areaDetector Update:

EPICS V4 and More

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Outline

• Last TWG areaDetector talk was April 2016
  – Releases since then: R2-5, R2-6 (very soon)
• EPICS V4 driver and plugin
• Other new and improved drivers
• Other new and improved plugins
• ImageJ plugins
• Future plans
EPICS Version 4 in a Nutshell

- New Protocol, “pvAccess”
- Structured data
- Introspection interface, “pvData”
- Dynamic typing
- Streaming
- Standard Scientific Types
- RPC and put/get
- New smart database
- Codec based transport
- All APIs in C++ and Java
- Python and Matlab
- High Performance
- High Reliability

$ eget -s XCOR:LI24:900:TWISS
non-normative type
structure
double energy 5.00512
double psix 37.7625
double alphax 13.6562
double betax -2.78671
double etax -0.00698294
double etaxp 0.00107115
double psiy 31.9488
double alphay 116.762
double betay 5.2592
double etay 0
double etayp 0

Figure: Example EPICS v4 pvAccess method “eget”, getting PV whose value is a structure giving the Courant-Snyder parameters at a corrector magnet. This example is from the LCLS control system at SLAC.
The EPICS V4 “Normative Types”

The Normative Types Spec defines a standard for commonly used data types, [http://epics-pvdata.sourceforge.net/alpha/normativeTypes/normativeTypes.html](http://epics-pvdata.sourceforge.net/alpha/normativeTypes/normativeTypes.html)

$ eget -s XCOR:LI24:900:RMAT
0.0727485 0.0289316 0 0 0.0652488 0.00125391
0.0578214 0.0391775 0 0 -0.027185 -0.000192344
0 0 0.00943029 1.14291 0 0
0 0 -0.0013367 -0.0348832 0 0
-0.000370971 -0.000283933 0 0 -0.0182387 -0.000198345
0.10031 0.018722 0 0 -10.5721 -0.179568

$ eget pva://mccas0.slac.stanford.edu:39633/QUAD:LTU1:880:RMAT?type=design

$ eget -s LCLS:ELEMENTS

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>ELEMENT_TYPE</th>
<th>EPICS_DEVICE_NAME</th>
<th>S_DISPLAY</th>
<th>OBSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATHODE</td>
<td>MAD</td>
<td>CATH:IN20:111</td>
<td>2014.7</td>
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<td>MAD</td>
<td>XCOR:IN20:121</td>
<td>2014.9</td>
<td>N</td>
</tr>
</tbody>
</table>

Figure: An extract of the Table of Contents of the Normative Types Specification document, together with examples of 4 selected types
What does an EPICS V4 PV for structured data look like?

The pvAccess PV name
EPICS V4 data type identifier “NTNDArray”

The image raw data

The image meta data; giving how to interpret the data in the value field, and other information.

Figure: A screenshot of the output of the EPICS V4 “pvget” command, showing data of a PV which encapsulates all the data of an areaDetector NDArray in Normative Type NTNDArray. Example from B. Martin’s AD work at BNL.
EPICS Version 3 basic block diagram

EPICS in the nominal usage: An EPICS client communicates over Channel Access (CA) protocol to an Input/Output Controller (IOC) Channel Access server (module rSrv in an IOC)

- Channel Access Client
- Channel Access (CA) protocol
- Input / Output Controller (IOC)
- CA Server (rSrv)
- IOC database
- Device I/O
EPICS Version 4 is an extension of V3

V4 IOC == V3 IOC + pvAccess Server

Use Case: Network efficient acquisition of archived meta data

Presently, only 1 PV per pvAccess channel. But plan is to get/monitor a group of PVs through one pvAccess channel.
EPICS Version 4 includes CA

The pvAccess API includes Channel Access support, so one client lib does both

Diagram:
- Channel Access Client
- pvAccess Client
- IOC database
- Device I/O
- rSrv
- pvaSrv
- pvAccess
- CA
A new smart database, “pvDatabase” can be used for data assembly and processing.

Examples; the SNS and NSLS-II beamline experiment high performance data acquisition and processing.

Device drivers etc stay only under IOC database.
EPICS Version 4 middleware support

RPC and Service Oriented Architecture (SOA)

Channel Access Client

CA

IOC

rSrv

pvaSrv

IOC database

Device I/O

pvAccess Client

CA

pvAccess

pvAccess Server

BYO back-end datasource

Examples: the SLAC/ESS model and infrastructure system; BNL/FRIB configurations; and NSLS-II experiment data support

pvDatabase
New plugin that converts NDArrays into the EPICSv4 normative type NTNDArray

An embedded EPICSv4 server serves the new NTNDArray structure as an EPICSv4 PV

High performance, ~3.2GB/s shown here

Can be received by any EPICSv4 client
- Java, Python, C++ versions of pvAccess
- CSS has a widget that can display NTNDArrays
- caQtDM has a new camera widget to display NTNDArrays
- Tim Madden is writing a version of the Java areaDetector ImageJ plugin based on pvAccess; will talk to this plugin
- Can include an NTNDArray receiver in another IOC
pvAccess Driver

- New pvAccess driver receives NTNDArrays over the network, converts to NDArrays and calls plugins
- Can be used to run areaDetector IOC and plugins on another machine or in another process
- High performance:
  - ~1.2 GB/s shown here with interprocess communication
  - Saturating 10 Gb Ethernet links has been demonstrated
pvAccess: Command Line Tools

>pvinfo 13SIM1:Pva1:Image
CHANNEL : 13SIM1:Pva1:Image
STATE : CONNECTED
ADDRESS : 164.54.160.82:5075
epics:nt/NTNDArray:1.0
  union value
    boolean[] booleanValue
    byte[] byteValue
    short[] shortValue
    int[] intValue
...
  uint[] uintValue
  ulong[] ulongValue
  float[] floatValue
  double[] doubleValue
...
  int uniqueId
  time_t dataTimeStamp
    long secondsPastEpoch
    int nanoseconds
    int userTag
...

>pvget 13SIM1:Pva1:Image -r
'field(uniqueId,dimension)'
13SIM1:Pva1:Image
structure
  int uniqueId 886580
  dimension_t[] dimension
    dimension_t
      int size 1024
      int offset 0
      int fullSize 1024
      int binning 1
      boolean reverse false
  dimension_t
    int size 1024
    int offset 0
    int fullSize 1024
    int binning 1
    boolean reverse false
NDPluginPVA and pvAccess Driver Demo
**NDDriverStdArrays**

- Driver that allows any EPICS Channel Access client to create NDArrays in an areaDetector IOC.
- Logical inverse of NDPluginStdArrays
  - That plugin converts NDArrays in an IOC into standard EPICS waveform records for use by Channel Access clients.
  - Also writes to additional records to describe the array structure. (SizeX, SizeY, ColorMode, etc.)
- **NDDriverStdArrays**
  - This driver receives EPICS waveform records from CA clients
  - Converts them to an NDArray in the IOC.
  - Clients must also write to additional EPICS records to define the structure of the NDArray.
- Similar in concept to pvaDriver
  - pvaDriver only works with EPICS V4 PVAccess clients
  - NDDriverStdArrays works with EPICS V3 Channel Access clients.
NDDriverStdArrays Use Case
David Vine, LBNL

- Display data from sscan record
- Simple Python client reads data from sscan record, writes to NDDriverStdArrays
- Allows real-time display of 2-D scans
- Can write data in standard HDF5 file format
- Any other AD plugins can be used on the scan data
NDDriverStdArrays

- Driver receives 1-D arrays, normally from an EPICS waveform record.
- NDimensions record controls actual number of dimensions to use when creating the NDArray.
- Dimensions array record controls actual size of each of the NDimensions dimensions.
- ColorMode record can be used to define the color mode (Mono, Bayer, RGB1, RGB2, or RGB3) of the NDArray.
- Data type of the NDArray set by the DataType record.
  - Int8, UInt8, Int16, UInt16, Int32, UInt32, Float32, or Float64.
- Datatype (FTVL) of the EPICS waveform record can be
  - CHAR, UCHAR, SHORT, USHORT, LONG, ULONG, FLOAT, or DOUBLE.
- Driver does any required type conversion between the waveform record data and the NDArray data.
NDDriverStdArrays

• 2 modes of operation, AppendMode=Disable/Enable
  – Disable: each write to the waveform record generates a complete NDArray.
  – Enable: waveform record contains just part of the NDArray data; data appended by multiple writes to the waveform record to construct the complete NDArray. sscan record client would work in this mode

• Records in Enable mode:
  – NewArray, NextElement, Stride, ArrayComplete
  – CallbackMode record controls when the driver does callbacks
    • OnUpdate, OnComplete, OnCommand
NDDriverStdArrays Demo

Runs Python Unit Tests
  • Complete NDArrays
  • Line scans (appends line at a time)
  • Point scans (appends pixel at a time)
    • 4 detectors signals, sent to 4 ROIs
Pilatus Driver Update

• Now supports Energy and ThresholdEnergy independently
  – ThresholdEnergy is used to set per-pixel discriminators
  – Energy is used to compute the correct flat-field normalization

• Previously EPICS only exposed ThresholdEnergy
  – Camserver was supposed to set Energy=2*ThresholdEnergy
  – Bug in some versions of camserver, e.g. our new 1M CdTe detector. It was freezing Energy at 60 keV, and we collected an entire run of improperly normalized data

• There are occasions when ThresholdEnergy = Energy/2 is not the optimum setting, i.e. to avoid strong fluorescence.
Pilatus Driver Update

• If camserver is saving TIFF files then driver now reads the TIFFImageDescription tag from the TIFF file.
  – This is a long string that camserver writes to the file containing all of the detector settings, including threshold, energy, etc.
  – Driver adds this information to the NDArray using an NDAttribute called TIFFImageDescription.

• The NDFileTIFF plugin in ADCore R2-6 was changed to write this complete attribute to the TIFFImageDescription tag in the new TIFF file.

• It will also be written by the NDFileNetCDF, NDFileHDF5, and NDFileNexus plugins.
  – However these plugins are currently limited to 256 character string attributes, so some of the information will be lost because the string is longer than 256 characters.
ADAndor

- Added support for Electron Multiplying (EM) Gain.
- Added ability to set the BaselineClamp in the Andor SDK.
- Enforce minimum values of ADShutterOpenDelay and ADShutterCloseDelay based on query of SDK.
- Implemented ReverseX and ReverseY.
- Fixed bug with AndorPreAmpGain; previously it was not actually calling SetPreAmpGain().
- Added support for Full Vertical Binning (FVB) readout mode.
- Added support for EPICS shutter control.
Pixirad driver update

• CdTe pixel array detector available with multiple chips.
  – Detector pool has Pixirad-2, 402x1024. Now working at 1-ID.

• Updated driver to work with new PIII chip.
  – Square 62 um pixels, not hexagonal.
  – Single chip is 402x512 pixels.
  – Pixel mode (PM). Each pixel is independent.
    • Highest rate capability (> 1MHz), no sharp color separation, multiple counts if threshold is low.
  – Neighbor Pixel Inhibit mode (NPI).
    • Only one counter per event allowed to count. The hit is allocated to the pixel receiving the highest fraction of the total charge. Highest position resolution and the lowest possible noise but sharpness of the color separation not completely solved yet
  – Pixel Summing mode (PSM).
    • The signals of 4 neighbor pixels are summed together in each pixel to correctly evaluate the total energy of any event involving up to 4 pixels.
Other detectors

• New ADCameraLink, ADPCO drivers
  – Drivers for PCO cameras from Tim Madden

• New ADLambda driver
  – Driver for Lambda pixel array detectors from John Hammonds

• Many detectors (Pilatus, Prosilica, Point Grey, marCCD, mar345, Andor, etc.)
  – Added support for SerialNumber, FirmwareVersion, SDKVersion, DriverVersion, and ADCoreVersion which were added in ADCore R2-6.

• ADSimDetector, ADCSimDetector, pvaDriver
  – Moved out of ADExample and into their own repositories

• ADExample no longer used
ADSupport

• New repository ADSupport
• Source code for all 3rd party libraries used by ADCore.
  • hdf5, jpeg, netCDF, nexus, szip, tiff, xml2, zlib
• ADBinaries no longer used.
  • Pre-built libraries for Windows too difficult to maintain, now all built from source using EPICS build system
• ADSupport can be built for
  • Windows (Visual Studio or MinGW, 32/64 bit, static/dynamic),
  • Linux (currently Intel architectures only, 32/64 bit),
  • Darwin
  • vxWorks (currently big-endian 32-bit architectures only).
• vxWorks previously supported only netCDF file plugin
  • All file saving plugins now supported on vxWorks 6.x (TIFF, JPEG, netCDF, HDF5, Nexus).
  • HDF5 and Nexus are not supported on vxWorks 5.x because the compiler is too old.
  • Could imagine migrating saveData to HDF5 since it now works on all platforms.
Optional Support

• All 3rd party libraries now optional.
  • For each library XXX 4 Makefile variables control support for that library. XXX can be JPEG, TIFF, NEXUS, NETCDF, HDF5, XML2, SZIP, and ZLIB.
  • WITH_XXX YES then drivers or plugins that use this library will be built. NO then drivers and plugins that use this library will not be built.
  • XXX_EXTERNAL YES then the library is not built in ADSupport, but assumed to be found external to the EPICS build system. NO then the XXX library will be built in ADSupport.
  • XXX_DIR If defined and XXX_EXTERNAL=YES then the build system will search this directory for the XXX library.
  • XXX_INCLUDE If defined then the build system will search this directory for the include files for the XXX library.

• All EPICS modules except base and asyn are now optional.
NDPluginOverlay

• New Ellipse shape to draw elliptical or circular overlays.
• Improved efficiency by only computing the coordinates of the overlay pixels when the overlay definition changes or the image format changes.
  • Important for ellipse because it uses trig functions
• Added CenterX and CenterY parameter for each overlay.
  • Can now specify the overlay location either by PositionX and PositionY, (upper left corner), or by CenterX and CenterY,
  • If CenterX/Y is changed then PositionX/Y will automatically update, and vice-versa.
• Changed the meaning of SizeX and SizeY for the Cross overlay shape.
  • Previously the total size of a Cross overlay was SizeX*2 and SizeY*2.
  • It is now SizeX and SizeY.
  • Now consistent with the Rectangle and Overlay shapes, i.e. drawing each of these shapes with the same PositionX and SizeX/Y will result in shapes that overlap in the expected manner.
Other Plugin Enhancements

• All plugins: ElapsedTime PV for last execution.
  • This gives the execution time in ms the last time plugin ran.
  • Works both with BlockingCallbacks=Yes and No.
  • Convenient for measuring plugin performance without having to run detector at high frame rates.

• NDPluginROI
  • Added CollapseDims to optionally collapse (remove) output array dimensions whose value is 1. For example an output array that would normally have dimensions [1, 256, 256] would be [256, 256] if CollapseDims=Enable

• NDPluginStats
  • Added calculations of 3rd and 4th order image moments, this provides skewness and kurtosis.
  • Added eccentricity and orientation calculations.

• NDPluginFile
  • If the NDArray contains an attribute named FilePluginClose and the attribute value is non-zero then the current file will be closed.
Base Class Enhancements

• asynNDArrayDriver, NDArrayBase.template, NDPluginBase.adl, ADSetup.adl, all plugin adl files
  – ADCoreVersion\_RBV, DriverVersion\_RBV.
  – Show the version of ADCore and of the driver or plugin that the IOC was built with.

• ADDriver, ADBase.template, ADSetup.adl
  – SerialNumber\_RBV, FirmwareVersion\_RBV, and SDKVersion\_RBV.
  – Show the serial number and firmware version of the detector, and the version of the vendor SDK library that the IOC was built with.

• Because NDPluginBase.adl and ADSetup.adl grew larger all plugin and driver adl files have changed their layouts.
Base Class Enhancements
Viewers

• EPICS_AD_Viewer enhancements
  – Automatically set the contrast when a new window is created.
    • Eliminates the need to manually set the contrast when changing image size, data type, and color mode in many cases.
  – When image window is automatically closed and reopened because the size, data type, or color mode changes the new window is now positioned in the same location as the window that was closed.

• Gaussian Profiler
  – Like the normal ImageJ line profile in “live” mode, but with fitting of Gaussian and live display of fit parameters
• EPICS_AD_Controller. Allows using the ImageJ ROI tools (rectangle and oval) to graphically define the following:
  – The readout region of the detector/camera
  – The position and size of an ROI (NDPluginROI)
  – The position and size of an overlay (NDPluginOverlay)
  – The plugin chain can include an NDPluginTransform plugin which changes the image orientation and an NDPluginROI plugin that changes the binning, size, and X/Y axes directions. The plugin corrects for these transformations when defining the target object.
  – Chris Roehrig wrote an earlier version of this plugin.
Viewer Demo
Future Ideas: ADCore R3-0

• Put more functionality into ADDriver base class
  – Currently it does not do much, all code is in each driver for:
    • Doing callbacks to plugins
    • Processing new exposure time with writeFloat64 function
  – writeFloat64 in ADDriver base class would call setExposure() in derived class
  – Derived class would call ADDriver::doPluginCallbacks(), which would handle setting attributes, getting timestamp, calling plugins, etc.

• Model 3 motor driver and quadEM, which also use asynPortDriver, are written this way

• Demultiplexor/multiplexor plugin
  – Allow multiple plugins to work on the same data stream when it saturates a single core

• Simplify file saving modes (no more Single, Capture, Stream)
Future Ideas: ADCore R4-0

- Change NDArray to NTNDArray for passing data to plugins
- Utilize EPICS V4 infrastructure
- Smart pointers automatically eliminate all unnecessary copying
- V4 clients can immediately receive data with no need to convert to waveform records
- Bruno Martins has demonstrated this working
- Seems like a good path for the future