Abstract.
The Persistency Framework consists of three software packages (CORAL, COOL and POOL) addressing the data access requirements of the LHC experiments in different areas. It is the result of the collaboration between the CERN IT Department and the three experiments (ATLAS, CMS and LHCb) that use this software to access their data. POOL is a hybrid technology store for C++ objects, metadata catalogs and collections. CORAL is a relational database abstraction layer with an SQL-free API. COOL provides specific software tools and components for the handling of conditions data. This paper reports on the status and outlook of the project and reviews in detail the usage of each package in the three experiments.
software developed by the Persistency Framework (PF), one of the four projects set up within the Application Area (AA) [1,2] of the LHC Computing Grid (LCG) to provide common software solutions for the LHC experiments, as originally defined in the LCG architecture blueprint [3].

The PF consists of three packages (CORAL, COOL and POOL) that address the data access requirements of the LHC experiments in different areas. POOL [4,5] is a generic hybrid store for C++ objects, metadata catalogs and collections, using streaming and relational technologies. CORAL [6,7] is a generic abstraction layer with an SQL-free API for accessing relational databases. COOL [8,9] provides specific software to handle the time variation and versioning of conditions data. All packages are written in C++, but Python bindings are also provided for CORAL and COOL. As shown in figure 1, all three packages are used directly by physics applications, but CORAL is also used internally by COOL and POOL to access relational databases (in fact, COOL and POOL include the design of specific tables and queries, unlike CORAL that allows users to design their own relational schemas).

![Figure 1. CORAL, COOL, POOL serve physics applications using lower level computing services.](image)

The PF software has been developed over several years (POOL since 2003, CORAL and COOL since 2004) through the well established collaboration of developers from the LHC experiments with a team in the CERN IT department, which has also ensured the overall project coordination. The PF also benefits from the close collaboration with other AA projects, especially ROOT (that provides the object streaming software for POOL and the Python binding software for COOL) and SPI (that provides and operates the build and test infrastructure for the software, described below). The development priorities to meet the requests of the LHC experiments are set with their representatives in the Architects Forum, where all AA projects are represented. The collaboration with the teams operating the relevant services, in particular the LCG distributed relational databases [10], has also been essential to ensure a better deployment of the PF software in a production environment [11].

The release process, which is well established, is slightly different in CMS (which performs its own builds using agreed tags) and in ATLAS and LHCb (which use the software libraries and binaries built and installed on shared disks by the SPI team). Regular production releases (the latest being the LCG60b configuration with CORAL 2.3.15, COOL 2.8.9a and POOL 2.9.13) are prepared whenever one of the experiments demands it, leading to one release per month on average [12]. This is generally motivated either by urgent bug fixes and functionality enhancements in the PF software, or by upgrades in the versions of the ‘external’ dependencies (ROOT, Boost, Python, Oracle...). These external versions vary quite frequently and may be different from those installed on a predefined O/S, as they must match those chosen by the experiments for their frameworks (Gaudi for LHCb, Athena for ATLAS and CMSSW for CMS), into which the PF packages are linked to build data-processing client applications. The software is supported on many production platforms on Linux, MacOSX and Windows, using one or more compilers on each O/S (e.g. gcc4.3 and icc11 on Linux SLC5). To
improve software quality and speed up the early adoption of new external versions, automatic builds and tests of CORAL, COOL and POOL are performed every night on all production platforms, as well as on a few test platforms using new compilers (such as gcc4.5 and llvm on Linux).

CORAL, COOL and POOL have been used in production by the LHC experiments since the first data-taking in 2008 (the following sections give details for each package, summarised in table 1). While the software is by now mature in its development cycle, the effort required for user support, service operation and software maintenance is still large (though expected to decrease with time, as the issues met during the LHC start-up phase are sorted out). User requests and service incidents normally result in bug fixes in the PF code, but often require a more global analysis involving other packages (such as Oracle, the Grid middleware or ROOT). In particular, while the PF only provides client components (with one notable exception, the CORAL server), understanding service operation issues often requires a detailed troubleshooting on the server side (typically, Oracle). Software maintenance includes the port to new externals and platforms, as well as internal tasks, like the recent consolidation of the CORAL and POOL test infrastructure. The development of new functionalities, due to explicit experiment requests, is also not over. Recent examples include the addition of a new ‘vector payload’ use case to the COOL relational schema and several enhancements in the POOL collections. Some R&D work is also in progress to evaluate new technologies relevant to data access optimization.

Table 1. Summary of CORAL, COOL and POOL usage in ATLAS, CMS and LHCb.

| Persistency Framework in the LHC experiments | ATLAS | CMS | LHCb |
|-----------------------------------------------|-------|-----|------|
| CORAL (Oracle, SQLite, XML authentication and lookup) | Conditions data (COOL) | Conditions data Geometry data (detector descr.) | Conditions data Conditions data (COOL) |
| CORAL + Frontier (Frontier/squid) | Conditions data (R/O access in Grid) | Conditions, Geometry, Trigger (R/O access in Grid, HLT, Tier0) | — |
| CORAL Server (Corrservlet, CorrservletProxy) | Conditions, Geometry, Trigger (R/O access in NLt) | — | — |
| CORAL + LFC (LFC authentication and lookup) | — | — | — |
| COOL | Conditions data | — | Conditions data (authentication/lookup in Grid) (only until 2010) |
| POOL (ROOT storage service) | — | — | Conditions data (payload) |
| POOL (collections) | Event data | Conditions, Geometry, Trigger | — |
| POOL (relational storage service) | — | — | Conditions data (payload) |

2. CORAL – the common abstraction layer for accessing relational databases
CORAL provides a set of libraries supporting data persistency for many relational database backends. Its API [6] consists of a set of SQL-free abstract C++ interfaces that isolate the user code from the specific implementation: users write the same code for all backends, as the SQL commands for each backend are executed by the relevant CORAL library, which is loaded at run-time by a special plugin infrastructure. As shown schematically in figure 2, direct remote access to Oracle servers and local access to SQLite files, the two main technologies supported by CORAL, are used by all of ATLAS, CMS and LHCb. The data stored in Oracle servers can also be read back by CORAL clients through a middle tier server and an optional data caching server in two ways: via the FroNTier/Squid web server/cache system [13], used since long in CMS [14] and recently adopted by ATLAS [15], or via the CORAL server/proxy technology, recently deployed in the ATLAS HLT as described in detail in
another contribution to this conference [7]. A plugin for accessing MySQL servers also exists, but this is no longer used in production by any LHC experiment after being dropped by ATLAS [7]. To address the challenges of the LCG distributed database environment, CORAL also provides components that allow the retrieval of user credentials and database replica metadata, from XML files (used by all experiments) or from an LFC server (used by LHCb until it was dropped in 2010).

CORAL has recently been and continues to be the most active of the PF sub-projects. To start with, this is the only package used by all three experiments (for conditions data, via COOL by ATLAS [16] and LHCb [17] and directly by CMS [18]; for event tags, via POOL by ATLAS [19]; for geometry and configuration data, directly by ATLAS [20, 21] and CMS [22, 23]). The support load is high also because of CORAL’s role as the gateway to relational databases. Issues reported in COOL and POOL must often be addressed in CORAL, which they use internally. Also, bugs in the underlying Oracle server software (such as one recently triggering an ORA-07445 error) often show up in CORAL-based applications. CORAL support also involves selecting and maintaining the appropriate Oracle client library version, and debugging complex OCI issues (as in the current priority, the improvement of CORAL automatic reconections to Oracle after a network glitch). Finally, this is the only PF package which required non-negligible effort to develop new components, the CORAL server and proxy [7].

Figure 2. Overview of the CORAL plugins and of their use in ATLAS, CMS and LHCb.

3. COOL – managing the time variation and versioning of conditions data
COOL [8] provides specific software components to handle the time variation and versioning of the conditions data of the LHC experiments. Each conditions data object is associated to its metadata (an interval of validity, a data item identifier and optionally a version) and its user defined data ‘payload’. The relational implementation of COOL, based on CORAL, fixes the relational schema of metadata tables and the SQL queries involved in payload lookup from metadata, whose optimization has been the project priority for many years [9]. COOL is the baseline conditions database implementation in ATLAS [16, 24] and LHCb [17, 25], where it is used to different degrees of complexity (payload is an XML string in LHCb, while it is a user-defined table row or an external object reference in ATLAS). Recently, COOL was also chosen as the conditions database of the Minerva [26] experiment at FNAL.
4. POOL – object persistency and collections using ROOT and relational databases

POOL is a generic hybrid store for C++ objects and object collections, using a mixture of streaming and relational technologies. The oldest PF package [4], now largely in maintenance mode, it consists of a large number of components that for simplicity have been split into three groups in table 1, according to the functionalities they provide and their usage in the experiments. The first group handles object streaming into ROOT files, one of the original motivations of the POOL and PF projects. It is used to store event data in ATLAS [27] and LHCb [25]; in ATLAS this is also used to store event collections [27], as well as conditions data payload whose metadata is in COOL [24]. This component often requires maintenance when a new ROOT version is released (as in the case for the recent ROOT I/O improvements [28]). A second group of components, dealing with object collections and their navigation, is now entirely developed and solely used by ATLAS [27], where it is the basis of the event ‘tags’ database [19]. POOL collections can be stored either in relational databases (using CORAL) or ROOT files. The final group deals with object streaming into relational databases [5]. This component, until recently maintained and solely used by CMS to store conditions data [18], is now no longer used, as CMS has reimplemented it (using CORAL) inside its software framework.

5. Conclusions

The Persistency Framework provides three packages (CORAL, COOL, POOL) that are essential ingredients in the data storage and access stack of the ATLAS, CMS and LHCb experiments at CERN and have been used for LHC data taking since 2008. While the software is by now mature in its development cycle, a large effort is still required for user support, service operation and maintenance tasks. A few new functionalities are also being developed, as requested by the experiments.

References

[1] P. Mato. CHEP 2006, Mumbai. Common application software for the LHC experiments (unpublished),
http://indico.cern.ch/contributionDisplay.py?contribId=258&confId=048
[2] A. Valassi. LCG-LHCC Referees Meeting (Feb. 2010). Applications Area status (unpublished),
http://indico.cern.ch/conferenceDisplay.py?confId=80461
[3] T. Wenaus et al. LHC Computing Grid Architecture Blueprint RTAG 2002. Final report,
http://lcgapp.cern.ch/project/blueprint/BlueprintReport-final.doc
[4] D. Duellmann, M. Frank, G. Govi, I. Papadopoulos and S. Roiser. Proc. CHEP 2003, La Jolla.
The POOL data storage, cache and conversion mechanism,
http://www.slac.stanford.edu/econf/C0303241/proc/papers/MOKT008.PDF
[5] G. Govi, R. Chytracek, D. Duellmann, I. Papadopoulos and Z. Xie. Proc. CHEP 2006, Mumbai.
POOL developments for object persistency into relational databases,
http://indico.cern.ch/contributionDisplay.py?contribId=330&sessionId=4&confId=048
[6] I. Papadopoulos, R. Chytracek, D. Duellmann, G. Govi, Y. Shapiro and Z. Xie. Proc. CHEP 2006, Mumbai.
CORAL, a software system for vendor-neutral access to relational databases,
http://indico.cern.ch/contributionDisplay.py?contribId=329&sessionId=4&confId=048
[7] A. Valassi, R. Bartoldus, A. Kalkhof, A. Salnikov and M. Wache. Proc. CHEP 2010, Taipei.
CORAL server and CORAL server proxy: scalable access to relational databases from CORAL applications,
http://cdsweb.cern.ch/record/1327671
[8] A. Valassi, S. A. Schmidt, M. Clemencic, D. Front and U. Moosbrugger. Proc. CHEP 2006, Mumbai.
COOL development and deployment: status and plans,
http://indico.cern.ch/contributionDisplay.py?contribId=337&sessionId=4&confId=048
[9] A. Valassi, R. Basset, M. Clemencic, G. Pucciani, S. A. Schmidt and M. Wache. Proc. NSS 2008, Dresden.
COOL, LCG conditions database for the LHC experiments,
http://cdsweb.cern.ch/record/1142723
[10] M. Girone. Proc. CHEP 2009, Prague. Distributed database services, a fundamental component of the WLCG service for the LHC experiments,
http://cdsweb.cern.ch/record/1177864
[11] R. Chytracek, D. Duellmann, G. Govi, I. Papadopoulos and A. Valassi. CNL 2006. Persistency Framework manages LCG databases,
http://cerncourier.com/cws/article/cnl/25825
[12] The LCG Persistency Framework project. Software release notes (unpublished),
https://twiki.cern.ch/twiki/bin/view/Persistency/PersistencyReleaseNotes

[13] D. Dykstra and L. Lueking. Proc. CHEP 2009, Prague. Greatly improved cache update times
for conditions data with FroNTier/Squid,
http://frontier.cern.ch/dist/Paper_CHEP09_Frontier-newcaching.pdf

[14] B. Blumenfeld, D. Dykstra, L. Lueking and E. Wiekklund. Proc. CHEP 2007, Victoria. CMS
conditions data access with FroNTier,
http://iopscience.iop.org/1742-6596/119/7/072007/pdf/jpconf8_119_072007.pdf

[15] D. A. Smith et al. CHEP 2010, Taipei. FroNTier use in ATLAS (unpublished),
http://cdsweb.cern.ch/record/1298655

[16] A. Vaniachine et al. Proc. CHEP 2009, Prague. Advanced technologies for scalable ATLAS
conditions data access on the Grid, http://iopscience.iop.org/1742-6596/219/4/042025

[17] M. Clemencic. Proc. CHEP 2007, Victoria. LHCb distributed conditions database,
http://iopscience.iop.org/1742-6596/119/7/072010

[18] G. Govi, V. Innocente and Z. Xie. Proc. CHEP 2009, Prague. CMS offline conditions
framework and services, http://iopscience.iop.org/1742-6596/219/4/042027

[19] F. Viegas et al. Proc. CHEP 2009, Prague. The ATLAS tags database distribution and
management> operational challenges of a multi terabyte distributed database,
http://iopscience.iop.org/1742-6596/219/7/072058

[20] V. Tsulaia, J. Boudreau, R. Hawking, A. Schaffer and A. Valassi. CHEP 2006, Mumbai.
Software solutions for a variable ATLAS detector description (unpublished),
http://indico.cern.ch/contributionDisplay.py?contribId=67&sessionId=3&confId=048

[21] A. dos Anjos et al. Proc. IEEE RTC 2007. The configuration system of the ATLAS trigger,
http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4448539

[22] M. De Gruttola et al. 2010 JINST 5 P04003. Persistent storage of non-event data in the CMS
databases, http://arxiv.org/abs/1001.1674

[23] L. Agostino et al. 2009 JINST 4 P10005. Commissioning of the CMS High Level Trigger,
http://arxiv.org/abs/0908.1065

[24] M. Borodin, P. Nevski and A. Vaniachine. Proc. CHEP 2010, Taipei. Scaling up ATLAS
database release technology for the LHC long run,
http://cdsweb.cern.ch/record/1322655/files/ATL-SOFT-PROC-2011-035.pdf

[25] LHCb Collaboration. LHCb Computing Technical Design Report (2005),
http://cdsweb.cern.ch/record/835156 what was this? POOL in lhcb

[26] H. Schellman. CHEP 2009, Prague. Offline computing for Minerva experiment (unpublished),
http://indico.cern.ch/contributionDisplay.py?contribId=497&sessionId=3&confId=5523

[27] P. van Gemmeren and D. Malon. Proc. IEEE Cluster 2010. Supporting high-performance I/O at
the petascale: the event data store for ATLAS at the LHC
http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5613100

[28] P. Canal. CHEP 2010, Taipei. ROOT I/O: the fast and the furious (unpublished),
http://indico2.twgrid.org/contributionDisplay.py?contribId=150&confId=3

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