

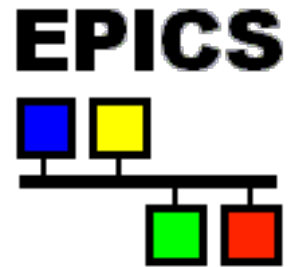
Experimental Physics and Industrial Control System Overview

Kay Kasemir

July 2026

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

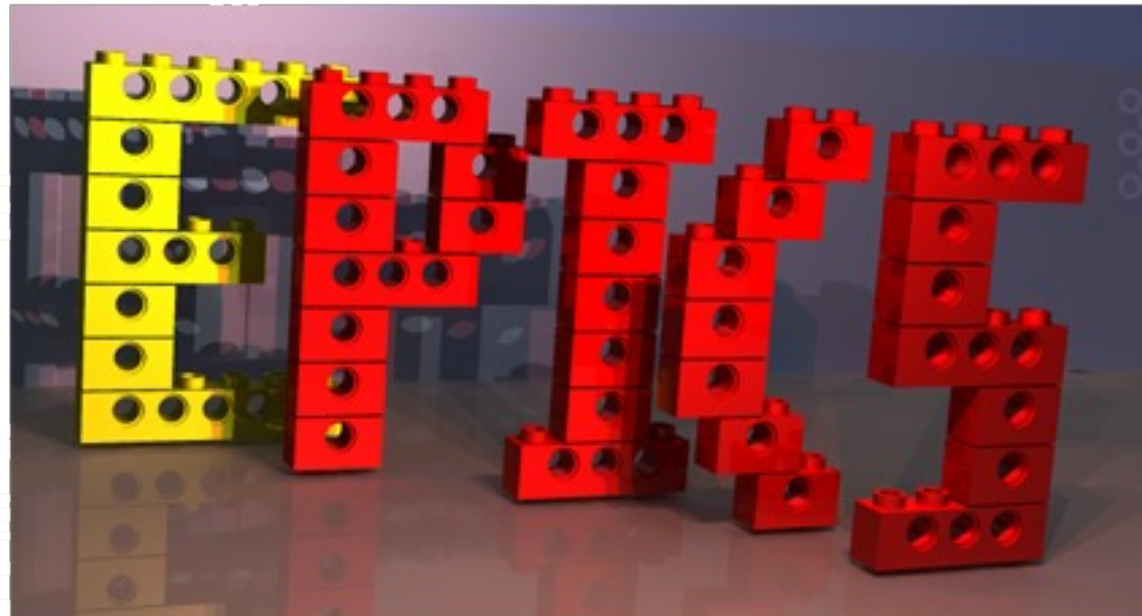
What EPICS looks like



Network Diagram, ~1990



Network Diagram, ~2019



Block Diagram, ca. 2000

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-a38c8alfe008>

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 thank 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

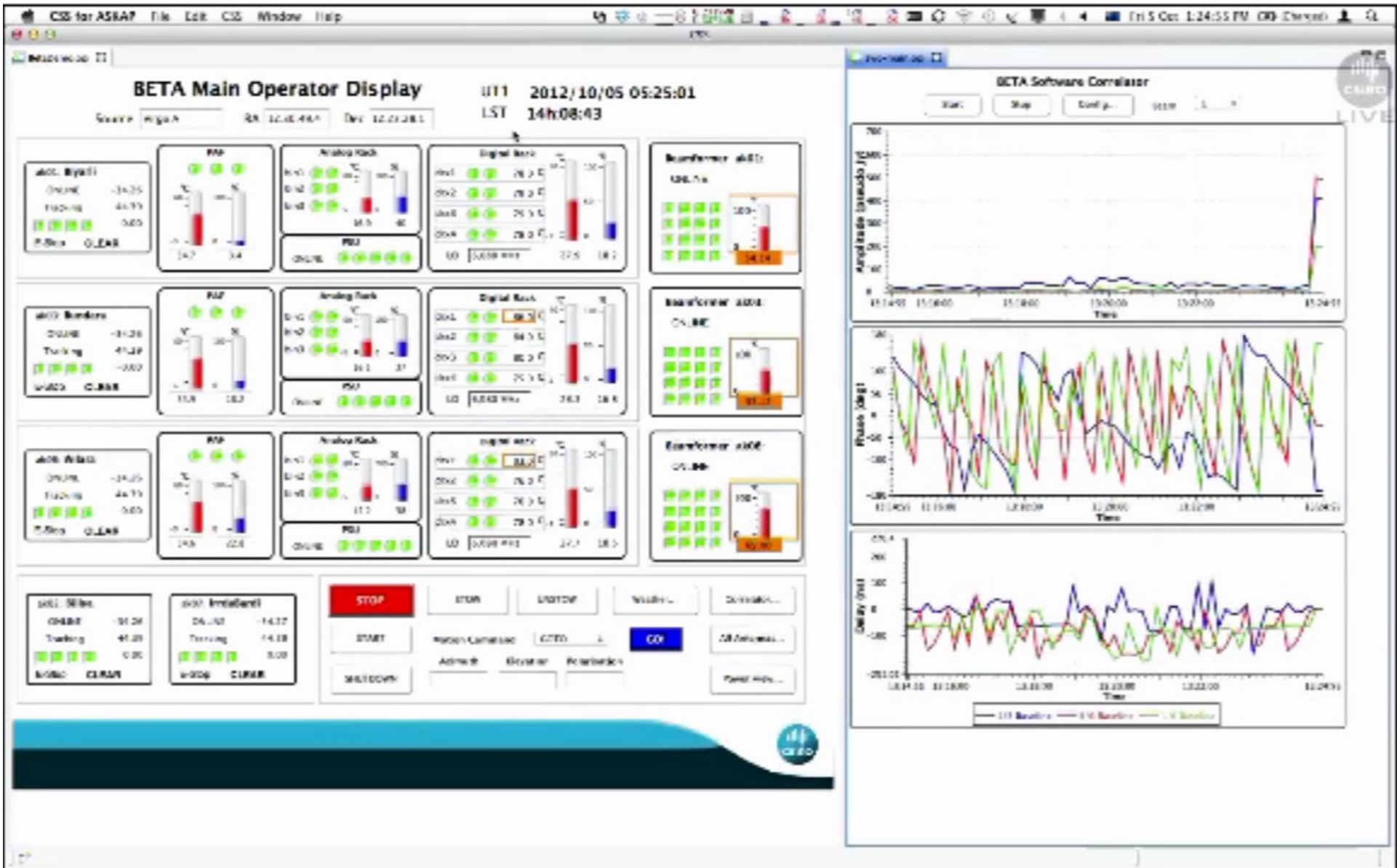
ASKAP Telescope Monitor and Control Team Leader

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



Hardware Monitor and Control Module

Date and Time: 2011/11/03 15:19:13 Set Fans Level (0<value<110): 100

Username: Unknown system PV user/ Submit

Hostname: fpacph.local

Used Memory: 143.230 MB

Free Memory: 79.922 MB

Available Memory: 227.562 MB

CENTELLIS TEMPERATURE MEASUREMENTS

FTM TEMP #1: 27.16 °C

FTM TEMP #2: 31.68 °C

FTM TEMP #3: 24.7 °C

CENTELLIS FANTRAY SPEEDS

Alarm Indicator LED

Fan#1 Speed (RPM): 2145

Fan#2 Speed (RPM): 2.178E3

Fan#3 Speed (RPM): 2211

CODAC SysSTATUS

- Not ready
- Ready
- Start of pulse sequence
- Wait for systems initialised
- Pre-pulse checks
- Final preparation
- Pulse
- After pulse checks

Stop

Exclude

MARTE SysSTATUS

Execute

- Off
- Not ready
- Ready
- Initialising
- Initialised
- Executing
- Post pulse

Stop

Plasma Operational SysStateMachine STATUS

Pulse N.: 13889 Authorisation: YES

Countdown: 0.0 PulseTime: 24.0

Plasma Shape

Loop Time

Throughput

Power Injection

ORNL HFIR CG-1D

The screenshot displays the EPICS/CSS control interface for the ORNL HFIR CG-1D beamline. The interface is divided into several sections:

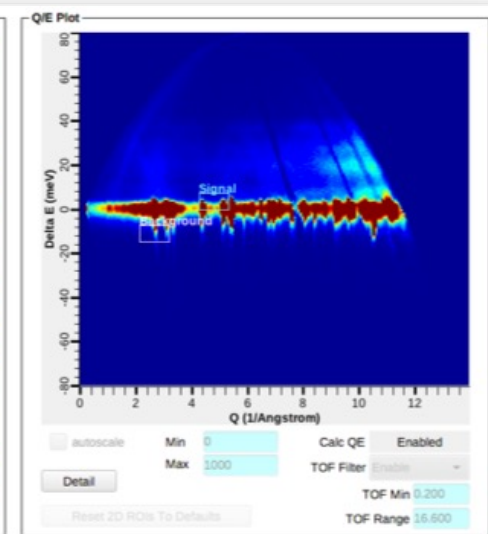
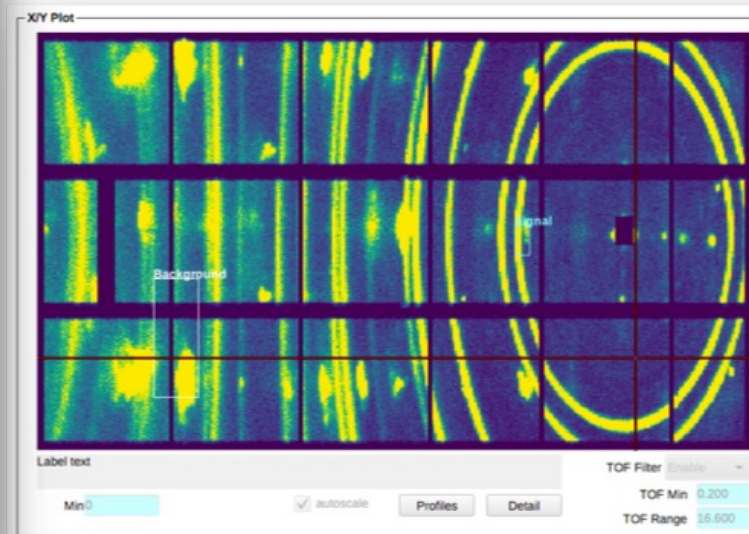
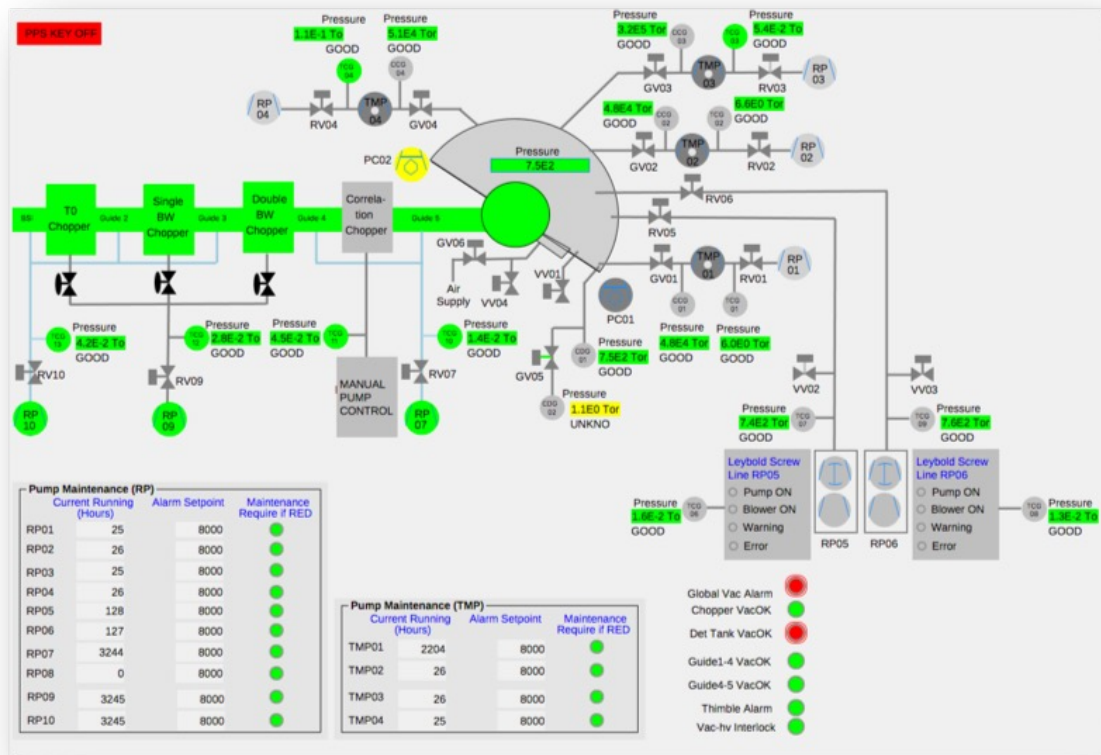
- Navigator:** Shows the file structure, including directories like 'GIT_cg1d', 'T_share', 'data', and 'Turbine_4_CT' with a list of FITS files.
- Camera Control:** Includes settings for Exposure Time (180.000), Binning (1), ADC Speed (1.00 MHz), Shutter Mode (Auto), and Camera State (Idle). It also features a 'Cooling' section with Cooler (On) and Temperature (-60.000) controls.
- Advanced:** Contains buttons for 'Full Control (Simulated)', 'Full Control (Andor)', 'File I/O Configure', and 'General Camera'.
- Camera View:** A central window showing a grayscale image of a turbine component with X and Y axes ranging from 0 to 2048.
- Motors:** A table listing motor parameters and their current status.
- CT Scan:** A configuration panel for the CT scan, including Start/End/Step values, Device selection, Exposure, Delay, and Directory.
- Console:** A table showing the status of scan jobs.

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

ID	Created	Name	State	%	Runtime	Finish	Command	Error
153	2013-01-08 17:54:24	Rotation Scan: Turbine_CT	Finished - OK	100%	14:35:06	08:29:31	- end -	
152	2013-01-08 17:38:07	Rotation Scan: Turbine_CT_test	Finished - OK	100%	00:15:35	17:53:42	- end -	

First EPICS/CSS operation with beam, 2013

ORNL SNS Beam Lines



X/Y ROI

	Min	Max	Mean	Total	Total +/-	Rate
Signal	11	363	116.194	22774	150.911	0 e/s
Background	0	1425	71.161	160824	401.029	0 e/s
S/B	0.000	0.255	1.633	0.142	0.001	0.000

Q/E ROI

	Min	Max	Mean	Total	Total +/-	Rate
Signal	44	8996	778.156	105051	324.116	0 e/s
Background	6	2090	182.778	24675	157.083	0 e/s
S/B	7.333	4.304	4.257	4.257	0.030	0.000

Data Collection

Total Counts	4890418	0 e/s
Proton Charge	4.0063559E-1 C	
Beam Power	1402537 Watts	
Data Collection State	Idle	
Data Collection Pause	Not Paused	

Q/E Axes & ROI Position Details

	ROI Start	ROI Size	Start	End	Bin Size	
Q Signal	4.268	1.067	Q Axis	0.0000	13.9396	0.0697
E Signal	0.000	7.500	E Axis	-80.0000	80.0000	0.8000
Q Background	2.134	1.067				
E Background	15.000	7.500				

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
 - European Spallation Source in Sweden; 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
 - Typically, >100 people
- 'Tech-Talk' email reflector usually provides responses within a few hours
 - <https://epics-controls.org>
 - Matrix-based chat



Left to right: Ryotaro Tanaka(ICALPECS2009 Chair), Jeffrey O. Hill, Martin R. Kraimer, Leo R. Daleisio, In Soo Ko(ICALPECS ISAC Chair), October 15, 2009, Kobe Japan.

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

Oak Ridge, 2016 & 2024



Chicago, 2018



Tzukuba, 2000



Berlin, 1998



...

Oxfordshire 2025



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

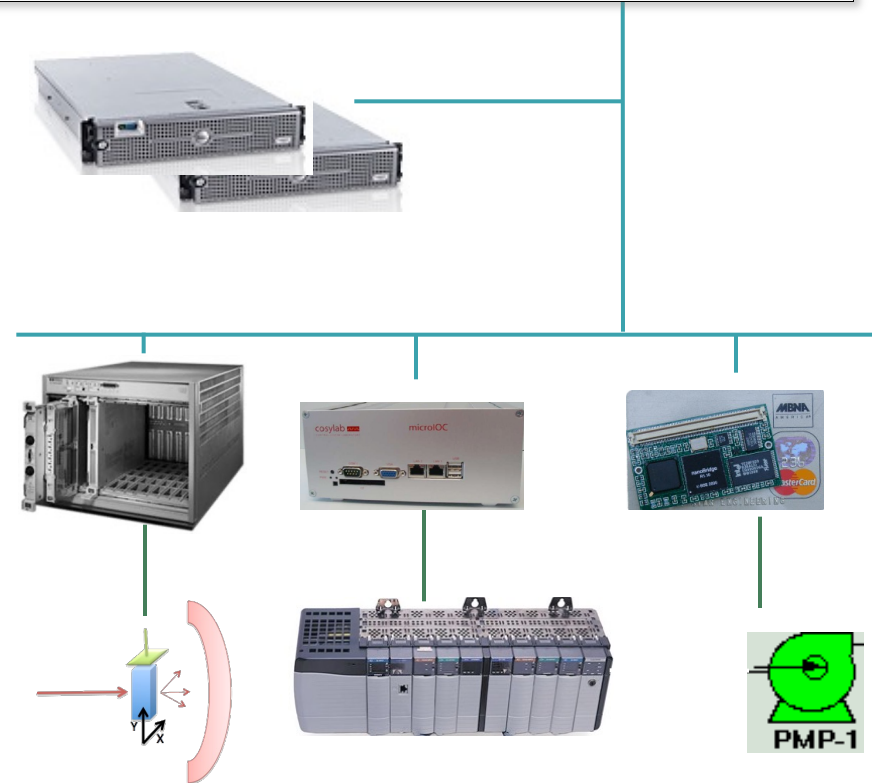
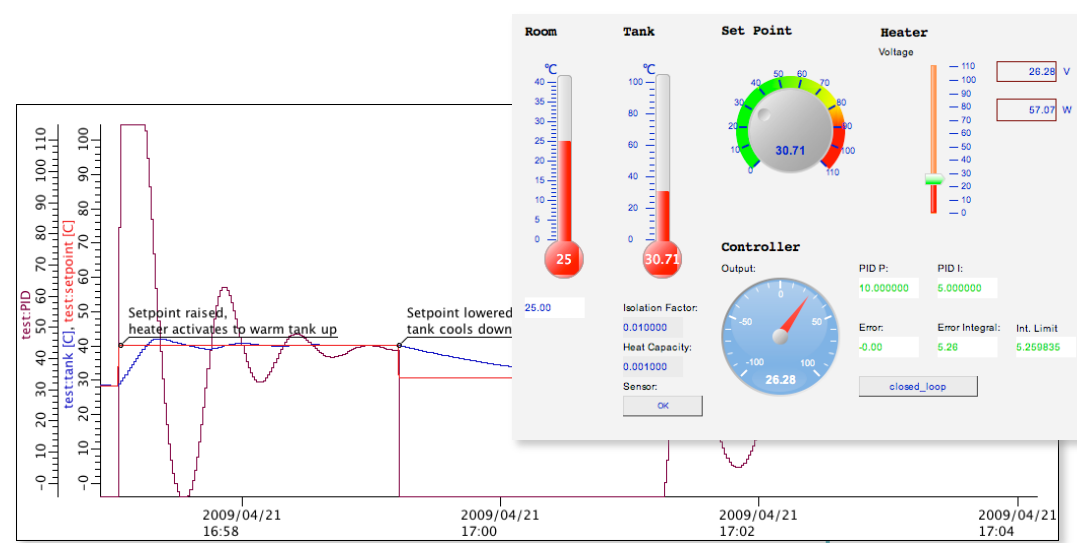
- Operator interface



- Services: Archive, ...

- Front-end IOCs

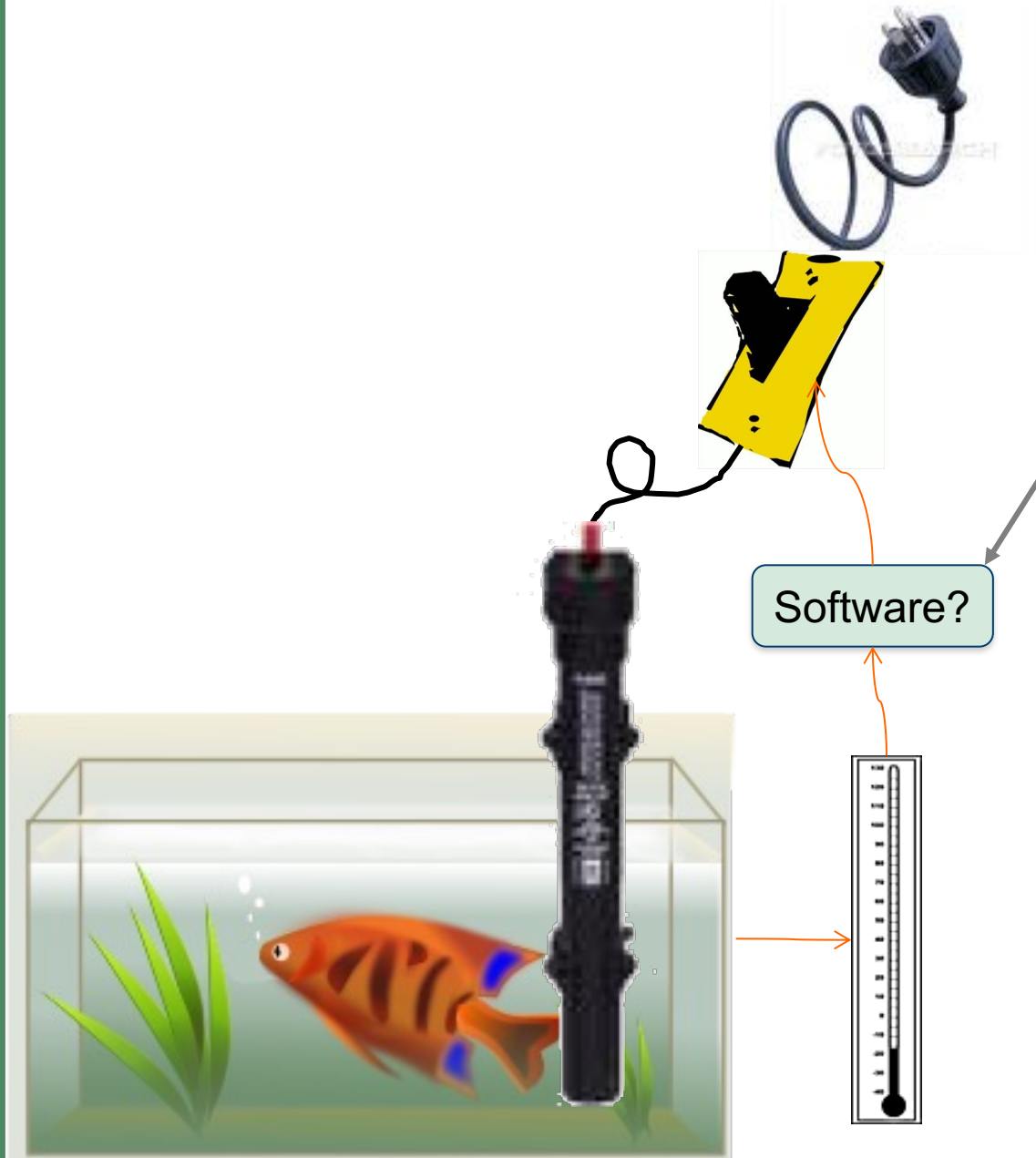
- I/O, PLCs, ..



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 PV Access

Example: Basic Temperature Control



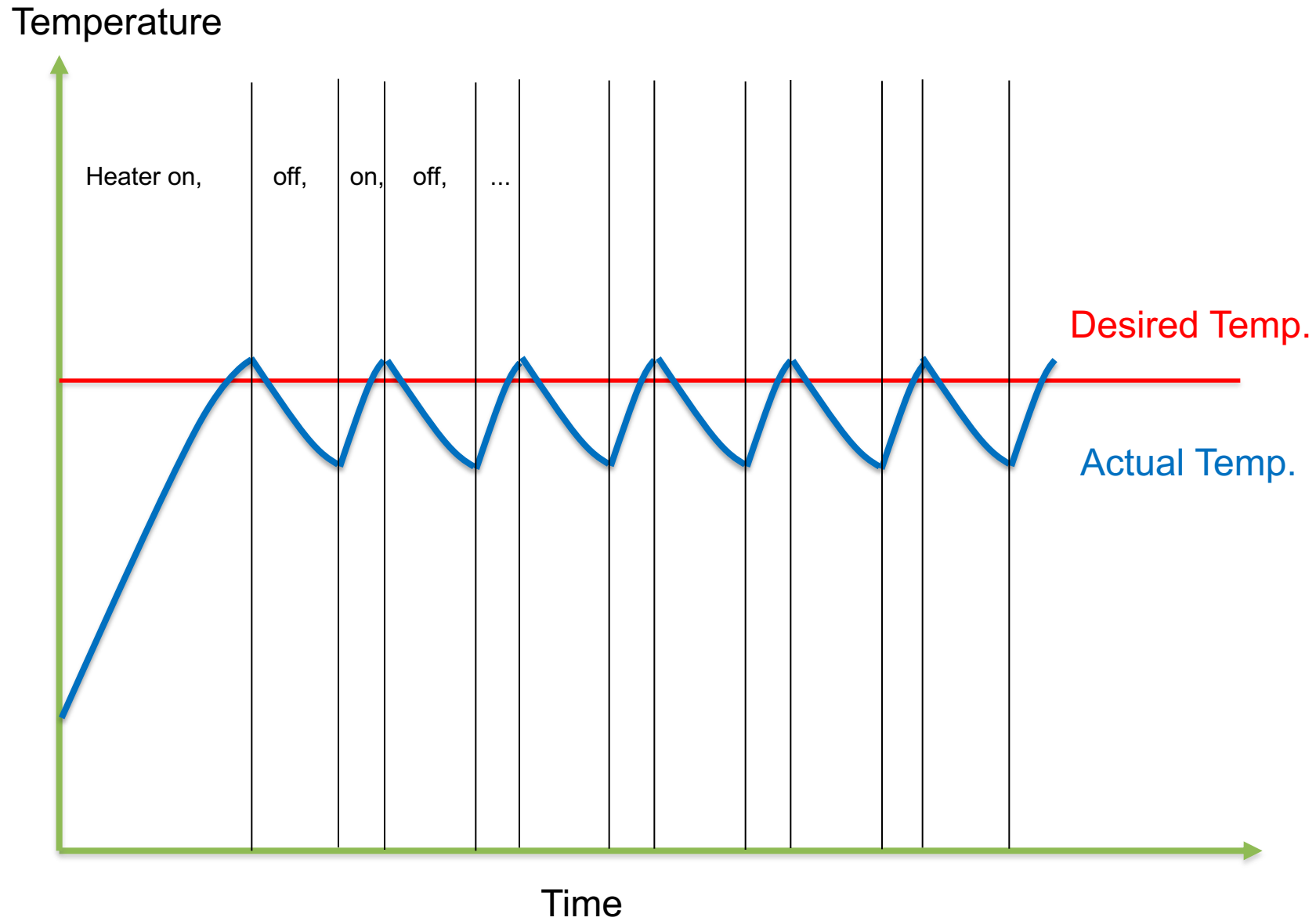
Task:

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);
```

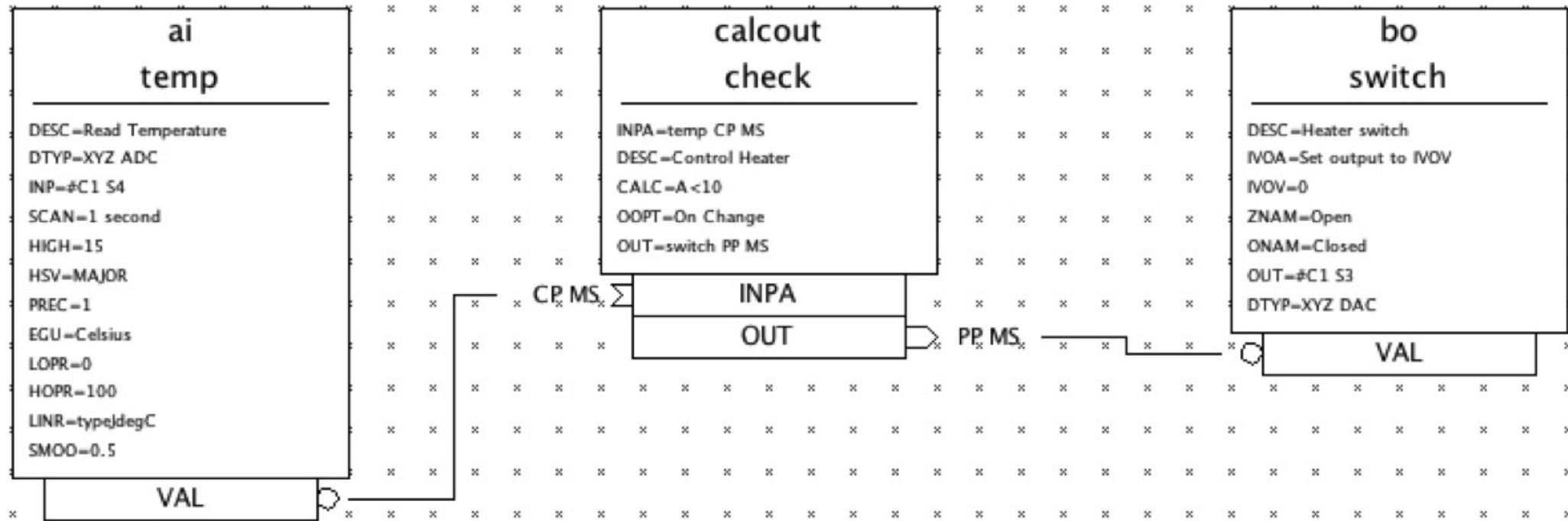
That basically works...



What we omitted

- **Error** checking
- Code **comments**
- **Smoothing** of 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?

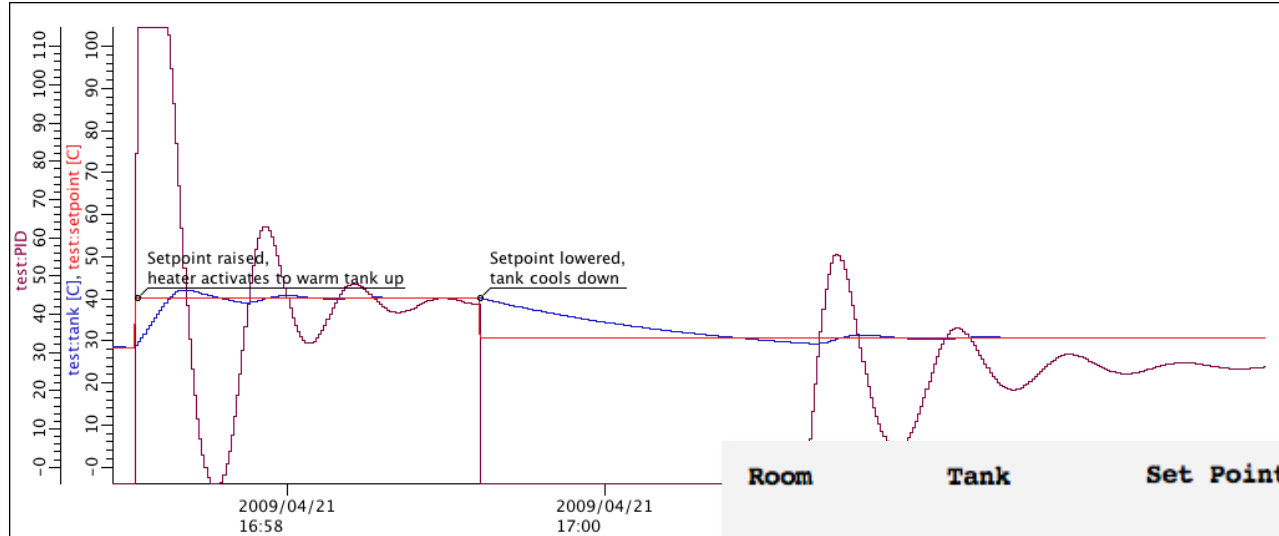
- Can be fast or slow, it depends how you use it!
- Use the correct tool for the job; Database, custom code (IOC) or custom code (client)
- Ultimately speed depends upon hardware
- Some benchmarks*:

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

2026 Example
SNS MPS IOC
60000 records,
8 CPU cores,
overall average 2%

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

Example Client: Operator Displays

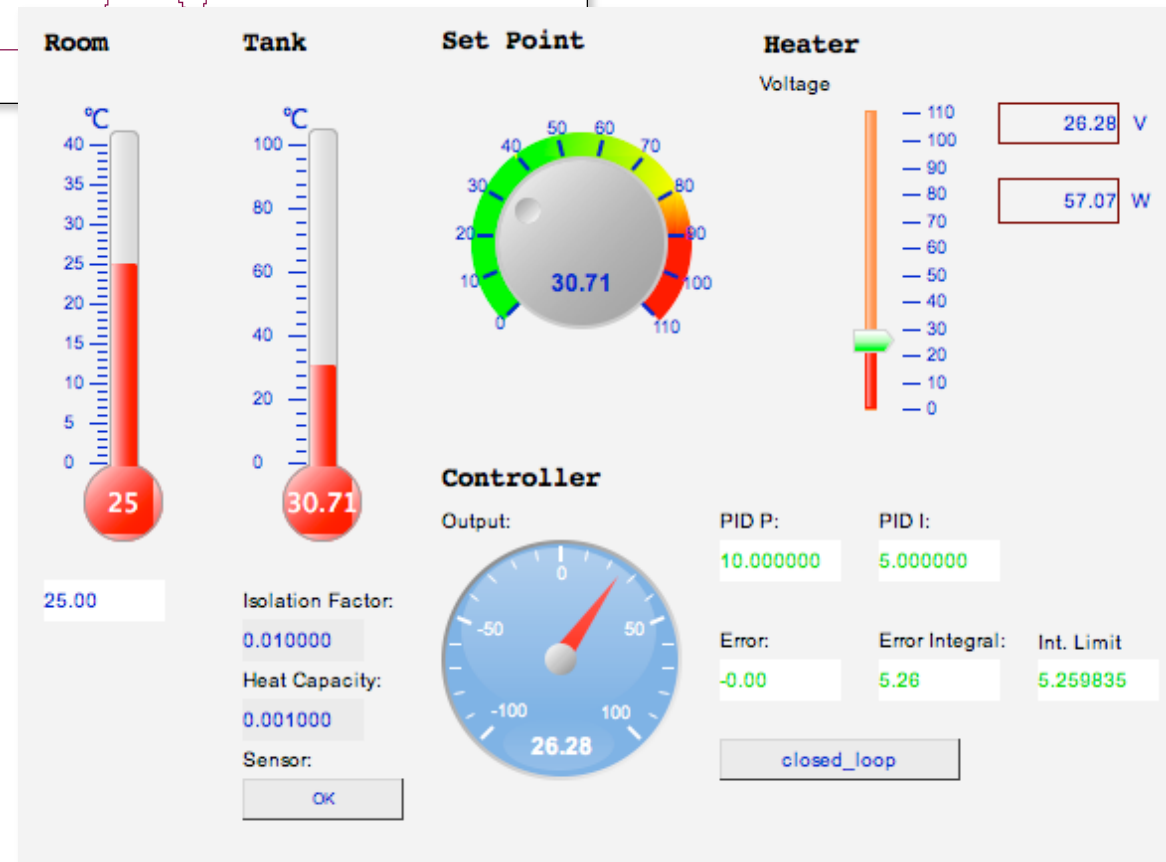


Created in Editor

- No coding, no 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 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

- ~~<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,
...

