RECENT ADVANCEMENTS AND DEPLOYMENTS OF EPICS VERSION 4

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Abstract

EPICS version 4 is a set of software modules that add to the base of the EPICS toolkit for advanced control systems. Version 4 adds the possibility of process variable values of structured data, an introspection interface for dynamic typing plus some standard types, high-performance streaming, and a new front-end processing database for managing complex data I/O. A synchronous RPC-style facility has also been added so that the EPICS environment supports service-oriented architecture. We introduce EPICS and the new features of version 4. Then we describe selected deployments, particularly for high-throughput experiment data transport, experiment data management, beam dynamics and infrastructure data.

EPICS BASE AND EPICS VERSION 4

The Experimental Physics and Industrial Control System (EPICS), is a software framework for high-performance distributed control and data acquisition in large scientific instruments, such as accelerators and telescopes.

The "base" of EPICS is software for supervisory control, closed loop control, archiving, alarm management, timing and other aspects of front-end processors and device facing hardware. Typically hosted in an embedded system processor such as RTEMS or VME, this software and its host are collectively known as the IOC (Input/Output Controller) in an EPICS control system. IOCs are optimized for low-latency I/O. They control and/or monitor a collection of devices such as actuators and measurement diagnostics. Each IOC node contains a memory resident real-time database.

The IOC database is a set of "smart" records, which are interconnected in a data flow pattern. They're smart in that their field values may come directly from hardware, or a result of processing that was dependent on the type of record. The records may contain "device support" code, to interface the processing to physical devices through device drivers. Much more information can be found on the EPICS base at [1, 2].

EPICS base and the software extensions built on top of it have proven very successful for the control aspects of scientific instruments, providing excellent low level I/O, DAQ and optimal control.

Figure 1: The basic architecture of EPICS version 4, showing the classic "base" components of EPICS in green, and components added by version 4 in blue. A new protocol, pvAccess, transports potentially complex data types encoded by pvData. pvAccess connects clients to IOCs, which may include a new database type, pvDatabase to support complex data processing services (and is the basis of the high-performance detector streaming applications described here), and to middleware services that can themselves connect to enterprise data stores, the web, etc. Note that hardware device I/O remains under the IOC database.

EPICS Version 4 for New Controls Problems

Modern control systems of large instruments call for more science to be done in the control system itself, than is possible with the EPICS base software alone. High output detectors call for pipelined data processing; physics applications deal with systems of process variables and their values rather than one process variable (PV) at a time; process variables may be structured, multi-modal, or require significant metadata associated with values in order to be understandable (such as images, or timing related metadata to give context when reviewing archives).
EPICS version 4 is a system of software modules that extend EPICS base to address these emerging requirements.

Core Modules of EPICS Version 4

Apart from EPICS base, the two core modules of EPICS version 4 are “pvData” and “pvAccess.” The pvData module is the high-performance structured data backbone of EPICS version 4. It provides an introspection interface for the dynamic creation and management of structured data types and arrays. Although types can be created on the fly, EPICS version 4 also defines a standard set of data types oriented towards scientific controls data (called “Normative Types” [3]). The types there defined include matrices, key-value sets, tables, histograms, continua, and images, among others both generic and application specific.

pvAccess is the network protocol of EPICS v4. Like the equivalent protocol in version 3, “Channel Access”, named endpoints (PVs) are discovered by broadcast, while data I/O is by TCP. In addition to the expected get, put, and put/get methods one would expect, pvAccess supplies a Remote Procedure Call (RPC) method, and a method to deal efficiently with exchanging only the changed elements of large arrays. Working in concert with pvData, the two include memory management and efficient encoding and deserialization, to minimise copy and wire transactions for even large complex data I/O. For example shows use of NTNamedValue to get and display the Courant-Snyder parameters of a quadrupole.

Figure 2: Examples of three normative types used with the new pvAccess command eget. The first shows an RPC request for the response matrix between two accelerator devices (sometimes called “rmat A to B”), in LCLS. The PV is “XCOR:IN20:491:RMAT”. An argument named “b” whose value is the name of the second device was also given. Since the returned data self identified as normative type NTMatrix, eget displayed the data appropriately. The second example is of eget being given the same request in URL form. In fact, in both the first and second examples, the server received its request in the form of the normative type NTURL. The last example shows use of NTNamedValue to get and display the Courant-Snyder parameters of a quadrupole.

$ eget -s XCOR:IN20:491:RMAT -a b BPMS:IN20:525 -0.57085 0.901274 0 0 0 0 1.333434 0.966896 0 0 0 0 0.358411 1.009578 0 0 0 0 1 0 0 0 0 0 1

$ eget pva://mccas0.slac.stanford.edu/XCOR:IN20:491:RMAT?b=BPMS:IN20:525

$ eget QUAD:1324;900:TWISS energy 5.0012 psix 37.7625 alphax 13.6562 betax -2.78671 etax -0.00698294 etapx 0.00107115 psy1 31.9488 alphay 116.7625 betay 5.2592 etay 0 etapx 0 z 2438.72

NEW DATA PROCESSING DATABASE

The pvAccess system is now codec based; the communication layer is decoupled from the transport layer, allowing alternative transport layer protocols such as one using zeroMQ. A codec for the former transport layer of pvAccess is provided.

Array handling has been greatly enhanced in the C++ implementations of the core modules. Reference counted shared vectors help minimize copy operations. Fixed and bounded arrays have been added in order to more easily facilitate high-performance array management. These complement the existing unbounded arrays. Stride length can be specified in put and get operations.

The Normative Types have been extended to include full dynamic typing (essentially an “Any” in the CORBA sense).

A plug-in architecture for implementing security schemes has been added, along with the plugin for Channel Access security.

The command line tools have been extended to better support time stamp, alarms, and correct display of enumerated types. All of the command line tools now support both pvAccess and Channel Access operations. A new tool, pvlist gives information about pvAccess servers on the network, including lists of the PVs they host.

Extensive API changes have been made to give greater flexibility for channel callbacks and converting from one introspection data type to another.
SELECTED DEPLOYMENTS

The primary uses of EPICS version 4 have so far been found to be in high-performance detector data fan out, and in middleware data services.

EPICS v4 is used at SNS in data acquisition and processing of neutron scattering experiments [4], see figure 3. Neutron scattering is a technique complementary to X-ray scattering used in the understanding of the structure and properties of materials. At SNS, detector image pixel data from an experiment is combined with meta-data such as probe pulse id and charge, into a pvData structure, which then fully describes an experiment observation event. The event data is then streamed by pvAccess to clients for processing and analysis. Clients may subscribe to the fields of the event structure of interest to them. The primary client – effectively an EPICS v4 plugin for areaDetector – includes statistical processing and publication of selected fields as histograms by Channel Access, for consumption by existing GUI tools.

Diamond and BNL have also developed an areaDetector pipeline based on EPICS version 4, and the BNL framework is being distributed with areaDetector [5, 6]. Figure 4 shows a CS-Studio image from an Eiger detector image processed with the BNL pipeline.

Both BNL and SNS have thoroughly investigated EPICS v4 network performance. Their findings are that pvAccess’ network efficiency is constant, well-behaved, and capable of delivering at or near 95% of the nominal maximum bit rate on 1 Gb/s or 10 Gb/s Ethernet, with no CPU saturation [4, 5].

BNL have also developed an interesting experimental beam-line data management system on EPICS version 4 [7]. The raw experiment data is dissociated from the metadata for storage and management, so that different and appropriate technologies can be used for the two different data categories. In particular, since the experiment data may itself be very differently structured from one experiment to the next, MongoDB is used for the store, and EPICS v4’s flexible data typing can be used for high-performance transport. One particular EPICS v4 service, the “databroker,” can interface to all experiment and metadata to provide a single interface to all.

FRIB and BNL have been using a PV configuration management tool named MASAR for some time. MASAR uses pvAccess to deliver sets of CA PV values to clients.

A collaboration of SLAC and ESS, are using EPICS version 4 for beam dynamics modelling services and device infrastructure data. Now EPICS (base and v4) provides all the data required for commissioning applications – both device PV values, plus optics, response matrices, device type lists etc. Services for beam synchronous data and mass archive data are planned.
CONCLUSIONS

EPICS can be easily integrated into an EPICS installation to supplement existing device support, DCS and SCADA. It effectively extends EPICS to support structured scientific data and complex processing. Early users have found it particularly useful for high-throughput detector data and for integration of beam dynamics and accelerator enterprise data, into the controls system.

THANKS

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REFERENCES


Figure 4: CS-Studio screenshots from NSLS-II, showing an EPICS V4 PV of the Normative Type for areaDetector images (NTNDArray) displayed using a CS-Studio “formula.” Thanks to Bruno Martins, BNL.