

Experimental Physics and Industrial Control System Overview

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Jan. 2022

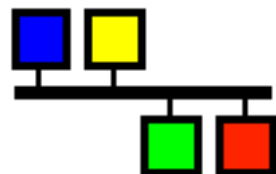
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U.S. DEPARTMENT OF
ENERGY

What EPICS looks like

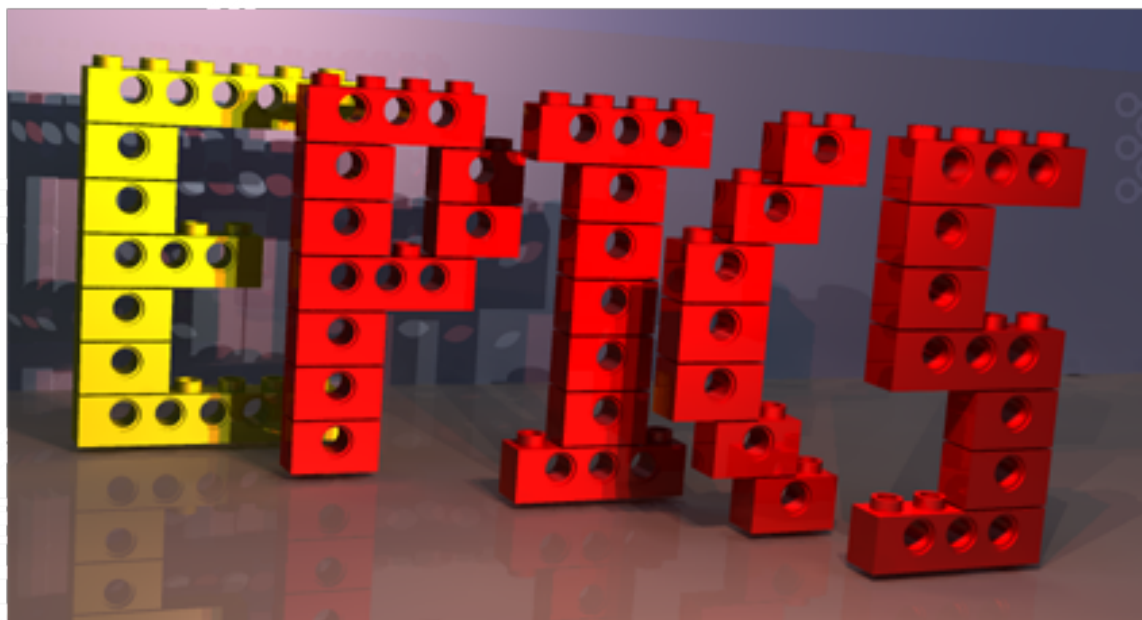
EPICS



Network Diagram

EPICS

Network Diagram (new)



Block Diagram

3



But is it easy?

- Experimental Physics and Industrial Control System
- Easy, Practical and Intuitive Control System!
- Free*, open-source, with documentation, mailing lists, ...

<https://epics.anl.gov/base/R7-0/6-docs/calcRecord.html>

Calculation Record (calc)

The calculation or "Calc" record is used to perform algebraic, relational, and logical operations on values retrieved from other records. The result of its operations can then be accessed by another record so that it can then be used.

Expression

At the core of the Calc record lies the CALC and RPCL fields. The CALC field contains the infix expression which the record routine will use when it processes the record. The resulting value is placed in the VAL field and can be accessed from there. The CALC expression is

Algebraic Operators

- ABS: Absolute value (unary)
- SQR: Square root (unary)
- MIN: Minimum (any number of args)
- MAX: Maximum (any number of args)
- + : Addition (binary)
- - : Subtraction (binary)
- * : Multiplication (binary)
- / : Division (binary)

base/...../calc/calcPerform.c

```
double *ptop; /* stack pointer */

case MAX:
    nargs = *pinst++;
    while (--nargs) {
        top = *ptop--;
        if (*ptop < top || isnan(top))
            *ptop = top;
    }
```

.. as in beer as well as speech

- No royalties
- Nothing hidden
- Modify as you wish

Antipodean Example

Subject: ASKAP Opening Ceremony webcast

From: <Juan.Guzman@csiro.au>

To: <tech-talk@aps.anl.gov>

Date: Tue, 23 Oct 2012 09:16:41 +1100

To the EPICS Community,

The Australian Square Kilometre Array Pathfinder (ASKAP) was officially opened in Western Australia's remote Murchison region on Friday 5 October 2012. Federal Minister for Science and Research, Senator Chris Evans, began one of the world's biggest data downloads by officially opening the telescope at the ceremony attended by international ambassadors, industry and government representatives and local stakeholders.

I invite all the EPICS community to watch the webcast from this link <http://webcast.viostream.com/?viocast=6134&auth=462ad6d8-6d19-4810-88a0-a38c8a1fe008>

This was a very important milestone within the ASKAP project. This is by no means the end and it is just the beginning as engineering and science commissioning of the instrument continues. Over the next few years we expect to deliver excellent science and build technologies for the next big project within the radio astronomy community, the SKA.

I would like to thanks the entire EPICS community for its strong support, collaboration and commitment to keep EPICS at the forefront of control systems technologies and facilitate its adoption in many new facilities like us. EPICS and CSS are very important technologies to us, and both have enabled us to deliver and continue development the control system of this major radio astronomical instrument.

Hope you enjoy the webcast and keep an eye at the end for a glimpse of the CSS BOY GUI we used during the event.

Best regards,

JC Guzman

ASKAP Telescope Monitor and Control Team Leader

Juan Carlos Guzman

Research Team Leader

ASKAP Computing IPT

CSIRO Astronomy and Space Science

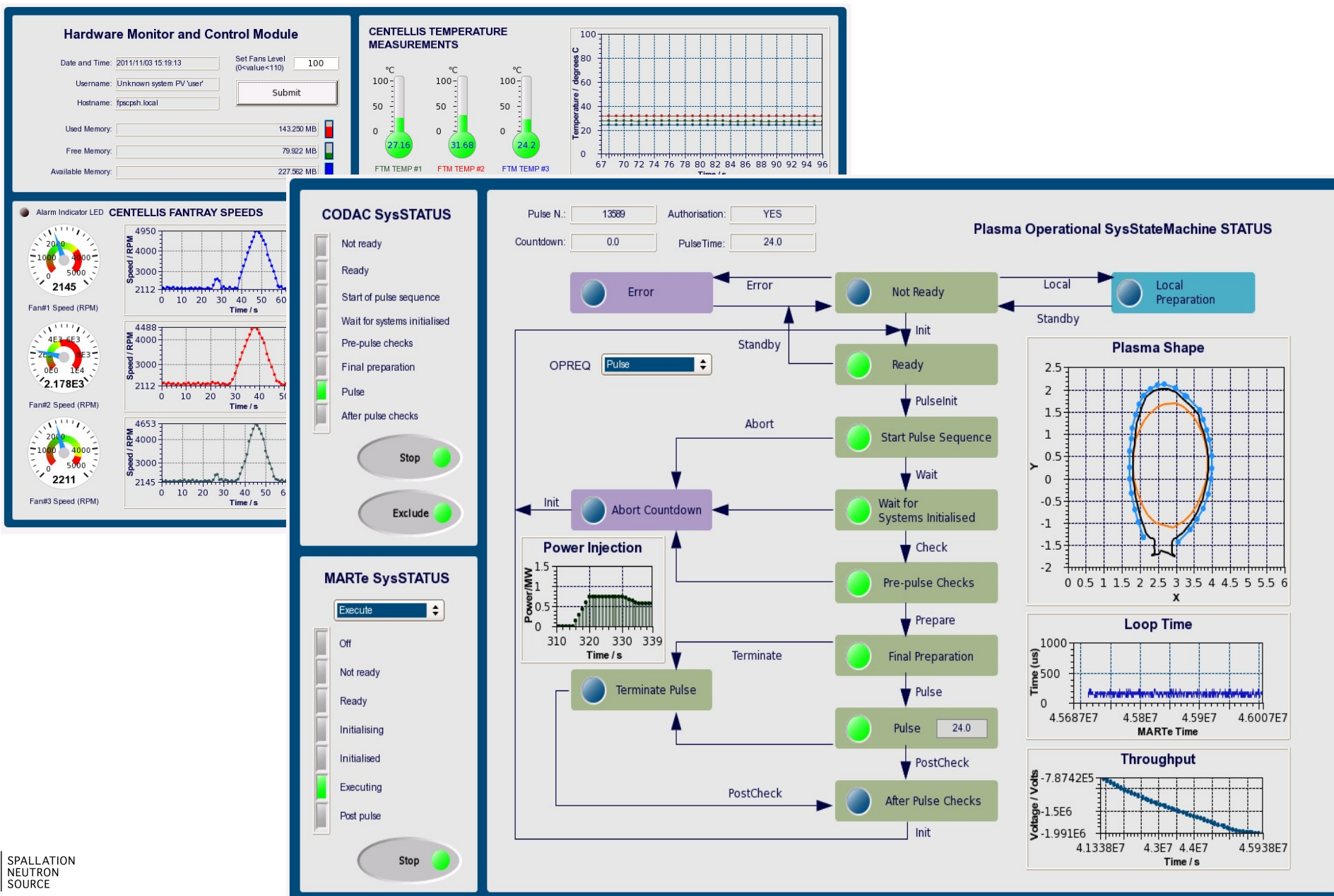
P.O.Box 76, Epping NSW 1710, Australia

Australian Square Kilometre Array Pathfinder (ASKAP), Oct. 5, 2012



ASKAP User Interface





ORNL HFIR CG-1D

Navigator

- IS
- Git_cg1d [cg1d master]
- T_share [share master]
- 1d
- data
- DF
- Tuesday
- Turbine_4_CT
 - 20130108_Turbine_CT_0180_000.000_0000.fits
 - 20130108_Turbine_CT_0180_000.650_0001.fits
 - 20130108_Turbine_CT_0180_001.300_0002.fits
 - 20130108_Turbine_CT_0180_001.950_0003.fits
 - 20130108_Turbine_CT_0180_002.600_0004.fits
 - 20130108_Turbine_CT_0180_003.250_0005.fits
 - 20130108_Turbine_CT_0180_003.900_0006.fits
 - 20130108_Turbine_CT_0180_004.550_0007.fits
 - 20130108_Turbine_CT_0180_005.200_0008.fits
 - 20130108_Turbine_CT_0180_005.850_0009.fits
 - 20130108_Turbine_CT_0180_006.500_0010.fits
 - 20130108_Turbine_CT_0180_007.150_0011.fits
 - 20130108_Turbine_CT_0180_007.800_0012.fits
 - 20130108_Turbine_CT_0180_008.450_0013.fits
 - 20130108_Turbine_CT_0180_009.100_0014.fits
 - 20130108_Turbine_CT_0180_009.750_0015.fits
 - 20130108_Turbine_CT_0180_010.400_0016.fits
 - 20130108_Turbine_CT_0180_011.050_0017.fits
 - 20130108_Turbine_CT_0180_011.700_0018.fits
 - 20130108_Turbine_CT_0180_012.350_0019.fits
 - 20130108_Turbine_CT_0180_013.000_0020.fits
 - 20130108_Turbine_CT_0180_013.650_0021.fits

Camera Control

Exposure Time (S)

Binning

ADC Speed

Shutter Mode

Camera State

Cooling

Cooler

Temperature

Status

Advanced

File Path

File Name Next File #

Last File Name

Andor Message

Camera

Motor

Motor	Readback	Position	Left/Move/Right	Limits
Lift Table	83.1 mm	83.1 mm	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Short Axis	80.0 mm	80.0 mm	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Long Axis	132.5 mm	132.5 mm	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Large Rotation T.	90.0 deg	90.0 deg	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Detector Table	225.0 mm	225.0 mm	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/> Enabled
Small Rotation T.	181.4 deg	181.4 deg	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Camera Vert.	70.0 mm	70.0 mm	<input type="button" value="Left"/> <input type="button" value="Move"/> <input type="button" value="Right"/>	<input type="button" value="STOP"/>
Robofocus	50	50	<input type="button" value="In"/> <input type="button" value="J"/> <input type="button" value="Out"/>	<input type="button" value="Cabinet..."/>

Motor Guide

CT Scan

Configuration

Start End Step

Device

Exposure Delay ☒ Simulate?

Directory

File name

Status

Angle Scan Active ☒

Camera

Last file

E-STOP

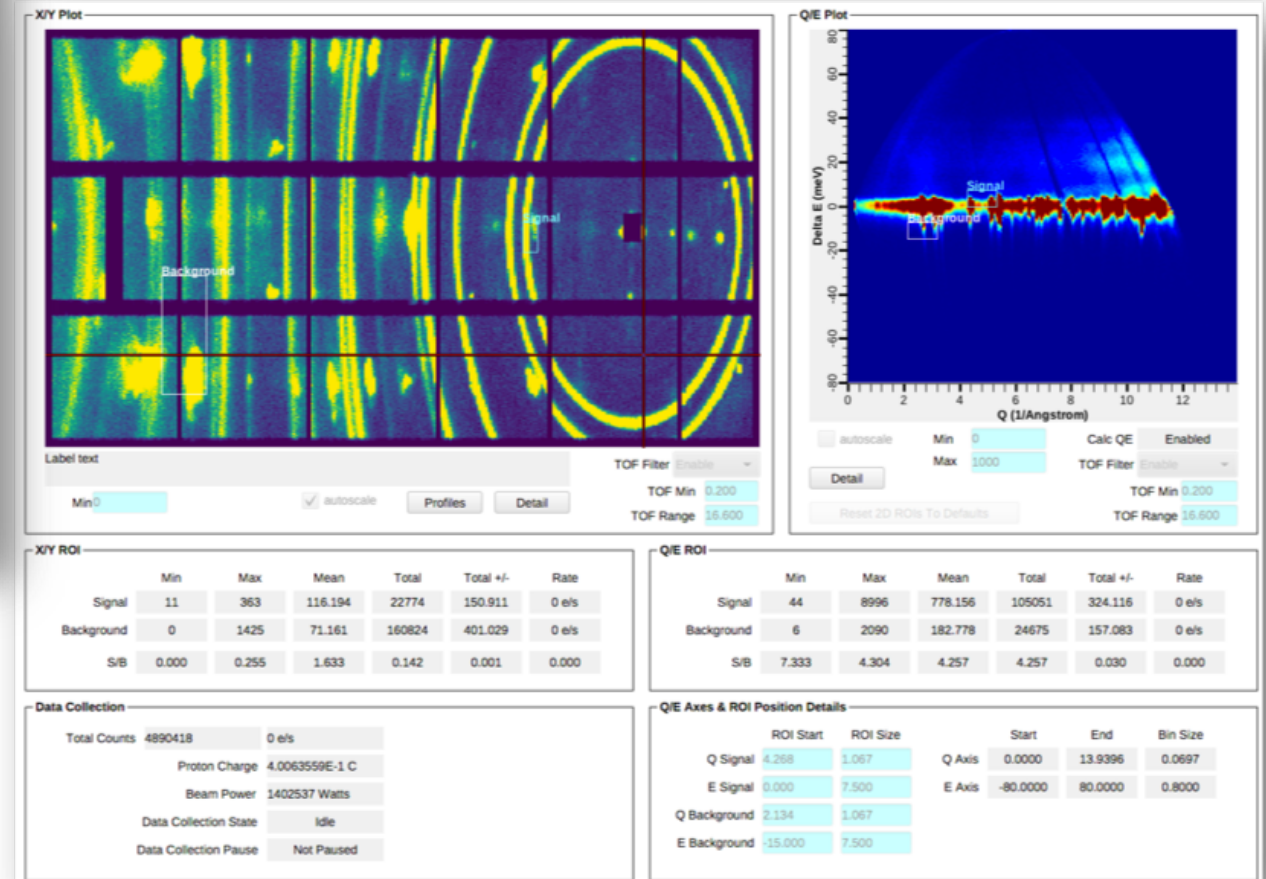
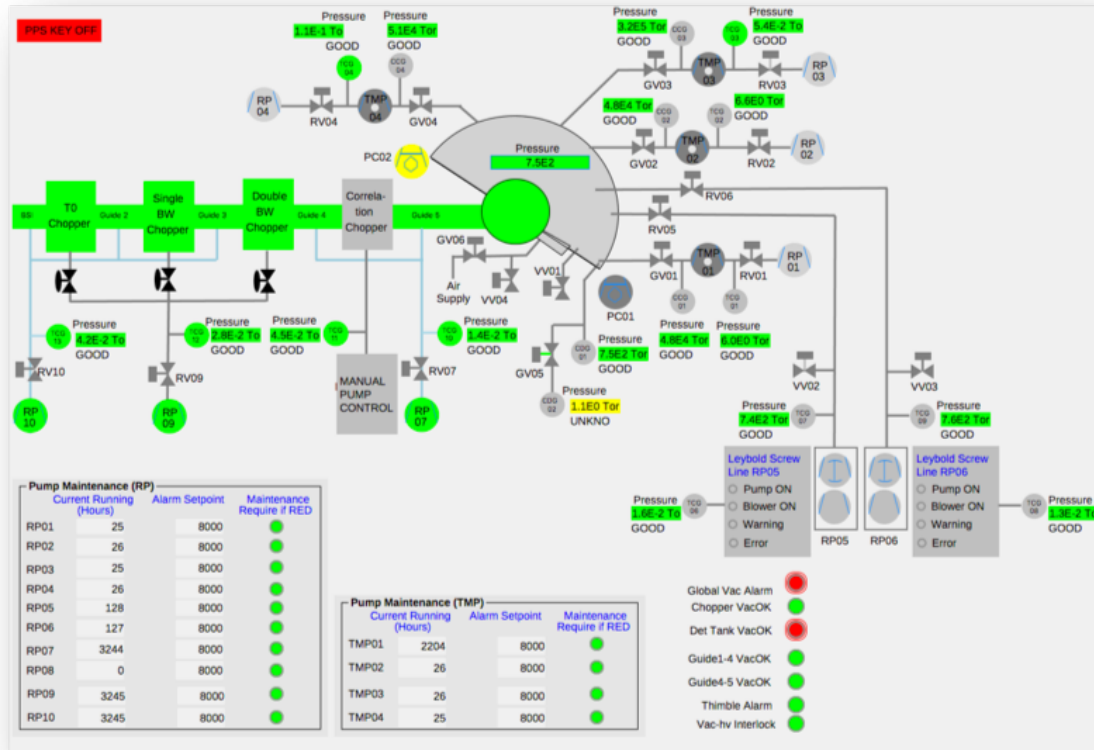
Console

ID	Created	Name	State	%	Runtime	Finish	Command	Error
153	2013-01-08 17:54:24	Rotation Scan: Turbine_CT	Finished - OK	<div></div>	14:35:06	08:29:31	- end -	
152	2013-01-08 17:38:07	Rotation Scan: Turbine_CT_test	Finished - OK	<div></div>	00:15:35	17:53:42	- end -	

Scan Server Memory: 25.1 MB / 1744.0 MB (1.4 %)

First EPICS/CSS operation with beam, Jan. 8, 2013

ORNL SNS Beam Lines



EPICS is not...

One product that you

- Install
- Run
- Done!

EPICS is a Collaboration

- ~1989: Started between
 - LANL Ground Test Accelerator
 - ANL Advanced Photon Source
- Until 2004: License agreement required
 - LANL registered >150
- Now:
 - SNS, ANL/APS, BNL, FRIB, SLAC, LANL, JLAB/CEBAF, LBNL, Fermilab D0, Keck & Gemini Telescopes ... in the USA
 - Canadian Light Source; DESY, BESSY, .. in Germany; PSI/SLS in Switzerland; Ganil, SACLAY in France; Diamond Light Source and ISIS in England; KEK, J-Parc in Japan; IHEP in China; NSRRC in Taiwan; PLS in South Korea; Australian Synchrotron, ...
- Yearly collaboration meetings
 - One each in US and elsewhere
 - ~100 people attended in 2016, 2018
- 'Tech-Talk' email reflector usually provides responses within a few hours
 - <https://epics-controls.org>

<https://epics-controls.org> Meetings

Oak Ridge, 2016



Chicago, 2018



Berlin, 1998



Tzukuba, 2000



Saskatoon, 2021
& Berlin, 2020
... online ...

EPICS is a Toolkit

... for distributed control systems

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

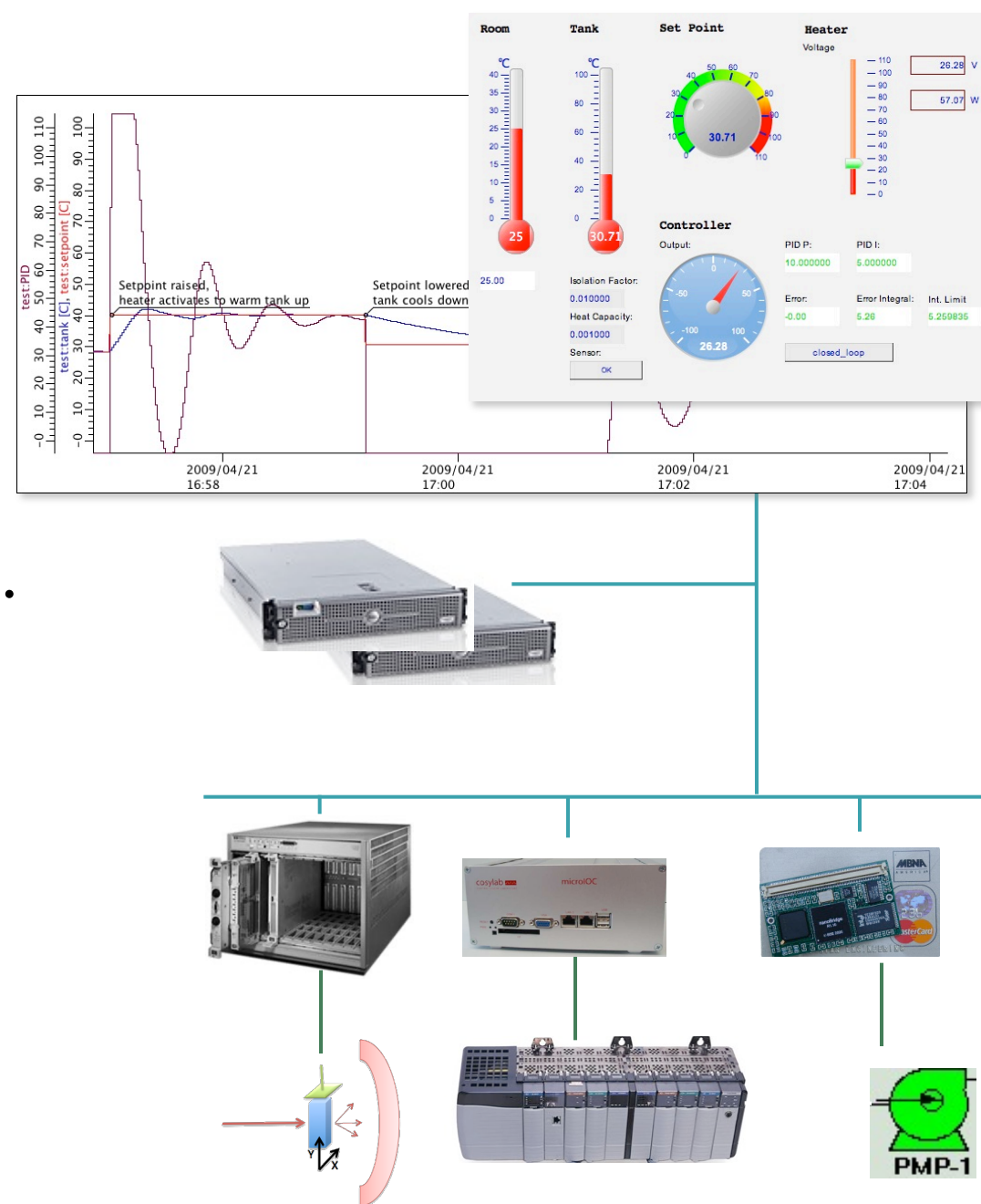
- Mostly Portable:
vxWorks, RTEMS, Linux, OS X, Windows

Distributed

- Operator interface



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



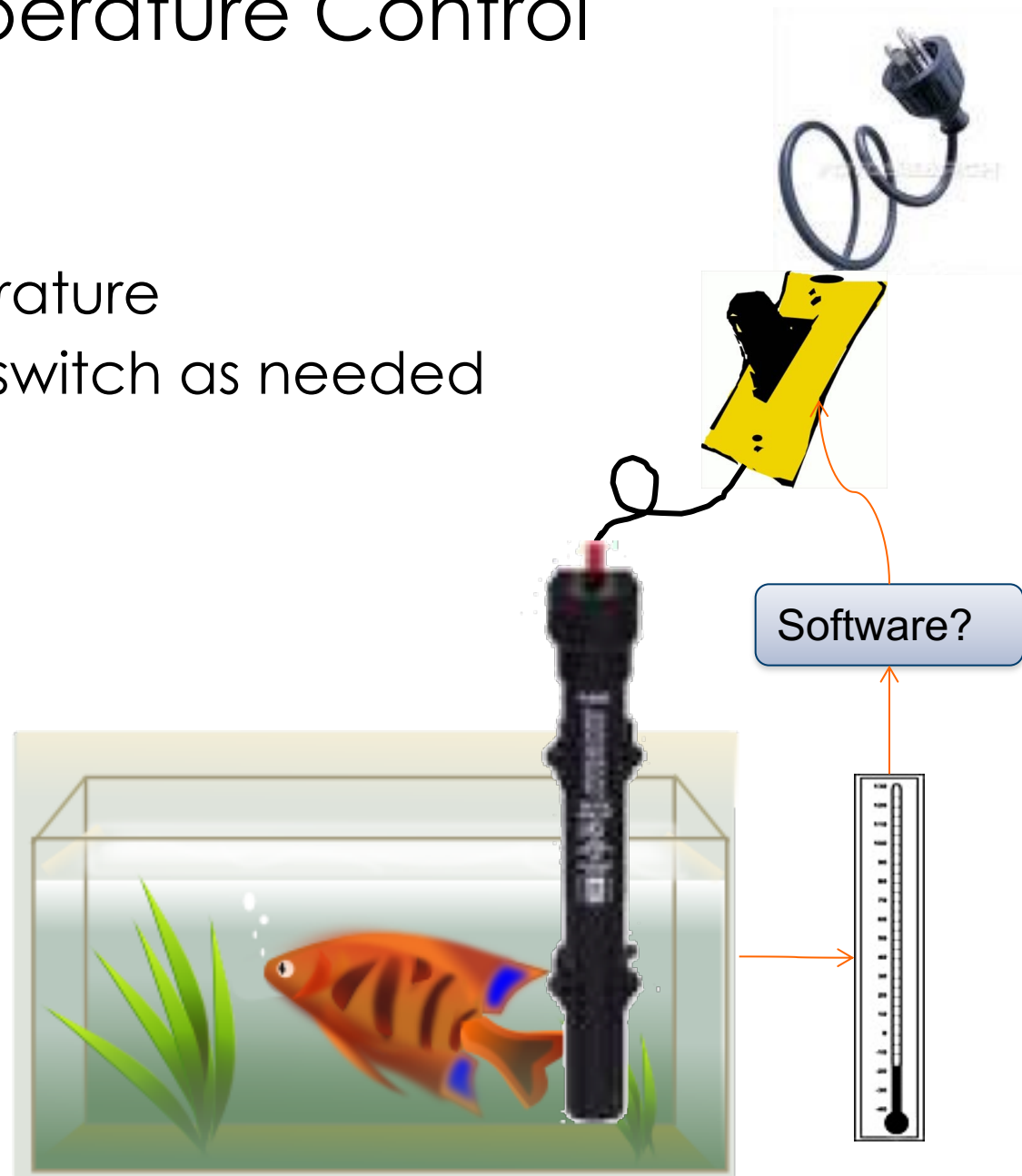
What an IOC does

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

Example: Basic Temperature Control

Task:

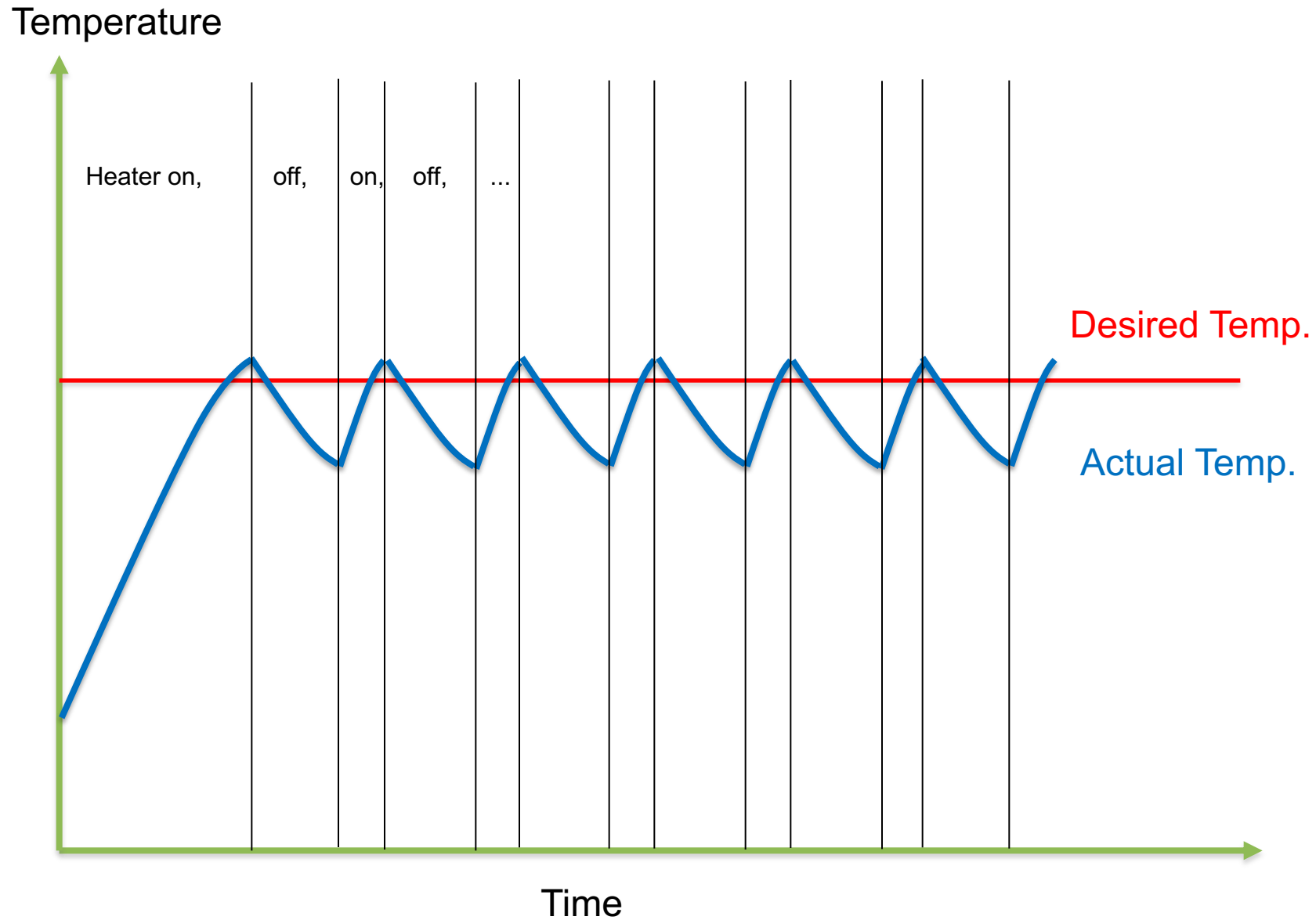
1. Read temperature
2. Open/close switch as needed
3. Repeat



Simplistic Code

```
Sensor temp = connectToSensor (...);  
Switch switch = connectToSwitch (...);  
Loop:  
    if (temp.value() < 10)  
        switch.close();  
    else  
        switch.open();  
    sleep(1.0);
```

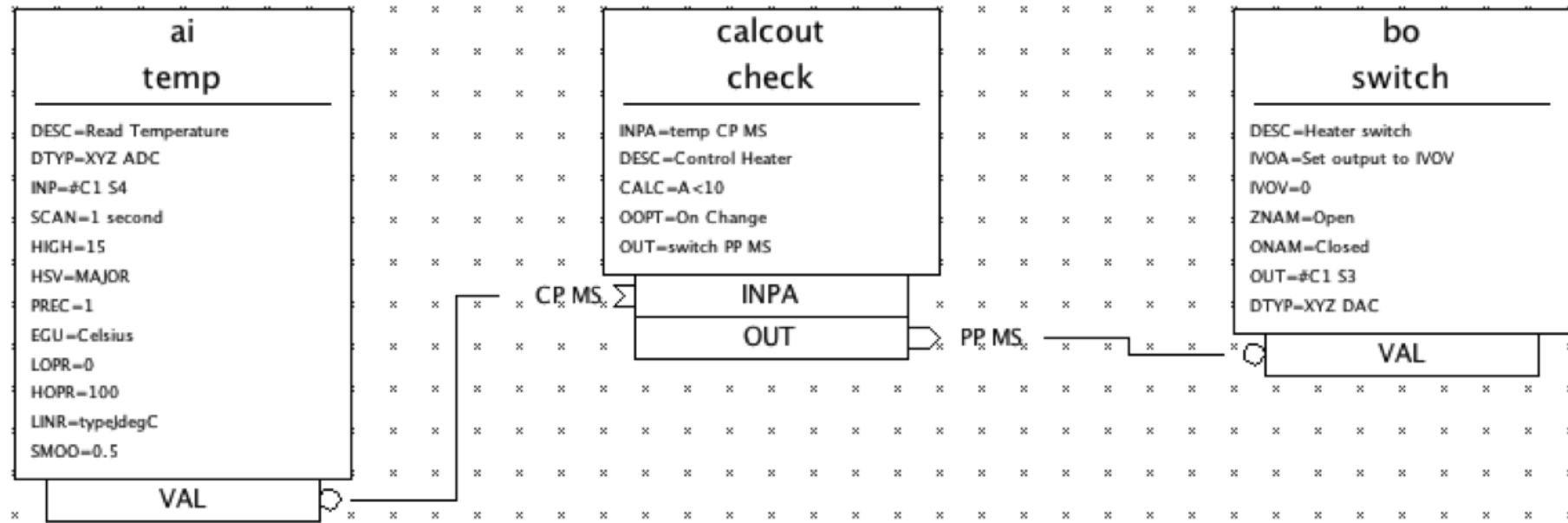
That basically works...



What we omitted

- **Error** checking
- Code **comments**
- Apply some **smoothing** to the temperature reading to filter noise.
- Send current temperature and switch state to **network** clients (**operator display**). With **units**.
- Attach a **time stamp** to the data, so that network clients can see for example when the switch was last opened.
- Send **alarm** when the temperature is too low or high.
- Allow **runtime changes** of the threshold from the remote operator interface.
- Allow runtime changes to the **scan rate**.
- Maybe allow runtime changes to the **device address**?
- What if we have more than one fishtank?

EPICS 'Database' for Fishtank



Takes getting used to, but handles what we omitted.

Some Detail on EPICS 'Records'

```
record(ai, temp) {  
    field(DESC, "Read Temperature")  
    field(SCAN, "1 second")  
    field(DTYP, "XYZ ADC")  
    field(INP, "#C1 S4")  
    field(PREC, "1")  
    field(LINR, "typeJdegC")  
    field(EGU, "Celsius")  
    field(HOPR, "100")  
    field(LOPR, "0")  
    field(SMOO, "0.5")  
    field(HIGH, "15")  
    field(HSV, "MAJOR")  
}
```

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

```
record(bo, switch) {  
    field(DESC, "Heater switch")  
    field(DTYP, "XYZ DAC")  
    field(OUT, "#C1 S3")  
    field(ZNAM, "Open")  
    field(ONAM, "Closed")  
    field(IVOA, "Set output to IVOV")  
    field(IVOV, "0")  
}
```

~~Programming~~ Configuration

- "SCAN=1 second" instead of start thread, delay until next multiple of 1 second, lock required resources, ...
- "SMOO=0.5" configures the smoothing algorithm.
- Almost any field in any record is accessible via network at runtime
 - Change scan rate, smoothing, ...

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...

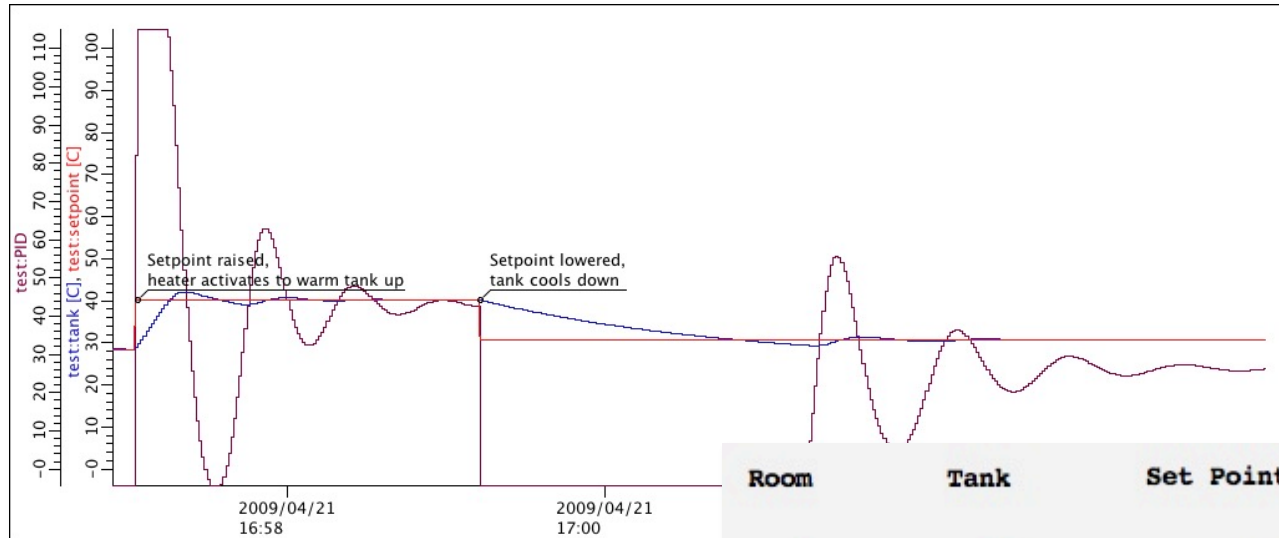
How fast?

- Can be fast or slow, it depends how you use it!
- Use the correct tool for the job; Database, custom code (IOC) or custom code (client)
- Ultimately speed depends upon hardware
- Some benchmarks*:

Machine	OS	CPU	Speed	Rec/sec	%CPU
MVME167	vxWorks	68040	33MHz	3,000	25
MVME2306	vxWorks	PPC604	300MHz	20,000	20
MVME5100	vxWorks	PPC750	450MHz	100,000	25
PC	Linux	PII	233MHz	10,000	27
PC	Linux	P4	2.4GHz	100,000	18

* Extrapolated from benchmark figures courtesy of Steve Hunt (PSI) and L.Hoff, (BNL)

Example Client: Operator Displays



Created in Editor

- No coding
nor compilation

Networked

- Open/close
- Multiple OPIs



EPICS Vocabulary

- **EPICS Base**
Code for IOC, database support, basic records, channel access
- **IOC**
Input Output Controller, the front-end software
 - **Hard IOC**
Using real-time OS in VME crate running nothing but IOC code
 - **Soft IOC**
IOC software just another process on host, typically communicating with networked I/O
- **Database**
Executes the EPICS **Records**
- **Record**
EPICS processing block
- **Device** support
Code that connects records to hardware Driver
- **Driver**
Code that talks to hardware. May be unaware of EPICS
- **Channel Access, PV Access**
EPICS network protocols. Expose **Channels** aka **Process Variables**

Information

- ~~<http://www.aps.anl.gov/epics>~~
~~<https://epics.anl.gov>~~
<https://epics-controls.org>

'Base'

- 'Record Reference Manual'
Everybody Must read!
- 'EPICS Application Developer's Guide'
Technical detail about 'makeBaseApp', build system,
device support, C/C++ API

'Modules', 'H/W by Manufacturer'

- Look there for device support

'Talk', 'tech-talk'

- Primary mailing list

EPICS Summary

- Control System Toolkit
 - Distributed, multi-platform, open source, extensible, ...
- Not fancy, but “works”
 - Accelerators,
Beam lines,
Telescopes,
Fusion experiments,
...

