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EPICS 7 PROVIDES MAJOR ENHANCEMENTS TO THE EPICS TOOLKIT

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Abstract

The release of EPICS 7 marks a major enhancement to the EPICS [1] toolkit. EPICS 7 combines the proven functionality, reliability and capability of EPICS V3 with the powerful EPICS V4[2] extensions enabling high-performance network transfers of structured data. The code bases have been merged and reorganized. EPICS 7 provides a new platform for control system development, suitable for data acquisition and high-level services. This paper presents the current state of the EPICS 7 release, including the pvAccess network protocol, normative data types, and language bindings, along with descriptions of new client and service applications.

INTRODUCTION

EPICS 7 provides support for Data Acquisition, Experiment Control, and Data Analysis with new data representation and mechanisms in the protocol and data representation while preserving the robust, high performance, and easily extendible capabilities that are expected a control system. EPICS 7 is the merge of EPICS 3 and EPICS 4. The release includes both communication mechanisms running seamlessly, side by side. The new capabilities are provided by the EPICS 4 communication improvements in pvAccess and pvData, the next generation communication protocol and data representation. The new protocol provides structured data support and a remote procedure call (RPC). that support the integration of all data into microservices: including real time data from I/O Controllers (IOCs), processed data from data aggregation, and configuration data required for plant integration. The most significant improvement is that pvData provides the ability to define arbitrary data structures for more complex data sets and pvAccess is designed to transport those structures in the most efficient manner. The new EPICS 7 release enables the development of services on all real time, configuration, and aggregated data.

NO CHANGES REQUIRED TO USE EPICS 7

All the features of EPICS V3 work as is. The IOC process database, device support and drivers are used by both pvAccess/pvData and Channel Access/DBRTypes [3] seamlessly. Control System Studio (CS Studio) [4][5], Archive Appliance, run both pvAccess and Channel Access protocols. The IOC severs all data over both pvAccess and Channel Access. The pvAccess services provides the improved metadata for multidimensional arrays. All IOC data provides better support for time stamps and alarm information.

NEW FEATURES OF EPICS 7

The new capabilities overcome limitations of EPICS V3 that give EPICS users the ability to develop applications that can provide data through a network service and access data from any service on the control network. The communication mechanisms are provided to support a service oriented architecture for real time data, aggregation data, and configuration database backends. In conjunction with EPICS 7, services are available for real time data from the IOC and areaDetector, configuration data from a Directory Service and save set service (MASAR), and aggregated data from the Data Index Service. Complex control is supported with the new ability to communicate with devices (groups of PVs on an IOC) in an always-consistent, transaction type way. The new capabilities extend the scope of EPICS V3 from instrumentation and control (I&C) to data acquisition, image processing, data analysis, configuration management, data management and beyond.

STRUCTURED DATA

EPICS 7 can do everything EPICS V3 can do but better. It can construct pvData structures used in EPICS V3 as DBR types. For example, the equivalent of a DBR_TIME_DOUBLE would be the NTScalar structure in Figure 1. The improvements include:

```
NTScalar
        double value
        alarm_t alarm
                int severity
                int status
                string message
        time_t timestamp
                long secondsPastEpoch
                int nanoseconds
                int userTag
```

Figure 1: pvData equivalent of DBR_TIME_double.

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A user tag that could be used for pulse ID and a string message on the alarm state. The data representation and transportation work together to only send those parts of the structure that have changed. In Figure 2, the fields that have changed are in bold, and are all that is sent.

```
NTScalar
        double value                      8.1
        alarm_t alarm
                int severity              2
                int status                3
                string message            HIHI_ALARM
        time_t timeStamp
        long secondsPastEpoch             1460589145
        int nanoseconds                   588698520
        int userTag                       0
```

Figure 2: pvAccess send only changed fields.

The RPC type services can use structures that are different for every call and different for put (request) and get (response). The pvData representation can encode complex data types like the table pictured in Figure 3.

```
NTTable
  string[] labels              [value, seconds, nanoseconds, status, severity]
  structure value
    double[] value             [     1.1,        1.2,        2.0]
    long[] secondsPastEpoch    [1460589140, 1460589141, 1460589142]
    int[] nanoseconds          [ 164235768,  164235245,  164235256]
    int[] severity             [       0,          0,          1]
    int[] status               [       0,          0,          3]
```

Figure 3: A pvData representation of NTTable.

These new mechanisms enable developers to create Representational State Transfer (REST) style services.

STATUS OF EPICS 7

The Build System of EPICS 7, builds both EPICS 3 and pvAccess into the single EPICS 7 release. Both pvAccess and pvData run alongside of Channel Access and DBR_types, either can be used. New Normative Types (NT) are used to represent commonly used data structures to support the development of client applications. Some of the new NTypes include: Tables, N-Dimensional Arrays, Heterogeneous Arrays, and Statistical Samples. Services pvAccess provides improved metadata for the IOC Database. There are REST style services over pvAccess that connection to Relational DB and No SQL Database Services. There is a Gateway Alpha Release that demonstrates the ability to pass all Version 3 types as well as area detector data, Field Programmable Gate Array (FPGA) buffers, and tables through a shared connection into the control network, limiting the impact of clients connected outside of the control network. The new network and data representation layers can replace and in most cases, improve existing functionality with one exception, pvAccess Database Links. This is expected to be complete in (2018 Q2). An Access Security plugin is defined, but there is not an implementation in use now. New data aggregation libraries for the pvAccess library are designed and planned for Java Client API in (2018 Q2).

Data Aggregation is planned for the C++ Client AP but is not yet scheduled. The new capabilities provided in EPICS 7 enable the development of services for complex monitoring and control applications in the current release.

SERVICES

In EPICS V3, the primary service was the IOC. No other dynamic service is in widespread use in the EPICS collaboration. EPICS 7 provides the ability to develop services for real time, aggregated, or configuration data.

The IOC service works the same as always for all scalar values and their metadata. The new connection to the IOC database, QSRV, adds the axis information to the metadata for vector values, such as the value field of the Waveform Record. The data acquisition and image manipulation library, areaDetector, [6] now has a pvAccess plugin that serves area detector images and has been demonstrated to run through areaDetector, pvAccess server and client, to the CSS viewer. An Image size (1692*1352) at 33 Hz. [7] Figure 4 shows the image on the left through pvAccess and the image on the right through pvAccess.

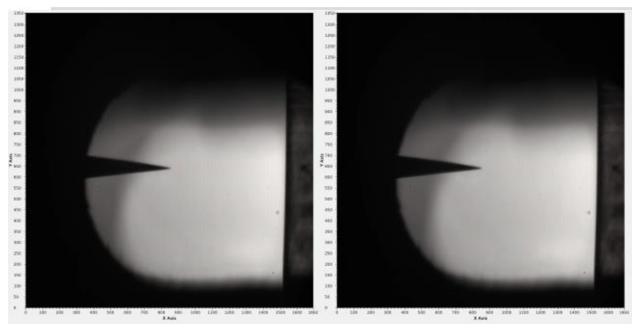

Figure 4: CSS display an image from V3 and pvAccess.

The server for pvAccess requires much less CPU time than Channel Access to serve the images of this size and this rate as it makes use of smart pointers throughout the pipeline. It also requires less CPU to display the images at this rate as the NTNDArray is very like the Vimage. The CPU load for these is shown in Figure 5.

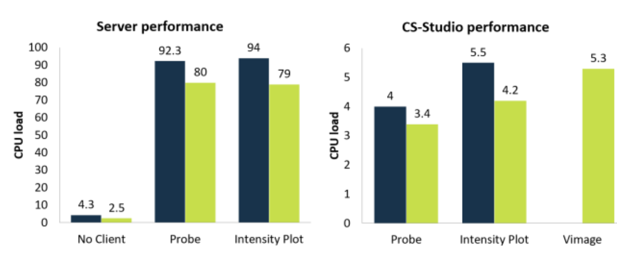

Figure 5: Server and CSS CPU usage.

The first pvAccess REST style service is the Directory Service. This service collects record name and property information and provides the data as a NTTable.

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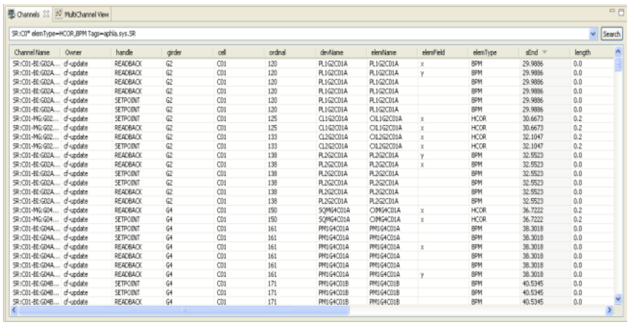
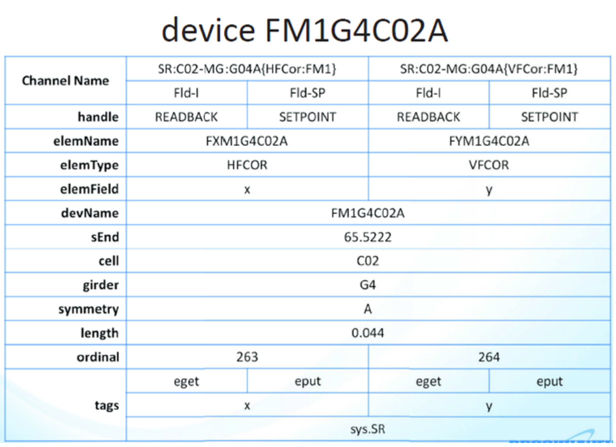


Figure 6: PV properties from ChannelFinder in CSS.

The data also includes runtime parameters such as IP address and connection status as shown in Figure 6. This service is used by physics application to map EPICS Process Variables (PVs) to physics device names. The physics view of the physics devices relates to how elements affect the beam at certain location in the beam transport. This was captured in a relationship view by Lingyun Yang at NSLS II and is shown in figure 7.

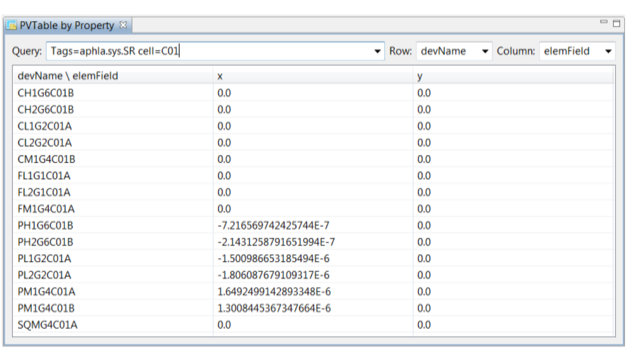


device FM1G4C02A

Channel Name	SR:C02-MG:G04A{HFCor:FM1}		SR:C02-MG:G04A{VFCor:FM1}	
	Fld-I	Fld-SP	Fld-I	Fld-SP
handle	READBACK	SETPOINT	READBACK	SETPOINT
elemName	FXM1G4C02A		FYM1G4C02A	
elemType	HFCOR		VFCOR	
elemField	x		y	
devName	FM1G4C02A			
sEnd	65.5222			
cell	C02			
girder	G4			
symmetry	A			
length	0.044			
ordinal	263		264	
tags	eget	eput	eget	eput
	x		y	
	sys.SR			

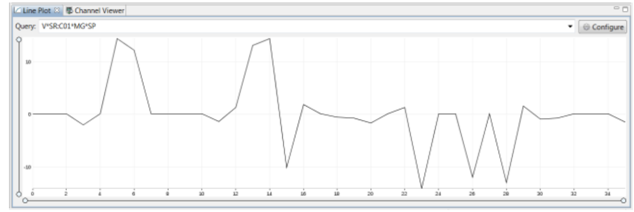
Figure 7: Corrector properties labelled on the left.

There are typically over 1 million PVs in a user facility such as NSLS II. As this is a service, CSS can also use the same query to access the correctors and display their value and readback to display them in a table widget. It can also be used to display all beam position monitors' x and y position as a table or an orbit as shown in Figures 8 and 9.



devName \ elemField	x	y
CH1G6C01B	0.0	0.0
CH2G6C01B	0.0	0.0
CL1G2C01A	0.0	0.0
CL2G2C01A	0.0	0.0
CM1G4C01B	0.0	0.0
FL1G1C01A	0.0	0.0
FL2G1C01A	0.0	0.0
FM1G4C01A	0.0	0.0
PH1G6C01B	-7.216569742425744E-7	0.0
PH2G6C01B	-2.1431258791651994E-7	0.0
PL1G2C01A	-1.500986653185494E-6	0.0
PL2G2C01A	-1.806087679109317E-6	0.0
PM1G4C01A	1.6492499142893348E-6	0.0
PM1G4C01B	1.3008445367347664E-6	0.0
SQMG4C01A	0.0	0.0

Figure 8: CSS uses directory service.



Figures 9: CSS uses directory service.

Any application can use this set of properties to create an ordered view with the order of the properties, such as geography or device, along with the value of a property such as the physical position along a trajectory such as the z axis of an accelerator beamline. CSS has a tool that allows users to create the hierarchical view using the tags and features in the Directory Service as shown in figure 10. The Directory Service has proven very versatile and useful in many other applications. Many of the physics applications that were developed by Dr. Yang at NSLS II, used this service and others as reported at the ICLAPECS 2013 [8].

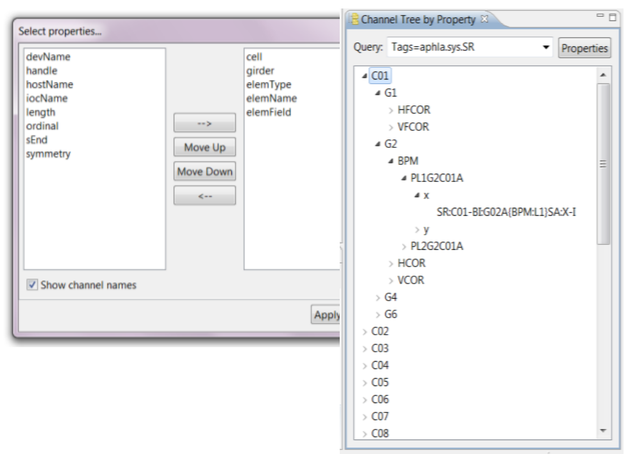


Figure 10: CSS orders properties in directory service.

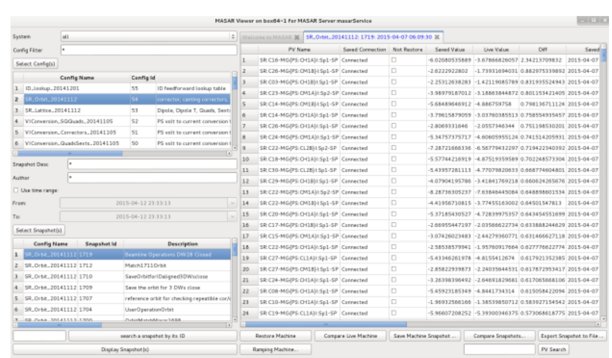


Figure 11: MASAR Uses Save Set Service

In addition to the Directory Service, the Save Set Service and Data Index Service have been developed to support physics applications. The Save Set Service manages snapshots of setpoints. The MASAR applications (one shown in Figure 11) use the Directory Service to build up Save Set configurations. They use the Save Set Service to store, retrieve, and annotate sets of data that are stored there. MASAR was one of the primary

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tools used for machine commissioning at NSLS II with over 1200 sets of setpoints stored as shown in Figure 12.

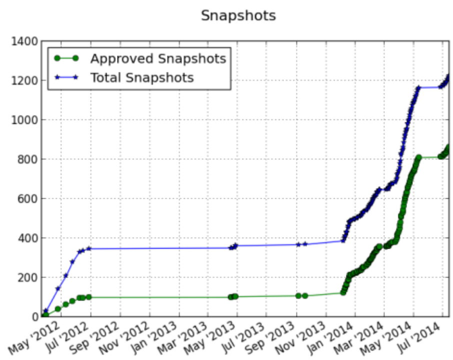

Figure 12: MASAR (Save/Restore) Use at NSLS II.

The Data Index Service, stores properties such as configuration data, user, comments, along with independent variables that are taken in real-time, that are used to locate a data set. This service uses Elastic Search to locate the proper data set in under 100 msecs given over 1 million data sets with over 120 dynamic values each. This service could be used to index Fast Machine Protection trip data, Beam Synchronous Acquisition data, or Detector Data from X-ray beamline experiments.

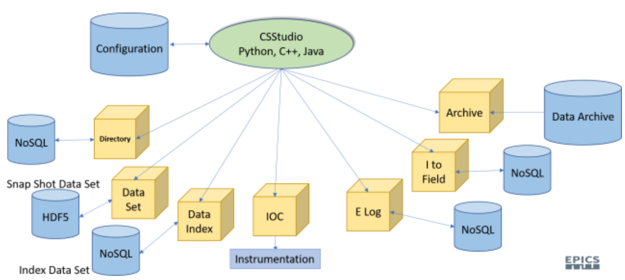

Figure 13: Service Use By CS-Studio

These are a few examples of services that have been developed. Other services are planned for Time Series Archived data, snapshot data managed as HDF5 or XML files, Electronic Log Book, and Data Aggregation Service such as hierarchical alarm views. EPICS 7 provides a way for facilities to develop applications that use a robust suite of services as illustrated in Figure 13. It also enables the developers to create new micro-services that can be shared by many applications at their facility. The EPICS 7 Architecture provides interconnectivity between services and applications that allow reuse of robust services.

CURRENT USE OF EPICS 7

EPICS 7 is being released 4th quarter of 2017. The sites listed here are making use of pvAccess and pvData from EPICS 4. These features will be seamlessly provided in the EPICS 7 release due out soon. ESS plans to deploy it for their entire facility. NSLS II, FRIB, and RAON have the Directory Service, Save Set Service and Data Index Service installed and running. The SNS experimental beam lines are upgrading to EPICS 7 and use the areaDetector service. LSLC I and LCLS II at SLAC are using the middle layer services for their physics environment. FHI has modified the Archive Appliance to save pvData structures. Diamond and NSLS II transmit areaDetector arrays between pvAccess servers and clients and attain 90% loading on a 10 Gbps link. As EPICS 7 will include pvAccess in the build system, these features will be readily available to any facility that downloads release.

FUTURE DIRECTION

EPICS 7 enables the development of services from real-time sources, aggregators, and static databases. A survey of the large applications that are built around a distributed control system give insight into the potential services that would be useful for facilities. For physics applications: Matlab Middle Layer Toolkit, XAL, and SDDS all share one common attribute, the large configuration that assigns physics names to EPICS PV names. Applications for experiment control such as, SPEC, Malcolm, BlueSky, and BluIce, all include data aggregation, file writing/retrieval, and mapping of variable names to detector and trajectories. Monitoring systems such as Nagios and Zabbix, point to the need to have new applications register and report availability of services and resources. Relational database applications like IRMIS and CCDB have been developed to map device instances to serial numbers and run time variables. These data stores can be integrated through the pvAccess protocol and their data transmitted by pvData arbitrary structure support (and most applications in Normative Types). Small, robust, high performance services can transform the way applications are written into small lightweight applications that use services that are proven at multiple facilities.

CONCLUSION

EPICS 7 provides mechanisms to make all data available as services. Data types used for generic services are provide as a set of normative types. These mechanisms and data types were used to integrate a set of services to integrate real time data, aggregated data, and configuration data. EPICS 7 is in use for physics applications and DAQ at multiple sites. The EPICS 7 release makes it possible for services to be developed by facilities throughout the community to provide an agile and high-performance environment for automation, data acquisition and data analysis.

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[7] Bruno Martins and Kunal Shroff reported at the areaDetector workshop, connected to ICLAPECS 2017. Information and links to the source code can be found at: `http://cars.uchicago.edu/software/epics/NDPluginPva.html`

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