Development Methodology of the Data Management System for the BM@N experiment

Методика разработки системы управления данными для эксперимента BM@N

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Methodology for developing the Data Management System (DMS) for BM@N, a fixed target experiment at the NICA (Nuclotron-based Ion Collider fAcility) project is presented. The Data Management System provides all the necessary tools for secure and efficient data transfer, file cataloging and replication of the experiment data. The goals of implementation of the DMS logging and monitoring services, integrity and consistency checks, user interfaces and authorization are described. One of the key points in the development methodology is focused on providing universal access to file replicas, as well as implementation of a file (or dataset) metadata service for the efficient search of data required for a specific processing or physics analysis.

Представлена методика разработки Системы Управления Данными (СУД) для BM@N, эксперимента с фиксированной мишенью проекта NICA (Nuclotron-based Ion Collider fAcility). Система управления данными предоставляет все необходимые инструменты для безопасной и эффективной передачи данных, каталогизации и репликации данных эксперимента. Описаны цели реализации сервисов логирования и мониторинга, проверок целостности и согласованности, пользовательских интерфейсов и авторизации. Одним из ключевых моментов методики разработки является обеспечение универсального доступа к репликам файлов, а также реализация сервиса метаданных файлов (или датасетов) для эффективной выборки данных, необходимых для конкретной обработки или физического анализа.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) project of the Joint Institute for Nuclear Research (JINR) in Dubna aims to study hot and dense QCD matter in heavy ion collisions. The rich heavy-ion physics program is defined for two experiments: BM@N (Baryonic Matter at Nuclotron) at beams extracted from the Nuclotron and MPD (Multi-Purpose Detector) at the NICA collider. BM@N is a fixed target experiment being the first one at the NICA facility. The experimental setup was installed in the fixed-target hall, where particle beams from the Nuclotron are extracted to perform the research program focused on the production of high-density baryonic matter in heavy-ion collisions at beam energies from 2 to 6 AGeV [1].

Such experiments require to collect a large amount of data, even though a number of events used for a particular physics analysis is only a fraction of all the collected events. In order to ensure secure and efficient data transfer, file cataloging and replication, it is necessary to develop a data management system (DMS). To improve the quality, efficiency, and predictability of its development, it is necessary to formulate a methodology for the implementation of the DMS for the BM@N experiment. This article

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presents the methodology formulated in the following sections, which can be wholly or partially applicable to the development of similar systems for other high-energy physics experiments.

1. ANALYZE THE SUBJECT AREA AND FORMULATE REQUIREMENTS FOR THE DATA MANAGEMENT SYSTEM BEING DEVELOPED

The first step in the development methodology is to perform a subject area analysis and formulate requirements for the data management system being developed. It is necessary to obtain a general understanding of the experiment and the data (datasets) it produces. There are a few key points that need to be clarified, such as what types of data are expected in the experiment and what are the key differences between them; what criteria are used to select data for analysis; what are the expected data volumes; what are the data reliability requirements, the planned number of replicas, and the replication policy; whether integration with computing systems of the experiment is necessary.

It is mandatory to find out which Storage Elements (SE) will be used to store data and what protocols (rules that define how data is accessed and transferred between the storage elements) they support. The Storage Element ensures a uniform interface to different type of storage resources. The SE provides the storage space to store files, interfaces, which can be used to access the files, a service to manage the available space and the lifetime of files, and a capability to queue and manage file transfers between the local SE and remote SEs [2].

The event data model of the BM@N experiment determines multistage data processing, which leads to three data formats of obtaining files: RAW, DIGI, DST. The Data Management System must provide selection of a set of data files for particular processing or physics analysis based on various criteria, such as the run number and time period, the beam and target particle, the beam energy, and so on. To ensure data reliability, it is proposed to employ at least two independent storage elements and to provide at least two replicas for each data file of the experiment.

2. PREPARE THE SOFTWARE INFRASTRUCTURE FOR THE DATA MANAGEMENT SYSTEM

2.1 Develop a unified user authentication and authorization service.

The primary goal of deploying an authentication and authorization service is to securely manage data access by ensuring that only verified users can interact with the system, and that their permissions to view, process, or manage specific datasets are precisely controlled based on their role and project affiliation. This safeguards sensitive experimental data, enables secure collaboration across a global research community, and ensures the integrity and traceability of all scientific work.

2.2 Create a virtual organization of the experiment using this user authentication and authorization service.

A VO is a set of users and real organizations that collectively provide resources they want to exploit for a common goal. Physical machines, services, applications, and datasets, just to name a few, can all be seen as resources. VOs achieve synergies by grouping users that share such an enlarged set of resources [3].

2.3 Register users of the virtual organization.

User registration can be either by invitation or initiated by the user. In either case, the user must first obtain a valid certificate and agree to the storage resource usage rules. If registration is initiated by the user, they must contact the VO manager.

2.4 Ensure delimitation of user rights within the data management system being developed.

Users can be divided into privilege groups based on permitted operations, access to various data, and the ability to administer the VO itself. When selecting a user group, adhere to the "least privileges" rule, granting the minimum possible set of privileges to perform the necessary functions.

3. DEVELOP A METADATA STRUCTURE FOR FILES AND THEIR SETS (DATASETS), AS WELL AS DATASET SELECTION SCENARIOS BASED ON POSSIBLE EXPERIMENTAL CRITERIA

3.1. Generate a set of file metadata and determine its types based on the specifics of the experiment.

Recalling the information collected during the analysis of the subject area, it is necessary to compile a list of metadata and selection scenarios according to which the data are selected. Metadata is essential for efficient data extraction for a particular processing. Knowing the general parameters of the specific experiment allows to quickly access the files that store its data. The proposed metadata for the BM@N experiment consist of run and period number, run type, start and end datetime stamp, beam and target particle, beam energy, field voltage, start and end event number which data are recorded, event count, file size.

3.2. Determine the presentation structure of file metadata and their sets.

The hierarchy and structure of metadata can vary depending on the requirements of the data unit being processed. This could be a file containing a collection of events, or entire datasets united by some common parameters.

3.3. Determine data selection scenarios in accordance with the proposed metadata.

The data selection query is a logical expression in terms of file and/or dataset metadata attributes. The file query returns a set of files, whereas the dataset query returns a set of datasets. The representation of metadata query results should be unambiguous and understandable to the user, free from irrelevant information, and easy to process. In the BM@N experiment REST API (application programming interface) has been implemented to process requests from users and experiment systems. Metadata lists are sent and received via JSON format. The query result for files that meet certain metadata criteria consists of their logical file names.

4. DEVELOP OR INTEGRATE AN EXISTING FILE CATALOG OF EXPERIMENTAL DATA AND DATASETS BASED ON THEM IN ACCORDANCE WITH THE SPECIFIED REQUIREMENTS

4.1 Develop or integrate an existing file catalog.

If an experiment plans to work with multiple replicas of a single file, it is needed to develop a service that provides unified access to them. This means having a single logical file name that can correspond to multiple physical copies of the file. The service's responsibilities include registering and storing records of files and replicas, as well as providing metadata management functions. Naturally, it is necessary to properly configure interaction with storage elements in accordance with the supported protocols.

4.2 Add experimental data storage elements to the catalog.

5. DEVELOP OR INTEGRATE A METADATA MANAGEMENT SERVICE WITHIN THE IMPLEMENTED FILE CATALOG, TAKING INTO ACCOUNT THE SPECIFIED REQUIREMENTS AND THE DEFINED PRESENTATION STRUCTURE

5.1 Develop or integrate a metadata management service within the implemented file catalog.

The metadata management service is a centralized catalog that provides a contextual index for the files and datasets, enabling efficient data discovery. It does not store the physics data itself, but the information about that data.

5.2 Add the generated list of metadata fields to the file catalog service in accordance with the developed structure.

6. DEVELOP OR INTEGRATE AN EXISTING EXPERIMENT DATA TRANSFER SERVICE FOR RELIABLE FILE TRANSFER TO USERS AND BETWEEN STORAGE ELEMENTS, SUPPORTING REQUIRED PROTOCOLS

The DMS API is used to execute basic operations on stored data of the experiment. However, bulk data operations require special mechanisms, so they can be performed asynchronously, without the user having to wait for the operation to complete in interactive mode. This service must also provide the ability to automatically retry data transfers in case of failure, transfer data between SEs using intermediate storage, and the ability to interact with multiple possible SE protocols.

7. DEVELOP SOFTWARE INTERFACES FOR WORKING WITH THE EXPERIMENT DATA MANAGEMENT SYSTEM

7.1 Develop application programming interfaces for interaction between other experiment software systems and users with the data management system.

In order for users or other software packages to interact with the DMS, it is necessary to develop an efficient, reliable, and standart-compilant software interfaces. In principle, API development best practices are essentially the same as those for general-purpose software. However, if a user not registered with the VO needs to access the DMS, an additional authentication service implementation is necessary. Currently, the BM@N implements two specific interfaces: the REST API and the C++ API. Both interfaces require authentication with the BM@N SSO (Single Sign-On) system. The C++ interface is required for interaction between the BmnRoot software package and the Data Management System.

7.2 Develop a graphical interface to simplify user interaction with the experiment data management system.

For instance, this might take the form of a web portal. Such a portal would not only enable the visualization of data from monitoring and logging services but also offer an alternative, user-friendly interface for accessing the data management system.

8. DEVELOP AUXILIARY SERVICES TO IMPROVE THE RELIABILITY AND EFFICIENCY OF WORKING WITH THE DATA MANAGEMENT SYSTEM

8.1 Implement a service for checking the integrity and consistency of the experiment file catalog and datasets.

Consistency verification, in this case, refers to the process of ensuring alignment between logical filenames and physical files present in the storage system. Discrepancies may arise, for instance, when a file is uploaded but not registered in the catalog, or when a catalog entry is removed while the corresponding file remains at the storage. Integrity verification, on the other hand, involves validating file hash sums to confirm that the contents of the files match the expected values and have not been altered or corrupted.

8.2 Implement a service for logging events and errors and for monitoring data management system operation.

Logging involves recording detailed, timestamped events (like errors or user actions) within an application or system, primarily for historical analysis and troubleshooting. Monitoring, on the other hand, involves continuously observing system metrics (like CPU usage or response times) to identify real-time issues and anomalies, often triggering alerts.

CONCLUSIONS

Thus, this article presents a methodology for developing a data management system for the BM@N experiment. The methodology takes into account the specifics of the experiment's data flows and requirements for data authentication and reliability. This methodology is currently being used to build a DMS for the BM@N experiment. Basic functions for data transfer, data retrieval based on required metadata, a REST API, and a C++ API have been implemented, and a file transfer service has been integrated. Integrity and consistency checks, logging and monitoring services, and a web interface are planned for the near future.

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