Data analysis with R in an experimental physics environment

Andreas Pfeiffer and Maria Grazia Pia

Abstract—A software package has been developed to bridge the R analysis model with the conceptual analysis environment typical of radiation physics experiments. The new package has been used in the context of a project for the validation of simulation models, where it has demonstrated its capability to satisfy typical requirements pertinent to the problem domain.

I. INTRODUCTION

SOFTWARE tools for data analysis are widely used throughout the experimental life-cycle in particle and nuclear physics, astrophysics and bio-medical physics. Among the analysis tools in these experimental environments some common open source ones are GnuPlot [1], SciPy [2] [3], ROOT [4] and systems implementing AIDA (Abstract Interfaces for Data Analysis) [5] interfaces; commercial products such as MATLAB and Origin are also used.

The development described in this paper addresses the requirements of data analysis in typical experimental physics environment through the cooperation of two systems, which are characterized by different underlying conceptual models and provide complementary functionality: AIDA-compliant tools and R [6].

II. THE AIDA PROJECT

The AIDA project started in 1999 as a collaborative effort of several developers of analysis toolkits and frameworks who were aiming at providing a full set of abstract interfaces for this task.

In addition to static 1D, 2D and 3D Histograms with predefined binning, a “dynamic” version of these histograms was defined, where the data was stored “as is” for a given number of fill calls to the histogram and the binning would be defined “a posteriori” given on the content (and excluding outliers) - a first in the field at the time. More classical data types like Profile Histograms (also in their 1D, 2D and 3D incarnations), ntuples, and free-form “Data Points”, vectors of N-dimensional data with errors attached, are part of the definition of the AIDA data types as well. In order to be able to attach some meta-data to the data types, an “Annotation” type was defined, allowing to add statistics and summary type of information to the data object as well as “free form” information provided by the user, e.g. to provide tags or labels to the object, in the form of key/value pairs of strings. Other interfaces were defined to describe higher level objects used in typical data analysis environments like Fitter, Plotter, Analyzer (“filters on the ntuple”), generic Functions (used for example in the Fitter) and a set of interfaces to manage the objects.

All the interfaces were defined for the C++ [7], [8], Java [9] and Python [10] programming languages in order to not limit applications and users to only one language. The main aim was to have a modular, flexible and inter-operable system using dynamically loadable libraries for each component, allowing the user to pick and choose components according to his/her requirements. This was done using the Factory pattern for the creation of the various objects and using plug-in modules for the different implementations (e.g. for different storage formats).

In addition to defining these interfaces, an XML format was defined for data storage and interchange, so that the files written in this format by one application/component could be easily read by another one implementing this standard - adding to the flexibility of the system.

The modularity inherent in the design of the AIDA interfaces was the reason they were adopted in several large software projects like the Geant4 detector simulation software [11], [12] and the Gaudi framework [13], which is used in the Atlas and LHCb experiments at the Large Hadron Collider (LHC) at CERN, in several experiments at SLAC and in a number of other systems.

III. R AND ITS ANALYSIS MODEL

R is a language and an open source software environment for data analysis. It provides rich functionality for data management, statistical computation and graphics; R kernel is complemented by a large number of specialised add-on packages contributed by the community.

R operates on an ample variety of UNIX platforms, Windows and MacOS. For computationally-intensive tasks, C, C++ and Fortran code can be linked and called at run time.

R is used in a wide variety of multi-disciplinary applications; despite its widespread use in the academic environment, it is hardly known and marginally used in experimental environments such as particle and nuclear physics experiments, astrophysics research and bio-medical physics.

The use of R in these experimental environments is hindered by its underlying analysis model: a typical R analysis scenario assumes that the data are all available at once, while in typical experimental environments analysis tools encompass functionality to produce and accumulate data managed by analysis objects in the course of a cyclic execution: for instance, in the course of online data taking, of the generation of simulated events, of the reconstruction and further processing of detector raw data and of physics analysis.
IV. INTERFACING AIDA WITH R

Based on the well defined XML format for AIDA object storage, a module – named aidar – to read these files into R was developed [14].

This way, the user can exploit the huge power of R for analysis while using the flexibility of AIDA in the code to generate histograms or ntuples in the simulation or analysis of raw experimental data.

The aidar package exploits the existing XML package [15] in R to read in and parse the file and then identify the various objects in the file by their name and convert them into R’s data.frames.

A small collection of helper functions allow the user to extract general information on the content of the file, and to get and show annotations of selected objects.

At the time of writing this contribution to the conference proceedings aidar is available as a development version directly from the development repository. Distribution as a regular R package is foreseen in the near future.

V. EXPERIENCE OF USE

A set of tests of aidar has been performed in the context of a project for the validation of Geant4 Compton scattering simulation documented in these proceedings [16]. Histograms and ntuples associated with physics observables relevant to the validation process were produced in a typical Geant4 test environment, using the iAIDA concrete implementation of AIDA interfaces. The resulting analysis objects stored by iAIDA in XML format were imported into R by means of the aidar package. The subsequent data analysis has taken place entirely in the R environment; a sample of the results is documented in [16].

VI. CONCLUSION AND OUTLOOK

The aidar package has been developed to bridge the conceptual environment of production of data analysis objects in the course of processing a large number of events, typical of physics experiments, with the rich functionality of R. It has proven its capabilities in a real-life application environment, related to the validation of Geant4 simulation models.

The provision of the aidar package as a regular R package is planned in a short time scale. Further tests to evaluate its performance in typical experimental environments are foreseen.

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