EPICS 7 PROVIDES MAJOR ENHANCEMENTS TO THE EPICS TOOLKIT

L.R. Dalesio, M.A. Davidsaver, M.R. Kraimer, Osprey DCS LLC, Ocean City, USA

S.M. Hartman, K.-U. Kasemir, ORNL, Oak Ridge, Tennessee, USA

A.N. Johnson, G. Shen, ANL, Argonne, Illinois, USA

H. Junkes, FHI, Berlin, Germany

T. Korhonen, ESS, Lund, Sweden

R. Lange, ITER Organization, St. Paul lez Durance, France

K. Shroff, BNL, Upton, Long Island, New York, USA

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 highperformance 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 Frepresentation while preserving the robust, high performance, and easily extendible capabilities that are expected a control system. EPICS 7 is the merge of $\stackrel{\text{\tiny O}}{\sim}$ 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 the i structures for more complex data sets and pvAccess is under designed to transport those structures in the most efficient manner. The new EPICS 7 release enables the be used 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

22

from this work may

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 doub	ble value
alarr	n talarm
	- int severity
	int status
	string message
time	e_t timestamp
	long secondsPastEpoch
	int nanoseconds
	int userTag

Figure 1: pvData equivalent of DBR TIME double.

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 alarm t alarm		8.1
	_	int severity	2
		int status	3
		string message	HIHI_ALARM
	time_t timeStam	ıp – – –	-
	long secondsPas	tEpoch	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.

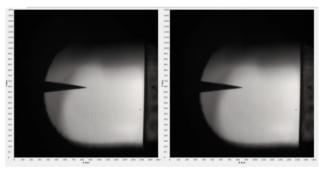
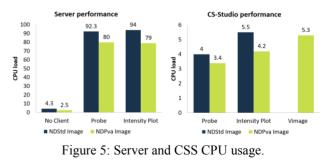


Figure 4: CSS display an image from V3 and pvAccess.

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.



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.

MOBPL01

R:CO* elemType=+	KCOR, BPM Tage	-aphia.sys.SR									×	Searc
Channel Name	Owner	handle	girder	cel	ordinal	devName	elenitiane	elen/Field	elemitype	sind v	length	
R:001-8E:G02A	d-update	READBACK	62	C01	120	PL1G2C01A	PL1G2C01A	х	8641	29.9886	0.0	
R:001-86:602A	d-update	READBACK	62	C01	120	PL162C01A	PL1G2C01A	Y	8PM	29.9886	0.0	_
R:001-86:682A	d-update	READBACK	62	C01	120	PL1G2C01A	PL1G2C01A		8PM	29.9886	0.0	
R:001-86:602A	d-update	READBACK	62	C01	120	PL1G2C01A	PLIG2CBLA		8PM	29,9895	0.0	
R:001-86:602A		SETPOINT	62	C01	120	PL1G2C01A	PLIG2COLA		8FM	29.9886	0.0	
R:001-88:602A	d-update	SETPOINT	62	C01	120	PL1G2C01A	PLIG2COLA		864	29.9885	0.0	
R:001-MG:602	d-update	SETPOINT	62	C01	125	CL1G2001A	O1162001A	x	HCOR	30.6673	0.2	
R:001-MG:602	d-update	READBACK	62	C01	125	CL1G2001A	O1162001A	×	HCOR	30.6673	0.2	
R:001-MG:602	d-update	READBACK	62	C01	133	CL2G2001A	O1252001A	x	HCOR.	32,1047	0.2	
R:001-MG:002	d-update	SETPOINT	62	C01	133	CL2G2C01A	C1262001A	×	HCOR	32,1047	0.2	
R:001-86-602A	d-update	READBACK	62	C01	138	PL262008A	PL2G2C01A	Y	BFM	32.5523	0.0	
R:001-88:682A	df-update	READBACK	62	C01	138	PL252001A	PL252001A	x	8PM	32,5523	0.0	
R:001-86:602A	d-update	SETPOINT	62	C01	138	PL252C01A	PL252C01A		8PM	32.5523	0.0	
R:001-86:602A	d-update	SETPOINT	62	C01	138	PL252001A	PL2G2C01A		8PM	32,5523	0.0	
R:001-80-602A	d-update	READBACK	62	C01	138	PL252001A	PL252001A		8PM	32,5523	0.0	
R:001-86-602A	d-update	READBACK	62	C01	138	PL2G2C01A	PL2G2CB1A		8911	32,5523	0.0	
R:001-MG:604	d-update	READBACK	64	C01	150	SOMG4001A	ONSIGILA	х	HCOR	36.7222	0.2	
R:001-MG:604	d-update	SETPOINT	64	C01	150	SOMG4001A	ONGIOLA	x	HCOR.	36.7222	0.2	
R:001-82:604A	d-update	SETPOINT	G4	C01	161	PN1G4C01A	PM1G4C01A		8PM	38.3018	0.0	
R:001-86:604A	d-update	SETPOINT	64	C01	161	PM1G4001A	PM1G4C01A		8PM	38.3018	0.0	
R:001-82-604A	d-update	READBACK	64	C01	161	PM1G4C01A	PM1G4C01A	×	8PM	38,3018	0.0	
R:001-82-604A	d-update	READBACK	64	C01	161	PM1G4C01A	PM1G4C01A		8PM	38,3018	0.0	
R:001-82-604A	d-update	READBACK	64	C01	161	PM1G4C01A	PM1G4CD1A		8PM	38,3018	0.0	
R:001-86:604A	of-update	READBACK	64	C01	161	PM1G4001A	PM164001A	Y	8PM	38.3018	0.0	
R:001-86:6048		SETPOINT	64	C01	171	PM1G4C018	PM1G4C018		8PM	40.5345	0.0	
R:001-86-6048		SETPOINT	64	C01	171	PM1G4C01B	PM1G4C018		8PM	40.5345	0.0	
R:001-88:6048	dundate	READBACK	64	C01	171	PM1G4001B	PM1G4C01B		8911	40.5345	0.0	-

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:G0	4A{HFCor:FM1}	SR:C02-MG:G04A{VFCor:FM1					
Channel Name	Fld-I	Fld-SP	Fld-I	Fld-SP				
handle	READBACK	SETPOINT						
elemName	FXM10	54C02A	FYM1G4C02A					
elemType	HF	COR	VFCOR					
elemField		x	У					
devName		FM1G	4C02A 5222					
sEnd		65.5						
cell	C02							
girder		G	64					
symmetry								
length		0.0	044					
ordinal	2	63	20	64				
	eget	eput	eget	eput				
tags		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.

Query: Tags=aphla.sys.SR cell=C	-01	Row:	devName 👻 Column: elemField	•					
devName \ elemField	x		у						
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						
SOMG4C01A	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].

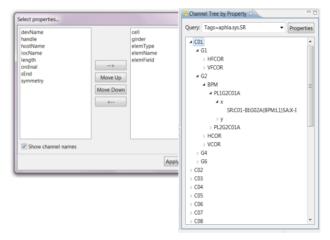


Figure 10: CSS orders properties in directory service.

System all		Welcome to MASAR & SR.Orbit.20141112:1719:2015-04-07.06:09:30 &									
Config Filter	Filter •				PV Nene	Saved Connection	Not Restore	Saved Value	Live Value	Det	Seve
Select Confeda		1	SR.C16-MG(P5:OH1A)(:Sp3	SP Corrected		-6.02080535889	-3.67866826057	2.34213709632	2015-04-0		
				2	SR C26-MG(PS: CH18) I Sp1	SP Corrected		-2.6222922802	-1.73931694031	0.882975339892	2015-04-0
	Config Name	Canfiglia		3	SR. C03-MG(PS: CH18)1.593	SP Cerrected		-2.25312638283	-1.42119085789	0.831935524943	2015-04-0
1 ID.100kup.20			ID feedforward lookup table	4	SR C23-MG(PS: CMLA)(-Sp)	-SP Corrected		-3.98979187012	-3.18863844872	0.801153421405	2015-04-0
2 SR_0(tkt_20)		51	corrector, carting correctors,	5	SR C14-MG(PS: CM18) I Sp1	SP Corrected		-5.68489546912	-4.886759758	0.798136711124	2015-04-0
3 SR.LMSce.21		53	Dipole, Dipole T, Guada, Senti	0	SR C14-MG(P5: OH1A)(:5p3	SP Corrected		-3.79615879059	-3.03760385513	0.758554935457	2015-04-0
	SQGuads_20141105	52	PS volt to current conversion 1	7	SR C26-MG(PS: OHDAH:Sp3	SP Corrected		-2.8069331646	-2.0557346344	0.751198530201	2015-04-0
	Cerrectors, 20141105	51	PS volt to current conversion (8	SR C24-MG(PS-CMLA)L5p	SP Corrected		-5.34757375717	-4.60605955124	0.741514205931	2015-04-
6 VIConversion	GuadeSects.20141105	50	PS volt to current conversion t	- 2	SR C22-MG(PS:CL28)15p2	SP Corrected		-7.28721666336	-6.56779432297	0.719422340392	2015-04-0
			10	SR C18-MG/PS (H1A1/ Sp1	SP Creeected		-5.57744216919	-4.87519359589	0.702248573304	2015-04-	
Author • • • • • • • • • • • • • • • • • • •				11	SR C30-MG(PS:CL28)15p1	SP Corrected		-5.43957281113	-4.77079820633	0.668774604801	2015-04-0
				12	SR C29-MG/PS (H18) (Sp1	SP Corrected		-4.07904195786	-3.41841769218	0.660624265676	2015-04-
				13	SR C22-MG(PS-CMLA)LSp	SP Corrected		-8.28736305237	-7.63846445084	0.648898601534	2015-04-0
Frans 2015-04-12 22:32:13			14	SR C22-MG(PS: CH18)1 Sp1	SP Carrected		-4.41956710815	-3.77455163002	0.64501547813	2015-04-0	
			15	SR C20-M04P5-OH1414543	SP Corrected		-5.37185430527	-4.72839975357	0.643454551699	2015-04-	
				16	SR C17-MG(PS: CH18)15p1	SP Corrected		-2.05955447197	-2.03566622734	0.033888244029	2015-04-0
Select Snapshot)	4			17	SR C15-MG/PS (MIA)LSH	SP Connected		-3.07626023683	-2.44279360771	0.631465627118	2015-04-
Config No	me Snapshot Id		Description	14	SR C22-MG(P5-CH1A)/-Sp3	SP Corrected		-2.58538579943	-1.91700917664	0.027778022779	2015-04-0
SR_0/14_201			erations DW28 Clesed	19	SR C27-MG/PS:CLIAH:Sp1			-5.43346261978	-4.8155412674	0.617921352385	2015-04-
SR_0rb8_201	41112 1712	Match1711	56YG	20	58 C27-MG/P5 (M18) 5v1			-2.85822939873	-2.20235644533	0.417872953417	2015-04-
3 SR_Orbit_20141112 1710 SaveOrbitforiDalignedBDWsclose		21	SR C24-MG/PS: CH1A(H:Sp1	SP Carrented		-3 26398396492	-2.64691829581	0.617065658106	2015-04-		
4 SR_Orbit_20141112 1709 Save the orbit for 3 DWs close		22	SR C08-M0/PS-OH1414:5e1			-5.45923185349	-4 8541734314	0.615058422094	2015-04-		
5 SR, Orbit. 20141112 1707 reference unbit for checking repeatible cork 6 SR, Orbit. 20141112 1704 UserOperationOrbit 7 GB, Oxbit. 20141133 3 3200 miniMissionEduce.1688		23	SR C10-MG/PS (041A)(Se1			1.00012566165	1 14510450712	0.583927154542	2015-04-		
		24	SR C19-MG/PS CL14H Sp1					0.573068618775			
					-						
	10	search a snap		10	Restore Nachine G	mare Uve Machine	Save Hactio		Compare Snapshat		wonted to Fi

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

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

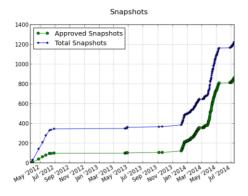


Figure 12: MASAR (Save/Restore) Use at NSLS II.

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.

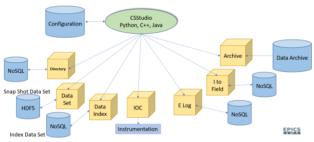


Figure 13: Service Use By CS-Studio

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 realtime 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.

ACKNOWLEDGEMENT

The EPICS 7 development has been performed by many dedicated engineers in the community. Among them are: Matej Sekoranyja (Cosylab), Marty Kraimer (Osprey DCS), Michael Davidsaver (Osprey DCS), Ralph and DOI Lange (ITER), Andrew Johnson (APS), Timo Korhonen (ESS), Heinz Junkes (FHI), Patrick Marschalik (FHI), Murali Shankar(SLAC), Bruno Martins(FRIB), Kunal Shroff(BNL), Arman Arkilic(BNL), Michael Dalesio (Osprey DCS), Anton Metzger (Independent), Greg White(SLAC), David Hickin (Formerly DLS), Guobao 을 Shen (APS), Sinesa Veseli (APS), Bob Dalesio (Osprey

REFERENCES

- [1] Matthias Clausen, L Dalesio, "EPICS Experimental Physics and Industrial Control System", International Committee for Future Accelerators, Beam Dynamics Newsletter 47, pp. 56-66. Dec. 2008
- [2] T. Korhonen, L.R. Dalesio, N. Malitsky, et al., "EPICS V4 Progress Report", in Proceedings of ICALEPCS 2013, San Francisco, CA, USA, TUCOCB04
- [3] J.O. Hill, "Channel Access: A Software Bus for the LAACS", ICALEPCS'89, Vancouver, Canada 1989.
- [4] M.R. Clausen, et al., "Control System Studio Integrated Configuration and Development", in Proceedings of ICALEPCS 2009, Kobe, Japan, THC002
- [5] J.D. Purcell, D.J.Armstrong, K.-U.Kasemir, et al., "CSS -We Didn't Invent It, We Made It Better", in Proceedings of ICALEPCS 2009, Kobe, Japan, TUP010
- Bruno Martins, reported at the areaDetector workshop, connected to ICLAPECS 2017. Information at: http://cars9.uchicago.edu/software/epics/NDP
- 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/NDP1
- L. Yang, J. Choi, Y. Hidaka, et al., "The Design of NSLS-II High Level Physics Applications", in Proceedings of ICALEPCS 2013, San Francisco, CA, USA, TUPPC130