State Notation Language and the Sequencer

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USPAS June 2010 — EPICS Control Systems

Outline

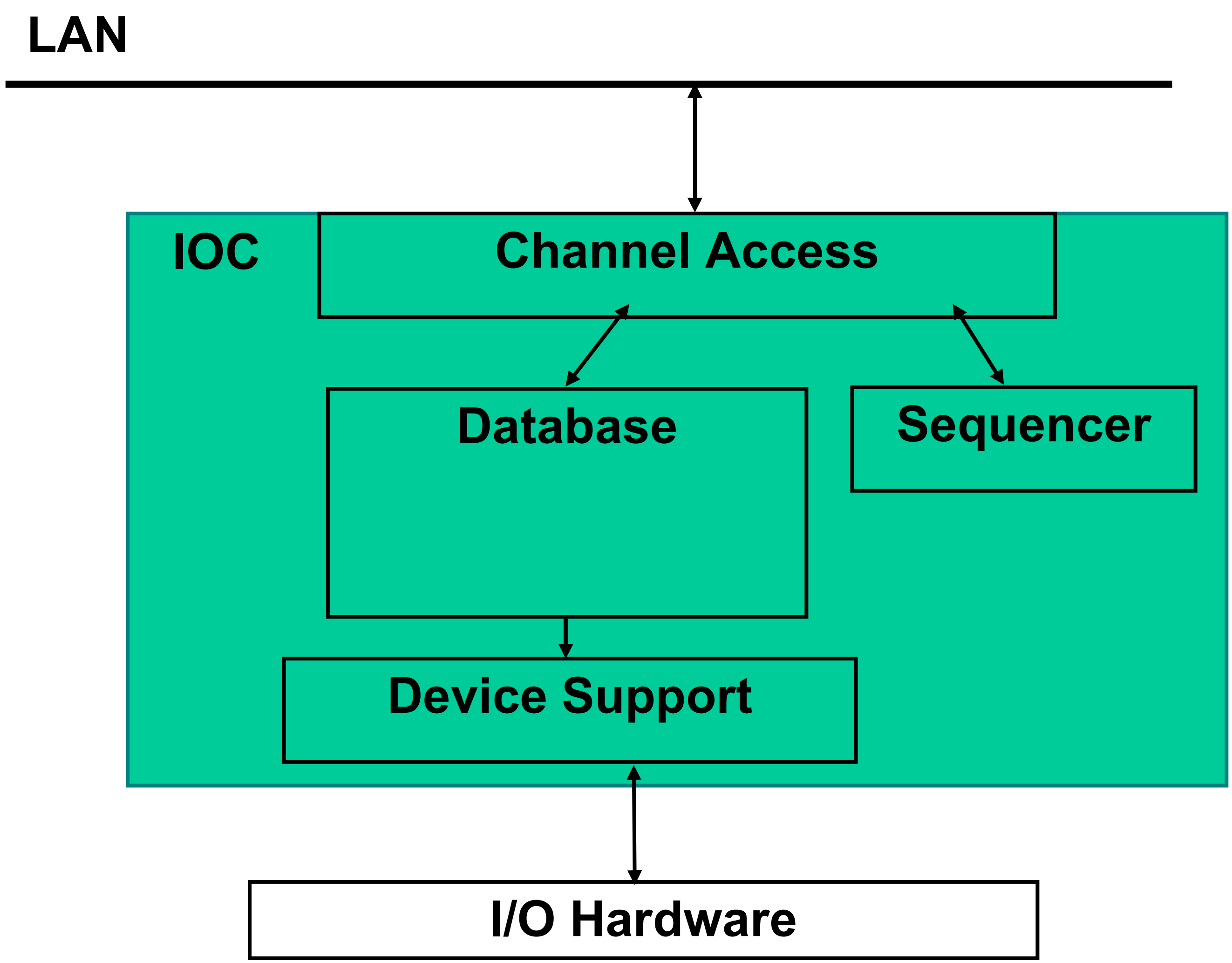
- What is State Notation Language (SNL)
- Where it fits in the EPICS toolkit
- Components of a state notation program
- Some notes on the Sequencer runtime
- Building, running and debugging a state notation program
- Additional features
- When to use it

- This talk does not cover all the features of the sequencer
- Consult the reference manual for more information
  - http://www-csr.bessy.de/control/SoftDist/sequencer/

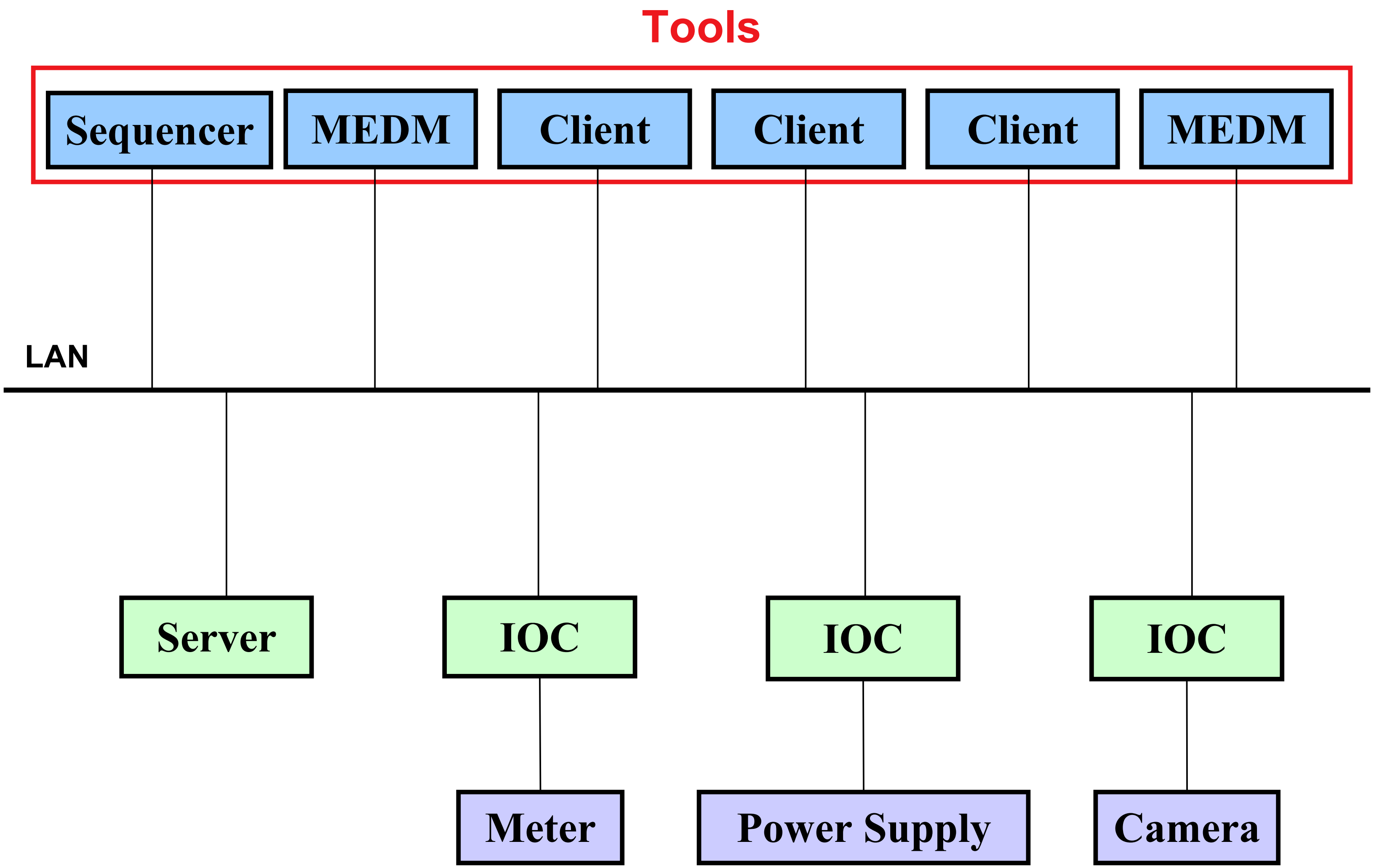
SNL and the Sequencer

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

Where is the Sequencer?



Where is the Sequencer?



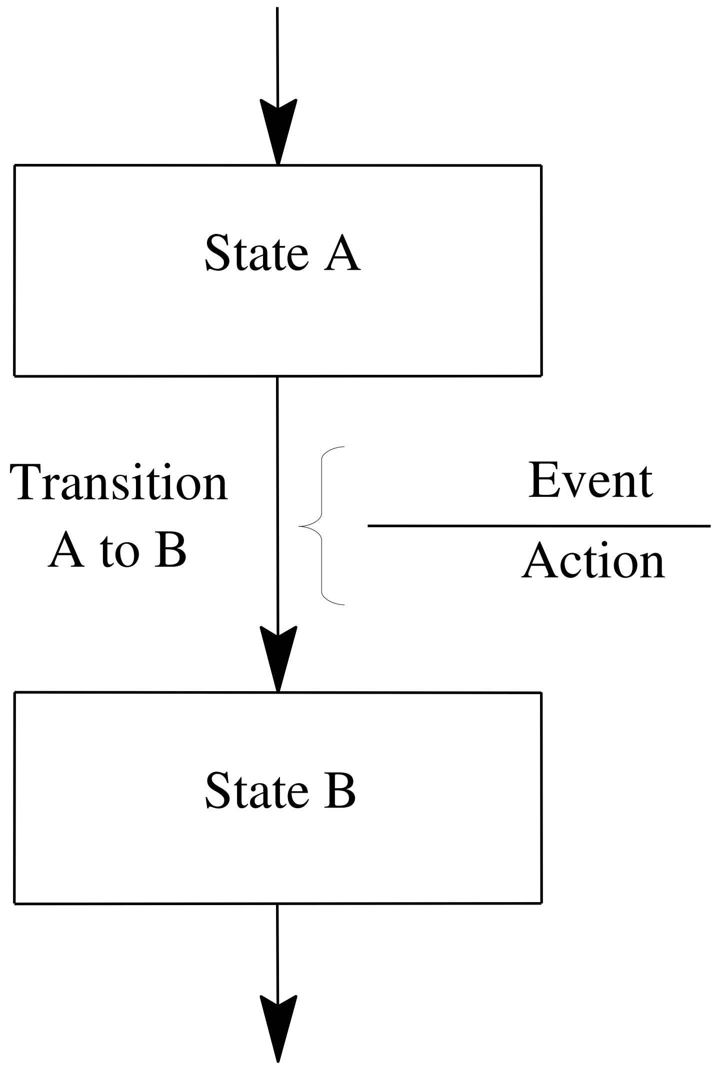
The Best Place for the Sequencer

- Traditionally sequencers run in the IOC
- Recent versions can be run either within an IOC or as a standalone program on a workstation
- Locating them within the IOC they control makes them easier to manage and independent of network issues
- 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

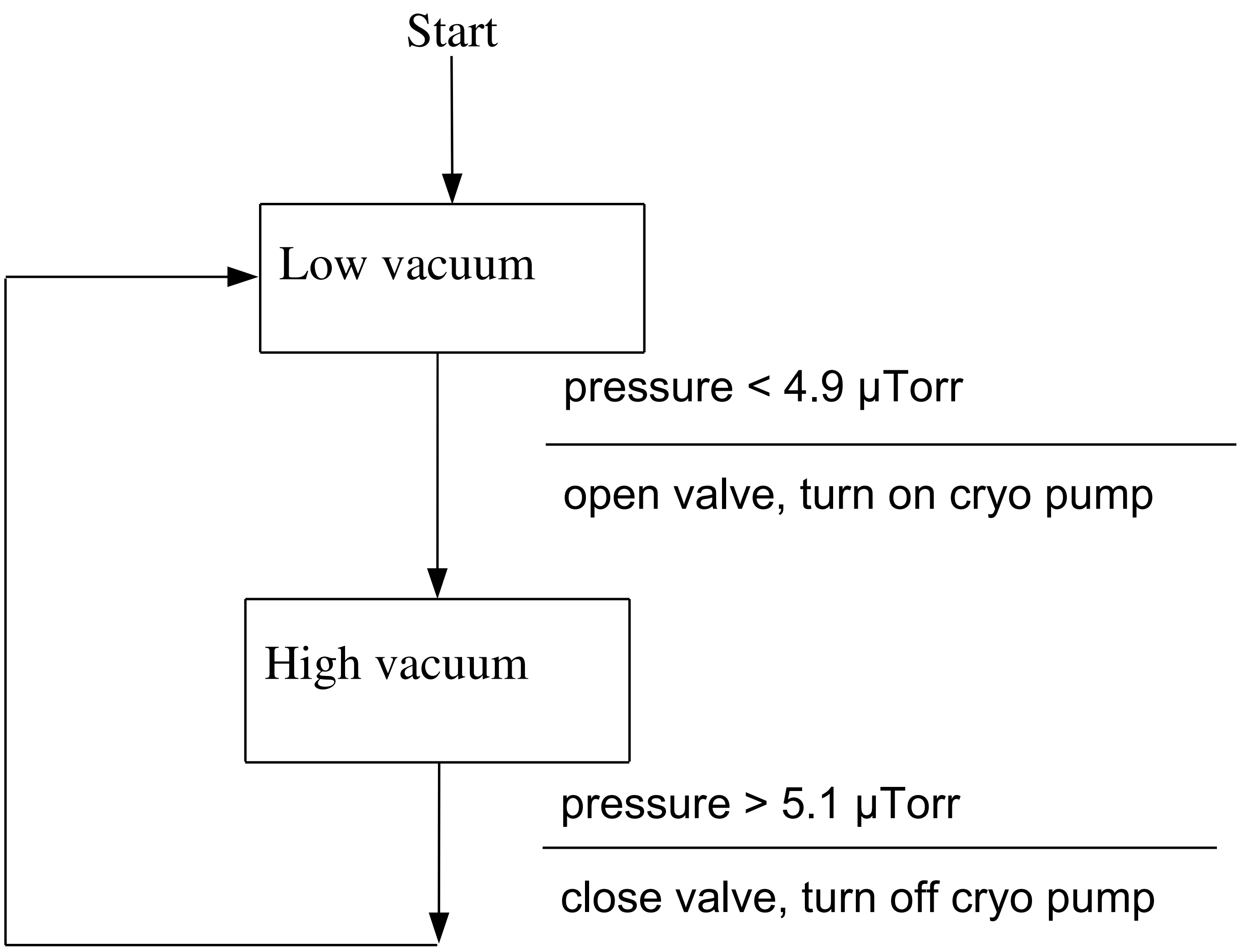
Some Definitions

- 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 evaluates to TRUE

SNL implements State Transition Diagrams



Example State Transition Diagram



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`* `{`	Each state set becomes a separate task or thread.
`state` *`name`* `{`	A state is somewhere the task waits for events. When an event occurs it checks to see which action it should execute. The first state defined in a state set is the initial state.
`option` *`flag`*`;`	A state-specific option.
`when` `(`*`event`*`) {`	Define events for which this state waits.
`}` **`state`** *`next`*	Specifies the state to go to when these actions are complete.
`entry` `{`*`actions`*`}`	Actions to do on entering this state. With **`option`** `-e;` it will do these actions even if it enters from the same state.
`exit` `{`*`actions`*`}`	Actions to do on exiting this 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 channels in when clauses, they must be monitored

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

- Use preprocessor macros to aid readability:

```
#define varMon(t,n,c) t n; assign n to c; monitor n;
varMon(float, pressure, "PressureRB1")
```

Declarations - Event Flags

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

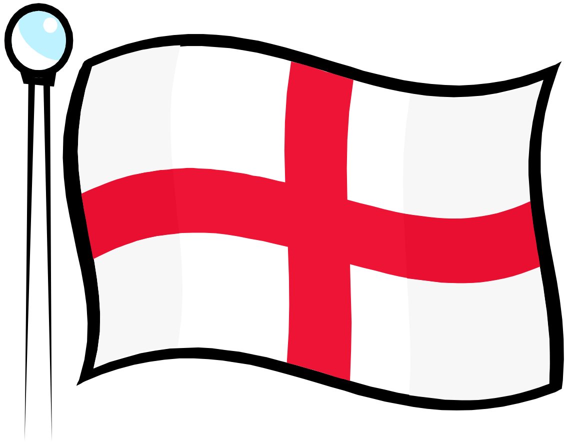
```
evflag     event_flag_name;
```

- 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, e.g.

```
evflag     pressure_event;
sync       pressure pressure_event;
```



Events

Event: A specific condition on which associated actions 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 (this is not a task delay!):

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

  - The delay time is in seconds and is a double; literal constant arguments to the delay function *must* contain a decimal point.
  - The timer starts when the state containing it was entered.
  - Use the state specific `option -t;` to stop it from being reset when transitioning to the same state.

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))
```

- Any combination of the above event types

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.*

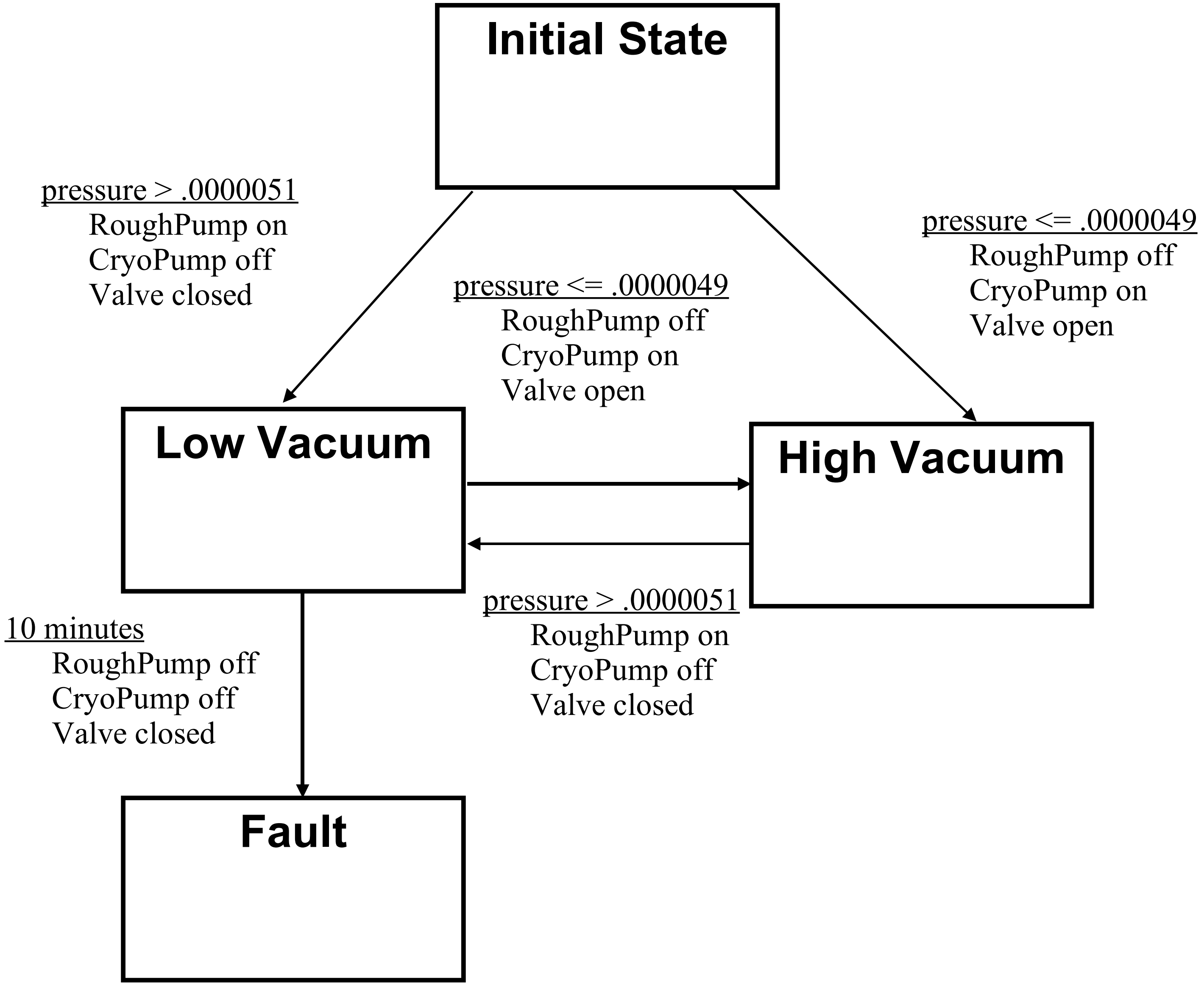
%% escapes one line of C code

%{

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 > .0000049){
                } 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 > .0000049){
                        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

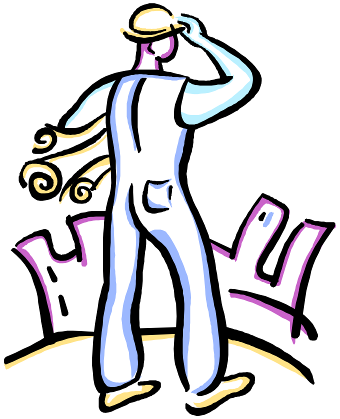
```
state high_vacuum{
            entry {
                  strcpy(CurrentState,"High Vacuum");
                  pvPut(CurrentState);
            }
            when (pressure > .0000051){
                  RoughPump = 1;
                  pvPut(RoughPump);
                  CryoPump = 0;
         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

`seqcar`

displays information on all channel access 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
```

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 variable's monitor queue. Remains true until queue is empty.

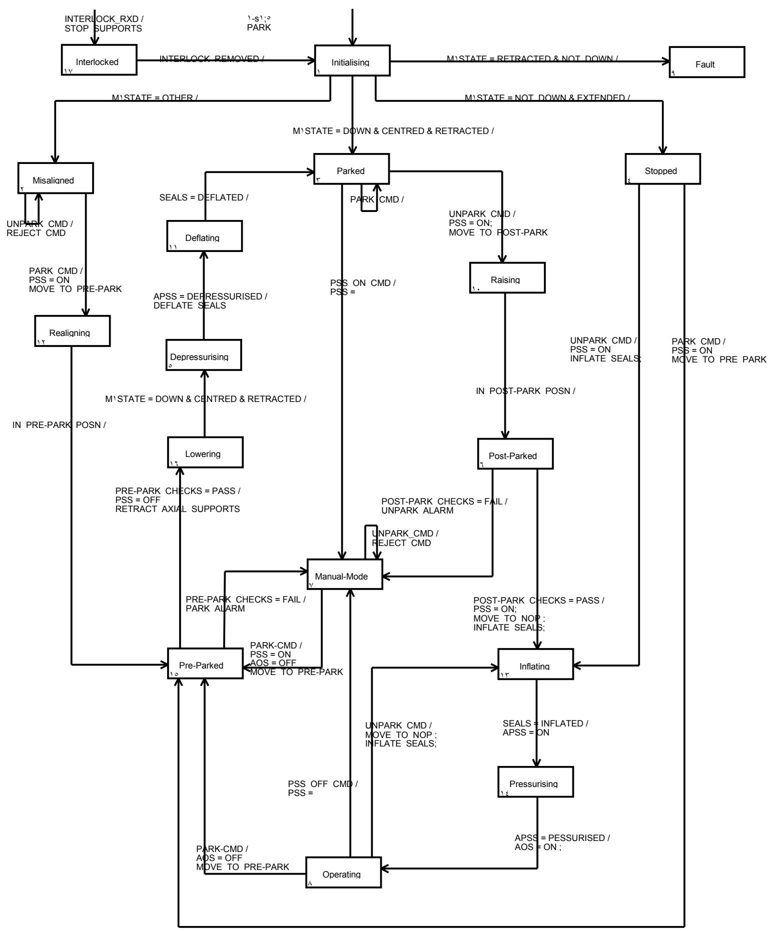
pvFreeQ(*var_name*)

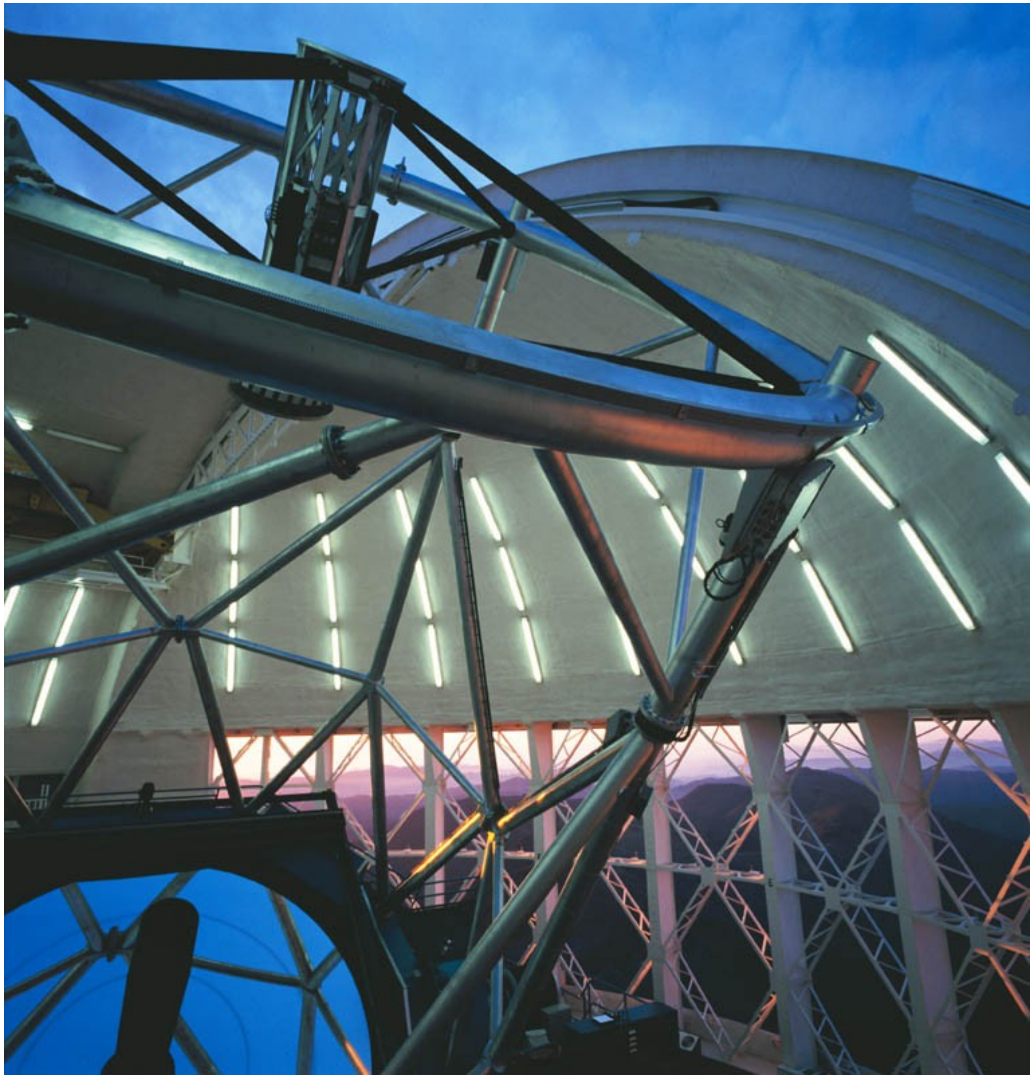
Advantages of SNL

- 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

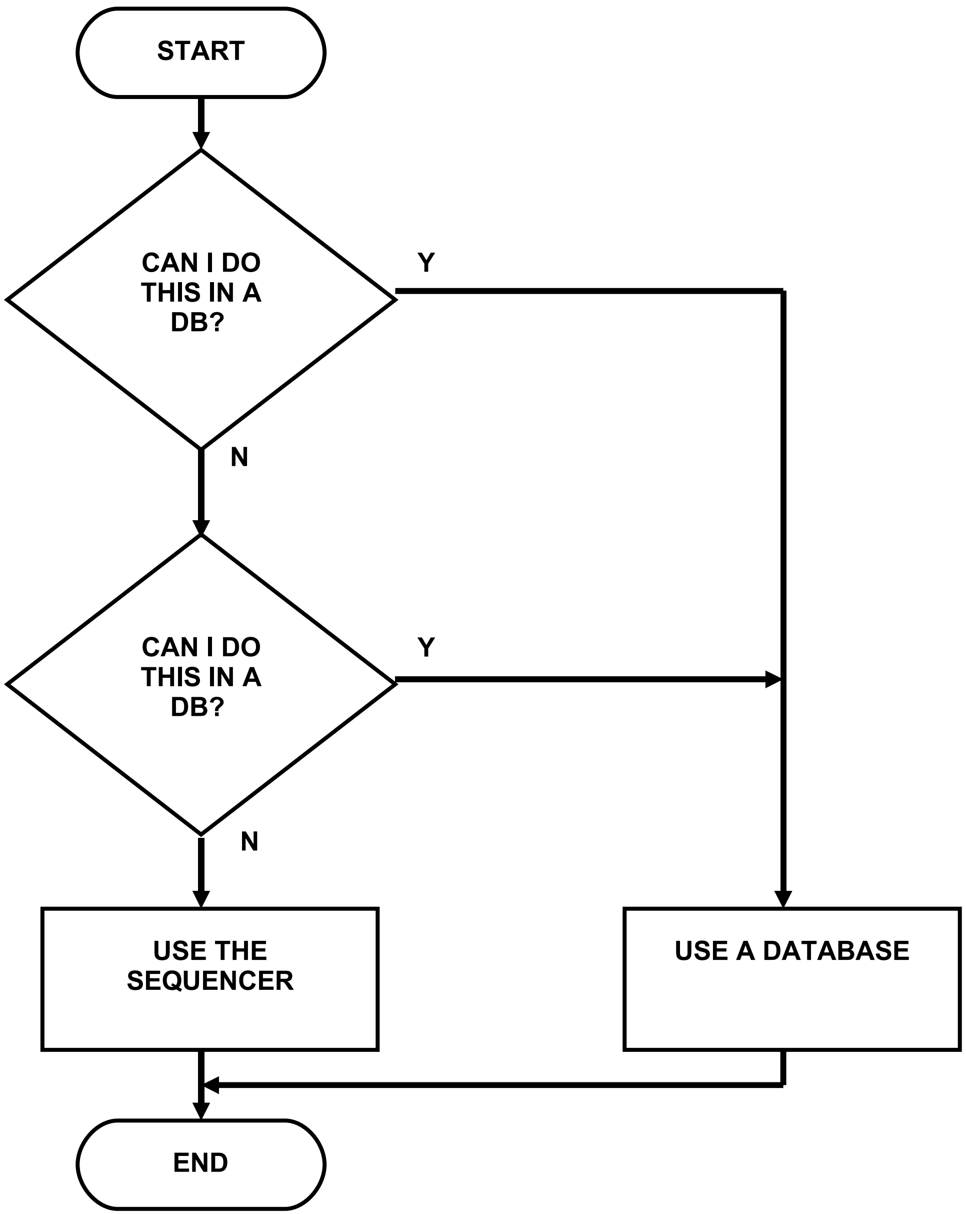
- For sequencing complex events
- E.g. parking and unparking a telescope mirror





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)