STAR Online Framework: from Metadata Collection to Event Analysis and System Control

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Abstract. In preparation for the new era of RHIC running (RHIC-II upgrades and possibly, the eRHIC era), the STAR experiment is expanding its modular Message Interface and Reliable Architecture framework (MIRA). MIRA allowed STAR to integrate meta-data collection, monitoring, and online QA components in a very agile and efficient manner using a messaging infrastructure approach. In this paper, we briefly summarize our past achievements, provide an overview of the recent development activities focused on messaging patterns and describe our experience with the complex event processor (CEP) recently integrated into the MIRA framework. CEP was used in the recent RHIC Run 14, which provided practical use cases. Finally, we present our requirements and expectations for the planned expansion of our systems, which will allow our framework to acquire features typically associated with Detector Control Systems. Special attention is given to aspects related to latency, scalability and interoperability within heterogeneous set of services, various data and meta-data acquisition components coexisting in STAR online domain.

1. STAR Online Meta-Data Collection Framework

The STAR experiment [1] started in 1999, with just one Time-Projection Chamber and a few trigger detectors, but today it is equipped of 18 subsystems. Initially, STAR Slow Control system had 40,000 control variables, now it is expanded to over 60,000 variables and this list is still growing due to the RHIC II upgrade, beam energy scan program, and possible upgrade to eRHIC in future. STAR had just 120 structures to migrate to the calibrations database at the early days of the experiment, and we now migrate over 3,000 structures annually. STAR's Data Acquisition – physics data taking component – was upgraded three times, adding one order of magnitude to the rates each time.

As every experiment has slightly different grouping of internal components, and varying operational meanings for those, let us define a common terminology first. In this paper we define the following cornerstones of "a" physics experiment's backend: Data Acquisition (DAQ), Detector Control System (DCS), Meta-data Archiver, and Alarm system. In this paper, DAQ is assumed to operate on physics signal only, with all accompanied meta-data being handled by DCS, operating on detector control data, and meta-data archiver, which records and stores detector conditions for the data taking period.

STAR's Messaging Interface and Reliable Architecture framework (MIRA [2]), was created as an attempt to improve meta-data archiver operations in 2010. It relies on an advanced message-queuing middleware, which provides the asynchronous, payload-agnostic messaging. We have selected AMQP [3] as a messaging middleware standard. It allowed us to design a loosely

coupled, modular framework architecture, resulting in a scalable service, suitable for a highly concurrent online environment.

During the deployment validation phase in 2010, just three subsystems used the MIRA framework. By 2014, all eighteen subsystems were completely integrated, with over sixty collector services deployed and continuously monitored by the framework. The total number of messages passing through the system reached three billion messages per year, with rates varying between one hundred and fifty messages per second to over two thousand messages per second. On average one message corresponds to structure of 24 variables, which gives a variable rate of three thousand to twenty five thousand channels readings processed per second. MIRA is using data compression technique to reduce archived record storage size. The overall disk usage is moderate: it progressed from thirty gigabytes (GB) to just over two hundred GB of recorded data per year. In addition to data archival feature, MIRA provides extensive data visualization capabilities. It allows detector experts to browse archived system state (variables) as structured hierarchical content, using user-friendly responsive web interface. Starting with around one hundred variables in 2010, MIRA was expanded to visualize 1,680 variables in 2014.

At its early stage of development, MIRA provided monitoring, storage and basic flow control over individual streams of data [4], covering for just the *Meta-Data Archiver* part of the fundamental building blocks. To allow further expansion, multi-stream real-time processing capabilities were requested and desirable. In the next paragraph, we describe the Complex Event Processing extension of the framework, implemented for Run 14.

2. Run 14 MIRA Extension: Complex Event Processing

While it is very convenient to have a framework which operates on individual data streams with automatic visualization and archival of the events, STAR experiment's needs required further development of MIRA to handle simultaneous multi-stream event processing. To accomplish this goal, we have integrated Complex Event Processor, bringing the possibility to merge streams, process them according to pre-assembled persistent queries, and produce output stream back to the system for processing via regular means. There are many open-source Event Processor toolkits, available at the market. We have settled on a WSO2 framework [5], opening the possibility for us to use the well-know Esper [6] and recently introduced Siddhi CEP engines interchangeably. Typical architecture of the CEP toolkit is presented at Fig. 1. It consists of a broker managing data format conversion, CEP processor instances handling event filtering, and a control component allowing to configure persistent queries for the processor. Complex Event Processor at STAR is configured to use existing AMQP topics and queues, provided by Apache *qpid* service [7] as input and output device, exactly in a way it was implemented for MIRA framework services.

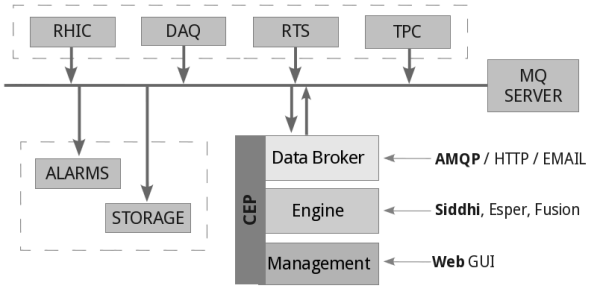

Figure 1. An overview of the Complex Event Processing components, attached to the messaging system: Broker, Engine and Management Console.

Let us describe a few practical use-cases, occurring in the STAR environment. The first example for CEP is to employ its stream processing power for a smart and flexible alarm system. In STAR, CEP provides the ability to reconfigure the existing alarm rules or add new sophisticated ones on the fly without stopping the existing monitoring services. This feature improves user experience and allows us to eliminate semi-permanent false or nuisance alarms (see Fig. 2). Second use-case is to perform CEP to detect anomalies in the detector conditions. By merging multiple streams and applying filters, which discard expected "normal" events, one

can get a stream of "abnormal" events, indicating hidden problems with various components or subsystems of the experiment. For example, we can find voltage fluctuations, happening during stable beam conditions, data-taking flag set to "on" and non-fluctuating collision rate. Fig. 3 illustrates such behavior. In general, CEP increases modularity of online services by doing "external" stream aggregation. Dedicated Event Processor lifts the burden of manual stream manipulation from clients, simplifying their data handling code. Also, it allows to do pre-testing of services attached to message-queuing broker, by feeding simulated data stream and validating the response to the incoming events well before the production deployment. Another use-case, which is expected to be implemented for Run 15 is to perform triggered data migration from the online to the offline domain. Having CEP trigger stream, which combines readiness and completion states of many processes, allows to decreased resource consumption by eliminating unnecessary online database polling.

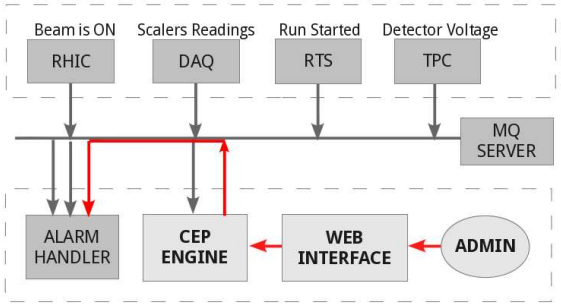

Figure 2. An overview of the Alarm handler use-case, describing the data flow and online configuration of persistent queries. Signals from many sources are combined to provide a clean and clear alarm one signal alone would not provide.

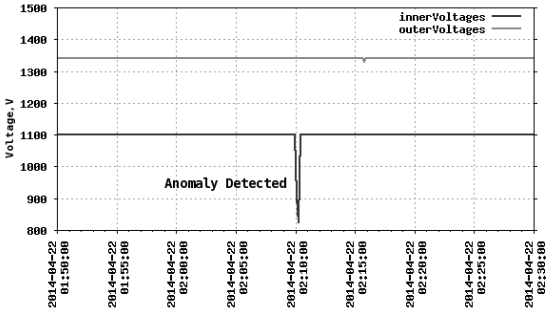

Figure 3. An example of the unexpected voltage drop, happening during data taking process, and registered by the event processing engine. Voltage drop is expected off physics running (and ramping up/down) but not during stable data taking (as in this example).

3. Framework Future: Control System Capabilities

The MIRA framework is still evolving. In the near future, we are planning to add features, commonly encountered in the Detector Control Systems domain: experiment workflow and hardware control. To implement MIRA's expansion to provide a *Detector Control* features, in addition to existing *Monitoring*, *Storage*, *Visualization* and *Alarms* capabilities, we have collected a list of requirements from our users and online software developers.

Requirements for the Detector Control system were collected during the initial preparation phase. We have identified the following key features: *Scalable Architecture*, *Low-overhead, Inter-operable, Messaging Protocol*, *Payload-agnostic Messaging*, *Quality of Service*, *Improved Finite State Machine*, *Real-time Remote Control*. Scalable Architecture is needed to accommodate for the growing number of detectors and channels. We expect STAR to double the number of channels in the next five years, hence, system scalability is our primary objective."A" low-overhead, inter-operable messaging protocol is desired to allow steady migration from wide variety of existing legacy hardware to the modern detector control equipment. It is very important to choose an easy-to-implement messaging protocol, as we need to support non-standard architectures from early days of the experiment. It implies that there are no publicly available, ready-to-use messaging libraries for this type of equipment. Payload-agnostic Messaging is needed to allow simultaneous handling of custom control protocols. The existing in-house developed protocols are predominantly text-based, and there is a strong

desire to use and test legacy and upgraded components in parallel during the transition phase. Eventually, all archaic protocols will be upgraded to use JSON notation (text) or MsgPack (binary JSON equivalent) data serialization formats. Quality of Service regulation – there is a clear need to provide different service levels for three distinct groups of clients: (a) sensors, which provide continuous stream of data, are tolerant to sporadic loss of messages, but require maximum throughput, (b) data storage backend services, which need "receive message at most once" mode of operations, to avoid data duplication (c) control services, which operate in "receive at least once" mode to ensure persistent control behavior. Improved Finite State Machine – our preliminary survey indicates that existing Finite State Machine (FSM) implementations are lacking features like state stack, complex state handling and sub-states. We plan to investigate the possibility of implementing hierarchical, stack-based FSM for the expanded MIRA.Real-time Remote Control – we plan to study the possibility of making soft real-time, low-latency Human-Machine Interface (HMI) using newest web technologies like WebSockets [8] from the HTML5 technology stack, in combination with the messaging libraries. Our goal is to provide a consistent interface for all client types from desktops to smartphones and tables. The development and transition to the fully upgraded MIRA is expected to happen in three years.

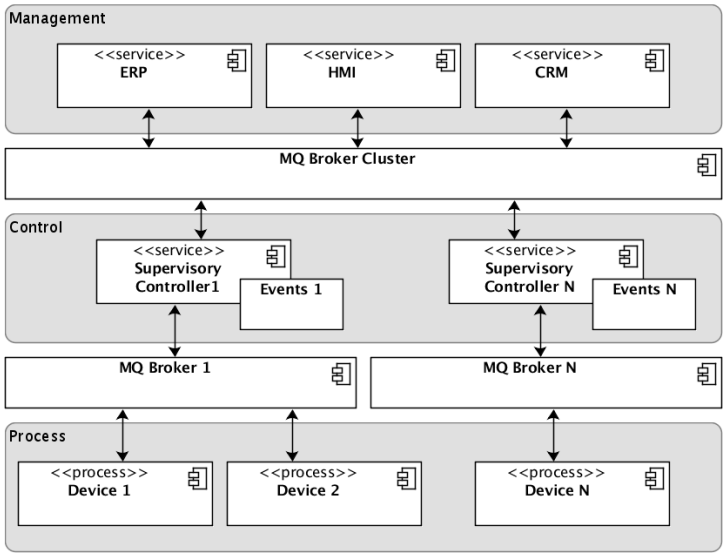

Figure 4. An overview of the preliminary version of tiered Control System architecture. Management, Control and Process tiers are communicating using messaging middleware services.

Important principle of our planned DCS implementation is the Observer Model methodology: clients are completely decoupled from data producers, any service attached to messaging broker may observe any process in the system. This allows us to embed rich monitoring, logging and reporting functionalities into the core of the framework. Also, we are going to implement this functionality as an extension of the MIRA framework, allowing us to reuse existing automatic archiving and visualization services.

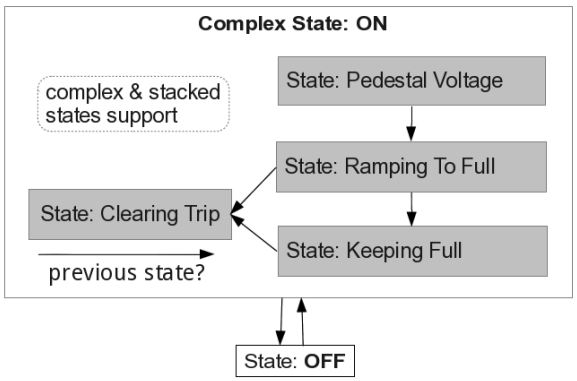

Figure 5. Illustration of the issue with the Finite State Machine having no stackable state support. Implementation of the exit state handlers using non-stackable state machine is possible, but is complicated compared to stack-enabled FSM.

The messaging part will be split into two distinct areas, corresponding to two distinct requirements: the *bottom layer* requires low-latency communications, while the *top layer* demands a rich transport protocol functionality and may not be satisfied by the same technology choice. We have selected MQTT protocol and AMQP protocol respectively. MQTT is a good choice for the sensor equipment due to its simplicity, while AMQP has larger overhead, but has a full stack of

features required for reliable queue management. For the engine core we are going to implement brokered, hierarchical, stack-based finite state machine. In our future studies, we plan to do a detailed review the open-source implementations of FSMs used in HEP/NP experiments, with the objective to provide an implementation capable of resolving multi-exit scenarios, including complex-state and sub-state support (Fig. 5). Our project is going to use MQTT protocol over WebSockets to implement Human-Machine Interface of the Control System. This allows to utilize single technology stack for local, remote and web clients. For the messaging middleware we have selected Apache Apollo, an open-source multi-protocol broker, written in Scala. This broker handles MQTT, AMQP and WebSocket connections, allowing us to reduce the maintenance to the single node, or a single cluster of brokers, removing the necessity to maintain several independent brokers.

4. Summary and Outlook

We presented an update on the status of MIRA, the STAR Meta-Data Collection Framework, and its recent achievements, current state and plans for near-term development and extensions. Message-Queuing services became an instrumental part of STAR online infrastructure. MIRA framework, featuring flexible, loosely coupled system of components, was very well accepted by STAR's collaborators and detector experts, covering the meta-data collection and monitoring needs of all eighteen STAR subsystems, which gradually moved to the new framework. MIRA provided STAR with a solution to handle the growing number of channels (x15), and data structures (x25), allowing smooth operation during Runs 10-14.

In 2014 we have extended MIRA with the stream-based Complex Event Processing capability, which successfully passed our tests. A few alarms implemented for Run 14 saved months of work for the core team and collaborators. More use-cases will be implemented for Run 15 and beyond, expanding the usage of CEP to automatic data migration handling and extensive error conditions detection.

In addition to the Complex Event Processing features, we extensively described our future plans for extending MIRA to enable Control System capabilities. Extended framework will benefit from multi-tiered, scalable architecture, improved Finite State Machine functionality and a real-time remote control interface.

Acknowledgments

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