Experimental Physics and Industrial Control System

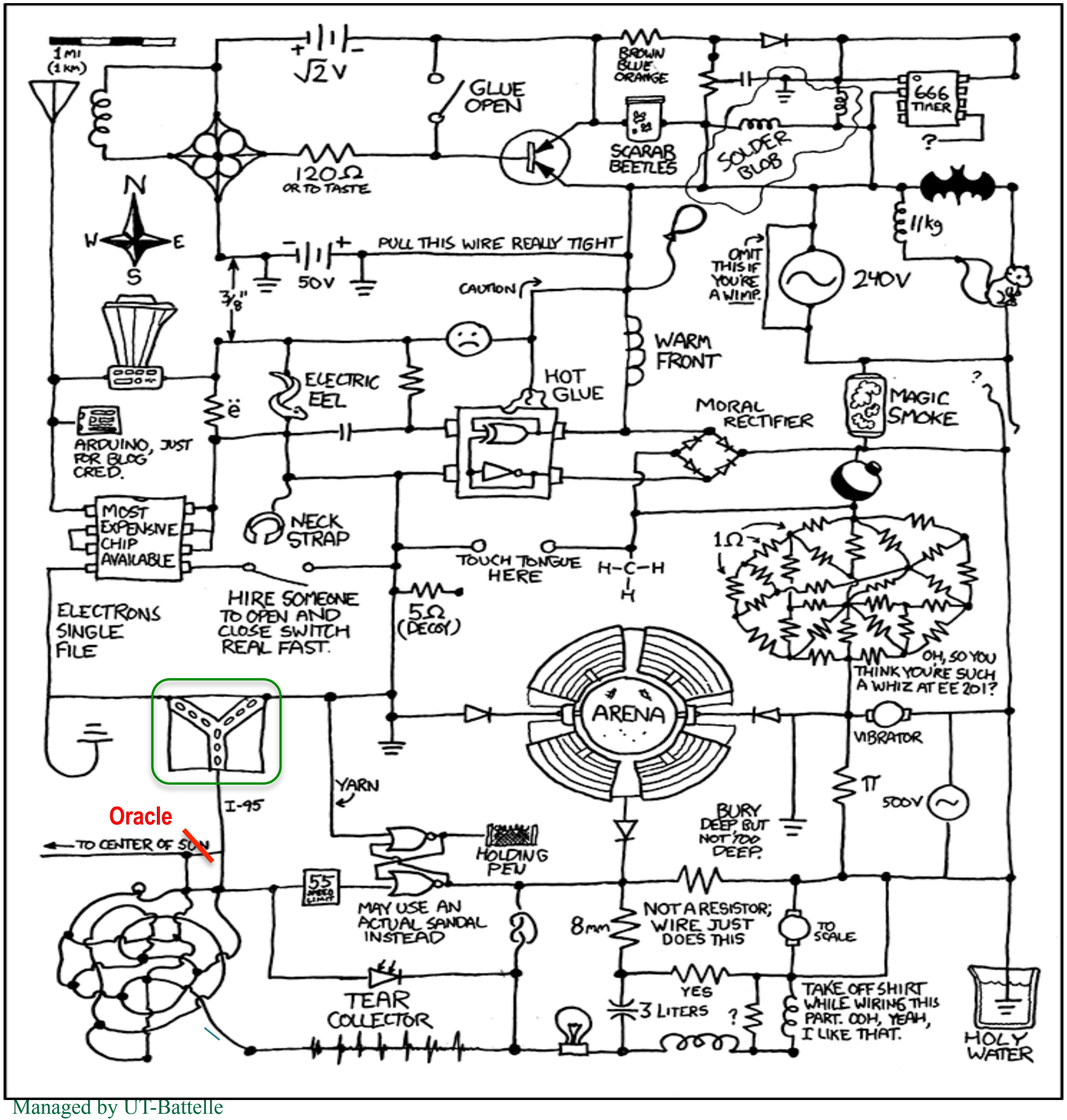
EPICS

Kay Kasemir

kasemirk@ornl.gov

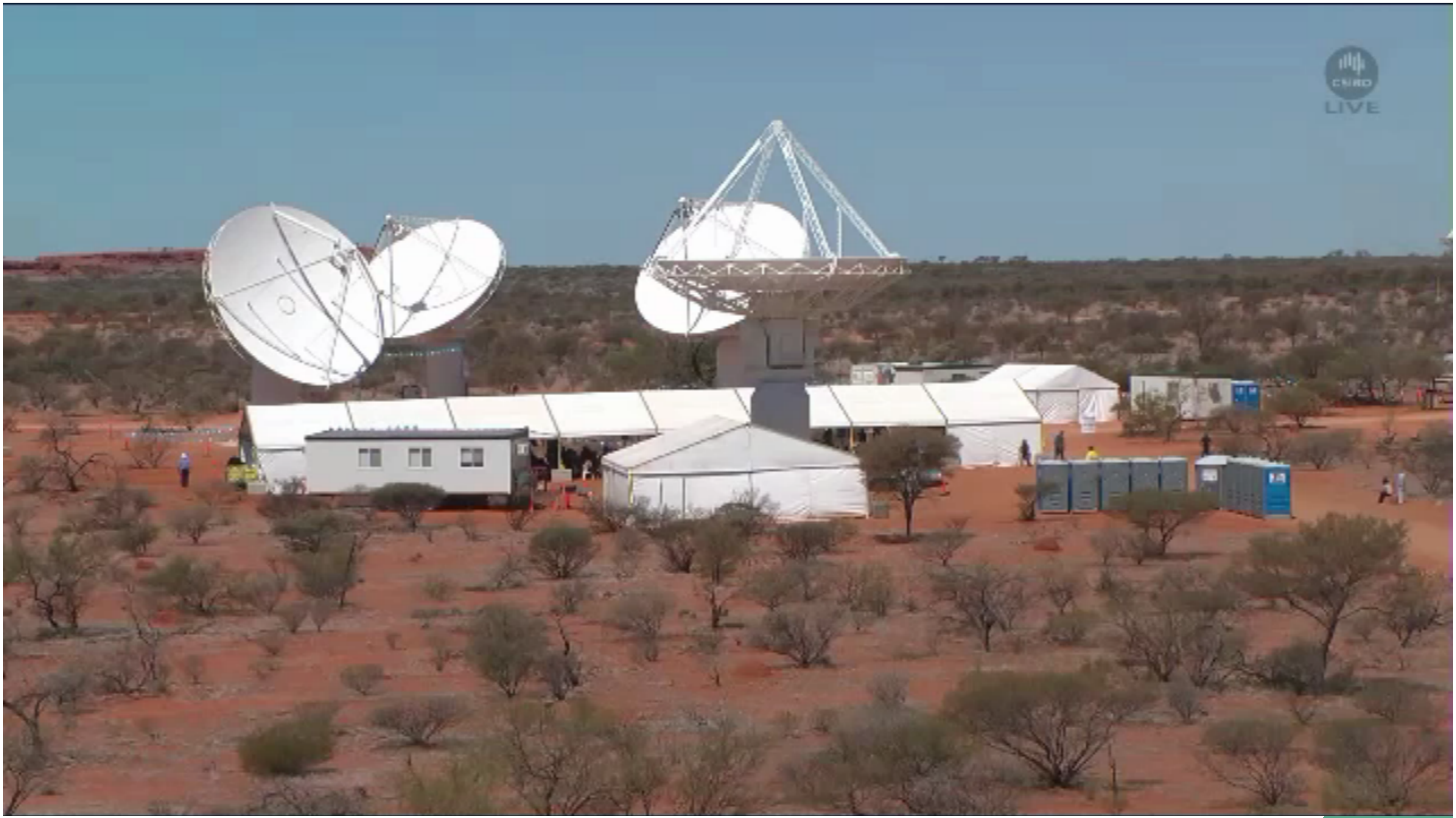
Sept. 2014

What EPICS looks like



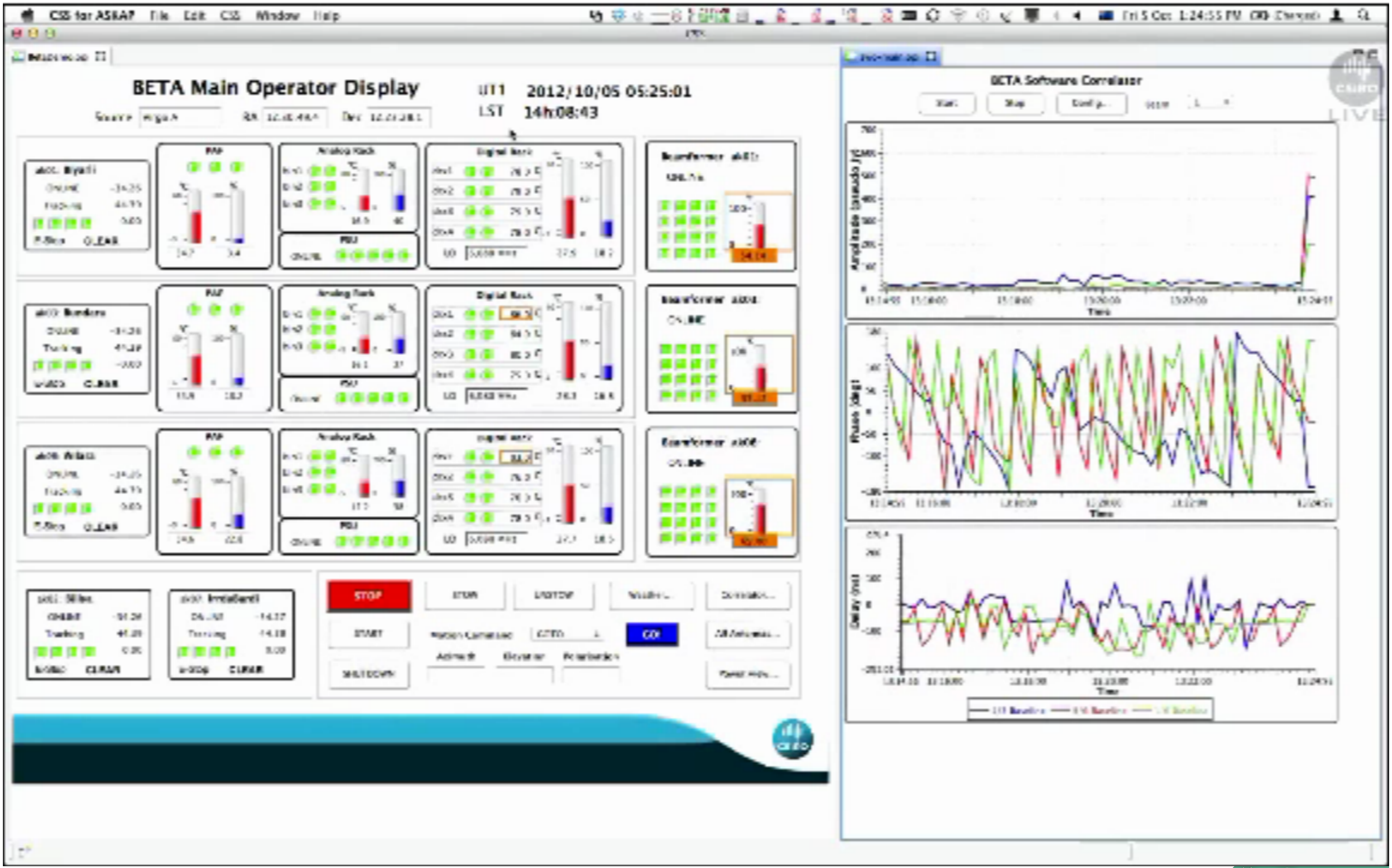
http://xkcd.com/730/

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



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

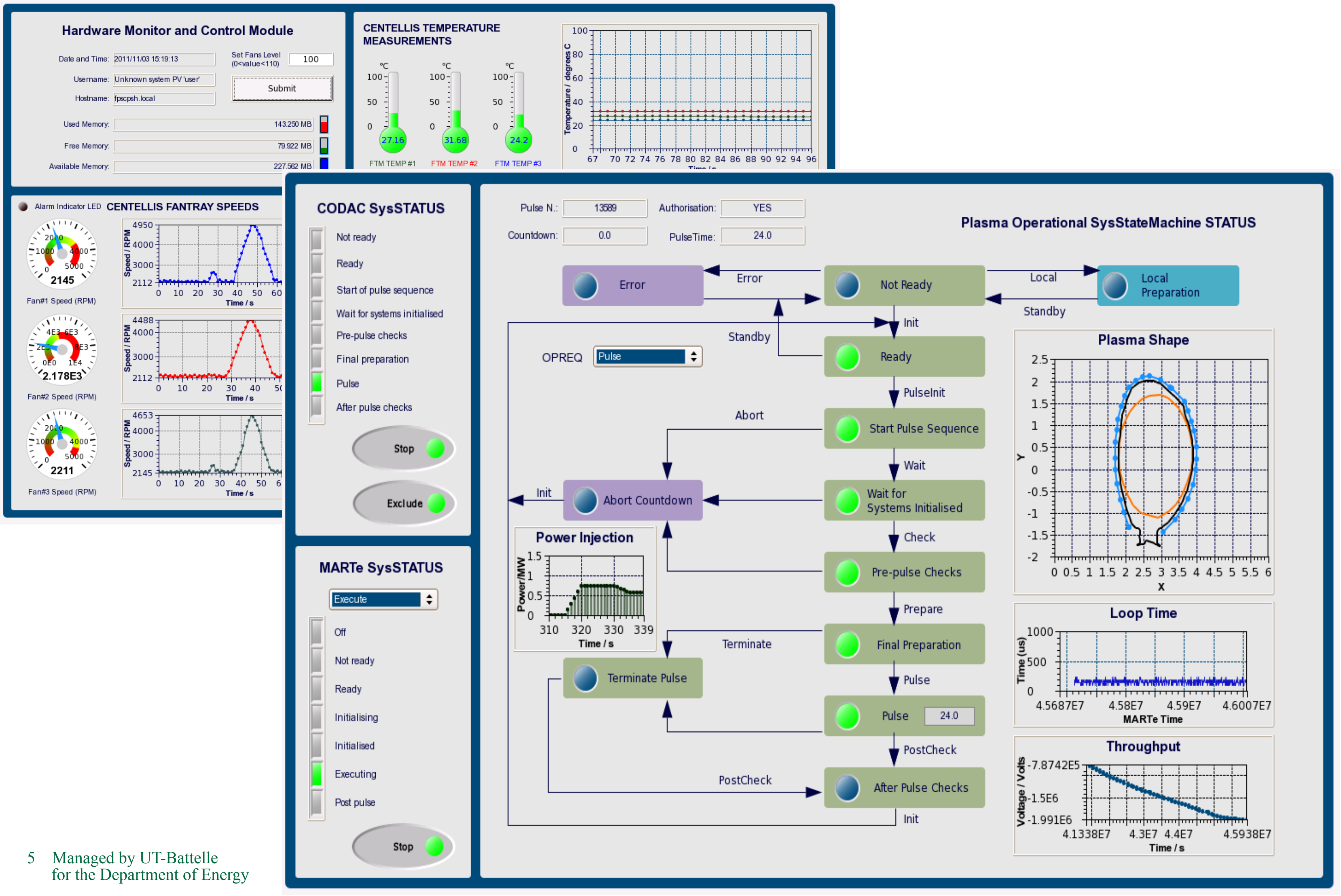
ASKAP User Interface



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

ITER

ITER-FPSC-vBetaVersionPanelsOPI-UserManual.doc, Nadine Utzel, 2011



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'

Hostname: fpscpsh.local

Used Memory: 143.250 MB

Free Memory: 79.922 MB

Available Memory: 227.562 MB

Alarm Indicator LED

CENTELLIS FANTRAY SPEEDS

Fan#1 Speed (RPM): 2145

Fan#2 Speed (RPM): 2.178E3

Fan#3 Speed (RPM): 2211

CENTELLIS TEMPERATURE MEASUREMENTS

FTM TEMP #1: 27.16

FTM TEMP #2: 31.68

FTM TEMP #3: 24.2

CODAC SysSTATUS

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

MARTe SysSTATUS

Execute

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

Plasma Operational SysStateMachine STATUS

Pulse N.: 13589

Authorisation: YES

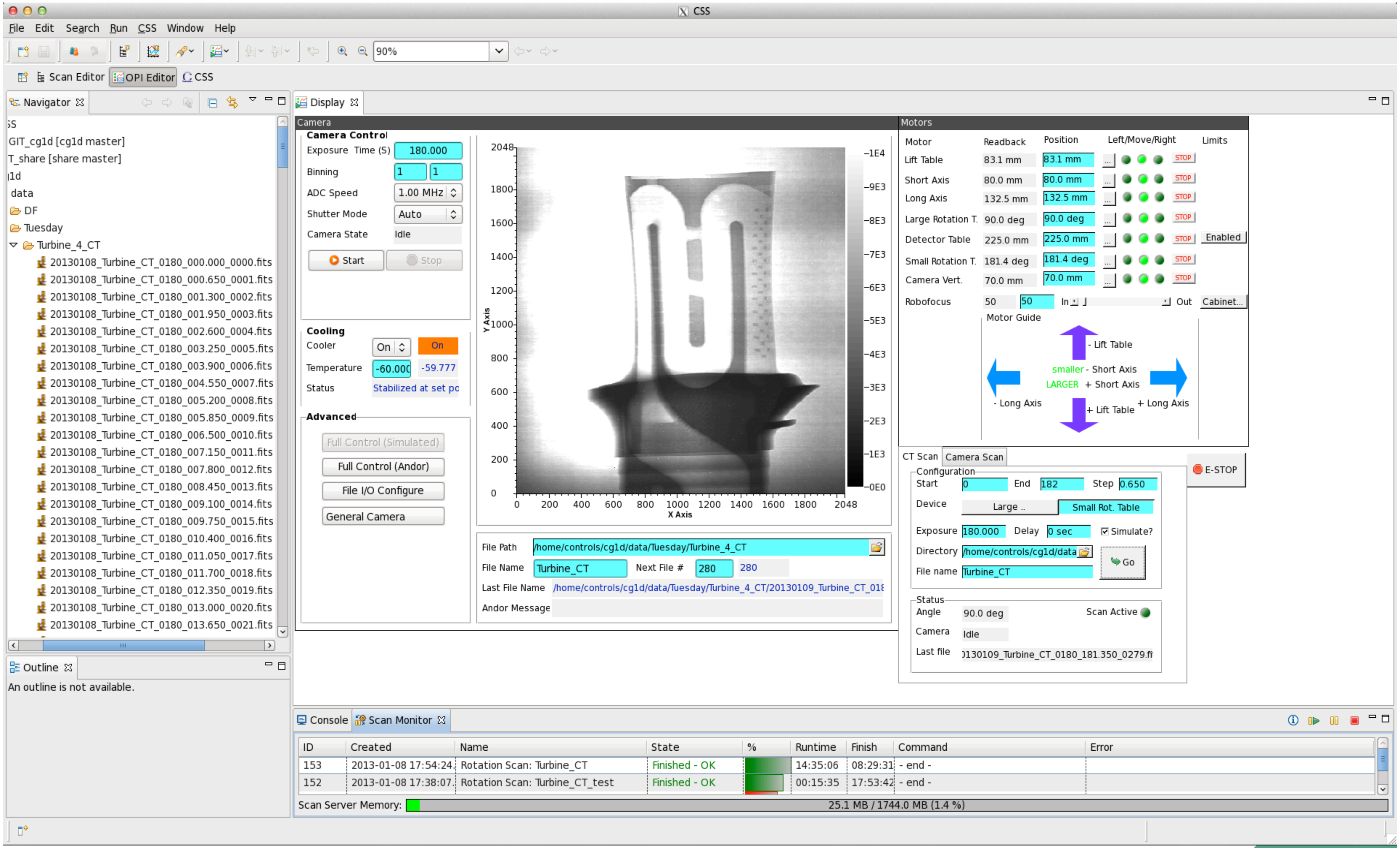
Countdown: 0.0

PulseTime: 24.0

OPREQ: Pulse

Pulse: 24.0

HFIR CG-1D



Navigator

- SS
- 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

Outline: An outline is not available.

Camera Control

Exposure Time (S) 180.000
Binning 1 1
ADC Speed 1.00 MHz
Shutter Mode Auto
Camera State Idle

Cooling

Cooler On On
Temperature -60.000 -59.777
Status Stabilized at set pc

Advanced

File Path /home/controls/cg1d/data/Tuesday/Turbine_4_CT
File Name Turbine_CT Next File # 280 280
Last File Name /home/controls/cg1d/data/Tuesday/Turbine_4_CT/20130109_Turbine_CT_018
Andor Message

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 Out	Cabinet...

CT Scan | Camera Scan

Configuration
Start 0 End 182 Step 0.650
Device Large .. Small Rot. Table
Exposure 180.000 Delay 0 sec ☑ Simulate?
Directory /home/controls/cg1d/data
File name Turbine_CT

Status
Angle 90.0 deg Scan Active ●
Camera Idle
Last file)130109_Turbine_CT_0180_181.350_0279.fi

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

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, 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 in England; KEK-K, J-Parc in Japan; IHEP in China; NSRRC in Taiwan; PLS in South Korea; Australian Synchroton, …
- Yearly collaboration meetings
  - One each in US and elsewhere
  - 100+ people attended in 2004, 05, 06.
- 'Tech-Talk' email reflector usually provides responses within a few hours
  - http://www.aps.anl.gov/epics

EPICS Meetings

Pohang, 2013

Santa Fe 2004

Tzukuba, 2000

Berlin, 1998

EPICS is a Toolkit

… for distributed control systems.

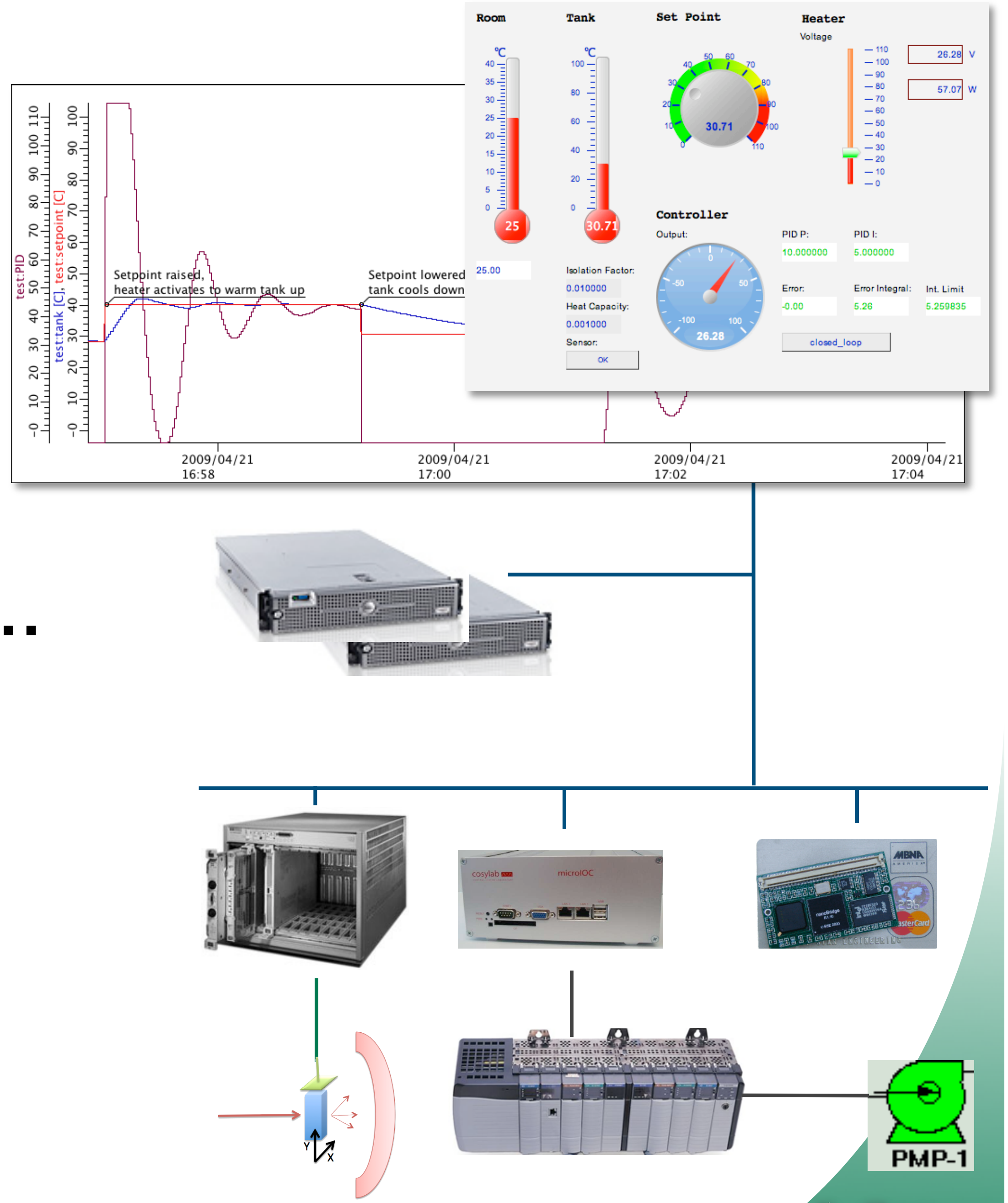
- Front-end: “Input/Output Controller” (IOC)
- Protocol: Channel Access
- Clients: Operator displays, alarm system, …

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

Distributed

- Operator interface

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



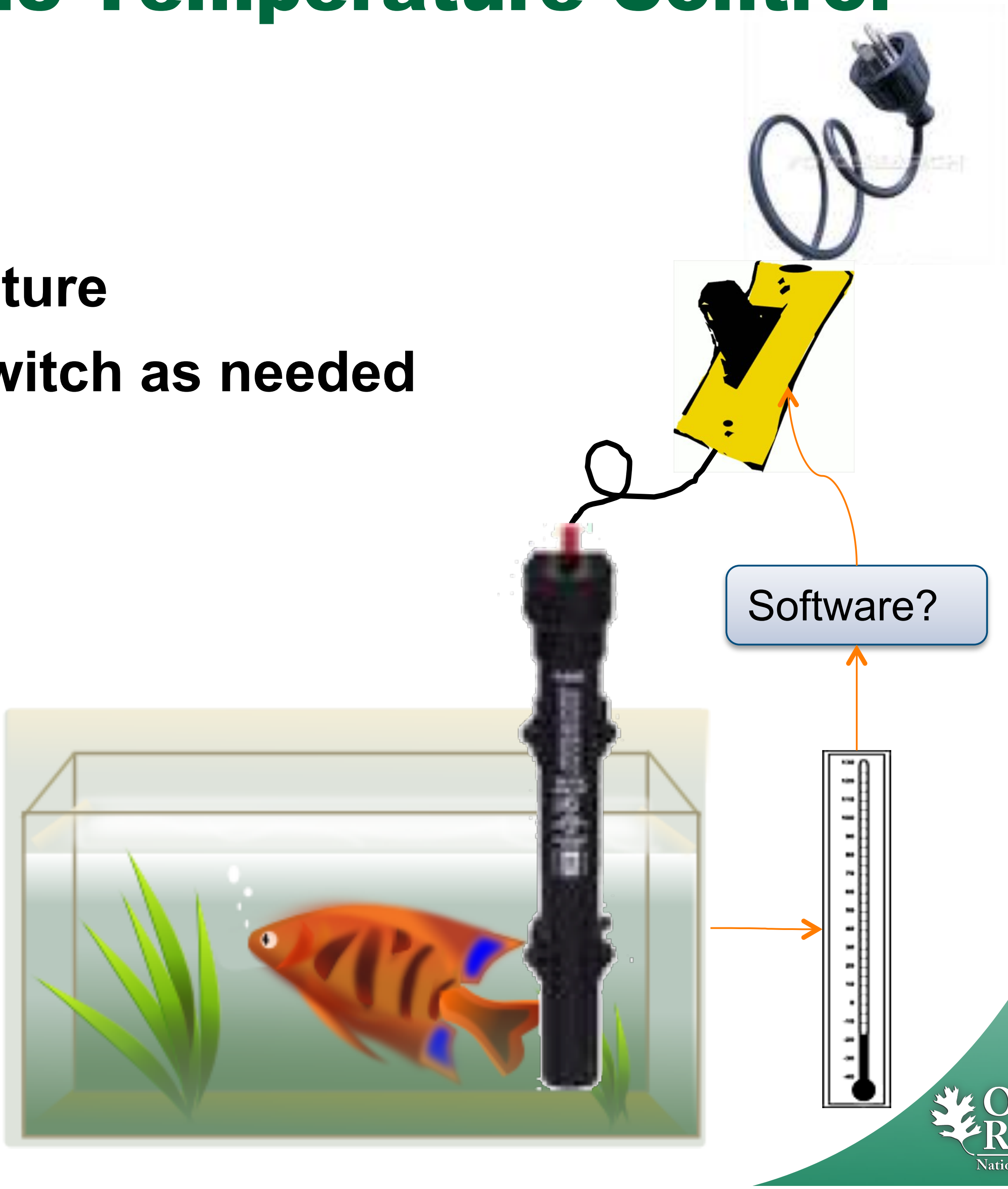
What an IOC does

- 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

Example: Basic Temperature Control

Task:

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



Software?

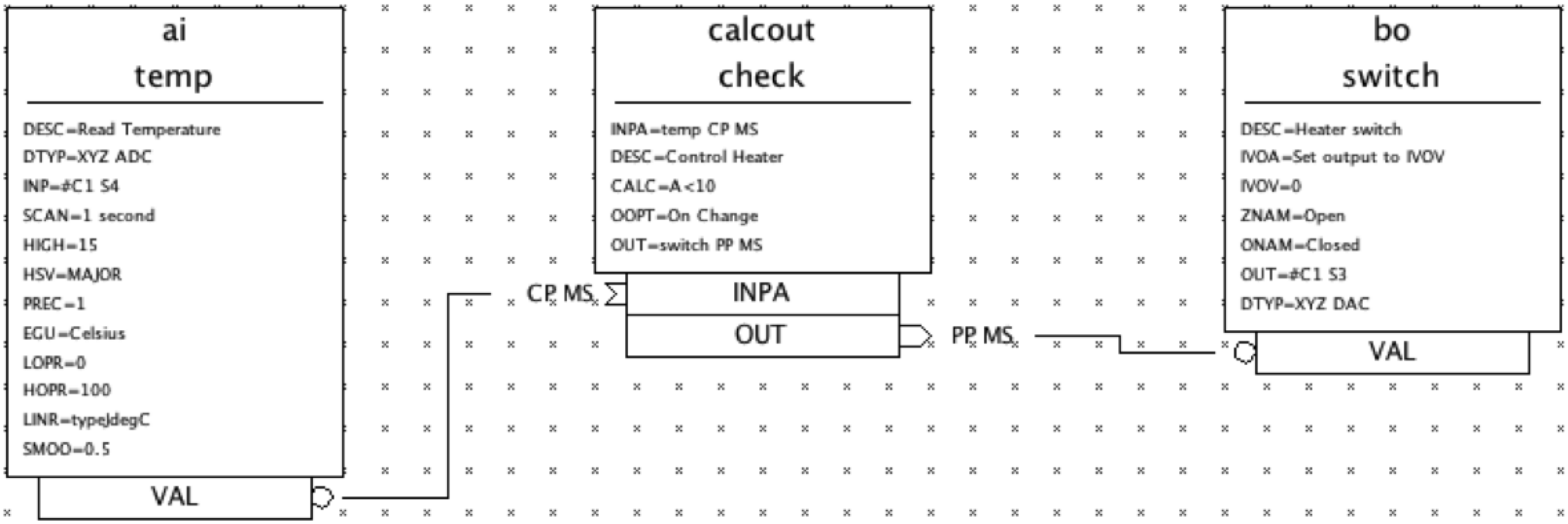
Simplistic Code

```
Sensor temp = connectToSensor(…);

Switch switch = connectToSwtich(…);

Loop:

      if (temp.value() < 25)
          switch.close();
      else
          switch.open();

      sleep(1.0);
```

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



ai
temp

DESC=Read Temperature
DTYP=XYZ ADC
INP=#C1 S4
SCAN=1 second
HIGH=15
HSV=MAJOR
PREC=1
EGU=Celsius
LOPR=0
HOPR=100
LINR=typeJdegC
SMOO=0.5

VAL

calcout
check

INPA=temp CP MS
DESC=Control Heater
CALC=A<10
OOPT=On Change
OUT=switch PP MS

INPA
OUT

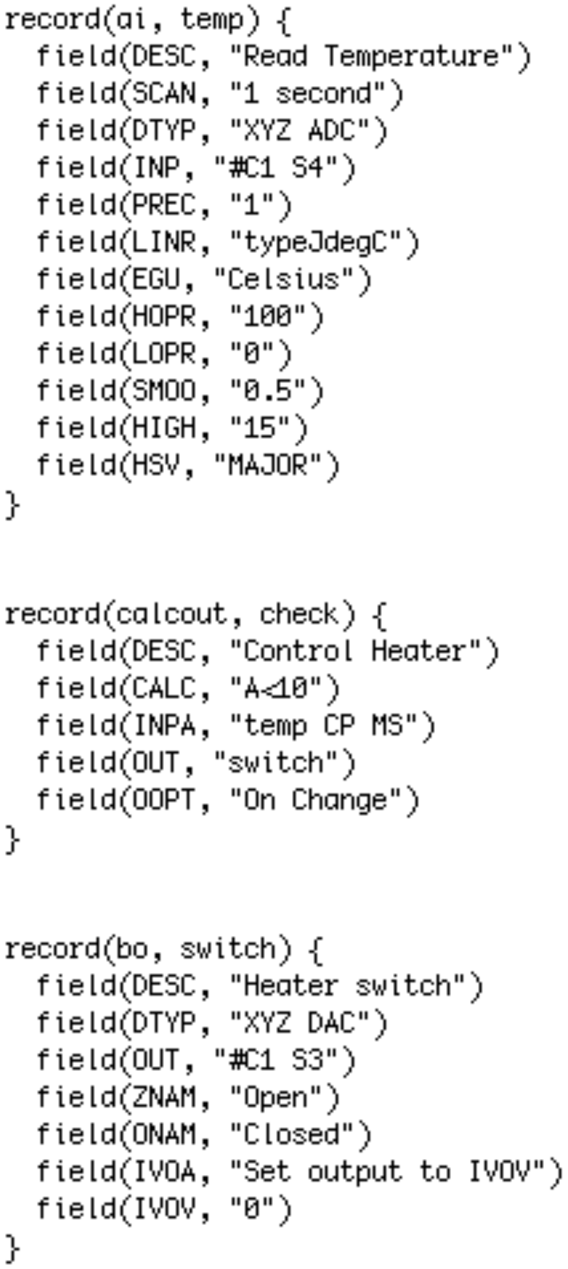
bo
switch

DESC=Heater switch
IVOA=Set output to IVOV
IVOV=0
ZNAM=Open
ONAM=Closed
OUT=#C1 S3
DTYP=XYZ DAC

VAL

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

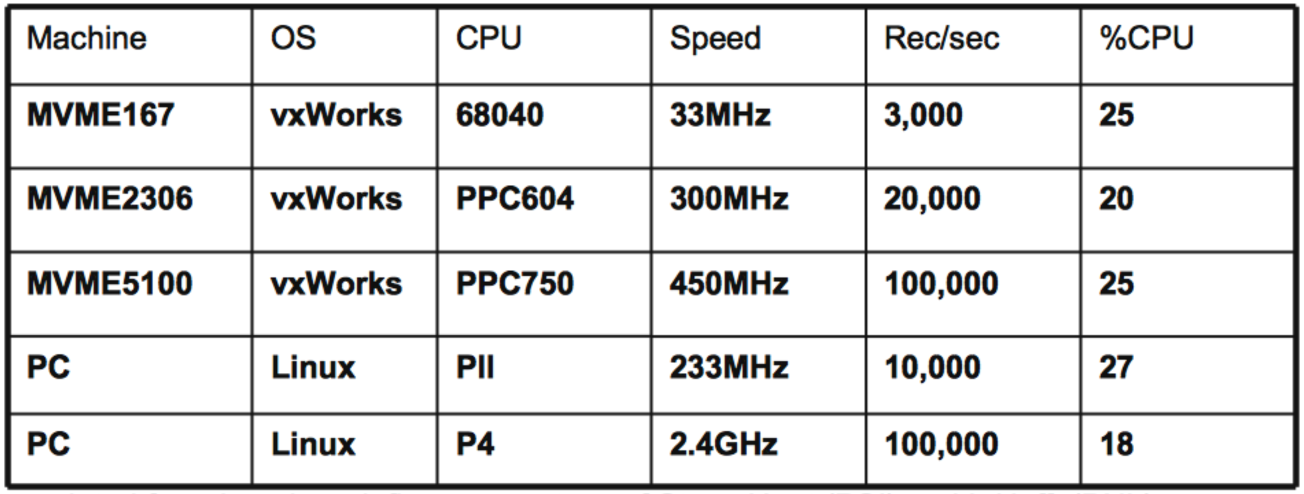
- "SCAN=1 second" instead of start thread, delay until next multiple of 1 second, lock required resources, …
- "SMOO=0.5" configures the smoothing algorithm.
- Almost any field in any record is accessible via network at runtime
  - Change scan rate, smoothing, …

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*:

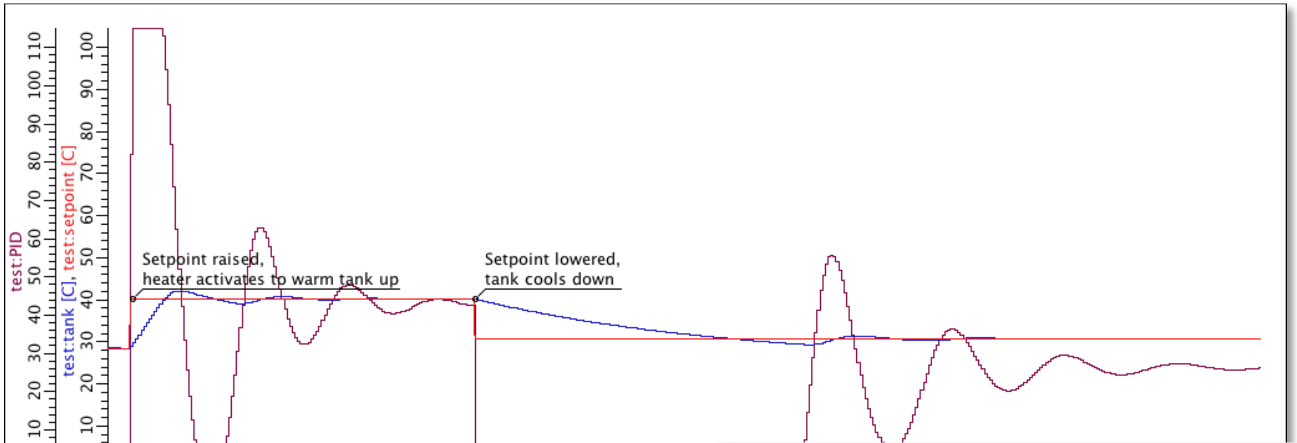


Machine	OS	CPU	Speed	Rec/sec	%CPU
MVME167	**vxWorks**	**68040**	**33MHz**	**3,000**	**25**
MVME2306	**vxWorks**	**PPC604**	**300MHz**	**20,000**	**20**
MVME5100	**vxWorks**	**PPC750**	**450MHz**	**100,000**	**25**
PC	**Linux**	**PII**	**233MHz**	**10,000**	**27**
PC	**Linux**	**P4**	**2.4GHz**	**100,000**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

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

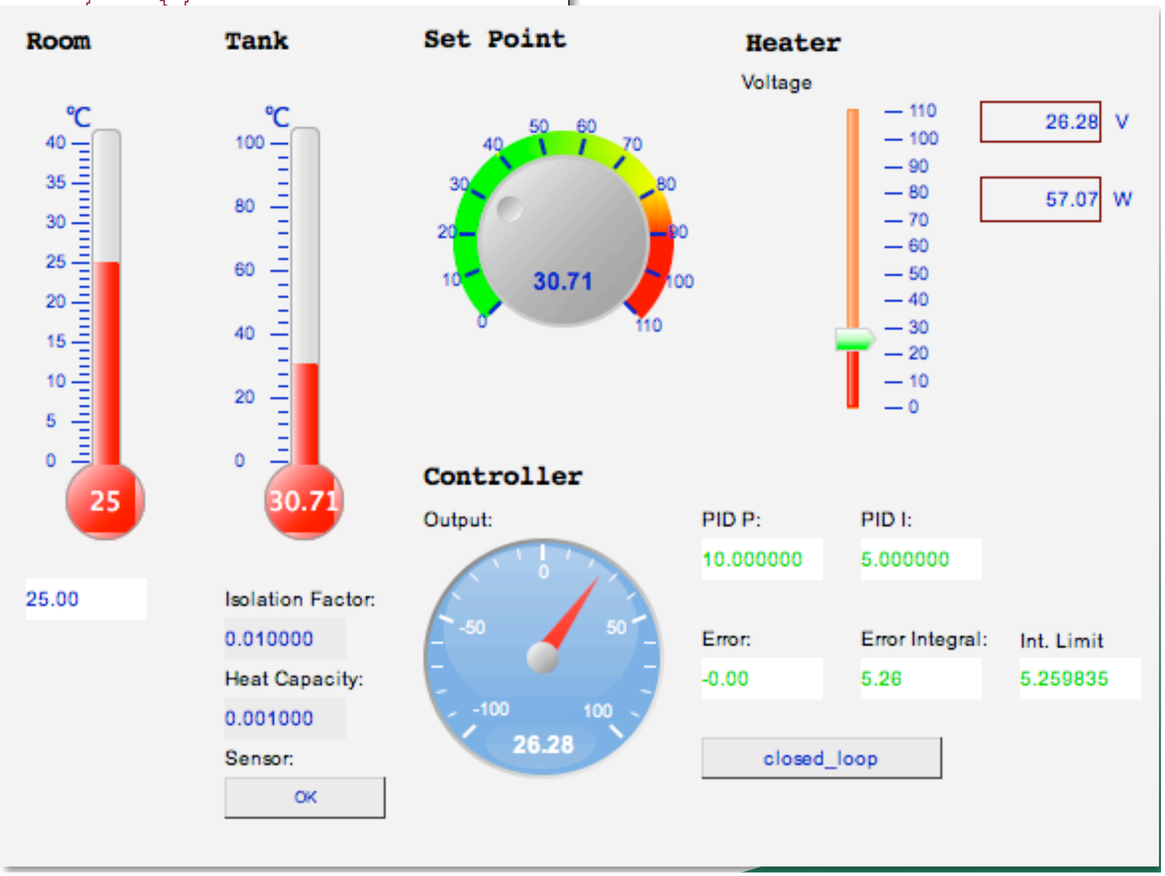
From Andrew Johnson (APS) EPICS Intro slide

Example Client: Operator Displays



Setpoint raised, heater activates to warm tank up

Setpoint lowered, tank cools down



26.28 V

57.07 W

25.00

Isolation Factor: 0.010000

Heat Capacity: 0.001000

Sensor: OK

PID P: 10.000000

PID I: 5.000000

Error: -0.00

Error Integral: 5.26

Int. Limit 5.259835

closed_loop

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
  - Soft IOC
    IOC software running on Linux, …, 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
  EPICS network protocol. Exposes Channels aka Process Variables

EPICS Summary

EPICS

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

Argonne NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

DESY

diamond

iter the way to new energy

Los Alamos NATIONAL LABORATORY EST. 1943

SNS SPALLATION NEUTRON SOURCE