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A GENERIC AND EFFICIENT AGGREGATION METHOD WITHIN NEUTRON SPECTROMETER DATA PROCESS FRAMEWORK BASED ON THE SYNCHRONOUS TRIGGER AND TAGGING SYSTEM

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Abstract

In the recent project of China Spallation Neutron Source (CSNS), a new designed distributed stream-processing framework is applied as the fundamental schema of data process system on user cooperative instruments. It is constructed with the open-source Apache Kafka software, which aims to aggregate the big data for manipulation sharing, and also with a synchronous trigger and tagging system, which provide synchronous ID for data correlation among different target hitting cycles. Correlated data could be identified among different measurements for aggregative analysis in a high efficient way, which greatly improve the performance of data processing. In concert with the real-time capability on stream-processing platform, WYSIWYG characteristics is achieved either. Performance and adaptability of this technique has been validated during the operation of constructed user cooperative instruments in CSNS. An increasing number of data-processing functions and experiment methods have got benefit from it.

INTRODUCTION

In the past few years, instruments on spallation neutron source have make a significant progress on beam luminance and detector technology [1-3]. Meanwhile the rise in data throughput and traditional data aggregation framework has become a new bottleneck for experiment [4-5]. Figure 1 shows a schematic view of traditional data aggregation, detector data and other measurement records are marked with a timestamp corresponding to the measuring time. Those records are saved as a file format via DAQ section, then sometime later each finished files are transported to the computing node to get analysis result. This procedure take a long chain and cost much delay on the file accumulating and transporting. Furthermore, experiments on neutron instrument usually take complementary data such as sample environment conditions, proton charge from accelerator and some meta data. Different data record associated to the identified target hitting cycle are correlated and must be synchronized correctly in aggregative analysis. For neutron experiment scientist expect to validate the physics status from data analysis in a "what you see is what you get" way. Considering the demand on WYSIWYG and low efficiency of traditional file transport framework in real-time capability, starting from the cooperative instruments of CSNS, the data process framework has been upgraded to a new designed framework "DSNI", which is constructed on the open-source streaming process platform Apache Kafka. As well as the read-time capability on streaming process platform, a synchronous trigger and tagging system is also introduced to proceed an efficient data correlation for aggregative analysis. With optimization and utilization on both hardware and software hierarchies, the DSNI framework is validated and applied to all user cooperative instruments in CSNS.

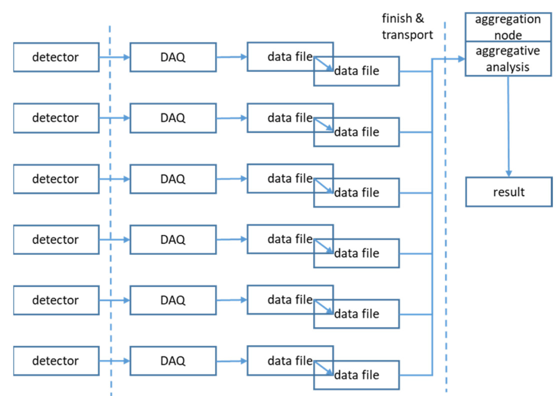

Figure 1: Traditional data aggregation framework on neutron instruments.

FRAMEWORK DESIGN

Overview

The conception of DSNI framework is to convert various measuring data into the streaming format with standard interface and then published on the distributed stream-processing platform for consumer sharing among various application. Meanwhile each streaming message are marked with a synchronous ID tag, which identify the trigger cycle number of data message corresponding to the measurement association. The distributed stream-processing platform provide many new features, e.g., scalability, fault tolerance, low latency and high performance. The most significant one is the real-time capability. On the other hand, data correlation and synchronization are simply referred to the consistent synchronous ID. With the assistance of advantages above, the later data manipulation could be setup on the unified interfaces and make aggregative analysis with efficiency.

Figure 2 shows a schematic view of DSNI framework developed on user cooperative instruments in CSNS. The synchronous and timing service consist of 2 subsystems.

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The synchronous trigger and tagging system provides hardware interface for synchronous trigger signal T0 as well as the associated encoding message pulseID, which could be adapted by most type of self-developed neutron detectors in CSNS. Meanwhile another WR timing system provides timestamp interface for exceptional measurement on general device. Different types of data record are converted into standard stream format by corresponding DAQ software and published to the stream-processing platform Kafka. DSNI managed to separate the data transportation and manipulation into 2 logical stages. The 1st stage is called as aggregation ring, which aggregate all data sources into the streaming platform and provide data manipulation exclusively for engineer perspective. While 2rd stage is called as analysis ring, data stream from 1st stage are selected and filter out with evaluated physics representation alone, so the data manipulation and control feeding could be managed in the physics perspective. Several template applications on data manipulation platform have provide common data analysing services, such as experiment status monitoring and selective data transport. Exclusive services could also be available by further development.

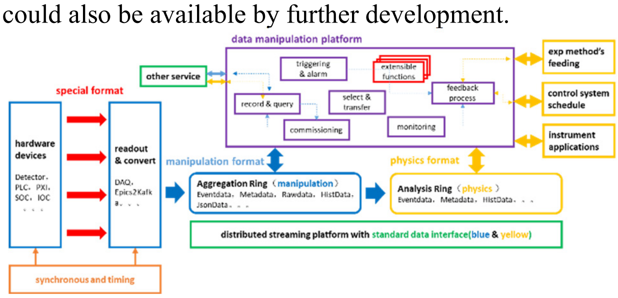

Figure 2: Schema of DSNI framework.

The Synchronous Trigger and Tagging System

The synchronous trigger and tagging system is the fundamental facility for synchronous measurement and correlated data identification [6], as shown in Fig. 3. For spallation neutron source, data correlation refers to the proton hitting the target during each neutron measurement. The time of proton hitting the target is called as T0. Synchronous trigger system generates a simultaneous signal at each identical T0 and fan out the signal to neutron instruments as a global trigger. With T0 signal all measurement during the experiment could be synchronized by triggering detectors and making a timestamp for each record. But only T0 signal and measurement timestamp is not effective for synchronous identification in the data analysis stage, since the data aggregation are performed in an asynchronous process and there is not a dedicated mark for synchronous identification in the record. DSNI upgrades the trigger system with a complementary tagging utility, which generates a numerical encoding message following each T0 event. Such numerical encoding message is called as pulseID. Figure 4 shows a schematic view of how T0 and pulseID proceed measurement synchronization via each interface. The self-developed detectors in CSNS have been adapted with both T0 and pulseID interfaces, so the readout data contain the dedicated pulseID record. Those dedicated pulseID record will be kept constantly during all later conversion and transportation, which could effectively process the synchronous identification in aggregative analysis.

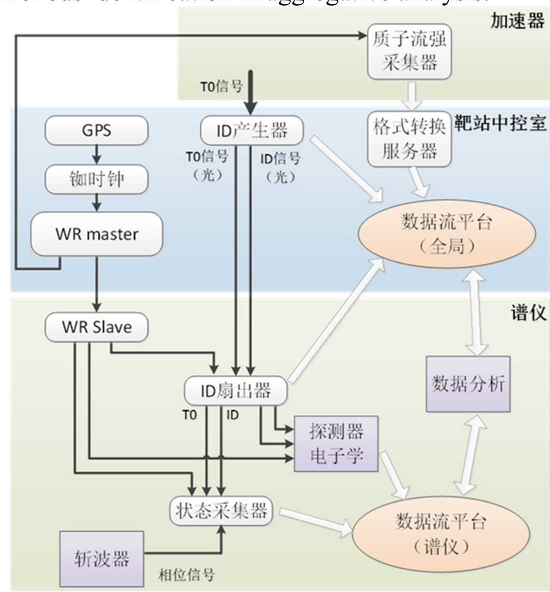

Figure 3: Schema of synchronous trigger and tagging system.

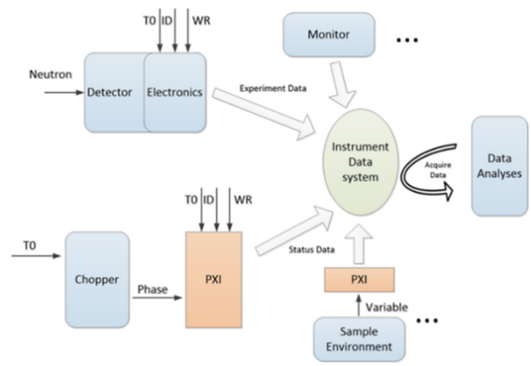

Figure 4: Schema of measurement synchronization on neutron instrument.

Conversion for EPICS Measurement

While the synchronous trigger and tagging system improves synchronous identification for aggregative analysis, there are still exceptional devices which do not adapt with T0 and pulesID interface. Measurements from EPICS devices record a timestamp for traditional synchronous identification instead, which process with low efficiency. DSNI provide a software application Epics2Kafka for handling those measurements, as shown in Fig. 5. When the record data are converted into the streaming format, Epics2kafka access another dedicated stream topic for T0 timestamp and pulseID pairing record. Referring to the T0 timestamp and pulseID pairing record, measurement timestamp could be mapped to an identical T0 and pulseID value, then the output streaming data will be construct with the dedicated tag.

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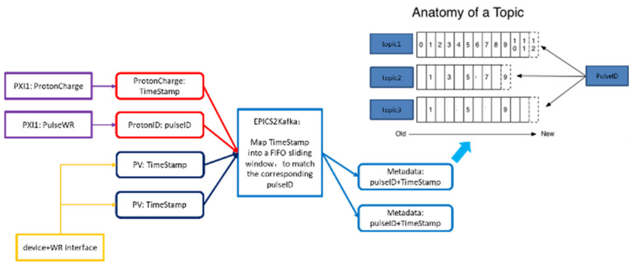

Figure 5: Schema of Epics2Kafka.

Aggregation on Data Manipulation Platform

Data manipulation base on processing template with the standard streaming data interface. Figure 6 shows a schematic view of the data processing template. DSNI has developed various standard streaming data interface for different kinds of data manipulation, e.g., EventData represent physical information of neutron measurement in position(represented by pixelID value) and time-of-flight parameter(represented by TOF value), while MetaData represent complementary measurement such as sample environment conditions via Epics2Kafka conversion. Each type of the standard streaming data interface refers to a pre-defined data structure which describe the representation of measurement record, while All types of the standard streaming data interface reserve a long integer field (64bit in size) for consistant pulseID record.

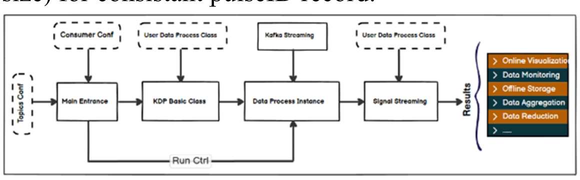

Figure 6: Schema of data processing template.

For aggregative analysis, different data stream are consumed in an asynchronous way via a multi-threading consumer group. The asynchronous consuming setting take advantage in efficiency and performance, while after the loading access, those asynchronous data record are filled into a sequential multi-entries buffer sorted by pulseID order. A sliding window is applied to verify and mark the aggregation range within which data are all loaded and synchronized. Then the aggregated ready records could be process via another multi-threading pool to organize various dedicated analysis. Figure 7 shows a schematic view of data aggregation from asynchronous consuming to synchronized processing.

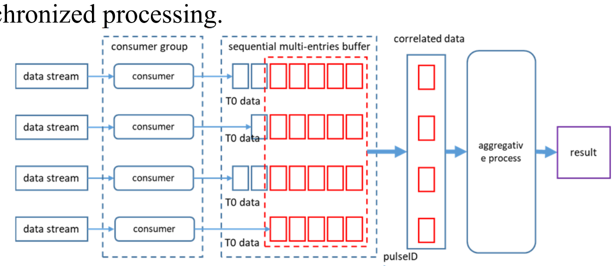

Figure 7: Schema of data aggregation on data manipulation platform.

Optimizations within Distributed Stream-Processing Platform

As a generic solution for traditional file transport framwork, many recently constructed neutron instruments have introduce the distributed stream-processing platform for decoupling [7]. DSNI is constructed with the open-source distributed stream-processing platform Kafka. Kafka provide high-performance, low-latency, scalable, and fault-tolerant features for the data process, and the most significant improvement is the real-time capability [8]. For neutron experiment scientist could make survey on the analysing result in a WYSIWYG style, which is very important for some dynamic measurement or massive scanning setup. Meanwhile there are also some shortcoming for Kafka platform on current storage architecture, e.g., the performance degradation under massive random IO access since the hard disk characteristic. Considering most massive random IO access comes from data consuming, DSNI managed to setup some utilities to avoid heavy degradation with high throughput, e.g., restriction on continual random offset access with a mandatory interval time, optimization from IO cache to system configuration. All these improvements help to mitigate the effects of massive random IO access under heavy throughput, so the measurement could keep running under higher stress without a data loss.

Furthermore, a location addressing algorithm for access data message with identical pulseID or timestamp value is also developed to reduce massive offset scanning. Figure 8 shows a schematic view of location addressing algorithm on single partition. A specific pulse trigger index and its storage offset in Kafka can be selected as a reference point. The storage offset of data corresponding to any pulse cycle (index) on the instrument can be calculated using the following relation:

$$x_i = x_0 + (t_n - t_0) * f = x_0 + (ID_n - ID_0),$$

where x is the Kafka storage offset, t is the neutron pulse trigger time, and ID is the index corresponding to the time. The algorithm estimate the destination offset by evaluating the delta range of current pulseID or timestamp to the specified one, then refers to forecasting offset for address verification and iteration.

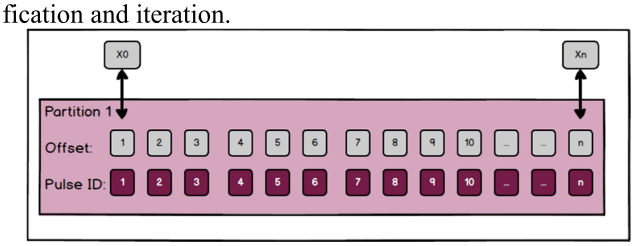

Figure 8: Schema of location addressing on single partition.

In cases where multiple partitions are configured for the data stream, the data volumes between partitions may not be strictly equal, making it difficult to precisely determine on which node in the Kafka cluster a particular event is stored. Figure 9 shows a schematic view of how location addressing algorithm deal with such situation. The algorithm first estimate the expected offset of the event and

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then introduce a buffer length to filter data from the pulses preceding the target event. The expected offset of the target event in each partition can be calculated using the following formula:

$$x_n^m = x_0 + \frac{(t_n - t_0) * f - L}{m} = x_0 + \frac{(ID_n - ID_0) - L}{m}.$$

Here m represents the number of partitions. If $x_n^m < 0$ all partitions of the data stream topic are read starting from the first record. The buffer length L needs to be optimized based on the pulse frequency f and the number of partitions m. For instance, with CSNS's current pulse frequency of 25 Hz and a configuration of 4 partitions, a buffer length of 1000 ensures the expected offset is before the target event. By applying event filtering, historical data retrieval can be successfully achieved.

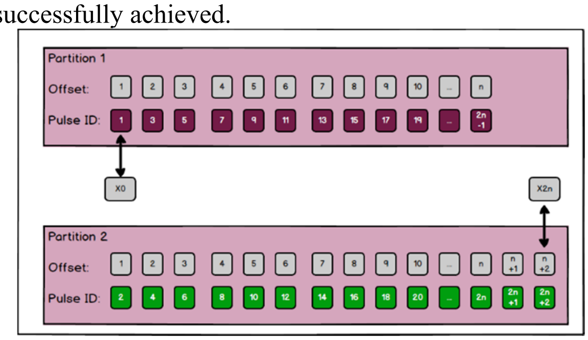

Figure 9: Schema of location addressing on duplicate partitions.

APPLICATION AND VALIDATION

As a brand-new designed framework for data process system, DSNI has been well developed and deployed on user cooperative instruments in CSNS. The common services running on data manipulation platform consist of total detector counting rate evaluation, TOF and pixel diagram filling on bank modules, streaming data validation on continuity and dynamic water level, etc. those application usually aggregate data from various streaming data sources to merge sub evaluations of each topic. During years of operation, those application are validated and show a real-time performance with WYSIWYG characteristic.

One of notable case for aggregative analysis comes from the frame-skipping operation, which has been applied and validated on several user cooperative instruments in CSNS. During frame-skipping operation the neutron instrument ramp down the chopper frequency in a division state to modulate a wider range of neutron energy within adjacent T0 cycles, while detectors are still referring to original 25 Hz T0 trigger signal with specified configuration for delay measuring, which match with the modulated neutron TOF range. Figure 10 shows a schematic view of aggregative compensation in frame-skipping operation. The detector record are merged from multi T0 cycles, referring to another streaming data of division pulseID record. TOF value from subsequent T0 period take compensation according to delay setting and pulseID sequence above. Figure 11 shows a TOF measurement result of frame-skipping operation during commissioning on testing facility BL20, identical distribution from 4 subsequent T0 period is validated, aggregation process present a real-time performance as well as WYSIWYG characteristic either.

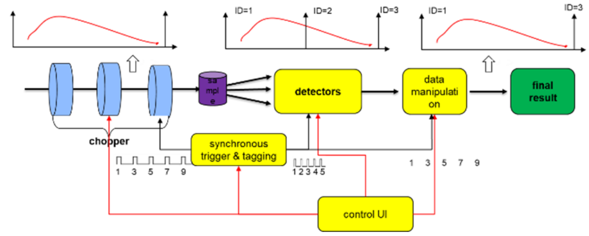

Figure 10: Schema of aggregative compensation in frame-skipping operation.

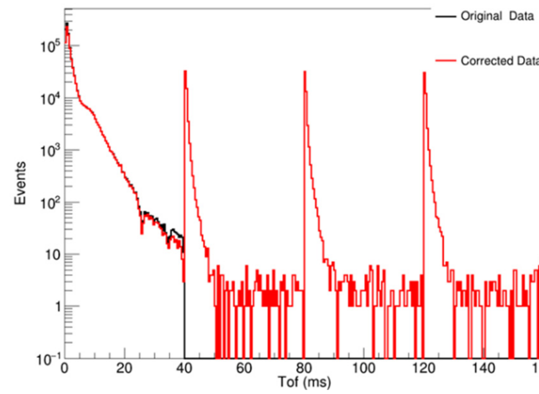

Figure 11: The TOF manipulate result of frame-skipping operation during commissioning on testing facility BL20. Peaks among subsequent T0 periods correspond to the fast neutron leakage from 25 Hz T0 chopper.

CONCLUSION

On the user cooperative instruments in CSNS, a generic and efficient aggregation method based on the synchronous trigger and tagging system is developed and validated within the new designed distributed stream-processing framework. Data correlation could be identified among different measurements with universality and efficiency, while data process in aggregative analysis could achieve great improvement in the real-time capability as well as with a WYSIWYG characteristics. Performance and adaptability of this technique has been validated during the operation of constructed user cooperative instruments in CSNS. Various type of experiment methods such as dynamic measurement and massive condition scanning will get benefit from it.

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