Argonne NATIONAL LABORATORY

... for a brighter future

State Notation Language and the Sequencer

Andrew Johnson
APS Engineering Support Division

January 2007

USPAS EPICS Course

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Outline

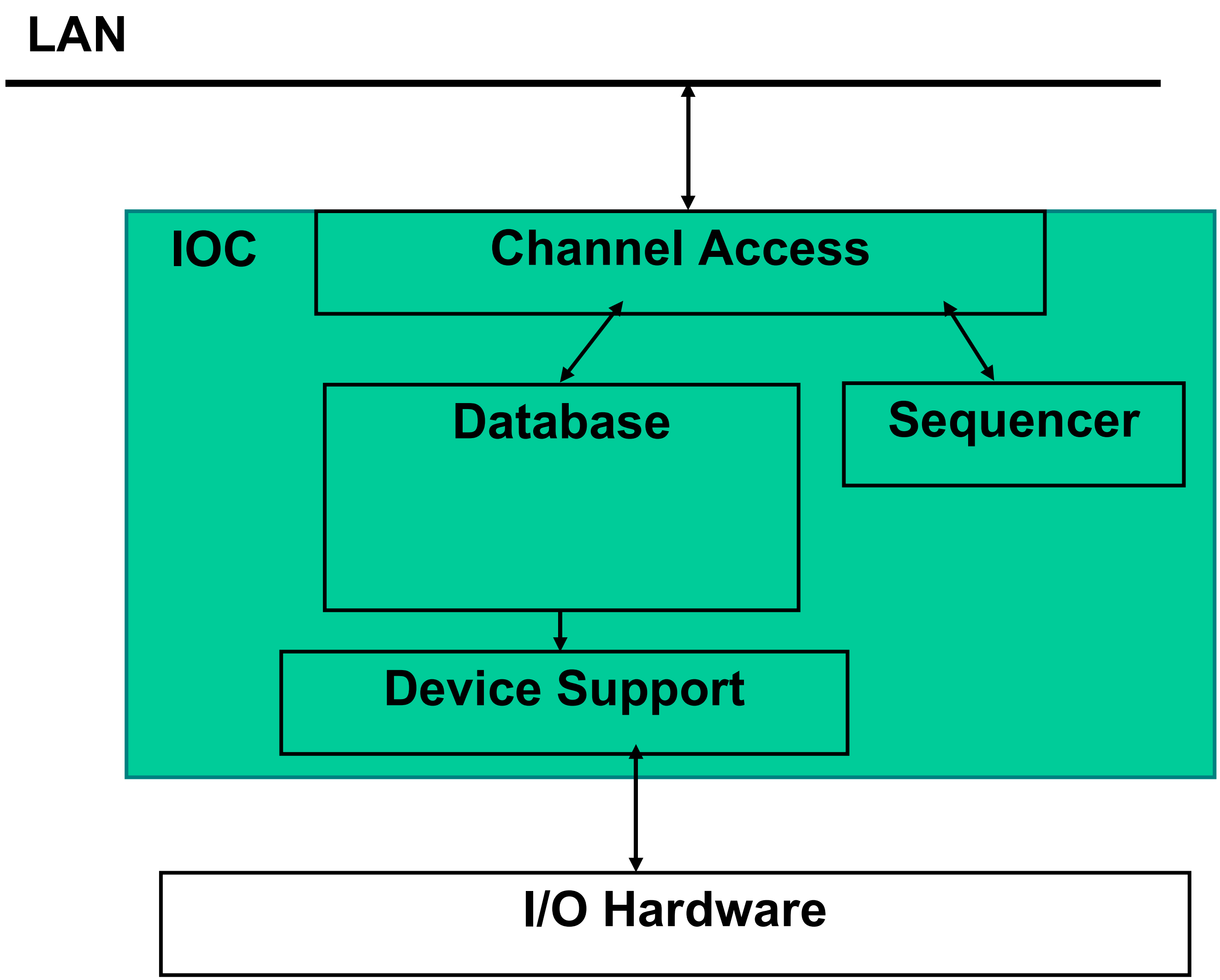
- What is State Notation Language (SNL)
- Where it fits in the EPICS toolkit
- Components of a state notation program
- Some notes on the Sequencer runtime
- Building, running and debugging a state notation program
- Additional Features
- When to use it
- This talk covers Sequencer version 2.0.8
- This talk does not cover all the features of SNL and the sequencer. Consult the manual for more information:
  http://www.slac.stanford.edu/comp/unix/package/epics/sequencer/

SNL and the Sequencer

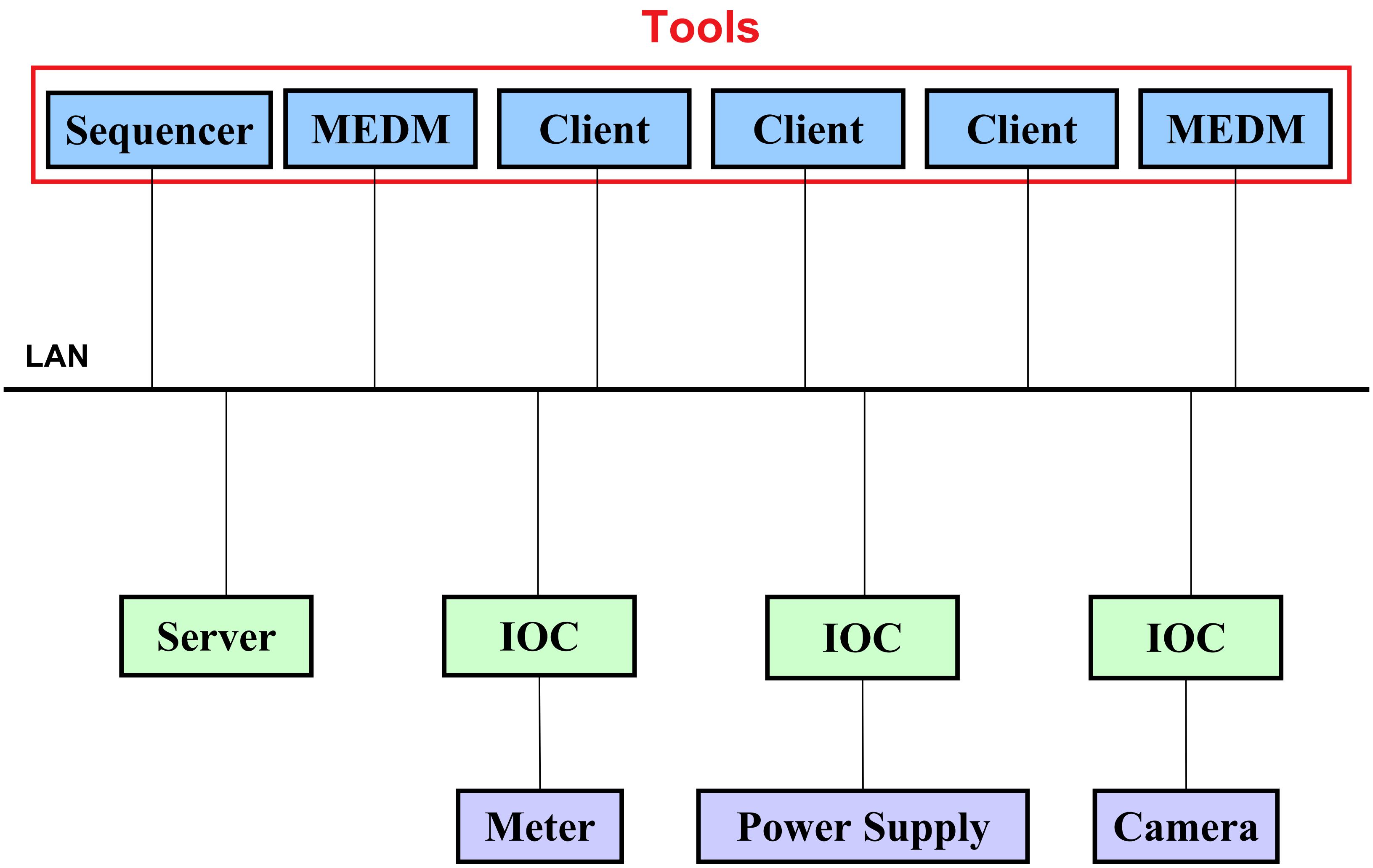
- The sequencer runs programs written in State Notation Language (SNL)
- SNL is a ‘C’ like language to facilitate programming of sequential operations
- Fast execution - compiled code
- Programming interface to extend EPICS in the real-time environment
- Common uses
  - Provide automated start-up sequences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

Where's the Sequencer?

The major software components of an IOC (IOC Core)



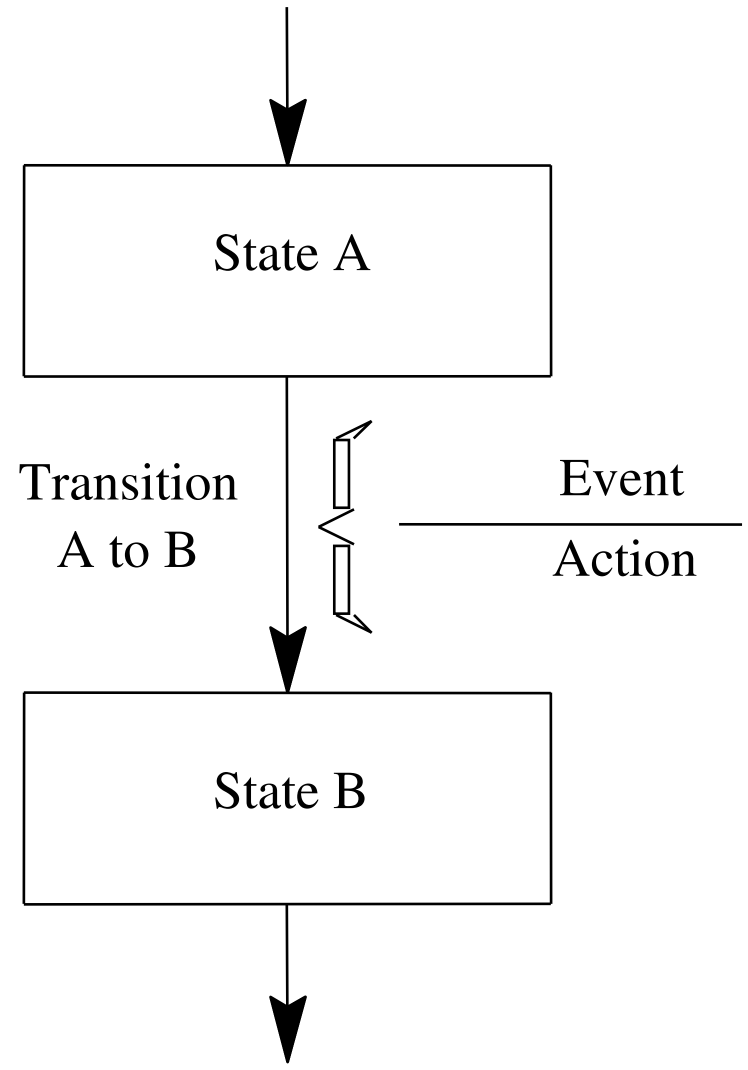
Where's the Sequencer Now?



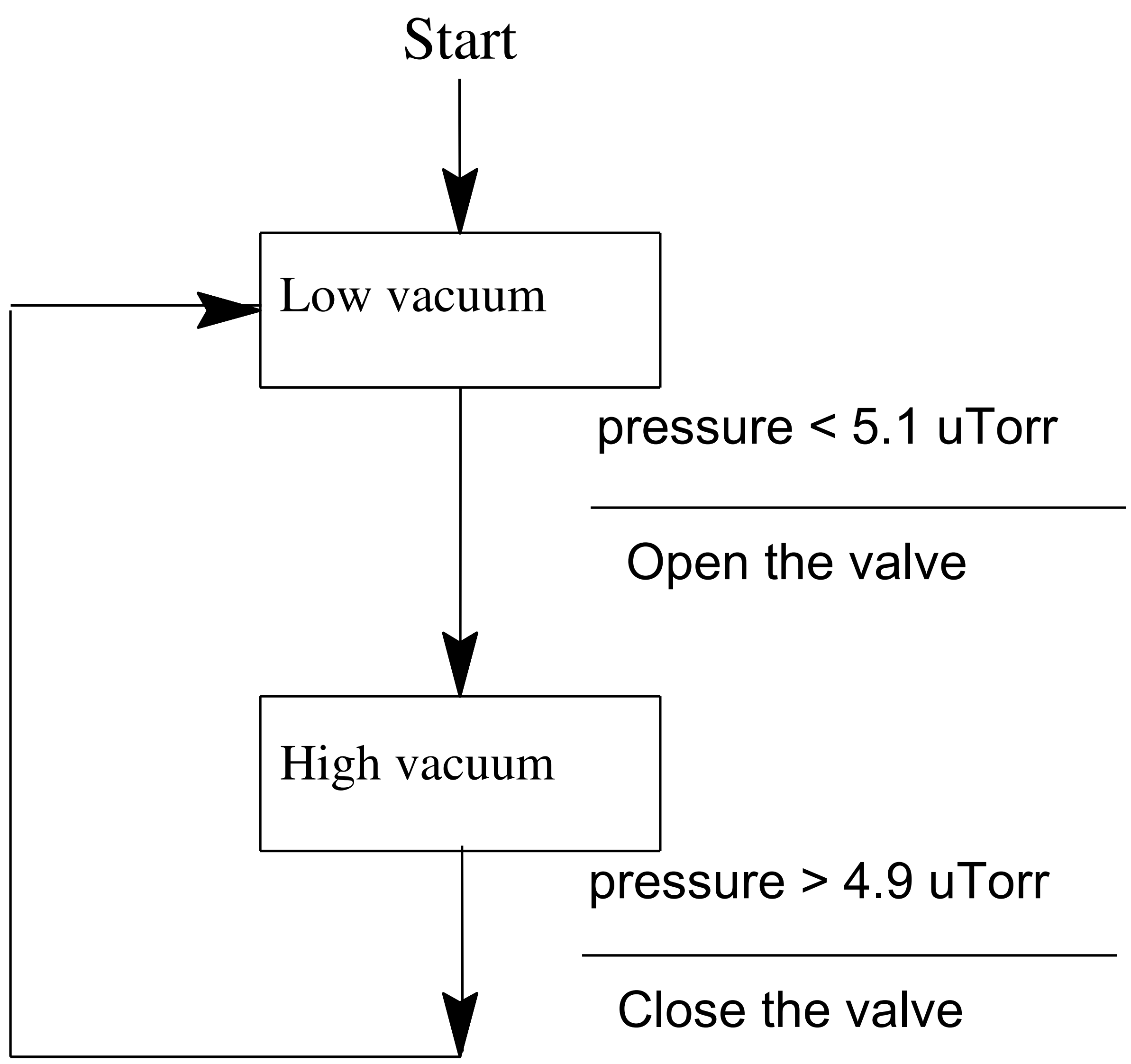
The Best Place for the Sequencer

- Recent versions of the sequencer can be run either in an IOC or as a standalone program on a workstation
- Traditionally sequencers run in 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 Transition Diagrams



STD Example



Start
Low vacuum
pressure < 5.1 uTorr
Open the valve
High vacuum
pressure > 4.9 uTorr
Close 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 {
       ...
    }
}
```

SNL: General Structure and Syntax

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 in the vxWorks environment.
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; it will do these actions even if it re-enters from the same state.
exit {*actions*}	Actions to do before exiting this state to another state. With **option** -x; it will do these actions 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 channel 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,   PressureRB1  )
```

Declarations – Event Flags

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

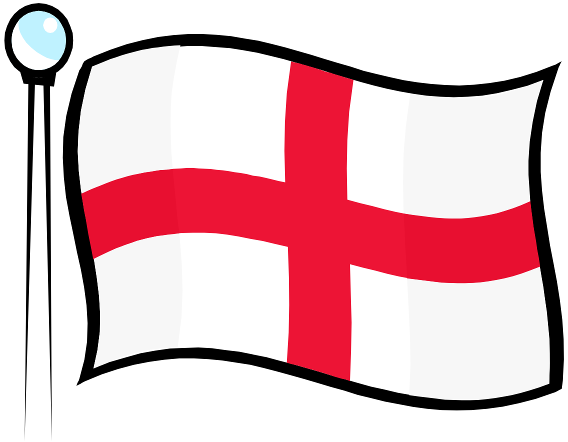
```
evflag    event_flag_name;
```

- 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. It is declared internally as a double; constant arguments to the delay function **must** contain a decimal point.

  – 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.*

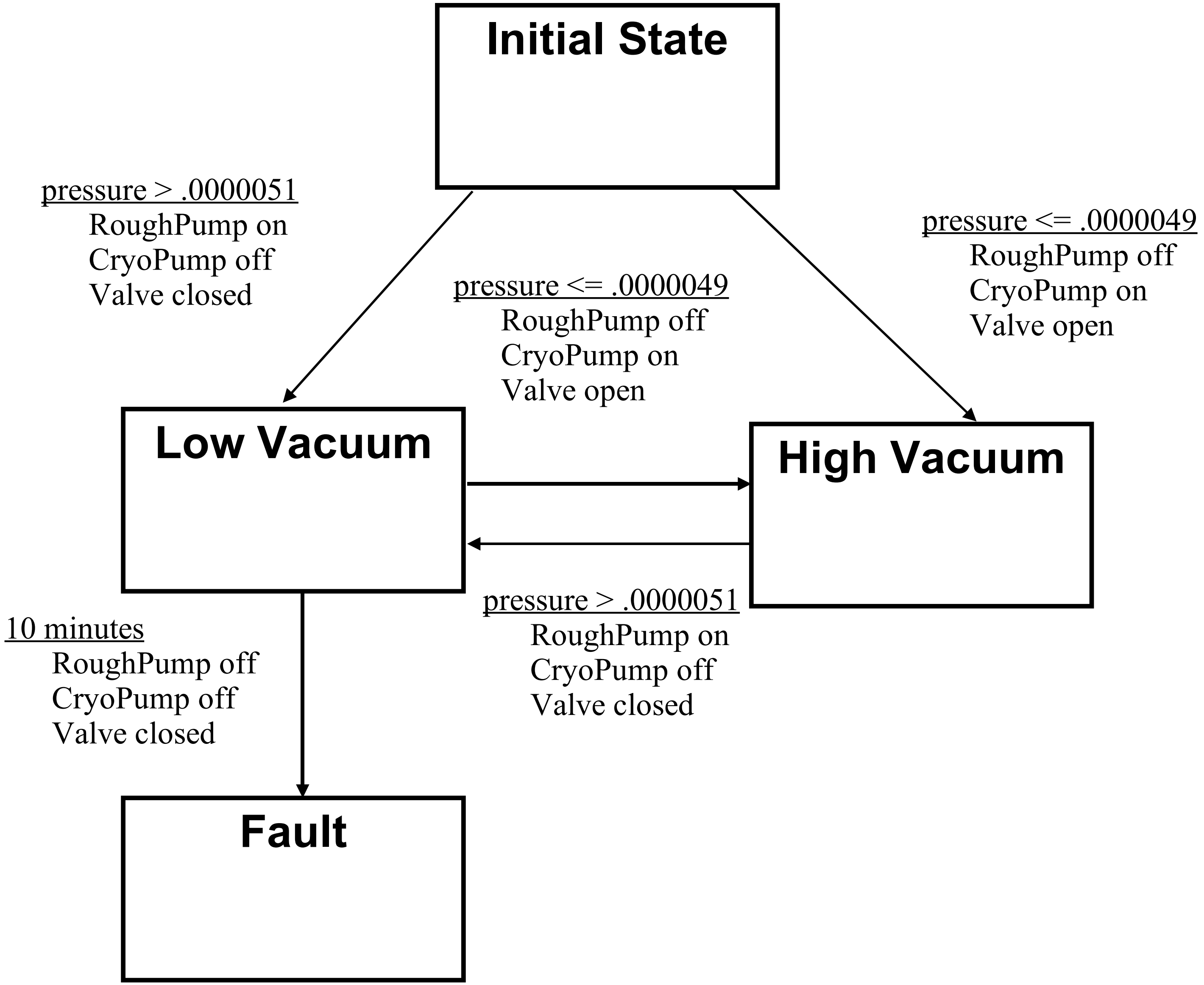
  %% escapes one line of C code

  %{

  escape any number of lines of C code

  }%

Example – State Definitions and Transitions



Example – Declarations

```
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  ;
```

Example – State Transitions, Actions Omitted

```
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 – Initial 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
      }
```

Example – State low_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
}
```

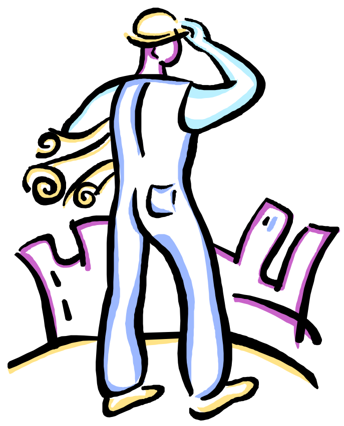
Example – State high_vacuum

```
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
    }
```

Example – State fault

```
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
- Commands are provided to display information about the state programs currently executing

Executing a State Program

From an IOC console

- On vxWorks:

```
seq &vacuum_control
```

- On other operating systems:

```
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);
```

- On vxWorks you can reload and restart

```
seqStop vacuum_control
```

... edit, recompile ...

```
ld < example.o
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`)

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.*

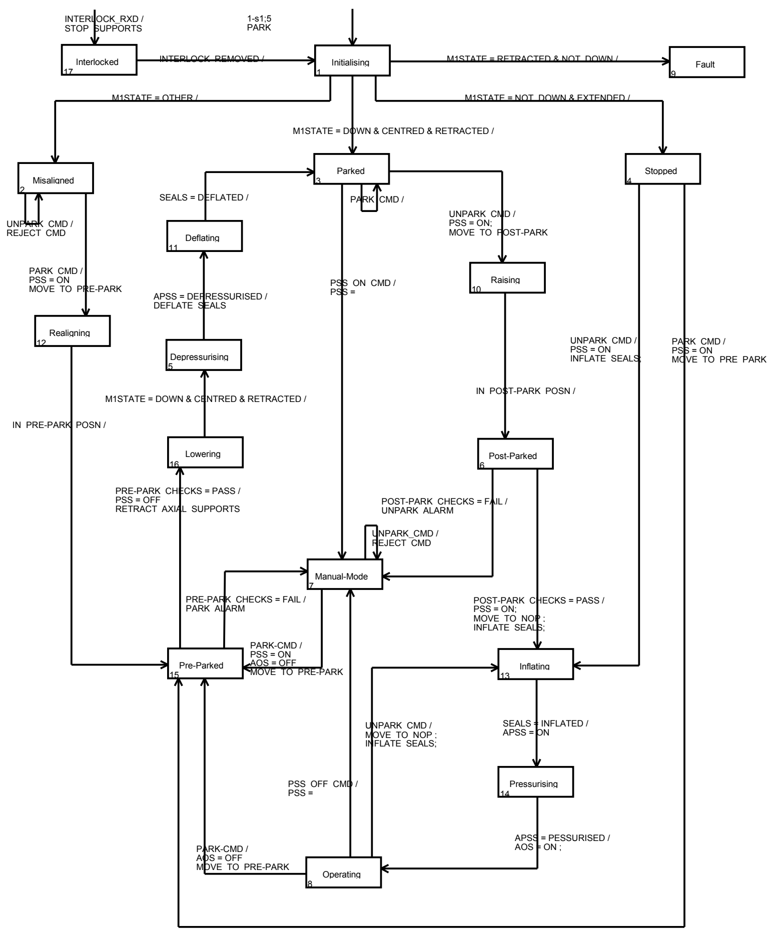
  pvFreeQ(*var_name*)

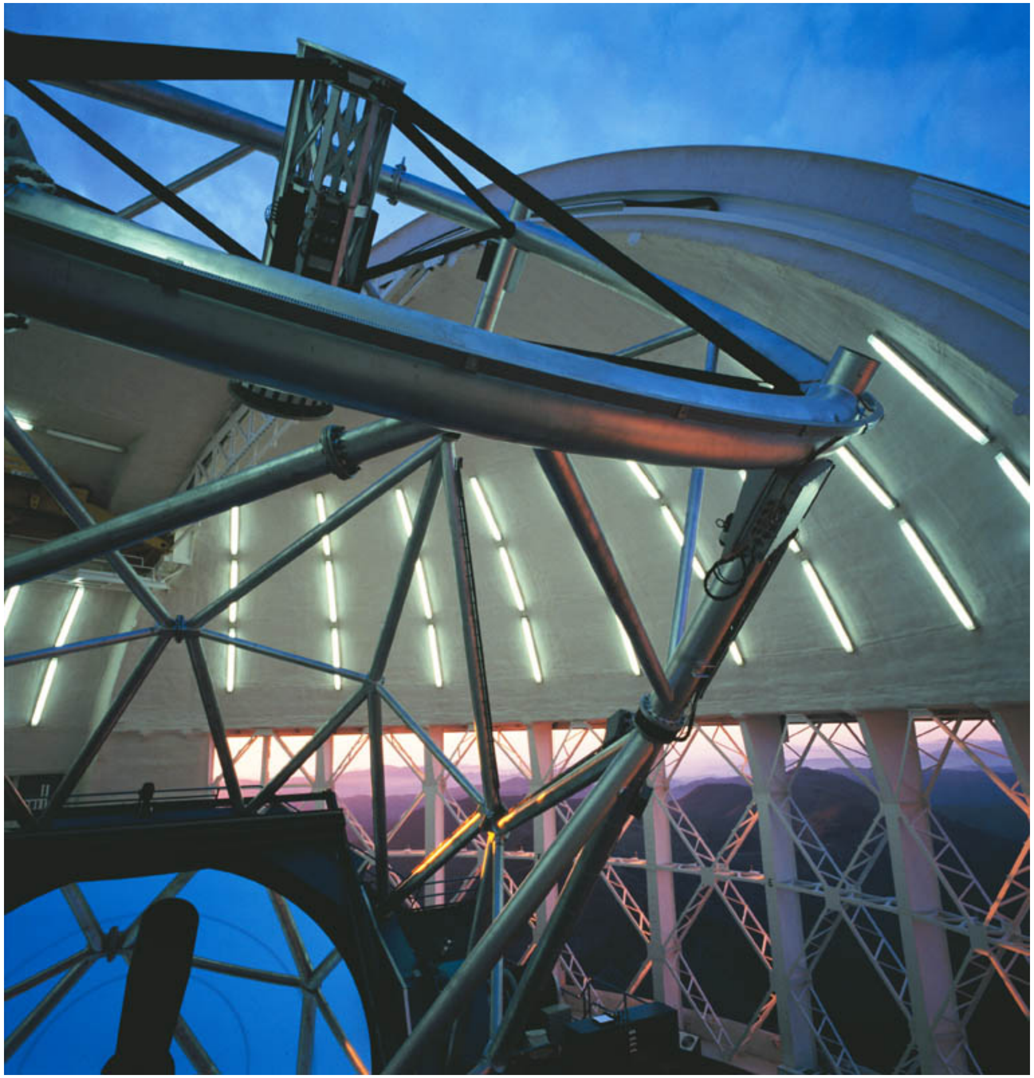
Advantages of SNL

- 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 for you
- File access can be implemented as part of the sequence

When to use the sequencer

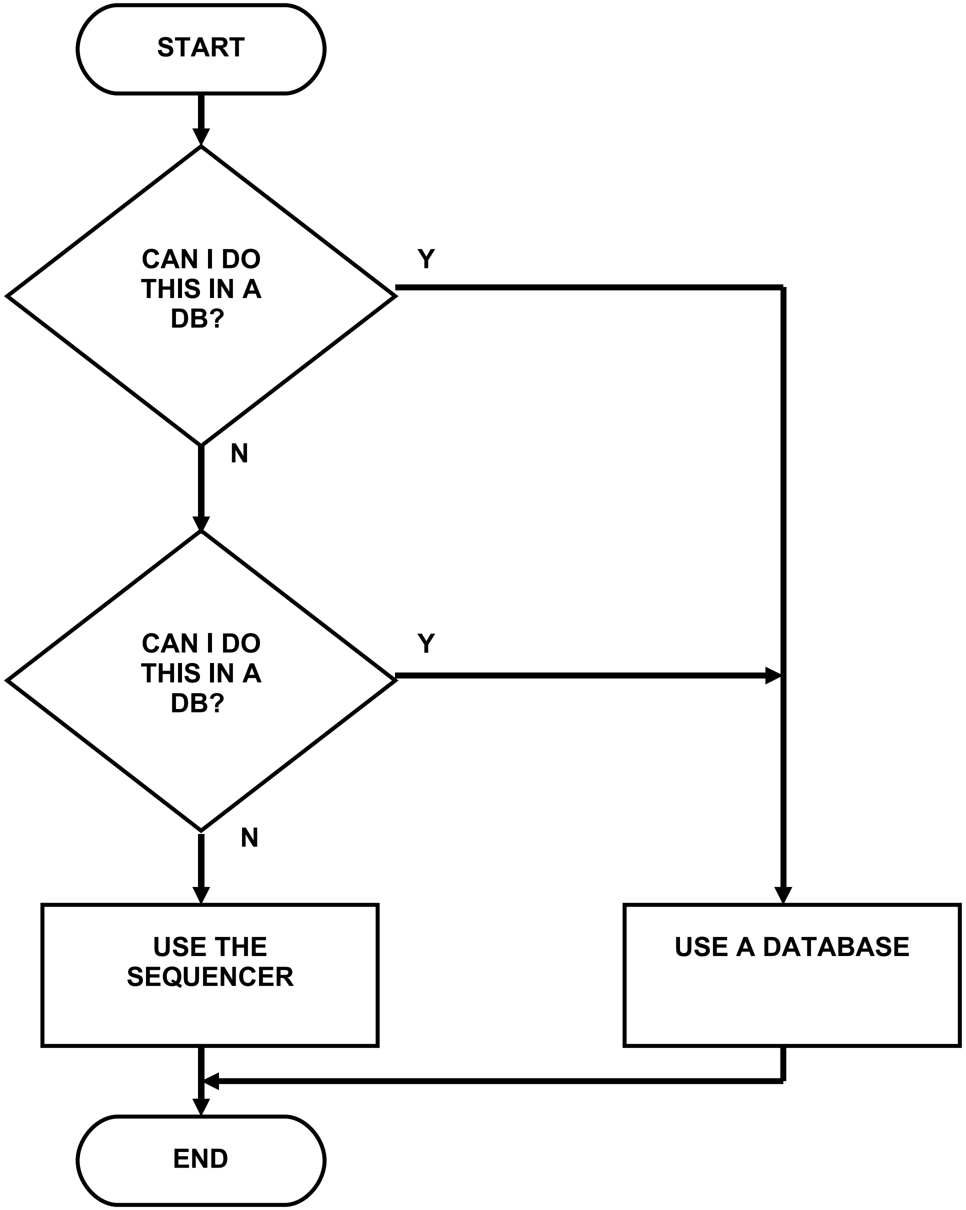
- For sequencing complex events
- E.g. parking and unparking a telescope mirror





Photograph courtesy of the Gemini Telescopes project

Should I Use the Sequencer?



Acknowledgments

- Slides for this presentation have been taken from talks prepared by the following people
  - Bob Dalesio (LANL/SNS/LCLS)
  - Deb Kerstiens (LANL)
  - Rozelle Wright (LANL)
  - Ned Arnold (Argonne)
  - John Maclean (Argonne)