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EPICS 4 beginners

Torsten Bögershausen

Many slides stolen from many sources
Steal it all. No, only steal the best.

Questions please at the end

www.europeanspallationsource.se

Outline: What is EPICS

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- History, overview
- How does EPICS look like ?
- EPICS IOC, EPICS process variable ”PV”
- Records and EPICS ”database”
- Network protocol: Channel Access
- Questions
- Bonus: better network protocol: pvAccess
- Questions

EPICS starting page

- 'Experimental Physics and Industrial Control System'
  - http://www.aps.anl.gov/epics
- Mailing list usually provides responses within a few hours
  - http://www.aps.anl.gov/epics/tech-talk/index.php

EPICS history and collaboration

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- ~1989: Started between
  LANL Ground Test Accelerator and ANL Advanced Photon Source
- Now:
  - SNS, ANL/APS, SLAC, LANL, JLAB/CEBAF, LBNL, Fermilab D0, Gemini, FRIB, Laser Interferometer Gravitational Wave Observatory in the US Canadian Light Source
  - Kek, J-PARC in Japan, KSTAR in Korea,
  - DESY, BESSY, .. in Germany; PSI/SLS in Switzerland; ITER, Ganil, SACLAY in France; Diamond light source, ISIS in UK; KEK-K, J-Parc in Japan; IHEP in China; NSRRC in Taiwan; PLS in South Korea; Australian Synchroton, ESS in Sweden, …
- Yearly collaboration meetings
  - 2 meetings / year, rotating through the continents
  - @ ESS, May 25th .. May 27th 2016

EPICS is used in big science

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Von: **Andrew Johnson** anj@aps.anl.gov

Betreff: Congratulations to everyone at LIGO **Datum:** 11. Februar 2016 17:21

An: EPICS tech-talk tech-talk@aps.anl.gov

... on finally detecting gravitational waves from a pair of merging black holes.

http://www.nature.com/news/einstein-s-gravitational-waves-found-at-last-1.19361

The earliest tech-talk message from a LIGO email address was from David Barker in 1996. I believe EPICS has always been a fundamental part of the observatories' control systems.

- Andrew

EPICS meeting Octobober 2014

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Juan Guzman, http://www.aps.anl.gov/epics/tech-talk/2012/msg02113.php

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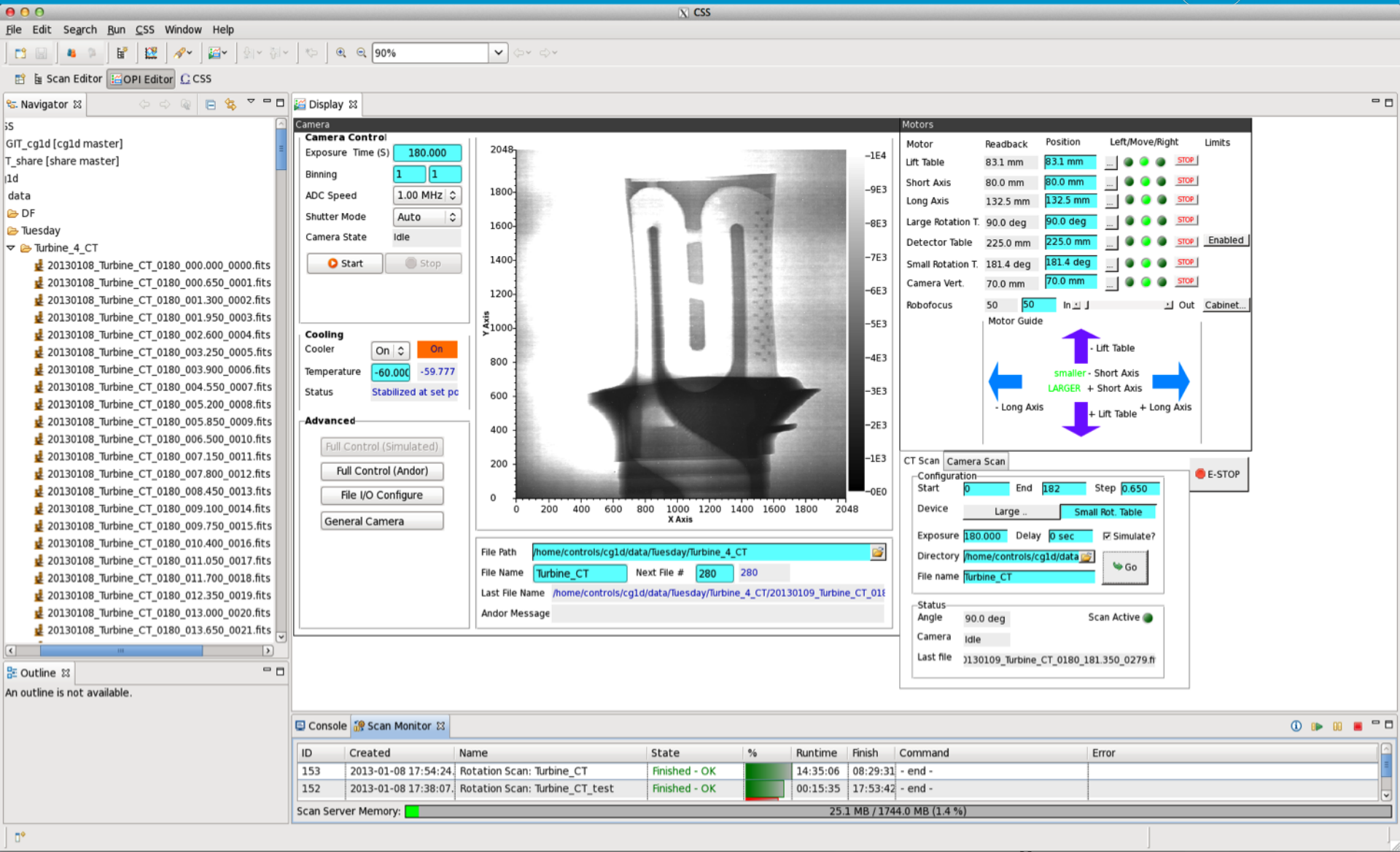
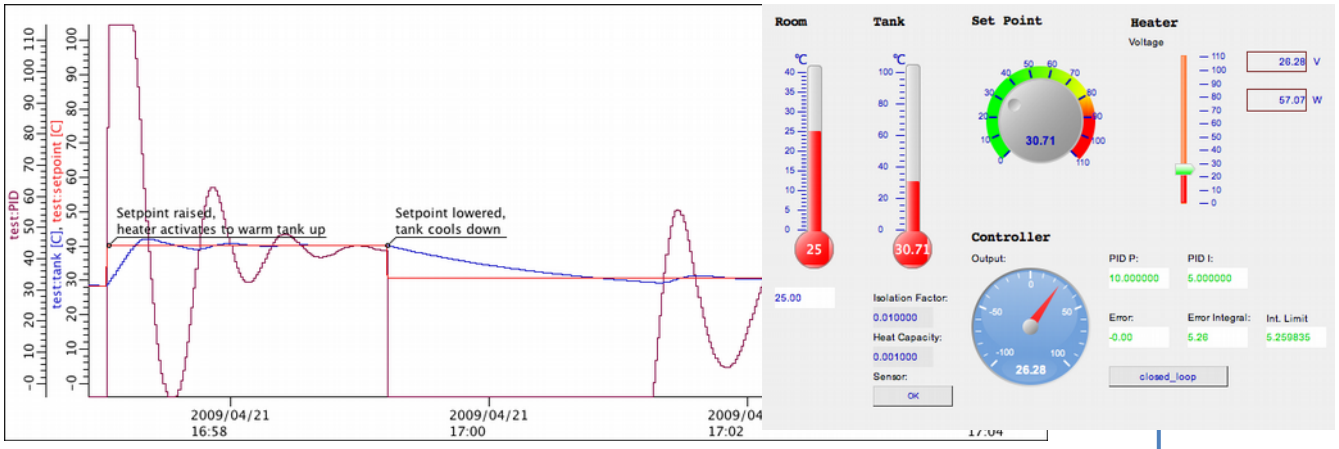
Example from SNS



EPICS is distributed

- Operator interface
- Services: Archive, CCDB
- Front-end IOCs
- I/O, PLCs, ..



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EPICS is a toolkit

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… for distributed control systems.

- Front-end: “Input/Output Controller” (IOC)
- Protocol: Channel Access, PV access
- Clients: Operator displays, alarm system, …

- Very portable: Linux, OS X, Windows, VxWorks, UNIX, RTEMS

What an IOC does

- Known set of ‘Records’
  - Read analog value
  - Write analog value
  - Perform computation
  - Control motor
- Runtime ‘Database’
  - Executes records
- Configuration
  - SCAN=1 second
  - INP=..what to read..
- Serve all via Channel Access

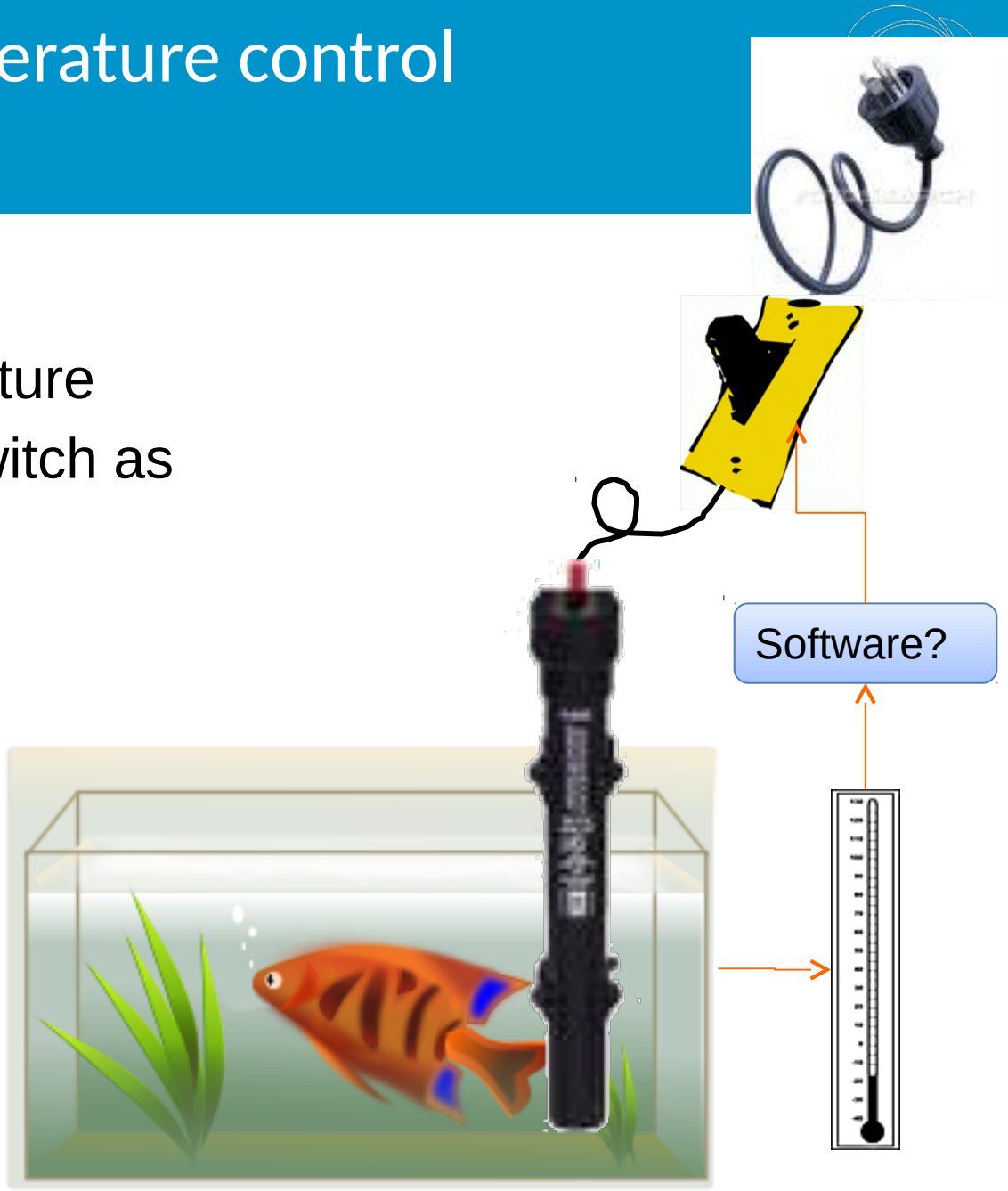
What is a process variable

- Process variable (“PV”):
  - a physical value is represented in SW, with metadata
  - has a unit (Celsius, Volt, mm)
  - may be analog (=floating point or integer)
  - may be binary (=single bit)
  - may represent a bit field
- Is part of a “record”
- Is hosted in an EPICS IOC (“IOC”, soft IOC, hard IOC)

Example: Temperature control

Task:

1. Read temperature
2. Open/close switch as needed
3. Repeat



Pseudo code

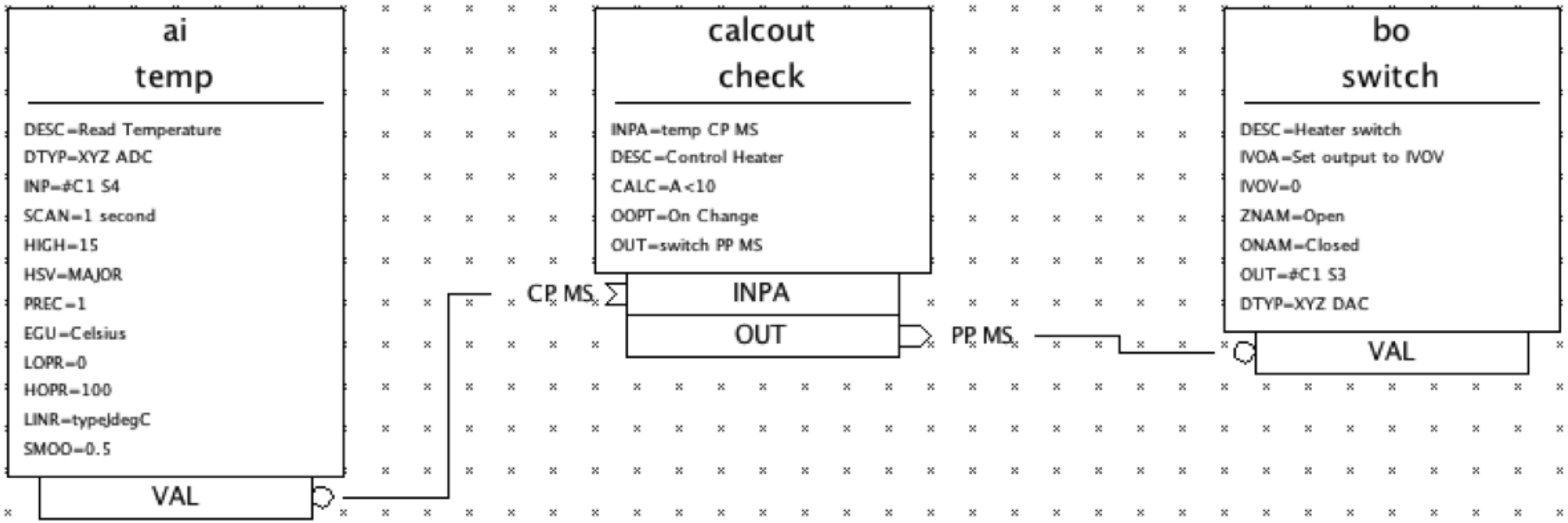
```
Sensor temp = connectToSensor();

Switch switch = connectToSwitch();
do forever {

   if (temp.value() < 10)
      switch.close();
        else
      switch.open();

   sleep(1.0);

}
```

EPICS 'Database' for Fishtank

Analog Input Record

calc Record

Binary Output Record



Record: Analog in

```
record (ai, temp) {
    field(DESC, "Read Temperature")
    field(EGU,  "Celsius")
    field(SCAN, "1 second")
    field(DTYP, "XYZ ADC")
    field(INP,  "#C1 S4")
    field(PREC, "1")
     #(less important, fields on next side)
```

Record: Analog in

```
    # continued from last side
     field(LINR, "typeJdegC")
     field(HOPR, "100")
     field(LOPR, "0")
     field(SMOO, "0.5")
     field(HIGH, "15")
     field(HSV,  "MAJOR")
}
```

Record: binary out

```
record (bo, switch)
    field(DESC,  "Heater Switch")
    field(DTYP,  "XYZ DAC")
    field(OUT,   "#C1 S3")
    field(ZNAM,  "#Open")
    field(ONAM,  "#Closed")
}
```

Record: calcout

```
record (calcout, check)
    field(DESC, "Control Heater")
    field(CALC,  "a<10")
    field(INPA,  ”temp CP MS")
    field(OUT,   ”switch")
    field(OOPT,  "On Change")
}
```

IOC Database

- A single record can handle the scanning, signal conditioning, alarming of a temperature, pressure, or similar analog reading.
- Combined with binary and computational records, it can express the data flow logic for a front-end computer
  - Avoiding the pitfalls of real-time, multithreaded and networked programming.
- Can have thousands of records in one IOC.
- kHz-rate processing with record chains is doable
  - Of course limited by CPU. Not 1000nds of kHz rate-records…

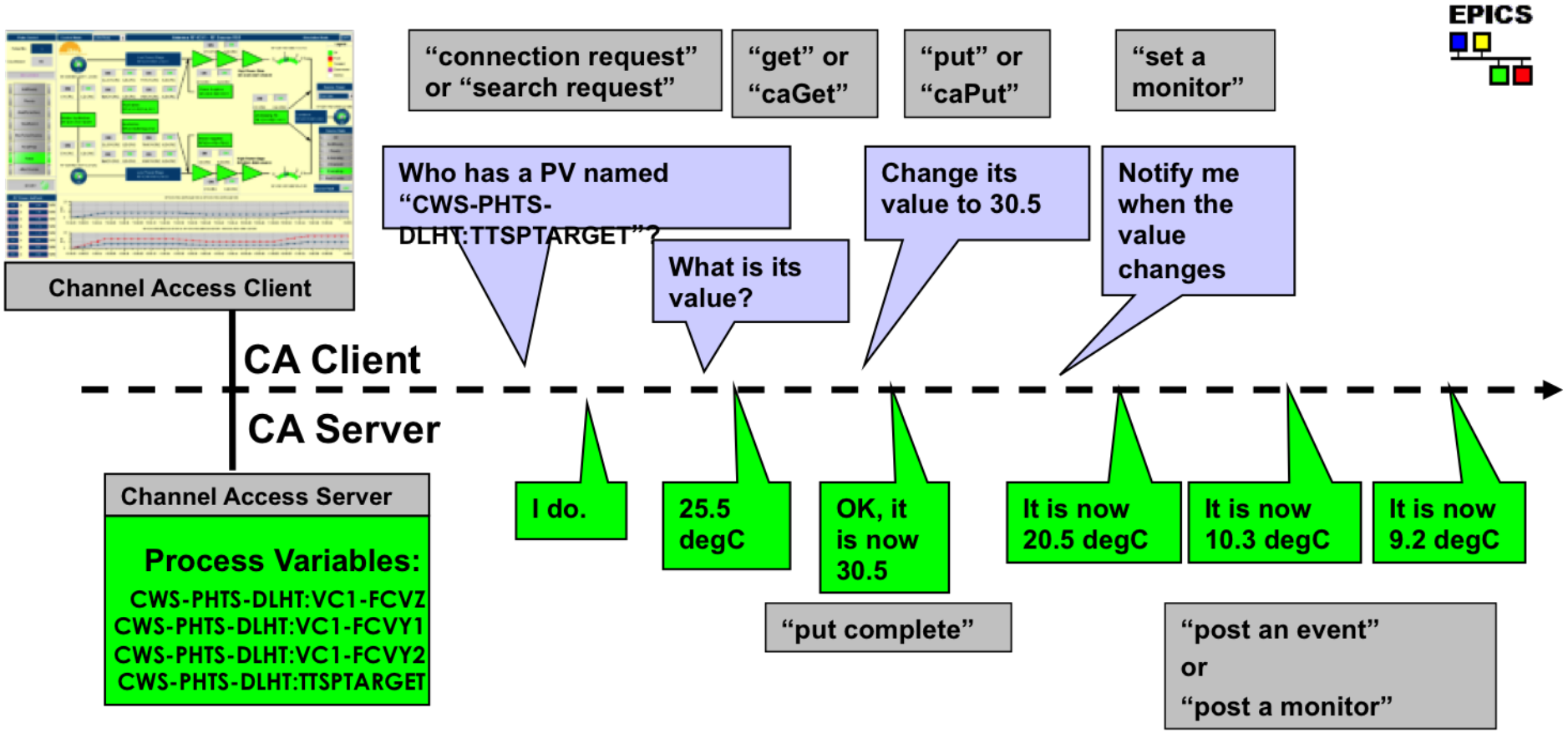
Records for writing code

- "SCAN=1 second"
  instead of start thread,
  delay until next multiple of 1 second,
  lock required resources, …
- "SMOO=0.5" configures the smoothing algorithm.
- Change scan rates at any time via the network:
  - scan rate
  - Smoothing
  - alarm levels

EPICS Vocabulary

- EPICS Base
  Code for IOC, database support, basic records, channel access
- IOC
  Input Output Controller, the front-end software
- Soft IOC
  IOC software running on Linux, …, typically communicating with networked I/O
- Database
  Executes the EPICS Records
- Record
  EPICS processing block
- Driver
  Code that talks to hardware. Devices with an ASCII-like command-set often use StreamDevice as a driver.
- Channel Access
  EPICS network protocol. Exposes Channels aka Process Variables
- SNL
  State notation language.

Channel access in one slide



EPICS @ ESS

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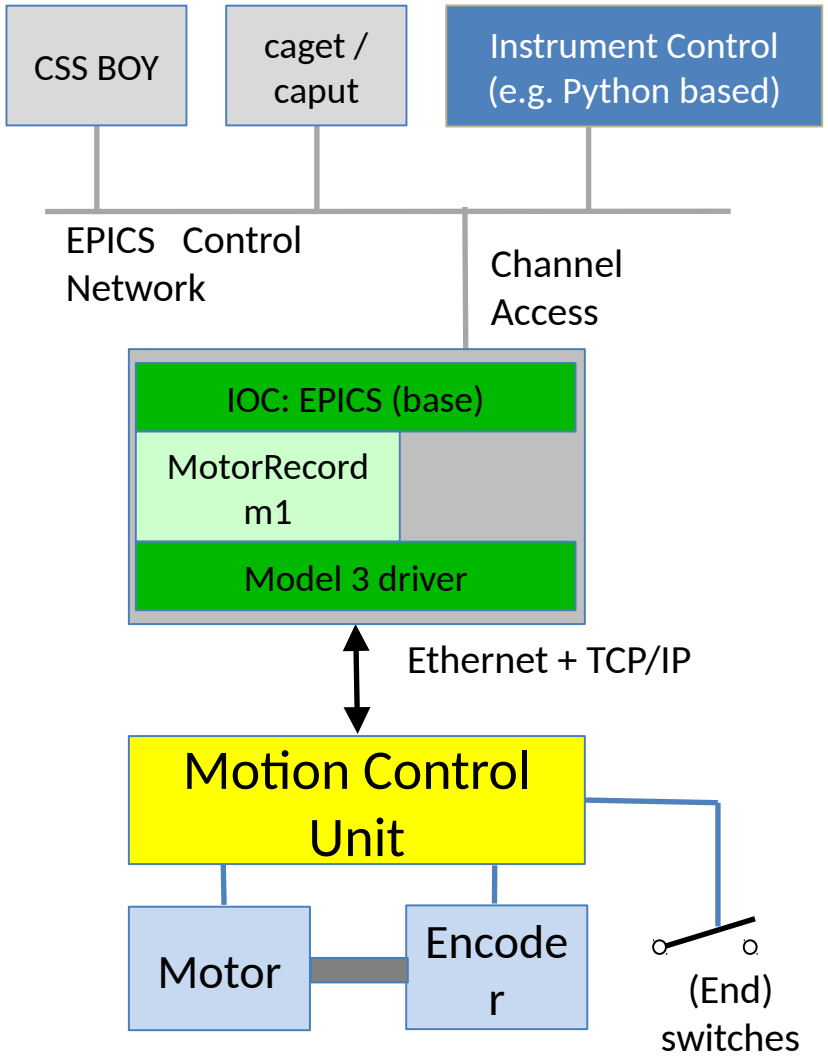
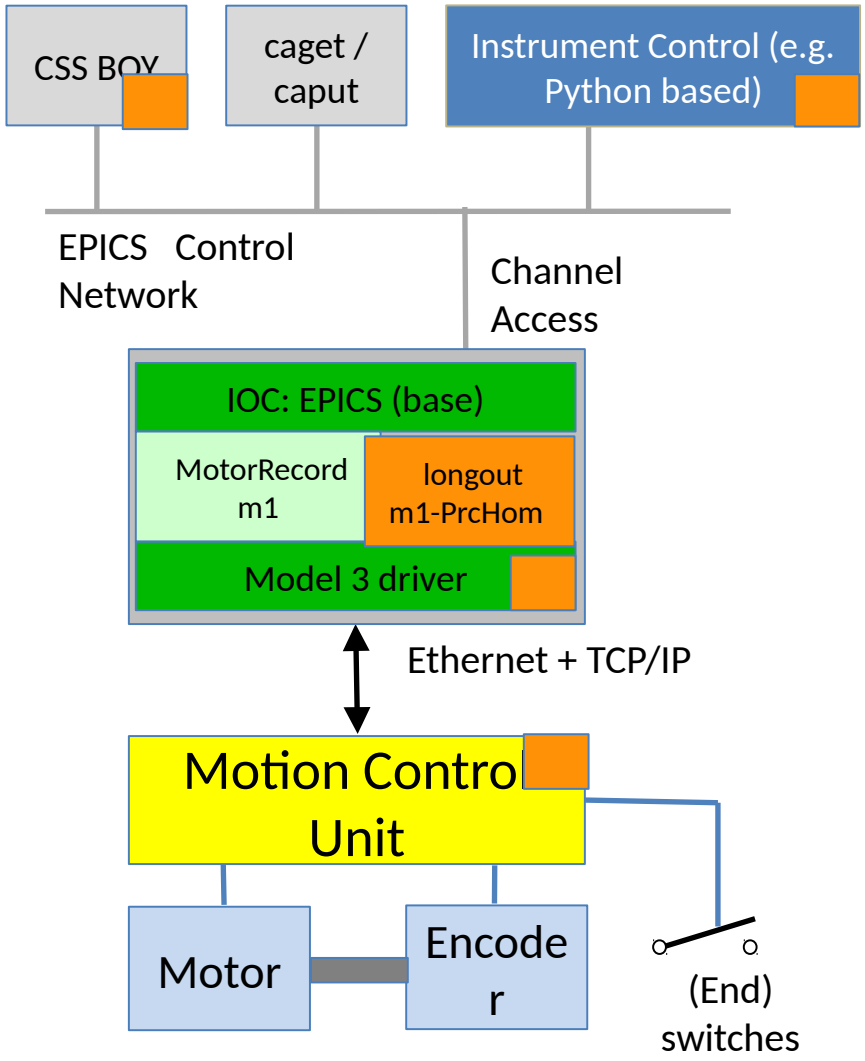
- Machine/Integrated Control Systems
  - HW platforms, network, archiver,
  - CCDB, naming convention
  - Make it possible to install EPICS @ InKind partners (”EEE” & ”Dev Env”)
- Science/DMSC:
  - Instrument control
- Science/NSS
  MCAG, SE, Chopper, Detector, Scientists

Motion Control Integration (today)



- 3 layers in control box:
  - EPICS IOC
  - Motor record (single axis)
  - Model 3 driver
- Basic functionalities for point-to-point movements
- Future extensions of functionality in additional records

Motion Control Integration (tomorrow)



- 3 layers in IOC:
  - Motor record (single axis)
  - longout record (homing)
  - Model 3 driver
- Basic functionalities for point-to-point movements
- Future extensions of functionality in additional records
- Current development includes a.o. jerk, homing procedures
- Extensions need to be implemented in user interfaces, model 3 driver and motion control unit as well (strong coordination necessary)

Move & monitor a motor (done on a simulator, Mac or raspi)

```
caput IOC:m1.VAL 60.1

Old : IOC:m1.VAL
              24.9

New : IOC:m1.VAL
              60.1
```

#Notes:

```
#caput:   Channelaccessput
#camonitor:   Channelaccessmonitor
#IOC:m1..DMOV: Field"donemoving"
#IOC:m1.RBV:  FieldReadbackvalue
```

- camonitor IOC:m1.RBV IOC:m1.DMOV
- IOC:m1.RBV 2016-02-02 10:58:16.157350 24.87
- IOC:m1.DMOV 2016-02-02 10:58:16.658745 1
- IOC:m1.DMOV 2016-02-02 10:58:16.658745 0
- IOC:m1.RBV 2016-02-02 10:58:30.124368 49.86
- IOC:m1.RBV 2016-02-02 10:58:31.138087 60.06
- IOC:m1.DMOV 2016-02-02 10:58:31.639072 1

Quiz - 1

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- Can I monitor a PV on the command line ?
- Is a PV is always a part of a record ?
- Is a record processed ?
- I can write a python script to control devices (Experiment control) ?
- An IOC can do real time processing ?

Quiz - 2

- When a PV changes, is there a time stamp associated with the change ?
- May a PV have a high-or low limit ?
- Can a PV be used to monitor the room temperature ?

Relax

- Time for questions

Why another protocol?

- EPICS Version 3 is targeted towards **control** applications
  - Simple data types, essentially scalar values with (very) limited metadata
    - Timestamp, alarm, engineering units, etc.
- Simple example: array of sampled values from an ADC.
  - What was the sampling rate?
  - Applications have to know that – knowledge is separate from data
  - Or, create lots of extra channels to hold the metadata
  - Applications have to stitch the information together from different channels

Scientifc applications need even more

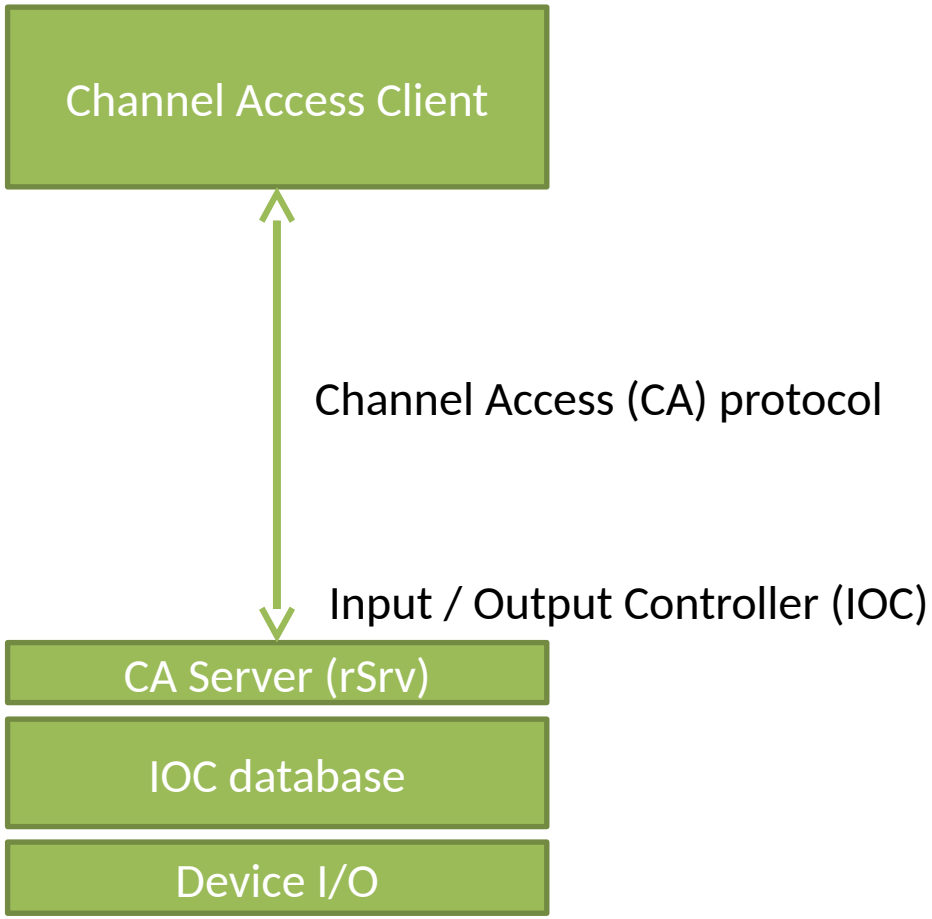
- Several (site-specific, incompatible) abstraction layers have been built on top of the simple EPICS channel structures
- (Large) data transport is inefficient
  - Use of EPICS channel access for large data transfer is not practical (solution: bypass EPICS)
  - Achieving synchronicity is difficult (sometimes even impossible)
  - E.g., set three parameters for an acquisition and start: needs minimum of three “ca_put”s
- Channel Access does not guarantee (atomic) delivery of waveform data

New protocol, pvAccess

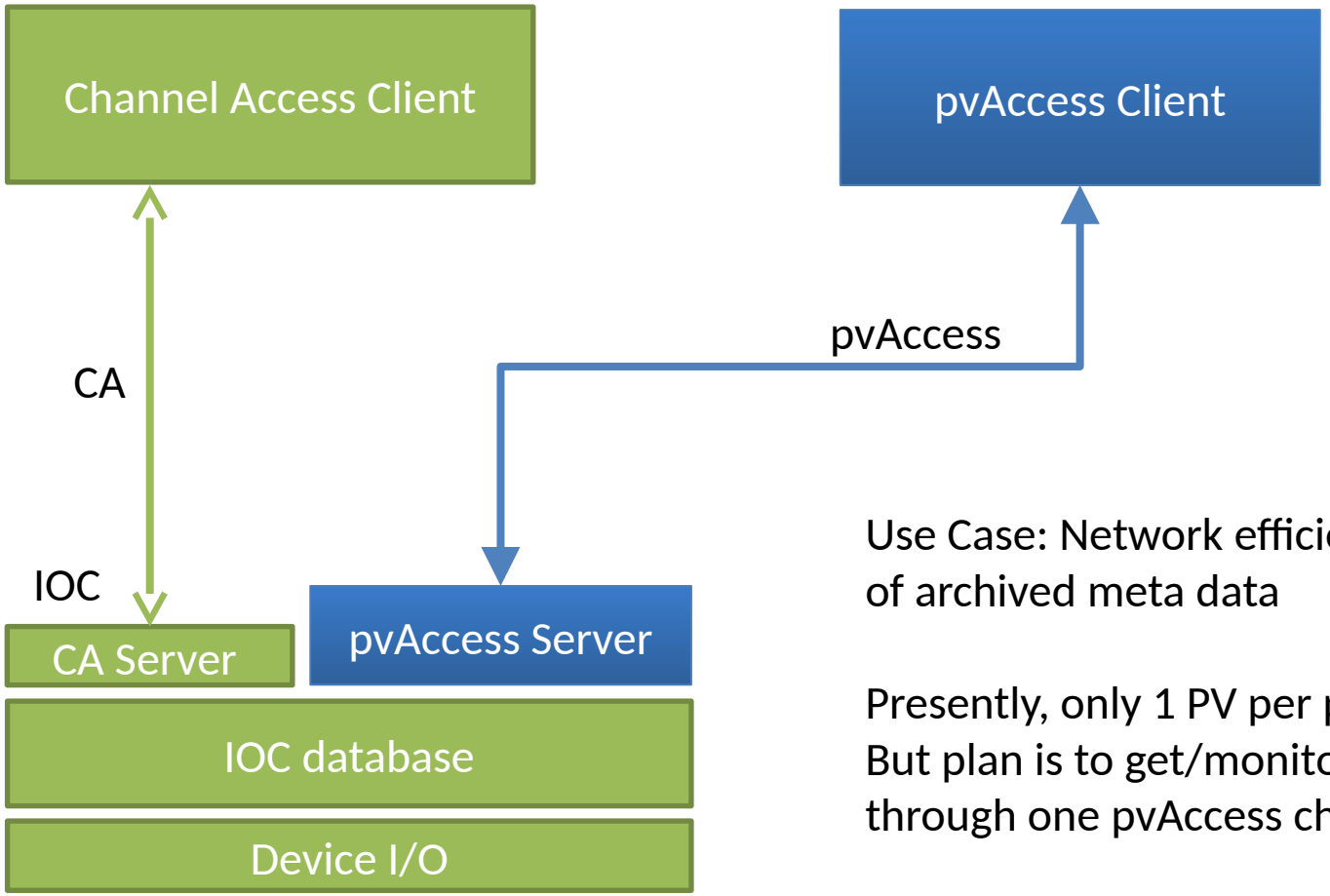
- Part of EPICS 7, which joined EPICS 3 and 4 together
- Structured data
- Introspection interface, “pvData”
- Dynamic typing
- Standard Scientific Types
- RPC and putGet added
- New smart database
- All APIs in C++ and Java
- Python
- High Performance

- EPICS 3 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)



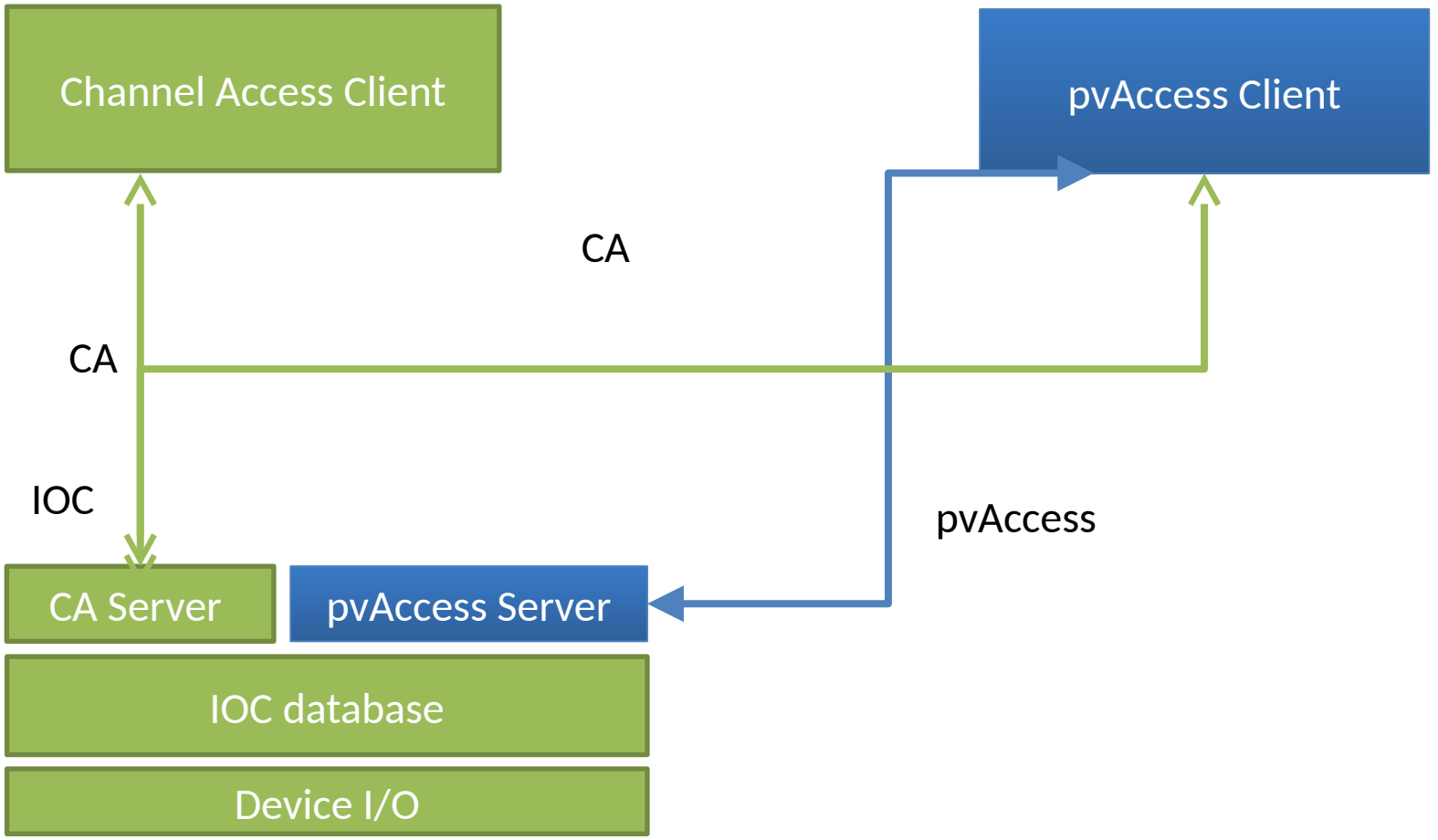
V4 IOC == V3 IOC + pvAccess Server



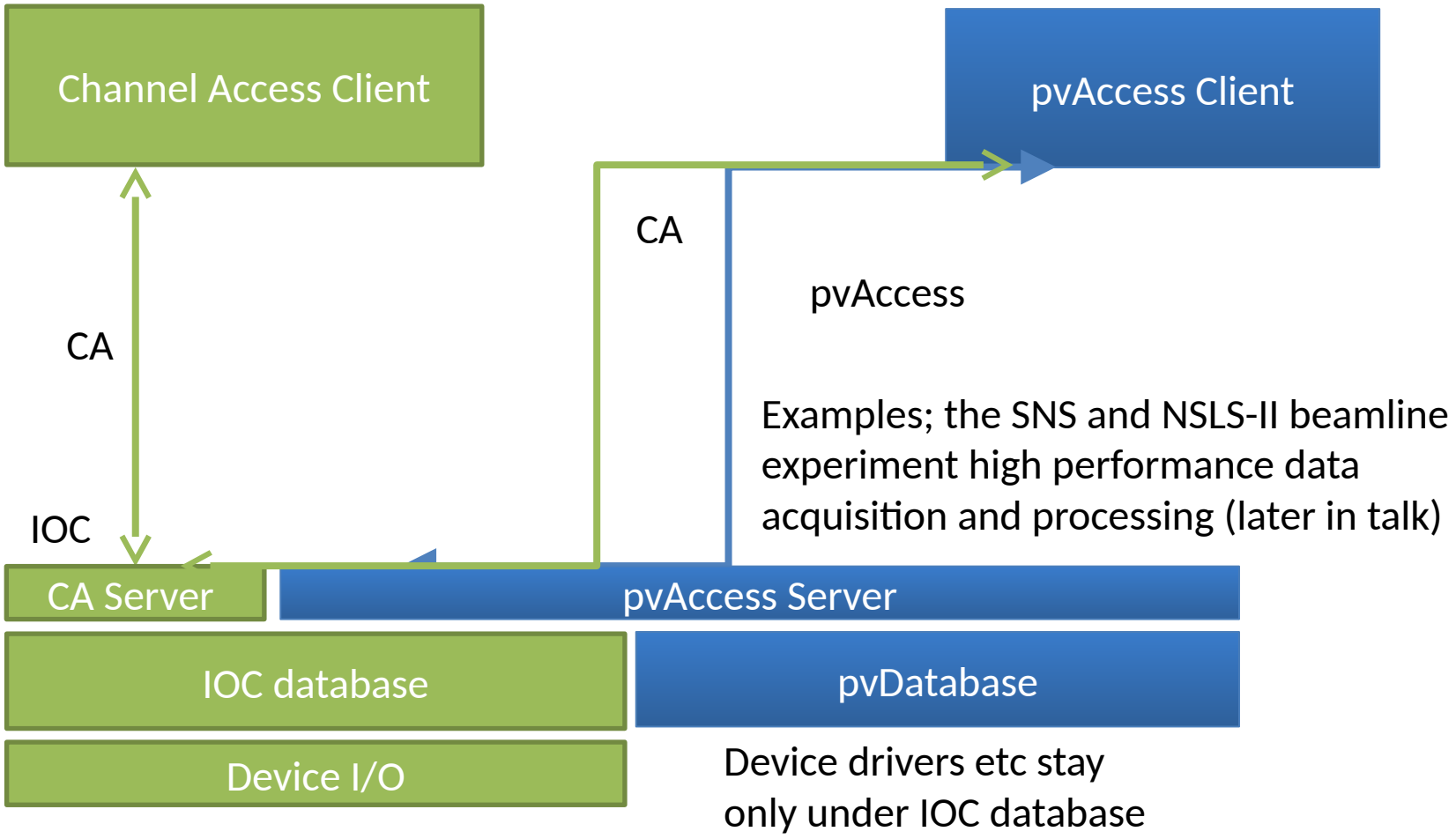
Use Case: Network efficient acquisition of archived meta data

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

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



A new smart database, “pvDatabase” can be used for data assembly and processing



ORNL SNS Deployment: Neutron event data aggregation and transport

Neutron Detector

SNS SEQUOIA detector ray consisting of >800 3He tubes covering a solid angle of 0.8 steradian

nED

- pvAccess Server
- pvDatabase
- Classic EPICS IOC

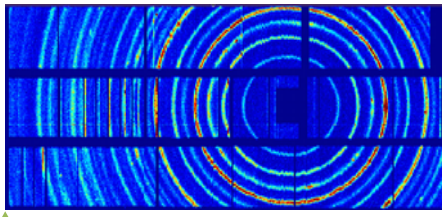
nED provides the driver interface to the detector electronics and streams experiment data using pvAccess

pvAccess streams event data at 80 Mbytes / sec

```
CHANNEL   : BL14B:Det:Neutrons
STATE     : CONNECTED
ADDRESS   : 10.111.29.150:57267
structure
    time_t timeStamp
        long secondsPastEpoch
        int nanoseconds
        int userTag
    epics:nt/NTScalar:1.0 proton_charge
        double value
    epics:nt/NTScalarArray:1.0 time_of_flight
        uint[] value
    epics:nt/NTScalarArray:1.0 pixel
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a1
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a2
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a8
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a19
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_a48
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b1
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b8
        uint[] value
    epics:nt/NTScalarArray:1.0 sample_b12
        uint[] value
    epics:nt/NTScalarArray:1.0 position_index
        uint[] value
    epics:nt/NTScalarArray:1.0 position_x
        uint[] value
    epics:nt/NTScalarArray:1.0 position_y
        uint[] value
    epics:nt/NTScalarArray:1.0 photo_sum_x
        uint[] value
    epics:nt/NTScalarArray:1.0 photo_sum_y
        uint[] value
```

The V4 data structure includes an array of pixels and a corresponding array of times of flight for each recorded neutron event. Additional fields record accelerator pulse information and detector diagnostic information

CS-Studio



Diffraction rings of a powder sample at SEQUOIA, histogram generated by ADnED and displayed in CS-Studio

ADnED

- CA Server
- areaDetector data processing
- pvAccess Client

ADnED, a pvAccess client, generates online histograms and counting statistics from the nED data stream and serves them using the CA protocol to clients including CS-Studio

Kay Kasemir, Steven Hartman, ORNL

ORNL SNS Deployment: Neutron event data aggregation and transport

SNS Conclusions:

Five beam lines currently using EPICS V4

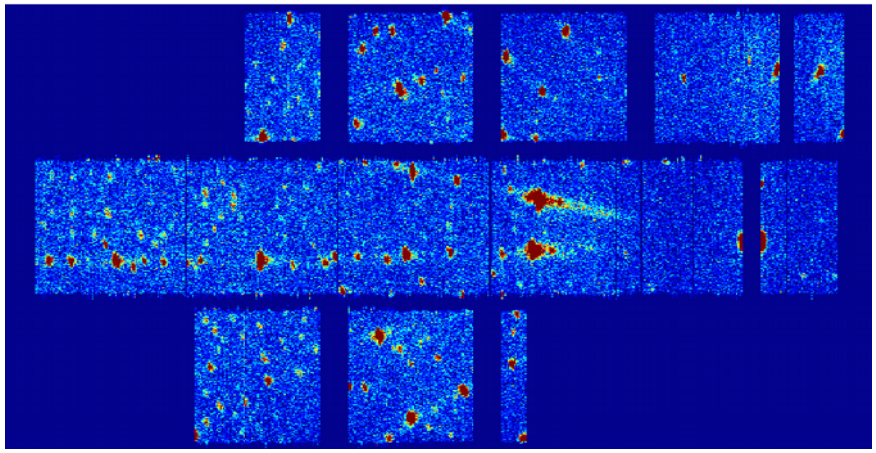
Plans to extend to all experiment beam lines.

Additionally, A pvaPy-based V4 client is used for detector calibration and diagnostics.

EPICS V4 meets the performance requirements for all existing SNS instruments

Demonstrated at data rates of 10M events per second

Excellent reliability.



ADnED plot of a diffraction pattern from neutron scattering of a single-crystal sample at SNS CORELLI

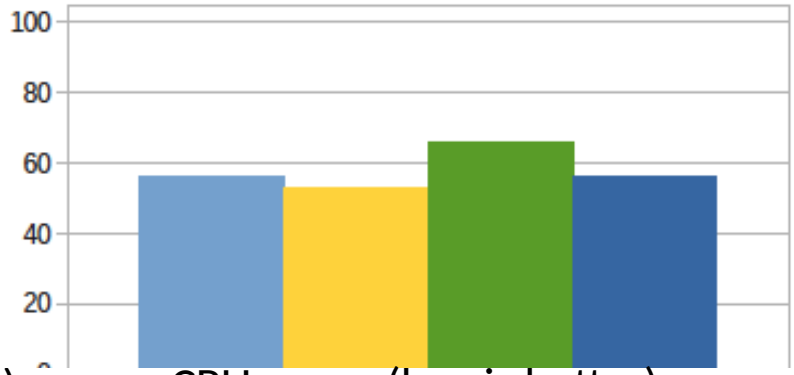
Fragment of the SNS V4 structure used for streaming experiment data at the 60 Hz rate of the pulsed neutron source

Kay Kasemir, Steven Hartman, ORNL

NSLS-II Deployment (1) – beamline image data transport and fanout

Test simDetecor datasource 5K x 5K @ 50Hz ~= 10 Gb/s over 10Gig Ethernet.
Non-blocking callbacks. AD ImageMode: Multiple. NumImages:10000

Frames through (%) (more is better)



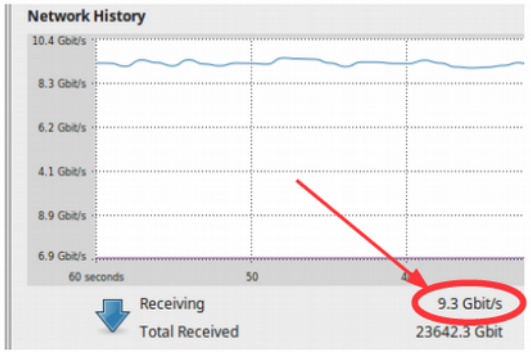
CPU usage (less is better)

Test pipeline stage

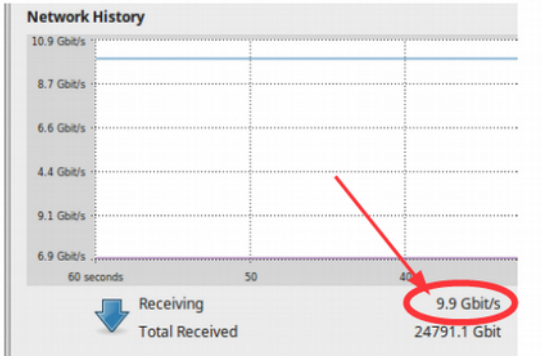
- simDetectorIOC - driver
- simDetectorIOC - plugin
- pvaDriverIOC - driver
- pvaDriverIOC - plugin

Transfer bandwidth: EPICS V4 & practical limit:

NDPvaPlugin + pvaDriver: **9.3 Gbps**



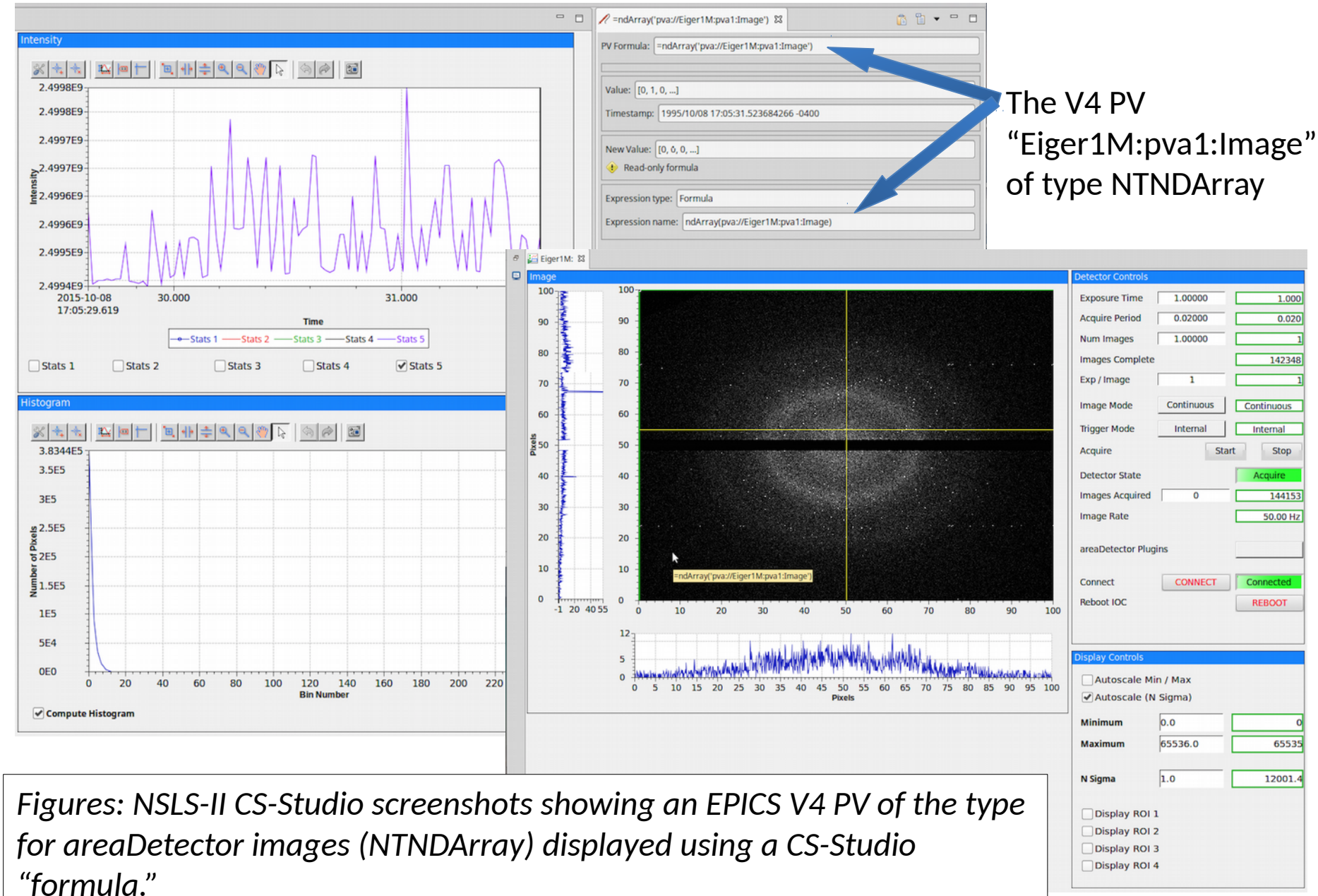
Baseline (iperf network tool): **9.9 Gbps**



Conclusions: EPICS V4 based areaDetector pipeline has high throughput, few frames lost, with no CPU saturation. Network bandwidth is close the practical maximum.

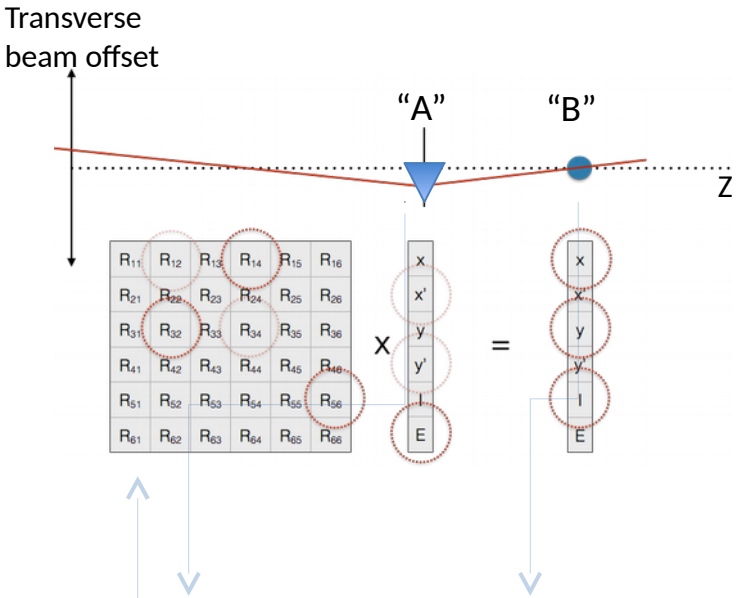
Bruno Martins, BNL (following work by James Rowland and Dave Hickin at Diamond)

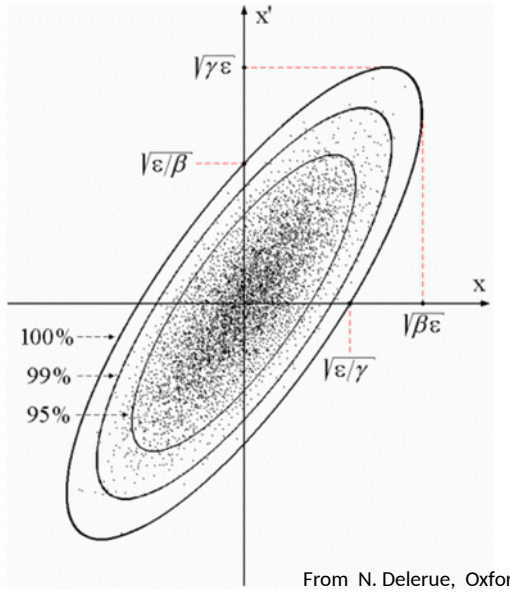
NSLS-II Deployment (1) – beamline image data transport and fanout



Figures: NSLS-II CS-Studio screenshots showing an EPICS V4 PV of the type for areaDetector images (NTNDArray) displayed using a CS-Studio "formula."

SLAC & ESS deployment: Modelling beam dynamics





From N. Delerue, Oxford Univ.

```
$ eget -s XCOR:IN20:491:RMAT -a b BPMS:IN20:525
      0.669591      0.694604             0             0  -3.08532e-19   2.41325e-19
     -0.570851      0.901275             0             0  -1.23627e-19   1.45491e-19
             0             0       1.33379      0.966896             0             0
             0             0      0.358415       1.00957             0             0
  -2.29302e-24  8.92892e-20             0             0             1   1.20724e-05
   1.00974e-28             0             0             0             0             1
```

```
$ eget XCOR:LI24:900:TWISS
    energy 5.00512
    psix 37.7625
    alphax 13.6562
    betax -2.78671
    etax -0.00698294
    etaxp 0.00107115
    psiy 31.9488
    alphay 116.762
    betay 5.2592
    etay 0
    etayp 0
    z 2438.72
```

Figure: EPICS V4 modelling service giving orbit response matrices and Twiss parameters for given devices. These are the basis of 95% of emittance minimization applications – feedback, steering, bumps, etc

Greg White, Murali Shankar SLAC; Ivo List, ESS

Questions

- Thank you