Building, running and dismantling the world’s largest scientific instrument with the same database tools

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Abstract

Many people have heard of CERN, the European Organisation for Nuclear Research, and its enormous scientific masterpiece LEP, the Large Electron Positron collider. This is a 27-kilometer long particle accelerator designed to peek deeply inside the structure of matter in the framework of fundamental research. Despite the millions of Internet users, few of them know that the World Wide Web was invented at CERN in 1989, the same year that LEP was commissioned. Even fewer people know that CERN was among the first European organisations to have purchased the Oracle RDBMS back in 1983 and effectively put it in use for mission critical data management applications. Since that date, Oracle databases have been used extensively at CERN and in particular for technical and scientific data. This paper gives an overview of the use of Oracle throughout the lifecycle of CERN's flagship: the construction, exploitation and dismantling of LEP.
1 Introduction

The city of Geneva hosts many international organisations such as WHO (World Health Organisation), ICRC (International Committee of the Red Cross), ILO (International Labour Office). CERN was founded in 1954 with the mission to re-launch the activities of fundamental research in physics sponsored originally by 12 European countries. The driving force was – and still is – man’s fundamental question “what is matter?”. The tools to try and find the answer to this question are particle accelerators. In a particle accelerator elementary particles such as protons or electrons are accelerated to very high energies and smashed into one another. The outcome of these high-energy collisions are observed and analysed in huge particle detectors by physicists. Around the world 110 particle accelerators at national and international laboratories are dedicated to high-energy physics research. These number among some 15000 particle accelerators in the applied field such as industry (55%) and medicine (35%).

Today CERN counts 20 member countries, roughly 2900 employees and more than twice that number of visiting physicists from laboratories and universities all over the world. The technologies used are various and often pushed to the limits (superconductivity, ultra-high vacuum, powering systems, etc). The requirements for data transmission, storage and treatment are equally stringent. The invention of the World Wide Web at CERN with the http protocol can be considered a successful implementation of one of the requirements for data transmission and availability.

The largest particle accelerator LEP took over 5 years to build. This machine is hosted in a circular, underground tunnel, 27 kilometres in circumference. LEP made a major contribution to scientific history, starting operation in 1989 and enabling several major discoveries during its lifetime. At the end of the year 2000, LEP was closed down and a dismantling phase started in order to make place for a new, yet more powerful, accelerator LHC, the Large Hadron Collider, to be operational in 2006.

2 Oracle’s history at CERN

In 1981 the engineers and physicists participating in the LEP project realised that in building a machine of this size and complexity and, at the same time, respecting time and cost constraints, a significant amount of data would be collected and would need to be shared. This could only be handled with a database management system (DBMS). The software built to manage the data used for the previous large project, the construction of the Super Proton Synchrotron (SPS), a mere 9 kilometres in diameter, demonstrated the power of database management. This experience convinced CERN that for LEP a commercial DBMS should be necessary [ref. 1]. Another major constraint was that the development of any data management software would have to be carried out by the machine experts, who frequently had very little, if any, software development experience. The only software fulfilling CERN’s requirements was ORACLE from Relational Software Inc., which had been on the market since 1979 and had reached version 2.3, a version running on a VAX computer in PDP/11 compatibility node!

ORACLE version 3, the first portable database, became the first production system to be used at CERN. Within a few months several major applications had been started to manage project planning, cables and magnet construction. At that time desktop computing, as we know it today was in its infancy. ASCII terminals were used for data entry and only the most privileged staff managed to have a terminal on their desks. It is doubtful whether the database would have been such a popular tool if it had had to compete with desktop software such as spreadsheets. Version 3 was the first native VMS version of ORACLE, involving a radical re-write of the software with the foreseeable bugs. The database had to be rebooted three times a day to keep it running and CERN seriously started to look at alternative systems which were beginning to emerge on the market. Fortunately version 4 was a considerable improvement. A few months prior to the decision to use ORACLE for building LEP, the administration sector had installed a Codasyl DBMS. An experience leading to a radical decision a few years later to move the entire administrative database to Oracle, buying commercial Oracle-based application software whenever it matched requirements. Since that time Oracle became CERN’s supported database management system.

The physics community collected a vast amount of data from the detectors installed for experiments using the LEP facility. The volume of this data and the analysis requirements made Oracle unsuitable as a data repository. However the more static data describing the experimental installations did reside in an Oracle DBMS. A commercial engineering data management system (EDMS) which uses Oracle as its
repository has been introduced to manage documents and other engineering data. The growing enthusiasm for object technology among the physics community has challenged the relational database model, but has not seriously threatened its use.

3 Oracle for LEP construction

The main data management development activities during the early LEP construction were centred on project planning, cables installation, and equipment specification. The project planning requirements were ambitious, describing 40'000 activities, which had to be carefully followed through the construction period. Major problems were the limited access to the tunnel where the machine was being installed and the strict sequence of events to be followed if blockages were to be prevented. The data collected was used to identify worst-case scenarios, and hence to avoid them. Two databases for cables were developed, one for planning the laying of thousands of kilometres of cable selecting the best access path. The second managed the existing cables for the SPS machine. The two systems were eventually merged after the cable-laying was completed.

Different teams of experts were responsible for designing, building, testing and commissioning the different types of equipment for the machine. Much of the data collected during the construction period was also used during the commissioning of the machine and later for exploitation and maintenance. Major components were the bending magnets made up of a laminated, iron cores set in concrete. Iron provided by one firm was cut into laminated parts by another. Each batch of laminations was tested and the data recorded with the properties and origin of both the iron and laminations. This information was used to recombine the parts into the final magnets in an optimum way. The magnets were then calibrated and the resulting measurements used to control the magnet fields necessary to steer the particle beam round LEP. The equipment composition data also proved to be useful when it was discovered that a surface treatment on some, but not all, of the particle detectors was disturbing the quality of the particle beam. The location and constructor of these detectors was described in the database permitting a rapid correction to the problem.

In the 1980's an investigation into the contracted software developments concluded that a mere 5% of software developed was ever used. This was largely avoided at CERN since the machine experts specified and built their own data management applications. However, as the database requirements and technology advanced, so did the expertise necessary for software development. Today the scenario would be very different.

4 Oracle for LEP exploitation

The LEP complex is fully remotely controlled from a central control room through a network of computers addressing each individual component. With high-level software applications the state or settings of any component in LEP can be read or set. A vast amount of information concerning the components must be collected and then made available. Data management is essential to ensure that all LEP components functioned together and correctly. The behaviour of the particles travelling around the LEP ring more than 11000 turns per second has to be continuously monitored.
Seen from an operational point of view, five major areas of data can be identified: layout data, control data, measurement data, logging data and alarms data. Separate databases have been assigned to these different areas. A schematic overview of the links between the databases is given in Figure 1. All the software plus the database design and implementation are in-house developments. The commissioning phase of LEP took place in 1989. During this time all components are tested individually and then as a whole. Unfortunately not all the data necessary for commissioning had been entered into the database, and this hampered the operation of LEP between 1989 and 1991.

4.1 The machine blue-print

The layout database contains relatively static data describing the relative positions and dimensions of all the individual components that build up the LEP ring. These include the magnets and electrostatic devices required to “steer” the particles and the observation equipment to monitor the particles. Basically all information is numeric; important attributes are electric, magnetic and geometric parameters. This data needs only to be modified if the LEP components are physically moved or changed, which may happen during the yearly technical stops. Note that components such as the magnets used for particle steering can weigh several tons!

The layout database was in place several years before the real installation of LEP in order to be able to simulate particle behaviour. Accelerator theorists, the main users of this database, perform these numerical calculations. Once the layout database contains the exact information on the current version of the LEP ring, a subset of the data can be copied to the controls database. Versioning has been anticipated in order to be able to compare LEP layouts of different years.

4.2 Controlling LEP

Vacuum valves need to be opened, cooling circuits need to be switched on, magnet currents need to be set and high voltage equipment must be tweaked. In other words thousands of parameters must be controlled correctly and coherently. Information from the layout database, identifying each LEP component, completed with data from the upstream control infrastructure, allows the high-level software tools to address and control the components.

All control information, such as possible read or set actions on individual pieces of equipment, sets of components, or higher level objects, are stored in the controls database. Moreover the history of these actions over time are kept and can be re-applied, allowing the fine-tuning of LEP using a heuristic approach [ref. 2, 3].

The software, mainly Pro*C applications with graphical interfaces running on Unix platforms, picks up the necessary information dynamically making the software 100% data driven. Interpretation of the software actions on the specific equipment is handled by low-level software known as black boxes, which allow the high-level to communicate transparently with the diverse and often very complex equipment.
4.3 Solving Network bottleneck

Equipment cannot be controlled without having adequate feedback from measurements. This challenging problem must take into consideration the different rates, data structures and communication methods of the diagnostics equipment. The same information may be required by many users or systems simultaneously causing bottlenecks. A solution to this problem was to disable direct access to the equipment and to put the real-time data into an Oracle database, which more efficiently handles multiple requests for these measurements [ref. 4].

Besides measurements from the equipment hardware, other data, such as digital settings and readings, static and dynamic states, and measurements made on the packets of particles using monitoring equipment, are stored in the database as well. The central control room is one of the main users of this measurement information, which is continually refreshed on dedicated computer screens at rates up to 1 Hz.

Measurement data is generally overwritten, but can be archived in medium term history tables, if required. For this purpose Oracle triggers are used extensively; for example, the software trigger logic can use real-time data for complex calculations and put the results into the database.

4.4 Data logging

In 1992 the Logging Database was implemented in an attempt to understand LEP behaviour which gave rise to fluctuations in the quality of the performance. Many different contributing parameters were to be recorded and logged on a long-term basis. The logging Database would enable a user to find a correlation between apparently unrelated parameters. Huge data volumes were anticipated: a 10 Gbyte database with tables of over a million rows. At that time, such a set-up was considered as a very large database. The original configuration was an Oracle 6.0 instance on a dedicated SUN platform [ref. 5].

The major risk of the LEP logging project was that the end users would perceive this database as a black hole where a lot of data would go in but nothing would come out. Therefore considerable effort was devoted to executing a proper database design. The handling of large tables needed special care, especially since data correlation was the final goal. Pro*C application programs proved to be quite efficient for data retrieval. In a later stage graphical tools were developed to ease data visualisation [ref. 6].

A subset of the logging data was needed to determine more precisely the energy of the particles in LEP, essential information for the experimental physicists. Consequently the recording and preserving of this data was of vital importance. A special backup strategy was set up which included an archived log mode, disk mirroring and a weekly full database backup.

To satisfy end-user requirements all data is kept available on-line and not archived to tape as originally anticipated. The read-only tablespaces provided by Oracle 7 were used for this purpose. Even after the shutdown of LEP, the data will still need to be consulted for many years. For this purpose the database is preserved on a frozen Oracle 7.3.4 instance.

4.5 Handling alarms

In an extremely complex technical environment such as LEP, anything that can fail must be hooked up to a messaging system, so that it can report to the central control room whenever a problem occurs. The message may provoke an automated procedure otherwise the control room operator will take action based on the message information. The degree of importance of an alarm message can vary from an unused power converter current moving outside tolerance, to a fire alarm triggered by a smoke detector in the LEP tunnel. The alarm system is not restricted to LEP equipment, but covers the complete CERN complex [ref. 7].

The Alarms Database was designed to handle all this data and has been running since 1987. The system includes a hot spare database on a separate HP-UX platform. Part of the data is static, organised per system, sub-system and equipment with a number of attributes describing the alarm. The dynamic part is the capturing of the instantaneous alarm messages, which may include additional information from the alarm generating equipment.
5 Oracle for LEP dismantling

In November 2000, the LEP high-energy physics program was stopped definitely. A project had been approved to build a new super-conducting particle accelerator called LHC in the same underground tunnel. This would start with the dismantling of the LEP machine. Roughly thirty thousand tons of material will be moved out of the tunnel. Since LEP is classified as a nuclear installation in France, special procedures have to be followed in addition to the normal environmental and safety issues.

One major facet of the project is the "traceability" of everything that comes out of the LEP tunnel, despite the fact that only a very limited amount of material may be slightly radioactive. This implies that each piece of equipment must be identified and tracked from its origin through any temporary storage to its final destination. Special procedures have to be followed for disposal of all materials even if they are not radioactive at all.

A dedicated LEP Traceability Database was developed in order to identify uniquely some forty thousand objects that will be removed during the 18-months dismantling period. By means of printed barcode labels and barcode readers, the tracking information in space and time is recorded in the on-line traceability database. The surrounding software needs were analysed, modelled with UML and implemented using Java, C++ and PL/SQL. The majority of the barcode readers are equipped with real-time RF connectivity, giving them connection to the database, so that reading the barcode results immediately in an additional event in the history of the object [ref. 8].

The database was implemented on a terminal Oracle 7 release instance, but will be migrated to an Oracle8i Release 3 (8.1.7) version, as will most production databases at CERN.

6 Oracle’s future at CERN

The LHC will not be commissioned before 2006, but the work on LHC components started several years ago. Much data is being gathered such as field measurement data of super-conducting magnets. The LHC layout database containing the provisional layout is already in place and is heavily used by the theorists. CERN has acquired commercial software for document and asset management; both use Oracle as a data repository.

Controls and software projects are emerging in which the data management issues will not be overlooked. It is unlikely that commercial software will be able to fulfil all requirements for control and some in-house development will be required. Despite the increasing use of object oriented models, techniques and languages, there is no perceived need for a truly object oriented database. It is felt that the technical data fits perfectly in relational structures. Due to the accumulated experience, the use of Oracle is currently recommended for complex data management problems.

For the physics experiments future data taking rates are estimated to be in the Terabyte range and more. CERN hopes to benefit from future Oracle developments in object management. This decision rests with the physics collaborations, which use CERN’s facilities.

7 Conclusions

The Oracle RDBMS is being used at CERN for managing technical and scientific data for almost twenty years now. Not all software survives for such a long time. This is particularly true in the technological demanding context of CERN where the limits are always being pushed further. Oracle was selected in 1981 so that data could be shared and could be exploited easily. The success of LEP was in part due to these features. An enormous capital of experience and expertise with developing with Oracle has been gained at CERN. The nurturing of this expertise is essential if CERN is to succeed with challenging current and future projects. With many other research laboratories, CERN is not driven by business and although the WEB was a CERN invention, it was intended for communication and is not used for e-commerce. CERN can benefit from commercial software to manage much of its information, however developments using Oracle will continue to be necessary for data management in the field of particle accelerators.
8 References


