Argonne NATIONAL LABORATORY

EPICS Database Principles

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Outline

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

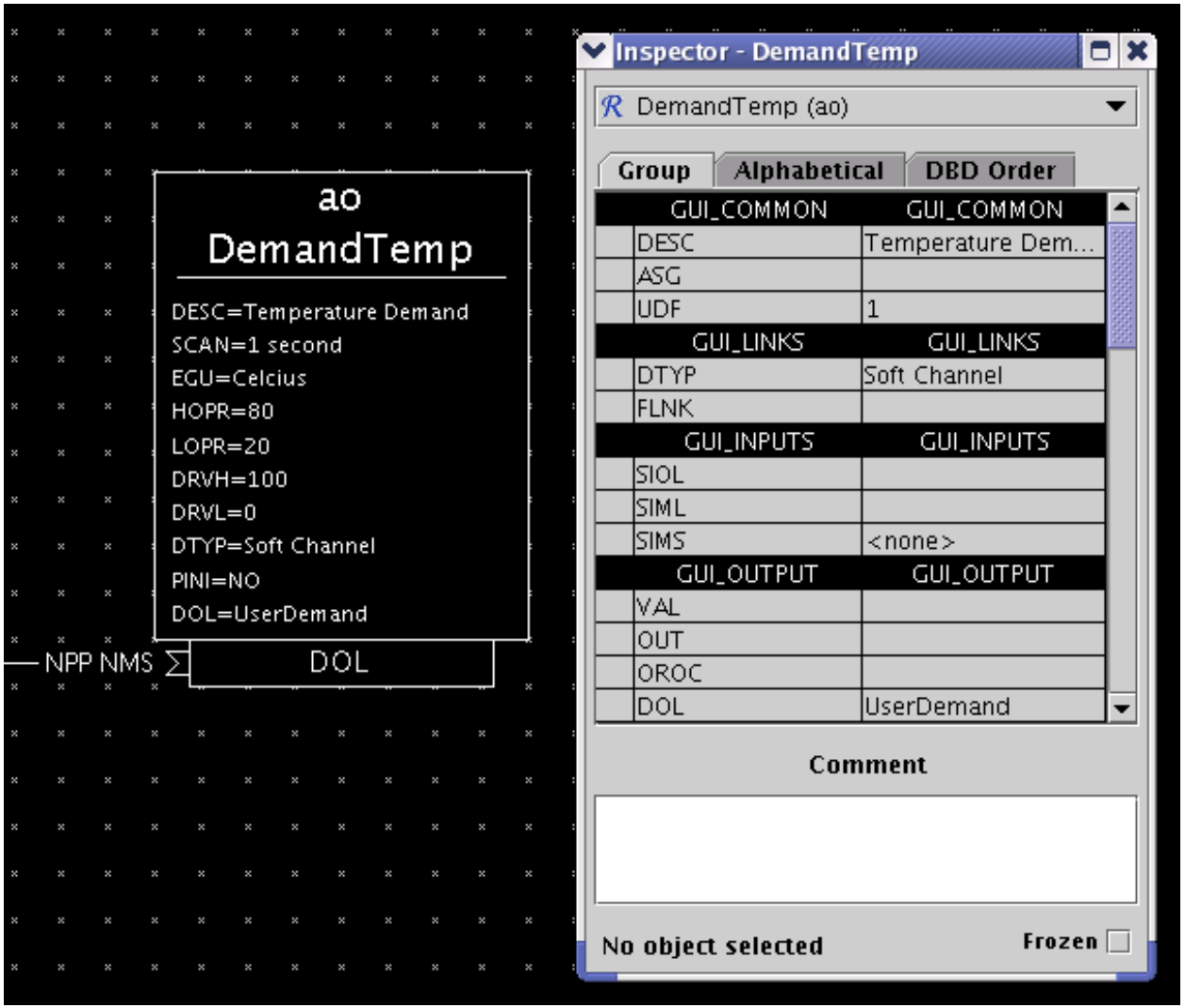
Record Activity

- 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

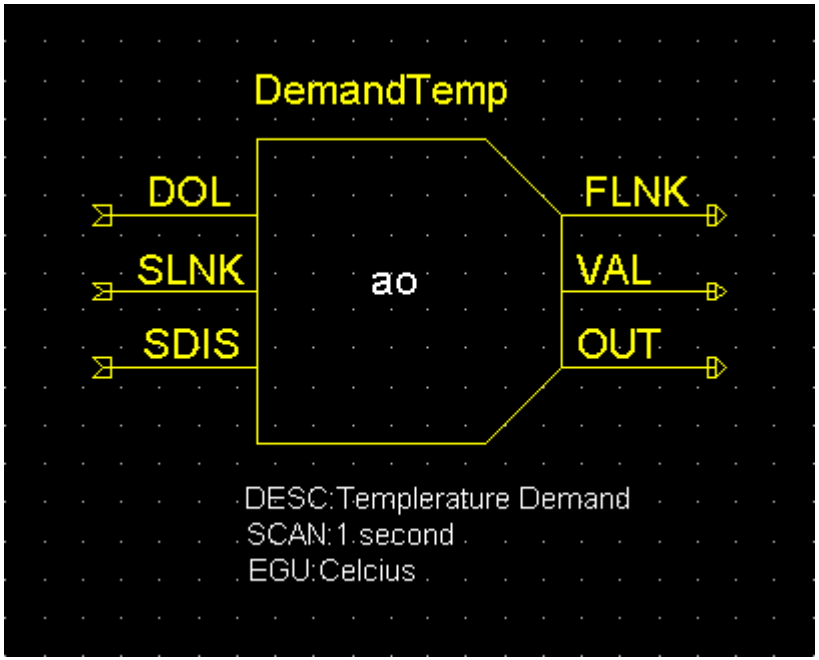
How is a Record implemented?

- A single record definition within an IOC database specifies
  - The record's type
  - One or more unique names for this record
  - Initial values for some of the fields
- Inside the IOC, each record is an instance of a 'C' struct with a data member for each field
  - All records start with a standard set of fields (dbCommon) that the IOC code needs, including pointers to record type information and field metadata
- The record type provides
  - Definitions of all the fields
  - Code which implements the record's unique behavior
- New record types can be added to an application as needed

A graphical view of a Record (VDCT)



Another graphical view of a Record (TDCT)



A text editor view

The full .db file entry for an Analogue Output Record

```
record(ao,"DemandTemp") {
  alias("AO:0:0")
  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(DOL,"")
  field(OMSL,"supervisory")
  field(OROC,"0.0e+00")
  field(OIF,"Full")
  field(PREC,"1")
  field(LINR,"NO CONVERSION")
  field(EGUF,"100")
  field(EGUL,"0")
  field(EGU,"Celcius")
  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 slide only shows design fields; other fields exist which are only used 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 operator acknowledgments
  - Processing time-stamp
  - Other data for internal use

Field types — fields can contain:

- Integers
  - char, short or long
  - signed or unsigned
- Floating-point numbers
  - float or double
- Fixed length strings
  - maximum useful length is 40 characters
- Enumerated/menu choices
  - select one of up to 16 strings
  - stored as a short integer
- Arrays of any of the above types
- Links
  - to other records in this or other IOCs
  - to hardware signals (device support)
  - provide a means of getting or putting a value
- Other private data
  - not accessible remotely

All Records have these design fields

NAME	*60 character unique canonical name for the record (names longer than 28 characters can cause problems)*
DESC	*40 character description*
ASG	*Access security group*
SCAN	*Scan mechanism*
PHAS	*Scan order (phase)*
PINI	*Process during IOC initialization?*
PRIO	*Scheduling priority*
SDIS	*Scan disable input link*
DISV	*Scan disable value*
DISS	*Disabled severity*
FLNK	*Forward link*

All Records have these Run-time fields

PROC	*Force processing*
PACT	*Process active*
STAT	*Alarm status*
SEVR	*Alarm severity*
TPRO	*Trace processing*
UDF	*Non-zero if record value undefined*
TIME	*Time when record was last processed*

Record Scanning

- **SCAN** field is a menu choice from
  - Periodic — 0.1 seconds .. 10 seconds (extensible)
  - I/O Interrupt (if device supports this)
  - Soft event — **EVNT** field
  - Passive (default)
- The number in the **PHAS** field allows the relative order in which records are processed within a scan to be controlled
  - Records with **PHAS=0** are processed first
  - Then those with **PHAS=1** , **PHAS=2** etc.
- The **PINI** field sets if/when records get processed once at startup or when IOC is paused
  - No, Yes, Run, Running, Pause, Paused
- **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

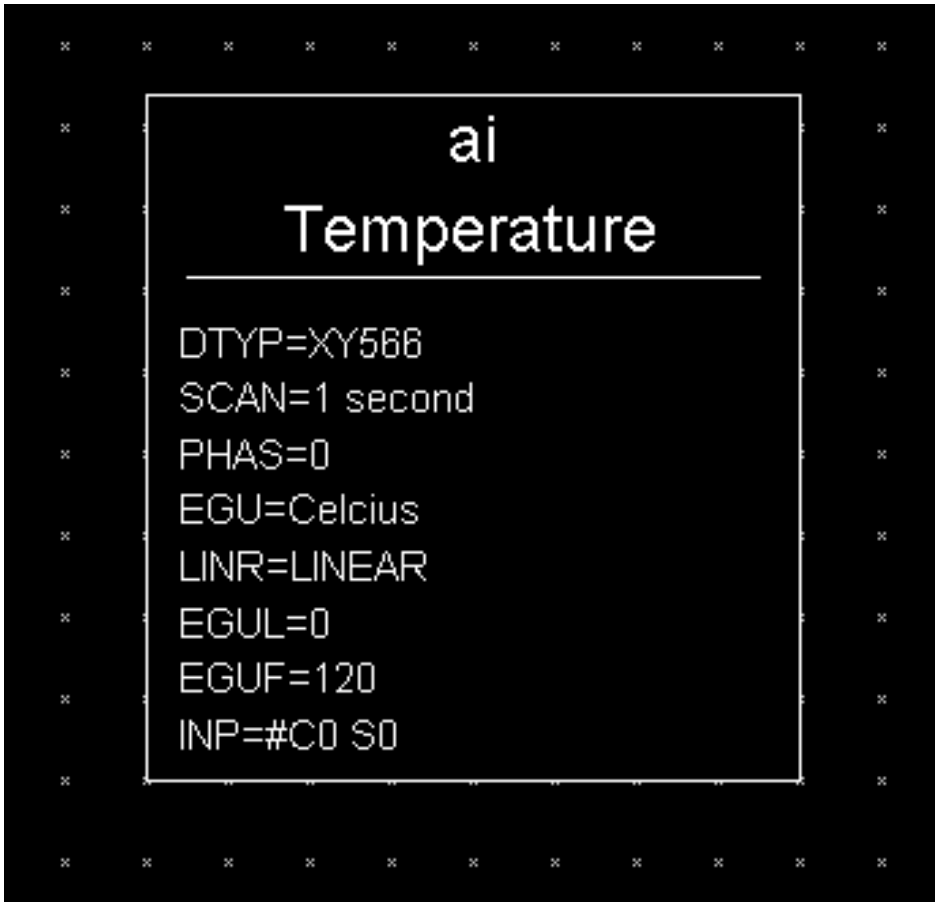
Input records often have these fields

`INP`	*Input link*
`DTYP`	*Device type*
`RVAL`	*Raw data value*
`VAL`	*Engineering value*
`LOPR`	*Low operator range*
`HOPR`	*High operator range*

Analogue I/O records have these fields:

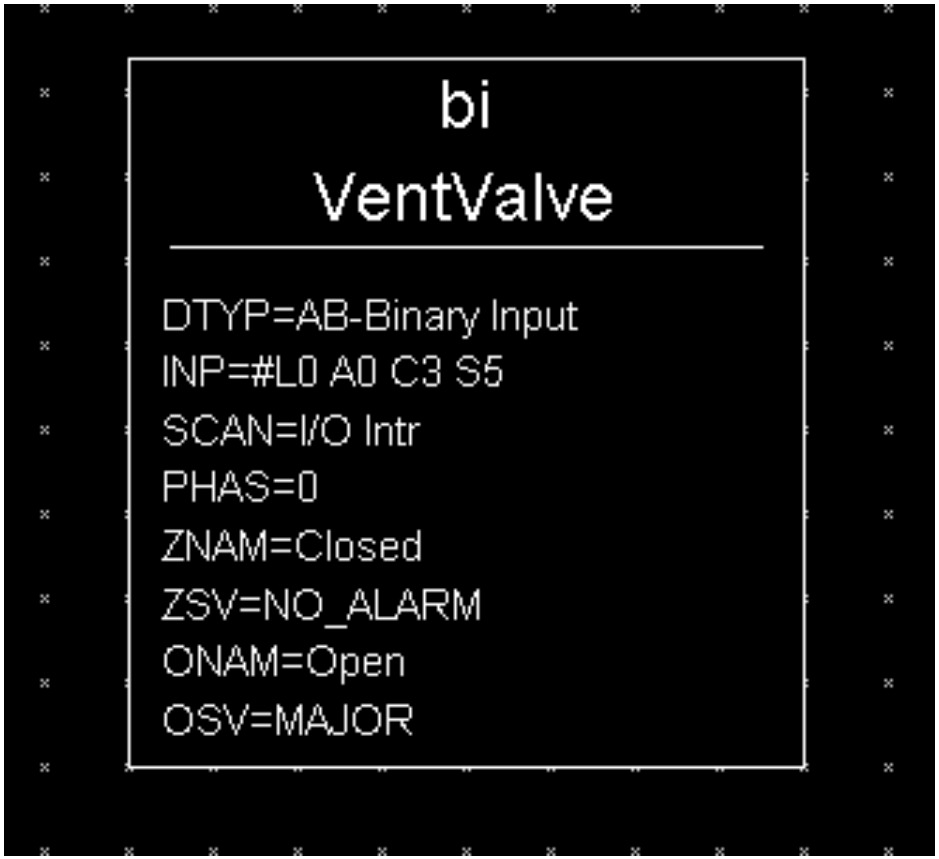
`EGU`	*Engineering unit string*
`LINR`	*Unit conversion control:* No conversion, Linear, Slope, *breakpoint table name*
`EGUL`	*Engineering unit low value*
`EGUF`	*Engineering unit high value (full-scale)*
`ESLO`	*Unit conversion slope*
`EOFF`	*Unit conversion offset*

Periodically Scanned Analog Input



- Analogue Input “Temperature”
- Reads from a 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



- Binary Input “VentValve”
- Reads from an 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

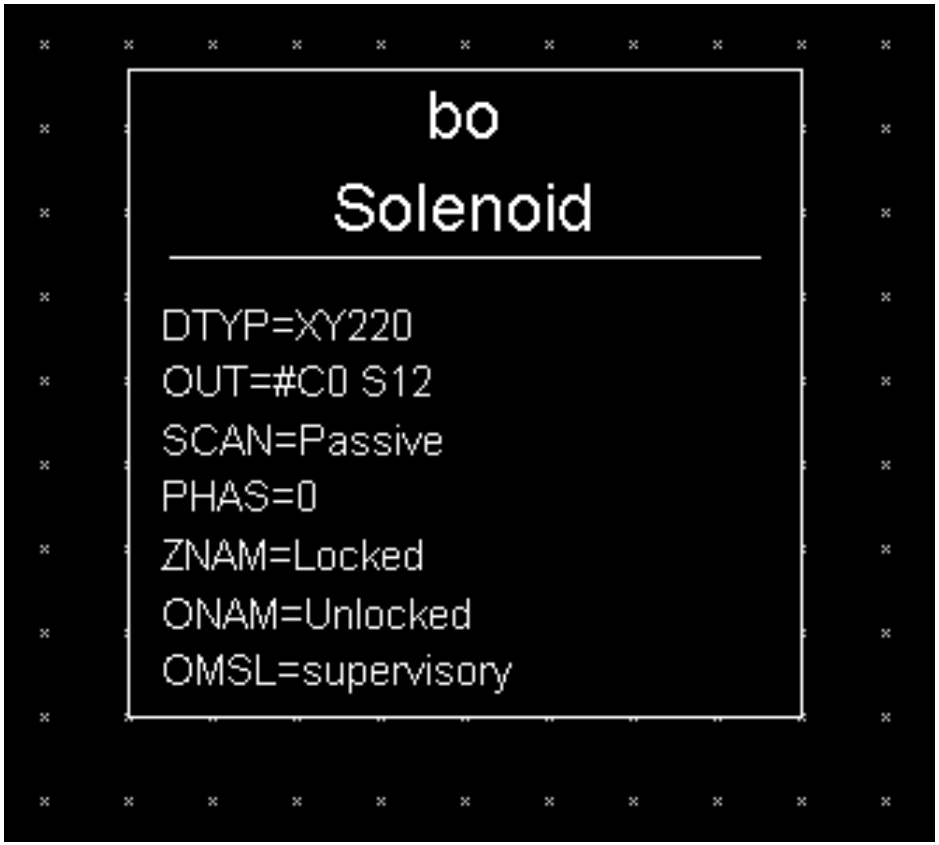
Most output records have these fields

OUT	*Output link*
DTYP	*Device type*
VAL	*Engineering value*
RVAL	*Raw output value*
DOL	*Input link to fetch output value*
OMSL	*Output mode select:* Supervisory, Closed Loop
LOPR	*Low operator range*
HOPR	*High operator range*

Analogue outputs also have these fields:

`OROC`	*Output rate of change*
`OIF`	*Incremental or Full output*
`OVAL`	*Output value*
`DRVH`	*Drive high limit*
`DRVL`	*Drive low limit*
`IVOA`	*Invalid output action*
`IVOV`	*Invalid output value*
`RBV`	*Read-back value*

Passive Binary Output



- 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 Forward Links here
  - Another record writes with `PP` flag
  - Another record reads with `PP` flag

Break time...

5 Minute break

Links

A link is a type of field, and is one of

- Input link
  - Fetches data
- Output link
  - Writes data
- Forward link
  - Points to a record to be processed when this record has finished processing

Input and Output links may be…

- Constant numeric value, e.g.:

  0

  3.1415926536

  -1.6e-19
- Hardware link
  - Address of a hardware I/O signal (fields named **INP** or **OUT** only)
  - The address format depends on the device support layer (**DTYP** field value)
- Process Variable link — names a record, at run-time becomes either
  - Database link
    - Target record must be present in this IOC
  - Channel Access link
    - Target record can be in a different IOC

Hardware link addresses

INST_IO	`@parm`	
		Device-specific parameter string
VME_IO	`#Cn Sn @parm`	
		Card, Signal
CAMAC_IO	`#Bn Cn Nn An Fn @parm`	
		Branch, Crate, Node, Address, Function
AB_IO	`#Ln An Cn Sn @parm`	
		Link, Adapter, Card, Signal
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)
    - **`PP`** If the target record has **`SCAN`**=Passive, process it before reading or after writing the value
  - Maximize Severity flag
    - **`NMS`** No maximize severity (default)
    - **`MS`** Maximize severity
    - **`MSS`** Maximize Status and Severity (new in R3.14.11)
    - **`MSI`** Maximize Severity when Invalid (new in R3.14.11)
- Example
  - **`M1:current.RBV NPP MS`**
- NB: Database links with the **`PP`** flag set do not wait for asynchronous record processing to finish, so an input link that triggers a read from slow hardware will return the previous value from the field

Channel Access links

- Like database links, but these name a record that may be located in a different IOC
- Use Channel Access to communicate with the target record
  - Just like any other CA client, even for local records
  - Input links set up a CA monitor on the channel
- May include a field name (default **.VAL**)
- **PP** link flags are ignored, get/put behavior is controlled by the target CA server
  - Input links always behave like **NPP**
  - Output links follow the **PP** attribute of target field
- **MS** Link flags apply to Input links
  - Input links honor **NMS** (default)/**MS**/**MSS**/**MSI**
  - 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 every CA monitor event
  - **CPP** Like **CP** but only process me if my **SCAN** is Passive

Link flag summary

Type	Input Links	Output Links
DB	PP or NPP NMS, MS, MSS or MSI	PP or NPP NMS, MS, MSS or MSI
CA	Always NPP MS or NMS CA forces link type CP process record on change CPP like CP but only process if SCAN=Passive	PP set by destination field Always NMS CA forces link type

Chapter 5 of the IOC Application Developer's Guide covers record links and scanning in detail, and is worth reading.

Device Support

- The standard record-types do not access hardware directly
- The Device Support layer performs I/O operations on request from its record type
  - Each device support performs I/O for one record type
- A record's **DTYP** field determines which device support it uses
  - Most record types default to Soft Channel support if you don't set **DTYP**
- The device support selected controls the format of the link (**INP** or **OUT** field) containing the device address
- Adding new device support layers does not require making any changes to or recompilation of the record type code
- Device support often calls other software to do work for it (Driver Support or other libraries)

Synchronous vs Asynchronous I/O

- IOC rules do not allow device support to busy-wait (i.e. hold up further record processing until the results of a slow I/O operation arrive)
  - Fast I/O should be handled synchronously
  - Slow operations must operate asynchronously
- Register-based VME/PCI cards usually give a fast response (<10µs), so should be synchronous
  - A synchronous read or write device support call finishes its I/O operation before returning
- Serial, network or field-bus I/O usually takes some time (>10ms) to return data, so should be asynchronous
  - Asynchronous device support starts an I/O operation when the record asks, flagging it as incomplete by setting **PACT** to true before returning
  - When the results are available (discovered by a CPU interrupt or polling background thread), the device support must call the record's process() routine to finish the record processing operations

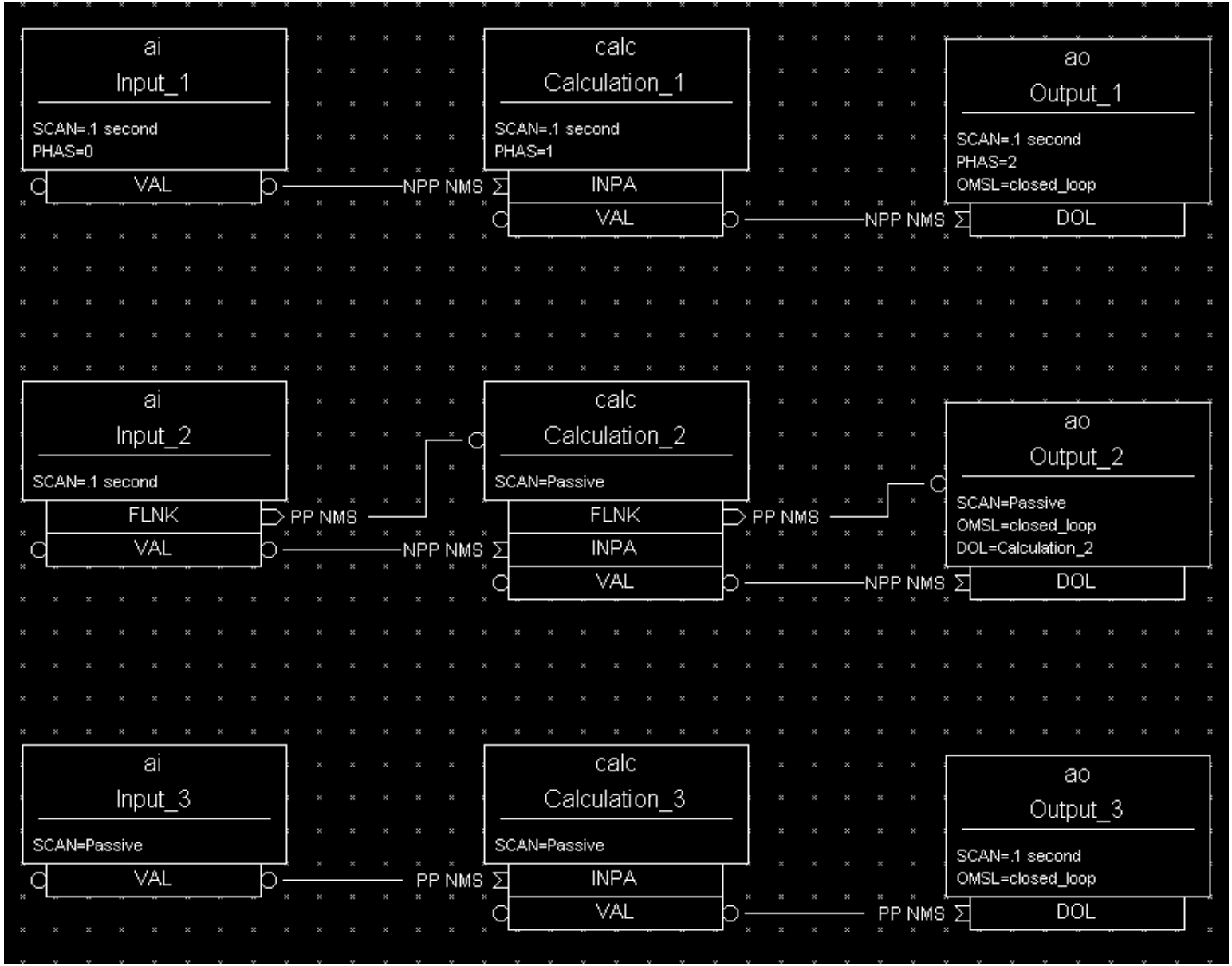
Soft Device Support

- "Hard" input and output records do hardware I/O via device support
- "Soft" records access data from other records via DB or CA links
- 2 or 3 kinds of support are provided in recent R3.14 releases:
  - Soft Channel
    - Get/Put **VAL** through link, no units conversion performed
  - Async Soft Channel (currently output records only)
    - Put **VAL** through CA link, no conversions, wait for completion
  - Raw Soft Channel
    - Inputs
      - Get **RVAL** via input link
      - Convert **RVAL** to **VAL** (record-type specific)
    - Outputs
      - Convert **VAL** to **RVAL** (record-type specific)
      - Put **RVAL** to output link

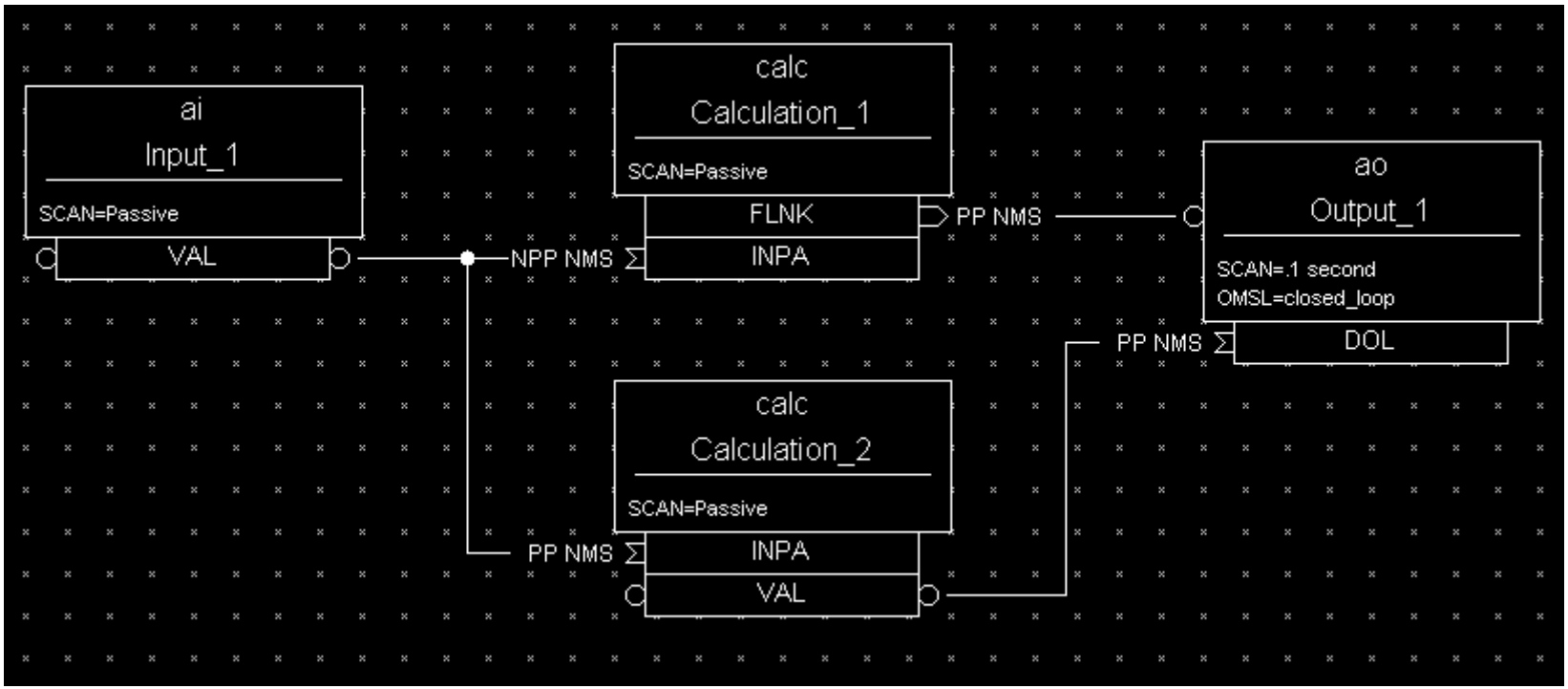
Forward links

- Do not pass a value, just causes subsequent processing
- Usually a Database link, referring to a record in same IOC
  - No **PP**/**NPP** or **MS** flags, although VDCT includes them erroneously
  - Destination record is only processed if its **SCAN** field is **Passive**
- Forward linking via Channel Access is possible
  - Use the **CA** flag if the target record is in the same IOC
  - The link must name the **PROC** field of the target record
  - The target record need not have **SCAN** set to **Passive**

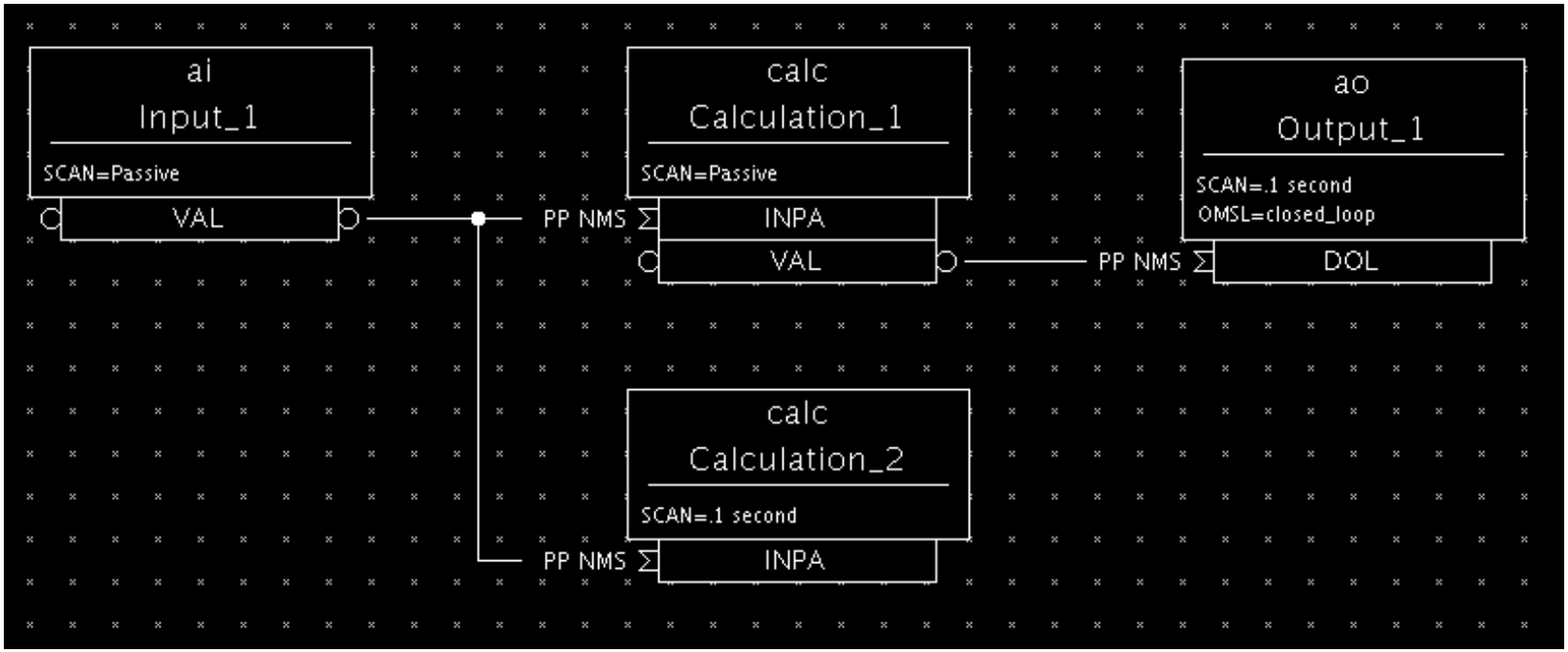
Processing chains



Quiz: Which record is never processed?



Quiz: How often is Input_1 processed?

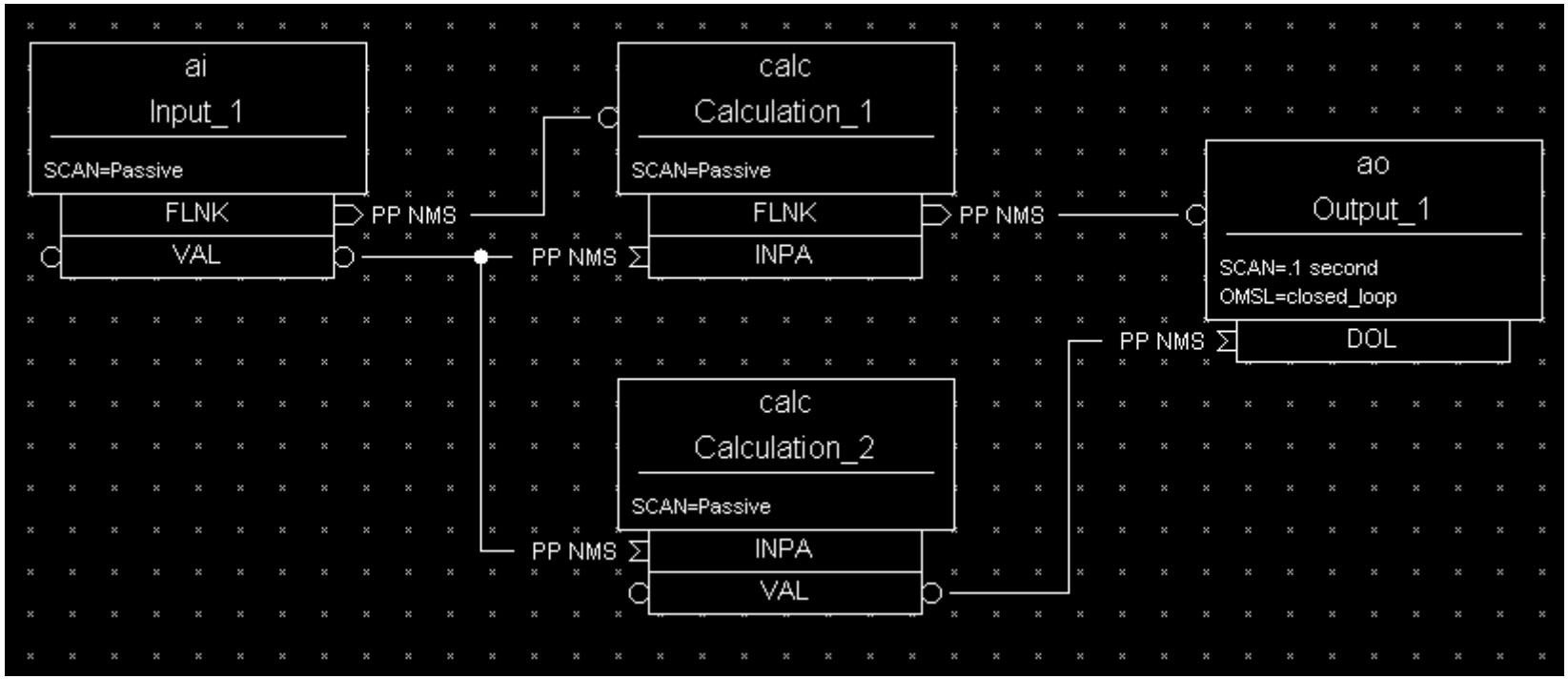


The PACT field

- All records have a boolean run-time field **PACT** (Process Active)
- **PACT** breaks loops of linked records
- It is set to true in the early stages of processing a record (but it's not the first thing that the process routine does)
  - **PACT** is true whenever a link from that record is used to get/put data or process **FLNK**
- **PACT** is reset to false after all record I/O and forward link processing have finished

- A **PP** link can never process a record that has **PACT** true
  - Input links just take the current value from the target field
  - Output links put their value to the target field
    - In some cases they ask the target record to reprocess itself again later
  - Forward links do nothing

Quiz: What happens here?



Preventing records from 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** (0 if the link is not set)
- If **DISA=DISV**, the record will *not* be processed
- The default value of the **DISV** field is 1
- A disabled record can raise an alarm by putting the desired severity in the **DISS** field
- The **FLNK** of a disabled record is never triggered

Break time...

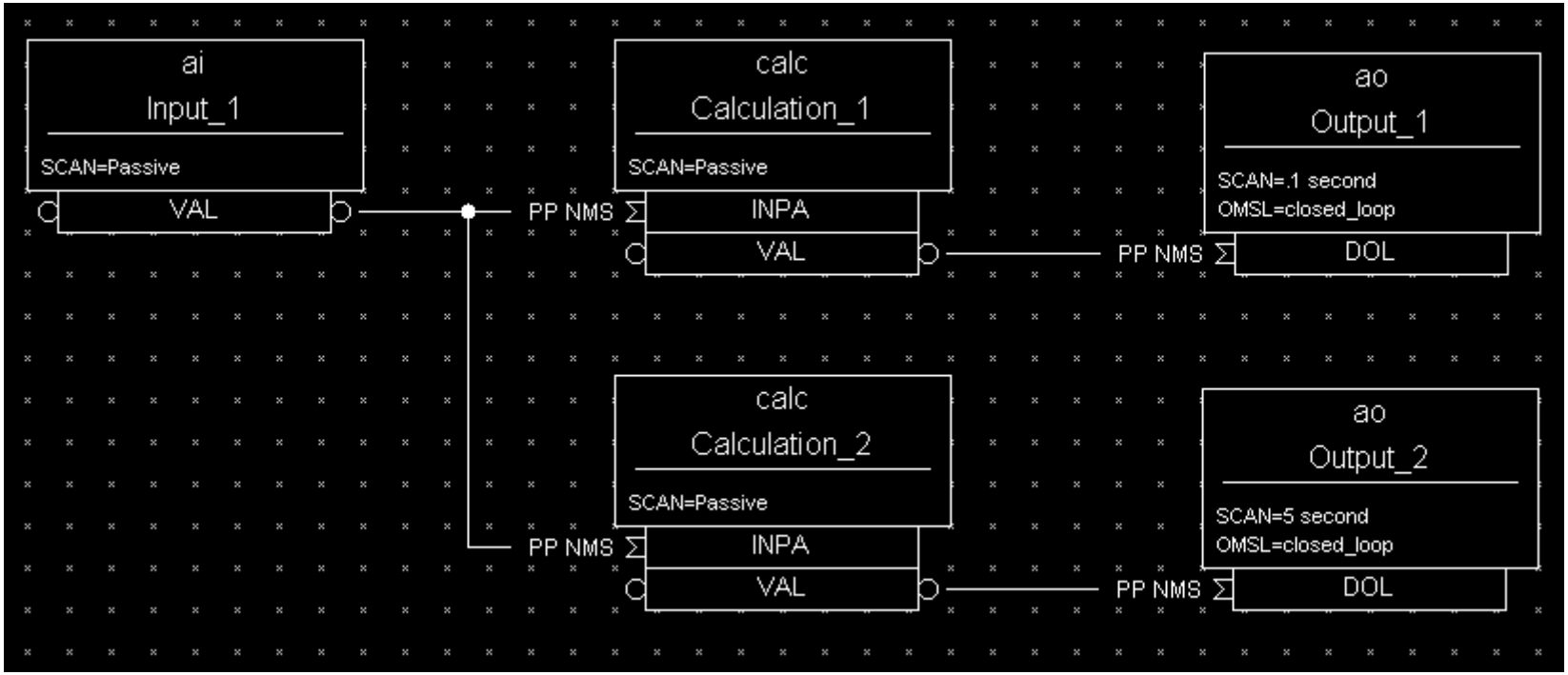
5 Minute break

How are records given CPU time?

Many different IOC threads are used to process records:

- scan*period* — Periodic scans
  - Each scan rate gets its own thread
  - Faster scans at higher thread priority (if supported by the Operating System)
- cbLow, cbMedium, dbHigh — Callback facility
  - One thread for each scheduling priority (PRIO field)
  - Used by device support, I/O Interrupts etc.
- scanOnce
  - IOC internal use for record reprocessing
- CAS-client — CA client-initiated processing
  - One thread for each CA client connected to the server
- Channel Access threads 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

Quiz: What could go wrong here?



Lock-sets

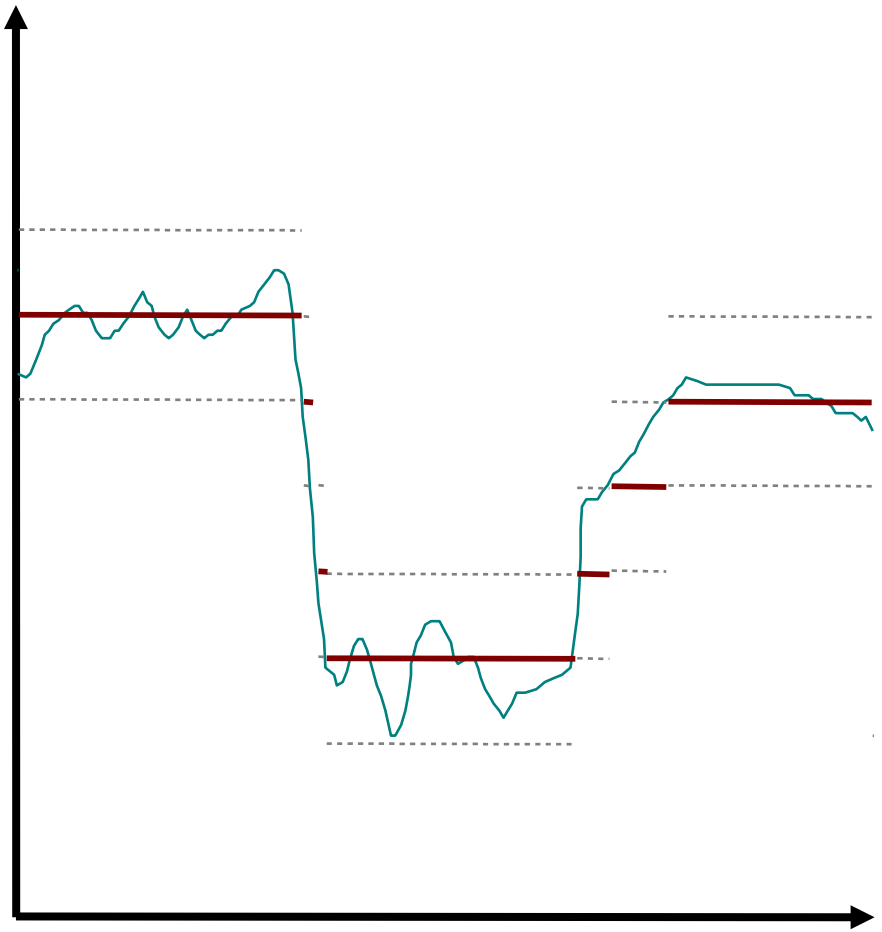
- Prevent records from being processed simultaneously by two different scan tasks
  - **PACT** can't do that, it isn't set early enough and it's not a Mutex
- A lock-set is a group of records interconnected by database links
- Lock-sets are determined automatically by the IOC at start-up, and recalculated whenever a database link is added, deleted or modified
- You can split two linked records into different lock sets by making the link(s) joining them into Channel Access ones, using the **CA** flag
  - Remember that CA links behave slightly differently than DB links, make sure your design still works!

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 compare **VAL** against the **HIHI**, **HIGH**, **LOW** and **LOLO** fields after its value has been determined
- The **HYST** field sets a hysteresis to prevent alarm chattering
- A separate alarm severity can be set for each numeric limit exceeded
  - Fields **HHSV**, **HSV**, **LSV**, and **LLSV**
- Discrete (binary) records can raise alarms on entering a particular state, or on a change of state (COS)

Change Notification: Monitor Dead-bands

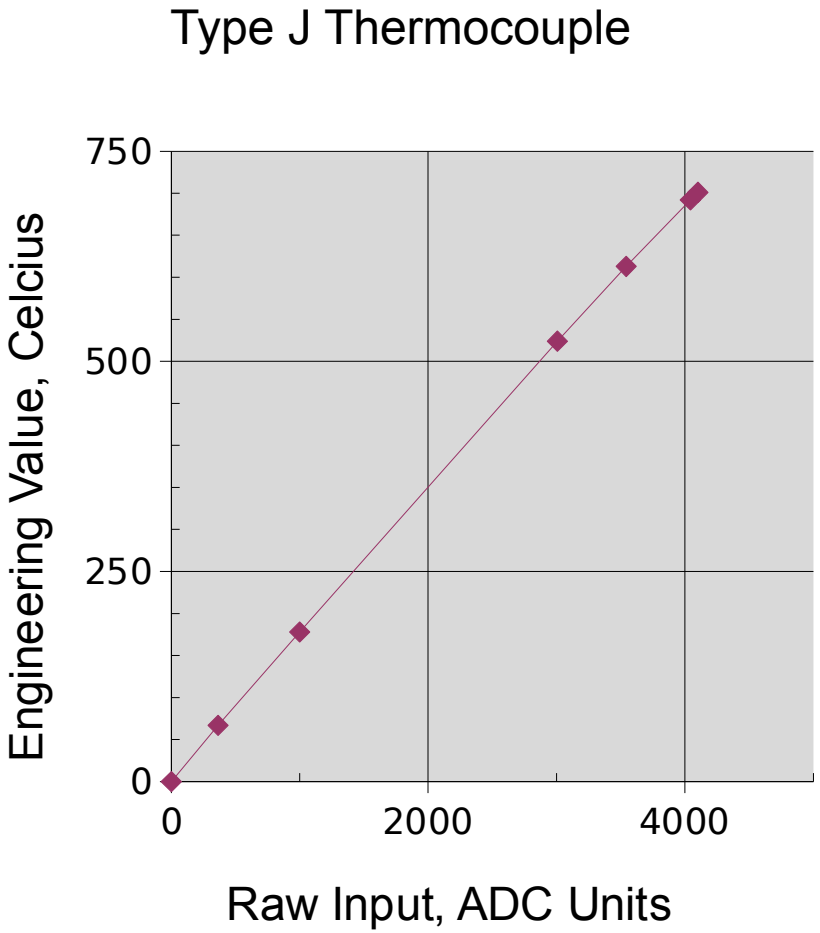
- Channel Access notifies clients that are monitoring a numeric record when
  - **VAL** changes by more than the value in field:
    - **MDEL** *Value monitors*
    - **ADEL** *Archive monitors*
  - Record's Alarm Status changes
    - **HYST** *Alarm hysteresis*
- The Analogue Input record has a smoothing filter to reduce noise on the input signal (**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
- Example breakpoint table (in some loaded .dbd file)

```
breaktable(typeKdegC) {
        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
  - **SVAL** Simulated value
  - **SIMS** Simulation alarm severity
- Before calling device support, records read **SIMM** through the **SIML** link
- If **SIMM=YES** (1) or **SIMM=RAW** (2) the device support is not used; record I/O is done through the **SIOL** link and **SVAL** field instead
- An alarm severity can be set whenever simulating, given by **SIMS** field

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 (the IOC or gateway)
- A record is placed in the Access Security Group named in its ASG field
  - DEFAULT is used if no group name is given
- Rules are specified for each group to determine whether a CA client can read or write to records in that group, based on
  - Client user ID
  - Client host-name or 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) {anj, kuk, wen}
HAG(hosts) {epics.uspas.fnal.gov, kay, eric}
ASG(DEFAULT) {
    RULE(1, READ)
    RULE(1, WRITE) {
        UAG(users)
        HAG(hosts)
    }
}
```

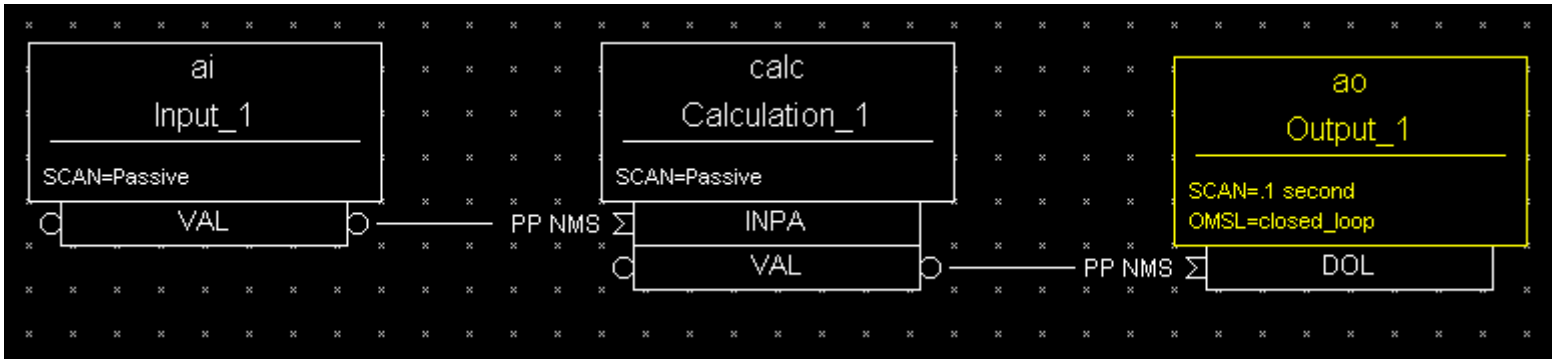
- If no security file is loaded, all Security checks will be turned off

- More details and the security rules file syntax can be found in Chapter 8 of the IOC Application Developers Guide

Optional Slides

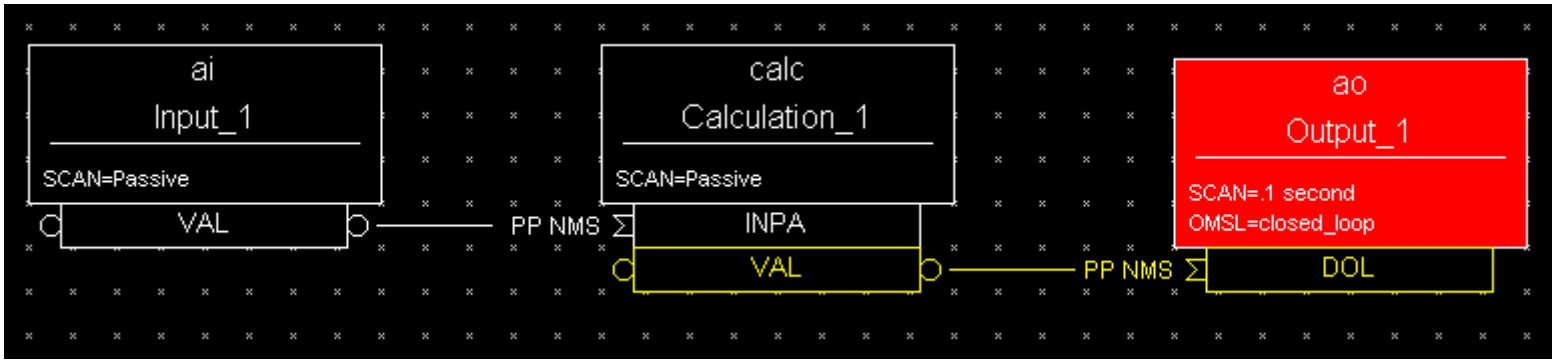
Detailed Order of Operations

Order of Operations (Synchronous I/O)



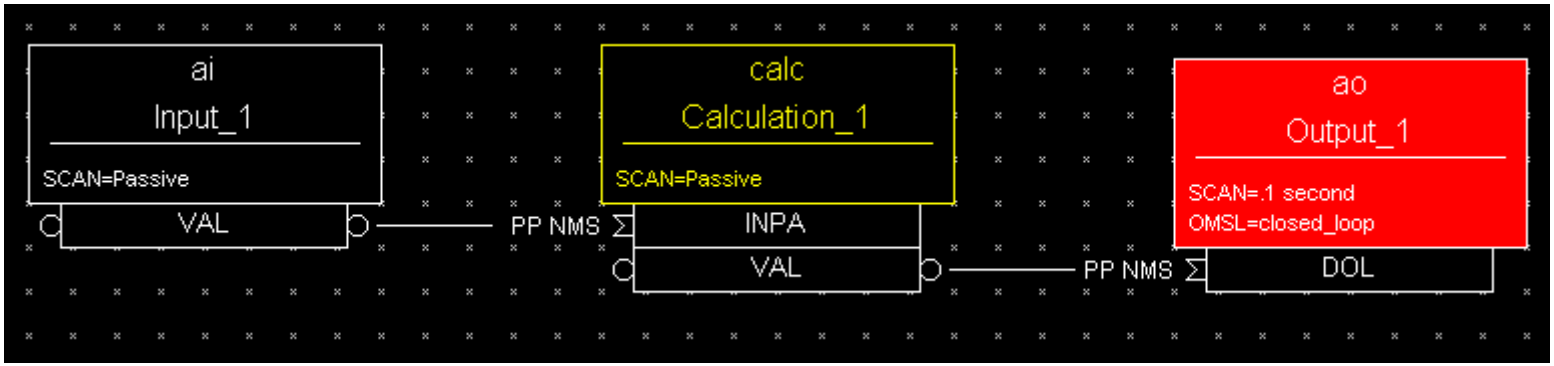
1. Every 0.1 seconds, iocCore will attempt to process the Output_1 record
2. The `Output_1.PACT` field is currently False, so the record is quiescent and can be processed
3. If set, the `Output_1.SDIS` link would be read into `Output_1.DISA`
4. Since `DISA DISV`, the ao record type's process() routine is called

Order of Operations (Synchronous I/O)



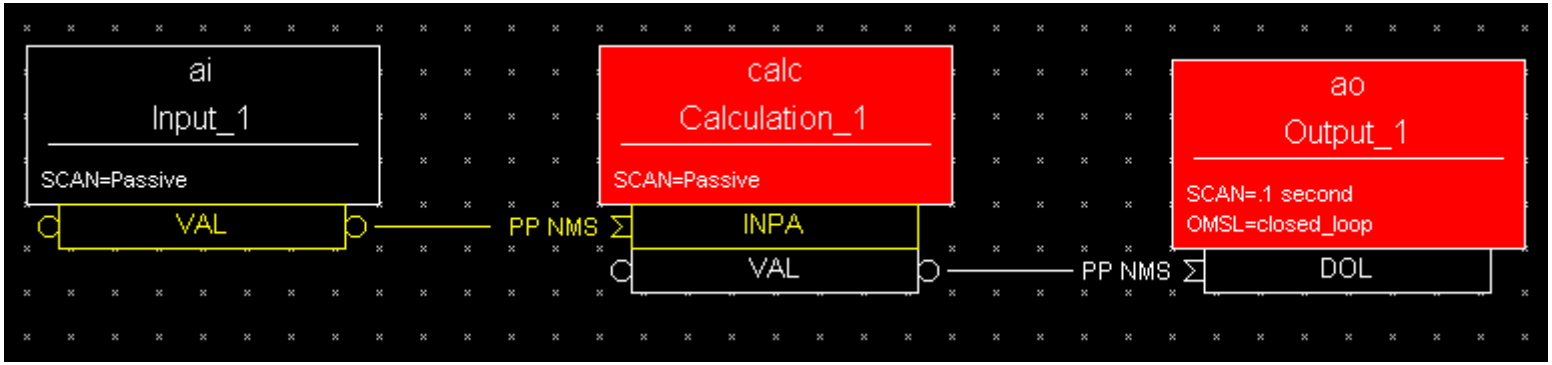
5. The ao's process() routine checks the `Output_1.OMSL` field; it is closed_loop, so
6. It sets `Output_1.PACT` to True, then
7. Reads a value through the `Output_1.DOL` link
8. The `Output_1.DOL` link contains `Calculation_1.VAL PP` so this first attempts to process the Calculation_1 record

Order of Operations (Synchronous I/O)



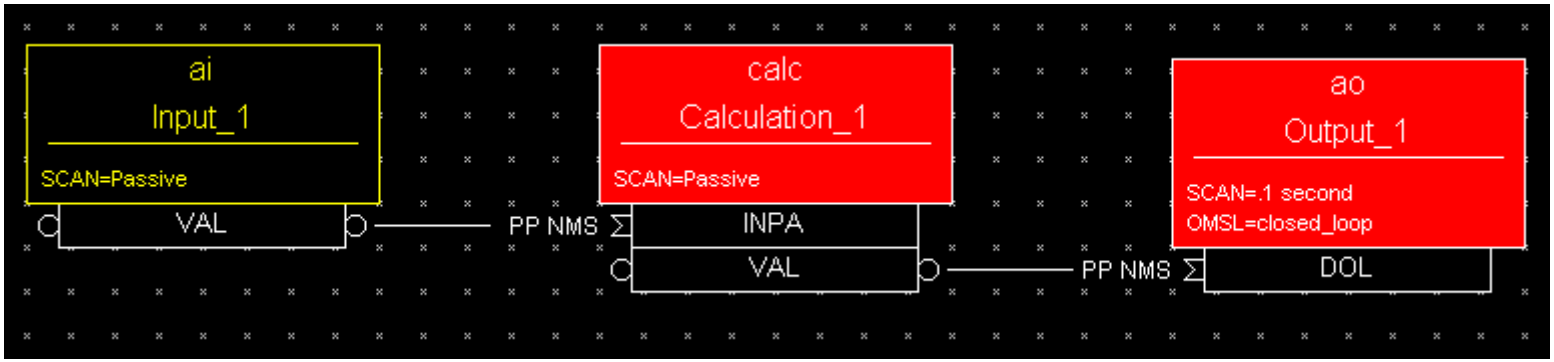
9. The `Calculation_1.SCAN` field is Passive and `Calculation_1.PACT` is False, so processing is possible
10. If set, the `Calculation_1.SDIS` link would be read into `DISA`
11. Since `DISA DISV`, the calc record type's process() routine is called

Order of Operations (Synchronous I/O)



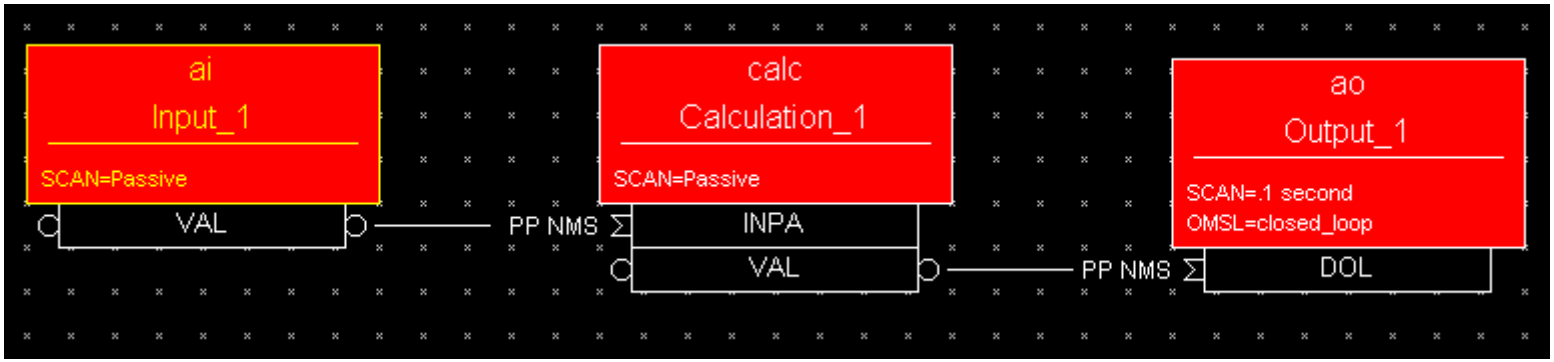
12. The calc's process() routine sets `Calculation_1.PACT` to True, then
13. Starts a loop to read values from the links `INPA` through `INPL`
14. The `Calculation_1.INPA` link is set to `Input_1.VAL PP` so this first attempts to process the Input_1 record

Order of Operations (Synchronous I/O)



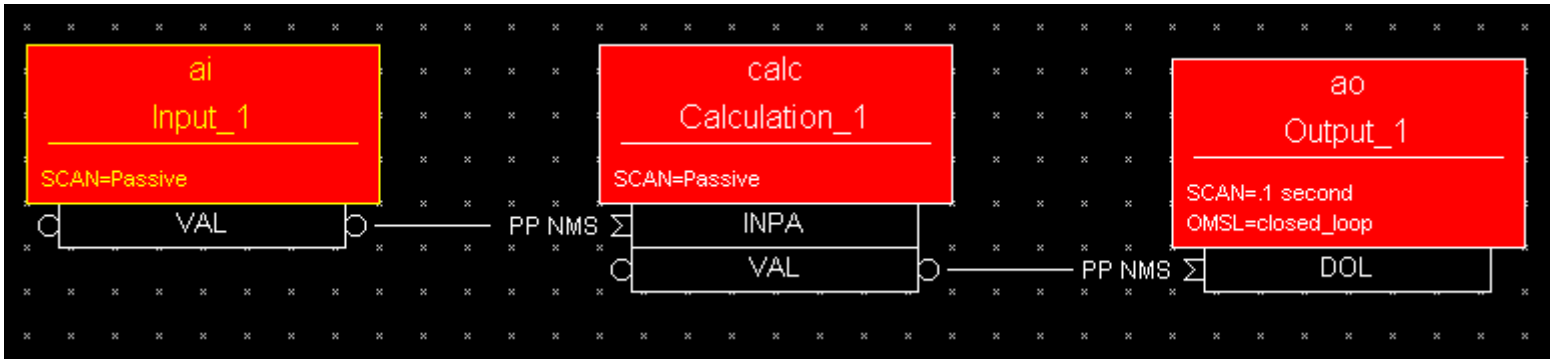
15. The `Input_1.SCAN` field is Passive and `Input_1.PACT` is False, so processing is possible
16. If set, the `Input_1.SDIS` link is read into the `Input_1.DISA` field
17. Since `DISA DISV`, the ai record type's process() routine is called
18. The ai's process() routine calls the associated device support to read a value from the hardware it's attached to

Order of Operations (Synchronous I/O)



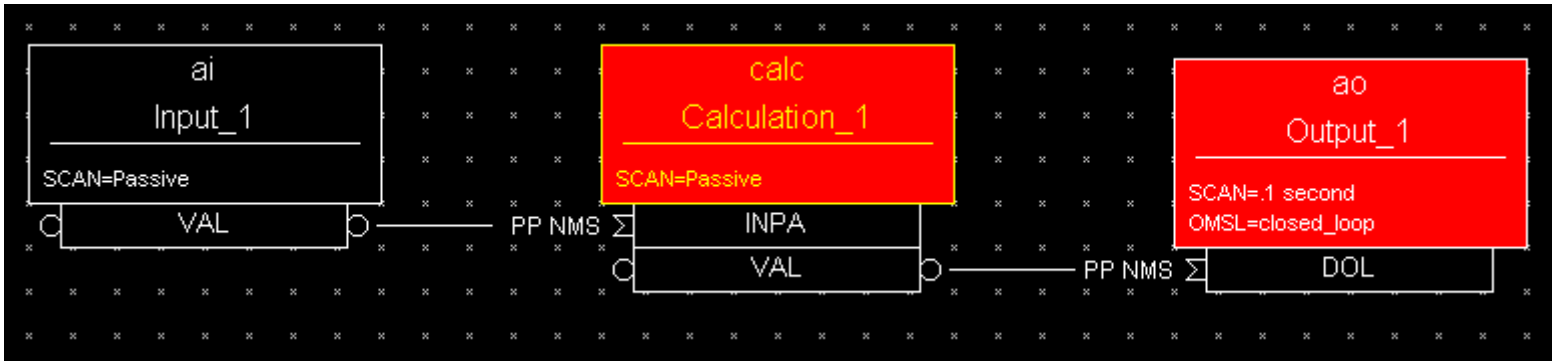
19. The device support is synchronous, so it puts the hardware input value into the `Input_1.RVAL` field and returns to the ai record's process() code
20. The `Input_1.PACT` field is set to True
21. The record's timestamp field `Input_1.TIME` is set to the current time
22. The raw value in `Input_1.RVAL` is converted to engineering units, smoothed, and the result put into the `Input_1.VAL` field

Order of Operations (Synchronous I/O)



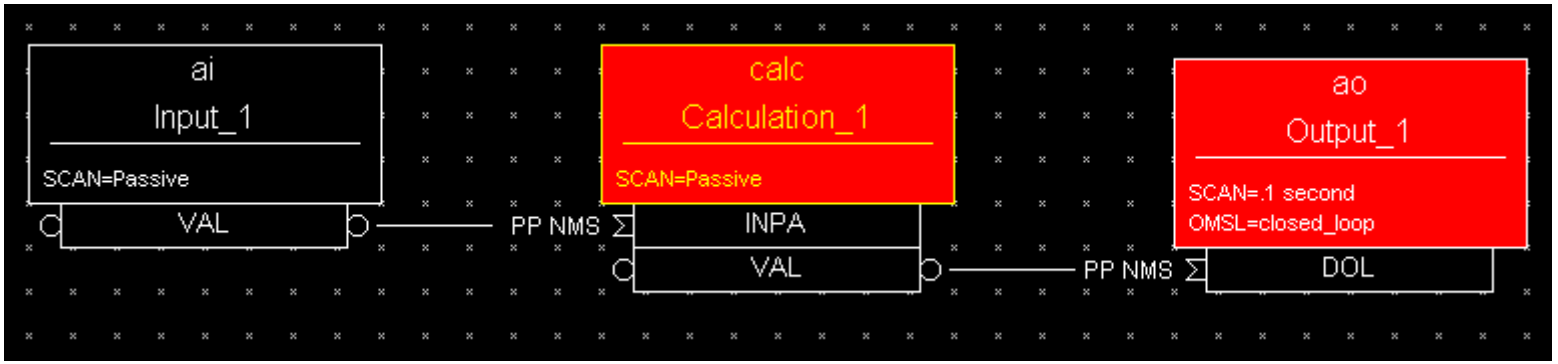
23. The `Input_1.VAL` is checked against alarm limits and monitor dead-bands, and appropriate actions is taken if these are exceeded
24. If the Forward Link field `Input_1.FLNK` is set, an attempt is made to process the record it points to
25. The `Input_1.PACT` field is set to False, and the process() routine returns control to the Calculation_1 record

Order of Operations (Synchronous I/O)



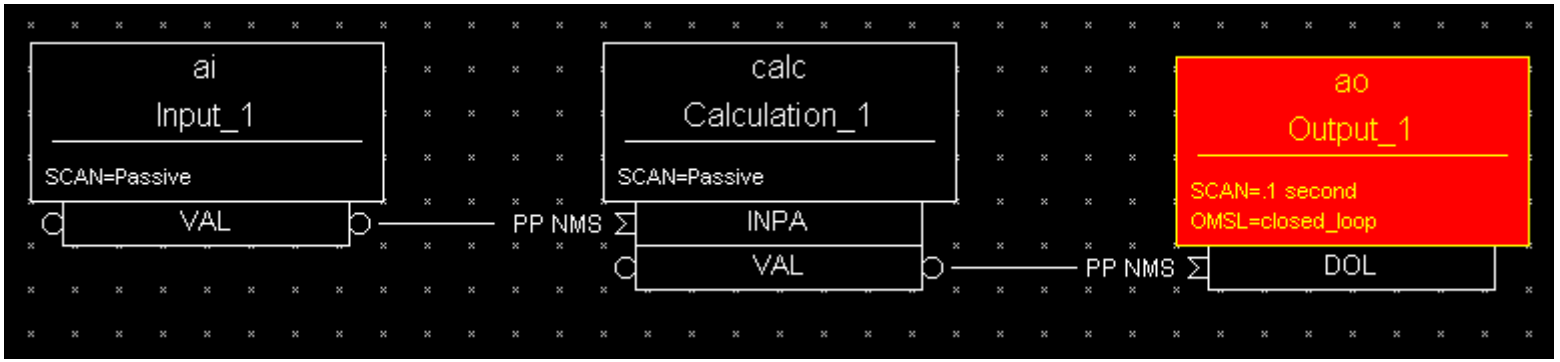
26. The value read through the `Calculation_1.INPA` link is copied into the `Calculation_1.A` field
27. The Calculation record type's process() routine continues to loop, reading its input links
28. In this example only the `INPA` link is set, so the routine finishes the loop and evaluates the `Calculation_1.CALC` expression (not shown)
29. The result of the expression is put in the `Calculation_1.VAL` field

Order of Operations (Synchronous I/O)



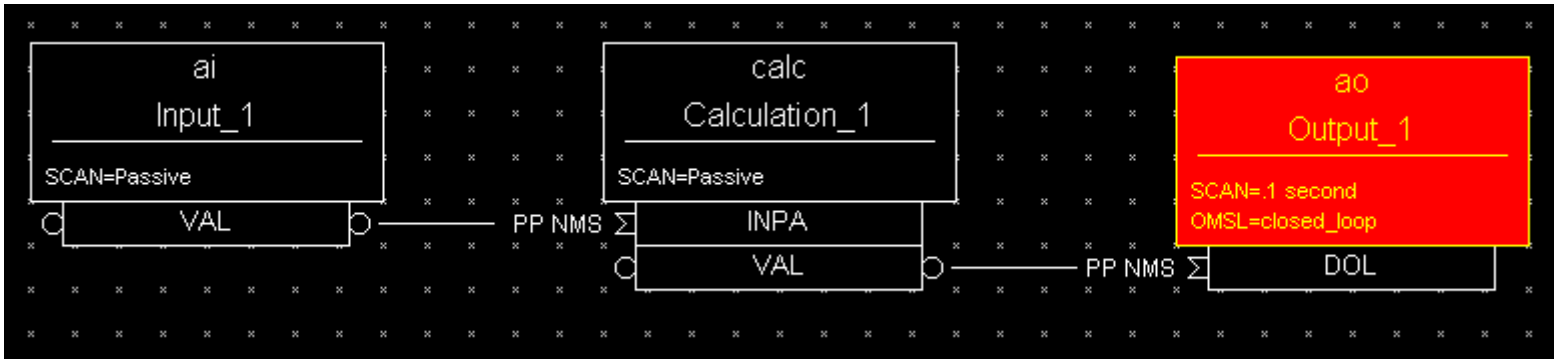
30. The record's timestamp field `Calculation_1.TIME` is set to the current time
31. `Calculation_1.VAL` is checked against alarm limits and monitor dead-bands, and appropriate action is taken if these are exceeded
32. If the Forward Link field `Calculation_1.FLNK` is set, an attempt is made to process the record it points to
33. The `Calculation_1.PACT` field is set to False, and the process() routine returns control to the Output_1 record

Order of Operations (Synchronous I/O)



34. The value read through the `Output_1.DOL` link would now be forced into the range `DRVL..DRVH` if those fields were set, but they aren't so it's copied to the `Output_1.VAL` field unchanged
35. The `Output_1.VAL` value is converted from engineering to raw units and placed in `Output_1.RVAL`
36. `Output_1.VAL` is checked against alarm limits and monitor dead-bands, and appropriate action is taken if these are exceeded
37. The associated device support is called to write the value to the hardware

Order of Operations (Synchronous I/O)



38. The device support is synchronous, so it outputs the value to the attached hardware and returns
39. The record's timestamp field `Output_1.TIME` is set to the current time
40. If the Forward Link field `Output_1.FLNK` is set, an attempt is made to process the record it points to
41. The `Output_1.PACT` field is set to False, and the process() routine returns