EPICS Training

HZB EPICS Summer School 2025

Žiga Oven

ziga.oven@cosylab.com

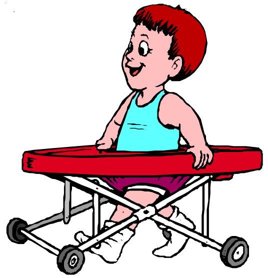
COSYLAB

Advancing humanity.
Engineering remarkable.

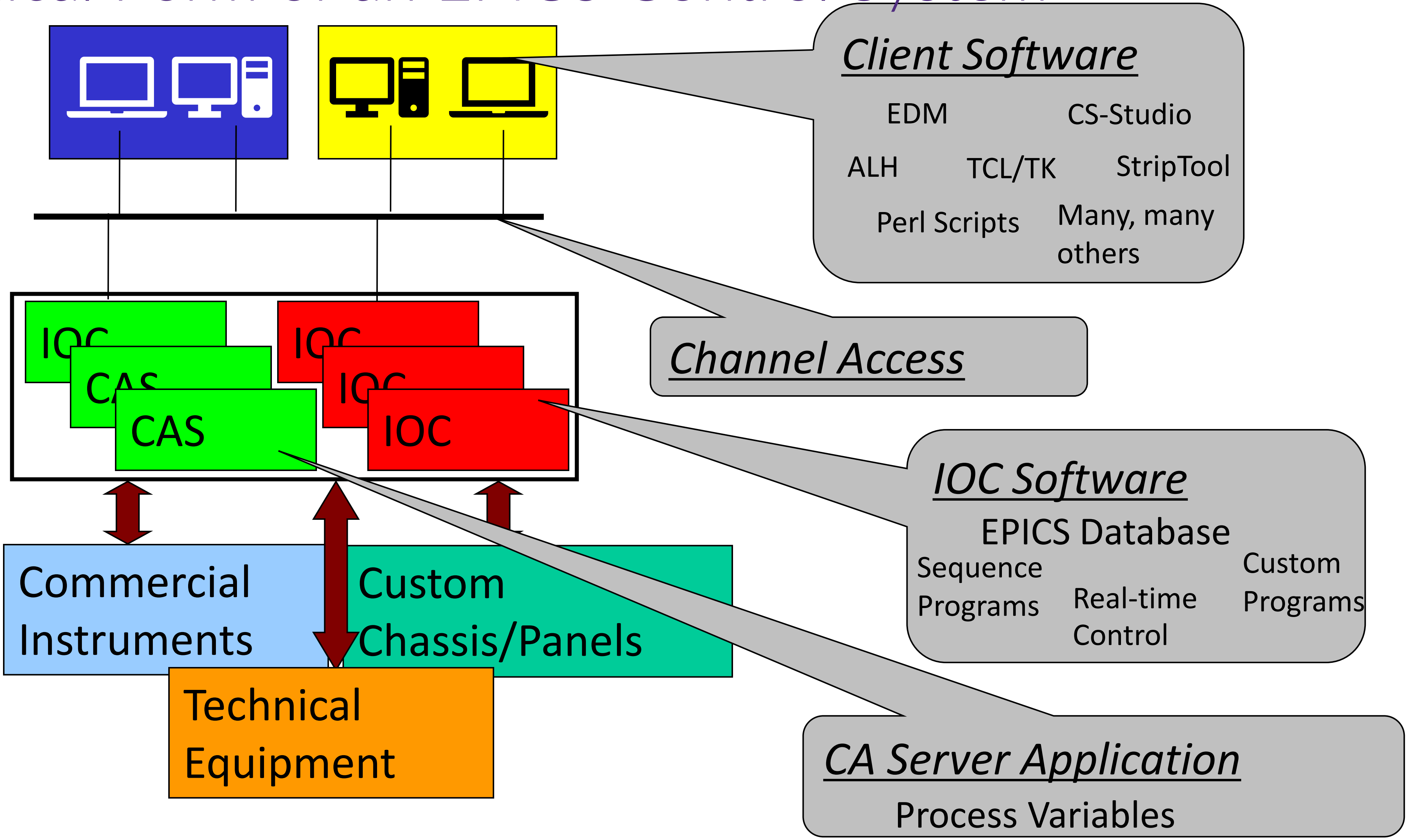
EPICS Foundations

Overview

- Lay the foundation for understanding an EPICS control system
- Introduce IOCs
  - Channel Access (CA)
  - Database
  - Sequencer
  - Device Support
- Choosing the correct tools for the job
  - When to use a database
  - The sequencer, what is it good for?
  - Why write your own CA client program?
- How fast is EPICS?
- How to find more information
  - Website walk through



Canonical Form of an EPICS Control System



IOC

CAS

CAS

IOC

IOC

IOC

Commercial Instruments

Custom Chassis/Panels

Technical Equipment

Client Software

EDM

CS-Studio

ALH

TCL/TK

StripTool

Perl Scripts

Many, many others

Channel Access

IOC Software

EPICS Database

Sequence Programs

Real-time Control

Custom Programs

CA Server Application

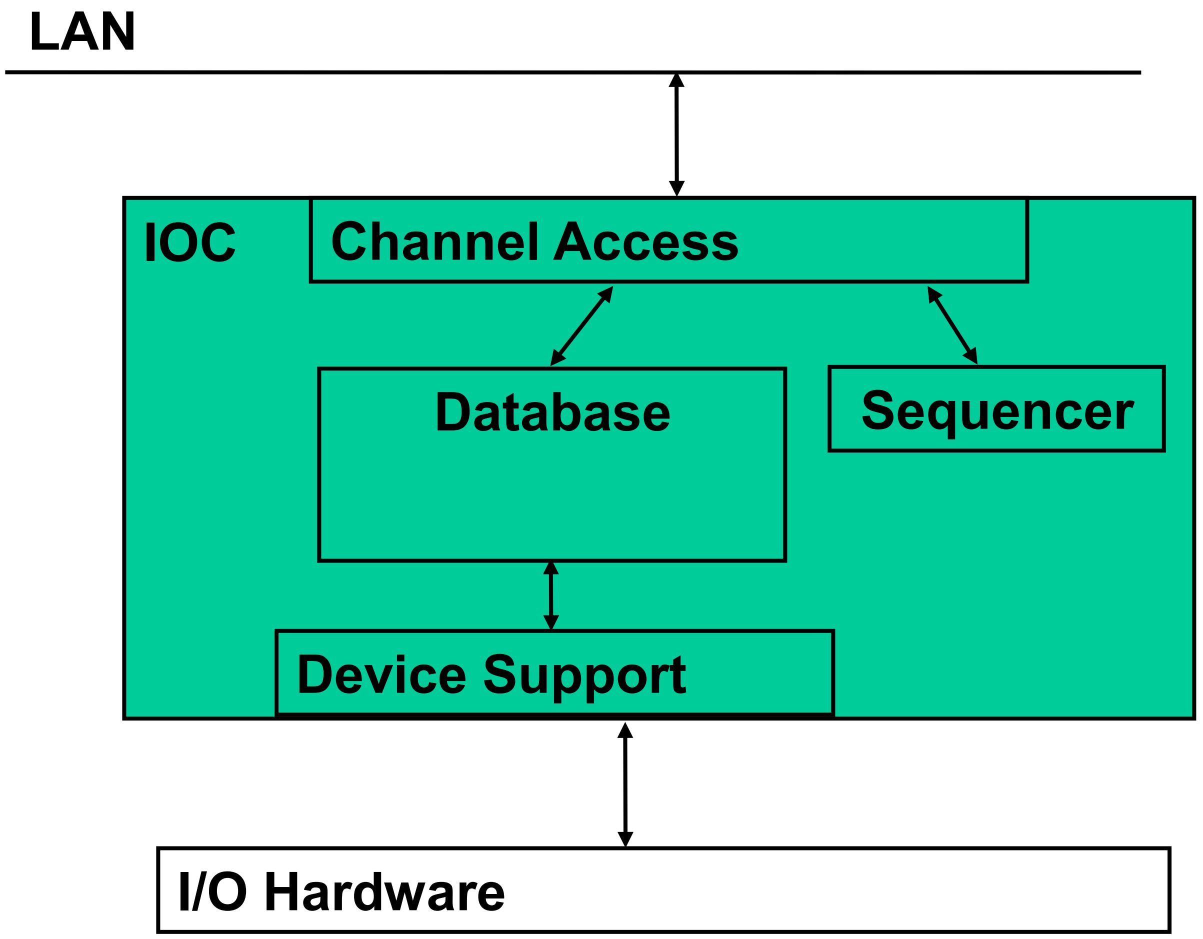
Process Variables

Introducing the IOC

- Input Output Controller
- A computer running software called “IOC Core”
- The computer can be:
    - VME based, running VxWorks (only choice until Release 3.14) or RTEMS
    - PC running Windows, Linux, RTEMS
    - Apple running OSX
    - UNIX Workstation running Solaris
- Usually has Input and/or Output devices attached
- An EPICS control system must consist of at least one Channel Access Server (usually an IOC)
- An IOC has one or more databases loaded.
    - The database tells it what to do

Inside an IOC

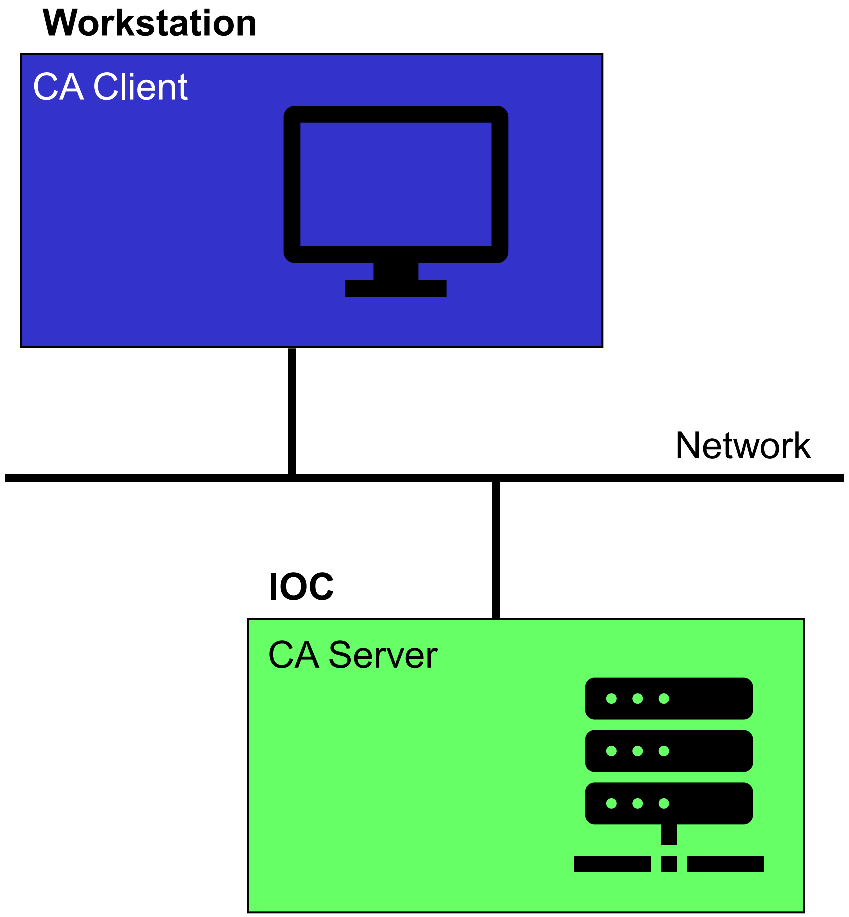
- The major software components of an IOC (IOC Core)



Channel Access

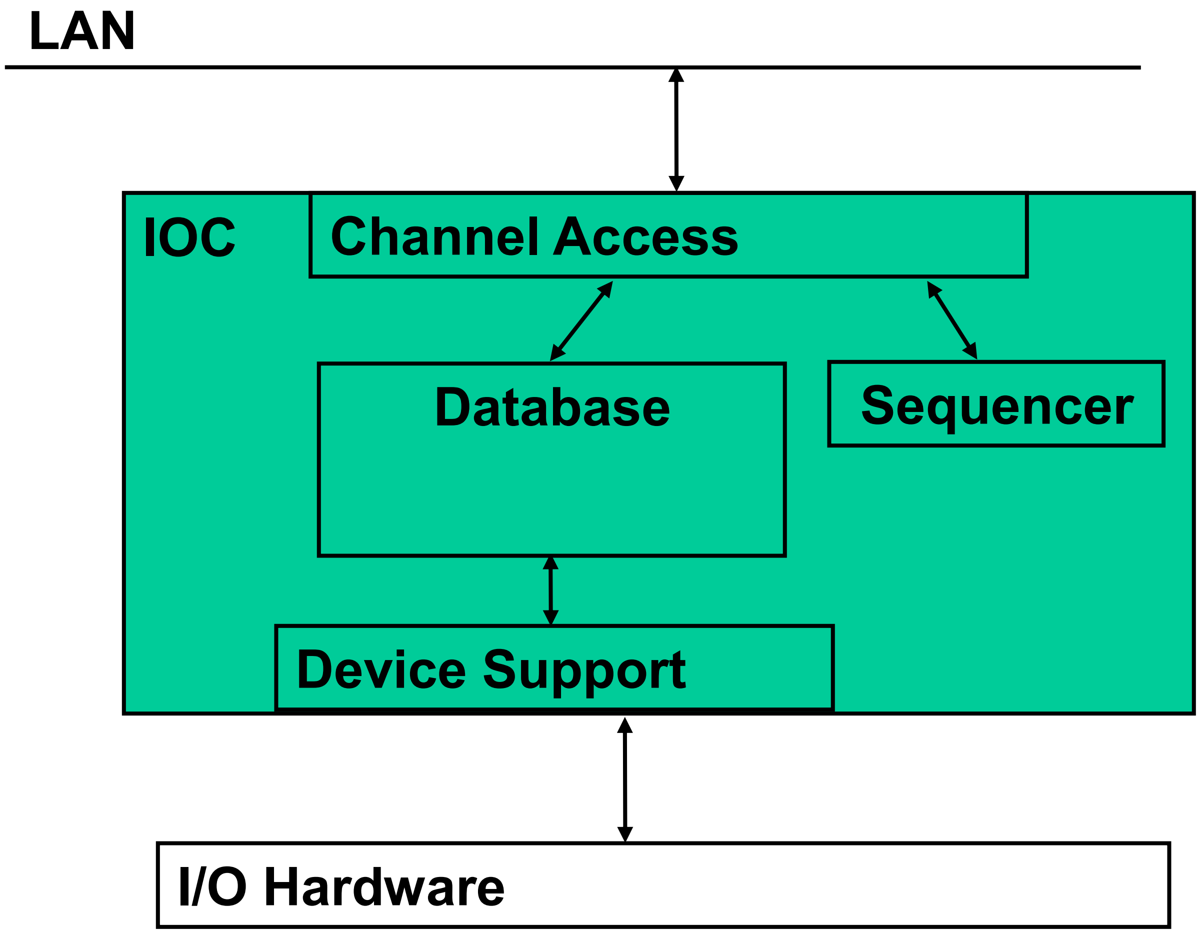
- Allows other programs (CA Clients) to see and change values of Process Variables in an IOC (CA Server)
- CA Clients may
  - Put (write)
  - Get (read)
  - Monitor

  data of Process Variables
- IOCs are both CA clients and CA servers. They can interact with data in other IOCs
- A CA Client can connect to many servers
- A CA Server may serve many clients
- A very efficient and reliable protocol



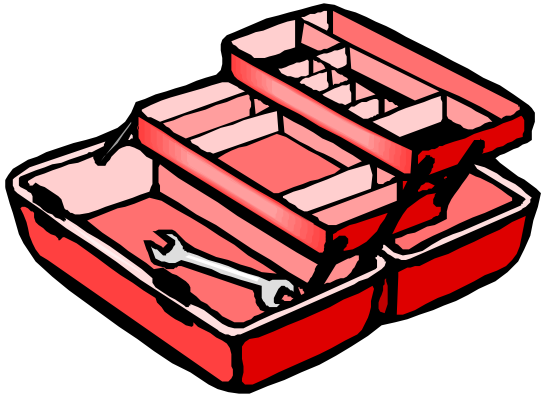
Inside an IOC

- The major software components of an IOC (IOC Core)



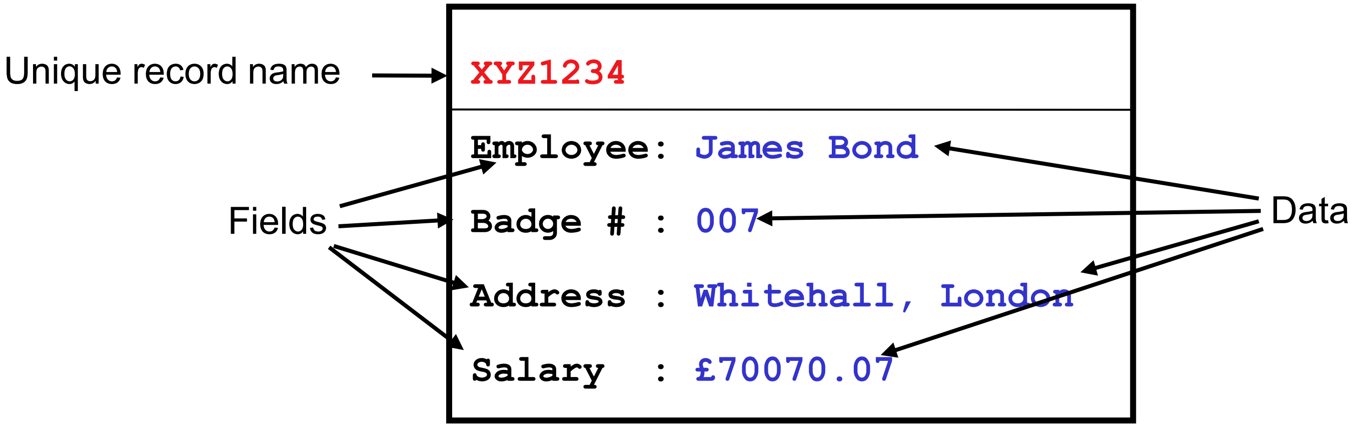
EPICS Databases – What are they for?

- Interface to process instrumentation
- Distribute processing
- Provide external access to all process information
- Use common, proven, objects (records) to collect, process and distribute data
- Provide a common toolkit for creating applications



What are records?

- A record is an object with
  - A unique name
  - Properties (fields) that contain information (data)
  - The ability to perform actions on that data
- For example, a personnel record in a relational database has a name, and fields containing data.



Unique record name

XYZ1234

Employee: James Bond

Badge # : 007

Address : Whitehall, London

Salary : £70070.07

Fields

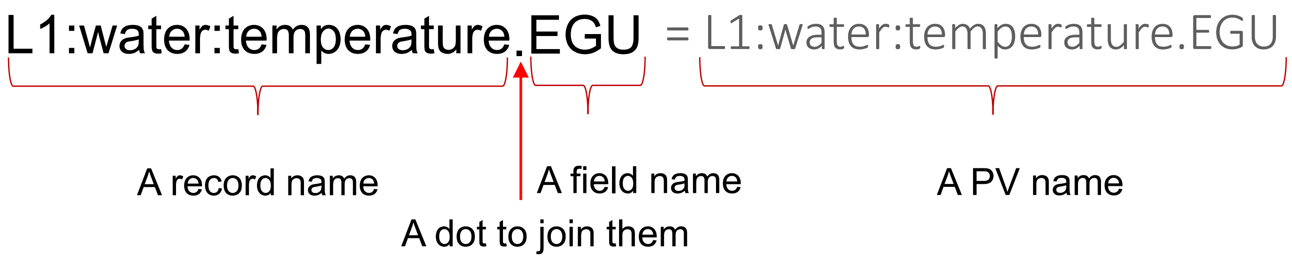
Data

What are EPICS records?

- A record is an object with…
  - A unique name e.g. **`S28:waterPressure`**.
  - Controllable properties (fields) e.g. **`EGU`**.
  - A behavior - defined by its record type.
  - Optional associated hardware I/O (device support).
  - Links to other records.
- Each field can be accessed individually by name.
- A record name and field name combined give the name of a process variable (PV).
- A Process Variable name is what Channel Access needs to access data.

A Process Variable Name

- A PV name is comprised of two parts
  - The record name, and
  - the name of a field belonging to that record
- For example…



L1:water:temperature.EGU = L1:water:temperature.EGU

A record name

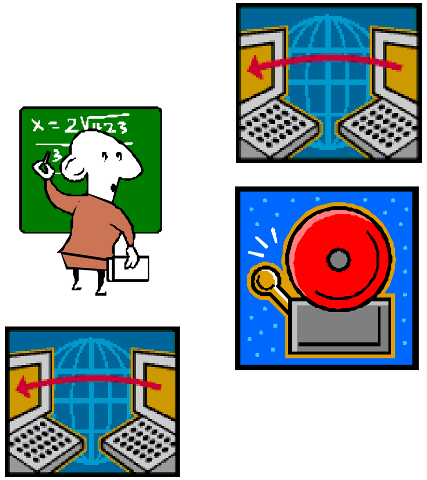
A field name

A PV name

A dot to join them

- **Note**: If no field name is given, Channel Access will default to using the `.VAL` field
  - i.e. to CA, “`L1:water:temperature`” = “`L1:water:temperature.VAL`”

What do records do?



- Records are active, they do things
  - Get data from other records or from hardware
  - Perform calculations
  - Check values are in range and raise alarms
  - Put data into other records or into hardware
  - Activate or disable other records
  - Wait for hardware signals (interrupts)
- What a record does depends upon its type and the values in its fields.
- A wide range of records have already been created.
- New record types can be added to a new application as needed.
- A record does nothing until it is *processed.*

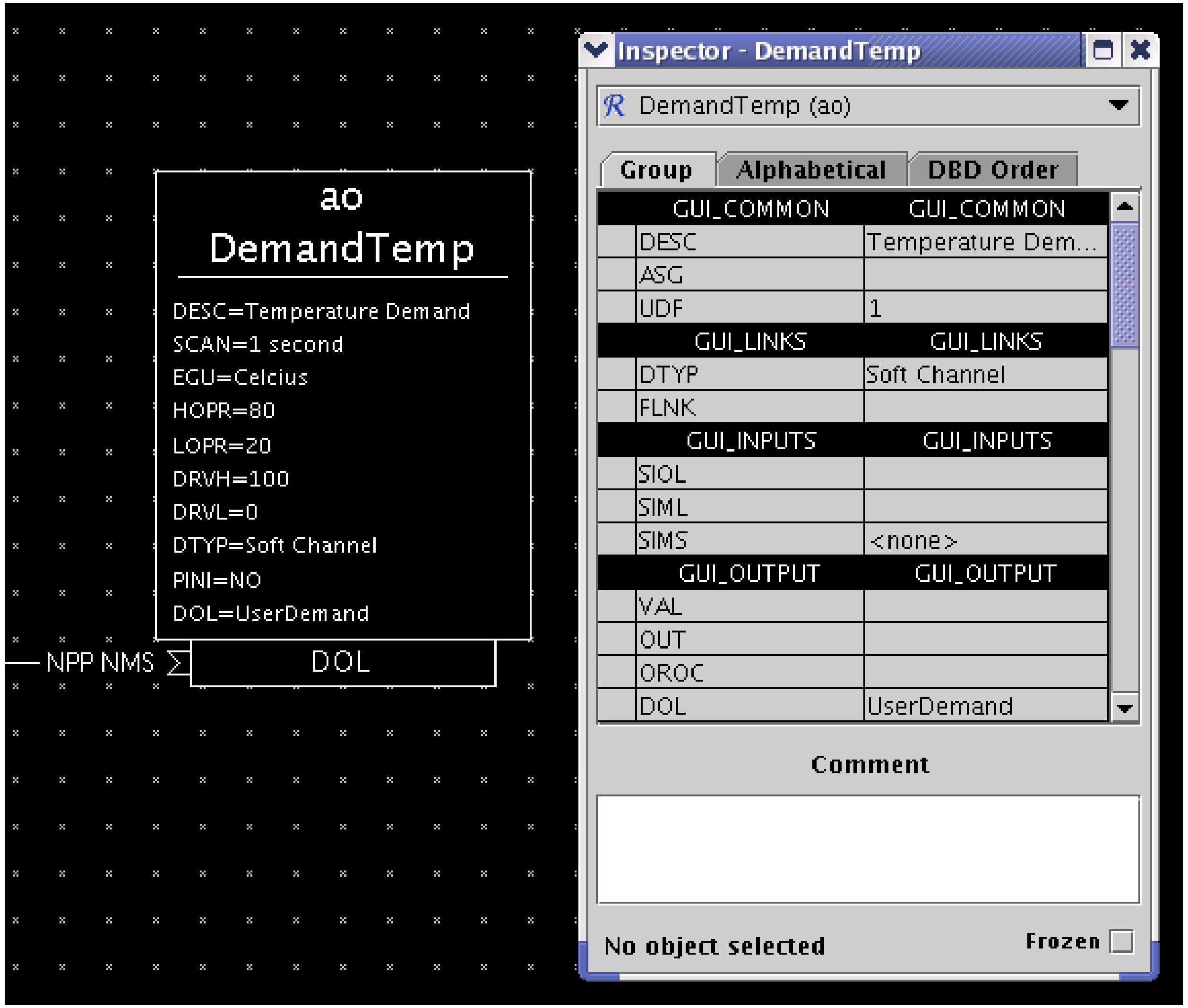
Record Types

- Classified into four general types
- Input, e.g.
    - Analog In (AI)
    - Binary In (BI)
    - String In (SI)
- Algorithm/control, e.g.
    - Calculation (CALC)
    - Subroutine (SUB)
- Output, e.g.
    - Analog Out (AO)
    - Binary Out (BO)
- Custom, e.g.
    - Beam Position Monitor
    - Multi-Channel Analyzer

Some Record Types

- Analog in
- Analog out
- Binary in
- Binary out
- Calculation
- Calculation out
- Compression
- Data fanout
- Event
- Fanout
- Histogram
- Motor
- Multi bit binary input
- Multi bit binary output
- PID control
- Pulse counter
- Pulse delay
- Scan
- Select
- Sequence
- String in
- String out
- Subarray
- Subroutine
- Waveform

Graphical View of a Record



ao
DemandTemp

DESC=Temperature Demand
SCAN=1 second
EGU=Celcius
HOPR=80
LOPR=20
DRVH=100
DRVL=0
DTYP=Soft Channel
PINI=NO
DOL=UserDemand

GUI_COMMON	GUI_COMMON
DESC	Temperature Dem...
ASG	
UDF	1
GUI_LINKS	GUI_LINKS
DTYP	Soft Channel
FLNK	
GUI_INPUTS	GUI_INPUTS
SIOL	
SIML	
SIMS	<none>
GUI_OUTPUT	GUI_OUTPUT
VAL	
OUT	
OROC	
DOL	UserDemand

Comment

No object selected

Frozen □

IOC View of a Record

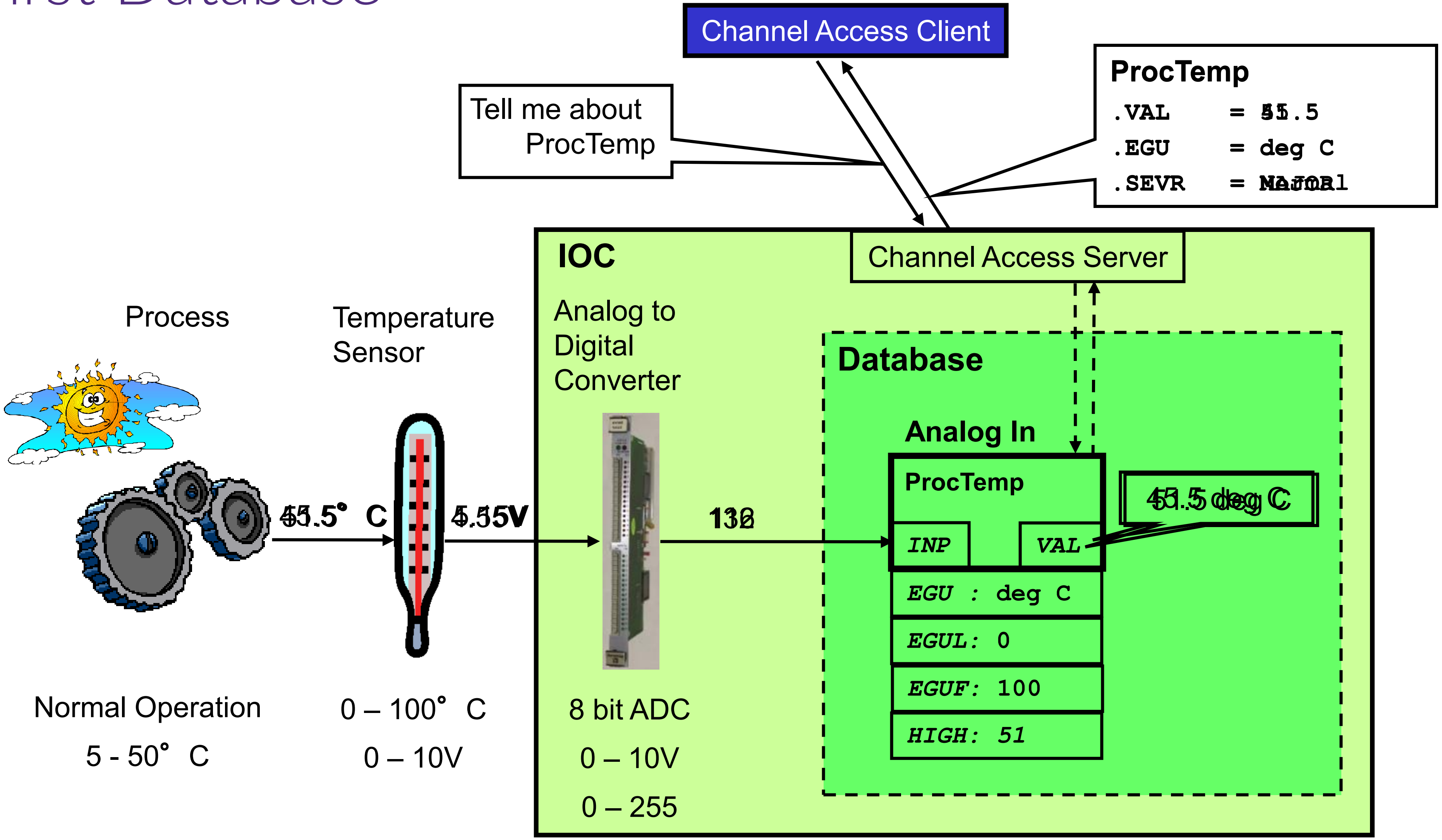
```
record(ao,"DemandTemp") {
    field(DESC,"Temperature")
    field(ASG,"")
    field(SCAN,"Passive")
    field(PINI,"NO")
    field(PHAS,"0")
    field(EVNT,"0")
    field(DTYP,"VMIC 4100")
    field(DISV,"1")
    field(SDIS,"")
    field(DISS,"NO_ALARM")
    field(PRIO,"LOW")
    field(FLNK,"")
    field(OUT,"#C0 S0")
    field(OROC,"0.0e+00")
    field(DOL,"")
    field(OMSL,"supervisory")
    field(OIF,"Full")
    field(PREC,"1")
    field(LINR,"NO CONVERSION")
    field(EGUF,"100")
    field(EGUL,"0")
    field(EGU,"Celsius")
```

```
   field(DRVH,"100")
    field(DRVL,"0")
    field(HOPR,"80")
    field(LOPR,"10")
    field(HIHI,"0.0e+00")
    field(LOLO,"0.0e+00")
    field(HIGH,"0.0e+00")
    field(LOW,"0.0e+00")
    field(HHSV,"NO_ALARM")
    field(LLSV,"NO_ALARM")
    field(HSV,"NO_ALARM")
    field(LSV,"NO_ALARM")
    field(HYST,"0.0e+00")
    field(ADEL,"0.0e+00")
    field(MDEL,"0.0e+00")
    field(SIOL,"")
    field(SIML,"")
    field(SIMS,"NO_ALARM")
    field(IVOA,"Continue
  normally")
    field(IVOV,"0.0e+00")
}
```

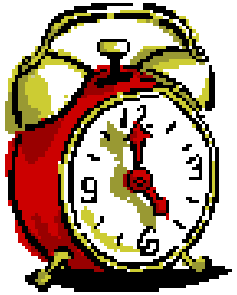
EPICS Databases – What are they?

- A collection of one or more EPICS *records* of various types.
- Records can be interconnected and are used as building blocks to create applications.
- A data file that’s loaded into IOC memory at boot time.
- Channel access talks to the IOC memory copy of the database.

Our First Database



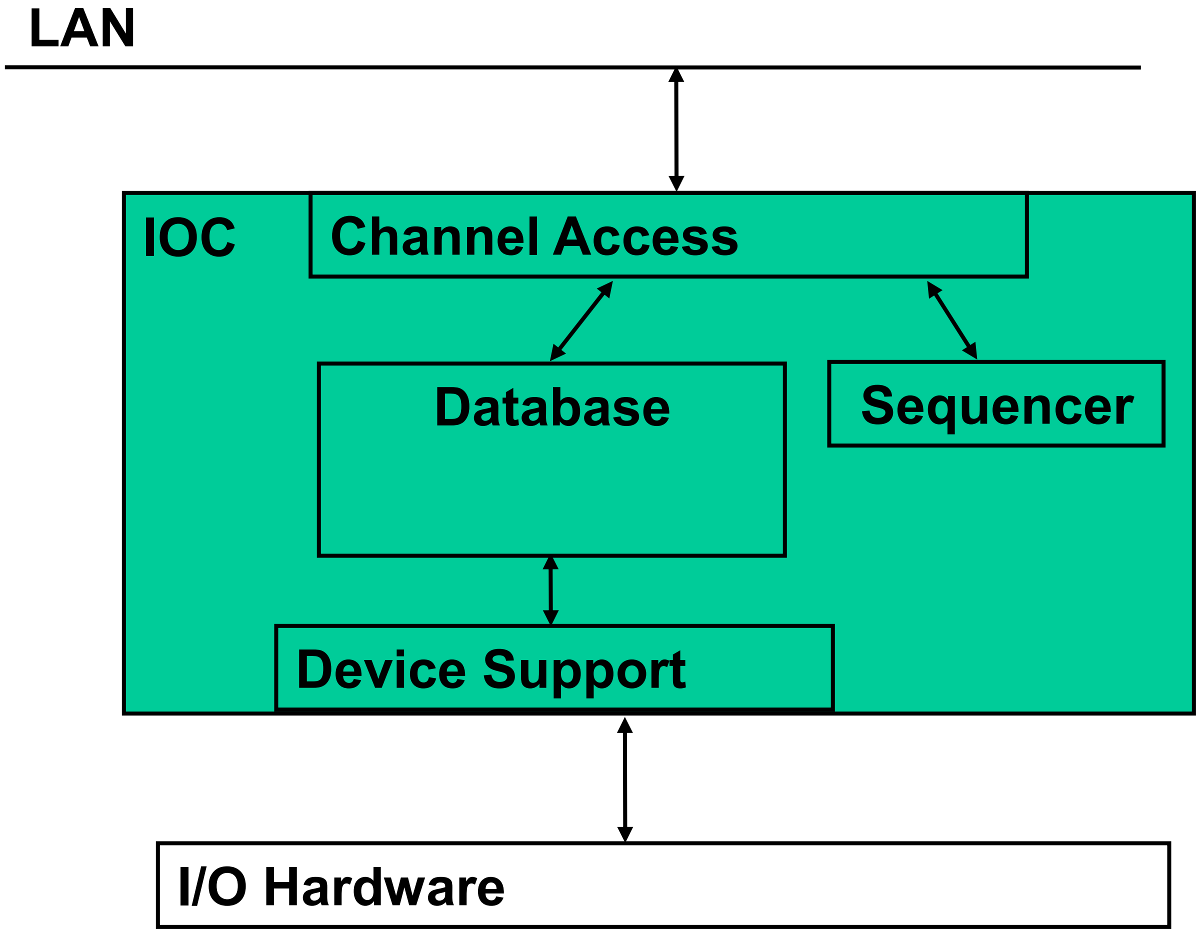
Record Processing



- Record processing can be periodic, or event driven.
- For *periodic* record processing, standard scan rates are:
  - 10, 5, 2, 1, 0.5, 0.2 and 0.1 seconds
  - Custom scan rates can be configured up to speeds allowed by operating system and hardware.
- For *event driven* record processing, events include:
  - Hardware interrupts
  - Request from another record via links
  - EPICS Events
  - Channel Access Puts

Inside an IOC

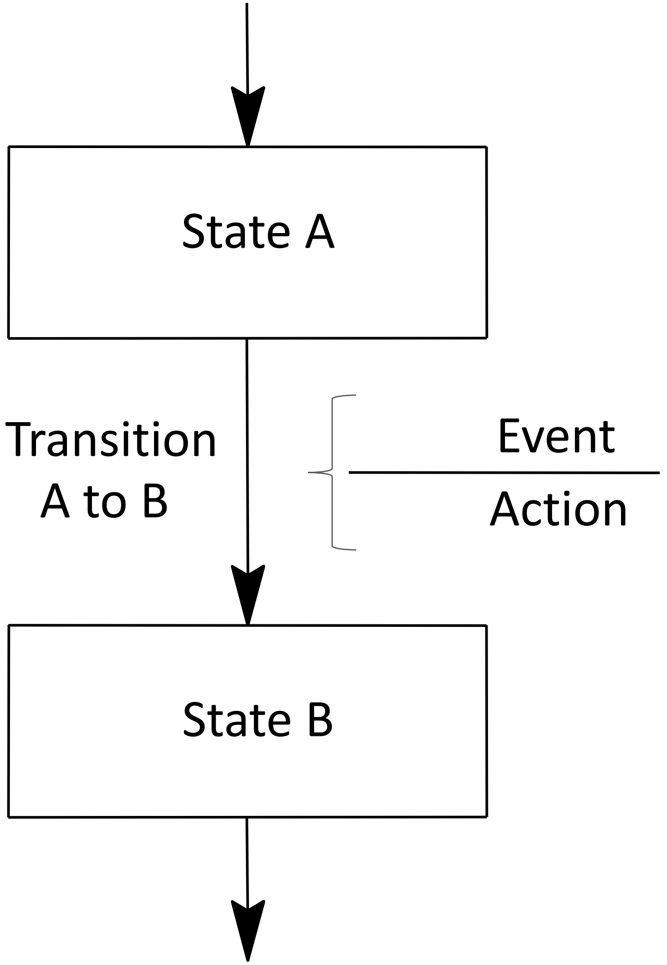
- The major software components of an IOC (IOC Core).



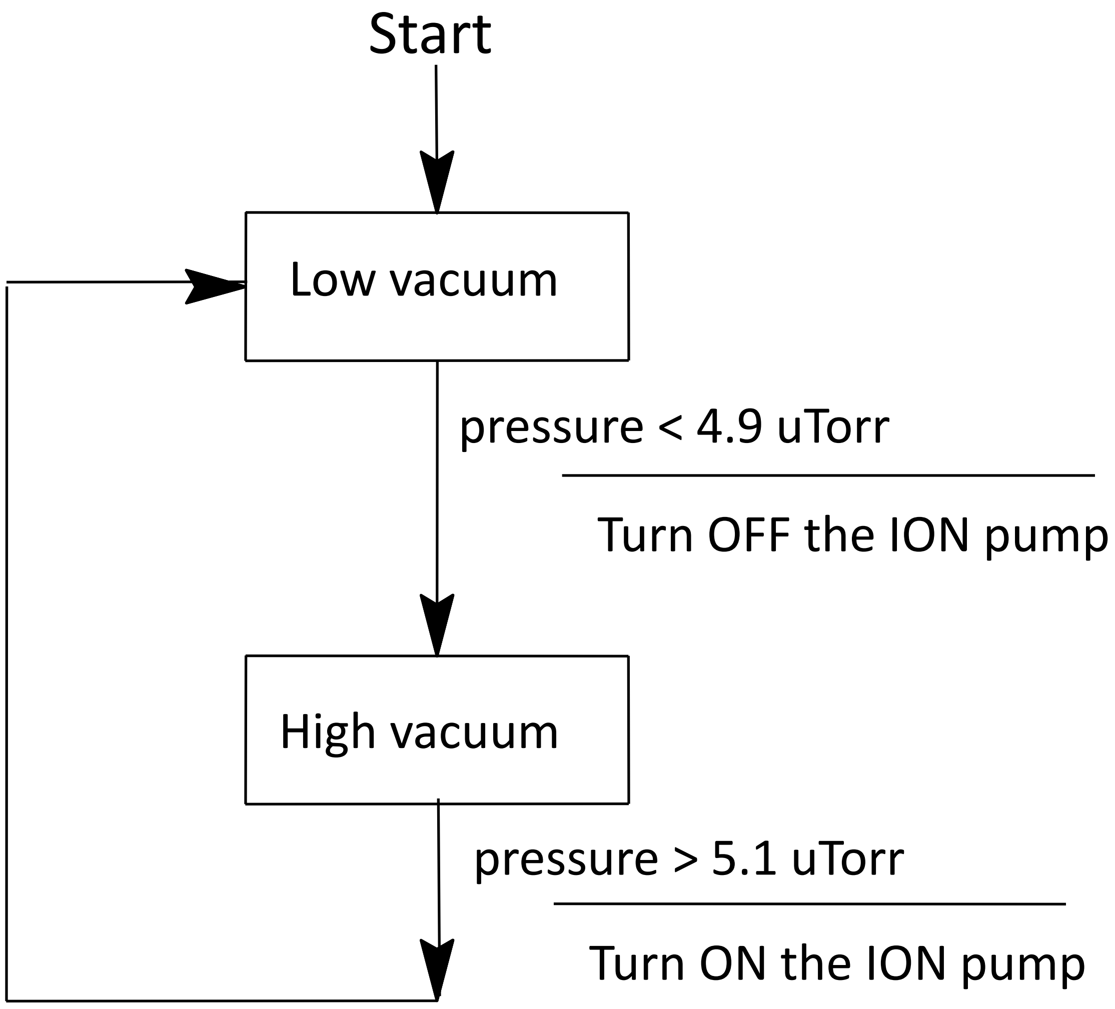
The Sequencer

- Runs programs written in State Notation Language (SNL).
- SNL is a ‘C’ like language to facilitate programming of sequential operations.
- Fast execution - compiled code.
- Programming interface to extend EPICS in the real-time environment.
- Common uses:
  - Provide automated start-up sequences like vacuum or RF where subsystems need coordination.
  - Provide fault recovery or transition to a safe state.
  - Provide automatic calibration of equipment.

SNL implements State Transition Diagrams

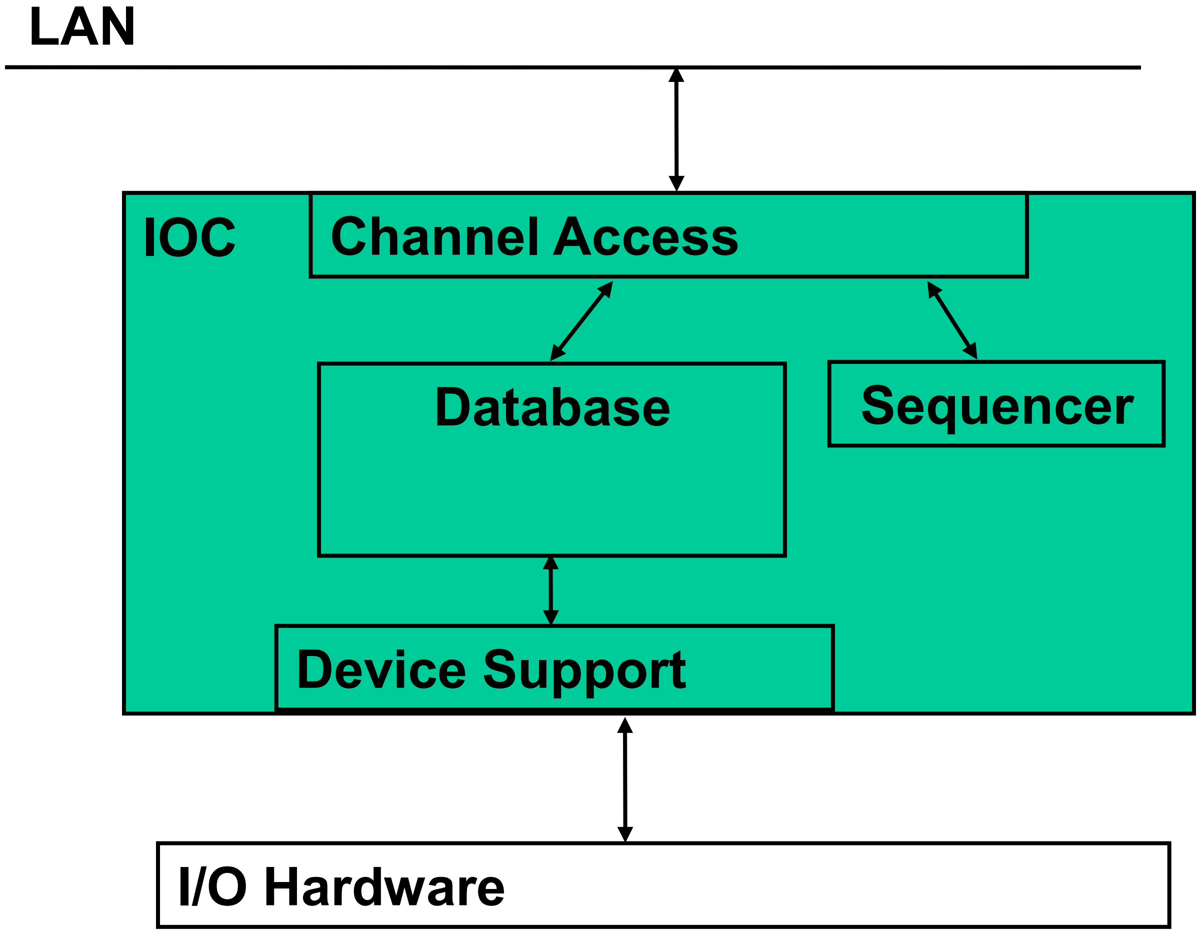


State Transition Diagram Example



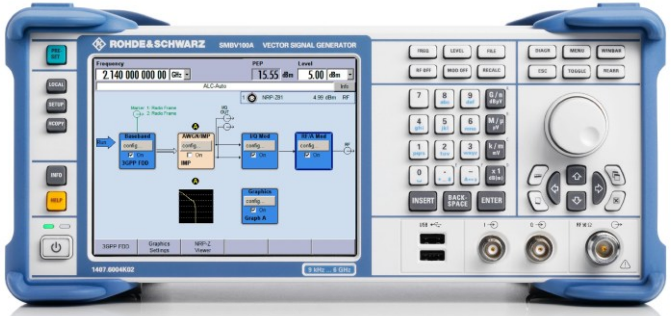
Inside an IOC

- The major software components of an IOC (IOC Core)



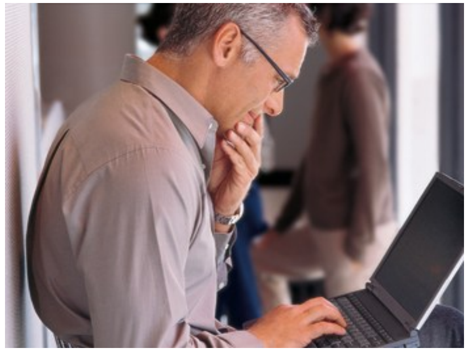
Device Support

- Device and driver support interface hardware to the database
- Examples of devices:
    - VME cards: ADC, DAC, Binary I/O etc.
    - Motor controllers
    - Oscilloscopes
    - PLCs
    - Cameras



Device Support

- Usually has to be written for ‘new’ hardware.
- Good news – someone, somewhere has usually written support for your device, or a very similar one.
- See the EPICS web site for available support.
- Or ask the EPICS community.



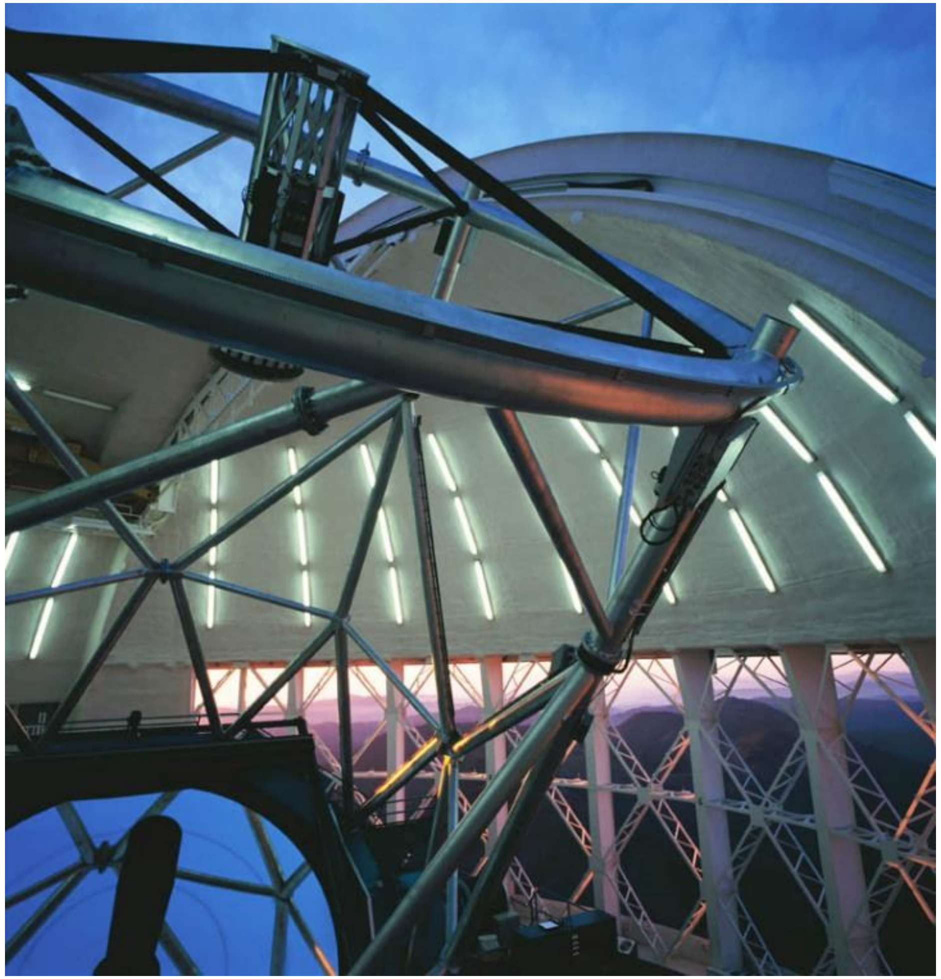
When to use databases

- Hardware connection
- Real time performance – no network latencies
- Whenever a database is good enough

Advantages	Disadvantages
Simplify hardware connection	If you have device support
Configuring not programming.	You need to understand database use
Database is easily understood by other EPICS developers	
Speed - All processing (often) in same machine	

When to use the sequencer

- For sequencing complex events
  - e.g. parking and unparking a telescope mirror



Photograph courtesy of the Gemini Telescopes project

When to use clients

- To interact with the control system
- Many already exist – CSS, ALH, Strip Tool, archiver, EDM etc.
- For data analysis or visualization
- Supervisory control
  - e.g. to manage an accelerator

Command Line Clients

Functionality	Channel Access	PV Access
Read PV	`caget <PV_name>`	`pvget <PV_name>`

How fast is EPICS?

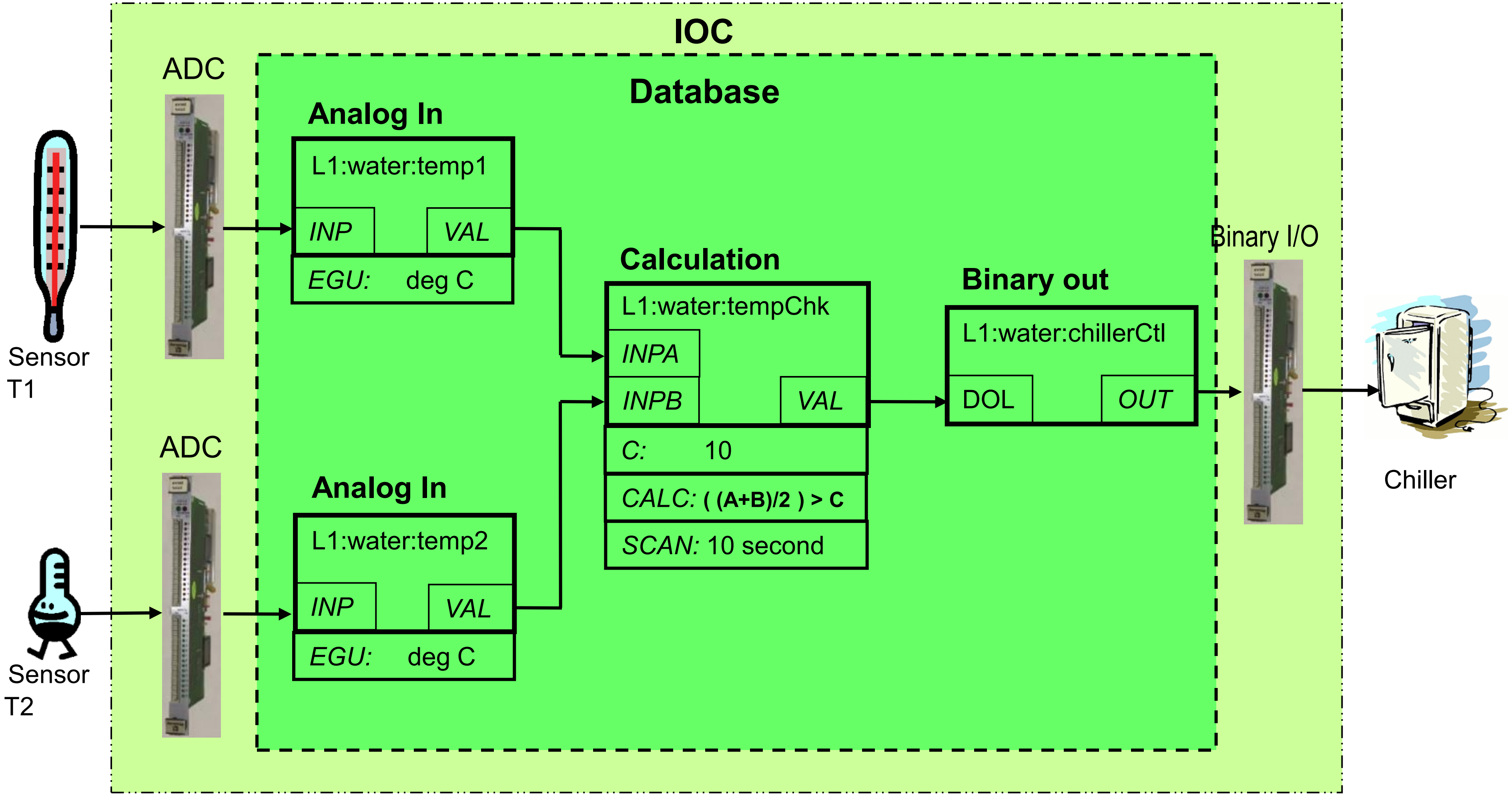
- Can be fast or slow, it depends how you use it!
- Use the correct tool for the job; Database, sequencer, custom code (ioc) or custom code (client).
- Ultimately speed depends upon hardware.
- Some (a bit old) benchmarks*:

Machine	OS	CPU	Speed	Rec/sec	%CPU
MVME167	vxWorks	68040	33MHz	6000	50
MVME 2306	vxWorks	PPC604	300MHz	10000	10
MVME5100	vxWorks	PPC750	450MHz	40000**	10**
PC	Linux	PII	233MHz	10000	27
PC	Linux	P4	2.4GHz	50000	9

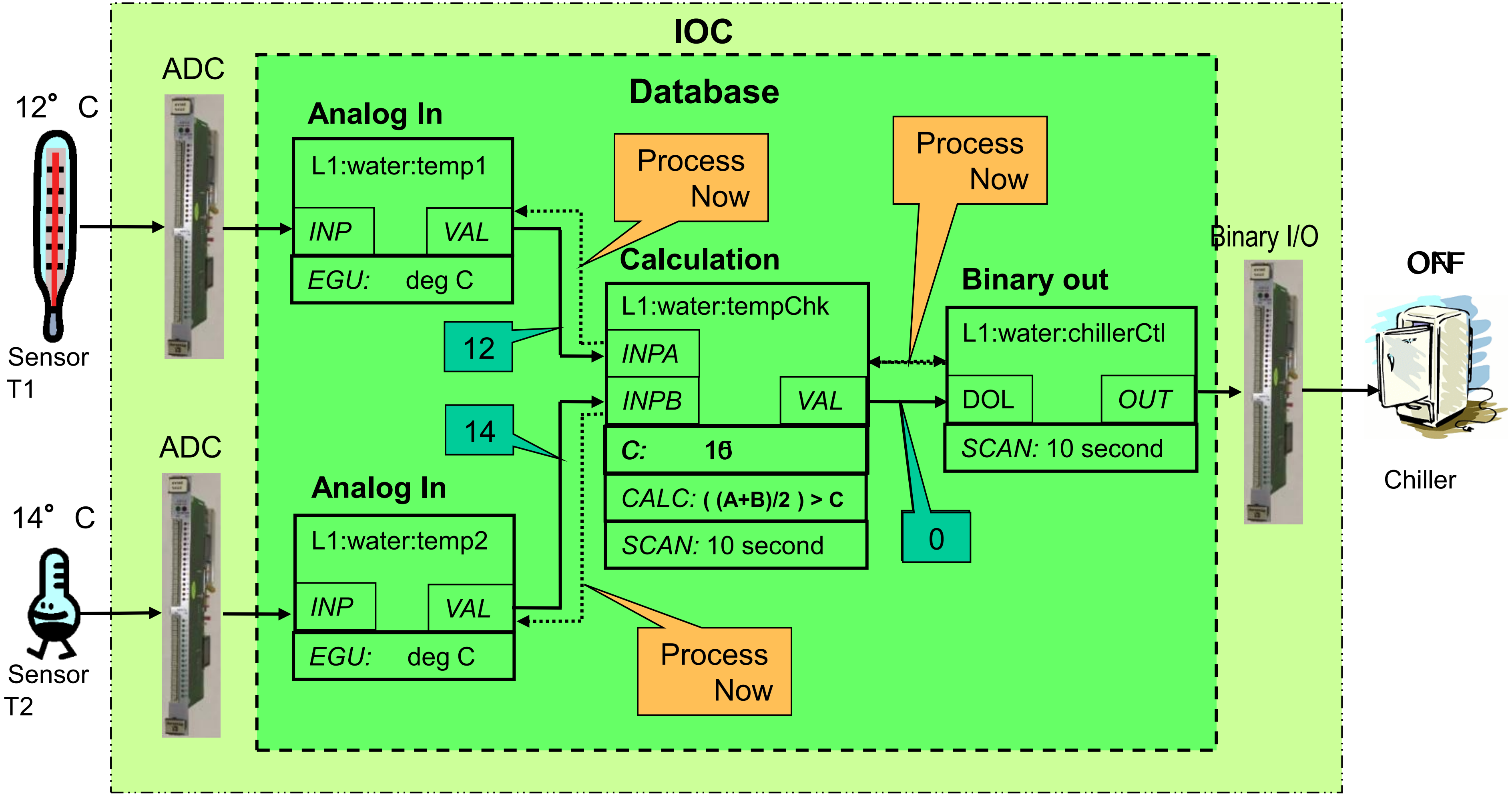
*Benchmark figures courtesy of Steve Hunt (PSI)
**Extrapolated from performance figures provided by L.Hoff, BNL

- Database design and periodic scanning affect *apparent* system speed

Database Processing



Apparent Performance



The EPICS Web Site

- The central site for EPICS information
- Documentation
  - Application Developer’s Guide
  - Component Reference Manual
  - https://docs.epics-controls.org/en/latest/
- CA Clients
- Device support
- Tech-talk
- https://epics-controls.org

COSYLAB

Based on a presentation by :
E. Norum (APS)

Getting Started with EPICS

IOC Overview

IOC Overview

- What is an EPICS Input/Output Controller (IOC)
- How to create a new IOC application.
- How to build an IOC application.
- How to run an IOC application on various platforms.
- Console interaction with an IOC application (`iocsh`).

What is an Input/Output Controller?

- Some definitions from the first lectures:
  - A computer running *iocCore*, a set of EPICS routines used to define process variables and implement real-time control algorithms.
  - *iocCore* uses database records to define process variables and their behavior.

What does an Input/Output Controller do?

- As its name implies, an IOC often performs input/output operations to attached hardware devices.
- An IOC associates the values of EPICS process variables with the results of these input/output operations.
- An IOC can perform sequencing operations, closed-loop control and other computations.

‘Host-based’ and ‘Target’ IOCs

- ‘Host-based’ IOC
  - Runs in the same environment as which it was compiled
  - ‘Native’ software development tools (compilers, linkers)
  - Sometimes called a ‘Soft’ IOC
  - IOC is a program like any other on the machine
  - Possible to have many IOCs on a single machine
- ‘Target’ IOC
  - Runs in a different environment than where compiled
  - ‘Cross’ software development tools
  - Linux, VxWorks, RTEMS
  - IOC boots from some medium (usually network)
  - IOC is the only program running on the machine

IOC Software Development Tools

- EPICS uses the GNU version of make
  - Almost every directory from the `{TOP}` on down contains a `Makefile`
  - Make recursively descends through the directory tree
    - Determines what needs to be [re]built
    - Invokes compilers and other tools as instructed in Makefile
  - GNU C/C++ compilers or vendor compilers can be used
- No fancy ‘integrated development environment’ yet…

IOC Application Development Examples

- The following slides provide step-by-step examples of how to:
  - Create, build, run the example IOC application on a 'host' machine (Linux)

- Each example begins with the use of `makeBaseApp.pl`

The **makeBaseApp.pl** Script

- Part of EPICS base distribution.
- Populates a new, or adds files to an existing, `{TOP}` area.
- Requires that your environment contain a valid `EPICS_HOST_ARCH`
  - EPICS base contains scripts which can set this as part of your login sequence
    - `linux-x86(_64)`, `darwin-ppc`, `solaris-sparc`, `win32-x86`
- Creates different directory structures based on a selection of different templates.
- Commonly-used templates include
  - `ioc` - Generic IOC application skeleton
  - `example` - Example IOC application

Exercise 1

Create an example EPICS Application

Creating and initializing a new {TOP}

- Create a new directory and run `makeBaseApp.pl` from within that directory:

```
1.  mkdir <dirName>

2.  cd <dirName>

3.  makeBaseApp.pl -t example ex1
```

  - The template is specified with the `-t` argument
  - The application name (`ex1App`) is specified with the argument `ex1` (created directory gets "`App`" appended to this name)

`{TOP}` directory structure

- The `makeBaseApp.pl` creates the following directory structure in `{TOP}` (`<dirName>`):
  - `configure/` - Configuration files
  - `ex1App/` - Files associated with the ‘ex1App’ application
    - `Db/` - Databases, templates, substitutions
    - `src/` - Source code

- Every directory also contains a `Makefile`

{TOP}/configure files

- Some may be modified as needed
  - CONFIG
    - Specify make variables (e.g. to build for a particular target):
    - `CROSS_COMPILER_TARGET_ARCHS = vxWorks-68040`
  - RELEASE
    - Specify location of other {TOP} areas used by applications in this {TOP} area.
- Others are part of the (complex!) build system and should be left alone.

Create a host-based IOC boot directory

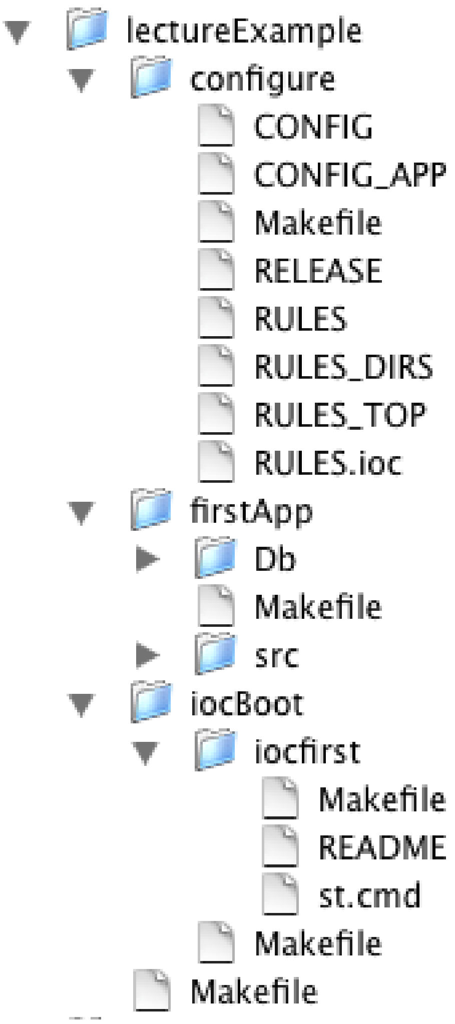
- Run `makeBaseApp.pl` from the `{TOP}` directory
- `-t example`: to specify template
- `-i`: to show that IOC boot directory is to be created
- name of IOC

```
4. makeBaseApp.pl -i -t example ex1
```

`{TOP}` directory structure

- The command from the previous slide creates an additional directory in `{TOP}`:
  - `iocBoot/` - Directory containing per-IOC boot directories
    - `iocex1/` - Boot directory for ‘iocex1’ IOC

{TOP} directory structure



```
▼ lectureExample
    ▼ configure
          CONFIG
          CONFIG_APP
          Makefile
          RELEASE
          RULES
          RULES_DIRS
          RULES_TOP
          RULES.ioc
    ▼ firstApp
        ▶ Db
          Makefile
        ▶ src
    ▼ iocBoot
        ▼ iocfirst
              Makefile
              README
              st.cmd
          Makefile
      Makefile
```

Exercise 2

Inspect EPICS database

Build the application

- Run the GNU make program
  - `make` on Darwin, Linux, Windows
  - `gnumake` on Solaris

- Or to clean things up completely
  - `make clean uninstall`

Exercise 3

Compile EPICS application

`{TOP}` directory structure after running make

- These additional directories are now present in `{TOP}`
  - `bin/` - Directory containing per-architecture directories
    - `linux-x86_64/` - Object files and executables for this architecture
  - `lib/` - Directory containing per-architecture directories
    - `linux-x86_64/` - Object libraries for this architecture
  - `dbd/` - Database definition files
  - `db/` - Database files (record instances, templates)
- There may be other directories under `bin/` and `lib/`.

IOC Startup

- IOCs read commands from a startup script
  - Typically, `st.cmd` in the `{TOP}/iocBoot/<iocname>/` directory
- IOCs read these scripts with the `iocsh` shell
- Command syntax can be similar but `iocsh` allows a more familiar form too.
- Script was created with the `makeBaseApp.pl -i` command.
- For a ‘real’ IOC you’d likely add commands to configure hardware modules, start sequence programs, update log files, etc.

Example application startup script

```
#!../../bin/linux-x86_64/ex1

## You may have to change ex1 to something else
## everywhere it appears in this file

< envPaths

cd ${TOP}

## Register all support components
dbLoadDatabase("dbd/ex1.dbd")
ex1_registerRecordDeviceDriver(pdbbase)

## Load record instances
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics,no=1,scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=2,scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=3,scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")

cd ${TOP}/iocBoot/${IOC}
iocInit()

## Start any sequence programs
#seq sncExample,"user=epics”
```

Example application startup script

```
#!../../bin/linux-x86_64/ex1
```

- This allows a host-based IOC application to be started by simply executing the `st.cmd` script.
- If you are running this on a different architecture, the `linux-x86_64` will be that of the architecture you are using.
- `ex1` refers to the IOC name that you created with the ‘`makeBaseApp.pl -i`’ command. For our example, it is `ex1`.
- Remaining lines beginning with a `#` character are comments.

Example application startup script

```
#!../../bin/linux-x86_64/ex1

## You may have to change ex1 to something else
## everywhere it appears in this file

< envPaths

cd ${TOP}

## Register all support components
dbLoadDatabase("dbd/ex1.dbd")
ex1_registerRecordDeviceDriver(pdbbase)

## Load record instances
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics,no=1,scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=2,scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=3,scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")

cd ${TOP}/iocBoot/${IOC}
iocInit()

## Start any sequence programs
#seq sncExample,"user=epics”
```

Example application startup script

```
< envPaths
```

- The application reads commands from the `envPaths` file created by `makeBaseApp -i` and `make`
- The envPaths file contains commands to set up environment variables for the application:
    - Architecture
    - IOC name
    - `{TOP}` directory
    - `{TOP}` directory of each component named in `configure/RELEASE`
- These values can then be used by subsequent commands:
    - `epicsEnvSet(IOC,"iocex1")`
    - `epicsEnvSet(TOP,"/home/$USER/ex1")`
    - `epicsEnvSet(EPICS_BASE,"/opt/epics/base")`

Example application startup script

```
#!../../bin/linux-x86_64/ex1

## You may have to change ex1 to something else
## everywhere it appears in this file

< envPaths

cd ${TOP}

## Register all support components
dbLoadDatabase("dbd/ex1.dbd")
ex1_registerRecordDeviceDriver(pdbbase)

## Load record instances
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics,no=1,scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=2,scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=3,scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")

cd ${TOP}/iocBoot/${IOC}
iocInit()

## Start any sequence programs
#seq sncExample,"user=epics”
```

Example application startup script

```
cd ${TOP}
```

- The working directory is set to the value of the `{TOP}` environment variable (as set by the commands in `envPaths`).
- Allows use of relative path names in subsequent commands.

```
dbLoadDatabase("dbd/ex1.dbd")
```

- Loads the database definition file for this application.
- Describes record layout, menus, drivers.

```
ex1_registerRecordDeviceDriver(pdbbase)
```

- Registers the information read from the database definition files.

Example application startup script

```
#!../../bin/linux-x86_64/ex1

## You may have to change ex1 to something else
## everywhere it appears in this file

< envPaths

cd ${TOP}

## Register all support components
dbLoadDatabase("dbd/ex1.dbd")
ex1_registerRecordDeviceDriver(pdbbase)

## Load record instances
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics,no=1,scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=2,scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=3,scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")

cd ${TOP}/iocBoot/${IOC}
iocInit()

## Start any sequence programs
#seq sncExample,"user=epics”
```

Example application startup script

```
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics, no=1, scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics, no=2, scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics, no=3, scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")
```

- Read the application database files
  - These define the records which this IOC will maintain.
  - A given file can be read more than once (with different macro definitions).

Example application startup script

```
#!../../bin/linux-x86_64/ex1

## You may have to change ex1 to something else
## everywhere it appears in this file

< envPaths

cd ${TOP}

## Register all support components
dbLoadDatabase("dbd/ex1.dbd")
ex1_registerRecordDeviceDriver(pdbbase)

## Load record instances
dbLoadRecords("db/dbExample1.db","user=epics")
dbLoadRecords("db/dbExample2.db","user=epics,no=1,scan=1 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=2,scan=2 second")
dbLoadRecords("db/dbExample2.db","user=epics,no=3,scan=5 second")
dbLoadRecords("db/dbSubExample.db","user=epics")

cd ${TOP}/iocBoot/${IOC}
iocInit()

## Start any sequence programs
#seq sncExample,"user=epics”
```

Example application startup script

```
cd ${TOP}/iocBoot/${IOC}
```

- The working directory is set to the per-IOC startup directory

```
iocInit()
```

- Activates everything
- After reading the last line of the `st.cmd` script the IOC continues reading commands from the console
  - Diagnostic commands
  - Configuration changes

Exercise 4

Start an IOC for your application

Running a host-based IOC

- Change to IOC startup directory (the one containing the st.cmd script)

```
cd iocBoot/iocex1
```

- Run the IOC executable with the startup script as the only argument

```
../../bin/linux-x86/ex1 st.cmd
```

- The startup script commands will be displayed as they are read and executed
- When all the startup script commands are finished the `iocsh` will display an `epics>` prompt and wait for commands to be typed.

```
iocInit()
#####################################################################
###  EPICS IOC CORE built on Jun 23 2004
###  EPICS R3.14.6 $R3-14-6$ $2004/05/28 19:27:47$
#####################################################################
Starting iocInit
## Start any sequence programs
#seq sncExample,"user=epics"
iocInit: All initialization complete
epics>
```

Some Useful `iocsh` Commands

- Display list of records maintained by this IOC:

```
epics> dbl
epics:aiExample
epics:aiExample1
epics:aiExample2
epics:aiExample3
epics:calcExample
epics:calcExample1
epics:calcExample2
epics:calcExample3
epics:compressExample
epics:subExample
epics:xxxExample
```

- Caution – some IOCs have many records.

Some Useful `iocsh` Commands

- Display a record:

```
epics> dbpr epics:aiExample
ASG:                DESC: Analog input  DISA: 0             DISP: 0
DISV: 1             NAME: epics:aiExample              RVAL: 0
SEVR: MAJOR         STAT: HIHI          SVAL: 0             TPRO: 0
VAL: 9
epics> dbpr epics:aiExample
ASG:                DESC: Analog input  DISA: 0             DISP: 0
DISV: 1             NAME: epics:aiExample              RVAL: 0
SEVR: MINOR         STAT: LOW           SVAL: 0             TPRO: 0
VAL: 4
```

- **`dbpr <recordname>`** 1 prints more fields
- **`dbpr <recordname>`** 2 prints even more fields, and so on

Some Useful `iocsh` Commands

- Show list of attached clients:

```
epics> casr
Channel Access Server V4.11
No clients connected.
```

- **`casr 1`** prints more information
- **`casr 2`** prints even more information

Some Useful `iocsh` Commands

- Do a ‘put’ to a field:

```
epics> dbpf epics:calcExample.SCAN "2 second"
DBR_STRING:          2 second
```

- Arguments with spaces must be enclosed in quotes

Some Useful `iocsh` Commands

- The `help` command, with no arguments, displays a list of all `iocsh` commands
  - 90 or so, plus commands for additional drivers
- With arguments it displays usage information for each command listed:

```
epics> help dbl dbpr dbpf
dbl 'record type' fields
dbpr 'record name' 'interest level'
dbpf 'record name' value
```

Terminating a host-based IOC

- Type **`exit`** at the `iocsh` prompt.
- Type your ‘interrupt’ character (usually `Ctrl-C`).
- Kill the process from another terminal/window.

Command-Line Tools

- These are client-side tools.
- The tools we will cover are:
  - `caget` – gets the value of one or more process variables
  - `caput` – sets the value of one process variables
  - `camonitor` – monitors the value changes of one or more process variables
  - `cainfo` – gets information about one or more process variables
- All accept `–h` to display usage and options.

- NOTE: equivalent commands are `pvget`, `pvput`, `pvmonitor`

caget Example

- Get the values of two process variables:

```
caget S35DCCT:currentCC S:SRlifeTimeHrsCC
```

- Returns:

```
S35DCCT:currentCC    102.037
S:SRlifeTimeHrsCC    7.46514
```

caput Example

- Set the value of a process variable:

```
caput Xorbit:S1A:H1:CurrentAO 1.2
```

- Returns:

```
Old : Xorbit:S1A:H1:CurrentAO    0
New : Xorbit:S1A:H1:CurrentAO    1.2
```

camonitor Example

- Monitor two process variables:

```
camonitor evans:calc evans:bo01
```

- Returns:

```
evans:calc    1970-08-05 17:23:04.623245 1
evans:bo01    1970-08-05 17:23:04.623245 On
evans:calc    1970-08-05 17:23:05.123245 2
evans:bo01    1970-08-05 17:23:05.123245 Off
evans:calc    1970-08-05 17:23:05.623245 3
evans:calc    1970-08-05 17:23:06.123245 4
evans:calc    1970-08-05 17:23:06.623233 5
evans:calc    1970-08-05 17:23:07.123183 6
```

- Use `Ctrl-C` to stop monitoring.

cainfo Example

- Get information about a process variable:

```
cainfo S35DCCT:currentCC
```

- Returns:

```
State:     connected
Host:      ctlapps4l188:5064
Access:    read, no write
Data type: DBR_DOUBLE (native: DBF_DOUBLE)
Element count: 1
```

Review

- IOC applications can be host-based or target-based.
- The `makeBaseApp.pl` script is used to create IOC application modules and IOC startup directories.
- `{TOP}/configure/RELEASE` contents specify location of other `{TOP}` areas used by this `{TOP}` area.
- `{TOP}/iocBoot/<iocname>/st.cmd` is the startup script for IOC applications.
- The EPICS build system requires the use of GNU `make`.
- The EPICS Application Developer’s Guide contains a wealth of information.

Based on a presentation by :
A. Johnson (APS)

COSYLAB

Getting started with EPICS

Database Concepts

Contents

- Records
- Fields and field types
- Record Scanning
- Input and Output record types
- Links, link address types
- Connecting records together
- Protection mechanisms
- Alarms, deadbands, simulation and security

Database = Records + Fields + Links

- A control system using EPICS will contain one or more IOCs.
- Each IOC loads one or more Databases telling it what to do.
- A Database is a collection of Records of various types.
- A Record is an object with:
  - A unique name
  - A behavior defined by its record type (class)
  - Controllable properties (fields)
  - Optional associated hardware I/O (device support)
  - Links to other records

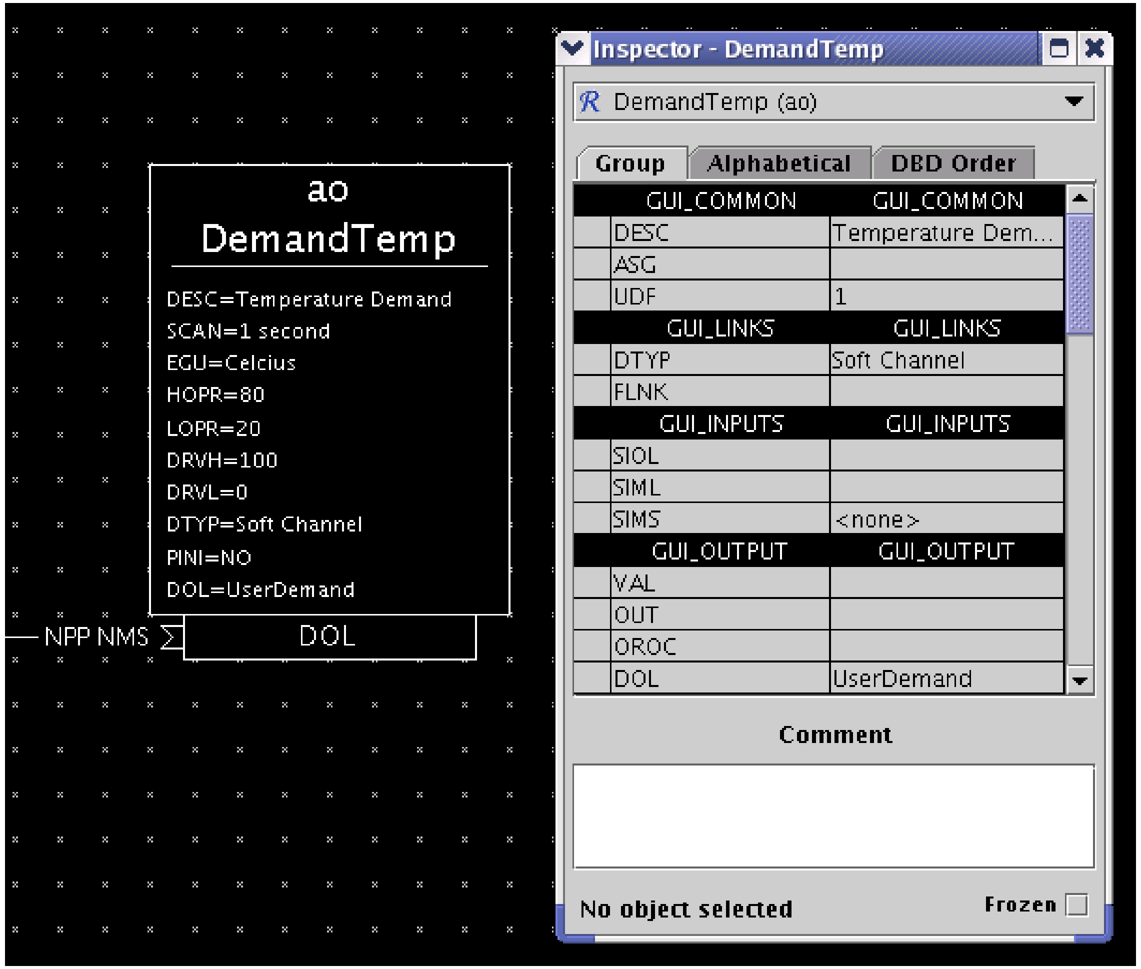
Record Activity

- Records are active — they can do things:
  - Get data from other records or from hardware
  - Perform calculations
  - Check values are in range & raise alarms
  - Put data to other records or to hardware
  - Activate or disable other records
  - Wait for hardware signals (interrupts)
- What a record does depends upon its record type and the settings of its fields.
- No action occurs unless a record is processed.

How is a record implemented?

- A ‘C’ structure with both data storage and pointers to record type information.
- A record definition within a database provides:
  - Record name
  - The record’s type
  - Values for each design field
- A record type provides:
  - Definitions of all the fields
  - Code which implements the record behavior
- New record types can be added to an application as needed.

A Graphical View of a Record



```
ao
DemandTemp
DESC=Temperature Demand
SCAN=1 second
EGU=Celcius
HOPR=80
LOPR=20
DRVH=100
DRVL=0
DTYP=Soft Channel
PINI=NO
DOL=UserDemand
```

NPP NMS DOL

Inspector - DemandTemp

DemandTemp (ao)

GUI_COMMON	GUI_COMMON
DESC	Temperature Dem...
ASG	
UDF	1
GUI_LINKS	GUI_LINKS
DTYP	Soft Channel
FLNK	
GUI_INPUTS	GUI_INPUTS
SIOL	
SIML	
SIMS	<none>
GUI_OUTPUT	GUI_OUTPUT
VAL	
OUT	
OROC	
DOL	UserDemand

Comment

No object selected

Frozen □

The IOC’s View

- The full `.db` file entry for an Analogue Output Record

```
record(ao,"DemandTemp") {
  field(DESC,"Temperature")
  field(ASG,"")
  field(SCAN,"Passive")
  field(PINI,"NO")
  field(PHAS,"0")
  field(EVNT,"0")
  field(DTYP,"VMIC 4100")
  field(DISV,"1")
  field(SDIS,"")
  field(DISS,"NO_ALARM")
  field(PRIO,"LOW")
  field(FLNK,"")
  field(OUT,"#C0 S0")
  field(OROC,"0.0e+00")
  field(DOL,"")
  field(OMSL,"supervisory")
  field(OIF,"Full")
  field(PREC,"1")
  field(LINR,"NO CONVERSION")
  field(EGUF,"100")
  field(EGUL,"0")
  field(EGU,"Celsius")
  field(DRVH,"100")
  field(DRVL,"0")
  field(HOPR,"80")
  field(LOPR,"10")
  field(HIHI,"0.0e+00")
  field(LOLO,"0.0e+00")
  field(HIGH,"0.0e+00")
  field(LOW,"0.0e+00")
  field(HHSV,"NO_ALARM")
  field(LLSV,"NO_ALARM")
  field(HSV,"NO_ALARM")
  field(LSV,"NO_ALARM")
  field(HYST,"0.0e+00")
  field(ADEL,"0.0e+00")
  field(MDEL,"0.0e+00")
  field(SIOL,"")
  field(SIML,"")
  field(SIMS,"NO_ALARM")
  field(IVOA,"Continue normally")
  field(IVOV,"0.0e+00")
}
```

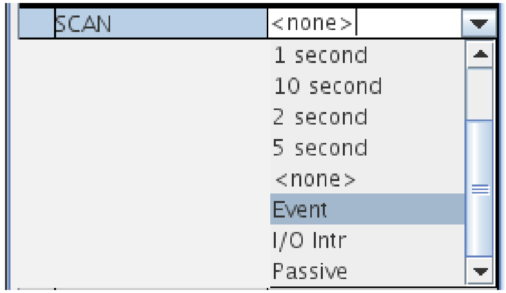
This shows only the design fields, there are other fields which are used only at run-time

Fields are for…

- Defining
  - What causes a record to process
  - Where to get/put data from/to
  - How to turn raw I/O data into a numeric engineering value
  - Limits indicating when to report an alarm
  - When to notify value changes to a client monitoring the record
  - A Processing algorithm
  - Anything else which needs to be set for each record of a given type
- Holding run-time data
  - Input or output values
  - Alarm status, severity and acknowledgements
  - Processing timestamp
  - Other data for internal use

Field Types

- Fields can contain
  - Integers [1, 2, …]
    - char, short or long
    - signed or unsigned
  - Floating-point numbers [0.1, 3.2, …]
    - float or double
  - Strings [“this is a string”]
    - maximum useful length is 40 characters
  - Menu choices
    - select one from up to 16 strings
    - stored as a short integer
  - Links
    - to other records in this or other IOCs
    - to hardware signals (device support)
    - provide a means of getting or putting a value



SCAN <none>

All Records Have These Fields

- Design fields
  - `NAME` - 60 Character unique name (using >40 characters can cause problems)
  - `DESC` - 40 Character description
  - `ASG` - Access security group
  - `SCAN` - Scan mechanism
  - `PHAS` - Scan order (phase)
  - `PINI` - Process at IOC initialization?
  - `PRIO` - Scheduling priority
  - `SDIS` - Scan disable input link
  - `DISV` - Scan disable value
  - `DISS` - Disabled severity
  - `FLNK` - Forward link
- Run-time fields
  - `PROC` - Force processing
  - `PACT` - Process active
  - `STAT` - Alarm status
  - `SEVR` - Alarm severity
  - `TPRO` - Trace processing
  - `UDF` - Set if record value undefined
  - `TIME` - Time when last processed

Other Interesting Fields

- Input/Output
  - `INP` - Input link
  - `OUT` - Output link
  - `DOL` - Desired output location
  - `RVAL` - Raw value
- Conversion
  - `EGU` - Engineering unit string
  - `LINR` - Unit conversion control
  - `EGUL` - Low engineering value
  - `EGUF` - High engineering value
  - `ESLO` - Unit conversion slope
  - `EOFF` - Unit conversion offset
- Limits
  - `HOPR` - High operating range
  - `LOPR` - Low operating range
  - `DRVH` - Drive high
  - `DRVL` - Drive low
- Calculus
  - `CALC` - Calculation

- Alarms
  - `HIGH` - High alarm limit
  - `LOW` - Low alarm limit
  - `HIHI` - HiHi alarm limit
  - `LOLO` - LoLo alarm limit
  - `HSV` - High alarm severity
  - `LSV` - Low alarm severity
  - `HHSV` - HiHi alarm severity
  - `LLSV` - LoLo alarm severity
  - `HYST` - Alarm deadband
- Monitors
  - `ADEL` - Archive deadband
  - `MDEL` - Monitor deadband
- Runtime data
  - `ORAW` - Old raw value
  - `PVAL` - Previous value
  - `ORBV` - Old readback value
  - `LALM` - Last Alarm Monitor Trigger Value
  - `ALST` - Last Archiver Monitor Trigger Value

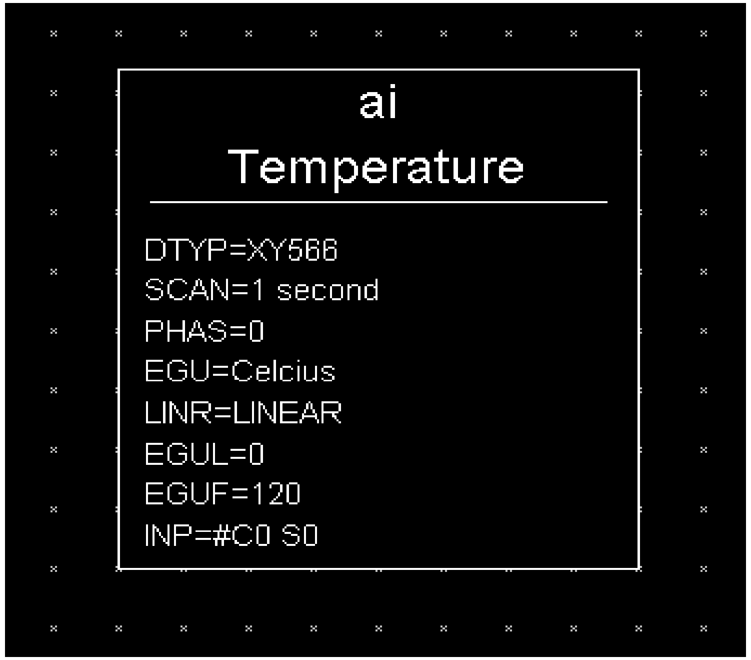
Record Scanning

- The **SCAN** field is a menu choice from:
    - Periodic – 0.1 seconds .. 10 seconds
    - I/O Interrupt (if device supports this)
    - Soft event – EVNT field
    - Passive (default)
- The number in the **PHAS** field allows the processing order to be set within a scan.
    - Records with PHAS=0 are processed first.
    - Then those with PHAS=1, PHAS=2 etc.
- Records with **PINI**=YES are processed once at start-up.
- **PRIO** field selects Low|Medium|High priority for Soft event and I/O Interrupts.
- A record is also processed whenever any value is written to its **PROC** field.

Exercise 5

EPICS Record Basics
(bullets 1, 2 and 3)

Periodically Scanned Analog Input



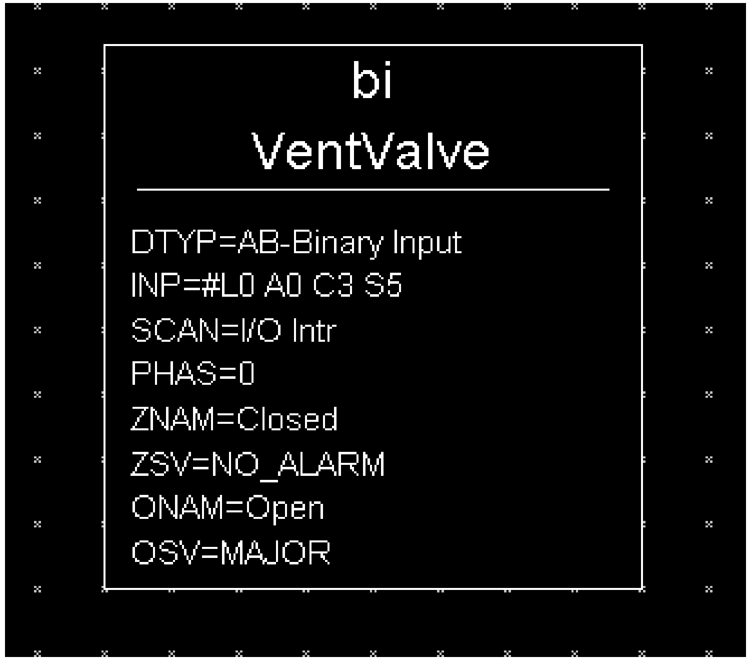
ai

Temperature

```
DTYP=XY566
SCAN=1 second
PHAS=0
EGU=Celcius
LINR=LINEAR
EGUL=0
EGUF=120
INP=#C0 S0
```

- Analogue Input “Temperature”
- Reads from the Xycom XY566 ADC Card 0 Signal 0
- Gets a new value every second
- Data is converted from ADC range to 0..120 Celsius

Interrupt Scanned Binary Input



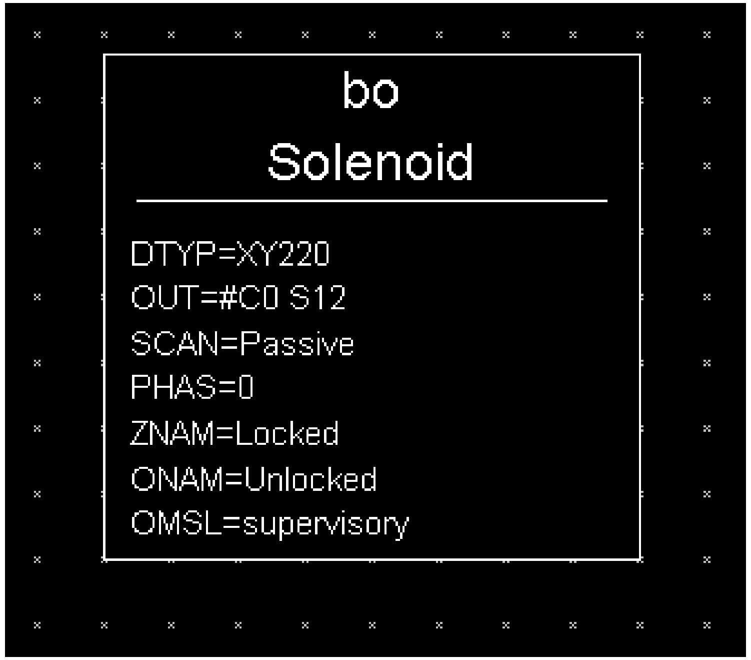
bi

VentValve

```
DTYP=AB-Binary Input
INP=#L0 A0 C3 S5
SCAN=I/O Intr
PHAS=0
ZNAM=Closed
ZSV=NO_ALARM
ONAM=Open
OSV=MAJOR
```

- Binary Input “VentValve”
- Reads from Allen-Bradley TTL I/O Link 0, Adaptor 0, Card 3, Signal 5
- Processed whenever value changes
- 0 = “Closed”, 1 = “Open”
- Major alarm when valve open

Passive Binary Output



bo

Solenoid

```
DTYP=XY220
OUT=#C0 S12
SCAN=Passive
PHAS=0
ZNAM=Locked
ONAM=Unlocked
OMSL=supervisory
```

- Binary Output “Solenoid”
- Controls Xycom XY220 Digital output Card 0 Signal 12
- Record is only processed by:
  - Channel Access ‘put’ to a `PP` field (e.g. `.VAL`)
  - Another record writes to this one using `PP` flag
  - Forward Link from another record
  - Another record reads from this one using `PP` flag

Links

- A link is a type of field, and is one of:
  - Input link
    - Fetches data
  - Output link
    - Writes data
  - Forward link
    - Points to the record to be processed once this record finishes processing.

Input and Output links may be…

- Constant numeric value, e.g.:
    - `0`
    - `3.1415926536`
    - `1.6e-19`
- Hardware link
    - A hardware I/O signal selector, the format of which **depends** on **the device support layer**
- Process Variable link — the name of a record, which at run-time is resolved into:
    - Database link
        - Named record is in this IOC
    - Channel Access link
        - Named record not found in this IOC

Device Support

- Records do not access hardware directly.
- The Device Support layer performs I/O operations on request.
- A particular device support provides I/O for a single record type.
- The **`DTYP`** field determines which device support to use.
- The device support selected determines the format of the link (**`INP`** or **`OUT`** field) containing device address information.
- Adding new device support does not require change to the record software.
- Device support may call other software to do work for it (Driver Support).

Hardware Links

- VME_IO
  - `#Cn Sn @parm`
  - Card, Signal
- INST_IO
  - `@parm`
- CAMAC_IO
  - `#Bn Cn Nn An Fn @parm`
  - Branch, Crate, Node, Address, Function
- AB_IO
  - `#Ln An Cn Sn @parm`
  - Or `#Ln Pn Cn Sn Fn @parm`
  - Link, Adaptor, Card, Signal, Flag
- GPIB_IO
  - `#Ln An @parm`
  - Link, Address
- BITBUS_IO
  - `#Ln Nn Pn Sn @parm`
  - Link, Node, Port, Signal
- BBGPIB_IO
  - `#Ln Bn Gn @parm`
  - Link, Bitbus Address, GPIB Address
- VXI_IO
  - `#Vn Cn Sn @parm`
  - or `#Vn Sn @parm`
  - Frame, Slot, Signal

Database Links

- These comprise:
  - The name of a record in this IOC
    - `myDb:myRecord`
  - An optional field name
    - `.VAL` default
  - Process Passive flag
    - `NPP` default, no processing action
    - `PP` in case of **INPUT** links, request the target to process before fetching data,
      in case of **OUTPUT** links, request the target to process after writing data
  - Maximize Severity flag
    - `NMS` default, no change in record severity
    - `MS` maximize severity, propagate alarm severity from source to destination
    - `MSS` maximize severity and status
    - `MSI` maximize severity but only if invalid
- Example:

```
field(INP, “M1:current.RBV NPP MS“)
```

- **Note:** An input database link with `PP` set that is pointing to an asynchronous input record will not wait for the new value from that record.

Channel Access Links

- Specified like a database link
- Name specifies a record not found in this IOC
- Use Channel Access protocol to communicate with remote IOC
- May include a field name (default `.VAL`)
- `PP` Link flags are ignored:
  - Input links are always `NPP`
  - Output links follow `PP` attribute of destination field
  - This behavior is identical to all other CA clients
- `MS` Link flags apply to Input links:
  - Input links honors a given `NMS` (default) or `MS` flag
  - Output links are always `NMS`
- Additional flags for CA links
  - `CA` Forces a “local” link to use CA
  - `CP` On input link, process this record on CA monitor event
  - `CPP` Like `CP` but only process if `SCAN` is Process Passive

pvAccess Links

- Possible to link records over PVAccess
  - Data and control flow between records
  - Similar to CA links
- Links can be internal or external
  - Pointing to records in the same IOC or a different IOC
- Propagation of
  - Record processing
  - Alarm severity
    - Linked record inherits alarm severity from link source
- Data queue/buffer control
  - Q, pipeline

```
record(longin, “<PV>") {
  field(INP, {pva:{
    pv:“<PV_name>",
    field:"",   # may be a sub-field
    local:false,# Require local PV
    Q:4,        # monitor queue depth
    pipeline:false, # require that server uses monitor flow control protocol
    proc:none,  # Request record processing (side-effects).
    sevr:false, # Maximize severity.
    time:false, # set record time during getValue
    monorder:0, # Order of record processing as a result of CP and CPP
    retry:false,# allow Put while disconnected
    always:false,# CP/CPP input link process even when .value field hasn't changed
    defer:false # Defer put
  }})
}
```

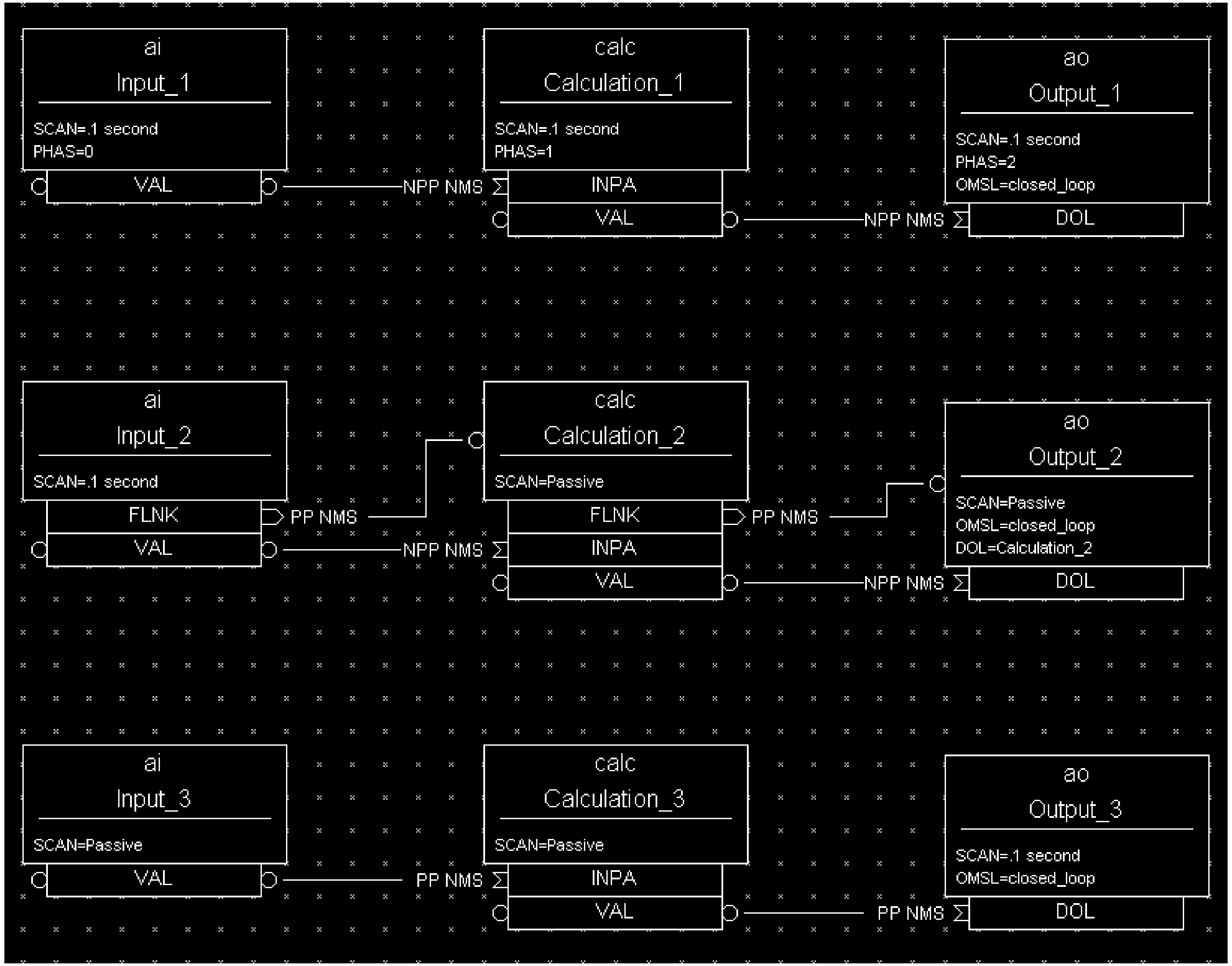
Forward Links

- Usually a Database link, referring to a record in the same IOC.
- Forward linking via Channel Access is possible but must explicitly name the `PROC` field of the remote record.
- No flags (`PP`, `NMS` etc.).
- Destination record is only processed if it has:
  - `SCAN = Passive`
- Does not pass a value, just causes subsequent processing.

Exercise 5

EPICS Record Basics
(bullet 4)

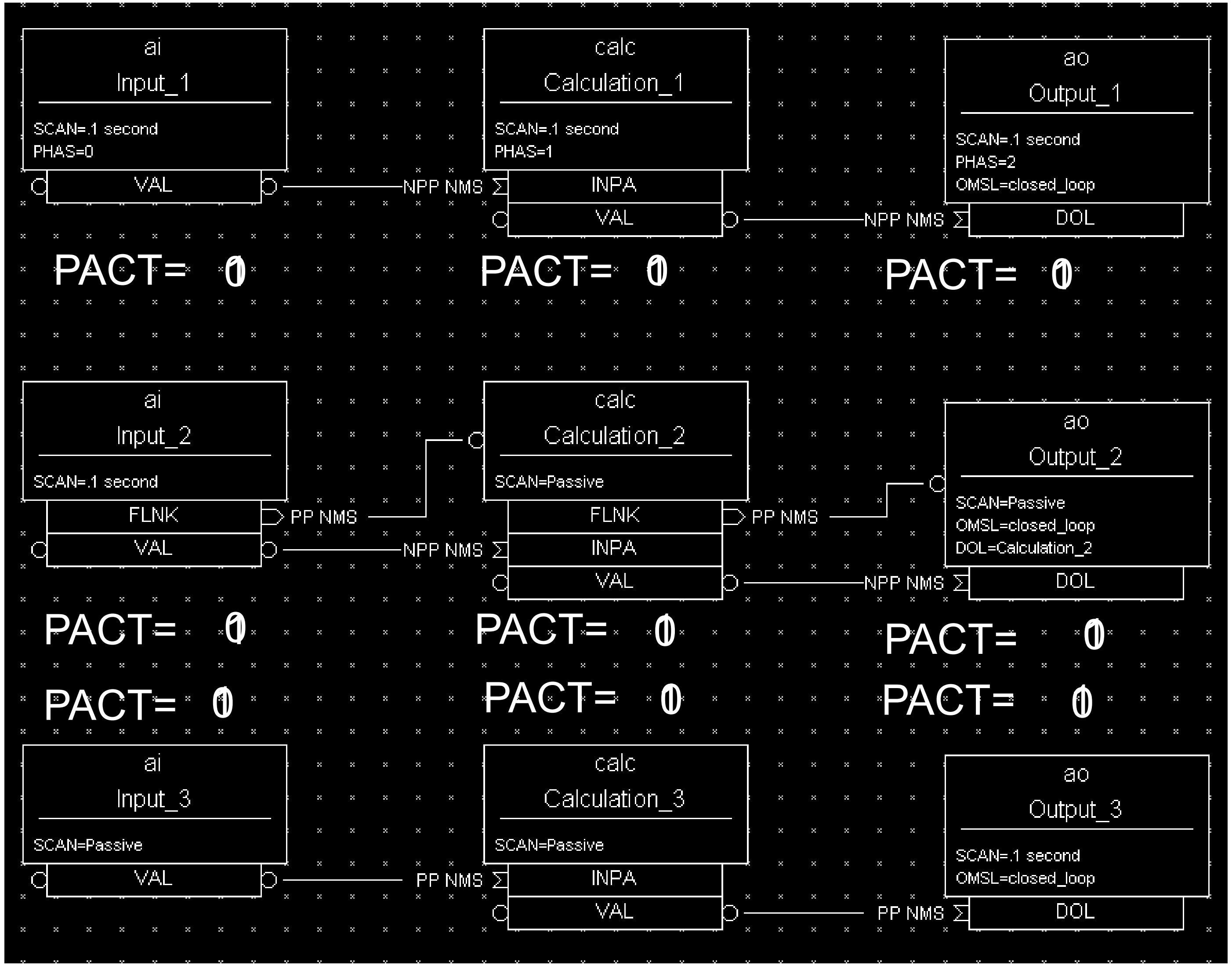
Processing Chains



The PACT Field

- Every record has a Boolean run-time field called `PACT` (Process Active)
- `PACT` breaks loops of linked records
- It is set to ‘true’ early in the act of processing the record
    - `PACT` is true whenever a link in that record is used to get/put a value
- `PACT` is set to false after record I/O and forward link processing are finished
- A `PP` link can never make a record process if it has `PACT` true
    - Input links take the current value
    - Output links just put their value

Processing Chains



ai
Input_1
SCAN=.1 second
PHAS=0
VAL

calc
Calculation_1
SCAN=.1 second
PHAS=1
INPA
VAL

ao
Output_1
SCAN=.1 second
PHAS=2
OMSL=closed_loop
DOL

ai
Input_2
SCAN=.1 second
FLNK
VAL

calc
Calculation_2
SCAN=Passive
FLNK
INPA
VAL

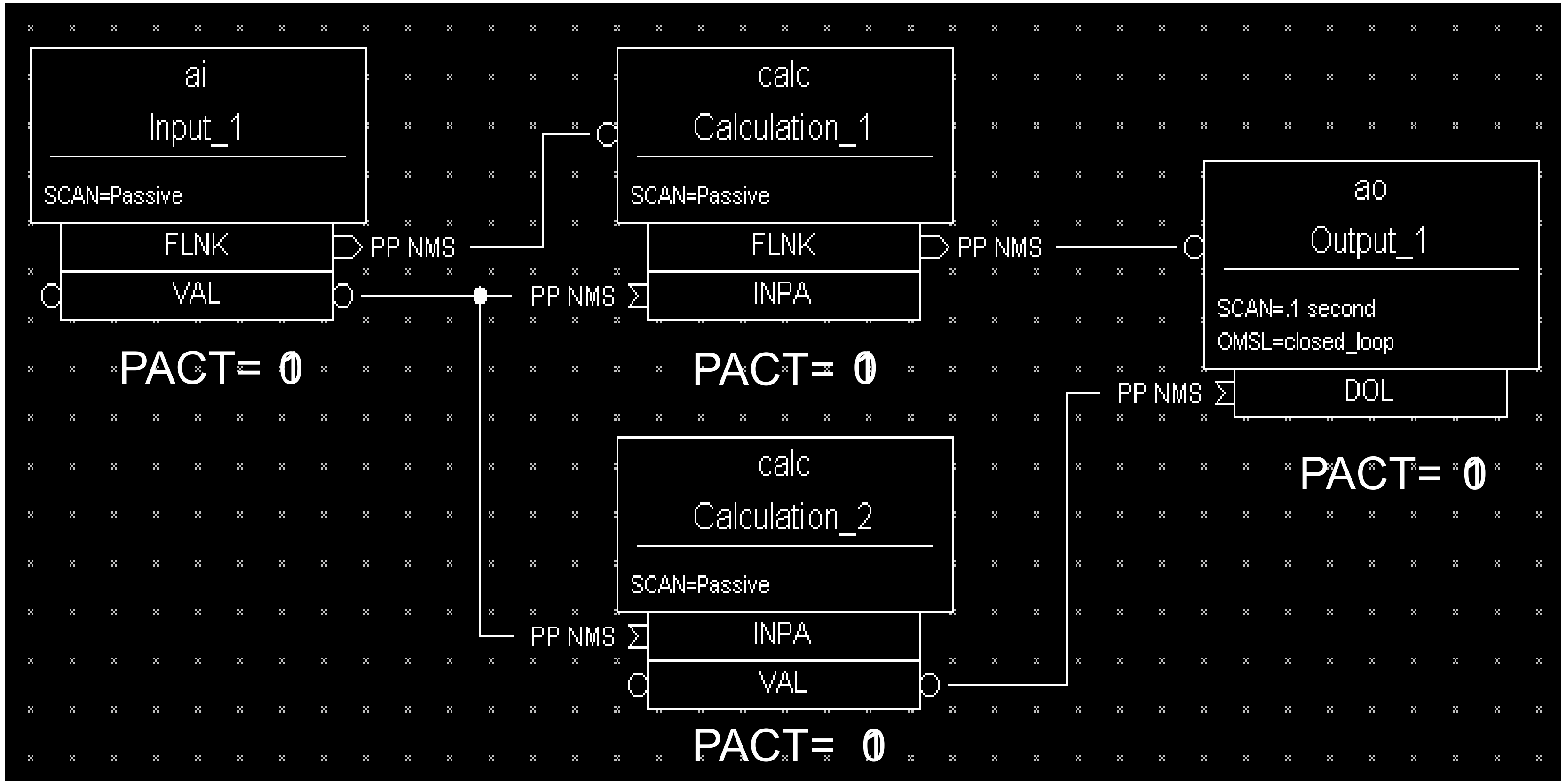
ao
Output_2
SCAN=Passive
OMSL=closed_loop
DOL=Calculation_2
DOL

ai
Input_3
SCAN=Passive
VAL

calc
Calculation_3
SCAN=Passive
INPA
VAL

ao
Output_3
SCAN=.1 second
OMSL=closed_loop
DOL

What happens here?

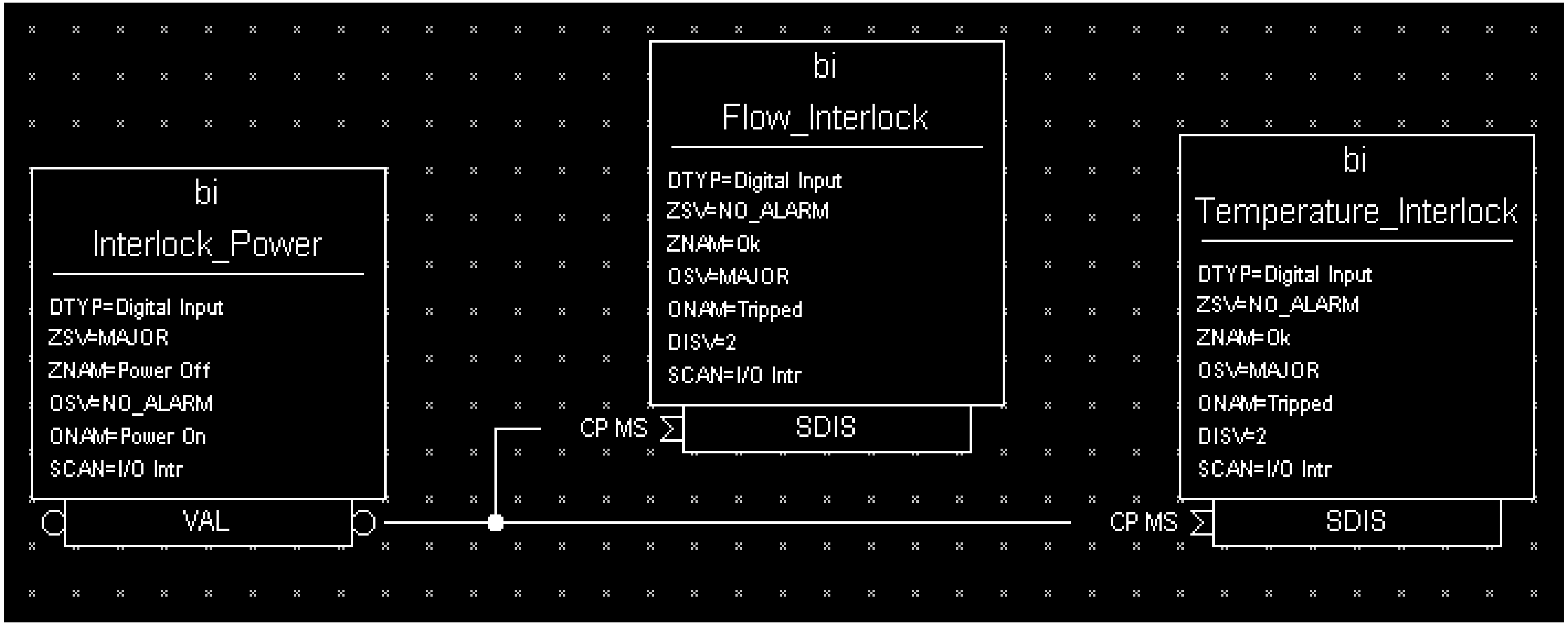


Disable Processing

- It is useful to be able to stop an individual record from processing on some condition
- Before record-specific processing is called, a value is read through the `SDIS` input link into `DISA`
- If `DISA=DISV`, the record will not be processed
- A disabled record may be put into an alarm by giving the desired severity in the `DISS` field
- The `FLNK` of a disabled record is never triggered

Database Example

- `Temp_Interlock` and `Flow_Interlock` get their values from the hardware. If the interlock power is `OFF`, both interlock records are disabled (their values do not change).



bi
Interlock_Power
DTYP=Digital Input
ZSV=MAJOR
ZNAM=Power Off
OSV=NO_ALARM
ONAM=Power On
SCAN=I/O Intr

bi
Flow_Interlock
DTYP=Digital Input
ZSV=NO_ALARM
ZNAM=Ok
OSV=MAJOR
ONAM=Tripped
DISV=2
SCAN=I/O Intr

bi
Temperature_Interlock
DTYP=Digital Input
ZSV=NO_ALARM
ZNAM=Ok
OSV=MAJOR
ONAM=Tripped
DISV=2
SCAN=I/O Intr

- How can we give the two interlock records an INVALID alarm severity when the Interlock Power is OFF?

`SDIS` field

- Are there any mistakes in the DB?

How do records allocate CPU time?

- Several IOC tasks are used:
  - `callback` (3 priorities) – I/O Interrupt
  - `scanEvent` – Soft Event
  - `scanPeriod` – Periodic
    - A separate task is used for each scan period
    - Faster scan rates are given a higher task priority (if supported by the IOC's Operating System)

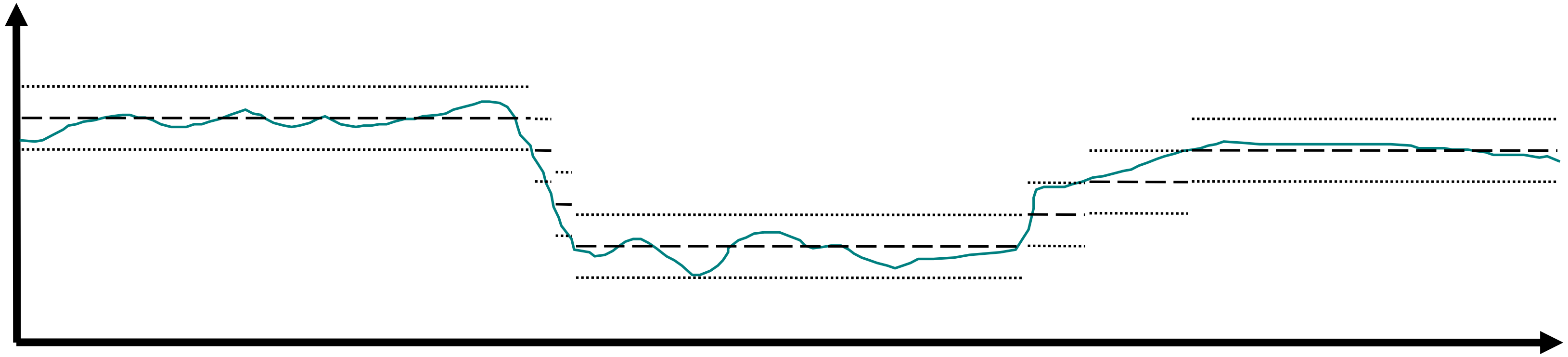
- Channel Access tasks use lower priority than record processing
  - If a CPU spends all its time doing I/O and record processing, you may be unable to control or monitor the IOC via the network

Alarms

- Every record has the fields
  - SEVR Alarm Severity
    - NONE, MINOR, MAJOR, INVALID
  - STAT Alarm Status (reason)
    - READ, WRITE, UDF, HIGH, LOW, STATE, COS, CALC, DISABLE, etc.
- Most numeric records check VAL against HIHI, HIGH, LOW and LOLO fields after the value has been determined
- The HYST field prevents alarm chattering
- A separate severity can be set for each numeric limit (HHSV, HSV, LSV, LLSV)
- Discrete (binary) records can raise alarms on entering a particular state, or on a change of state (COS)

Change notification: Monitor deadbands

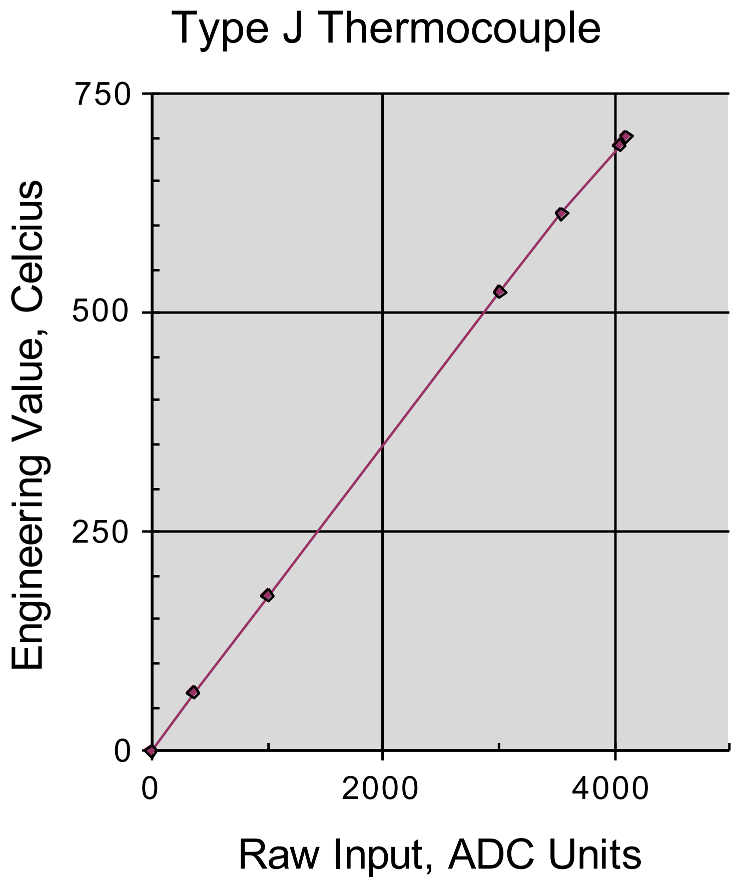
- Channel Access notifies clients which are monitoring a numeric record when
  - `VAL` changes by more than the value in field:
    - `MDEL` Value monitors
    - `ADEL` Archive monitors
  - Record’s Alarm Status changes
    - `HYST` Alarm hysteresis
  - Analogue Input record provides smoothing filter to reduce input noise (`SMOO`)



Breakpoint Tables

- Analogue Input and Output records can do non-linear conversions from/to the raw hardware value
- Breakpoint tables interpolate values from a given table
- To use, set the record’s `LINR` field to the name of the breakpoint table you want to use (e.g. `typeJDegC`)
- Example breakpoint table (in some loaded .dbd file)

```
breaktable(typeJDegC) {
       0.000000   0.000000
     299.268700  74.000000
     660.752744 163.000000
    1104.793671 274.000000
    1702.338802 418.000000
    2902.787322 703.000000
    3427.599045 831.000000
    ...
}
```



Simulation

- Input and output record types often allow simulation of hardware interfaces

`SIML`	Simulation mode link
`SIMM`	Simulation mode value
`SIOL`	Simulation input link
`SIMS`	Simulation alarm severity

- Before using its device support, a record reads `SIMM` through the `SIML` link
- If `SIMM=YES`, device support is ignored; record I/O uses the `SIOL` link instead
- An alarm severity can be set whenever simulating, given by the `SIMS` field.

Exercise 5

EPICS Record Basics
(bullets 5, 6 and 7)

Access Security

- A networked control system must have the ability to enforce security rules
  - Who can do what from where, and when?
- In EPICS, security is enforced by the CA server (typically the IOC).
- A record is placed in the Access Security Group named in its ASG field
  - DEFAULT is used if no group name is given
- Rules for each group determine whether a CA client can read or write to records in the group, based on
  - Client user ID
  - Client IP address
  - Access Security Level of the field addressed
  - Values read from the database

Access Security Configuration File

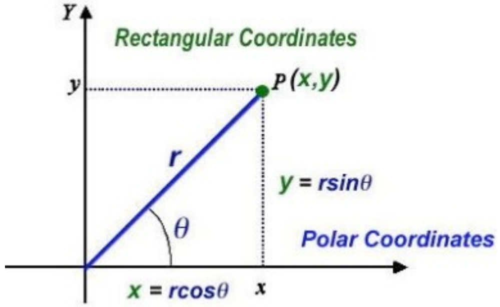
- Security rules are loaded from an Access Security Configuration File, for example:

```
UAG(users) {user1, user2}
HAG(hosts) {host1, host2}
ASG(DEFAULT) {
    RULE(1, READ)
    RULE(1, WRITE) {
        UAG(users)
        HAG(hosts)
    }
}
```

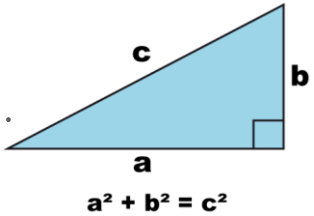
- If no security file is loaded, Security will be turned off and nothing refused
- For more details and the rule syntax, see Chapter 8 of the IOC Application Developers Guide.

EPICS 7 enhancement

Atomic access



- A simple semi-realistic example
  - Rotating unit vector
    - Polar vs. Cartesian coordinates
  - Internally incrementing angle PV
  - Cartesian coordinate PVs
    - circle:X
    - circle:Y
  - Test on client side: use Pythagoras' theorem on received values. Radius `r` should always be `1`.



- Using CA: two independent channels.
  - Correctness depends on simultaneity ("mostly" OK but not guaranteed)
  - May appear to work if run on one host, or on a simple network.
- Using PVA: calculated and transported as a single unit.
  - Correctness guaranteed, regardless of network or IOC load.
- Using `info` tags in the EPICS database, we can create group PVs
  - Combine data from different records
  - group PVs are served by the PVA server. Addressed by the group name.

EPICS 7 enhancement

Groups

- Use of `info` tags to configure groups
  - Added to “V3” EPICS records; no other configuration needed.
  - Would be a no-op in a V3 IOC
  - Use `trigger` keyword to process the group (send monitors)
- Example on right: creates a group `circle`
  - NTTable normative type (version 1.0)
  - `Value` consists of two scalars, `X` and `Y`

Using pvget we see:

```
$ pvget circle
circle epics:nt/NTTable:1.0
    structure record
        structure _options
            uint queueSize 0
            boolean atomic true
    double angle 16
    alarm_t alarm
        int severity 0
        int status 0
        string message NO_ALARM
    time_t timeStamp 2019-06-24
16:08:17.546
        long secondsPastEpoch 1561385297
        int nanoseconds 546217000
        int userTag 0
    structure value
        double X 0.961262
        double Y 0.275637
```

```
record(calc, "circle:angle") {
  field(PINI, "RUNNING") # bootstrap
  field(INPA, "circle:angle NPP")
  field(INPB, "circle:step NPP")
  field(INPD, "360")
  field(CALC, "C:=A+B;(C>=D)?C-D:C")
  info(Q:group, {
        "circle":{ +id:"epics:nt/NTTable:1.0",
            "angle":{+type:"plain",
                                +channel:"VAL”}}
  })
}
record(calc, "circle:x") {
  field(INPA, "circle:angle NPP")
  field(CALC, "cos(A*PI/180)")
  field(TSEL, "circle:angle.TIME")
  field(FLNK, "circle:y")
  field(PREC, "3")
  info(Q:group, {
        "circle":{ "":{+type:"meta", +channel:"VAL"},
            "value.X":{+type:"plain",
                                  +channel:"VAL",
                                  +trigger:”*”} }
  })
}
record(calc, "circle:y") { <idem> } (except “trigger”
keyword)
```

Exercise 6

Processing Chains

Based on a presentation by :
T. Mooney (APS)

COSYLAB

Getting Started with EPICS

Record Types and Examples

Scope

- This lecture:
  - Existing record types and what they can do
  - Record-type documentation
  - Where to look for record types
- Related topics not covered in this lecture:
  - What is a record?
    - Database – Concepts and linking
  - How do I connect a record instance to a device?
    - set the link field (Database– Concepts and linking)
  - How do I connect a record type to a device?
    - Finding and deploying I/O support -- or, if not found...
    - Writing device support
  - How do I write a new record type?
    - Writing Record Support

EPICS Record Types

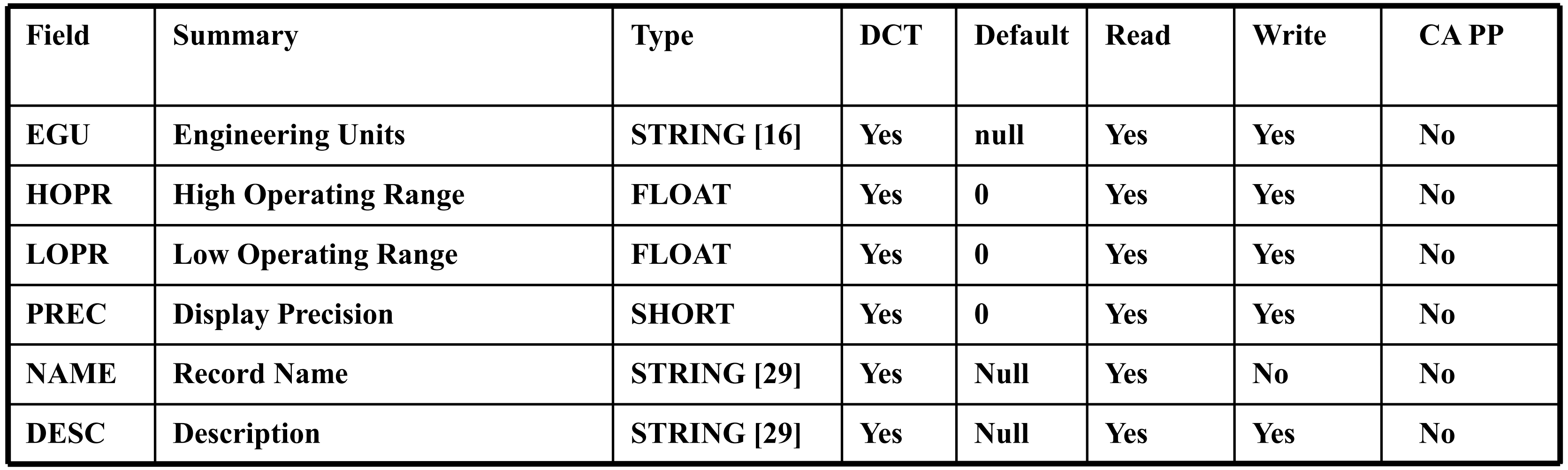
- Where do record types come from?
  - EPICS Base (`<base>/modules/database/src/std/rec`)
    - General purpose record types
    - No record-type specific operator displays or databases
    - Documentation in EPICS Component Reference Manual
  - EPICS collaboration
    - General purpose, and application-specific, record types
    - Some are supported for use by collaborators (some are NOT)
    - Some come with record-type specific displays, databases
  - Custom record types can be written by an EPICS developer and added to an EPICS application.
    - Not in the scope of this lecture

Component Reference Manual

- Where is it?
  - Software > EPICS Base > EPICS 7 > `<release>` > Other Links > IOC Component Reference Documentation
  - https://epics.anl.gov/base/R7-0/9-docs/ComponentReference.html
- What is in it?
  - Database Concepts (good review)
  - Fields common to all records
  - Fields common to many records
  - Record Types – provides a description of the record processing routines for most of the record types in the base.
- When would I use it?
  - Skim through before writing any databases
  - Read through before writing any records
  - Otherwise, use as reference

Component Reference Manual (cont.)

- Introduction to EPICS, Process Database Concepts
  - Note special meaning of the words scan, process, address, link, and monitor
- Record references
  - Descriptions of record fields, processing, and useful info for writing device support
  - Contains lots of tables like the following:



Field	Summary	Type	DCT	Default	Read	Write	CA PP
EGU	Engineering Units	STRING [16]	Yes	null	Yes	Yes	No
HOPR	High Operating Range	FLOAT	Yes	0	Yes	Yes	No
LOPR	Low Operating Range	FLOAT	Yes	0	Yes	Yes	No
PREC	Display Precision	SHORT	Yes	0	Yes	Yes	No
NAME	Record Name	STRING [29]	Yes	Null	Yes	No	No
DESC	Description	STRING [29]	Yes	Null	Yes	Yes	No

Collaboration Supported Records

- Where are they found?
  - Soft-support list (search for record)
    - https://epics-controls.org/resources-and-support/modules/soft-support/
  - The tech-talk email list: tech-talk@aps.anl.gov
  - The soft-support list contains entries like this (among entries for other kinds of soft support):

Class	Name	Description	Contact	Link
record	epid	Enhanced PID record	Mark Rivers	CARS:epidRecord
record	genSub	Multi-I/O subroutine, handles arrays	Andy Foster	OSL:epics
…	…	…	…	…
record	table	Control an optical table	Tim Mooney	APS:synApps/optics

Record Types

Input Records

- `ai` - Analog input [BASE]
  - Read analog value, convert to engineering units, four alarm levels, simulation mode
- `bi` - Binary input [BASE]
  - Single bit, two states, assign strings to each state, alarm on either state or change of state, simulation mode
- `mbbi` - Multi-bit binary input [BASE]
  - Multiple bit, 16 states, assign input value for each state, assign strings to each state, assign alarm level to each state, simulation mode
- `mbbiDirect` – mbbi variant [BASE]
  - Read an unsigned short and map each bit to a field (32 `bi` records in one)

Input Records (cont.)

- `stringin` - String input [BASE]
  - 40 character (max) ascii string, simulation mode
- `longin` - Long integer input [BASE]
  - Long integer, four alarm levels, simulation mode
- `int64in` – 64bit integer input [BASE]
  - 64bit integer, four alarm levels, simulation mode
- `waveform` – array input [BASE]
  - Configurable data type and array length

Output Records

- `ao` - Analog output [BASE]
  - Write analog value, convert from engineering units, four alarm levels, closed_loop mode, drive limits, output rate-of-change limit, INVALID alarm action, simulation mode
- `bo` - Binary output [BASE]
  - Single bit, two states, assign strings to each state, alarm on either state or change of state, closed_loop mode, momentary 'HIGH', INVALID alarm action, simulation mode
- `longout` [BASE]
  - Write long integer value, four alarm levels, closed_loop mode, INVALID alarm action, simulation mode
- `int64out` [BASE]
  - Write 64bit integer value, four alarm levels, closed_loop mode, INVALID alarm action, simulation mode

Output Records (cont.)

- `mbbo` - Multi-bit binary output [BASE]
  - Multiple bit, 16 states, assign output value for each state, assign strings to each state, assign alarm level to each state, closed_loop mode, INVALID alarm action, simulation mode
- `mbboDirect` - mbbo variant [BASE]
  - 32 settable bit fields that get written as a short integer to the hardware, closed_loop mode, INVALID alarm action, sim. mode
- `motor` [synApps]
  - Controls stepper and servo motors
- `stringout` [BASE]
  - Write a character string (40 max), closed_loop mode, INVALID alarm action, simulation mode

Algorithms/Control Records
Calc

- `calc` - run-time expression evaluation [BASE]
  - 12 input links, user specified “calc expression” (algebraic, trig, relational, Boolean, Logical, “?”), four alarm levels
  - Sample expressions:
    - `0 read: “<calc_record>.VAL = 0”`
    - `A note ‘A’ refers to <calc_record>.A`
    - `A+B`
    - `sin(a)`
    - `(A+B)<(C+D)?E:F+L+10`
- `calcout` – calc variant [BASE]
  - Conditional output link, separate output CALC expression (.`OCAL`), output delay, and output event
  - Output-link options : `Every Time`, `On Change`, `When Zero`, `When Non-zero`, `Transition To Zero`, `Transition To Non-zero`

Algorithms/Control Records
Calc

- `sCalcout` – calcout variant [synApps]
  - Has both numeric fields (A,B,..L) and string fields (AA,BB,..LL)
  - Supports both numeric and string expressions. E.g.,
    - `A+DBL("value is 3.456") -> 3.456`
    - `printf("SET:VOLT:%.2lf", A+4) -> "SET:VOLT:5.00"`
  - Additional output-link option: "Never"
- `transform` – calc/seq variant [synApps]
  - Like 16 calcout records (but outlinks are not conditional)
  - Expressions read all variables but write to just one.
  - Uses sCalcout record's calculation engine
  - Example expressions:
    - `A: 2 read: "<transform>.A = 2"`
    - `B: A+1+C uses new value of 'A', old value of 'C'`

Algorithms/Control Records
Subroutine

- Goal: Connect subroutine (C code) to a record

- `sub` – Subroutine [BASE]
  - 12 input links, user provided subroutine
- `aSub` – Array subroutine [BASE]
  - Type of data could be selected
  - Up to 21 inputs and outputs
- Fields:
  - `INAM` - Initialization Subroutine Name
  - `SNAM` - Subroutine Name
  - `SUBL` - Subroutine Link [`aSub`]
- Processing
  - Synchronous
  - Asynchronous

Algorithms/Control Records
Subroutine (impl.)

- C subroutine example (synchronous).

```
long subInit(subRecord *psub) {
    printf("subInit was called\n");
    return(0);
}

long subProcess(subRecord *psub) {
    psub->val++;
    return(0);
}
```

Algorithms/Control Records
Processing

- `dfanout` – Data fanout [BASE]
  - Writes a single value to eight output links
- `fanout` [BASE]
  - Forward links to 16 other records.
  - Selection mask
- `sel` - Select [BASE]
  - 12 input links, four select options [specified, highest, lowest, median], four alarm levels
- `seq` - Sequence [BASE]
  - 16 “Input link/Value/Output link” sets: [in-link, delay, value, out-link]
  - Selection mask

Algorithms/Control Records
Analysis

- `subArray` [BASE]
  - Extracts a sub-array from a waveform.
- `compress` [BASE]
  - The data compression record is used to collect and compress data from arrays.
  - Input link can be scalar or an array.
  - Algorithms include N to 1 compression (highest, lowest, or average), circular buffer of scalar input.
- `histogram` [BASE]
  - Accumulates histogram of the values of a scalar PV

Examples of Custom Records

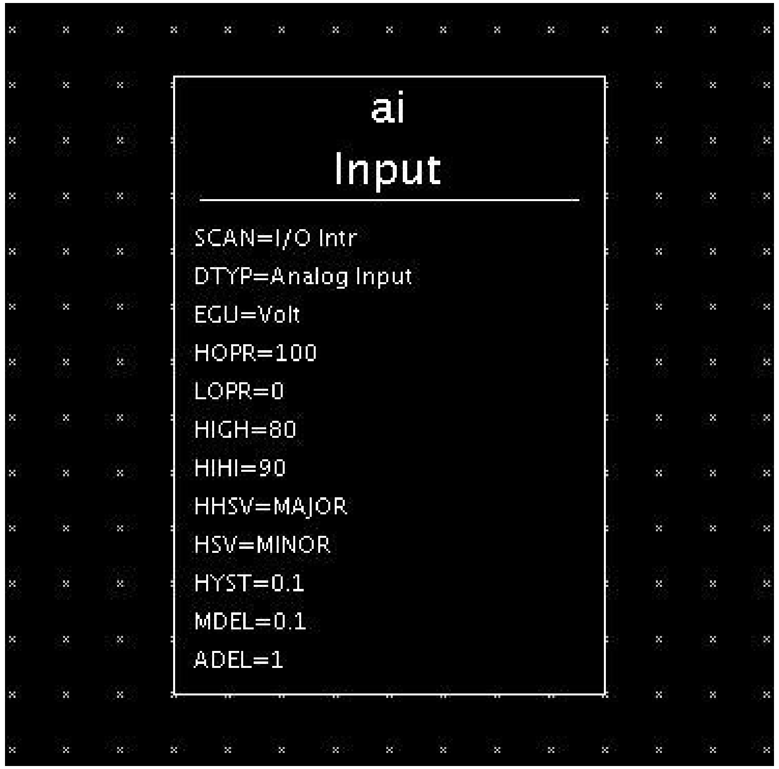
- `rf` - RF Amplitude Measurements [ANL]
  - Sample time, measurement in watts and db, waveform acquired through sweeping sample time
- `bpm` - Beam Position Monitor [ANL]
  - Four voltage inputs, numerous calibration constants, X-Y-I outputs, waveforms for each input
- Many others that are site-specific

Examples

Database Example
Analog Input (AI)

- An analog input record
  - Reading a voltage in Volts
  - Operating range from 0 V to 100 V.
  - Limit for a minor alarm is 80 V
  - Limit for a major alarm is 90 V

There is a hysteresis associated with the alarm limits and a deadband for reporting value changes to monitors and archivers.



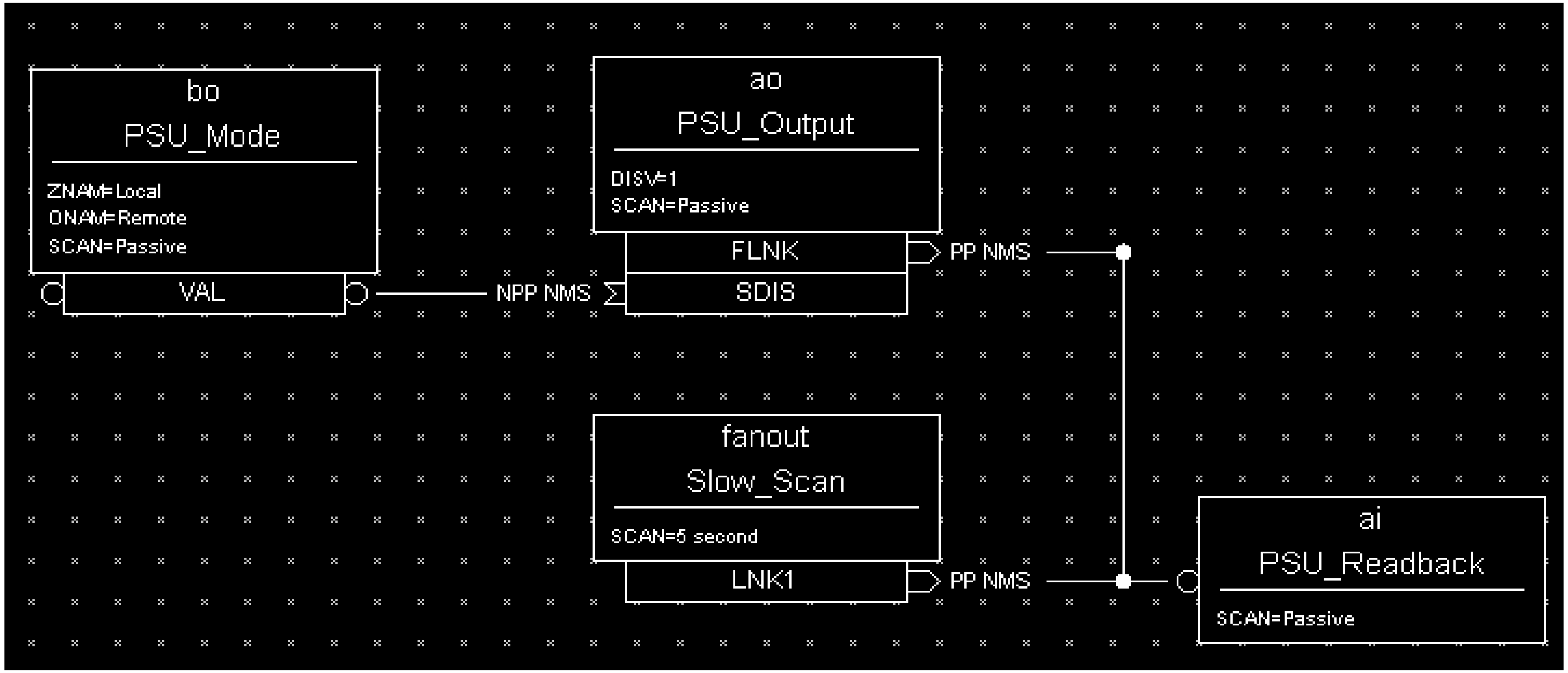
ai

Input

```
SCAN=I/O Intr
DTYP=Analog Input
EGU=Volt
HOPR=100
LOPR=0
HIGH=80
HIHI=90
HHSV=MAJOR
HSV=MINOR
HYST=0.1
MDEL=0.1
ADEL=1
```

Database Example
Processing

- Slow Periodic Scan with Fast Change Response



bo
PSU_Mode
ZNAM=Local
ONAM=Remote
SCAN=Passive
VAL

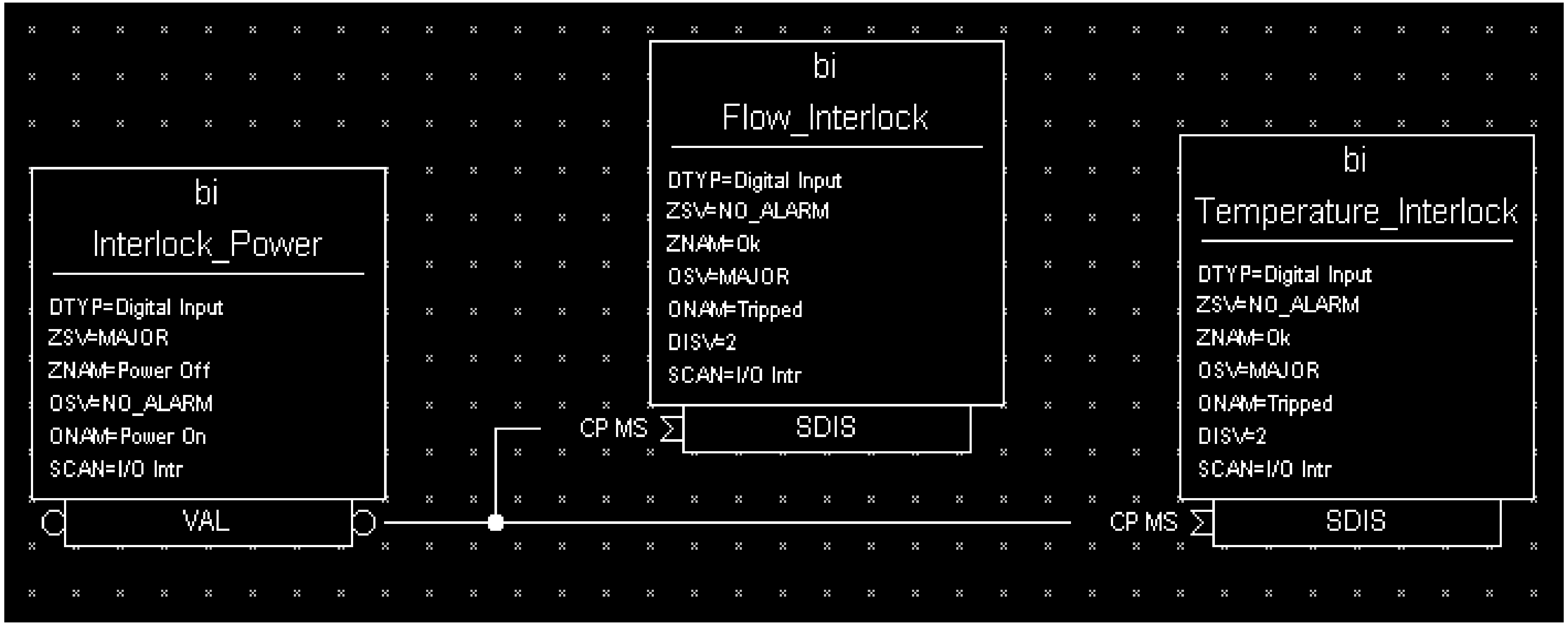
ao
PSU_Output
DISV=1
SCAN=Passive
FLNK
SDIS

fanout
Slow_Scan
SCAN=5 second
LNK1

ai
PSU_Readback
SCAN=Passive

- The `ai` record gets processed every 5 s AND when the associated `ao` record is changed. This provides an immediate response to a change even though the desired scan rate is very slow. Changes to the power supply settings are inhibited by the `bo` record, which could represent a Local/Remote switch.

Database Example
(Process Control)



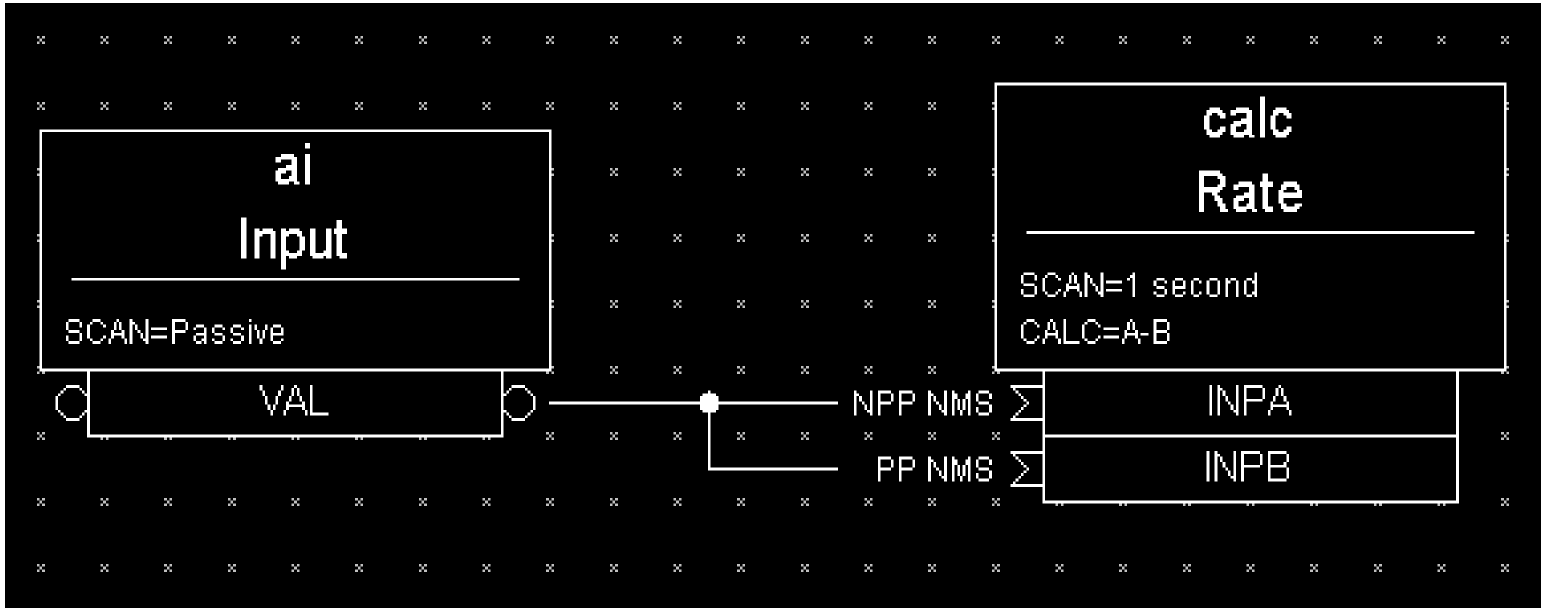
```
bi
Interlock_Power
DTYP=Digital Input
ZSV=MAJOR
ZNAM=Power Off
OSV=NO_ALARM
ONAM=Power On
SCAN=I/O Intr
```

```
bi
Flow_Interlock
DTYP=Digital Input
ZSV=NO_ALARM
ZNAM=Ok
OSV=MAJOR
ONAM=Tripped
DISV=2
SCAN=I/O Intr
```

```
bi
Temperature_Interlock
DTYP=Digital Input
ZSV=NO_ALARM
ZNAM=Ok
OSV=MAJOR
ONAM=Tripped
DISV=2
SCAN=I/O Intr
```

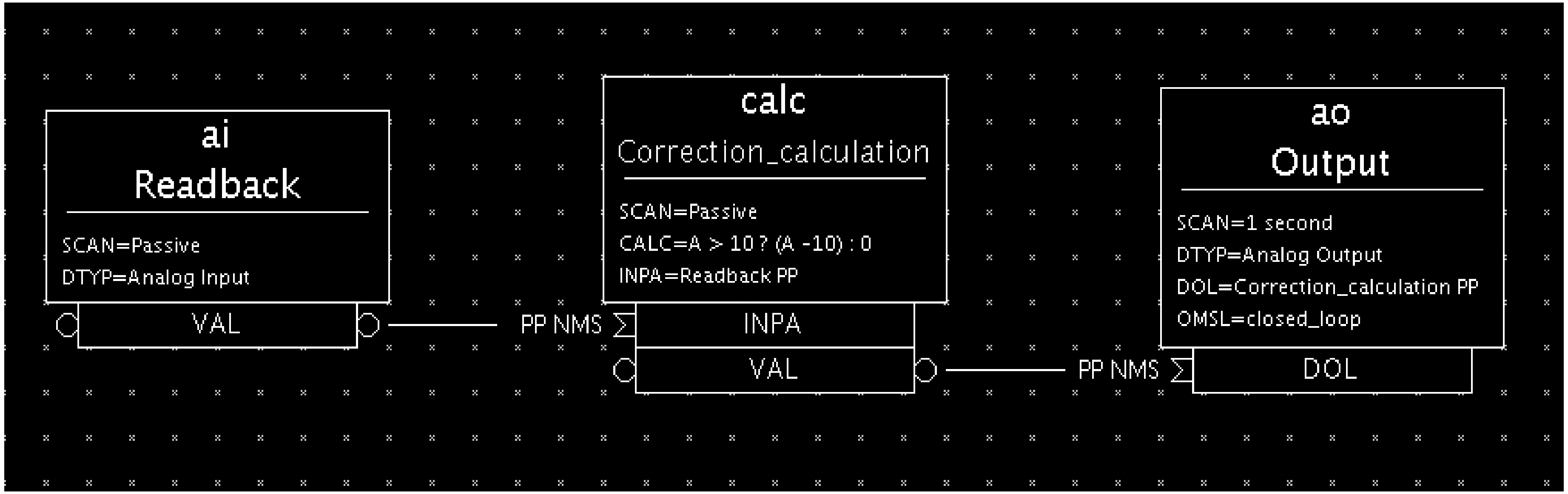
- `Temp_Interlock` and `Flow_Interlock` get their values from the hardware. Both trigger a `MAJOR` alarm if their value is `1`. If the interlock power is `OFF`, both interlock records are disabled (their values do not change).
- How can we give the two interlock records an `INVALID` alarm severity when the Interlock Power is off? Are there any mistakes in the DB?

Database Example
Calc ("Rate-of-Change" of Input)



- `INPA` fetches data that is 1 s old because it does not request processing of the `ai` record. `INPB` fetches current data because it requests the `ai` record to process. The subtraction of these two values reflects the 'rate of change' (difference/sec) of the reading.

Database Example
Simple Control



ai
Readback

SCAN=Passive
DTYP=Analog Input

calc
Correction_calculation

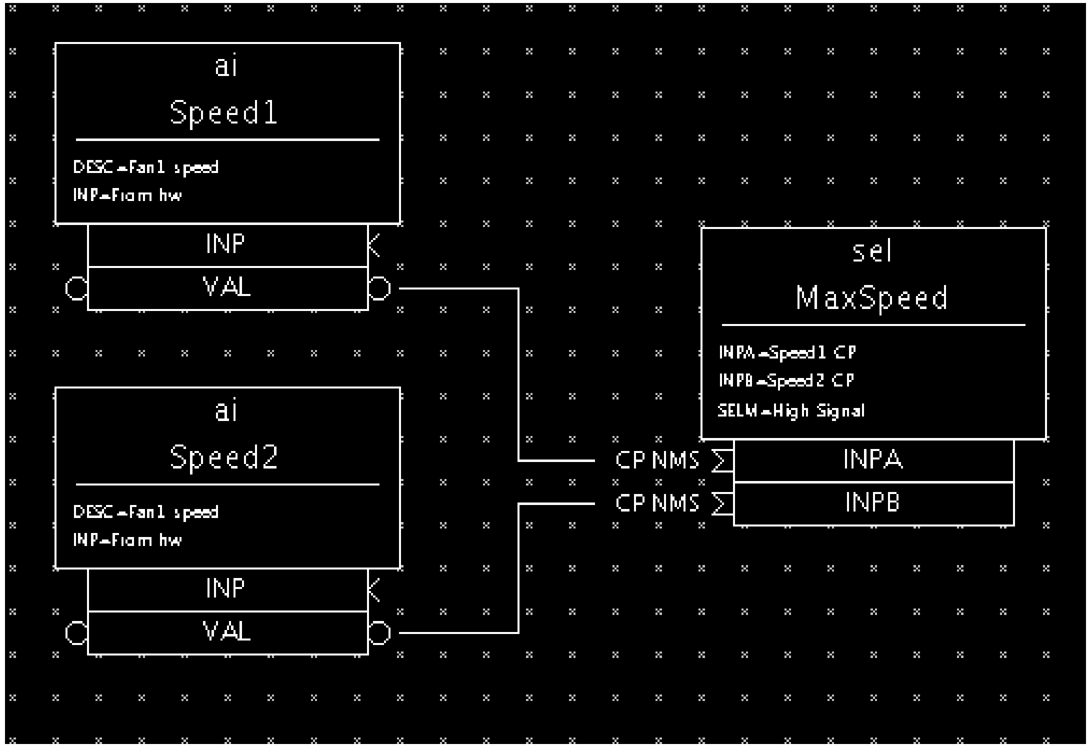
SCAN=Passive
CALC=A > 10 ? (A -10) : 0
INPA=Readback PP

ao
Output

SCAN=1 second
DTYP=Analog Output
DOL=Correction_calculation PP
OMSL=closed_loop

- An `ao` record triggers every second and requests the correction calculation from the `calc` record. The calc record requests the readback value from `ai` record, calculates the correction and the `ao` finishes its processing and outputs the correction.

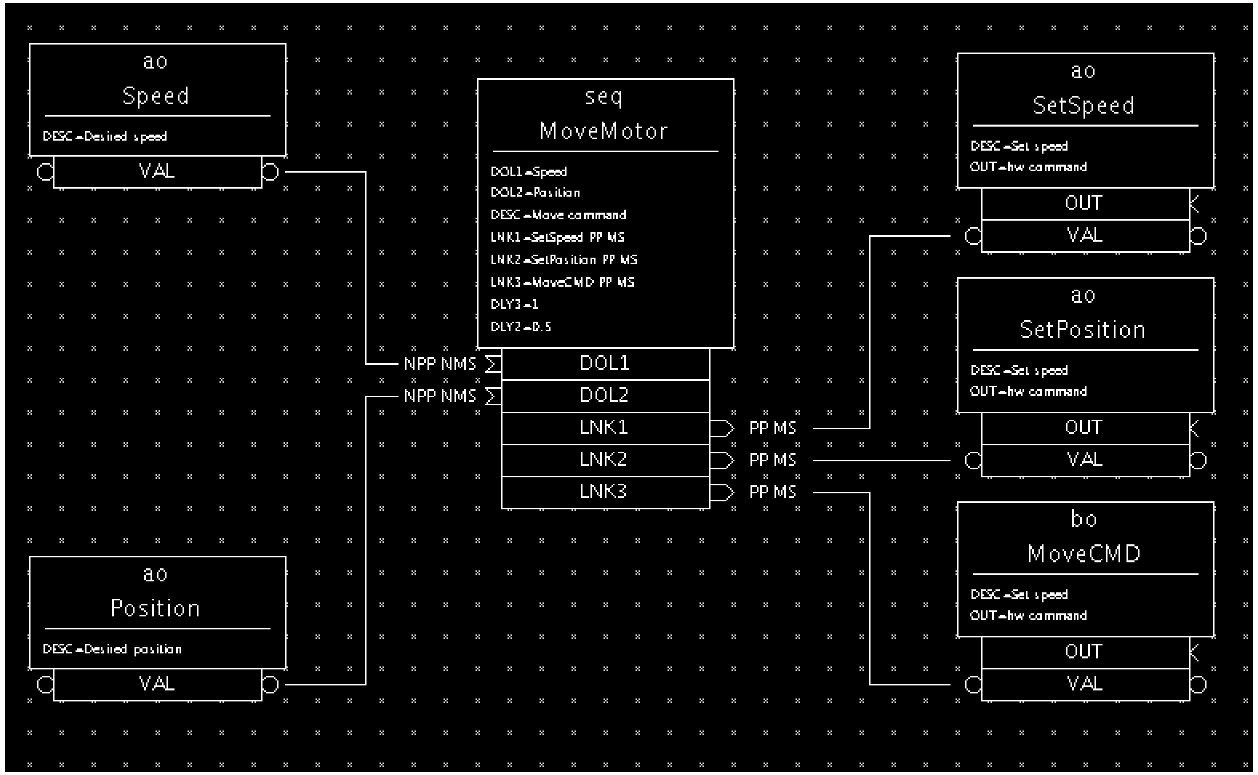
Database Example
Select



- The speeds of two fans are read from the hardware. The `select` record monitors their values and sets its value to the highest speed.

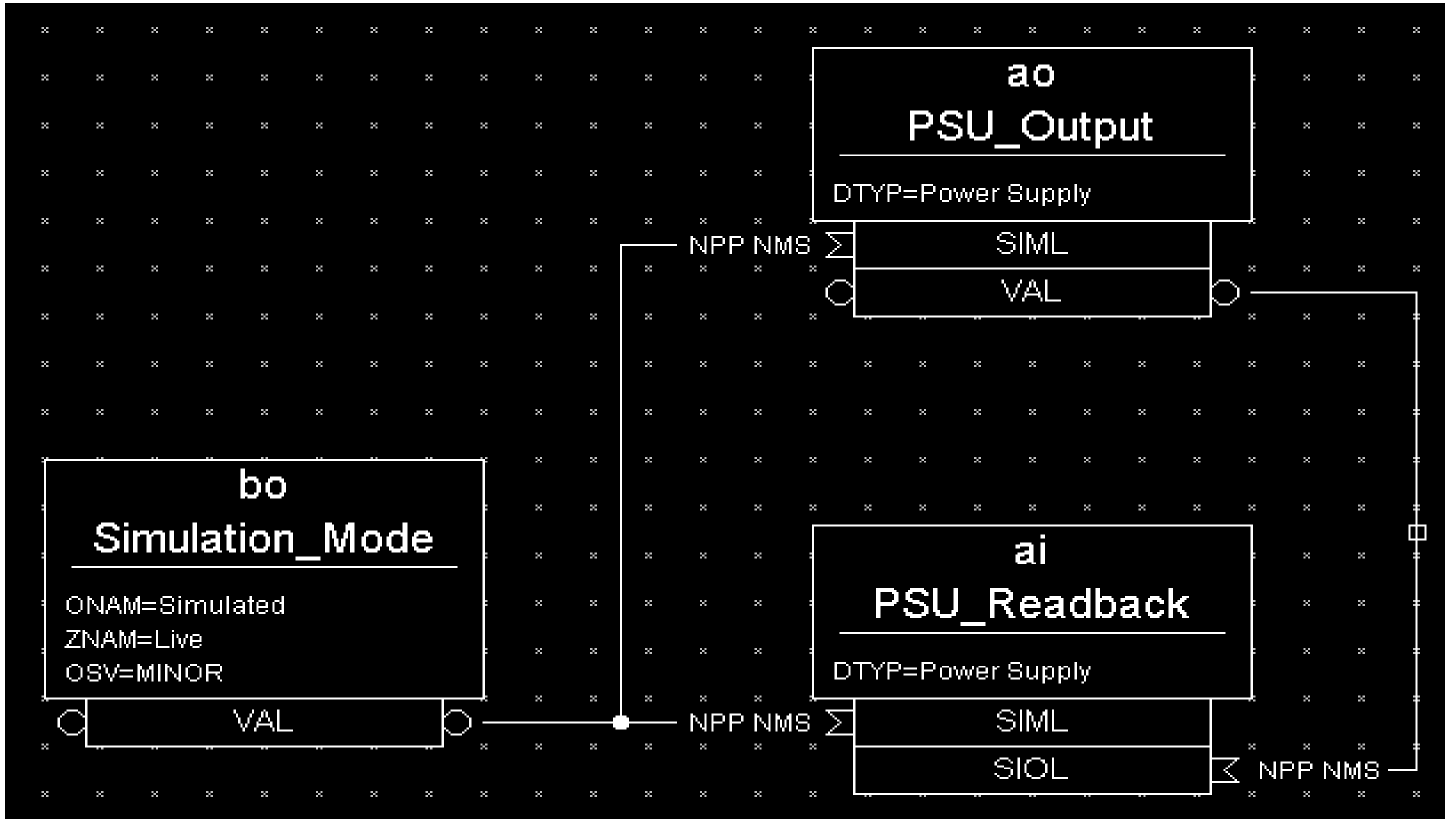
Database Example

seq



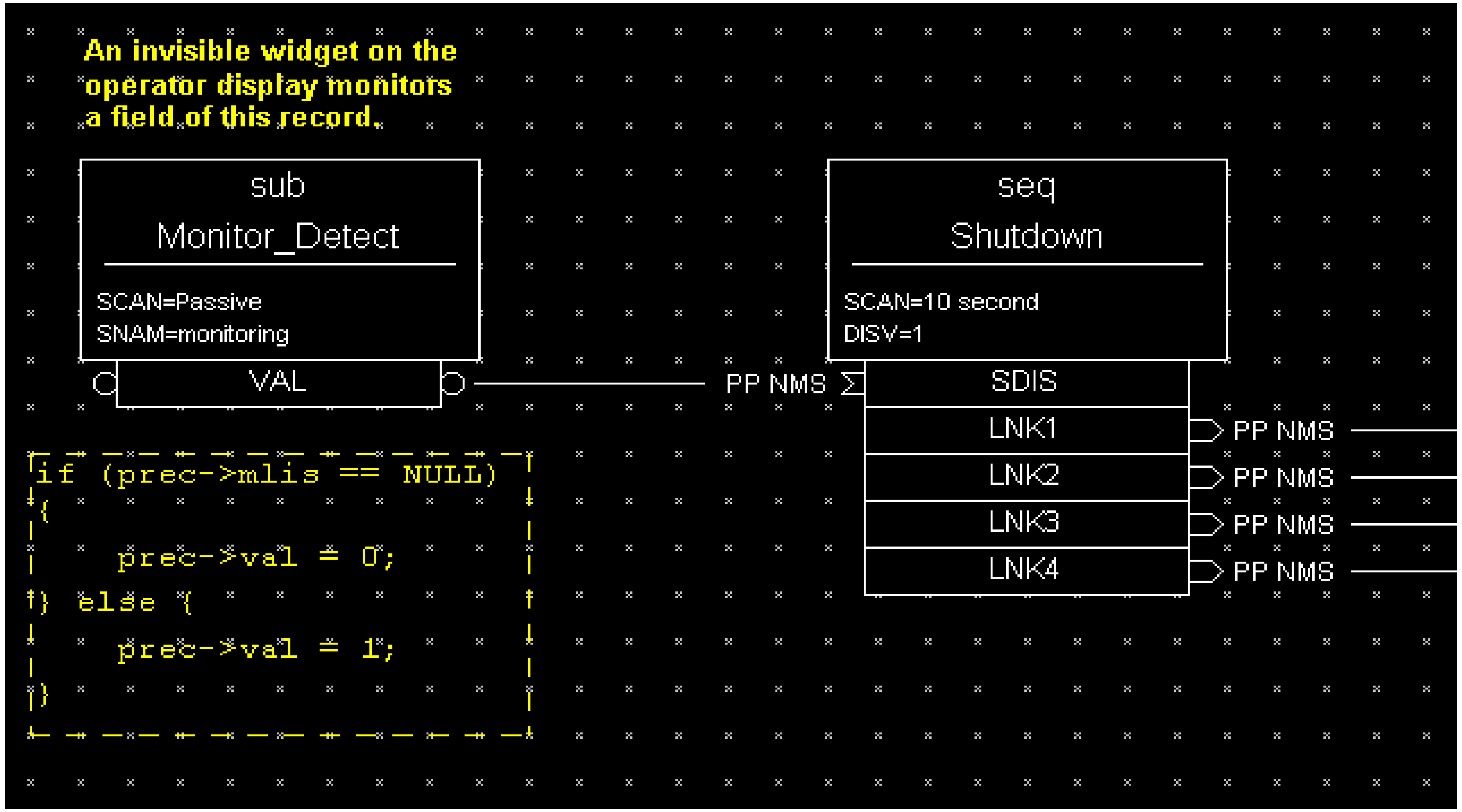
- Users set motor speed and desired position with the `ao` records. When an actual move is desired, the `seq` record fetches data from the `ao` records and sends it to the hardware. When the speed and position are set, the move command is executed.

Database Example
Simulation Mode



- When in simulation mode, the `ao` record does not call device support and the `ai` record fetches its input from the `ao` record.

Database Example
Automatic Shutdown on Logout



An invisible widget on the operator display monitors a field of this record.

sub
Monitor_Detect
SCAN=Passive
SNAM=monitoring

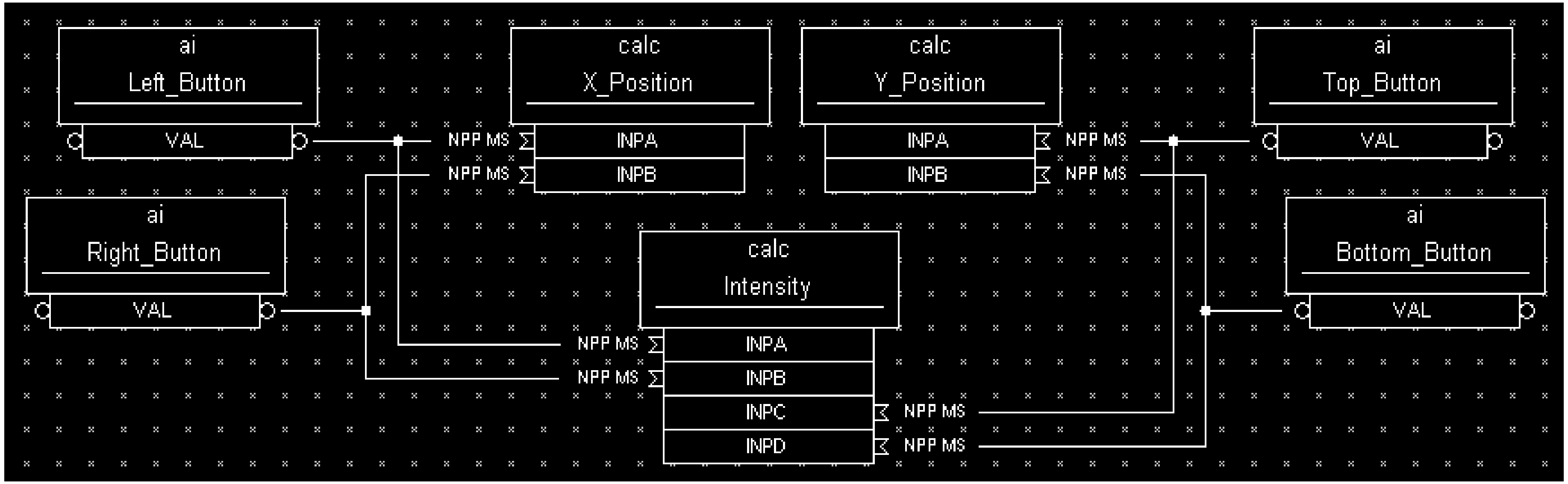
seq
Shutdown
SCAN=10 second
DISV=1

```
if (prec->mlis == NULL)
{
    prec->val = 0;
} else {
    prec->val = 1;
}
```

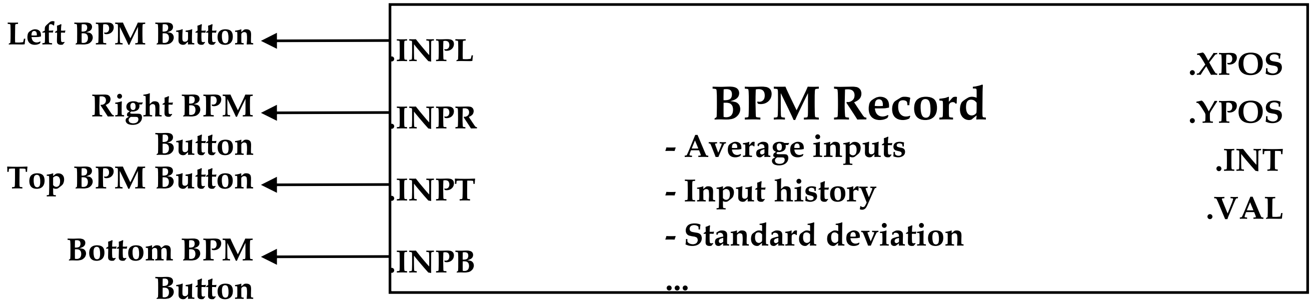
- If no CA monitor exists on the `sub` record (i.e. the operator logs out), `MLIS` will be `NULL`. The subroutine will then set the `VAL` field to `0`, causing the sequence record to process.

Database Examples

- Quick Prototyping with Standard Records



- Custom Record Definition


Left BPM Button

Right BPM Button

Top BPM Button

Bottom BPM Button

.INPL

.INPR

.INPT

.INPB

BPM Record

- Average inputs
- Input history
- Standard deviation

...

.XPOS

.YPOS

.INT

.VAL

RECORDS

Summary

Which record is right for …

- There are different ways to do things, but there are also some guidelines.
- "operator entered" soft parameters
  - `ao` has DRVH, DRVL, OROC, closed loop
  - `mbbo` provides enumerated options which can be converted to constants (`DTYP = Raw Soft Channel`)
  - Normally one does not use input records for this purpose
- Multiple output actions
  - `seq` record can have a different data source for each output link
  - `dfanout` record "fans out" a single source to multiple links
- Different output actions based on an operator selection
  - `calcout` records that conditionally process sequence records
  - `mbbo` (`DTYP = Raw Soft Channel`) forward linked to a single sequence record in "masked" mode. Mask is provided in MBBO for each state.

Creating Database Files

- Since the database file is a simple ASCII file, it can be generated by numerous applications… as long as the syntax is correct.
    - Text editor
    - Script
    - Relational Database Tool
    - EPICS-aware Database Configuration Tools:
        - VDCT
- An EPICS-aware tool will read the `.dbd` file (library provided) and provide menu selections of enumerated fields. It may also detect database errors prior to the boot process
- A graphical tool can be helpful for complex databases.

Macro Substitutions

- EPICS features simple string substitution macros
  - `$(macro)` can be used in `.db` files
  - This allows `db` files to function as templates (e.g. use the same db file for all vacuum sectors, just with different names (and possibly other parameters))
- Database with `$(macro)` cannot be loaded – all macros need to be expanded
- This can be done in `st.cmd` (as in Exercise 1) or by means of a separate substitutions file
  - Creating a new EPICS application using example template will provide an example substitution file
- For more complex macro handling, there is an EPICS extension called msi.

Defining the Database

- How does an IOC know what record types and device support options are available?
  - Record types, device support options, enumerated menus, and other configuration options are defined in “database definition files” (`.dbd`)
  - During the IOC booting process, one or more `.dbd` files are loaded
  - `.dbd` files are created on the workstation to include the desired information for that IOC.
- How does an IOC know about record instances (the user’s database) ?
  - Record instances are describe in “database files” (`.db`)
  - During the IOC booting process, one or more `.db` files are loaded
  - `.db` files are created on the workstation to include the desired information for that IOC.

Database Definition
File Formats

- Typical content of a database definition file (.dbd)

```
menu(menuPriority) {
  choice(menuPriorityLOW,    "LOW")
  choice(menuPriorityMEDIUM, "MEDIUM")
  choice(menuPriorityHIGH,   "HIGH")
}
menu(menuScan) {
  choice(menuScanPassive,   "Passive")
  choice(menuScanEvent,     "Event")
  choice(menuScanI_O_Intr,  "I/O Intr")
  choice(menuScan10_second, "10 second")
  choice(menuScan5_second,  "5 second")
  choice(menuScan2_second,  "2 second")
  choice(menuScan1_second,  "1 second")
  choice(menuScan_5_second, ".5 second")
  choice(menuScan_2_second, ".2 second")
  choice(menuScan_1_second, ".1 second")
}
```

```
device(ai,CONSTANT,devAiSoftRaw,
            "Raw Soft Channel")
device(ai,BITBUS_IO,devAiIObug,
            "Bitbus Device")
device(ao,CONSTANT,devAoSoftRaw,
            "Raw Soft Channel")
device(ao,VME_IO,devAoAt5Vxi,
            "VXI-AT5-AO")
device(bi,VME_IO,devBiAvme9440,
            "AVME9440 I")
device(bi,AB_IO,devBiAb,
            "AB-Binary Input")
driver(drvVxi)
driver(drvMxi)
driver(drvGpib)
driver(drvBitBus)
```

Database Definition
File Formats

- Typical content of database definition file (`.dbd`):

```
recordtype(ai)
{
  include "dbCommon.dbd"
  field(VAL,DBF_DOUBLE)
  {
    prompt("Current EGU Value")
    promptgroup(GUI_INPUTS)
    asl(ASL0)
    pp(TRUE)
  }
…
  field(PREC,DBF_SHORT)
  {
    prompt("Display Precision")
    promptgroup(GUI_DISPLAY)
    interest(1)
  }
}
```

```
menu(scalerCNT)
{
  choice(scalerCNT_Done,"Done")
  choice(scalerCNT_Count,"Count“)
}
…
field(CNT,DBF_MENU)
{
  prompt("Count")
  special(SPC_MOD)
  menu(scalerCNT)
  pp(TRUE)
  interest(1)
}

device(ao,CONSTANT,devAoSoftRaw,
            "Raw Soft Channel")

driver(drvVxi)
```

Database File Formats

- A typical database file (`.db`)

```
record(calc,"$(user):rampM") {
    field(CALC,"A>6.27?0:A+.1")
    field(SCAN,"1 second")
    field(INPA,"$(user):rampM.VAL NPP NMS")
}
record(calc,"$(user):cathodeTempM") {
    field(DESC,"Measured Temp")
    field(SCAN,"1 second")
    field(CALC,"C+(A*7)+(SIN(B)*3.5)")
    field(INPA,"$(user):cathodeCurrentC.OVAL NPP NMS")
    field(INPB,"$(user):rampM.VAL NPP NMS")
    field(INPC,"70")
    field(EGU,"degF")
    field(PREC,"1")
    field(HOPR,"200")
    field(LOPR,"")
    field(HIHI,"180")
    field(LOLO,"130")
    field(HIGH,"160")
    field(LOW,"140")
    field(HHSV,"MAJOR")
    field(HSV,"MINOR")
    field(LLSV,"MAJOR")
    field(LSV,"MINOR")
}
```

Loading Database Files into the IOC

```
dbLoadDatabase("../../dbd/linacApp.dbd")

dbLoadRecords("../../db/xxLinacSim.db","user=studnt1")

iocInit          /* starts ioc software */
```

- Part of a typical startup script (`st.cmd`)
- One or more database definition files (`.dbd`) must be loaded first.
- Any record type specified in the database files must have been defined in the definition file
- Macros (variables) within the database files (e.g. `$(user)`) can be specified at boot time. This allows the same database to be loaded with different names or channel assignments.

Exercise 7

A Chiller Application

Based on a presentation by :
Andrew Johnson (APS)

COSYLAB

Getting Started with EPICS

SNL – State Notation Language

Outline

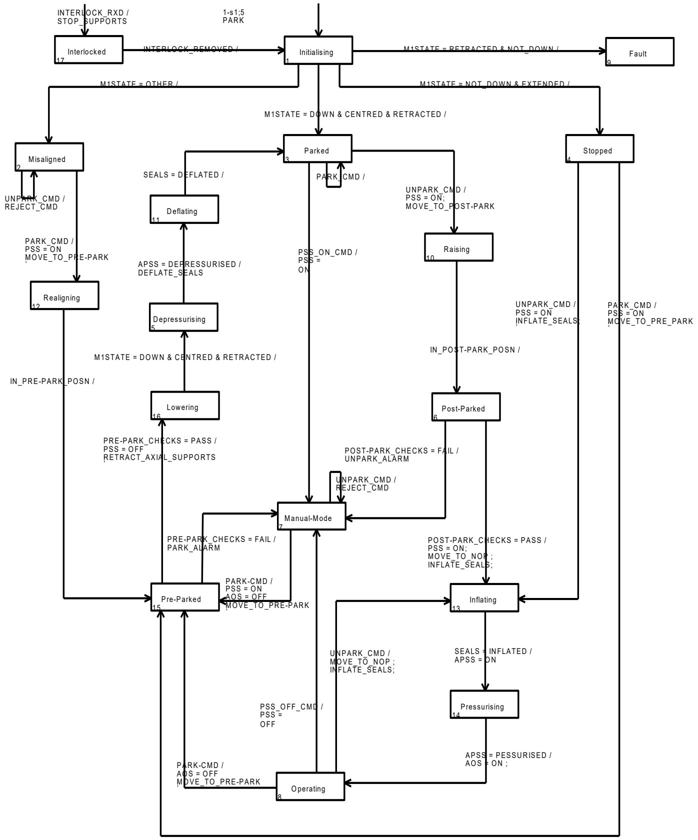
- What is State Notation Language (SNL)
- When to use it
- Where it fits in the EPICS toolkit
- Components of a state notation program
- Some notes on the Sequencer runtime
- Building, running and debugging a state notation program
- Additional Features
- This talk does not cover all the features of SNL and the sequencer. Consult the manual for more information:
    - https://github.com/epics-modules/sequencer/

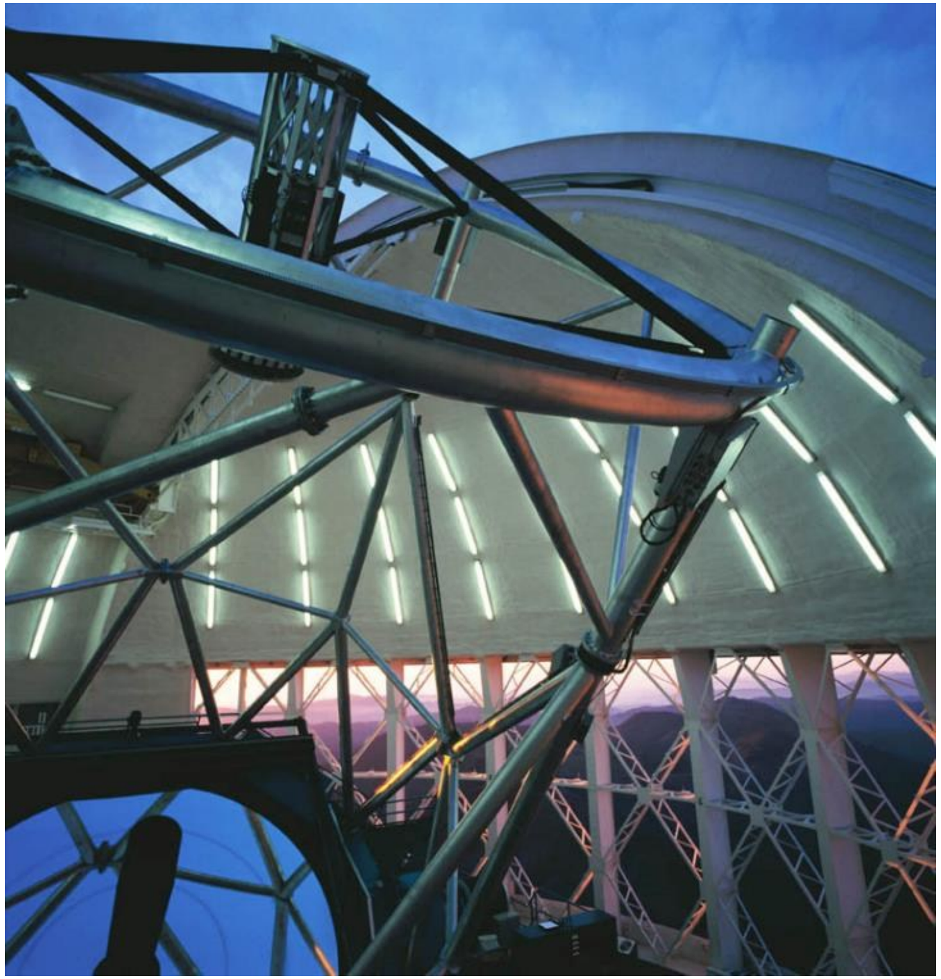
SNL and the Sequencer

- The sequencer runs programs written in State Notation Language (SNL)
- SNL is a ‘C’ like language to facilitate programming of sequential operations
- Fast execution - compiled code
- Programming interface to extend EPICS in the real-time environment
- Common uses
  - Provide automated start-up sequences like vacuum or RF where subsystems need coordination
  - Provide fault recovery or transition to a safe state
  - Provide automatic calibration of equipment

When to use the sequencer

- For sequencing complex events
  - e.g. parking and unparking a telescope mirror

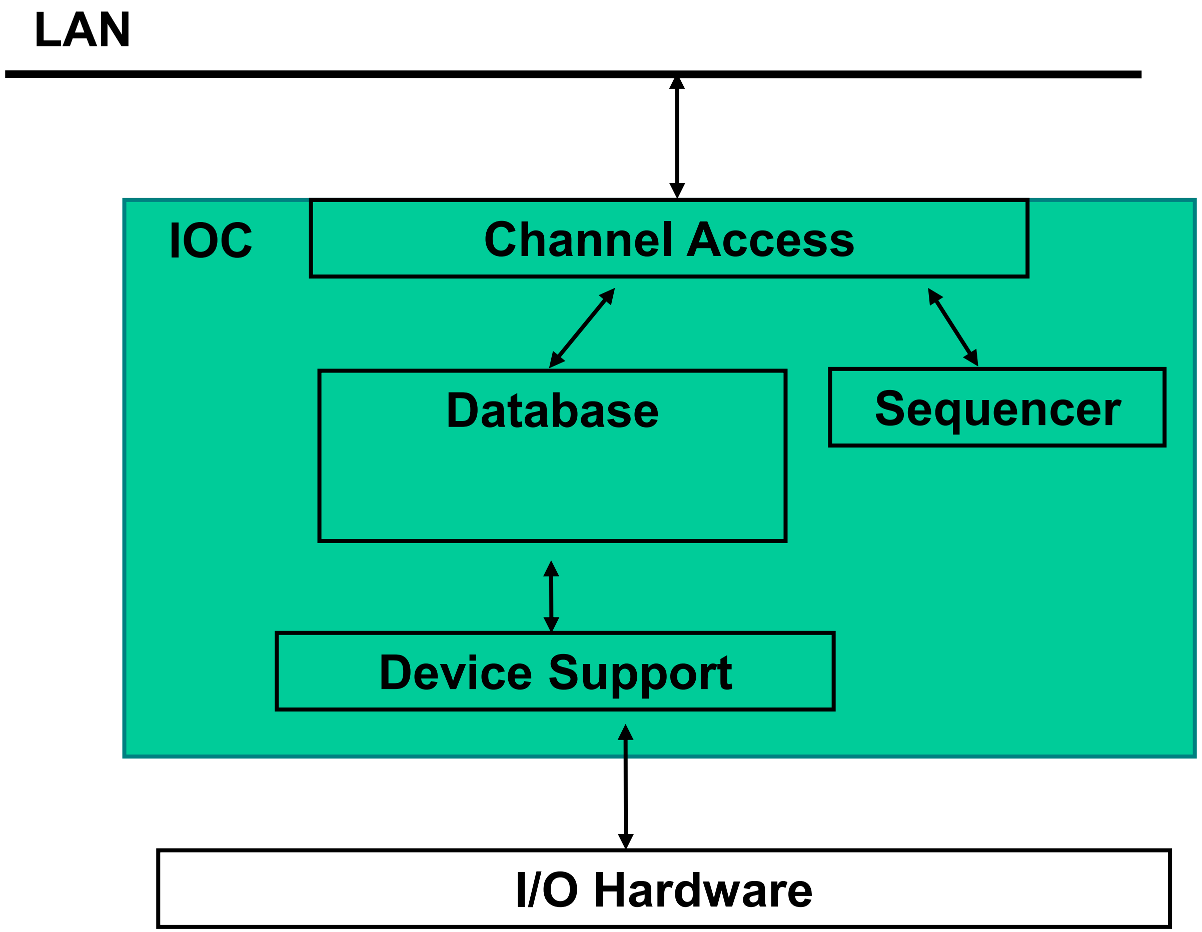




Photograph courtesy of the Gemini Telescopes project

Where's the Sequencer?

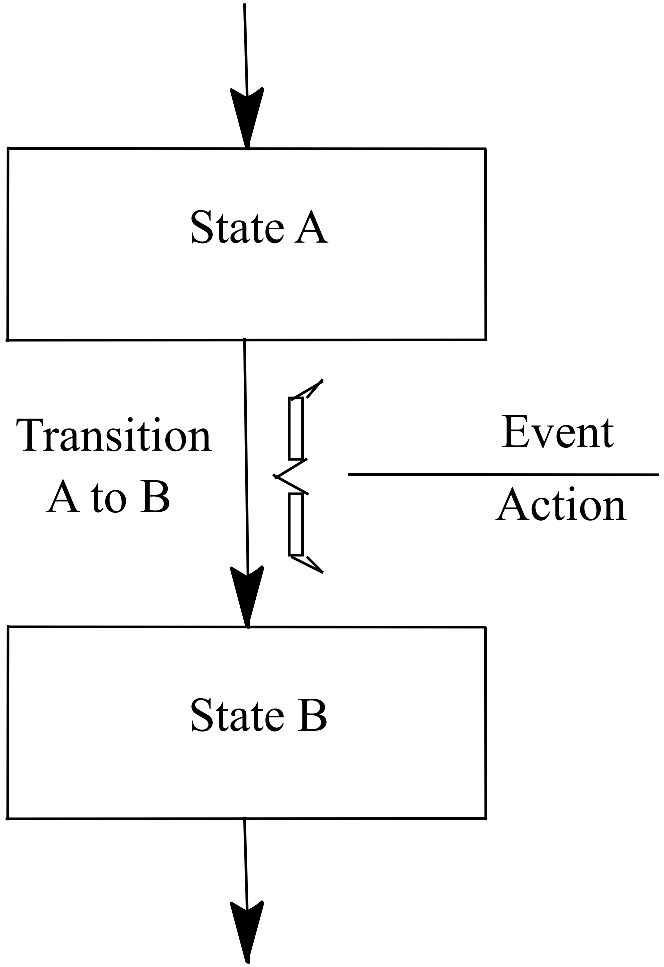
- The major software components of an IOC (IOC Core)



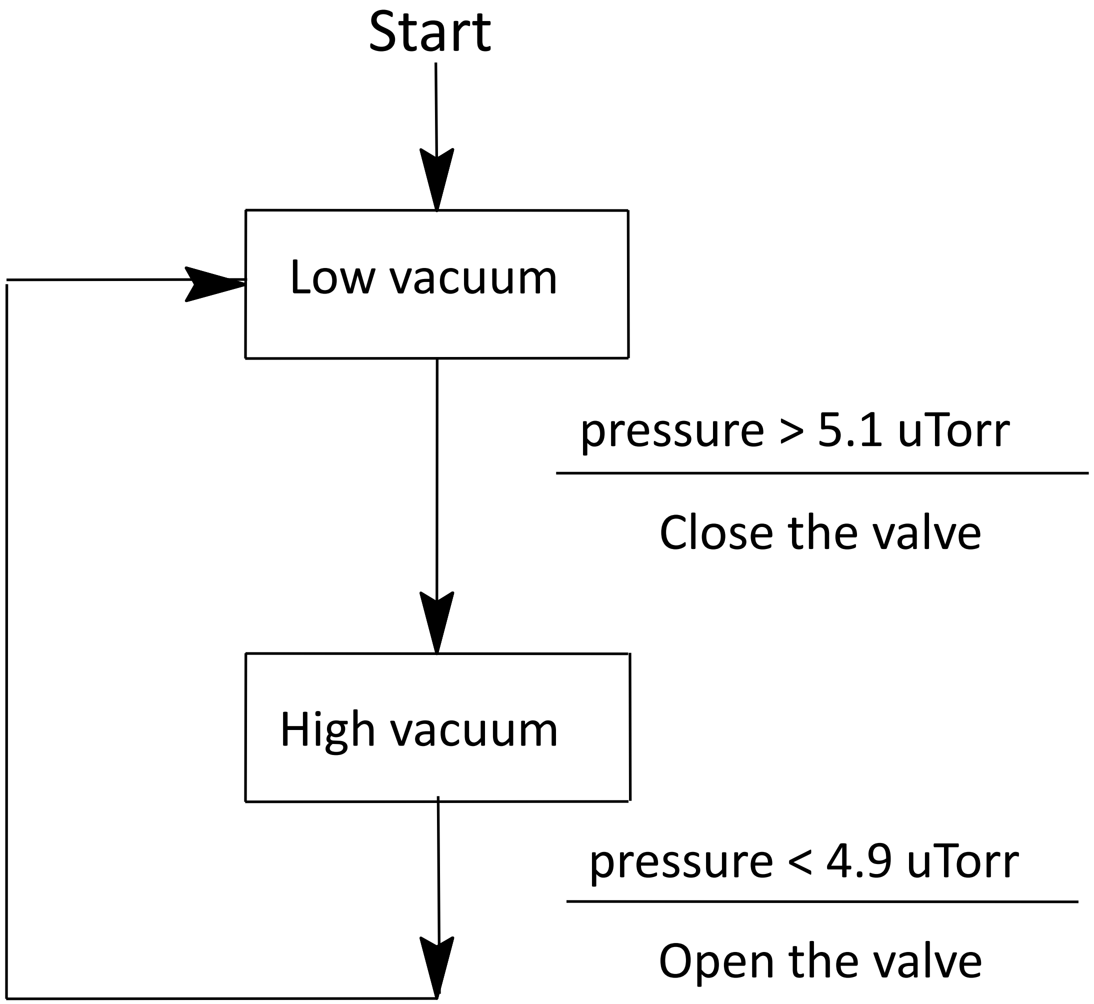
The Best Place for the Sequencer

- Sequencer can run either on an IOC or as a standalone program on a workstation
- Traditionally, sequencers run on the IOC
- Locating them within the IOC they control makes them easier to manage
- Running them on a workstation can make testing and debugging easier
- On a workstation, SNL provides an easy way to write simple CA client programs

SNL implements State Machines



SM Example



Start

Low vacuum

pressure > 5.1 uTorr

Close the valve

High vacuum

pressure < 4.9 uTorr

Open the valve

Some Definitions

- SNL : State Notation Language
- SNC : State Notation Compiler
- Sequencer : The tool that executes the compiled SNL code
- Program : A complete SNL application consisting of declarations and one or more state sets
- State Set : A set of states that make a complete finite state machine
- State : A particular mode of the state set in which it remains until one of its transition conditions is evaluated to be `TRUE`

SNL: General Structure and Syntax

```
program program_name
declarations

ss state_set_name {

  state state_name {
    entry {
      entry action statements
    }

    when (event) {
      action statements
    } state next_state_name

    when (event) {
…
    } state next_state_name

    exit{
      exit action statements
    }
  }

  state state_name {
…
  }
}
```

`program` *`name`*	A program may contain multiple state sets. The program name is used as a handle to the sequencer manager for state programs.
`ss` *`name`* `{`	A state set becomes a task.
`state` *`name`* `{`	A state is an area where the task waits for events. The related task waits until one of the events occurs and then checks to see which it should execute. The first state defined in a state set is the initial state.
`option` *`flag;`*	A state specific option
`when (`*`event`*`) {`	Defines the events for which this state waits.
`} state` *`next`*	Specifies the following state after the actions complete.
`entry {`*`actions`*`}`	Actions to do on entry to this state from another state. With `option -e`; these actions will trigger even if it re-enters from the same state.
`exit {`*`actions`*`}`	Actions to do before exiting this state to another state. With `option -x`; these actions will trigger even if it exits to the same state.

Declarations – Variables

- Appear before a state set and have a scope of the entire program.
- Scalar variables

```
int             var_name;
short           var_name;
long            var_name;
char            var_name;
float           var_name;
double          var_name;
string          var_name;   /* 40 characters */
```

- Array variables: 1 or 2 dimensions, no strings

```
int             var_name[num_elements];
short           var_name[num_elements];
long            var_name[num_elements];
char            var_name[num_elements];
float           var_name[num_elements];
double          var_name[num_elements];
```

Declarations – Assignments

- Assignment connects a variable to a channel access PV name

```
float  pressure;
assign pressure to “CouplerPressureRB1”;
double pressures[3];
assign pressures to {“CouplerPressureRB1”, ”CouplerPressureRB2”, ” CouplerPressureRB3”};
```

- To use these channels in when clauses, they must be monitored

```
monitor pressure;
monitor pressures;
```

- Use preprocessor macros to aid readability:

```
#define varMon(t,n,c) t n; assign n to c; monitor n;
varMon(float, pressure, “CouplerPressureRB1”)
```

Declarations – Event Flags

- Event flags are used to communicate between state sets, or to receive explicit event notifications from Channel Access
- Declare like this:

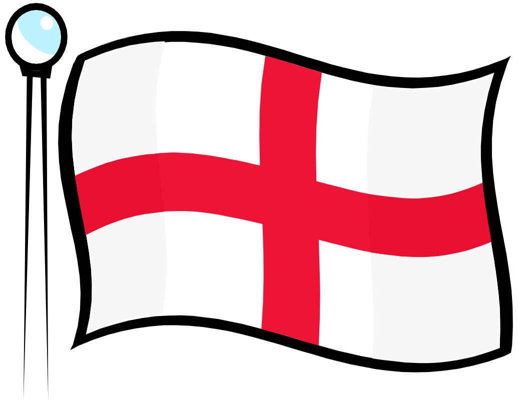
```
evflag      event_flag_name;
```

- An event flag can be synchronized with a monitored variable

```
sync var_name event_flag_name;
```

- The flag will then be set when a monitor notification arrives

```
evflag      flag_monitor;

sync pressure flag_monitor;
```



Events

- Event: The condition on which actions associated with a when are run and a state transition is made.
- Possible events:
  - Change in value of a variable that is being monitored:

    ```
    when (achan < 10.0)
    ```

  - A timer event (not a task delay!):

    ```
    when (delay(1.5))
    ```

    - The delay time is in seconds.
    - A delay is normally reset whenever the state containing it is exited.
    - Use the state specific `option -t;` to stop it from being reset when transitioning to the same state.

Possible Events (continued)

- The state of an event flag:

  ```
  when (efTestAndClear(myflag))
  ```

  ```
  when (efTest(myflag))
  ```

  - `efTest()` does not clear the flag. `efClear()` must be called sometime later to avoid an infinite loop.
  - If the flag is synced to a monitored variable, it will be set when the channel sends a value update
  - The event flag can also be set by any state set in the program using `efSet(event_flag_name)`

- Any change in the channel access connection status:

  ```
  when (pvConnectCount() < pvChannelCount())
  ```

  ```
  when (pvConnected(mychan))
  ```

Action Statements

- Built-in action function, e.g. :

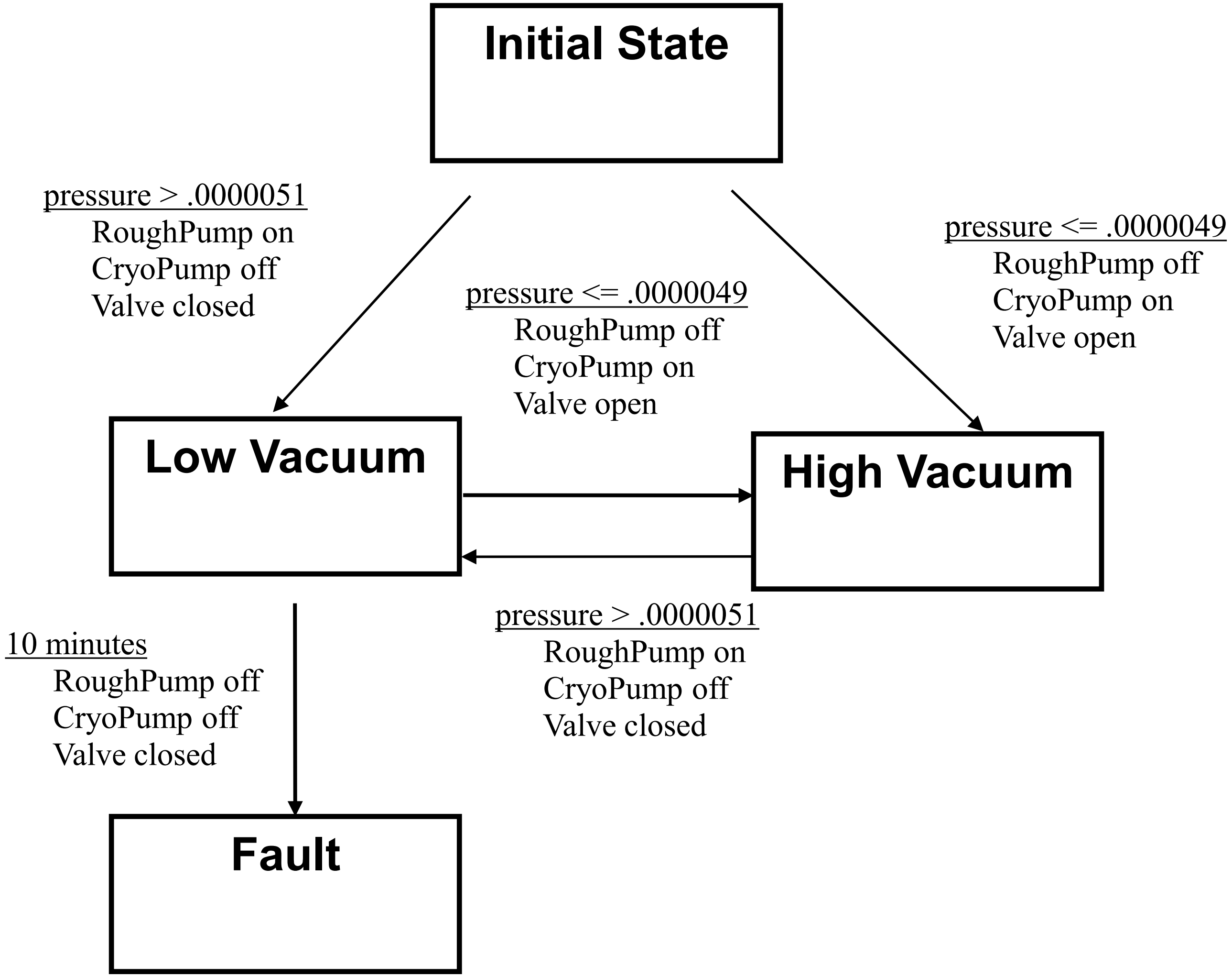
```
pvPut(var_name);
pvGet(var_name);
efSet(event_flag_name);
efClear(event_flag_name);
```

- Almost any valid C statement
  - `switch()` is not implemented and code using it must be escaped.
  - `%%` *escapes one line of C code*
  - `%{`

    escape any number of lines of C code

    `}%`

Example – State Definitions and Transitions



Example – Declarations and State Transitions (actions omitted)

```
double  pressure;
assign  pressure to
        “Tank1Coupler1PressureRB”;
monitor pressure;

short    RoughPump;
assign  RoughPump to
        “Tank1Coupler1RoughPump”;

short    CryoPump;
assign  CryoPump to “Tank1Coupler1CryoPump”;

short    Valve;
assign  Valve to
        “Tank1Coupler1IsolationValve”;

string  CurrentState;
assign  CurrentState to
        “Tank1Coupler1VacuumState”;
```

```
program vacuum_control
ss coupler_control
{
  state init{
    when (pressure > .0000051){
    } state low_vacuum
    when (pressure <= .0000049){
    } state high_vacuum
  }
  state high_vacuum{
    when (pressure > .0000051){
    } state low_vacuum
  }
  state low_vacuum{
    when (pressure <= .0000049){
    } state high_vacuum
    when (delay(600.0)){
    } state fault
  }
  state fault {
  }
}
```

Example – init state and low_vacuum state

```
state init {
  entry {
    strcpy(CurrentState,”Init”);
    pvPut(CurrentState);
  }
  when (pressure > .0000051){
    RoughPump = 1;
    pvPut(RoughPump);
    CryoPump = 0;
    pvPut(CryoPump);
    Valve = 0;
    pvPut(Valve);
  } state low_vacuum
  when (pressure <= .0000049){
    RoughPump = 0;
    pvPut(RoughPump);
    CryoPump = 1;
    pvPut(CryoPump);
    Valve = 1;
    pvPut(Valve);
  } state high_vacuum
}
```

```
state low_vacuum{
  entry {
  strcpy(CurrentState,”Low Vacuum”);
  pvPut(CurrentState);
  }
  when (pressure <= .0000049){
    RoughPump = 0;
    pvPut(RoughPump);
    CryoPump = 1;
    pvPut(CryoPump);
    Valve = 1;
    pvPut(Valve);
  } state high_vacuum
  when (delay(600.0)){
  } state fault
}
```

Example – high_vacuum state and fault state

```
state high_vacuum{
  entry {
  strcpy(CurrentState,”High Vacuum”);
  pvPut(CurrentState);
  }
  when (pressure > .0000051){
    RoughPump = 1;
    pvPut(RoughPump);
    CryoPump = 0;
    pvPut(CryoPump);
    Valve = 0;
    pvPut(Valve);
  } state low_vacuum
}
```

```
state fault{
  entry{
    strcpy(CurrentState,”Vacuum Fault”);
    pvPut(CurrentState);
  }
}
```

Building an SNL program

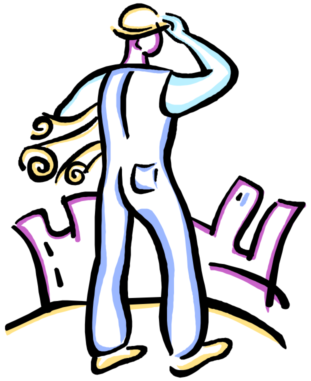
- Use editor to build the source file. File name must end with `.st` or `.stt`, e.g. `example.st`
- `make` automates these steps:
  - Runs the C preprocessor on `.st` files, but not on `.stt` files.
  - Compiles the state program with SNC to produce C code:

    ```
    snc  example.st  ->  example.c
    ```

  - Compiles the resulting C code with the C compiler:

    ```
    cc example.c -> example.o
    ```

  - The object file `example.o` becomes part of the application library, ready to be linked into an IOC binary.
  - The executable file `example` can be created instead.



Run Time Sequencer

- The sequencer executes the state program
- It is implemented as an event-driven application; no polling is needed
- Each state set becomes an operating system thread
- The sequencer manages connections to database channels through Channel Access
- It provides support for channel access get, put, and monitor operations
- It supports asynchronous execution of delays, event flag, pv put and pv get functions
- Only one copy of the sequencer code is required to run multiple programs

  ```
  options +r; // use macro
  ```
- Commands are provided to display information about the state programs currently executing

Executing a State Program

- From an IOC console

```
seq vacuum_control
```

- To stop the program

```
seqStop vacuum_control
```

Debugging

- Use the sequencer's query commands:

```
seqShow
```

  - displays information on all running state programs

```
seqShow vacuum_control
```

  - displays detailed information on program

```
seqChanShow vacuum_control
```

  - displays information on all channels

```
seqChanShow vacuum_control,”-”
```

  - displays information on all disconnected channels

Debugging (continued)

- Use `printf` functions to print to the console

```
printf("Here I am in state xyz \n");
```

- Put strings to pvs

```
sprintf(seqMsg1, "Here I am in state xyz");
pvPut(seqMsg1);
```

- Reload and restart (if running independently of IOC)

```
seqStop vacuum_control
```

  - … edit, recompile …
  - `seq vacuum_control`

Debugging – seqShow

```
epics> seqShow
Program Name      Thread ID  Thread Name       SS Name
stabilizer        ede78      stabilizer        stabilizerSS1
beamTrajectory    db360      beamTrajectory    bpmTrajectorySS
autoControl       ed620      autoControl       autoCtlSS
```

Debugging – seqShow

```
epics> seqShow stabilizer
State Program: "stabilizer"
  initial thread id = ede78
  thread priority = 50
  number of state sets = 1
  number of syncQ queues = 0
  number of channels = 3
  number of channels assigned = 3
  number of channels connected = 3
  options: async=0, debug=0, newef=1, reent=0, conn=1, main=0

  State Set: "stabilizerSS1"
  thread name = stabilizer;  thread id = 974456 = 0xede78
  First state = "init"
  Current state = "waitForEnable"
  Previous state = "init"
  Elapsed time since state was entered = 88.8 seconds
```

Debugging – seqChanShow

```
epics> seqChanShow stabilizer
State Program: "stabilizer"
Number of channels=3

#1 of 3:
Channel name: "stabilizerC"
  Unexpanded (assigned) name: "stabilizerC"
  Variable name: "enableButton"
    address = 154120 = 0x25a08
    type = short
    count = 1
  Value = 0
  Monitor flag = 1
    Monitored
  Assigned
  Connected
  Get not completed or no get issued
  Put not completed or no put issued
  Status = 17
  Severity = 3
  Message =
  Time stamp = <undefined>
Next? ( skip count)
```

Additional Features

- Connection management:

```
when (pvConnectCount() != pvChannelCount())
when (pvConnected(Vin))
```

- Macros:

```
assign Vout to "{unit}:OutputV";
```

  - must use the `+r` compiler options for this if more than one copy of the sequence is running on the same IOC

```
seq example, "unit=HV01"
```

- Some common SNC program options:
  - `+r` make program reentrant (default is `-r`)
  - `-c` don't wait for all channel connections (default is `+c`)
  - `+a` asynchronous pvGet() (default is `-a`)
  - `-w` don't print compiler warnings (default is `+w`)

```
program dynamic
option -c; /* don't wait for db connections */
```

Additional Features (continued)

- Access to channel alarm status and severity:

```
pvStatus(var_name)
pvSeverity(var_name)
```

- Queued monitors save CA monitor events in a queue in the order they come in, rather than discarding older values when the program is busy

```
syncQ var_name to event_flag_name [queue_length]
pvGetQ(var_name)
```

  - removes oldest value from variables monitor queue. Remains true until queue is empty.

```
pvFreeQ(var_name)
```

Advantages of SNL

- Can implement complicated algorithms
- Can stop, reload, restart a sequence program without rebooting
- Interact with the operator through `string` records and `mbbo` records
- C code can be embedded as part of the sequence
- All Channel Access details are taken care of
- File access can be implemented as part of the sequence

Getting Started with EPICS

Device Support

Writing Device Support – Outline

- Introduction
  - What this for?
  - What is ‘Device Support’?
  - The `.dbd` file entry
  - The driver DSET
  - Device addresses
  - Support routines
- Example
- Asynchronous processing
  - Using interrupts
  - Asynchronous input/output
  - Callbacks

Device Integration Task

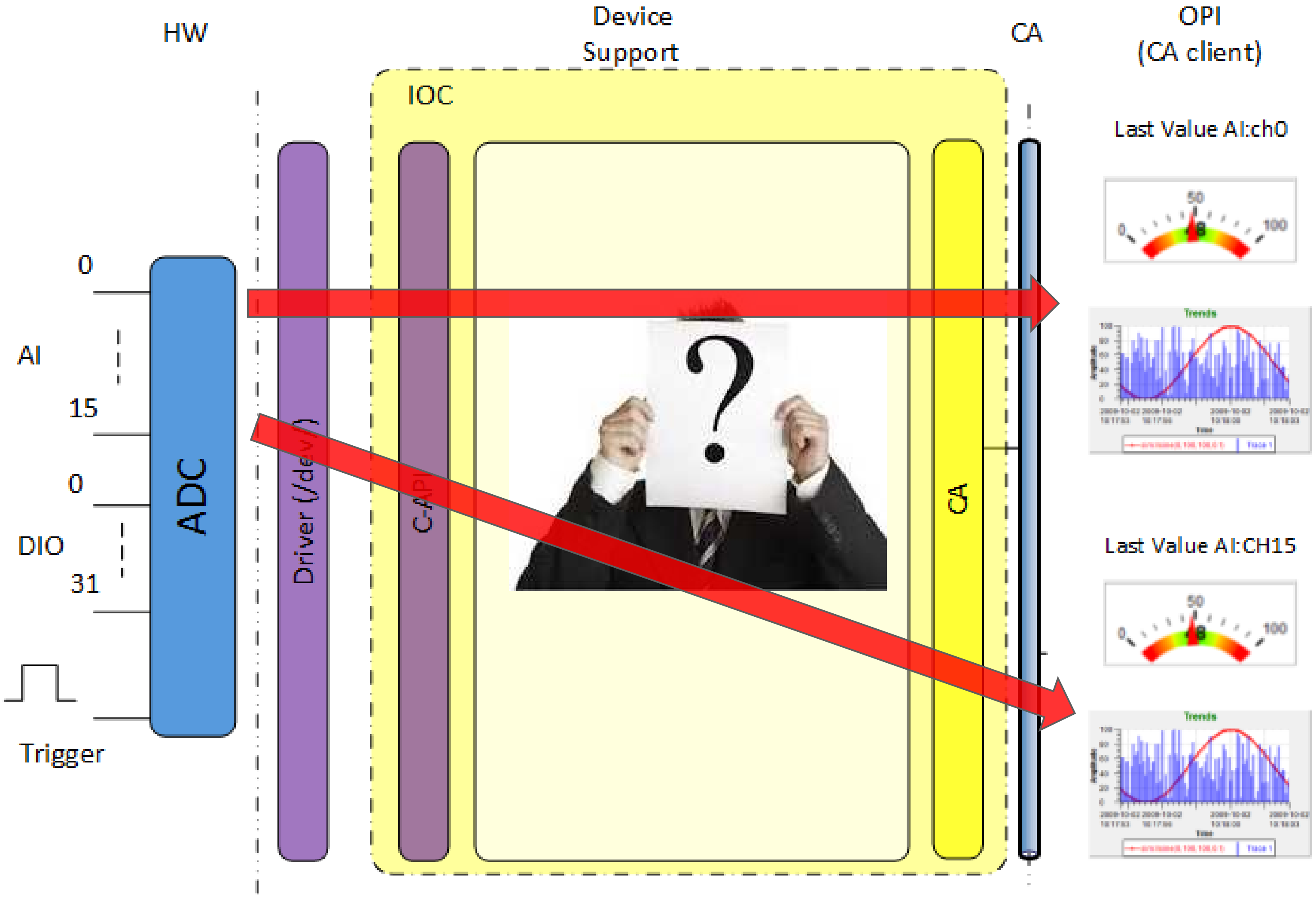
- Steps
  - Use Case collection
  - Requirements specification
  - **Design**
  - **Implementation**
  - Verification

Writing Device Support – Scope

- An overview of the concepts associated with writing EPICS Device Support routines.
- Examples show the “stone knives and bearskins” approach.

- The ASYN package provides a framework which makes writing device support much easier.
  - The concepts presented here still apply.

Goal



HW

Device Support

CA

OPI (CA client)

IOC

0

AI

15

0

DIO

31

Trigger

ADC

Driver (/dev/)

C-API

?

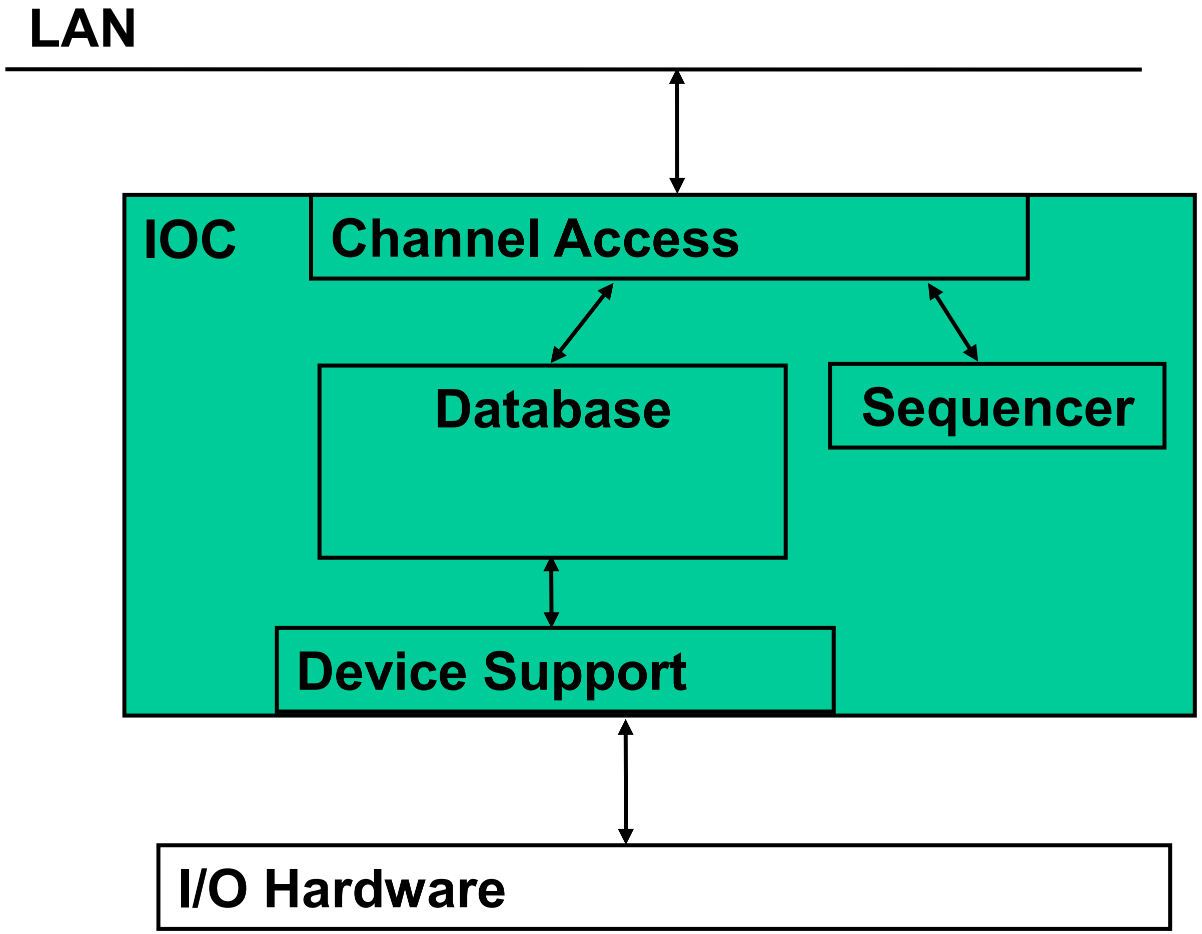
CA

Last Value AI:ch0

Last Value AI:CH15

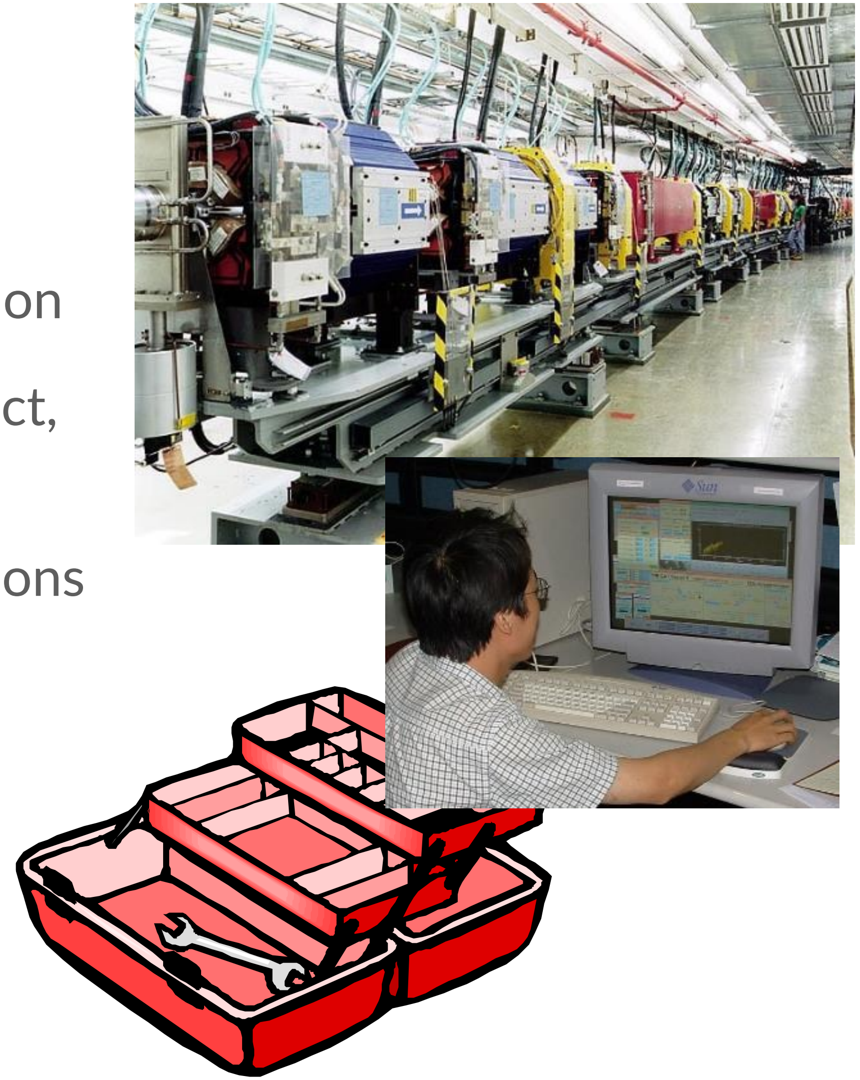
Inside the IOC

- The major software components of an IOC (IOC Core)



EPICS Databases – What are they for?

- Interface to process instrumentation
- Distribute processing
- Provide external access to all process information
- Use common, proven, objects (records) to collect, process and distribute data
- Provide a common toolkit for creating applications



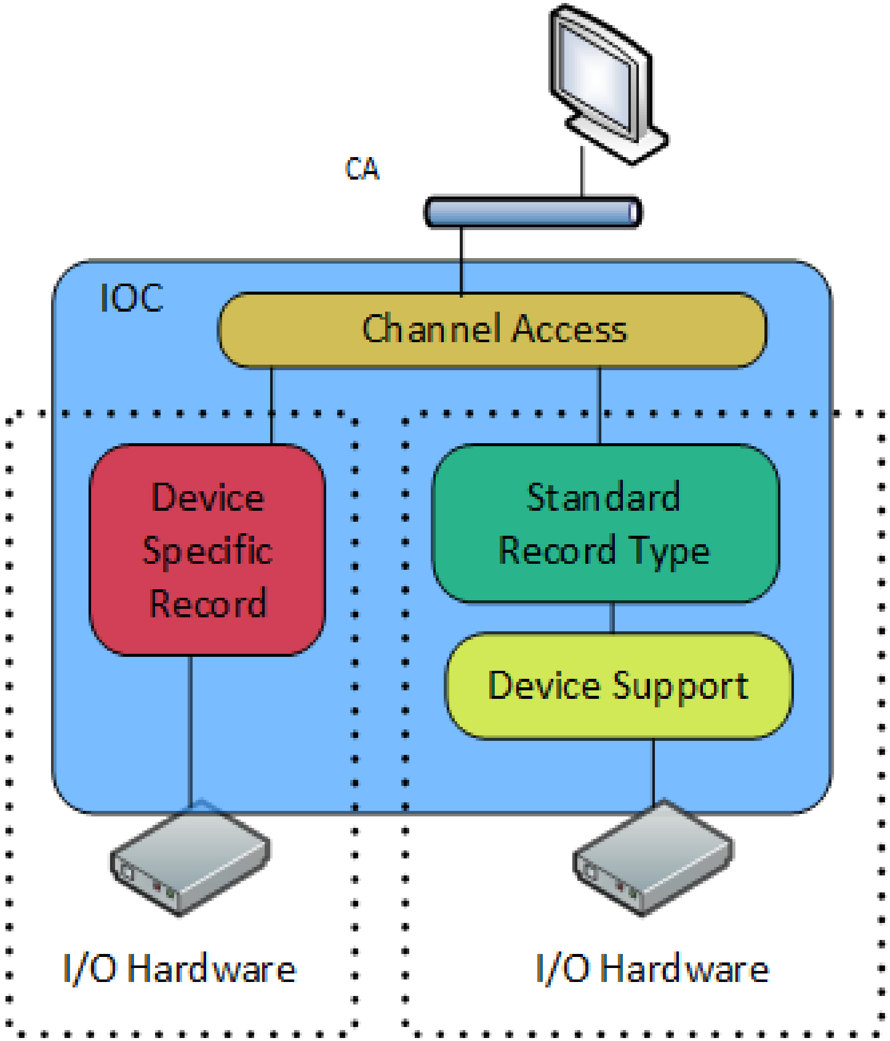
How is a Record implemented?

- A ‘C’ structure with both data storage and pointers to record type information

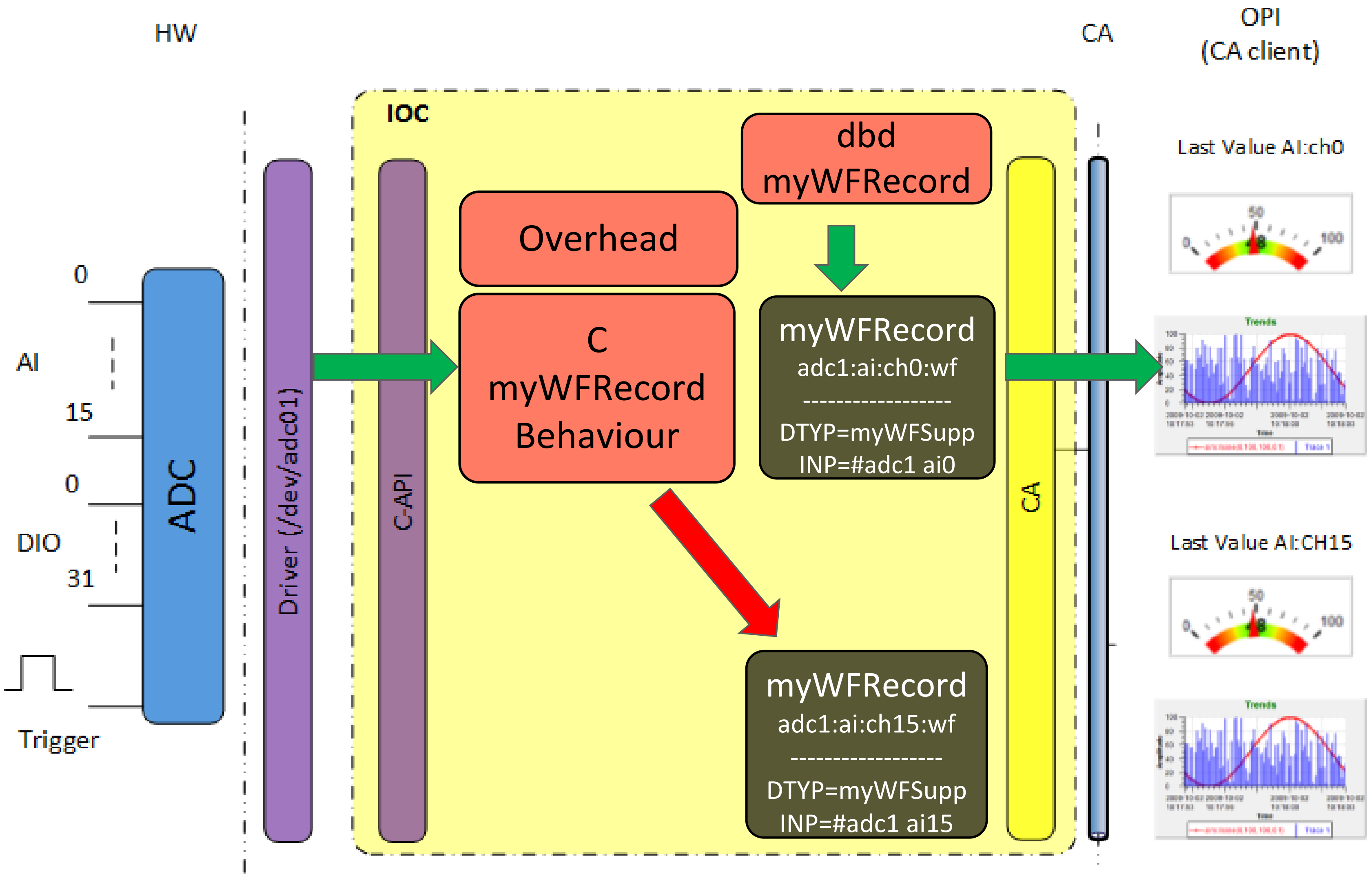
- A record definition within a database provides
  - Record name
  - The record’s type
  - Values for each design field
- A record type provides
  - Definitions of all the fields
  - Code which implements the record behavior

- New record types can be added to an application as needed
  - Check EPICS example application (`xxxRecord`)

Device support diagram



Specific record implementation



HW

CA

OPI
(CA client)

IOC

dbd
myWFRecord

Overhead

C
myWFRecord
Behaviour

myWFRecord
adc1:ai:ch0:wf

DTYP=myWFSupp
INP=#adc1 ai0

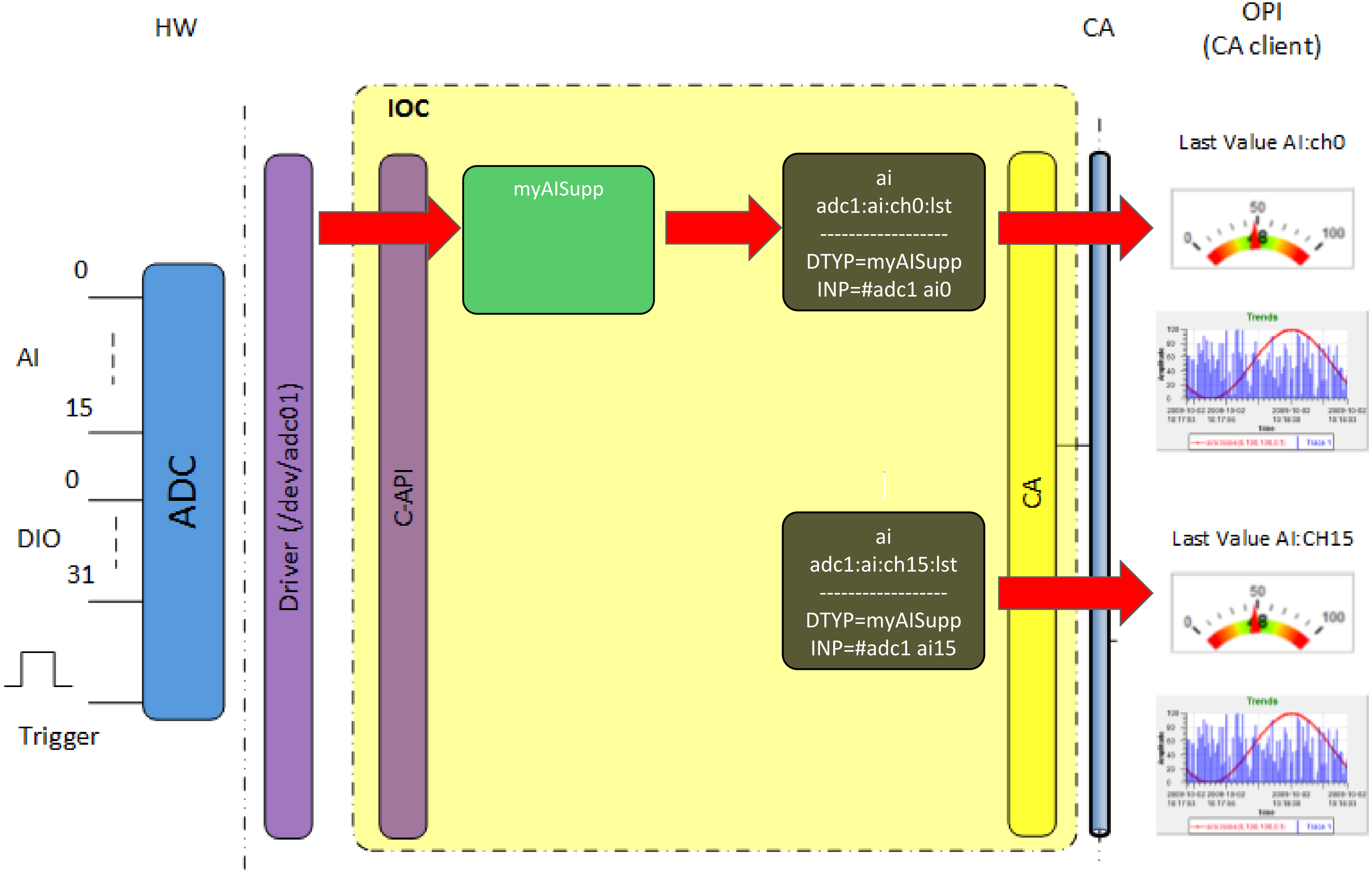
myWFRecord
adc1:ai:ch15:wf

DTYP=myWFSupp
INP=#adc1 ai15

What is ‘Device Support’?

- Interface between record and hardware
- A set of routines for record support to call
  - The record type determines the required set of routines
  - These routines have full read/write access to any record field
- Determines synchronous/asynchronous nature of record
- Performs record I/O
  - Provides interrupt handling mechanism

Device Support Architecture



HW

CA

OPI
(CA client)

IOC

AI

0

15

DIO

0

31

Trigger

ADC

Driver (/dev/adc01)

C-API

myAISupp

ai
adc1:ai:ch0:lst

DTYP=myAISupp
INP=#adc1 ai0

ai
adc1:ai:ch15:lst

DTYP=myAISupp
INP=#adc1 ai15

CA

Last Value AI:ch0

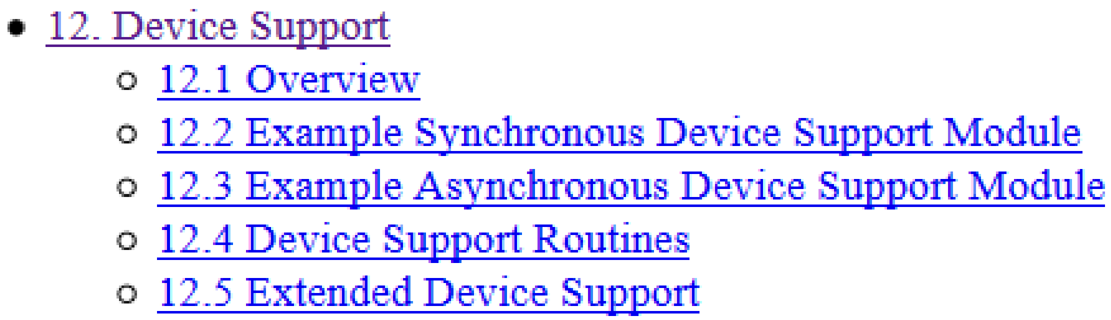
Last Value AI:CH15

Why use device support?

- Could instead make a different record type for each hardware interface, with fields to allow full control over the provided facilities.
- A separate device support level provides several advantages:
    - There is no needs for USERs learn a new record type for each type of device
    - Increases modularity
        - I/O hardware changes are less disruptive
        - Device support is simpler than record support
        - Hardware interface code is isolated from record API
- Custom records are available if really needed.
    - By which I mean “really, really, really needed!”
    - Existing record types are sufficient for most applications.

Where to look for help?

https://epics.anl.gov/base/R3-16/2-docs/AppDevGuide/AppDevGuide.html



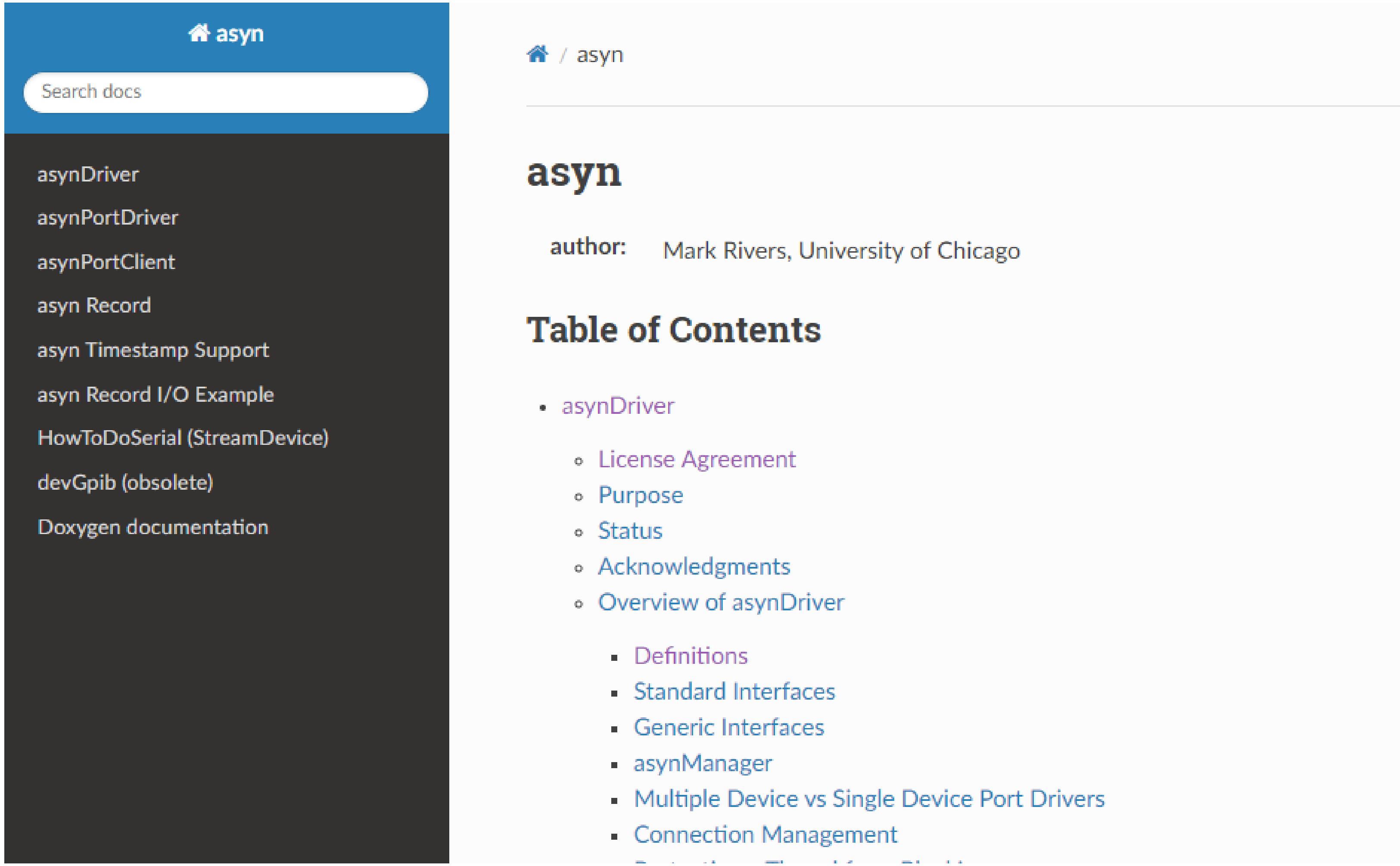
- 12. Device Support
  - 12.1 Overview
  - 12.2 Example Synchronous Device Support Module
  - 12.3 Example Asynchronous Device Support Module
  - 12.4 Device Support Routines
  - 12.5 Extended Device Support

EPICS
Advanced part

Asyn Driver

AsynDriver on the Web

https://epics-modules.github.io/asyn/



asyn

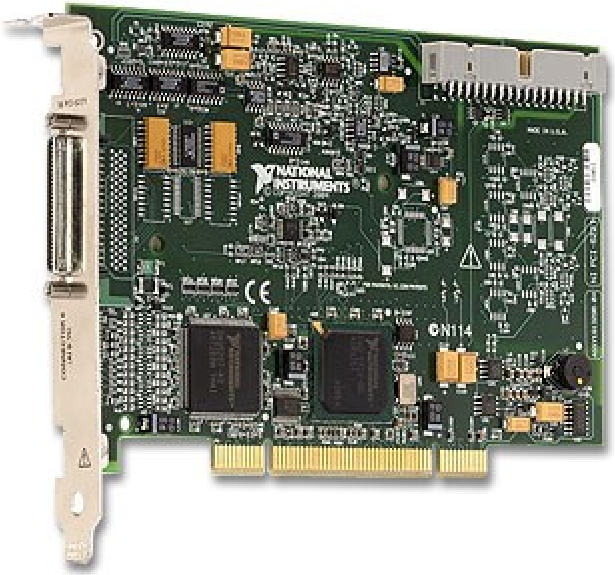
author: Mark Rivers, University of Chicago

Table of Contents

- asynDriver
  - License Agreement
  - Purpose
  - Status
  - Acknowledgments
  - Overview of asynDriver
    - Definitions
    - Standard Interfaces
    - Generic Interfaces
    - asynManager
    - Multiple Device vs Single Device Port Drivers
    - Connection Management

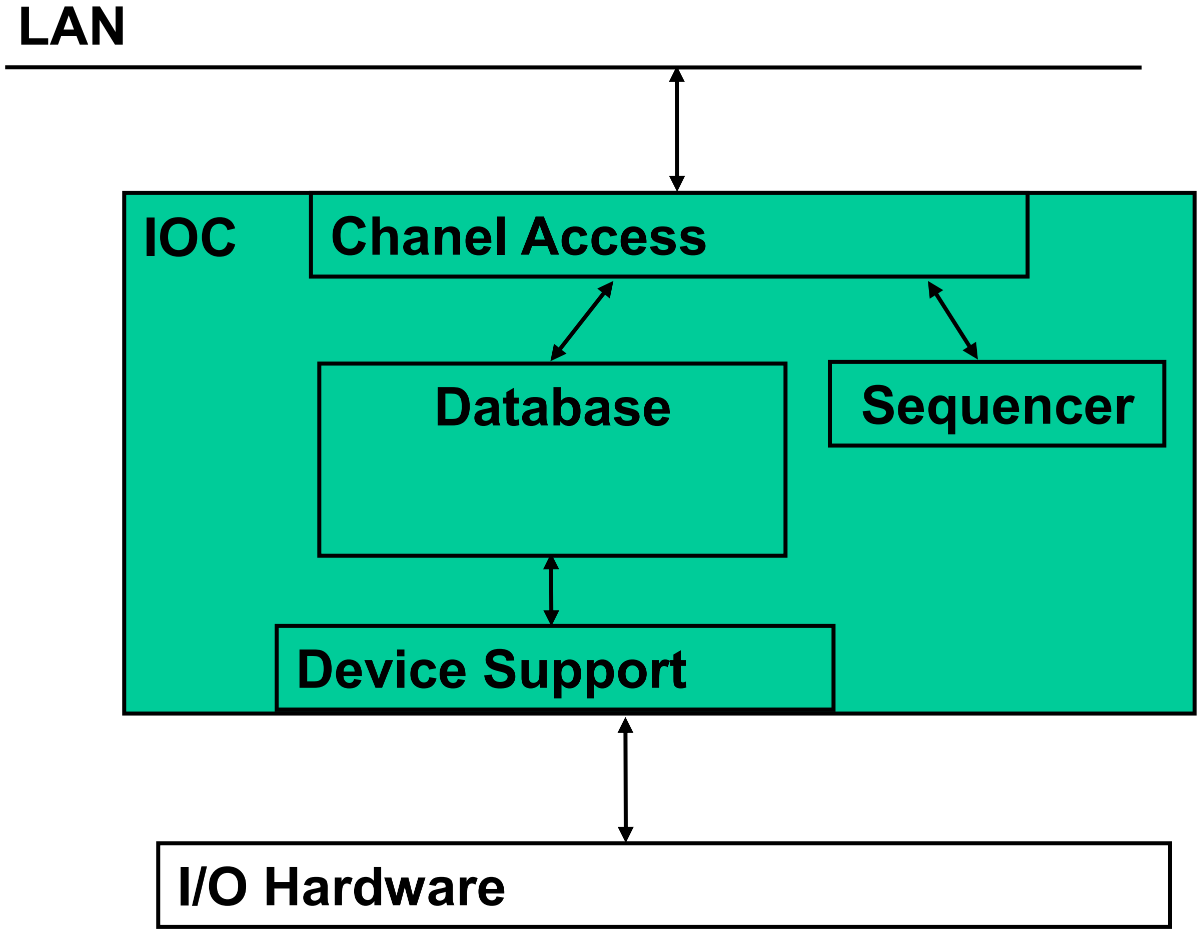
Goal

- Card
  - Card parameters
- Channel groups
  - Channels
    - Range
    - Offset
    - Gain
    - ???
  - Triggers

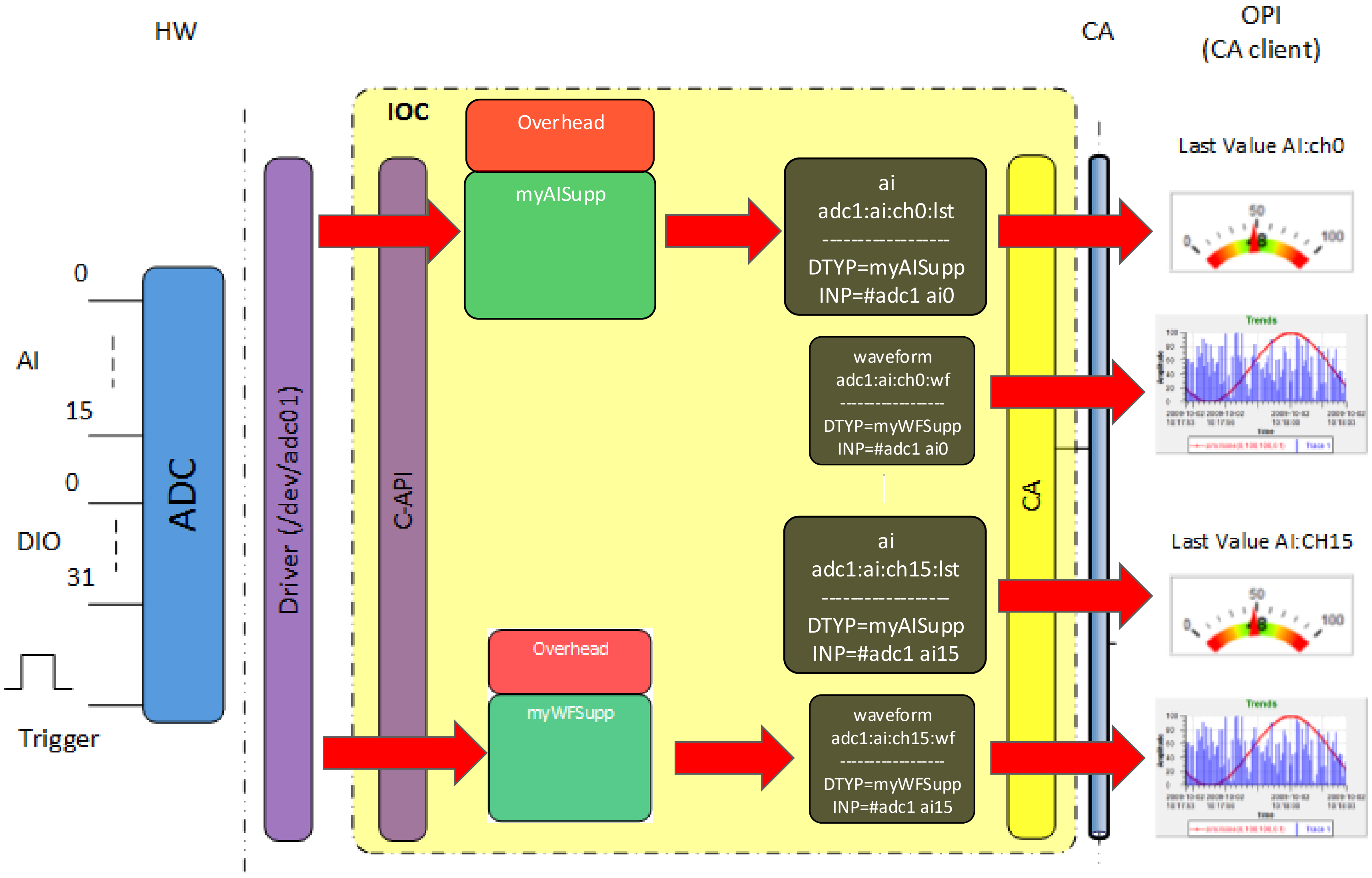


Inside an IOC

- The major software components of an IOC (IOC Core)



Device Support Architecture



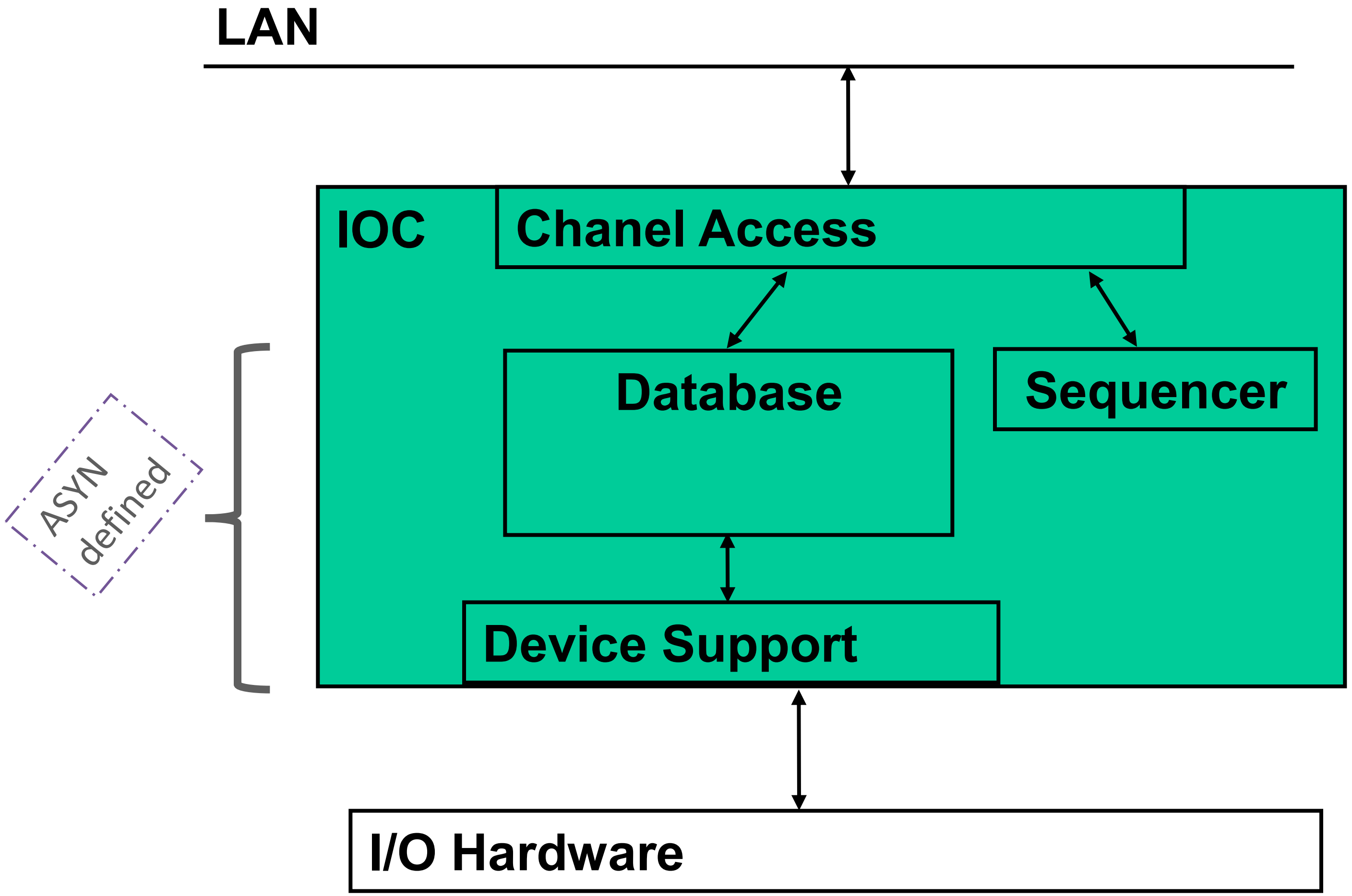
Device Support Approach

- Device state management
- Device parameters
- Channel parameters

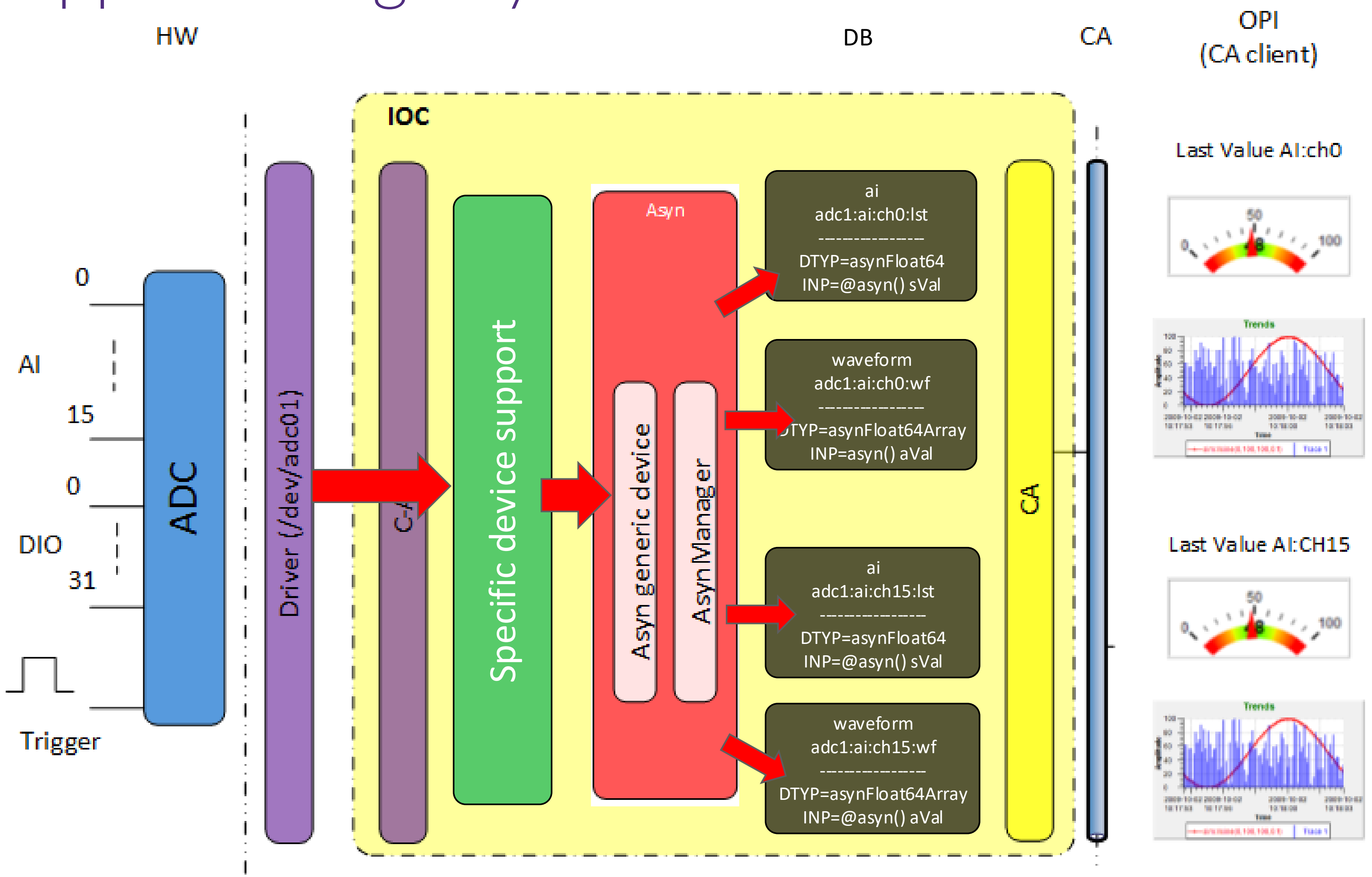
- Each required data type (interface) must be implemented
- Asynchronous processing / Interrupts

ASYN Definition

- The major software components of an IOC (IOC Core)



Device Support Using Asyn



HW

DB

CA

OPI
(CA client)

IOC

AI

0

15

DIO

0

31

Trigger

ADC

Driver (/dev/adc01)

C-/

Specific device support

Asyn

Asyn generic device

Asyn Manager

ai
adc1:ai:ch0:lst

DTYP=asynFloat64
INP=@asyn() sVal

waveform
adc1:ai:ch0:wf

DTYP=asynFloat64Array
INP=asyn() aVal

ai
adc1:ai:ch15:lst

DTYP=asynFloat64
INP=@asyn() sVal

waveform
adc1:ai:ch15:wf

DTYP=asynFloat64Array
INP=@asyn() aVal

CA

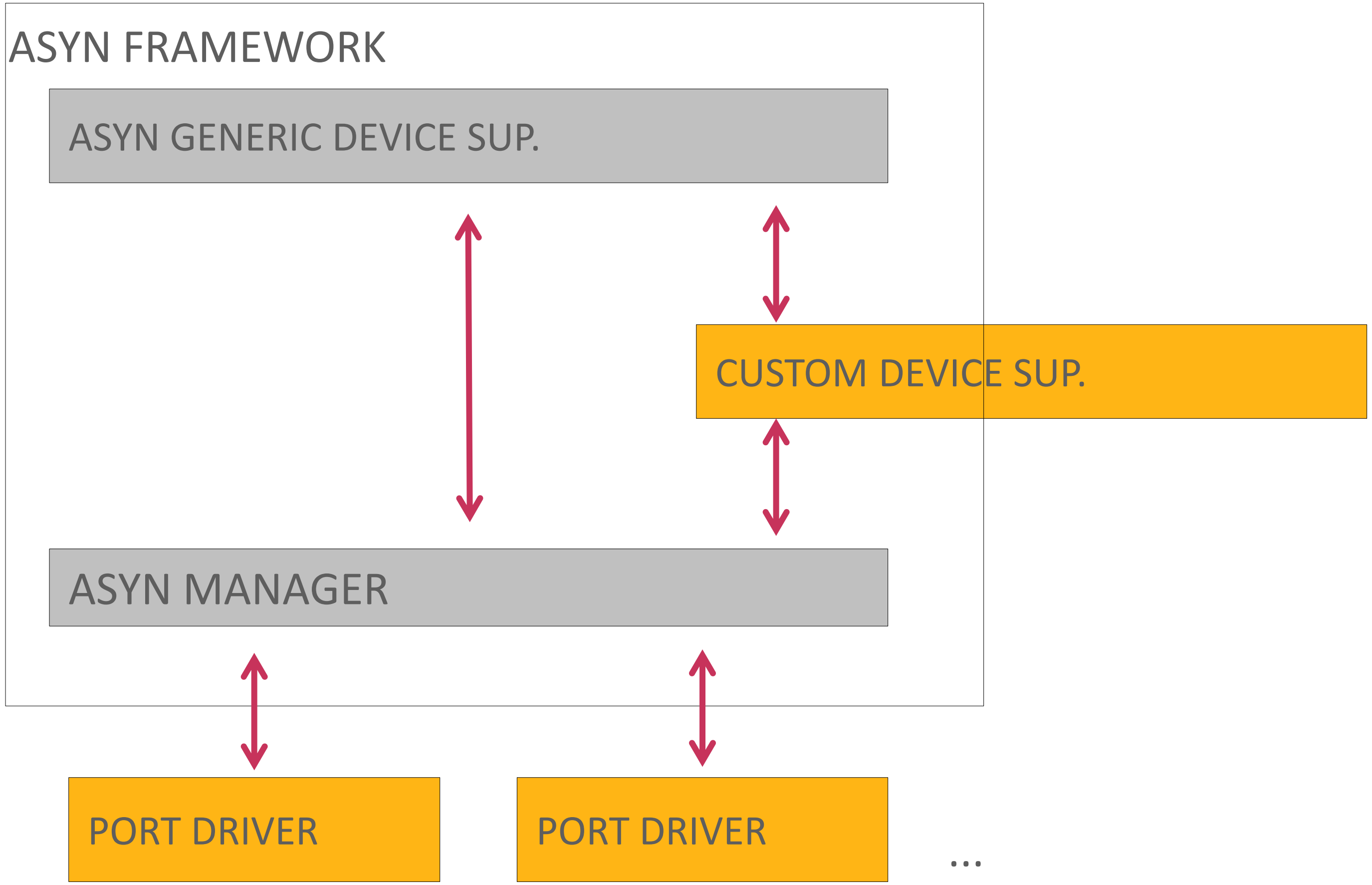
Last Value AI:ch0

Last Value AI:CH15

Why is this so cool?

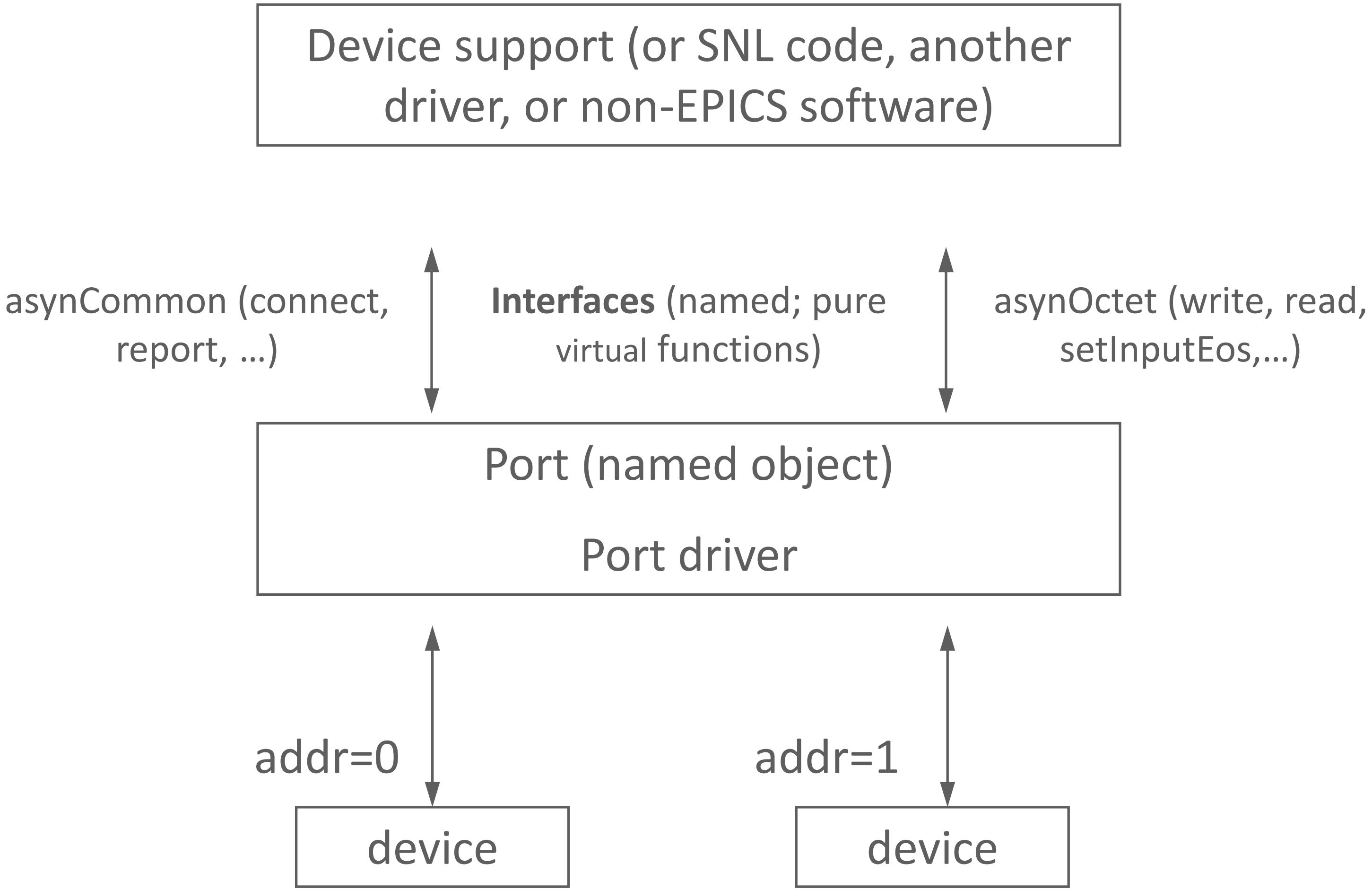
- Handles complex stuff that is common
  - Write/Read operations
  - Asynchronous processing/Interrupts
  - Multiplicity
- Simplify writing of drivers, prevents bad design
- No need for EPICS device support (most cases)
- C/C++ Interfaces

Asyn Architecture



- Asyn manager has access to asyn port driver

Asyn Architecture (Cont.)



Device support (or SNL code, another driver, or non-EPICS software)

asynCommon (connect, report, …)

Interfaces (named; pure virtual functions)

asynOctet (write, read, setInputEos,…)

Port (named object)

Port driver

addr=0

addr=1

device

device

Generic Device Support

- asyn includes generic device support for many standard EPICS records and standard asyn interfaces
- Eliminates need to write device support in many cases. New hardware can be supported by writing just a driver.
- Examples:

  `asynInt32`
  - `ao, ai, mbbo, mbbi, longout, longin`

  `asynInt32Average`
  - `ai`

  `asynUInt32Digital, asynUInt32DigitalInterrupt`
  - `bo, bi, mbbo, mbbi`

  `asynFloat64`
  - `ai, ao`

  `asynOctet`
  - `stringin, stringout, waveform`

How is it done?

```
device(ai,       INST_IO, asynAiInt32,  "asynInt32")
device(ai,       INST_IO, asynAiInt32Average, "asynInt32Average")
device(ao,       INST_IO, asynAoInt32,  "asynInt32")
device(bi,       INST_IO, asynBiInt32,  "asynInt32")
device(bo,       INST_IO, asynBoInt32,  "asynInt32")
device(mbbi,     INST_IO, asynMbbiInt32, "asynInt32")
device(mbbo,     INST_IO, asynMbboInt32, "asynInt32")
device(longin,   INST_IO, asynLiInt32,  "asynInt32")
device(longout,  INST_IO, asynLoInt32,  "asynInt32")
…
```

Record Configuration

```
record (longin, "$(app)-LONGIN-MAX-INT32")
{
        field(DTYP, "asynInt32")
        field(INP, "@asyn(S0,1) getMaxInt32")
        field(PINI, "YES")
}
```

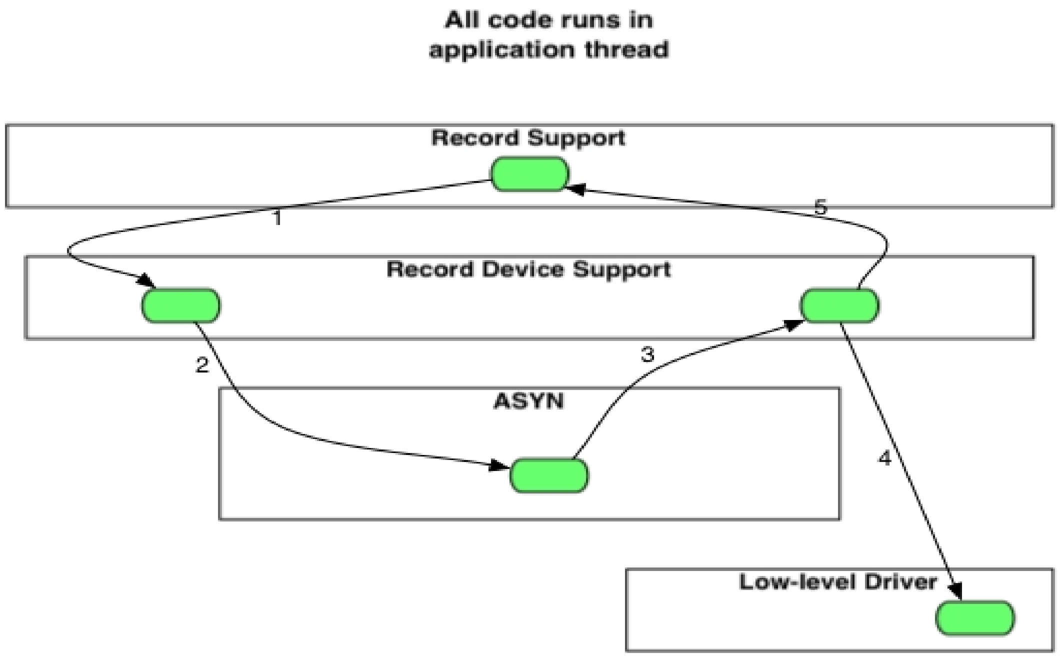
Asyn Interface which is used to handle this PV

(Port name, address)

Port name configured in st.cmd.

Reason which defines handler behavior

Synchronous Flow



- Sometimes blocking is desired
- We don't write extra stuff for blocking support

Synchronous Methods

- Read

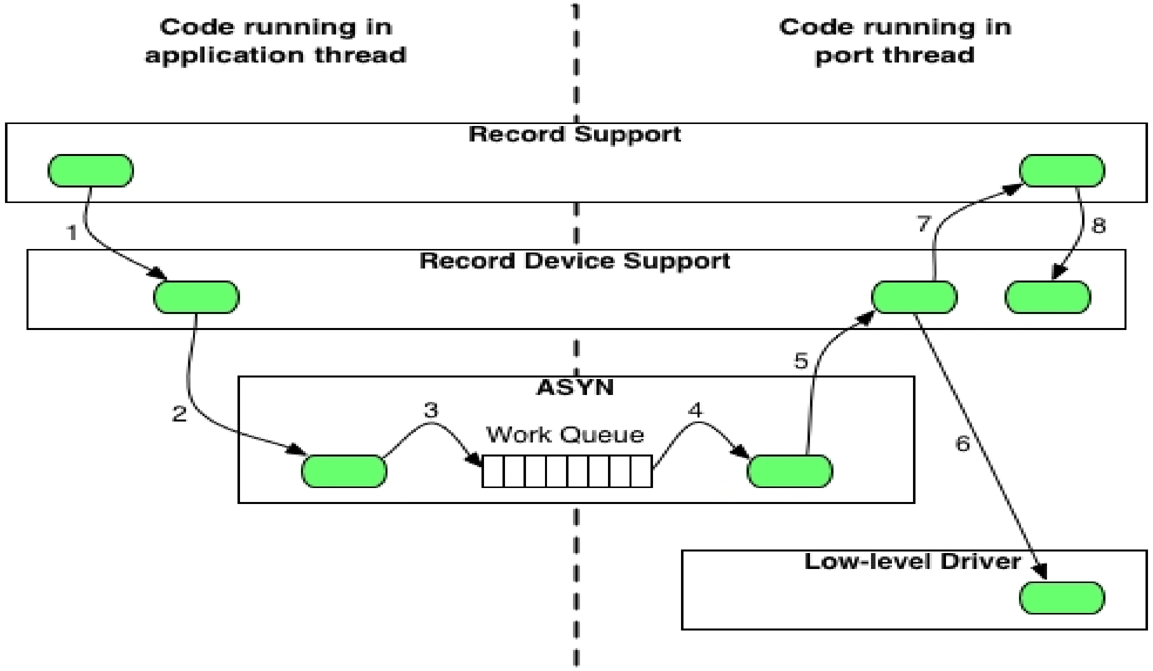
```
asynStatus (*read) (
    asynUser *pasynUser,
    epicsXXX *pvalue,
    size_t nelem,
    size_t *nIn,
    double timeout );
```

- Write

```
asynStatus (*write) (
    asynUser *pasynUser,
    epicsXXX *pvalue,
    size_t nelem,
    double timeout );
```

`asynUser` - is an interface between generic device support and specific driver. It is managed by asynManager.

Asynchronous Flow



- An `asynUser` is the means by which asynManager manages multiple requests
- An `asynUser` should be created for each “atomic” access to low level driver

Support for Interrupts

- Interfaces with interrupt callback support: `asynInt32`, `asynInt32Array`, `asynUInt32Digital`, `asynFloat64` and `asynFloat64Array`

- `registerInterruptUser(…,userFunction, userPrivate, …)`
  - Driver will call `userFunction(userPrivate, pasynUser, data)` whenever an interrupt occurs
  - Callback will not be at interrupt level, so callback is not restricted in what it can do

- Callbacks can be used by device support, other drivers, etc.

Adding ASYN: Application Conf.

- Register asyn in the config file (`config/RELEASE`)

```
ASYN=$(EPICS_BASE)/../modules/asyn
```

Adding ASYN: DB Configuration

- DBD:

```
include "asyn.dbd"
```

- Record Configuration:
  - DTYP

    ```
    field(DTYP,"asynXXX")
    ```

  - INP/OUT

    ```
    field(INP,"@asyn(portName, addr, timeout) reason")
    ```

    - or

    ```
    field(INP,"@asynMask(portName, addr, mask, timeout) reason")
    ```

ASYN Port Implementation

- C version
  - Define/implement common ASYN interfaces

    `asynCommon`

    `asynDrvUser`
  - Define/implement device support interfaces

    `asynInt32`
    - …
- C++ version
  - Extend asynPortDriver class
    - No need to define separate interfaces everything already defined
- Provide asynPort initialization function.

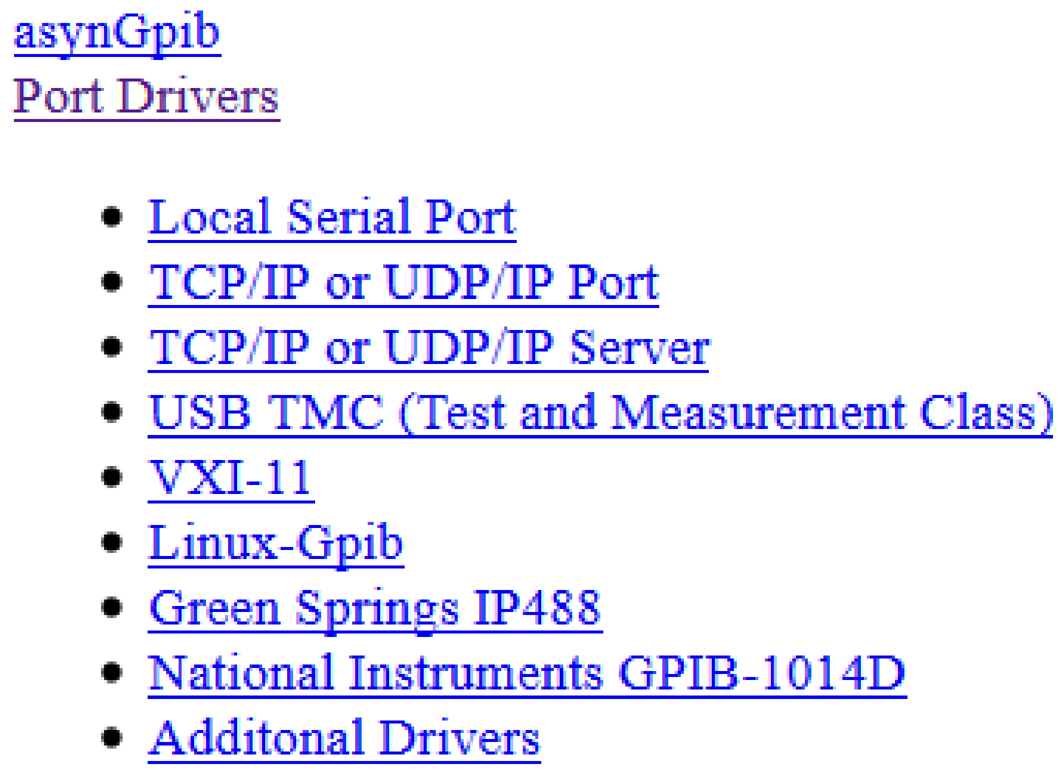
ASYN Port Implementation (cont.)

- Define supported reasons

```
asynUser.reason
```

- Register interrupt callback functions
  - For SCAN = I/O Interrupt PVs

Existing Port Drivers



asynGpib
Port Drivers

- Local Serial Port
- TCP/IP or UDP/IP Port
- TCP/IP or UDP/IP Server
- USB TMC (Test and Measurement Class)
- VXI-11
- Linux-Gpib
- Green Springs IP488
- National Instruments GPIB-1014D
- Additonal Drivers

EPICS
Advanced part

Stream Device

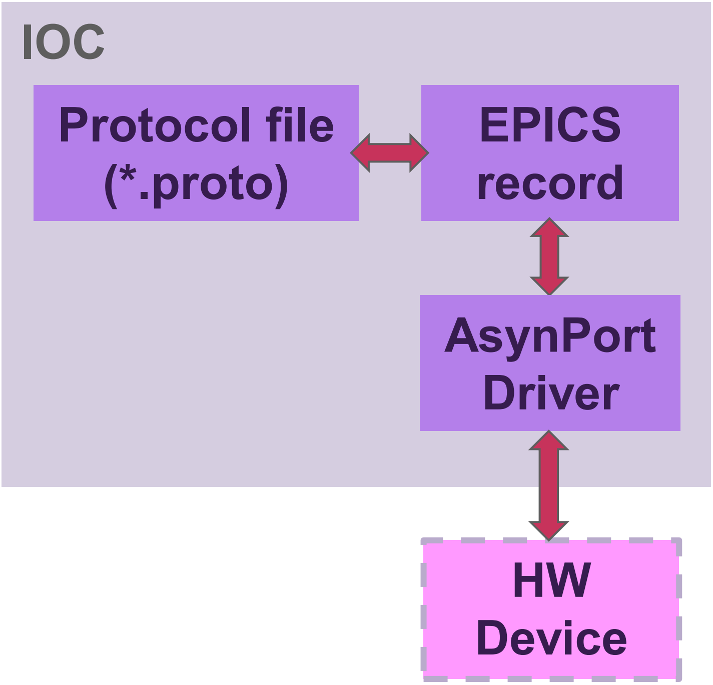
Overview

- What is Stream Device?
- Architecture
- Build Configuration
- Protocol Files
- Features
- Example Protocol File
- Conclusion

What is StreamDevice?

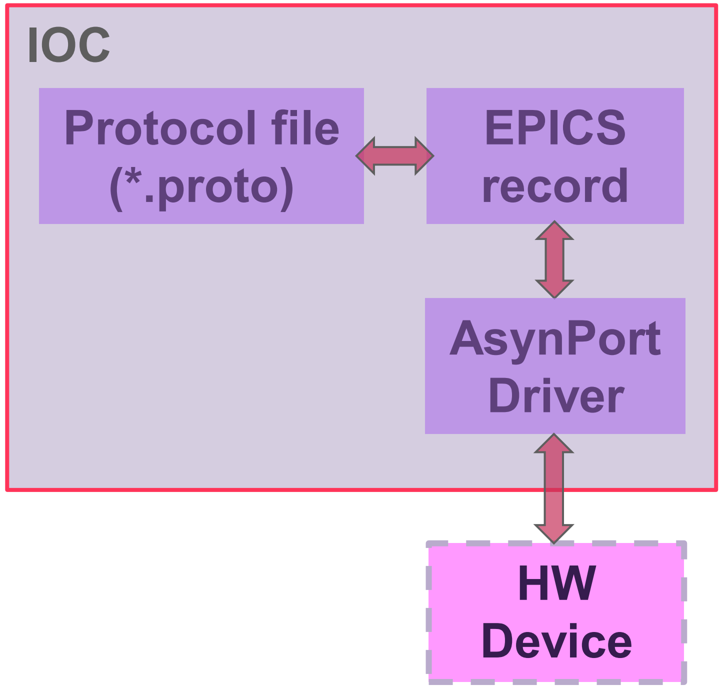
- EPICS module used to define string-based communication protocols between EPICS records and devices
    - E.g. Message sent: `V?`; Message received: `V=2.1`
- Based on AsynDriver, has all of its advantages:
    - Thread handling
    - Proper resource locking
    - Queueing (by priority)
- But yet simple configuration, no programming required
- Based on plain text protocol files
- All documentation: https://paulscherrerinstitute.github.io/StreamDevice/

Architecture



- Protocol file includes a set of protocols
  - A protocol is a set of “instructions” how to make a particular data exchange with a particular device
- Records may use one protocol to configure how they function
- Records communicate with HW device by exchanging the messages described in their assigned protocol via an AsynPort Driver

Include Stream Device Support



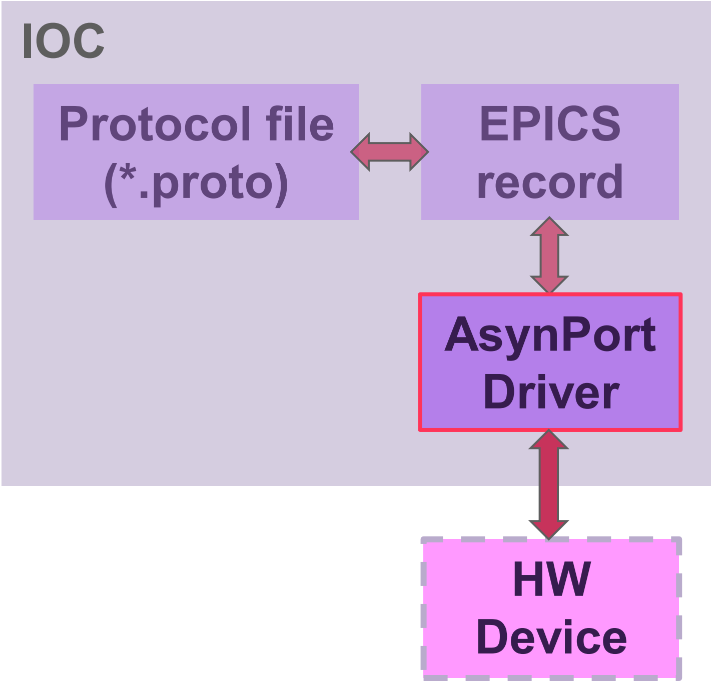
- Stream Device support must be loaded in EPICS Application
  - In configure/RELEASE add the following lines

```
STREAM = /opt/epics/stream-<version>/
ASYN = /opt/epics/asyn-<version>/
```

  - In <AppName>App/src/Makefile, include:

```
<AppName>_DBD += stream-base.dbd
<AppName>_DBD += asyn.dbd
<AppName>_DBD += drvAsynIPPort.dbd


<AppName>_LIBS += stream
<AppName>_LIBS += asyn
```

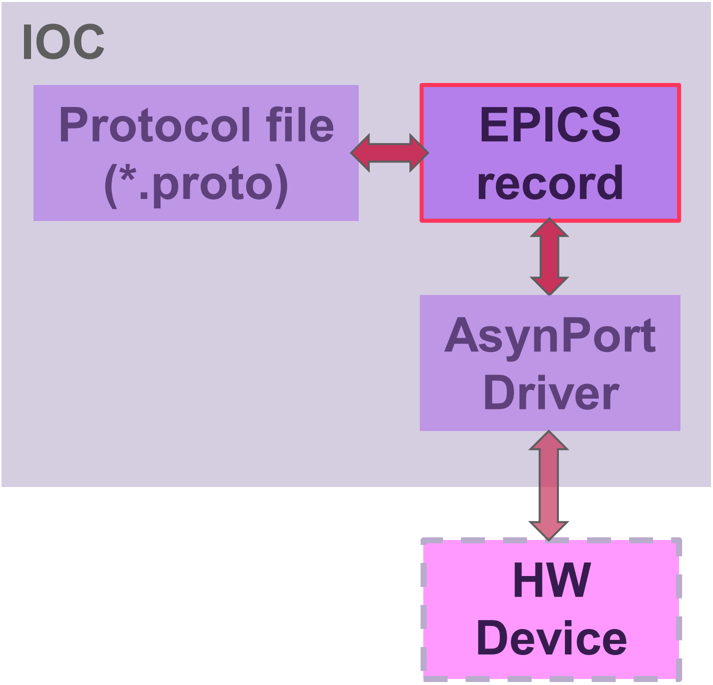
Asyn Port Driver Configuration



- AsynPort is initialized in IOC start file `st.cmd`
- IP connection:
  `drvAsynIPPortConfigure ("DEV1", "192.168.1.212:8080")`
  Creates a connection called `DEV1` with a network device reachable at `192.168.1.212` over port `8080`
- Serial connection:
  `drvAsynSerialPortConfigure("DEV2", "/dev/ttyS1")`
  Creates a connection called `DEV2` with a serial device connected to `/dev/ttyS1`
- Optional asyn parameters (line terminators, serial communication parameters…) may be specified with other commands

- For debugging, the asyn trace mask can be used to output to shell exactly what is being transmitted:
  ```
  asynSetTraceMask("DEV1",-1,0x9);
  asynSetTraceIOMask("DEV1",-1,0x2)
  ```
- Check `asynDriver.h` for details

Record Configuration



- Records that may use Stream Device out of the box:
  `ai, ao, bi, bo, mbbi, mbbo, mbbiDirect, mbboDirect, longin, longout, stringin, stringout, waveform, calcout, scalcout`
- Others may as well, but require support

- Two fields are used to tell a record to use Stream Device
- Device Type (`DTYP`):

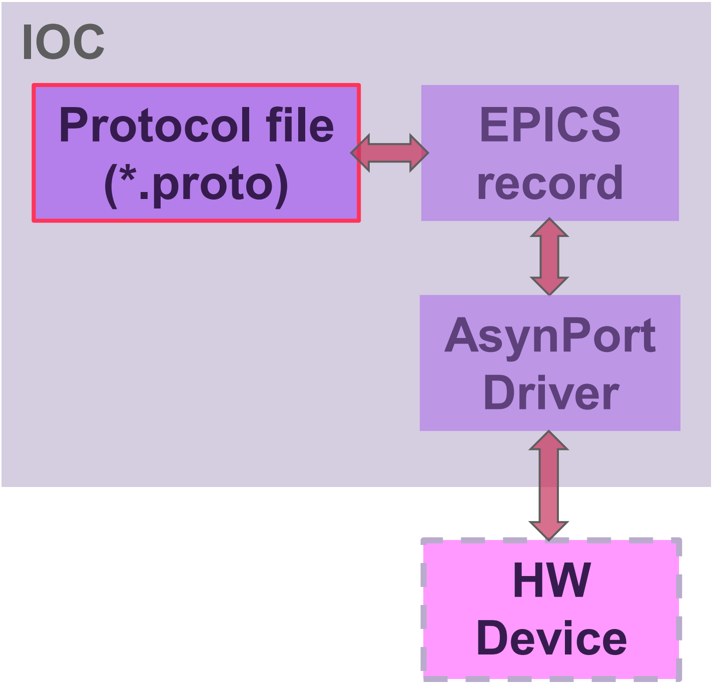
```
field (DTYP, "stream")
```

- Either Input (`INP`) or Output (`OUT`):

```
field(INP,"@protoFile.proto getFrequency DEV1")
field(OUT,"@protoFile.proto setFrequency DEV1")
```

- First example tells input record to acquire its value using protocol `getFrequency`, specified in the file `protoFile.proto`, from device connection `DEV1`
- Second example tells output record to send its value using protocol `setFrequency`, specified in the file `protoFile.proto`, to device connection `DEV1`

Protocol File Locations



- Records are given the name of a protocol file, but not a path to find it
- Paths to protocol files are declared in `st.cmd`
- Using command:
  `epicsEnvSet("STREAM_PROTOCOL_PATH", "/path1/:/path2/")`
- Multiple paths can be provided using a colon as a separator.

Protocol Files

- Plain text ASCII files containing a set of protocols
- Each protocol has a name and a sequence of commands
  - `in` *`string`*`;` - reads message that matches “string”
  - `out` *`string`*`;` - sends message that matches “string”
  - others: `wait`, `event`, `exec`, `disconnect`, `connect`
- “Strings” are matched using format converters
  - doubles or floats: `%f`, `%e`, `%E`, `%g`, `%G`
  - shorts, ints or longs: `%d`, `%i`, `%u`, `%o`, `%x`, `%X`
  - strings or chars: `%s`, `%c`
  - enumerations: `%{string0|string1|...}`
  - others: `%[charset]`, `%b`, `%Bzo`, `%r`, `%R`, `%D`, `%<checksum>`, `%/regex/`, `%#/regex/subst/`, `%m`, `%T(timeformat)`
- Optional width and flags can modify behaviour of format converters
  - Width specifies number of characters string should have
  - Flags: `*`(skip), `#`(format), `+`(positive int prefix), `0`(pad), `-`(left justify), `?`(allow fail), `=`(compare), `!`(impose width)

Features

- **Protocol nesting** – one protocol may call another
- **Redirection** – protocols may read/write from/to other records and/or fields *(in general not a good practice, but possible)*
- **System variables** – preset variables (can be local or global): `LockTimeout`, `WriteTimeout`, `ReplyTimeout`, `ReadTimeout`, `PollPeriod`, `Terminator`, `OutTerminator`, `InTerminator`, `MaxInput`, `Separator`, `ExtraInput`
- **User variables** – free to customize, called with `$` prefix
- **Arguments** – arguments can be passed from the record to the protocol it calls (up to 9, called with `\$1..\$9`)
- **Exception handlers** – clauses that are called only when certain conditions are met: `@mismatch`, `@writetimeout`, `@replytimeout`, `@readtimeout`, `@init`

Example Protocol File

```
Terminator = CR LF;          # sets line terminators for both inputs and outputs to "\r\n"
f = "FREQ";                  # User variable: sets f to "FREQ" (including the quotes)
f1 = $f " %f";               # User variable: sets f1 to "FREQ %f"
getFrequency {               # ai  record could call this using INP="@protoFile.proto getFrequency DEV1"
    out $f "?";              # same as: out "FREQ?";
    in $f1;                  # same as: in "FREQ %f";
}
setFrequency {               # ao record could call this using OUT="@protoFile.proto setFrequency DEV1"
    out $f1;                 # same as: out "FREQ %f";
    @init { getFrequency; }  # Exception handler calling another protocol: initial sync
}
getSwitch {                  # bi  record could call this using INP="@protoFile.proto getSwitch DEV1"
    out "SW?";
    in "SW %{OFF|ON}";       # if input is "SW OFF" then VAL=0,  if input is "SW ON" then VAL=1
}
setSwitch {                  # bo  record could call this using OUT="@protoFile.proto setSwitch DEV1"
    out "SW %{OFF|ON}";      # if VAL=0, send "SW OFF", if VAL=1, send "SW ON"
    @init { getSwitch; }     # Exception handler calling another protocol: initial sync
}
move {                       # longout record could call this using OUT="@protoFile.proto move(X) DEV1"
    out "\$1 GOTO %d";       # Message sent would be "X GOTO %d"
}
debug {                      # Generic command for stringout record: any string written to
    ExtraInput = Ignore;     # ... record's VAL field is sent to device, any reply from device
    out "%s"; in "%39c";     # ... will be written to record's VAL field cropped at 39 chars.
}
```

Messages don’t get mixed up!

- **Use-case:** Two records that use similar protocols for the same device are triggered to process at (almost) the same time
  - Record A protocol: { `out “V PS1?”; in “%f”;` }
  - Record B protocol: { `out “V PS2?”; in “%f”;` }
- If both output messages are sent to the same device at the same time, how will the responses not get mixed up?
  - AsynDriver sends the first output message it receives (either A or B).
  - Second output message gets buffered in a queue and doesn’t get sent (yet).
  - Only once the first protocol is completed (a proper reply is received within the timeout), the second output message gets sent automatically.
- AsynDriver takes care of everything!

Conclusion

- Stream Device offers universal support to integrate all message-based devices
- AsynDriver takes care of all the complicated low-level stuff and provides out-of-the-box support for most low-level drivers:
  serial, TCP/IP, VXI-11, IEEE-488, …
- Only configuration, no coding
- Protocols are reloadable → Faster development
- Support for most common record types
- Extendable:
  - Write your own format converters
  - Write support for other record types
  - Use StreamDevice with other non-Asyn low-level drivers
- However:
  - Not a programming language (no *for*s, *if*s, etc.)
  - Everything is a string (no other datatypes, just format converters)
  - Line terminators can cause headaches (use Asyn Trace Mask for debugging!)
  - Timeouts and errors must be handled
  - Although quick to setup, can take time to make fail-safe (80/20 rule!)

Exercise 8

Application based on Stream Device

CS-Studio

Outline

- What is CS-Studio
- The motivation behind it
- CS-Studio core architecture
- CS-Studio functionalities - tools

What is CS-Studio?

- Control System Studio

- Common platform for control system applications
  - Users – single point of control
  - Developers – write portable applications

- Front-end to different control systems

Motivation

- Too many CS technologies
  - X-Probe - Single-PV inspection
  - StripTool - Plot live data over time
  - Archive Data Viewer - Plot historic data over time
  - Display Manager: EDM, MEDM – HMI display (and editor)
  - …
- Different look and feel of applications
- No simple unified way of usage
- No inherent ability to exchange information between applications
- CS-Studio effectively combines all of those into one application

CS-Studio Phoebus

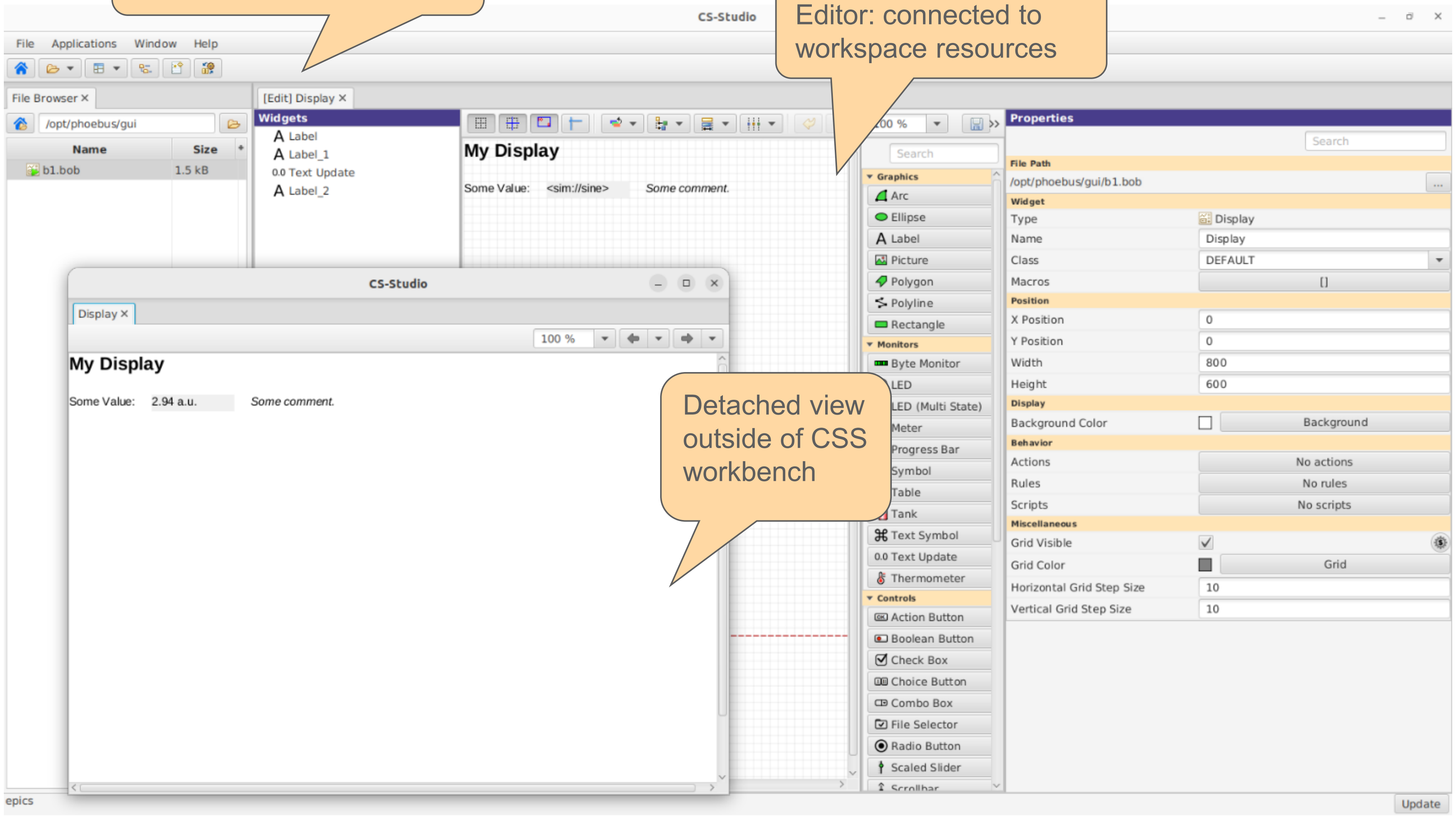
- Part of a wide community of users and developers:
  BNL, DESY, FRIB, SNS, ITER, ESS, …
- Java – OS independent
- Open-source
- CS-Studio is simply a collection of plugins
- Some concepts:
  - Editors (OPI editor, plot editor…)
  - Views – windows that provide a view of data
  - Perspectives – arrangement of views, editors, toolbars…

CSS Look

Workbench Users can arrange views and editors

Editor: connected to workspace resources

Detached view outside of CSS workbench



Properties

File Path
/opt/phoebus/gui/b1.bob

Widget
Type: Display
Name: Display
Class: DEFAULT
Macros: []

Position
X Position: 0
Y Position: 0
Width: 800
Height: 600

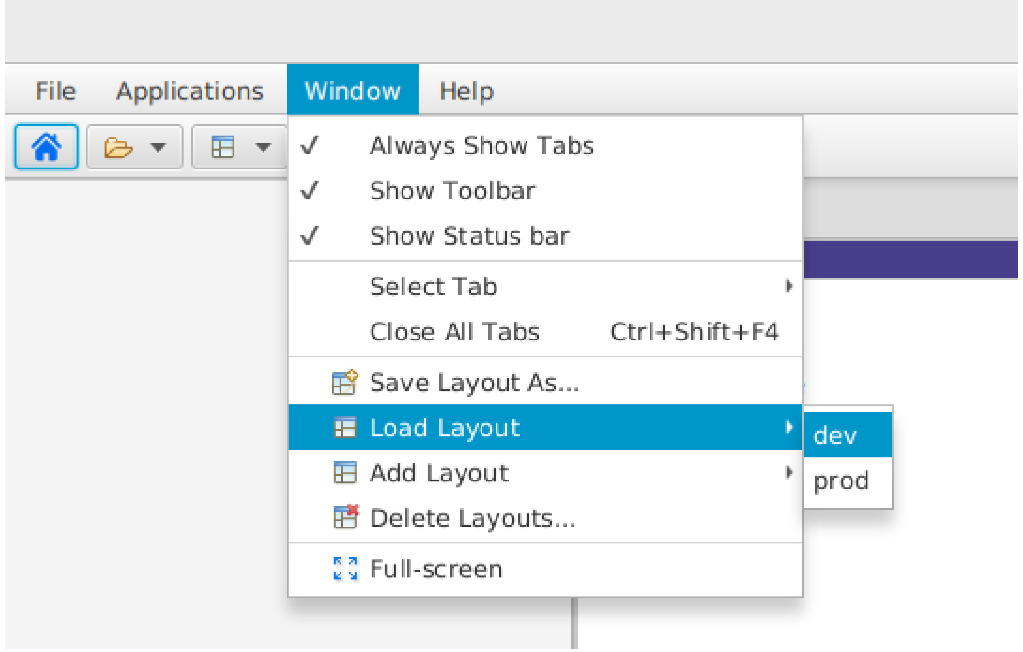
Display
Background Color: □ Background

Behavior
Actions: No actions
Rules: No rules
Scripts: No scripts

Miscellaneous
Grid Visible: ☑
Grid Color: ■ Grid
Horizontal Grid Step Size: 10
Vertical Grid Step Size: 10

Layouts

- Different layouts can be used for different tasks
  - Development
    - Display Editor – Develop HMIs
    - File Browser – List of all development files
  - Production
    - Alarm - Monitor alarms
    - Data Browser - Plot data trends
    - OPI Runtime - Interact with Control System through HMIs



Advantages

- CS-Studio allows you to display/set global settings that impact the behavior of all tools
- Tools interact – drag-and-drop, open related displays from alarm tool…
- Perspectives – save personal or global arrangements of panels as different perspectives – alarm, archiving …
- Create custom CS-Studio – separate product
- In short - integration

Disadvantages

- Steeper learning curve
- Too many options for unexperienced users
- Lower performance and higher hardware requirements
- That’s about it

CS-Studio

GUI editor

Outline

- What is Display Builder?
- Runtime
- Editor
  - Widgets
  - Widget properties
  - Scripting

What is Display Builder?

- Development and runtime environment
  - Display Builder
    - 2nd, improved version of dev and run-time environment
    - Still in development
  - Working on OPI files with extension `.bob`
- A Control System Studio tool – integrated with alarms, archiving ...
- Maintained by the EPICS / CS-Studio community
- Two Modes:
  - Runtime – Use widgets to interact with PVs
  - Editor – Design OPI by placing and configuring widgets

Runtime / Editor

- OPIs can be opened in different modes depending on the tool used:
  - Runtime
    - OPI is not editable
    - OPI tries to connect to corresponding PVs (as CA clients)
    - Can also be invoked with Ctrl+G or by clicking on the button: ▶
  - Editor
    - OPI is editable
    - No interaction with PVs, no CA requests
  - Text Editor (to view OPI source, not practical in most cases)

CS-Studio

Run-time

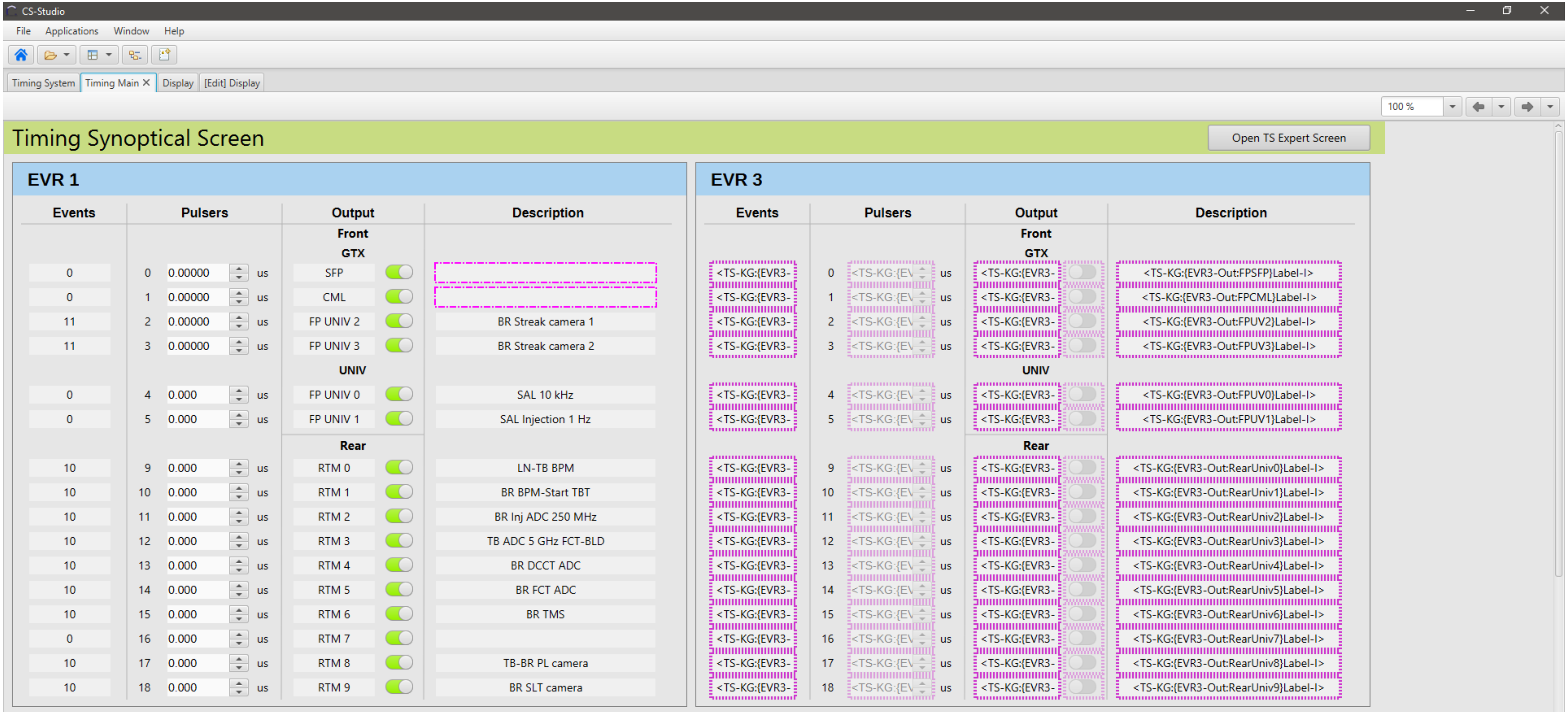
Runtime

- Displays an already created screen
  - Connect to the CS
  - Draw widgets and update them to PVs
  - Control PV values

- Very simple and straightforward operation

- Browser-like behavior
  - Default – links to other screens open in the same window
  - Possible – new tab or new window

What Does It Look Like



Timing Synoptical Screen

EVR 1

Events	Pulsers			Output		Description
				Front		
				GTX		
0	0	0.00000	us	SFP	●	
0	1	0.00000	us	CML	●	
11	2	0.00000	us	FP UNIV 2	●	BR Streak camera 1
11	3	0.00000	us	FP UNIV 3	●	BR Streak camera 2
				UNIV		
0	4	0.000	us	FP UNIV 0	●	SAL 10 kHz
0	5	0.000	us	FP UNIV 1	●	SAL Injection 1 Hz
				Rear		
10	9	0.000	us	RTM 0	●	LN-TB BPM
10	10	0.000	us	RTM 1	●	BR BPM-Start TBT
10	11	0.000	us	RTM 2	●	BR Inj ADC 250 MHz
10	12	0.000	us	RTM 3	●	TB ADC 5 GHz FCT-BLD
10	13	0.000	us	RTM 4	●	BR DCCT ADC
10	14	0.000	us	RTM 5	●	BR FCT ADC
10	15	0.000	us	RTM 6	●	BR TMS
0	16	0.000	us	RTM 7	●	
10	17	0.000	us	RTM 8	●	TB-BR PL camera
10	18	0.000	us	RTM 9	●	BR SLT camera

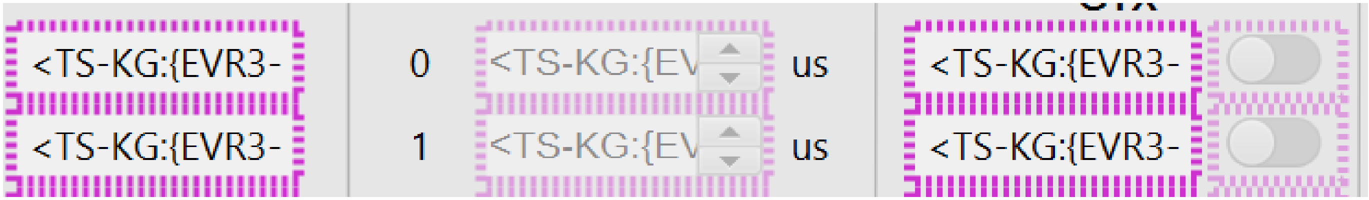
EVR 3

Events	Pulsers			Output		Description
				Front		
				GTX		
<TS-KG:{EVR3-	0	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPSFP}Label-I>
<TS-KG:{EVR3-	1	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPCML}Label-I>
<TS-KG:{EVR3-	2	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPUV2}Label-I>
<TS-KG:{EVR3-	3	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPUV3}Label-I>
				UNIV		
<TS-KG:{EVR3-	4	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPUV0}Label-I>
<TS-KG:{EVR3-	5	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:FPUV1}Label-I>
				Rear		
<TS-KG:{EVR3-	9	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv0}Label-I>
<TS-KG:{EVR3-	10	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv1}Label-I>
<TS-KG:{EVR3-	11	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv2}Label-I>
<TS-KG:{EVR3-	12	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv3}Label-I>
<TS-KG:{EVR3-	13	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv4}Label-I>
<TS-KG:{EVR3-	14	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv5}Label-I>
<TS-KG:{EVR3-	15	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv6}Label-I>
<TS-KG:{EVR3-	16	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv7}Label-I>
<TS-KG:{EVR3-	17	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv8}Label-I>
<TS-KG:{EVR3-	18	<TS-KG:{EV	us	<TS-KG:{EVR3-	○	<TS-KG:{EVR3-Out:RearUniv9}Label-I>

PV Connectivity

- Widgets automatically connect / reconnect to PVs
  - If you restart IOC, no need to reopen / refresh OPI

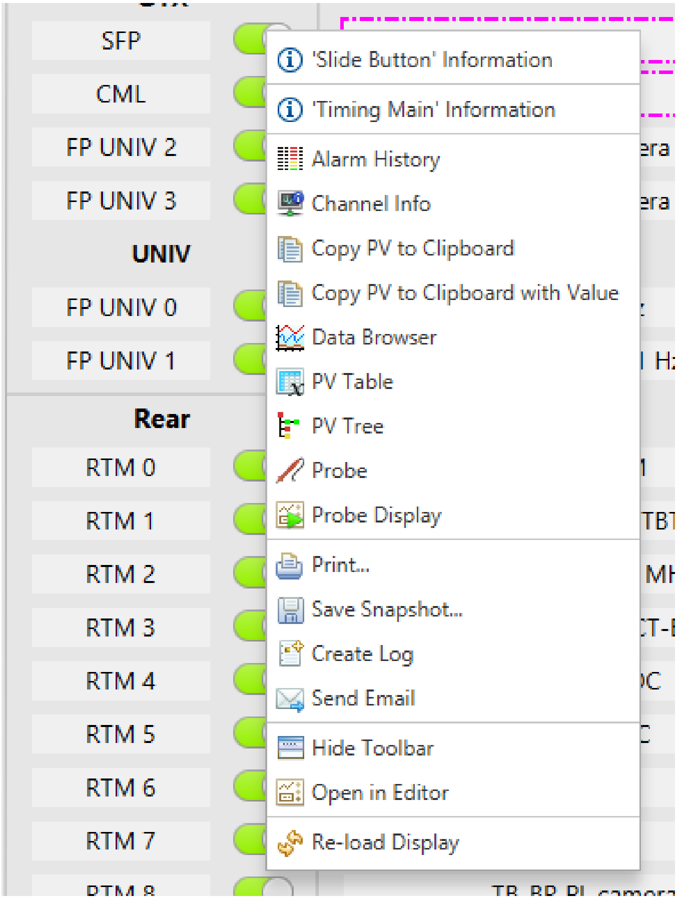
- Common look for disconnected widgets

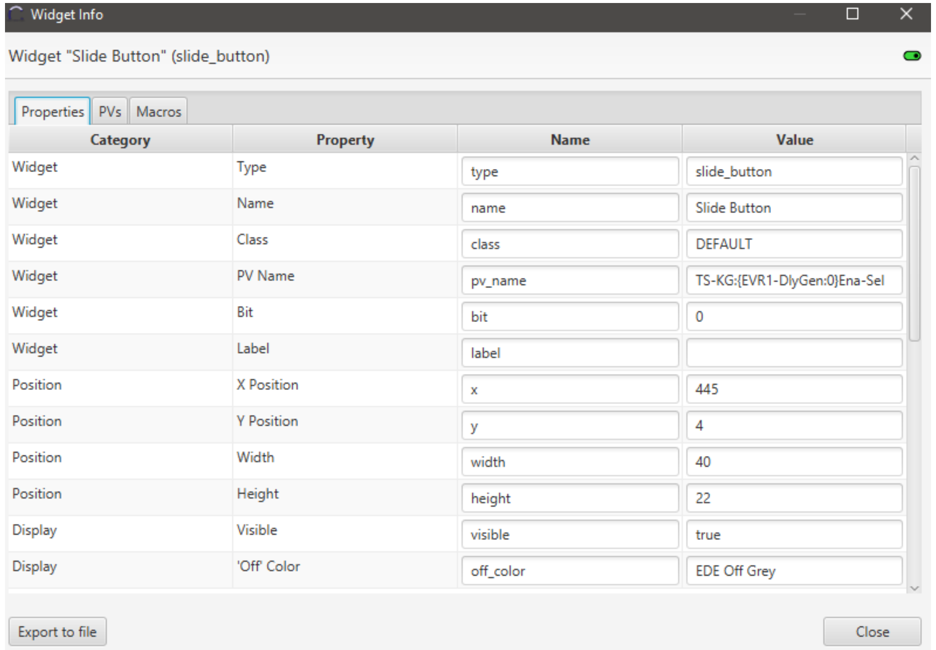


- If PV is write-disabled control widget will be disabled too

Runtime: Common PV Tools

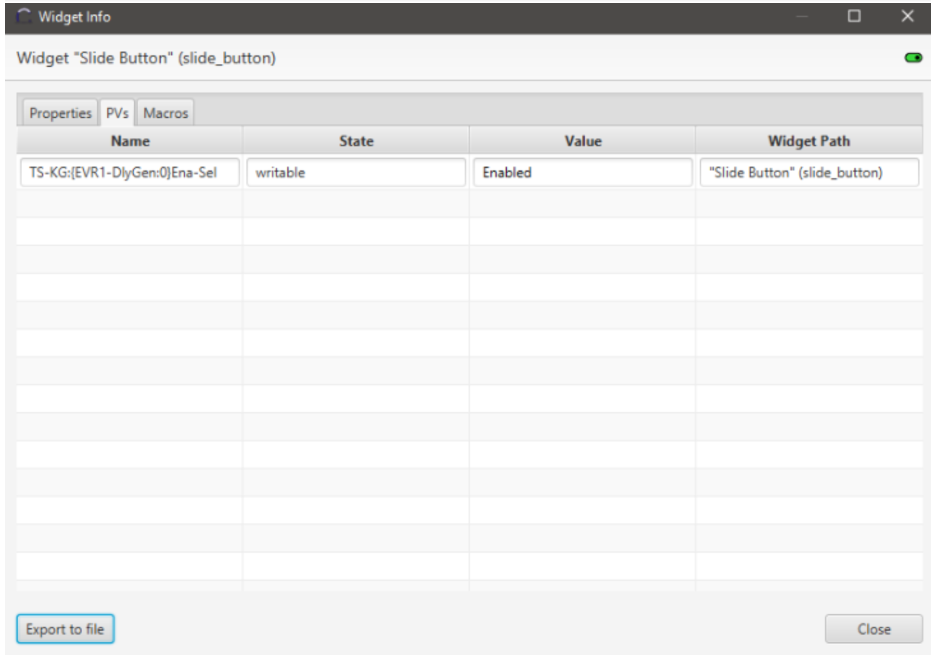
- Context menu





Widget "Slide Button" (slide_button)

Category	Property	Name	Value
Widget	Type	type	slide_button
Widget	Name	name	Slide Button
Widget	Class	class	DEFAULT
Widget	PV Name	pv_name	TS-KG:{EVR1-DlyGen:0}Ena-Sel
Widget	Bit	bit	0
Widget	Label	label	
Position	X Position	x	445
Position	Y Position	y	4
Position	Width	width	40
Position	Height	height	22
Display	Visible	visible	true
Display	'Off' Color	off_color	EDE Off Grey



Widget "Slide Button" (slide_button)

Name	State	Value	Widget Path
TS-KG:{EVR1-DlyGen:0}Ena-Sel	writable	Enabled	"Slide Button" (slide_button)

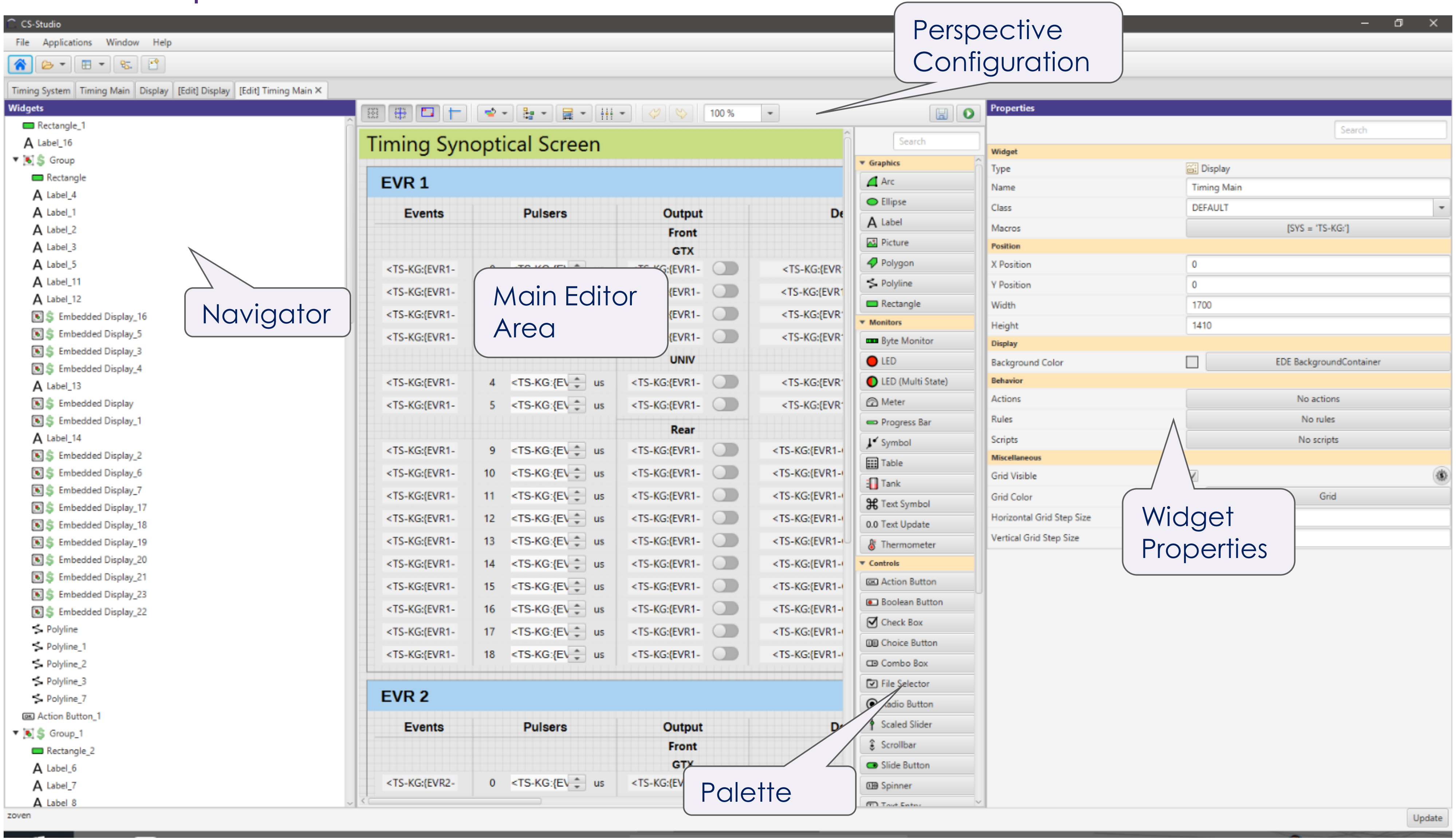
CS-Studio

Editor

Editor

- Simple screen creation + advanced functionality
- WYSIWYG - What You See Is What You Get
- Standard operations
  - Edit multiple widgets at once
  - Copy/paste
  - Move, resize, delete
  - Undo/redo
  - Align widgets with grid, other widgets
  - Zoom
  - ...

Editor Perspective



Perspective Configuration

Navigator

Main Editor Area

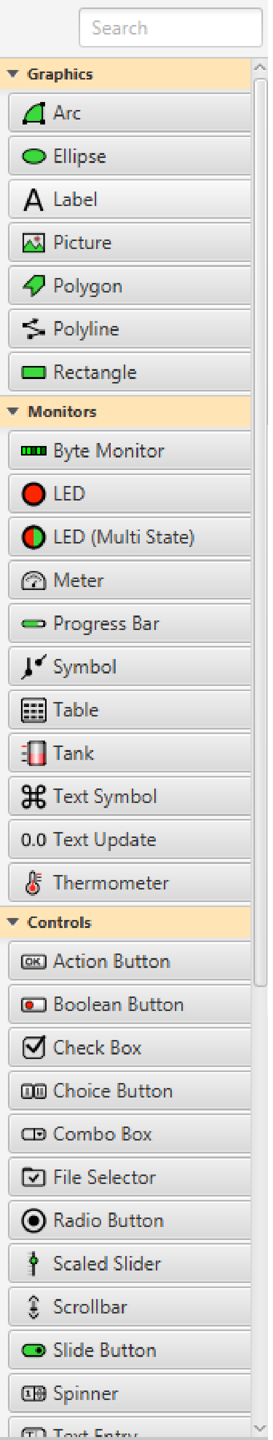
Widget Properties

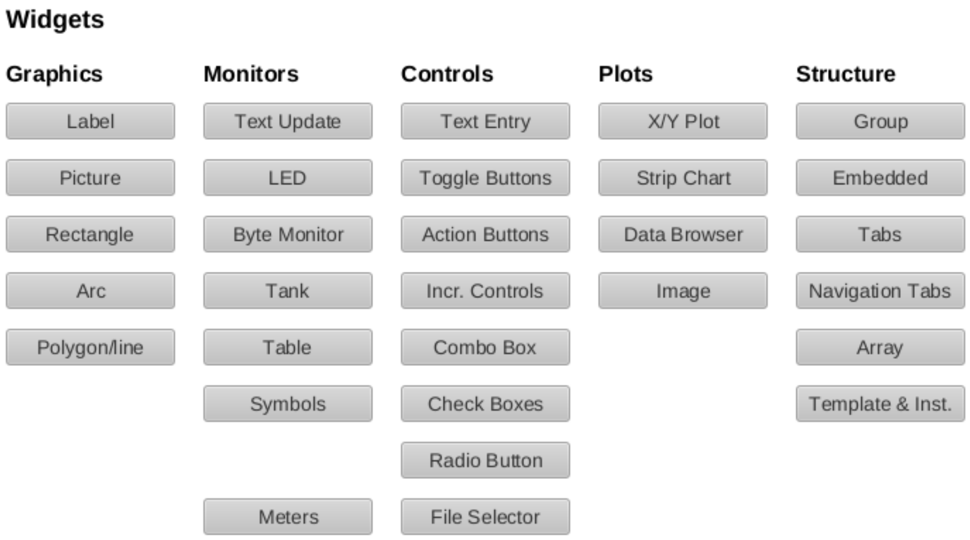
Palette

Widget	
Type	Display
Name	Timing Main
Class	DEFAULT
Macros	[SYS = 'TS-KG:']
Position	
X Position	0
Y Position	0
Width	1700
Height	1410
Display	
Background Color	EDE BackgroundContainer
Behavior	
Actions	No actions
Rules	No rules
Scripts	No scripts
Miscellaneous	
Grid Visible	✓
Grid Color	Grid
Horizontal Grid Step Size	
Vertical Grid Step Size	

Widgets

- All available widgets are found in palette
- An OPI consists of a set of widgets laid out on a grid with certain configurable attributes
- Categories of widgets:
  - Graphics – illustrative only, no I&C interaction
  - Monitors – display read-only PV data
  - Controls – editable fields to write PV data
  - Other (containers, groupings…)



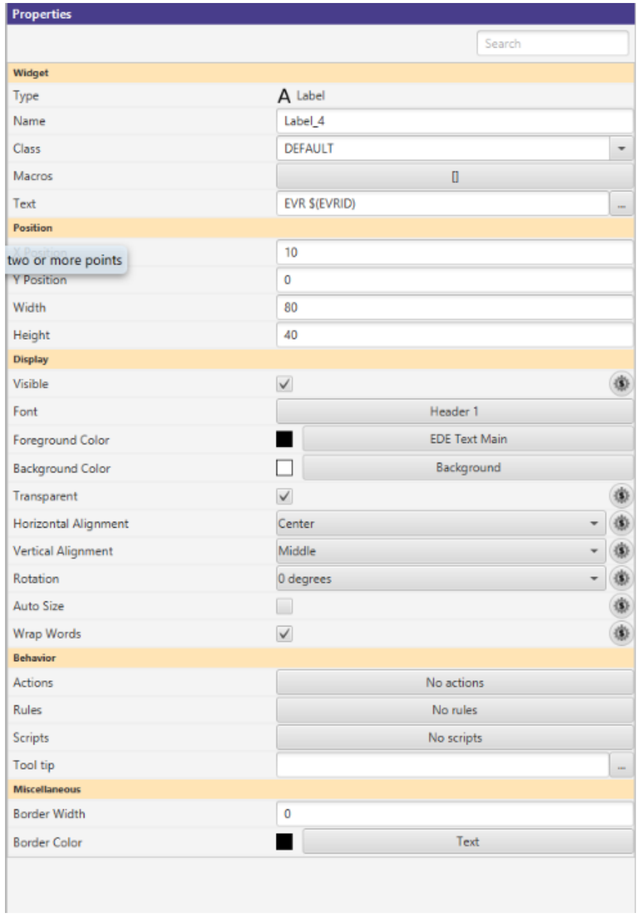


Widgets

Graphics	Monitors	Controls	Plots	Structure
Label	Text Update	Text Entry	X/Y Plot	Group
Picture	LED	Toggle Buttons	Strip Chart	Embedded
Rectangle	Byte Monitor	Action Buttons	Data Browser	Tabs
Arc	Tank	Incr. Controls	Image	Navigation Tabs
Polygon/line	Table	Combo Box		Array
	Symbols	Check Boxes		Template & Inst.
		Radio Button		
	Meters	File Selector		

Widget Properties

- Every widget has configurable properties that depend on the widget type.
- Properties are grouped in logical categories, some of which are:
  - Widget (type of widget, name, class, associated PV, …)
  - Position (coordinates, size)
    - Position can also be modified by moving or resizing the widget in the editor, or via Toolbar buttons to align etc.
  - Behavior (actions, rules, scripts, tooltip, alarm sensitivity …)
  - Miscellaneous (color, style,…)



Properties

Search

Widget	
Type	A Label
Name	Label_4
Class	DEFAULT
Macros	[]
Text	EVR $(EVRID)
Position	
X Position	10
Y Position	0
Width	80
Height	40
Display	
Visible	☑
Font	Header 1
Foreground Color	■ EDE Text Main
Background Color	□ Background
Transparent	☑
Horizontal Alignment	Center
Vertical Alignment	Middle
Rotation	0 degrees
Auto Size	□
Wrap Words	☑
Behavior	
Actions	No actions
Rules	No rules
Scripts	No scripts
Tool tip	
Miscellaneous	
Border Width	0
Border Color	■ Text

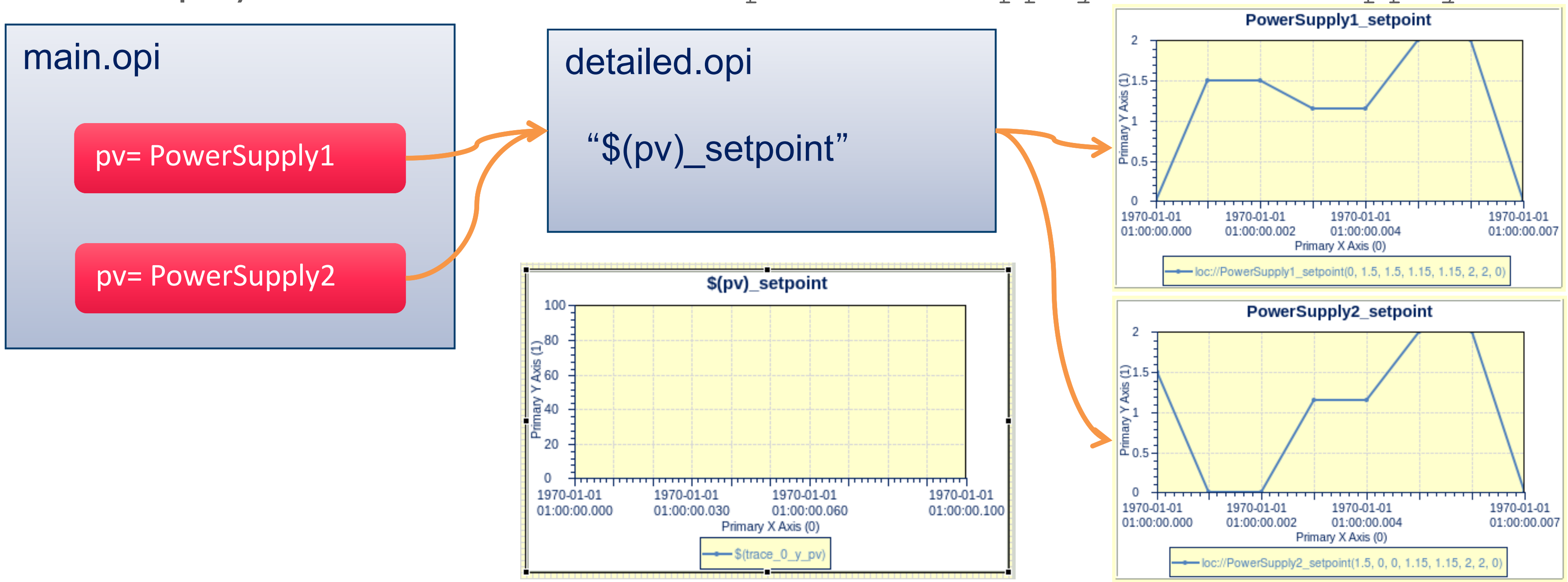
two or more points

PV Names

- `ca://some_pv_name`
    - – EPICS Channel Access PV
- `some_pv_name`
    - – Typically same, since “ca://” is the default
- `sim://sine`
    - – Simulated PV. Read online help for details
- `loc://x(4)`
    - – Local PV, initialized to value 4
- `pva://some_pv_name`
    - – EPICS PV Access protocol

Macros

- Similar OPIs are often used to control similar devices
- No need to create new OPIs for each device of the same type.
- Instead use macros: `$(macro)` or `${macro}`
  - Most often used for partial PV name - `$(pv)_setpoint` or `$(pv)_readback`
  - Such a display can then be invoked with `pv=PowerSupply1` or `PowerSupply2`



main.opi

pv= PowerSupply1

pv= PowerSupply2

detailed.opi

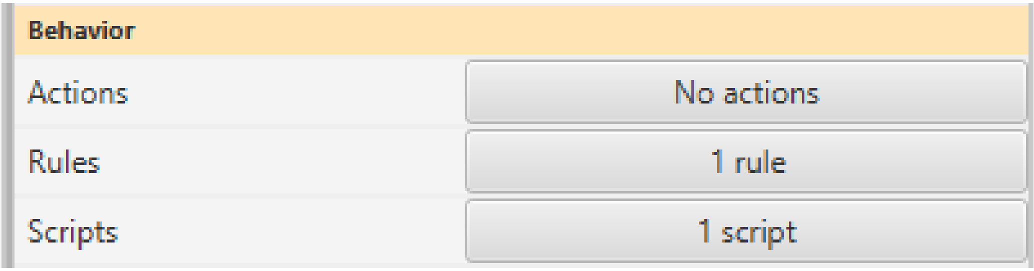
“$(pv)_setpoint”

CS-Studio

Behavior

Widgets' Behavior

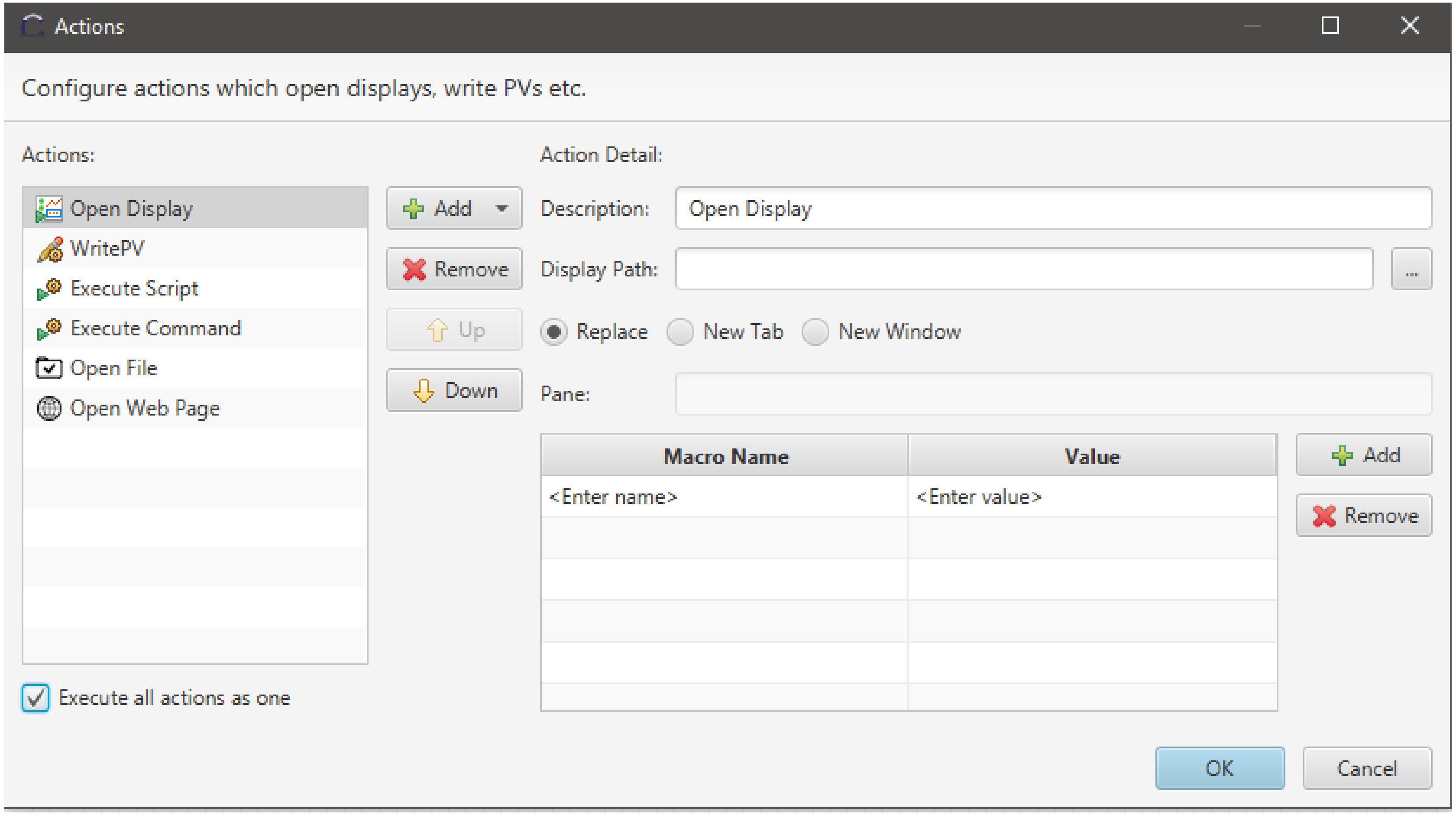
- Rules
- Scripts
- Actions



Behavior	
Actions	No actions
Rules	1 rule
Scripts	1 script

Actions

- Widgets can have one ore more actions associated
  - Open another OPI
  - Write to PV
  - Execute script
  - Execute command
  - Open file
  - Open webpage



Actions

Configure actions which open displays, write PVs etc.

Actions:

- Open Display
- WritePV
- Execute Script
- Execute Command
- Open File
- Open Web Page

Action Detail:

Description: Open Display

Display Path:

● Replace ○ New Tab ○ New Window

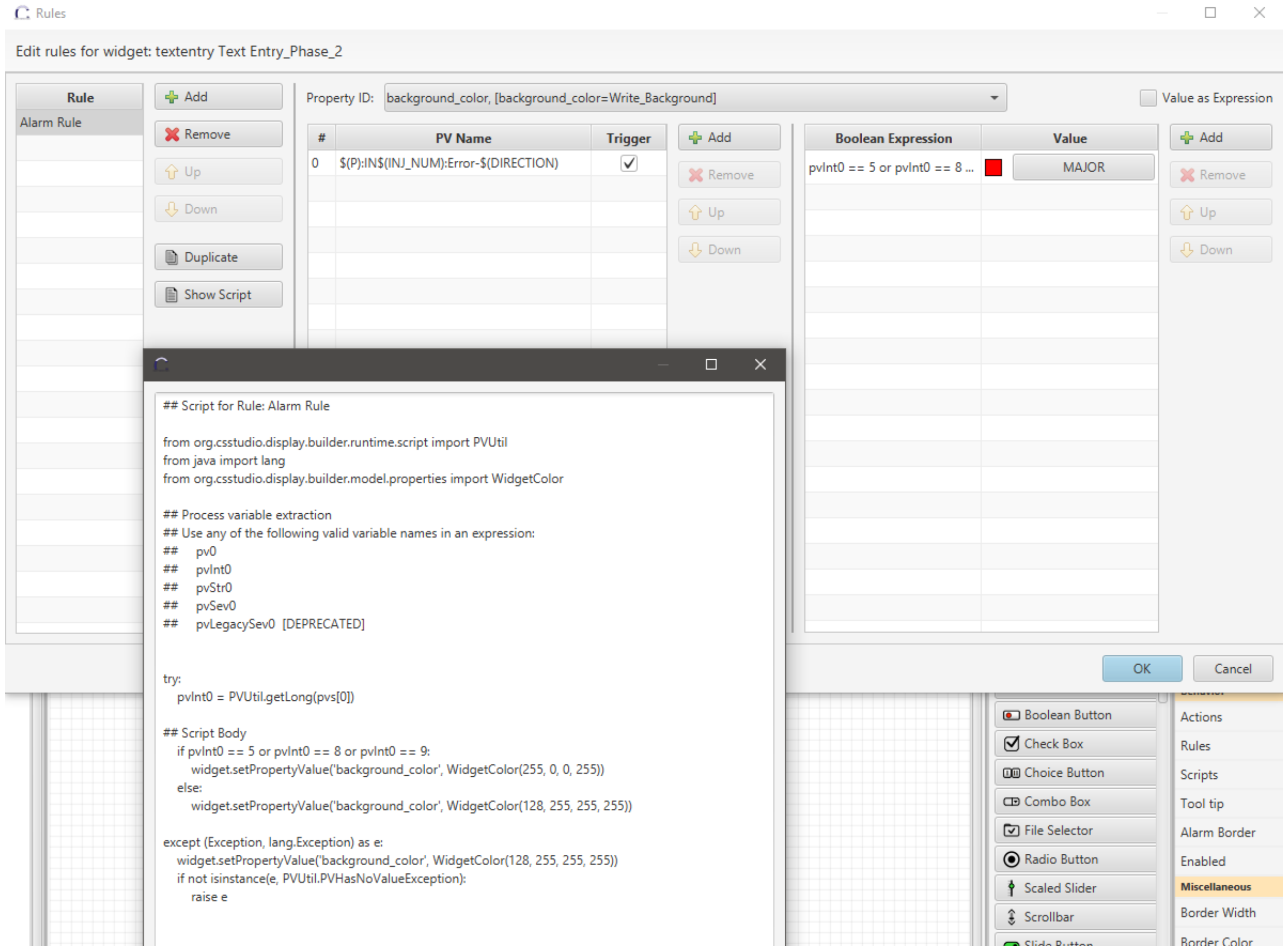
Pane:

Macro Name	Value
<Enter name>	<Enter value>

☑ Execute all actions as one

Rules

- Dynamic property changes – based on PV values
- Rules use Boolean expressions to alter one specific property
    - Implemented as JavaScript (generated automatically)
    - Easier to maintain and control → use scripts only when a rule can't



Edit rules for widget: textentry Text Entry_Phase_2

Rule
Alarm Rule

Property ID: background_color, [background_color=Write_Background]

□ Value as Expression

#	PV Name	Trigger
0	$(P):IN$(INJ_NUM):Error-$(DIRECTION)	☑

Boolean Expression		Value
pvInt0 == 5 or pvInt0 == 8 ...	🟥	MAJOR

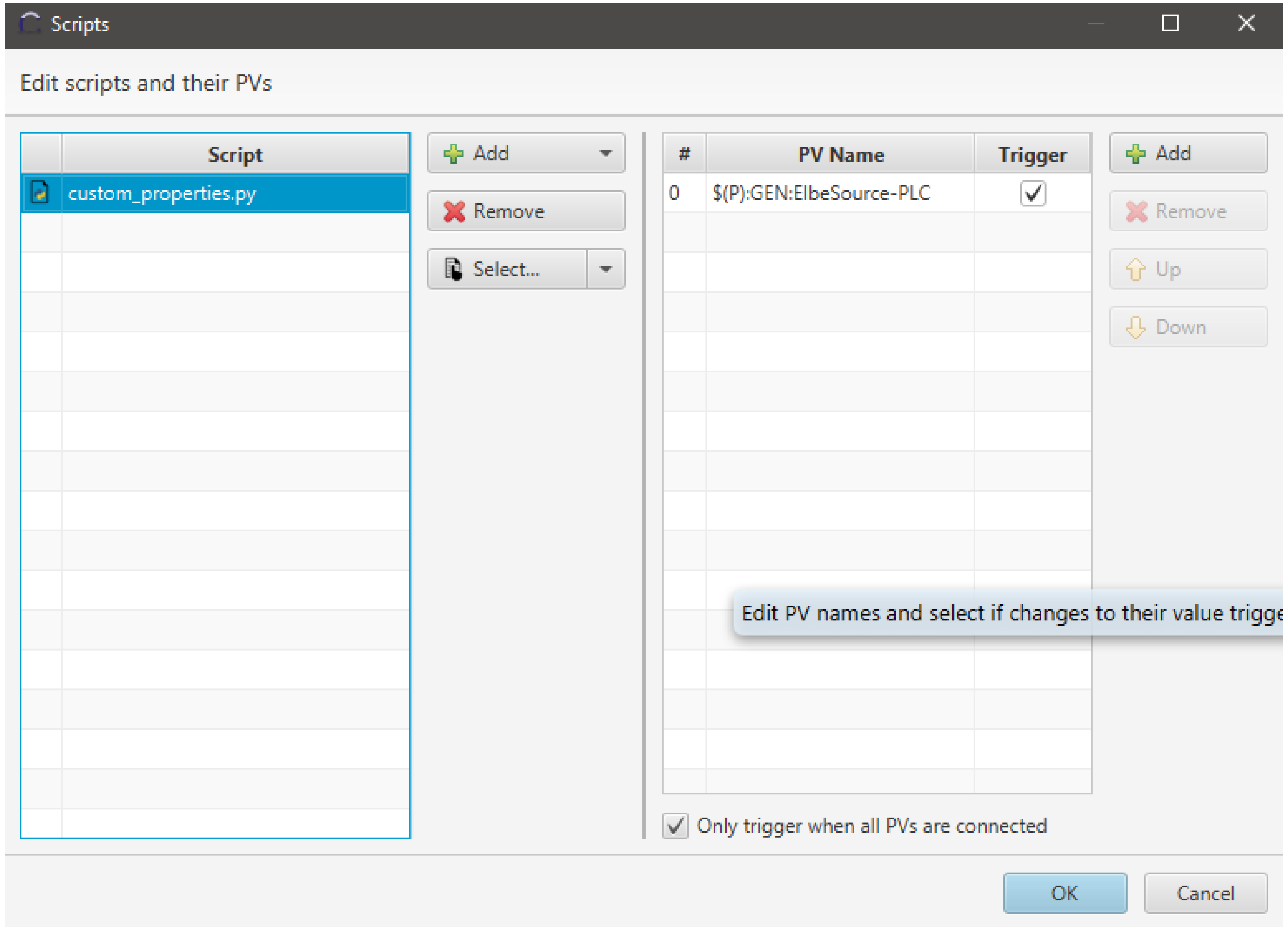
```
## Script for Rule: Alarm Rule

from org.csstudio.display.builder.runtime.script import PVUtil
from java import lang
from org.csstudio.display.builder.model.properties import WidgetColor

## Process variable extraction
## Use any of the following valid variable names in an expression:
##     pv0
##     pvInt0
##     pvStr0
##     pvSev0
##     pvLegacySev0  [DEPRECATED]


try:
   pvInt0 = PVUtil.getLong(pvs[0])

## Script Body
   if pvInt0 == 5 or pvInt0 == 8 or pvInt0 == 9:
      widget.setPropertyValue('background_color', WidgetColor(255, 0, 0, 255))
   else:
      widget.setPropertyValue('background_color', WidgetColor(128, 255, 255, 255))

except (Exception, lang.Exception) as e:
   widget.setPropertyValue('background_color', WidgetColor(128, 255, 255, 255))
   if not isinstance(e, PVUtil.PVHasNoValueException):
      raise e
```

Rules (cont.)

- How to define a rule
  - Behavior → Rules
  - Name new Rule
  - Select property to modify
  - Use PVs as parameters for Boolean expression
  - Write conditions that override property value
  - Rule gets generated as a script

Scripts

- Complex behavior – attach JavaScript to widget
- Access widget and it’s properties
- Access PVs related to the widget
- Script is triggered by input PVs



Edit scripts and their PVs

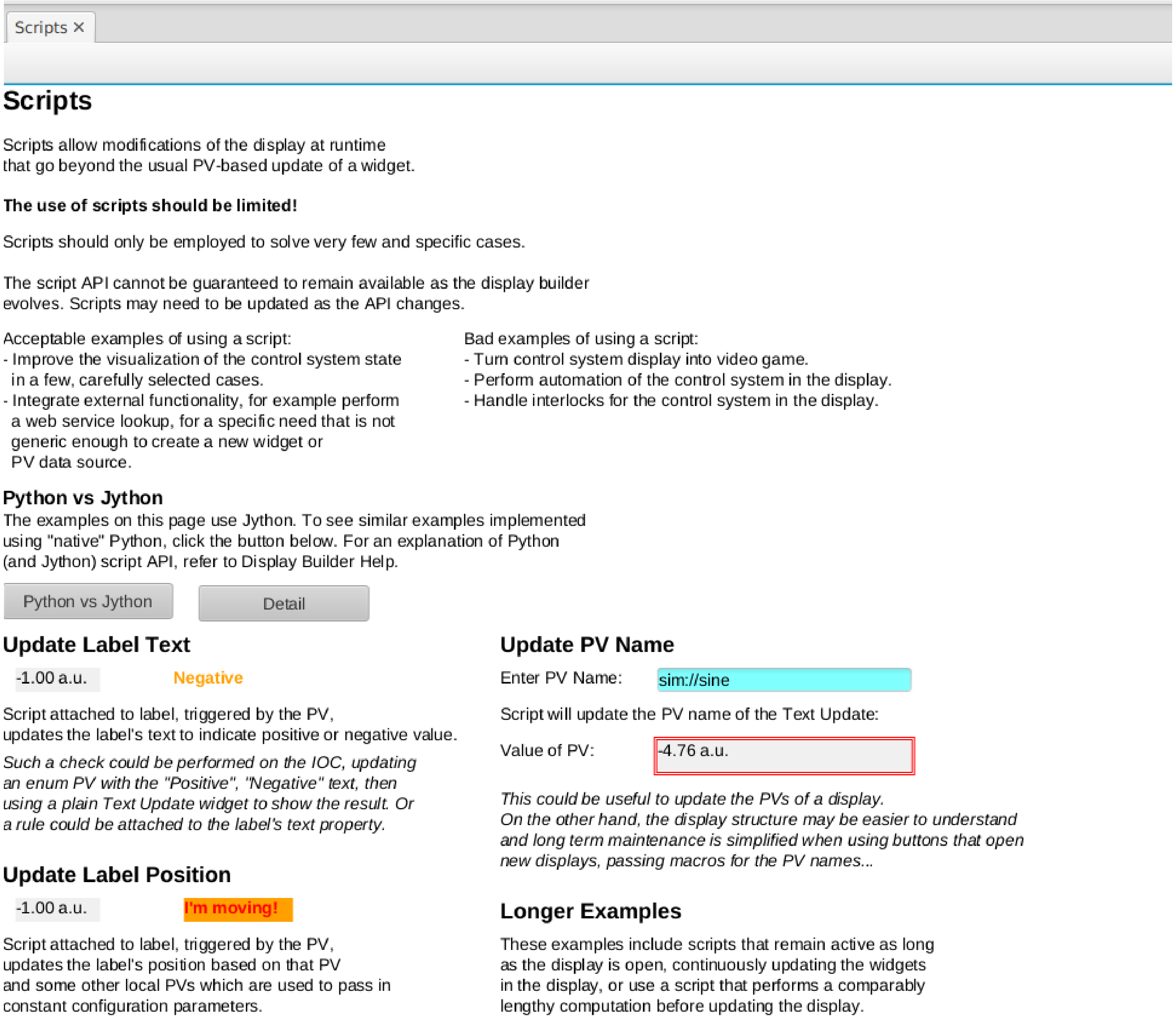
Script
custom_properties.py

#	PV Name	Trigger
0	$(P):GEN:ElbeSource-PLC	☑

Edit PV names and select if changes to their value trigge

☑ Only trigger when all PVs are connected

Scripts (cont.)



Scripts

Scripts allow modifications of the display at runtime
that go beyond the usual PV-based update of a widget.

The use of scripts should be limited!

Scripts should only be employed to solve very few and specific cases.

The script API cannot be guaranteed to remain available as the display builder
evolves. Scripts may need to be updated as the API changes.

Acceptable examples of using a script:
- Improve the visualization of the control system state in a few, carefully selected cases.
- Integrate external functionality, for example perform a web service lookup, for a specific need that is not generic enough to create a new widget or PV data source.

Bad examples of using a script:
- Turn control system display into video game.
- Perform automation of the control system in the display.
- Handle interlocks for the control system in the display.

Python vs Jython

The examples on this page use Jython. To see similar examples implemented
using "native" Python, click the button below. For an explanation of Python
(and Jython) script API, refer to Display Builder Help.

Update Label Text

-1.00 a.u. Negative

Script attached to label, triggered by the PV,
updates the label's text to indicate positive or negative value.

Such a check could be performed on the IOC, updating an enum PV with the "Positive", "Negative" text, then using a plain Text Update widget to show the result. Or a rule could be attached to the label's text property.

Update Label Position

-1.00 a.u. I'm moving!

Script attached to label, triggered by the PV,
updates the label's position based on that PV
and some other local PVs which are used to pass in
constant configuration parameters.

Update PV Name

Enter PV Name: sim://sine

Script will update the PV name of the Text Update:

Value of PV: -4.76 a.u.

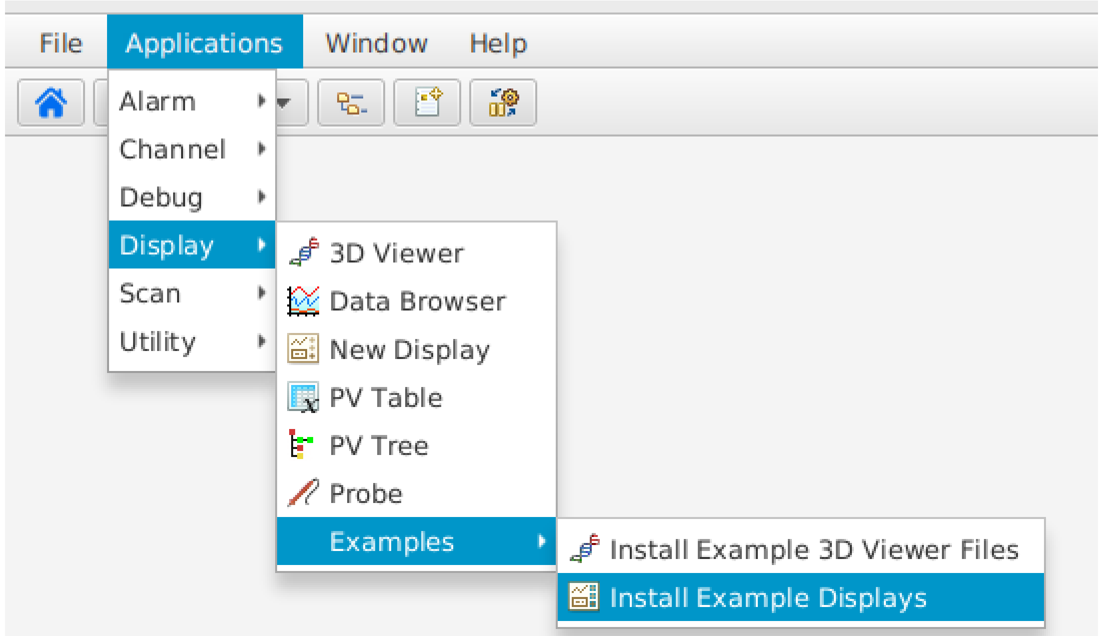
This could be useful to update the PVs of a display. On the other hand, the display structure may be easier to understand and long term maintenance is simplified when using buttons that open new displays, passing macros for the PV names...

Longer Examples

These examples include scripts that remain active as long
as the display is open, continuously updating the widgets
in the display, or use a script that performs a comparably
lengthy computation before updating the display.

Examples

- Install and check examples!!!



- **Note:** Location of the examples could vary, depends on CS-Studio distribution.

Exercise 9

Control System Studio

CS-Studio Tools

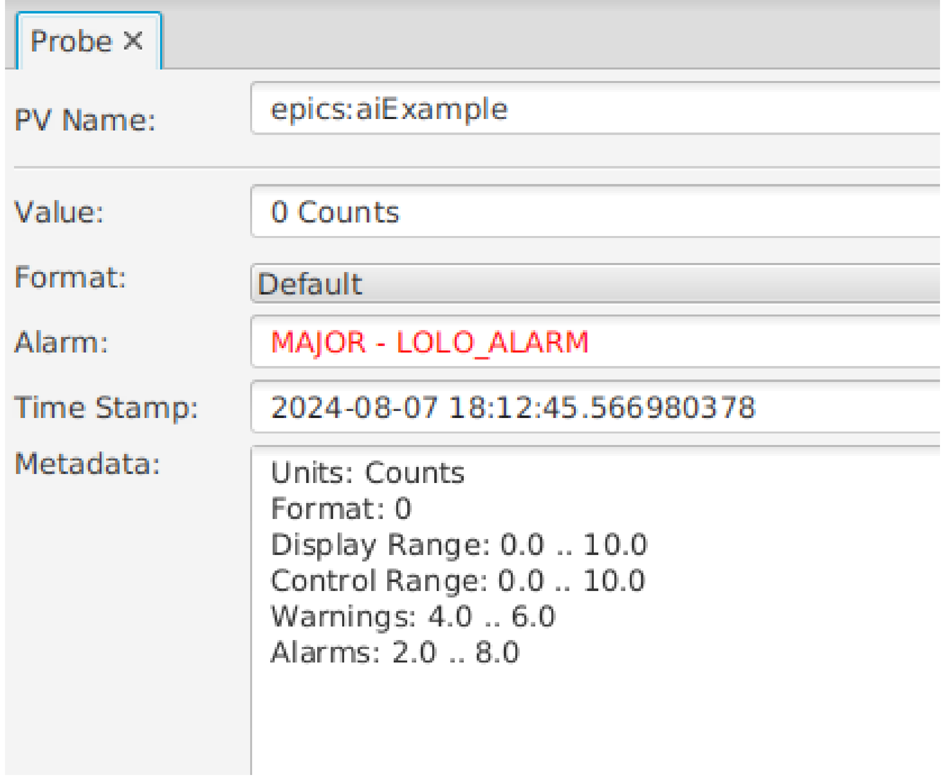
Included in the CSS

- Probe
- PV Tree
- PV Table
- Data Browser

- Connected to external services
  - Alarms
  - Data Browser
  - Channel Finder
  - Scan Editor/Monitor

Probe

- Allows basic reading and writing of PVs
  - Display value, timestamp and alarms
  - Adjust the value and update on IOC



PV Name: epics:aiExample

Value: 0 Counts

Format: Default

Alarm: MAJOR - LOLO_ALARM

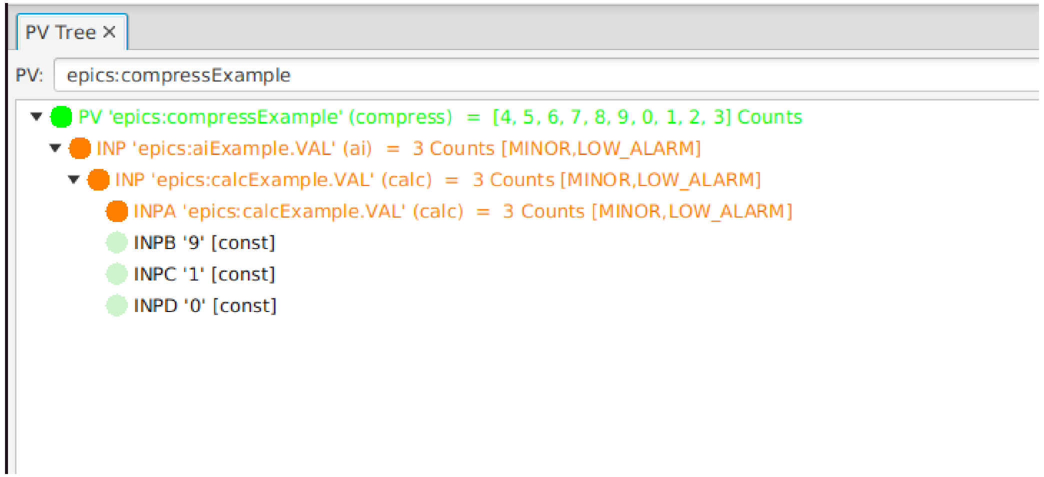
Time Stamp: 2024-08-07 18:12:45.566980378

Metadata:

```
Units: Counts
Format: 0
Display Range: 0.0 .. 10.0
Control Range: 0.0 .. 10.0
Warnings: 4.0 .. 6.0
Alarms: 2.0 .. 8.0
```

PV Tree

- Displays hierarchical data flow between EPICS records

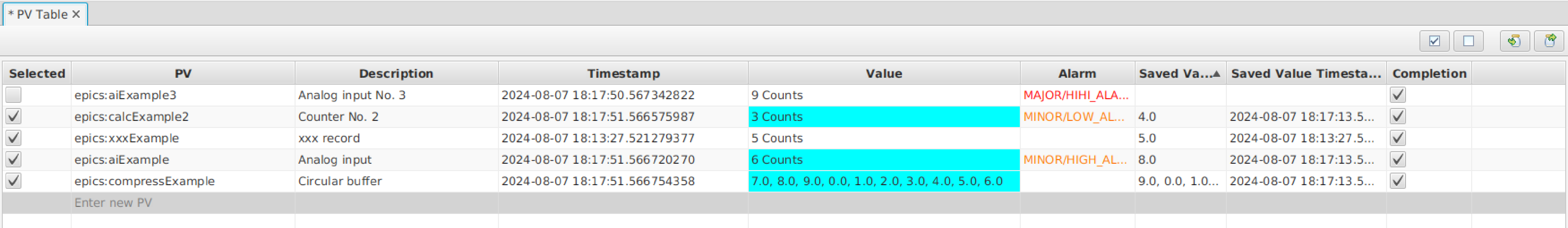


PV: epics:compressExample

```
▼ ● PV 'epics:compressExample' (compress)  =  [4, 5, 6, 7, 8, 9, 0, 1, 2, 3] Counts
  ▼ ● INP 'epics:aiExample.VAL' (ai)  =  3 Counts [MINOR,LOW_ALARM]
    ▼ ● INP 'epics:calcExample.VAL' (calc)  =  3 Counts [MINOR,LOW_ALARM]
        ● INPA 'epics:calcExample.VAL' (calc)  =  3 Counts [MINOR,LOW_ALARM]
        ● INPB '9' [const]
        ● INPC '1' [const]
        ● INPD '0' [const]
```

PV Table

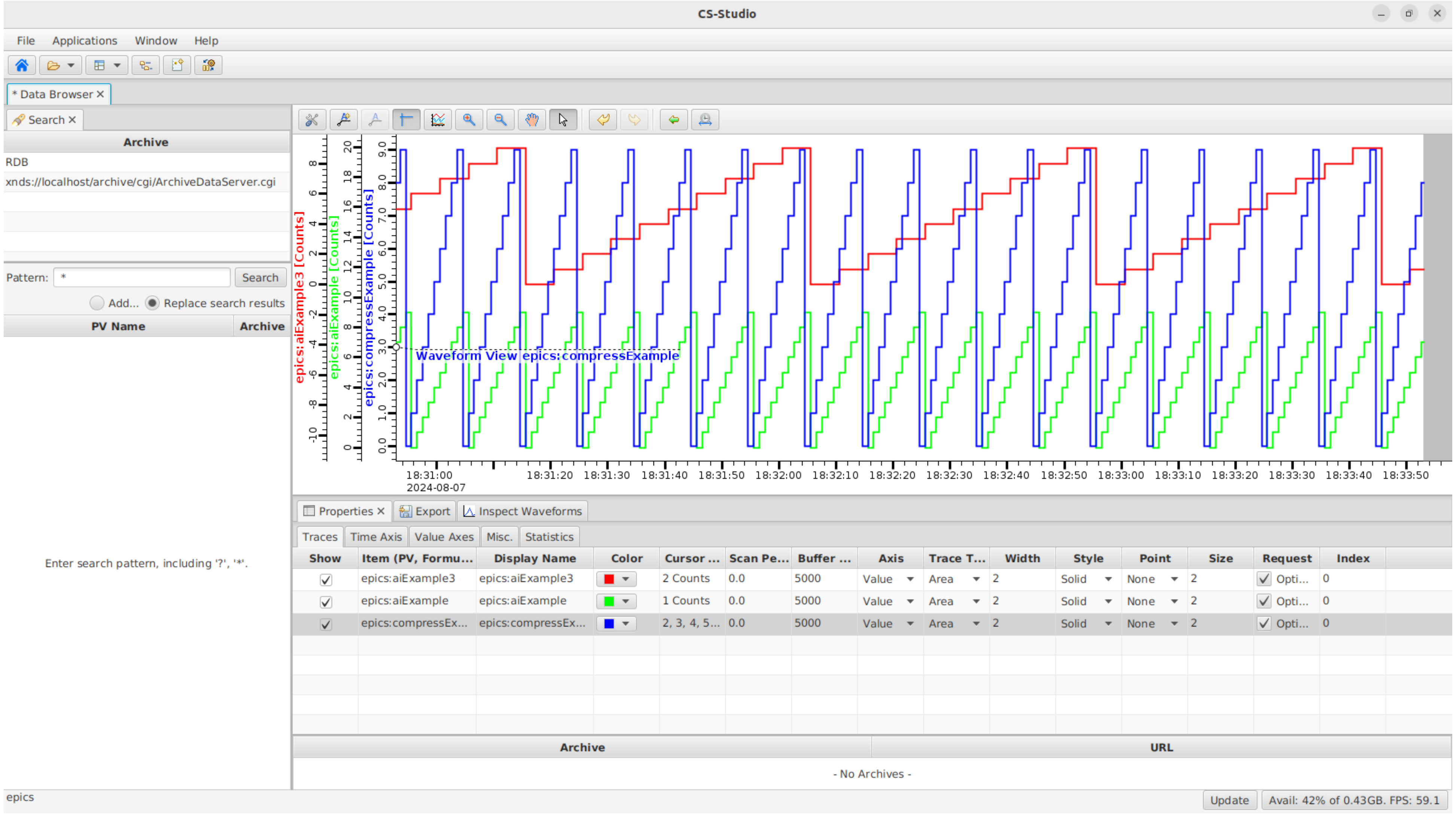
- Tabular view of PV names and their current value
  - Start/stop live update
  - Snapshot of current values
  - Indicating differences between current values and snapshot



Selected	PV	Description	Timestamp	Value	Alarm	Saved Va...▲	Saved Value Timesta...	Completion
☐	epics:aiExample3	Analog input No. 3	2024-08-07 18:17:50.567342822	9 Counts	MAJOR/HIHI_ALA...			☑
☑	epics:calcExample2	Counter No. 2	2024-08-07 18:17:51.566575987	3 Counts	MINOR/LOW_AL...	4.0	2024-08-07 18:17:13.5...	☑
☑	epics:xxxExample	xxx record	2024-08-07 18:13:27.521279377	5 Counts		5.0	2024-08-07 18:13:27.5...	☑
☑	epics:aiExample	Analog input	2024-08-07 18:17:51.566720270	6 Counts	MINOR/HIGH_AL...	8.0	2024-08-07 18:17:13.5...	☑
☑	epics:compressExample	Circular buffer	2024-08-07 18:17:51.566754358	7.0, 8.0, 9.0, 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0		9.0, 0.0, 1.0...	2024-08-07 18:17:13.5...	☑
	Enter new PV							

Data Browser

-



Archive
RDB
xnds://localhost/archive/cgi/ArchiveDataServer.cgi

Pattern: * Search

○ Add... ● Replace search results

PV Name	Archive

Enter search pattern, including '?', '*'.

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Žiga Oven

ziga.oven@cosylab.com