THE DESCRIPTION OF THE ATLAS DETECTOR

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Abstract

The ATLAS Detector consists of several major subsystems: an inner detector composed of pixels, micro-strip detectors and a transition radiation tracker; electromagnetic and hadronic calorimetry, and a muon spectrometer. Over the last year, these systems have been described in terms of a set of geometrical primitives known as GeoModel. Software components for detector description interpret structured data from a relational database and build from that a complete description of the detector. This description is now used in the GEANT-4 based simulation program and also for reconstruction. Detector-specific services that are not handled in a generic way (e.g strip pitches and calorimetric tower boundaries) are added as an additional layer which is synched to the raw geometry. The ATLAS geometry system in the last year has undergone extensive visual debugging, and experience with the new system has been gained not only though the data challenge but also through the combined test beam. This paper gives an overview of the ATLAS detector description and discusses operational experience with the system in the data challenges and combined test beam.

THE COMPONENTS OF THE ATLAS GEOMETRY MODEL

The software description of the ATLAS detector is based on a geometry kernel, called GeoModel, whose functionality and infrastructure is described in [1]. Using this package, one can build and visualize an in-memory geometry model, starting from a static set of primary numbers stored in a relational database. The kernel contains geometry primitives which can be assembled into a tree of nodes representing a tree of volumes. Transforms define the relative positioning of the volumes, and tags allow their fast identification. Moreover, the model provides access to runtime dependent quantities and describes detector misalignments and deformations. We refer to [1] for a discussion of the geometry kernel and describe in this section the storage of primary numbers in a relational database.

A relational database for detector description

The relational database holding primary numbers for detector description is an essential part of geometry versioning system, which was designed and implemented following the strong demand from ATLAS software and physics community. The database schema has two components:

- A data component consisting of data tables, each holding primary numbers for some specific piece of detector geometry.

- A Hierarchical Versioning System (HVS) component, developed in common with the LCG Conditions DB [2] and consisting of a few auxiliary tables, which logically organize data tables into a hierarchy of nodes. We distinguish two types of nodes: leaf nodes corresponding to data tables, and branch nodes used to group their children in order to build a hierarchy of versioned tables.

This structure allows to:

- Tag records in leaf nodes (data tables);

- Collect tags of child nodes into a tag of the mother branch node;

- Retrieve records from data tables by providing a tag of either the child node or any of its parent nodes;

- Add data and tags incrementally, without affecting existing tagged data.

Presently the CERN Oracle server is used as a central storage of ATLAS detector description database. It is foreseen to replicate this database to remote sites using again

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Oracle servers or MySQL databases, which also can run on laptops without network connections. This system, which is now becoming operational, replaces a prototype relational database [3], used effectively during Data Challenge 2 [4] (DC2) prior to the development of HVS.

Each subsystem of the ATLAS detector organizes its data within separate branches of a hierarchical versioning tree. Subsystem specialists administer their own data. Two mechanisms to load the data are supported: SQL scripts (mainly for bulk inserts and updates and leaf node tagging) and an interactive web interface, for various operations on both branch and leaf nodes as well as read-only browsing.

A dedicated service, running within ATLAS's analysis framework (ATHENA), provides an interface to versioned data. The retrieved data is presented to the application as a set of records, which can be considered as a snapshot of the data table: only those records corresponding to the requested tag are present in the set. Clients can then access the records either randomly or iteratively, and retrieve each attribute within the record by name.

The implementation of this service is based on the POOL Relational Access Layer, which provides a common interface to access data in different RDBMS (Relational Database Management System). The choice of a concrete RDBMS (Oracle or MySQL in our case) is made at run time by loading the corresponding plug-in.

THE IMPLEMENTATION OF THE ATLAS DETECTOR DESCRIPTION

The ATLAS detector is a large (about 40 m in length and 10 m in radius) and complex apparatus consisting of an inner detector, electromagnetic and hadronic calorimeters, a muon detector and four magnet systems, one of those, being a set of superconducting coils providing an air-core toroidal field, is interleaved with detector components. The beam pipe, some shielding materials and many support and service structures are relevant for a complete description and an accurate simulation of ATLAS. An overall view of the apparatus, based on the geometry model described here, is shown in Fig. 1.

The inner tracker is based on three different technologies: three layers of pixel detectors in a barrel-like arrangement around the interaction point, closed by two wheels in the forward region; eight silicon micro-strip detection layers both in the barrel and in the end-caps; stacks of straw tubes arranged axially in the barrel modules, 3 along the track path, and radially in the end-cap wheels, 18 longitudinally, constitute a transition radiation tracker. Electromagnetic calorimetry is performed with a sampling Lead/Liquid Argon detector, built in two half-barrel shells, and two coaxial wheels in each end-cap. The special feature of this device is the accordion shape of the absorber plates and of the kapton electrodes which ensure azimuthal hermeticity (see fig.2). Liquid Argon is also exploited as the sensitive medium for hadronic calorimetry in the end-cap, where copper planar disks are used as absorber, and in the forward calorimeter which consists of three consecutive disks per end-cap, where sensitive tubes, with an axial rod-shaped electrode, are embedded in a matrix of copper (innermost disk) or tungsten. In the barrel region, scintillating tile is used for hadronic calorimetry. The tile calorimeter consists of three barrel-like sections, with a three-fold radial segmentation, each composed of 64 modules in the azimuthal direction. Finally the muon spectrometer consists of three separate precision measurement stations, instrumented with monitored drift tubes (MDT) at $|\eta| < 2$, and of cathode strip chambers (CSC) in the forward region; three stations of fast and less precise muon detectors, both in the barrel (RPC) and in the end-caps (TGC), partecipate in the Level-1 trigger and provide a measurement of the second coordinate.

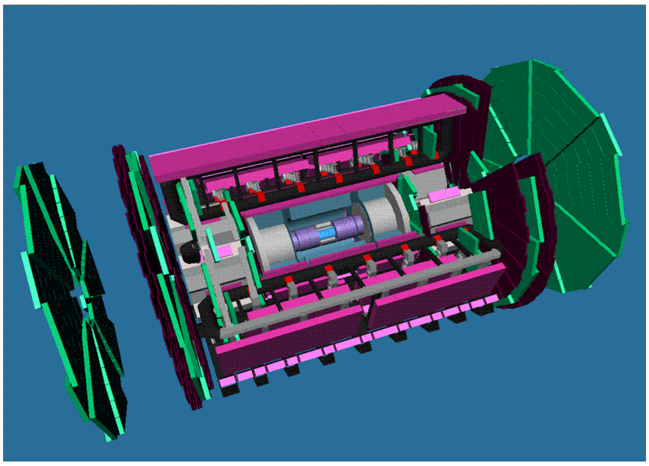

Figure 1: A complete view of the Atlas Detector

Each sub-detector is described, in the GeoModel implementation, as a separate tree of nodes belonging to a general mother volume, the *ATLAS experiment*. A Factory is responsible, for each system, to retrieve primary data from the database and build the sub-system tree-top volume, along with a Detector Manager providing access to any geometry information requested by clients. To give a somewhat detailed example, we'll describe here the Muon Spectrometer representation. The ATLAS Muon Spectrometer is a rather complex subsystem, since it consists of four different detection technologies. Moreover, due to various constraints coming from the toroidal arrangement of the magnets and from the support structures its design has a low level of symmetry. The logical hierarchy of the spectrometer is made of

- stations, each one associated with a $\eta \times \phi \times \mathrm{R}$ location;
- components, belonging to the stations, which can be *detector elements* or passive materials and detector internal components, depending on the specific technology;
- sub-structures belonging to the station components.

The layout of the Muon Spectrometer which has been simulated for DC2, called version P03, has 92 types of stations, differing in the internal construction, i.e. the sequence and type of constituent internal detectors. The total number of stations in layout P03 is 1744. The first layer of daughters of the Muon mother volume consists of 1744 Physical Volumes, defined with a shape and a material. The tree also holds tags for each node, for station identification, and an Alignable Transform in order to define and correct, frequently, the default position of the station using data from the optical alignment system. The components inside the stations represent a new level of volumes in the geometry tree, with their own associated transforms. Some of them, corresponding to sensitive components, are described in the model as Full Physical Volumes. These objects differ from simple Physical Volumes (as described in [1]) because they hold in cache their global transform and therefore they are well suited for detectors which will be often accessed by clients and requested for the position of detector channels belonging to them. Layout P03 requires, therefore, more than 4900 Full Physical Volumes, accounting for MDT, RPC, TGC and CSC together. The total number of components (detectors and passive materials together) is 9034. However, the architecture of the geometry kernel allows the re-use of objects in a tree, so that identical components can share the same Physical Volume and identical detectors can be represented by a clone copy of the same Full Physical Volume: cached transforms remain independent, but the rest of the volume representation, including its internal sub-structure, is shared. This memory saving mechanisms allows the second layer of the Muon Spectrometer tree to be described with only 433 different objects. Further levels of child-nodes are developed to describe in full details the internal structure of the detectors or of complex structures. MDT multi-layers, for example, require a large amount of memory since individual tubes, three cm in diameter, need to be described as sensitive detectors. In this case volume parametrization, discussed in [1] is applied in order to strongly reduce memory allocation. RPC, TGC and CSC have a typical internal structure consisting of a set of gas gaps (from 2 to 4), which correspond to the sensitive detectors, and layers of pick up strips, insulating materials, support panels, support frames. Note that parameterization in GeoModel does *not* imply that parameterization is applied in simulation. That behaviour can be switched on or off (usually off) at runtime.

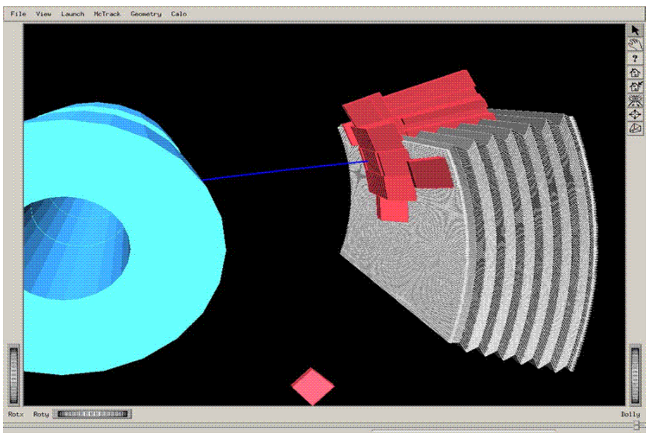

Figure 2: Clusters in the Liquid Argon electromagnetic calorimeter.

The Muon Detector Manager holds the reference to the Muon tree-top volume, a map of the Alignable Transforms in the tree and arrays of pointers to Muon Readout Elements. Muon Readout Elements, which are instantiated as technology specific objects, are associated to each detector component, MDT multilayer, RPC module, TGC station, CSC layer, and therefore each Full Physical Volume in the tree. They represent the Readout Geometry layer in the model, and their role is to provide the full geometry interface, both material geometry (via the transform of the associated Full Physical Volume), and data like strip size, wire pitch, and readout side, which are generally needed to reconstruct a position in space given a generic detector channel identifier. The Muon Manager, for layout P03, holds pointers to 2288 MDT Readout Elements, 1092 RPC Readout Elements, 64 CSC Readout Elements, 1584 TGC Readout Elements. When the Alignable Transform of a station is updated, the cache of all Detector Elements belonging to it is cleared and for any detector it will be recomputed when accessed again following a query to the corresponding Muon Readout Element.

Finally the three toroidal magnets, the ATLAS feet, the rails and many support structures falling inside the Muon Spectrometer volume, are described as daughters of the tree-top volume. The total memory allocated by the muon system is 10 MBytes. Compact systems, as the Liquid Argon Electromagnetic Calorimeter, are described with a very low amount of memory, on the order of hundreds of kilobytes. The Inner Detector system is described with 14 Mbytes. Finally, the whole Atlas detector requires 25 Mbytes in total.

A Geometry Model for simulation and reconstruction

The complete representation of the ATLAS detector obtained with the geometry toolkit can be fed to GEANT4 with a special tool, developed in order to translate the raw geometry, i.e. the volume tree (with relative transforms, materials and shape), into a GEANT4 representation. Memory optimization is preserved in the translation, as discussed in [1]. In DC2, the ATLAS simulation has been based on GEANT4 and the underlying geometry model described here [5]. The tags in the tree attached to volumes corresponding to sensitive detectors are used to associate a unique identifier to the detector and, as a consequence to the hits generated in such volume. Simulated hits are then stored as a sensitive detector identifier and a set of local coordinates in a local reference frame.

The digitization process uses specific data, held by the readout geometry, to determine a *channel identifier*, built out of the sensitive detector identifier and a few more integers, describing typically, strip, cell or wire number. The channel identifier, in addition to some detector specific data, like time or charge, represent the *digit* or *reconstruction input object* used directly from a reconstruction process. Clustering or tracking algorithms need to determine positions in space, with associated errors, querying the subdetector geometry manager for the Readout Elements of the identifiers of the digits in the data collection.

A unique geometry service is thus used in the whole processing chain, from simulation to reconstruction, enforcing coherence of the whole geometry description.

The Test Beam setup

The software description of the ATLAS detector discussed here has also been successfully used in a real setup, the combined test beam run of 2004 in the H8 beam line. The beam test setup follows rather closely the structure of a projective tower of ATLAS, from the pixel detector upstream of the setup, to three stations of barrel muon chambers, passing through production modules of the electromagnetic and tile calorimeters. End-cap muon chambers are placed downstream of the whole setup. Almost all data processing tasks use the geometry service described here [6]. Alignment corrections and environmental parameters are also available, in the test beam, via a relational database of run-dependent conditions. This exercises the model's ability to handle mis-alignments and represent deformations. Work is underway to exploit and implement the inherent features of the geometry model in the various subsystems. Some results of alignment correction have been already demonstrated in the Inner Detector software as discussed in [7]. The beam test setup represents an extremely valuable exercise and validation of the detector model which forced a clarification of many conventions and definitions. A simulation of the whole setup has also been developed with the same tools and methods as the full ATLAS simulation.

VALIDATION PROCEDURES

The first tool for a direct and extensive validation of the geometry is the visualization program, based on Open Inventor and its HepVis extensions, which allows users to browse the raw geometry tree, inspect the inner structure of any component, show the materials associated to volumes. A more complete check of the whole detector description requires additional checks of the readout geometry layer. A complete self-consistency test of the implementation of the ATLAS detector description has been set up and used to validate the geometry used for the Data Challenge 2. The procedure, usually referred to as *Hit relocation*, consists of the following steps:

1. production of simulated hits by tracking high energy particles through the detector. By disabling multiple scattering and all physical processes leading to the production of secondary particles along the track, one insures that the hits are located on the particle's true trajectory. The magnetic field is also switched off in order to obtain straight tracks;

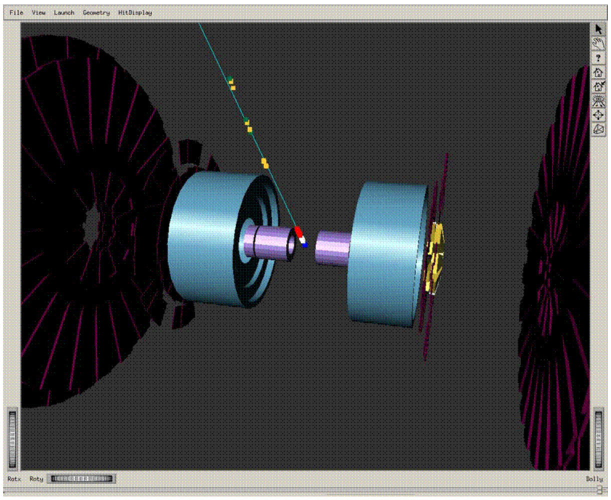

Figure 3: A visualization of hits *relocated* in the ATLAS global frame, along with the track producing them.

2. the geometry service is used to calculate the position of each hit in the global reference frame by selecting the appropriate readout element and converting the hit local coordinates into a position in the global reference frame by means of the detector element's absolute transform.

3. the distance between the reconstructed hit position in the global reference frame and the track from which the hits originate is calculated and histogrammed.

This procedure showed residuals of the order of femtometers.

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