Getting Started with EPICS IOCs:

Record Types and Examples

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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 1 & 2 – Concepts and linking*
  - How do I connect a record *instance* to a device?
    - set the link field *(Database 1 & 2 – 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>/src/rec)
    - General purpose record types
    - No record-type specific operator displays or databases
    - Documentation in *EPICS Record 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*

The Record Reference Manual

- **Where is it?**
  - EPICS Home > Base > R3.13 > Reference Documents (html)
- **What is in it?**
  - Database Concepts (good review)
  - Fields common to all records (covered earlier)
  - Fields common to many records (covered earlier)
  - Record Types – provides a description of the record processing routines for most of the record types *in base*.
- **When would I use it?**
  - Skim through before writing any databases
  - Read through before writing any records
  - Otherwise, use as reference

...The Record Reference Manual

- **Preface, Chapter 1: Essential background information**
  - Note special meaning of the words *scan*, *process*, *address*, *link*, and *monitor*
- **Chapter 2-39: Record reference**
  - Somewhat out of date
  - Descriptions of record fields, processing, and useful info for writing device support
  - Contains lots of tables like the following:

Field	Summary	Type	DCT	Initial	Access	Modify	Rec Proc Monitor	PP
EGU	Engineering Units	STRING [16]	Yes	null	Yes	Yes	No	No
HOPR	High Operating Range	FLOAT	Yes	0	Yes	Yes	No	No
LOPR	Low Operating Range	FLOAT	Yes	0	Yes	Yes	No	No
PREC	Display Precision	SHORT	Yes	0	Yes	Yes	No	No
NAME	Record Name	STRING [29]	Yes	Null	Yes	No	No	No
DESC	Description	STRING [29]	Yes	Null	Yes	Yes	No	No

Collaboration supported records

- **Where are they found?**
  - Soft-support list http://www.aps.anl.gov/epics/modules/soft.php
  - The tech-talk email list: *tech-talk@aps.anl.gov* *(for information, send a blank message to listserv@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:epid Record
record	genSub	Multi-I/O subroutine, handles arrays	Andy Foster	OSL:epics
...	...	...	...	...
record	table	Control an optical table	Tim Mooney	APS:synAps/optics
record	timestamp	...exports its timestamp as a string	Stephanie Allison	SLAC:timestamp

...Collaboration supported records

- **What should I expect to find?**
  - EPICS 3.13-compatible records:
    - varies with source
    - at minimum: xxxRecord.dbd, xxxRecord.c
  - EPICS 3.14 and later:
    - a buildable *module*
    - a statement of requirements (e.g., which version of base)
    - maybe record-type specific displays, databases, programs, etc.

Input Records

- **ai - Analog input [BASE]**
  - Read analog value, convert to engineering units, four alarm levels, simulation mode
- **aai – Array analog input [BASE]**
  - Read array of analog values, 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, sixteen 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 (16 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
- **waveform – array input [BASE]**
  - Configurable data type and array length (16,000 bytes max for CA in EPICS 3.13)
- ***mbbi32Direct [ORNL] longMbbiDirect [KEK] – 32-bit mbbiDirect***
  - Read an unsigned long and map each bit to a field (32 BI records in one)
- ***mca – multichannel analyzer [synApps]***
  - Supports multichannel analyzers, multichannel scalers, and other array-input hardware

Input Records (cont..)

- ***pulseCounter [ANL RecRefMan]***
  - Written to support a Mizar 8310 timing module
- ***scaler [synApps]***
  - Controls a bank of counters
- ***swf [BESSY] , wftime [SLAC] – waveform variants***
  - Includes scaling and time (wftime) information
- ***timestamp [SLAC]***
  - Exports its timestamp as a string

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”)` -> 4.456
    - `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 - Array

- **compress [BASE]**
  - Input link can be scalar or 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
- **subArray [BASE]**
  - Extracts a sub-array from a waveform.
- ***aConcat* [KEK], *joinArray* [SLS]**
  - Concatenate waveforms
- ***genSub – sub variant* [OSL]**
  - Multiple inputs and outputs
  - Handles arrays and structures

Algorithms/Control Records – List

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

Algorithms/Control Records – List

- ***lseq – seq variant [JACH]***
  - 16 sets, instead of 10
- ***sseq – seq variant [synApps]***
  - seq record for string or numeric data
  - optional wait for completion after each set executes
- ***wfselector – waveform/sel variant [KEK]***
- *genSub* ***[OSL]***
- *sCalcout* ***[synApps]***
- *transform* ***[synApps]***

Algorithms/Control Records - Loop

- **scan [ANL]**
  - Four “positioners”, two “detector triggers”, fifteen “detectors”.
  - Systematically sets conditions, triggers detectors, and acquires data into arrays.
  - Database detects completion and drives scan to next step.
- **sscan – scan variant [synApps]**
  - Uses ca_put_callback() to detect completion.
  - Four triggers, 70 detector signals (arrays, scalars, or mixed)
  - Array-prepare trigger at end of scan
  - 2000 data points in EPICS 3.13; “unlimited” number in EPICS 3.14
  - Supports scan pause; before/after-scan action; move-to-peak.
  - Handshake permits data-storage client to write old data while new data is being acquired.

Algorithms/Control Records - Subroutine

- **sub – Subroutine [BASE]**
  - 12 input links, user provided subroutine, four alarm levels
- **genSub – sub variant [OSL]**
  - Multiple inputs and outputs
  - Handles arrays and structures

Algorithms/Control Records - Other

- **event [BASE]**
  - Posts a “soft” event which may trigger other records to process.
  - Simulation mode
- **PID [ANL], CPID [JLAB], EPID [synApps]**
  - Proportional/Integral/Derivative Control
- **pal [3.13 BASE]**
  - Emulates Programmable Array Logic
- **cvt – ai/ao variant [BESSY]**
  - 1 or 2 inputs, 1 output, conversion types: linear, subroutine, 1D or 2D table
- **Permissive – handshake [BASE]**
  - Implements a client-server handshake
- **state – string state value [BASE]**
  - Implements a string, for client-server communication

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
- **aao – Array analog output [BASE]**
  - ao for arrays
- **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

Output Records (cont..)

- **mbbo - Multi-bit binary output [BASE]**
  - Multiple bit, sixteen 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]**
  - 16 settable bit fields that get written as a short integer to the hardware, closed_loop mode, INVALID alarm action, sim. mode
- **mbbo32Direct - mbbo variant [ORNL]**
- **longMbboDirect - mbbo variant [KEK]**
  - 16 settable bit fields that get written as a long integer, closed_loop mode, INVALID alarm action, simulation mode
- **motor [synApps]**
  - Controls stepper and servo motors
  - Has its own lecture (*Motors*)

Output Records (cont..)

- **steppermotor [3.13 BASE]**
  - Position control, retry, speed, ramps, etc
- **pulseDelay [3.13 BASE]**
  - Written to support a Mizar 8310 timing module
- **pulseTrain [3.13 BASE]**
  - Written to support a Mizar 8310 timing module
- **stringout [BASE]**
  - Write a character string (40 max), closed_loop mode, INVALID alarm action, simulation mode

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**
  - See list associated with this lecture

Which record is right for …

- **"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**
  - Sequence record can have a different data source for each output link vs. the dfanout record which "fans out" a single source to multiple links
- **Different output actions based on an operator selection**
  - CALCOUT records that conditionally process sequence records
  - MBBO (Soft Raw Channel) forward linked to a single sequence record in "masked" mode. Mask is provided in MBBO for each state.

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 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 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(INP,DBF_INLINK) {
        prompt("Input Specification")
        promptgroup(GUI_INPUTS)
        interest(1)
}
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(bo,"$(user):gunOnC") {
   field(DESC,"Controls e-gun")
}
record(bo,"$(user):gunOnC") {
   field(DESC,"Controls e-gun")
   field(DTYP,"Soft Channel")
   field(ZNAM,"Beam Off")
   field(ONAM,"Beam On")
}
record(ao,"$(user):cathodeCurrentC") {
   field(DESC,"set cathode current")
   field(DTYP,"Raw Soft Channel")
   field(SCAN,"1 second")
   field(OROC,".5")
   field(PREC,"2")
   field(EGU,"Amps")
   field(DRVH,"20")
   field(DRVL,"0")
   field(HOPR,"20")
   field(LOPR,"0")
}
```

```
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

- **Part of a typical startup script (st.cmd)**

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

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

iocInit          /* starts ioc software */
```

- **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.**

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 (recommended for new designs)*
    - *CAPFAST (a schematic entry application)*
    - *JDCT (not graphical)*
    - *GDCT (no longer supported)*
- **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 is helpful for complex databases**

Steps to Creating and Loading a New Database File

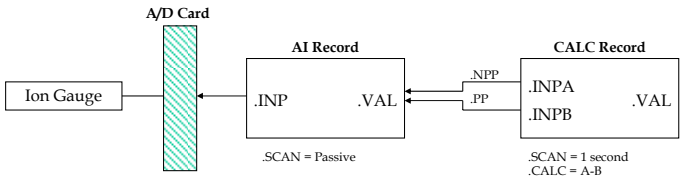
- **Create the database file in an appropriate Db directory**
- **If gnumake is to build and install .db file:**
  - Edit Db/Makefile so the .db file is handled properly
  - run gnumake
- **Edit the IOC's startup script (st.cmd) to load the new database**
  - dbLoadRecords(_____)
- **Reboot the IOC**

JDCT

- **Start *jdct* (usually in a Db directory)**
- **Open one or more .dbd files (usually in the directory '../../dbd') to define available record types, menus, available device options, etc)**
- **Create, copy, edit record instances**
- **Save the .db file**
- **If gnumake is to build and install the .db file:**
  - run gnumake to install the .db into another directory
  - modify Makefile when a new database file is added

Database Examples

Calculating "Rate-of-Change" of an Input

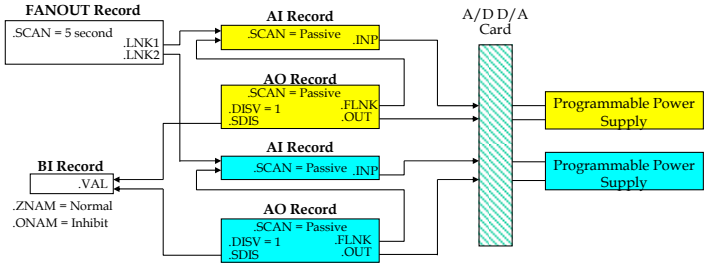


INPA fetches data that is 1 second old because it does not request processing of the AI record. INPB fetches current data because it requests the AI record to process. The subtraction of these two values reflects the 'rate of change' (difference/sec) of the pressure reading.

* The direction of the arrows indicates where a link points to, not necessarily the direction of the data flow.

Database Examples

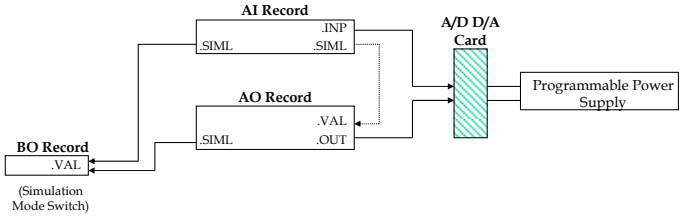
Slow Periodic Scan with Fast Change Response



AI records get processed every 5 seconds AND when the associated AO record is changed. This provides immediate response to a change even though the desired scan rate is very slow. Changes to the power supply settings are inhibited by the BI record, which could represent a Local/Remote switch.

Database Examples

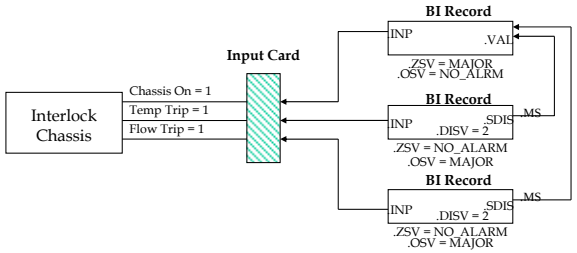
Simulation Mode



When in simulation mode, the AO record does not call device support and the AI record fetches its input from the AO record.

Database Examples

Maximize Severity



If chassis is powered off, Temp Trip and Flow Trip indicate Normal. Force these PVs into an alarm state by specifying .SDIS with .MS (maximize severity) to the Chassis On record. Set .DISV (disable value) to 2 so processing will never be disabled.

Database Examples

Different Actions Based on Operator Selection

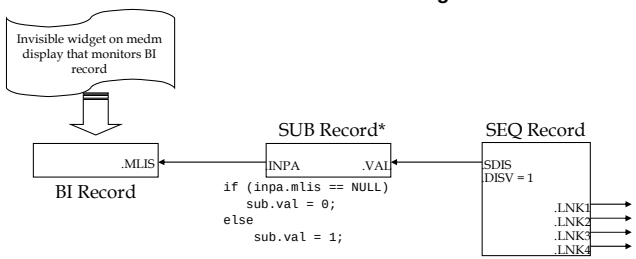
```
record(mbbo,"$(user):PS:Control") {
        field(DTYP,"Raw Soft Channel")
        field(FLNK,"$(user):PS:ControlSQ.VAL PP NMS")
        field(ZRVL,"0x3") BIT MAP: 0000000000000011 -> do LNK1, LNK2
        field(ZRST,"Off") menu item operator sees
        field(ONVL,"0x5") BIT MAP: 0000000000000101 -> do LNK1, LNK3
        field(ONST,"On") menu item operator sees
        field(TWVL,"0xc") BIT MAP: 0000000000001100 -> do LNK3, LNK4
        field(TWST,"Set @ Default") menu item operator sees
}
record(seq,"$(user):PS:ControlSQ") {
        field(SELM,"Mask")
        field(SELL,"$(user):PS:Control.RVAL NPP NMS")
        field(DLY1,"0")
        field(DOL1,"0")
        field(LNK1,"$(user):PS:setCurrent.VAL PP NMS")
        field(DLY2,"2")
        field(DOL2,"0")
        field(LNK2,"$(user):PS:pwrControl.VAL PP NMS")
        field(DLY3,"0")
        field(DOL3,"1")
        field(LNK3,"$(user):PS:pwrControl.VAL PP NMS")
        field(DLY4,"1")
        field(DOL4,"3.75")
        field(LNK4,"$(user):PS:setCurrent.VAL PP NMS)
}
```

Off
On
Set @ Default

Different links in the sequence record are executed for each selection of the mbbo. This allows much functionality to be specified in only two records.

Database Examples

Automatic Shutdown on Logout

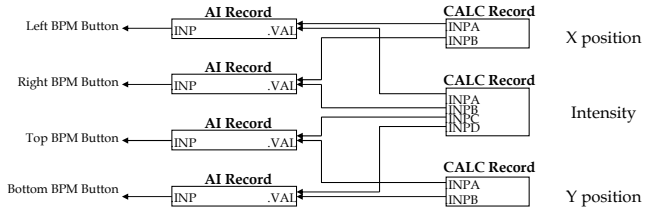


If no monitor exists on the BI record (i.e. the operator has logged out), .MLIS will be NULL. The subroutine record .VAL field will become 0, which will cause the sequence record to process.

* A subroutine record is required because the .MLIS field is defined as a NO_ACCESS field (for links).

Database Examples

Quick Prototyping with Standard Records



Custom Record Definition