# What is an EPICS Database?

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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, deadbands, simulation and security**

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# *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 behaviour defined by its record type (class)
  - ❖ Controllable properties (fields)
  - ❖ Optional associated hardware I/O (device support)
  - ❖ Links to other records

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# *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**

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# *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 behaviour
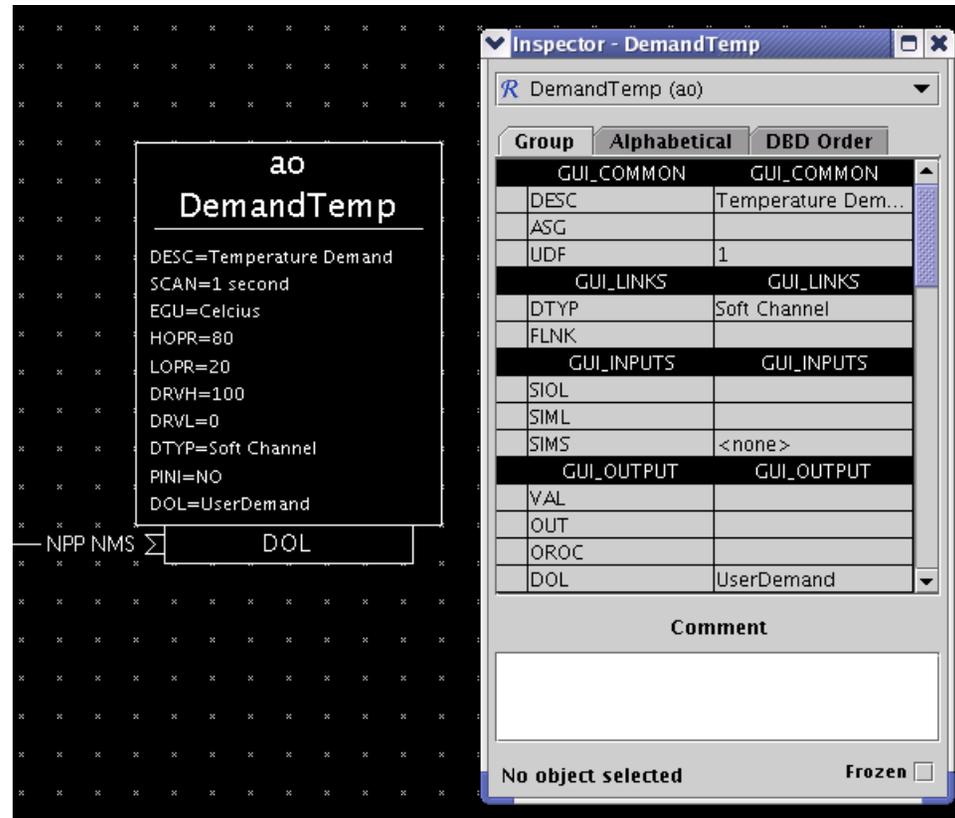- ◆ New record types can be added to an application as needed

# *One view of a Record*

# A graphical view of a Record

# *Another graphical view of a Record*

```
  DOL ──┐        ┌── FLNK ▷
  SLNK ─┤   ∘∘   ├── VAL  ▷
  SDIS ─┘        └── OUT  ▷
```
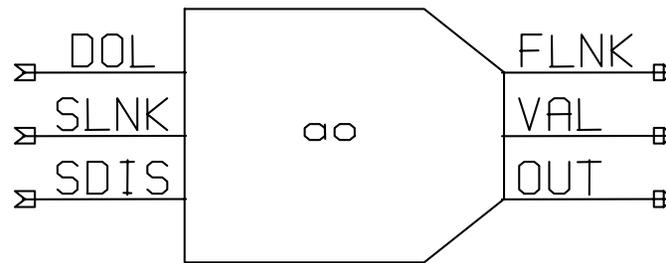
The small CapFast symbol for an Analogue Output record

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# *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,"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 shows only the design fields, there are other fields which
are used only at run-time

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# *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

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# Field types

◆ *Fields can contain*
- ❖ **Integers**
  - ◆ **char, short or long**
  - ◆ **signed or unsigned**
- ❖ **Floating-point numbers**
  - ◆ **float or double**
- ❖ **Strings**
  - ◆ **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**
- ❖ **Other private data**
  - ◆ **not directly accessible**

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# *All Records have these fields*

**Design fields**

| | |
|---|---|
| **NAME** | **60 Character unique name (using more than 28 char's can cause problems)** |
| **DESC** | **28 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** |

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# *Record Scanning*

- **`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 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 startup**
- **`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 | Low engineering value |
| EGUF | High engineering value |
| ESLO | Unit conversion slope |
| EOFF | Unit conversion offset |

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# Periodic Input
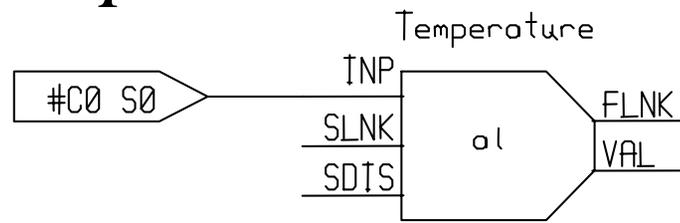
```
                              Temperature
                        INP
           ┌─────────────┐      ┌──────────┐  FLNK
           │  #C0 S0      >──────┤          ├───
           └─────────────┘  SLNK │    al    │  VAL
                            ─────┤          ├───
                             SDIS│          │
                            ─────┤          │
                                 └──────────┘

                        DTYP:XY566
                        SCAN:.1 Second
                        PHAS:0
                        LINR:LINEAR
                        EGUL:0
                        EGUF:120
                        EGU:Celclus
```

# *Interrupt Input*

VentValve

```
                            INP ┌──────────┐ FLNK
#L0 A0 C3 S5 ───────────   SLNK │    bl    │ VAL
                            SDIS └──────────┘
```
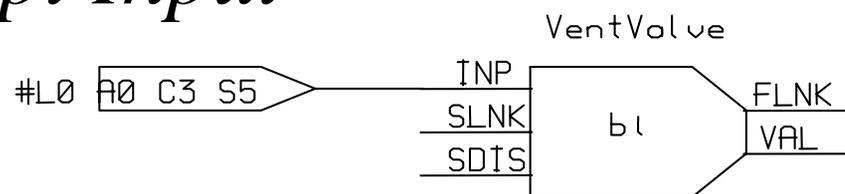
DTYP:AB-Binary Input
SCAN:I/O Intr
PHAS:0
ZNAM:Closed
ONAM:Open
ZSV:NO_ALARM
OSV:MAJOR_ALARM

# *Output records often 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 Output*

```
                    Solenoid
       _____ ┌────────────┐ _____
        DOL        │            │  FLNK
       _____ │    bo      │ _____
        SLNK       │            │  VAL
       _____ │            │ _____
        SDIS       │            │  OUT         ◁────── #C2 S12
                   └────────────┘
```
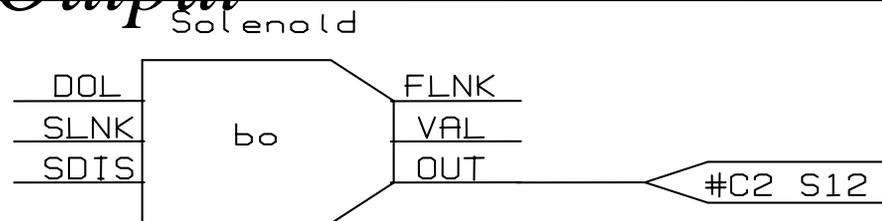
```
DTYP:XY220
SCAN:Passive
PHAS:0
ZNAM:Locked
ONAM:Unlocked
```

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# *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

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# *Input and Output links may be...*

◆ **Constant numeric value, eg:**

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*

# *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)**
  `PP`
- ❖ **Maximize Severity flag**
  `NMS` **(default)**
  `MS`

*For example:*
`M1:current.RBV NPP MS`

- ◆ *NB: 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*

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# *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 behaviour is identical to all other CA clients*
- ◆ `MS` *Link flags apply to Input links:*
  - ❖ *Input links honour 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***

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# *Link flag summary*

| Type | Input Links | Output Links |
|------|-------------|--------------|
| DB | `.PP` or **`.NPP`** <br> `.MS` or **`.NMS`** | `.PP` or **`.NPP`** <br> `.MS` or **`.NMS`** |
| CA | Always **`.NPP`** <br> `.MS` or **`.NMS`** <br> `.CA` to force link type. <br> `.CP` to process this record on change. <br> `.CPP` is like `.CP` but only process if `SCAN=Passive` | `.PP` behavior of destination field. <br> Always **`.NMS`** <br> `.CA` to force link type. |

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

# *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)**

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# *Synchronous vs Asynchronous I/O*

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- ◆ **EPICS rules do not allow device support to busy-wait (delay record processing while waiting for the results of a slow I/O operation)**
    - ❖ Fast I/O can be handled synchronously
    - ❖ Slow operations must operate asynchronously
- ◆ **Register-based VME cards usually give an immediate response: synchronous**
- ◆ **When called, synchronous device support performs all I/O before returning**
- ◆ **Serial and most I/O field-bus devices take a long time (>10ms) to return data: asynchronous**
- ◆ **Asynchronous device support starts I/O when record calls it, flags it as incomplete by setting `PACT` true before returning**
- ◆ **Once results are available (CPU interrupt), device support calls the record's process routine which finishes the operation**

# *Soft Device Support*

- ◆ **"Hard" Input and Output records perform 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 preformed*
  - ❖ Async Soft Channel (new, for 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

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# *Forward links*

- ◆ **Usually a Database link, referring to a record in same IOC**
- ◆ **Forward linking via Channel Access is possible, 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**
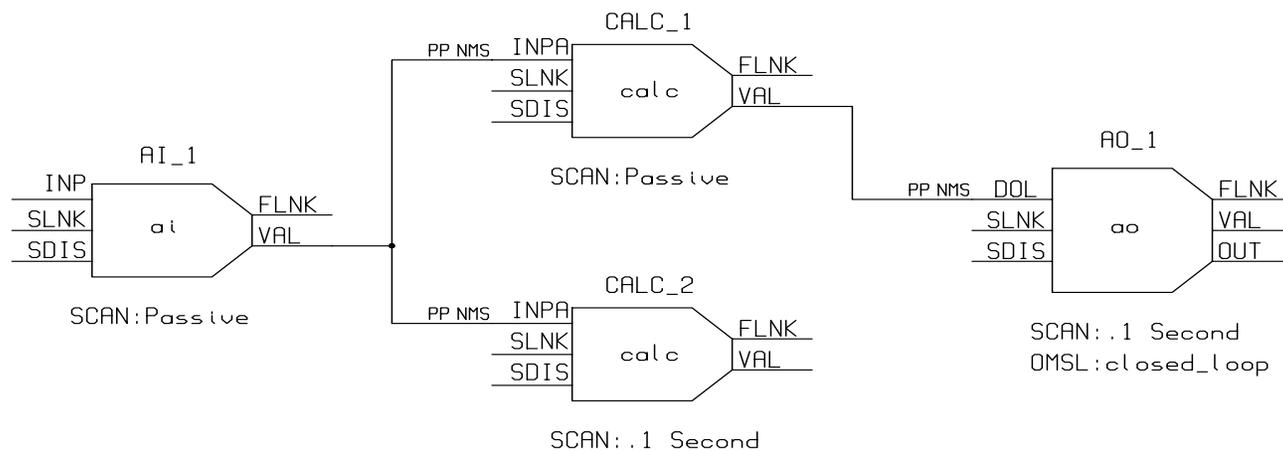
# *Processing chains*
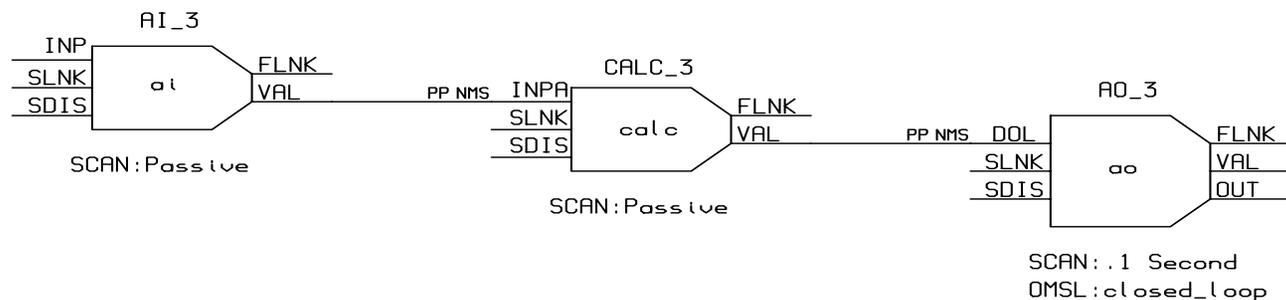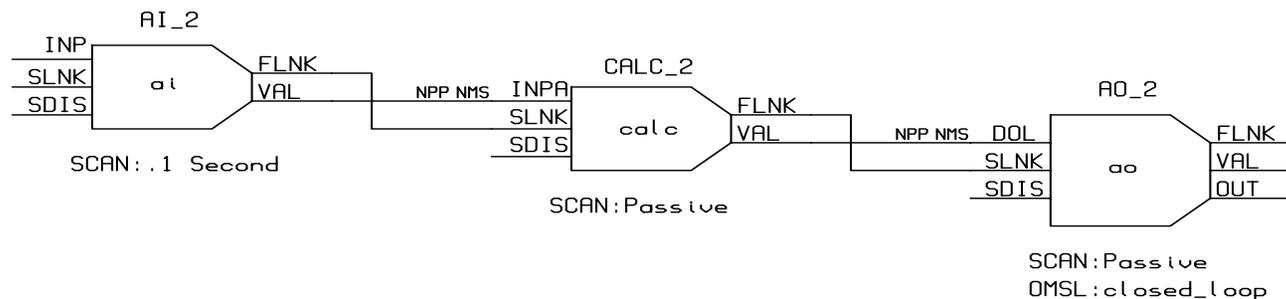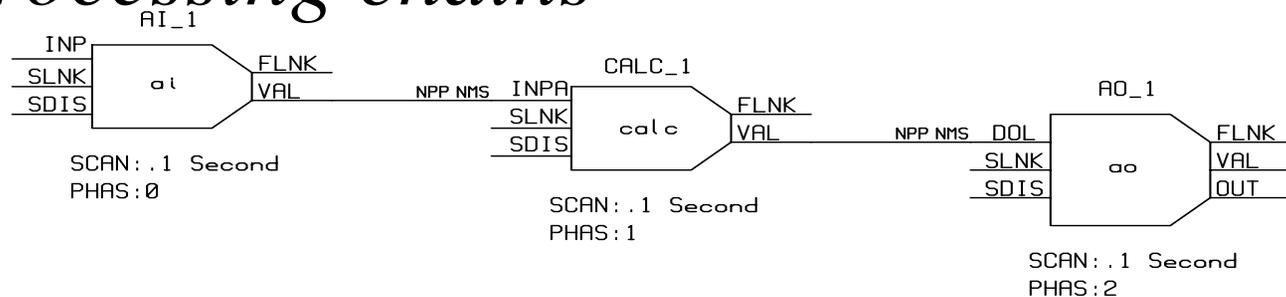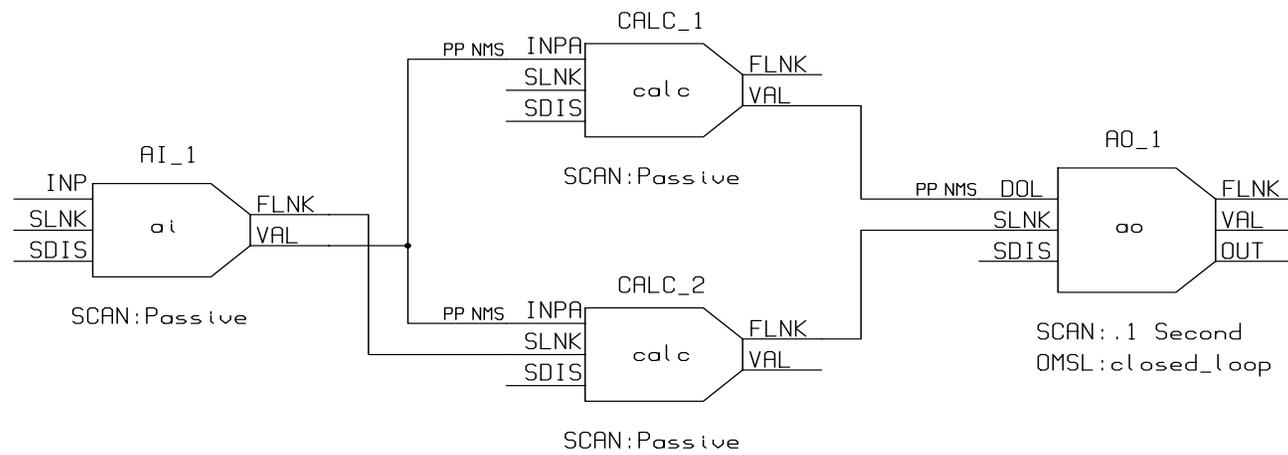
# *Which record is never processed?*
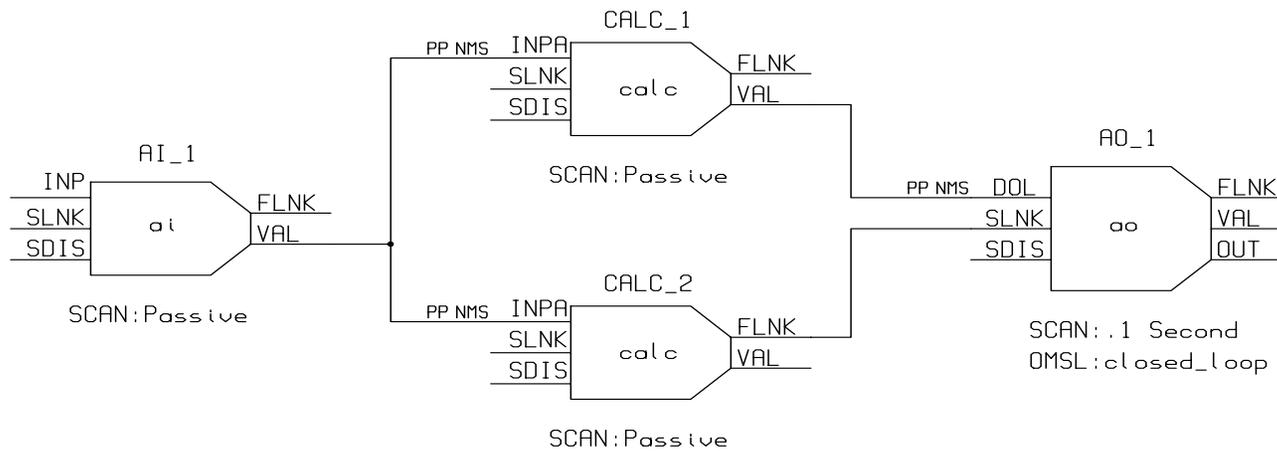
# *Which record is processed twice?*

# *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

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# *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`**

- ◆ **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**

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# *How are records given 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

# *What could go wrong here?*
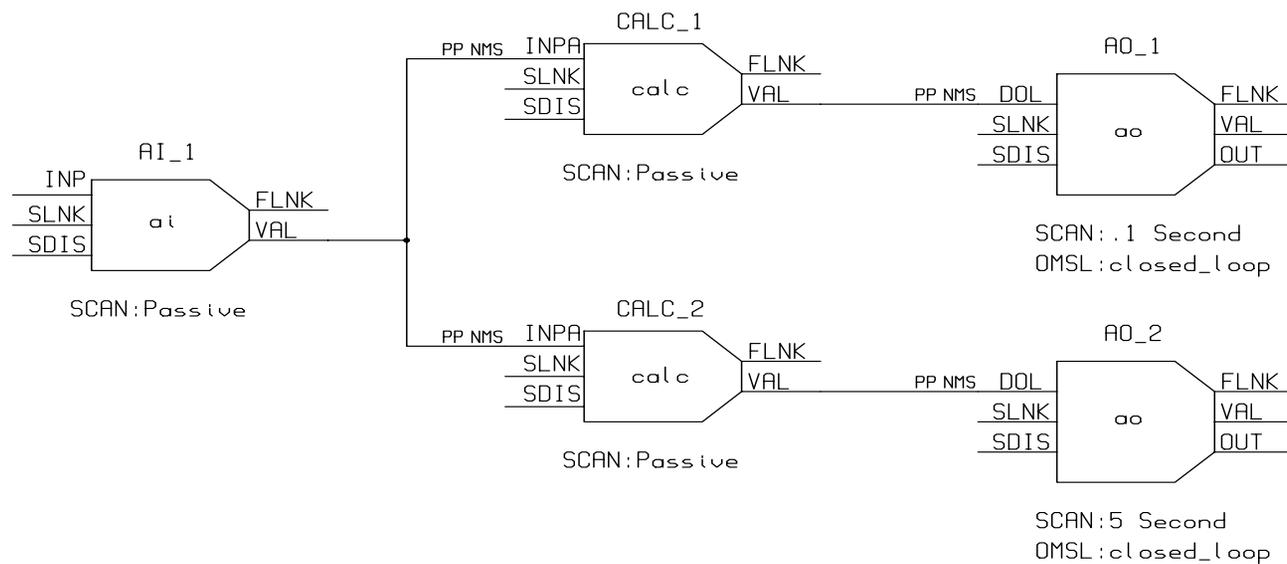
# *Lock-sets*

- ◆ **Prevent a record from being processed simultaneously from two scan tasks**

- ◆ **A lock-set is a group of records interconnected by database links:**
  - ❖ Output links
  - ❖ Forward links
  - ❖ Input links which are `PP` or `MS`
  - ❖ Any link transporting an Array

- ◆ **Lock-sets are determined automatically by the IOC at start-up, or whenever a database link is added, deleted or modified**

**You can split a lock set with**

- ◆ **Channel Access links, using `CA` flag**

- ◆ **Database links which are both `NPP` and `NMS`**

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# *Alarms*

◆ **Every record has the fields**

    `SEVR` Alarm Severity

      *NONE, MINOR, MAJOR, INVALID*

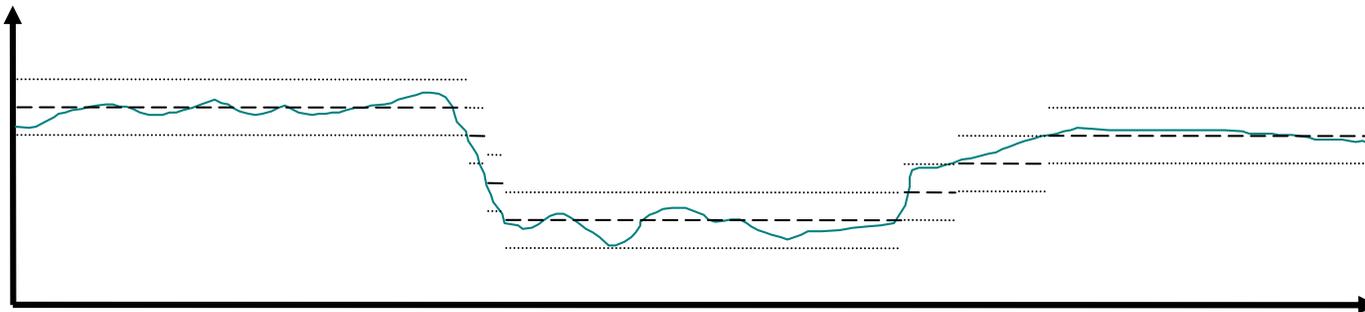    `STAT` Alarm Status (reason)

      *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)**

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# *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*

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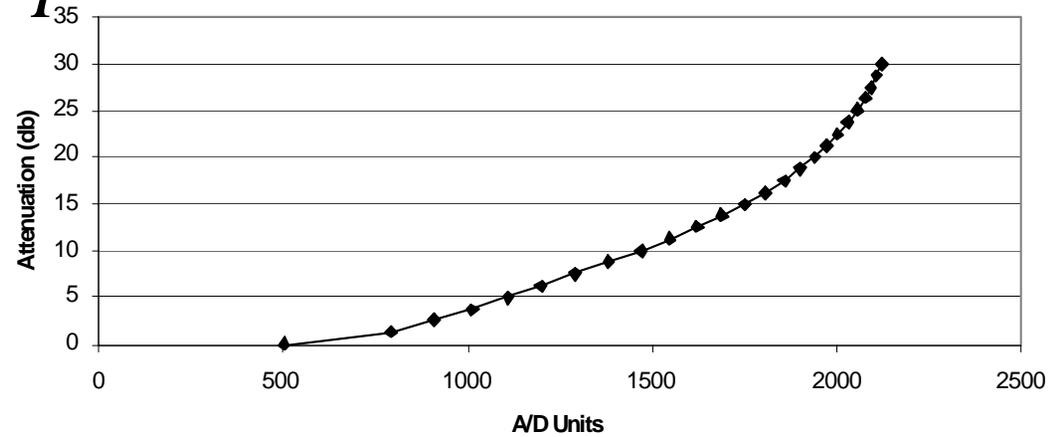
# *Simulation*

◆ **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 `SIMS` field**

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# *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

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# *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**