Conditions data creation workflows and management tools, authentication and authorization are all examples of topics that deserve further attention.

extends to the correct simulation, digitisation and reconstruction of the data. The most obvious examples of conditions data are calibration and alignment constants, but this is not a complete picture. In general, from the detector perspective, conditions data is the subset of non-event data required to maintain, operate and optimise detectors. This in turn can be broken down into the following categories:

a. Detector and readout configuration parameters.

b. Detector Control System (DCS) data, typically monitoring values of, e.g. voltage and current that are provided directly by hardware.

c. Higher-level detector and system monitoring information, typically provided by custom software with the purpose of evaluating detector performance.

d. Detector calibration and alignment data.

Conditions data in the detector context thus largely consists of (d), together with the subset of (a) and (b) that are required for event data processing. Other non-event data may also be required for event data processing, for example particle physics accelerator parameters. Thus, in practice, *any non-event data from any source that are required for event data processing can be considered as conditions data.*

The use cases for conditions data are described in section 2.1. In general, conditions data vary with time but with a granularity much coarser than a particle collision event, typically having an interval of validity ranging from one year to one data acquisition run[2].

2.1 Workflows and use cases

The original use cases for conditions data were in offline software, but with the advent of software-based high level triggers this is no longer the only use case. Broadly speaking, the major conditions data access use cases are:

1) Online event data processing of raw detector event data

2) Offline event data processing of
    (a) raw detector event data
    (b) fully reconstructed event data
    (c) simulated event data

3) Higher-level analysis of processed event data

[2]The minimum granularity is of course arbitrary, but care should be taken to keep the conditions data volume reasonable, further discussed in section 2.2.

To a large extent this paper deals with the first two use cases while analysis is covered briefly in section 2.1.1. Online event data processing typically has infrequent updates of conditions, with stability and predictability preferred over optimal performance. The exceptions are those conditions that are critical to the performance of trigger algorithms, e.g. the position of the beam-spot in the case of ATLAS and CMS. Online event data processing runs on dedicated resources with a dedicated server for conditions data access.

Offline event data processing in general starts with the reconstruction of raw detector event data, while for simulated data it requires simulation, digitisation and reconstruction of the generated events. In modern experiments, there is usually subsequent data reduction of the output of fully reconstructed event data to produce smaller samples that are better targeted for physics analysis. Offline event data processing is typically repeated several times following improvements in software and/or conditions. It generally involves distributed event data processing on the grid, making it the most challenging use case for conditions data access, requiring conditions data caching to run at scale. HPC and similar off-grid resources are also viable offline event data processing locations and have their own special requirements, in particular a lack of external connectivity.

2.1.1 Conditions for analysis

Versions of conditions data for analysis have often been managed in ad hoc ways, if at all, with hard-coding of conditions data into analysis software releases being considered normal[3]. Belle II [5, 6] has adopted a different approach where conditions data for analysis will be treated in the same way as the rest of their conditions data. They will use a conditions data access management system similar to the one presented here and, given the growing interest in the analysis community, feedback on the suitability of these solutions is expected in the near future.

2.2 Data volumes, read and write rates

Typically, write-rates for conditions data must support of the order of 1 Hz to ensure good support for several independent systems writing conditions data every minute, with the majority of conditions data being updated much less frequently than this. On the other hand, read-rates up to several kHz must be supported for distributed computing workflows, where thousands of jobs needing the same conditions data may start at the same time. Conditions data are typically written once and read frequently.

Conditions data tend to scale in a controlled way during the lifetime of an experiment, typically producing data volumes of gigabytes to terabytes. It is worth

[3]The situation is improving for running experiments, albeit with different solutions than those used for offline event data processing.

noting however that for ATLAS, where the same database instances were used for conditions data as well as the DCS and trigger data, the DCS and trigger data dominated the offline and online database instances, respectively. Raw DCS data, which typically have very high granularity, are not generally needed for event data processing. Smoothed DCS data which have been treated to provide a granularity appropriate for event data processing are used instead. High granularity raw DCS data are vital for understanding problems with detectors, but mixing these two very different use cases in the same database schema led to several difficulties. Firstly it was difficult to optimise the database tables, and secondly conditions data access for offline event data processing required overly complicated database clients and infrastructure to cope with offline conditions data access at scale. It is therefore strongly recommended by this working group to factorise conditions data access from other use cases, even where these are related.

3 Conditions Database Archetype

The archetypal solution to a conditions database management system (CDMS) is shown below. The conditions data payloads are stored in a master database and are accessed using a client-server design through a REST interface. All of the experiments consulted gave feedback that achieving a high degree of separation between client and server was very desirable. Due to the read-rate requirements, caching is extremely important and good experience was seen when using web-proxy caches, e.g. the Squid cache shown here. Some key design principles are detailed in the rest of this section.

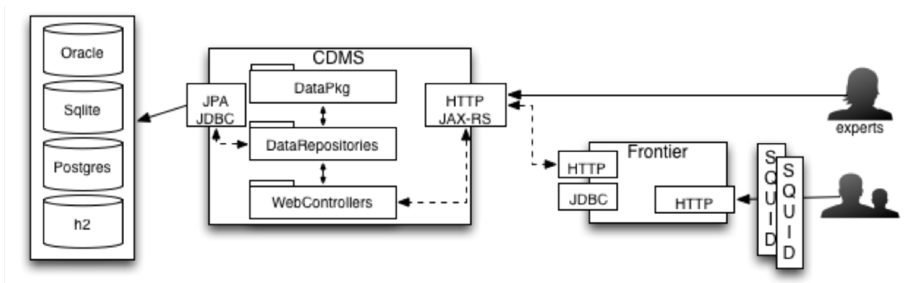

Figure 1: The Conditions Database Management System archetype.

3.1 Payload technology

Experiments will inevitably choose their favourite payload technology. This working group recommends placing most emphasis on homogeneity and long-term maintenance when making this choice. Inhomogeneity and home-grown solutions all place additional burdens on projects that typically lack the resources to support this after the initial build and commissioning phase of an experiment. CMS [2] has very good experience of removing choice and only supporting boost-serialised C++ objects, with all classes belonging to one package in their software framework. Such a strategy lends itself more readily to long-term maintenance and minimises hurdles to data preservation. It is noted that there are payload formats used routinely in industry which would lend themselves more to higher-level functionality without the need of the software framework but, while this is attractive, the choice of format tends to be driven by software framework developers.

One very important consideration for payload technologies is the issue of schema evolution. This is further exacerbated in the (frequent) case that the experiment uses the same framework for the online and offline event data processing use cases. Conditions payloads are determined offline and therefore their versioning follows the offline release which will usually evolve more rapidly than the online release. This implies a forward compatibility constraint such that the online software can correctly process conditions payloads generated by the offline software which may use a later version. In the case of CMS, as boost does not support forward-compatibility in its schema evolution, conditions payloads for a particular set of event data must be written by a version of the software framework that is at most as old as the version used by the online software when recording those event data.

3.2 Database back-end

One of the key features of the design is that it is agnostic to particular choices of database back-end. This was also one of the key features of COOL [7, 8], but due to the lack of caching in COOL, the queries themselves had to become more complicated. Thus on ATLAS, which uses an Oracle back-end, a significant amount of Oracle DBA effort was required to tune the queries and make them performant. It is therefore important to realise that real flexibility with respect to choices in database back-ends only comes when the system as a whole is simplified.

3.3 Client-side requirements

The client layer should be as simple as possible and should be as agnostic of the rest of the architecture as it is possible to be in order to improve maintainability. The database insertion tools in particular benefit from adopting a simple, e.g. REST, interface. The client layer needs to take care of payload deserialisation, as the remaining architectural components will deal with serialised objects. Experience also shows that clients should be able to manage multiple proxies and servers to provide robustness against server failures.

3.4 Caching

CMS and ATLAS absolutely require an intermediate layer, Frontier [9, 10], between the client and server to provide caching capabilities. Considering offline event data processing using distributed computing resources, where thousands of jobs start at the same time and require the same conditions data, this is a clear requirement and one that can be well met using web-proxy technologies. An alternative solution would be to use a distributed file-system with good caching capabilities, and the LHCb [11] and ALICE [12] experiments have gained experience using CVMFS [13]. The simplicity of this solution makes it very attractive and it has thus been adopted as a strategy by the NA62 [14] experiment. This in turn suggests that, as a design requirement, it should be possible to represent a conditions database on a file-system. The primary challenge here is to make the file-system mapping use the CVMFS caching layers efficiently. Several experiments also have experience using SQLite replicas, including for HPC usage. These are attractive for workflows where the exact subset of conditions is known in advance, e.g. some simulated data workflows, but in general a performant caching layer is preferable thanks to its flexibility.

3.5 Data Model

The data model for conditions data access management is an area where the experiments have almost universally agreed on a design, shown in figure 2.

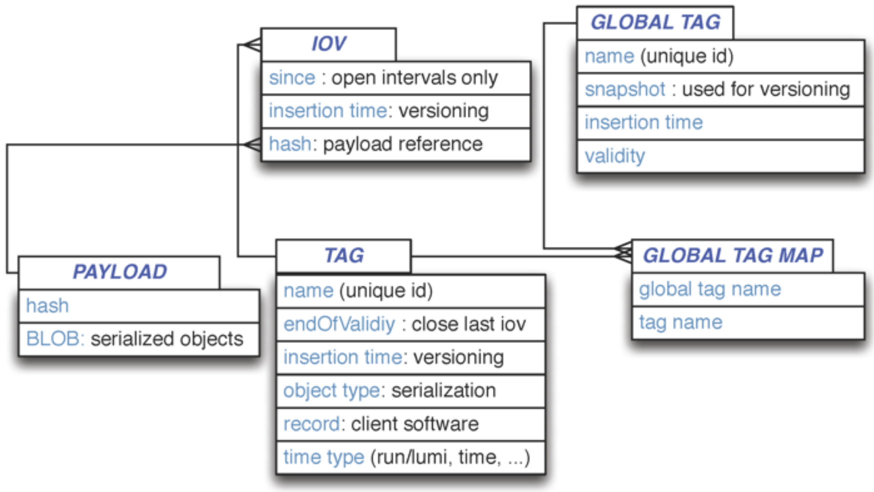
IOV
since : open intervals only
insertion time: versioning
hash: payload reference
GLOBAL TAG
name (unique id)
snapshot : used for versioning
insertion time
validity
PAYLOAD
hash
BLOB: serialized objects
TAG
name (unique id)
endOfValidiy : close last iov
insertion time: versioning
object type: serialization
record: client software
time type (run/lumi, time, ...)
GLOBAL TAG MAP
global tag name
tag name

Figure 2: The data model for conditions data access management (see text).

A global tag is the top-level configuration of all conditions data. For a given payload type[4] and a given interval of validity[5], a global tag will resolve to one, and

[4]A payload type can be e.g. the muon detector alignment.
[5]A period of time for which a conditions data payload is considered valid.

only one, conditions data payload. The **Global Tag** resolves to a particular payload type **Tag** via the **Global Tag Map** table. A payload type **Tag** consists of many non-overlapping intervals of validity or entries in the **IOV** table. Finally, each entry in the **IOV** table maps to a payload via its unique hash key in the **Payload** table. A relational database is a good choice for this design.

The data model design has several key features. Firstly, conditions data payloads are uniquely identified by a hash which is the sole reference to any given conditions data payload. The payload data has been separated from the data access management metadata and can both in principle and in practice be placed in a separate storage system. This could also be important for data preservation, as the entire metadata component will occupy a trivial data volume and could exist in, e.g. an SQLite file, while the payload storage could be handled separately. Secondly, IOVs are resolved independently of payloads and are also cacheable. Efficient caching is a key design requirement for any conditions database access system that must support high rate data access.

3.6 A git-based approach

For workflows which are completely offline and asynchronous with respect to data-taking, a subset of the problems discussed previously, LHCb has adopted a different approach. Using git as the versioning system, conditions data payloads are placed in a directory structure, one directory for each payload type. A file is used to map timestamps to payload files, and a simple format is used to allow a level of indirection to improve performance. The file format allows a timestamp to point either directly to a payload file or to a directory, thus allowing partitioning of the lookup. Versioning is taken care of by creating a git tag, which is equivalent to a global tag, while the conditions data payloads are stored on CVMFS.

4 Future and roadmap

The conditions data access management model described here will be tested by Belle II in 2019 and by CMS and ATLAS in LHC Run 3. Assuming they work as expected, this will meet the conditions data access performance demands of HEP for the coming decade. Even at the HL-LHC [15], conditions data volumes are not expected to exceed a Terabyte per year and the rate of requests, determined by the computing resources of the experiments, are expected to peak at tens of kHz. Based on experience with similar conditions data access management systems, particularly the Run 2 CMS implementation, the outlook is positive.

Nevertheless there are concerns. The most important issue for experiments will be maintenance and operation in the face of evolving hardware and infrastructure and a dwindling number of conditions data management experts. These concerns provide even more motivation to consolidate the conditions data access model to a simple and modular design, such as that presented here. Going further, the logical next step of the collaborative, cross-experiment work started by members of this working group would ultimately result in an experiment-agnostic HEP conditions data service. The challenge for the community is realising that ambition.

5 Conclusion

Conditions data management is an important component of HEP software and one that has relatively few experts. While conditions data volumes are easily accommodated by several database technologies, conditions data access use cases can be demanding. In particular, it is critical that solutions support access rates at the level of tens of kHz.

Several experiments have converged on a common design for conditions data access management. A key feature is a high degree of separation between a relatively simple client and the server, a design that is well-suited to REST interfaces. Loosely-coupled industry standard components provide much of the robust software stack. An intermediate layer with caching capability is required to support kHz rates of read requests, and web-proxies have performed very well. Combined with a relational data model that isolates payloads from metadata, the design can support a wide variety of HEP workflows both now and in the coming decade. The main challenges the community faces will be finding resources for the maintenance and operation of this solution in the face of evolving hardware and infrastructure. Having achieved a common design, the solution to this problem may be the logical next step, a common HEP conditions data service.

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