The Spin Model Checker
- Advanced Features

Moonzoo Kim

CS Dept. KAIST

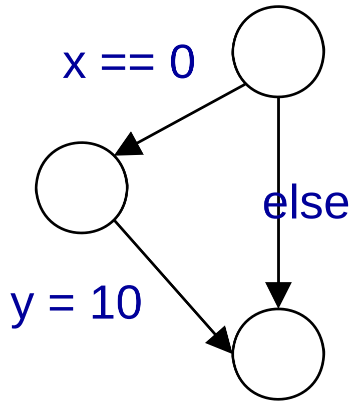
Review: 6 Types of Basic Statements

- Assignment: always executable
  - Ex. **`x=3+x`**, **`x=run A()`**
- Print: always executable
  - Ex. **`printf(“Process %d is created.\n”,_pid);`**
- Assertion: always executable
  - Ex. **`assert( x + y == z)`**
- Expression: depends on its value
  - Ex. **`x+3>0`**, **`0`**, **`1`**, **`2`**
  - Ex. **`skip, true`**
- Send: depends on buffer status
  - Ex. **`ch1!m`** is executable only if **`ch1`** is not full
- Receive: depends on buffer status
  - Ex. **`ch1?m`** is executable only if **`ch1`** is not empty

Usages of If-statement

```
/* find the max of x and y */
If
:: x >= y -> m =x
:: x <= y -> m = y
fi
```

```
/* necessity of else */
/* in C, if(x==0) y=10; */
If
:: x == 0 -> y = 10
:: else /* i.e., x != 0 */
fi
```



```
/* Random assignment */
If
:: n=0
:: n=1
:: n=2
fi
```

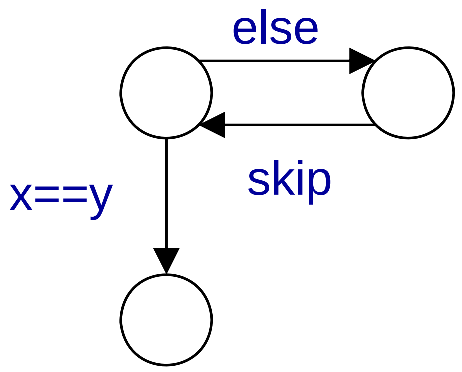
```
/* dubious use of else with receive statement */
If
:: ch?msg1 -> …
:: ch?msg2 ->
:: else -> … /* use empty(ch) instead*/
fi
```

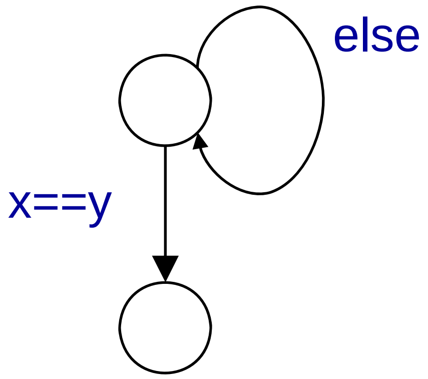
Usages of Do-statement

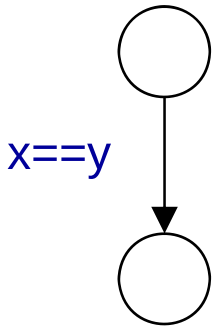
```
do
:: (x == y) -> break
:: else -> skip
od
```

```
Loop:   if
        :: (x == y) -> skip
        :: else -> goto Loop
        fi
```

```
(x == y)
```







Note that break or goto is not a statement, but control-flow modifiers

More Usages of Various Operators

- More operators
  - The standard C preprocessors can be used
    - #define, #if, #ifdef, #include
  - To overcome limitation of lack of functions
    - #define add(a,b,c) c = a + b
    - inline add(a,b,c) { c = a + b }
    - Note that these two facilities still do not return a value
  - Build multi-dimension array
    - typedef array {byte y[3];}
      array x[2];
      x[2].y[1] = 10;
  - (cond -> v1: v2) is used as (cond? v1: v2) in C

More Usages of Various Operators

- Predefined variable
  - else: true iff no statement in the current process is executable
  - timeout : 1 iff no statement in the model is executable
  - _: a scratch variable
  - _pid: an ID of current process
  - _nr_pr: a total # of active processes
  - _last: an ID of the process executed at previous step
  - STDIN: a predefined channel used for simulation
  - Remote reference
    - name[pid]@label_name
      - name: proctype name
    - name[pid]:var_name

Atomic

- atomic { g1; s1;s2;s3;s4}
  - A sequence of statements g1;s1;s2;s3;s4 is executed without interleaving with other processes
  - Executable if the guard statement (g1)is executable
    - g1 can be other statement than expression
- If any statement other than the guard blocks, atomicity is lost.
  - Atomicity can be regained when the statement becomes executable

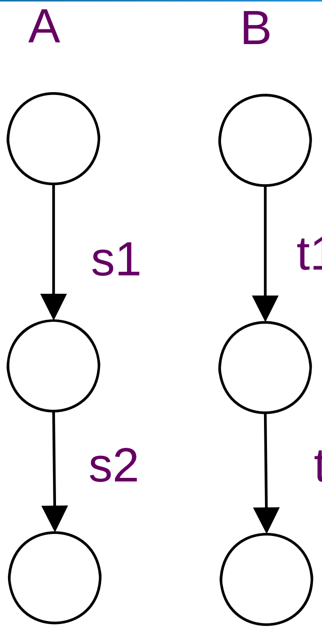
d_step

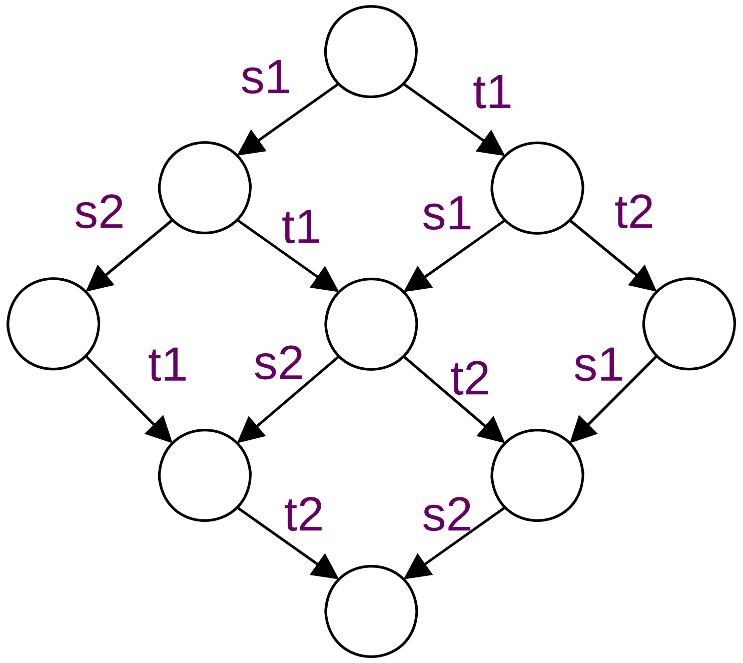
- d_step { g1; s1; s2;s3}
  - g1,s1, s2, and s3 must be deterministic (non-determinism is not allowed)
  - g1,s1,s2, and s3 must not be blocked
- Used to perform intermediate computations as a single indivisible step
  - If non-determinisim is present inside of d_step, it is resolved in a fixed and deterministic way
    - For instance, by always selecting the first true guard in every selection and repetition structure
  - Ex. Sorting, or mathematical computation
- Goto-jumps into and out of d_step sequences are forbidden

atomic v.s. d_step

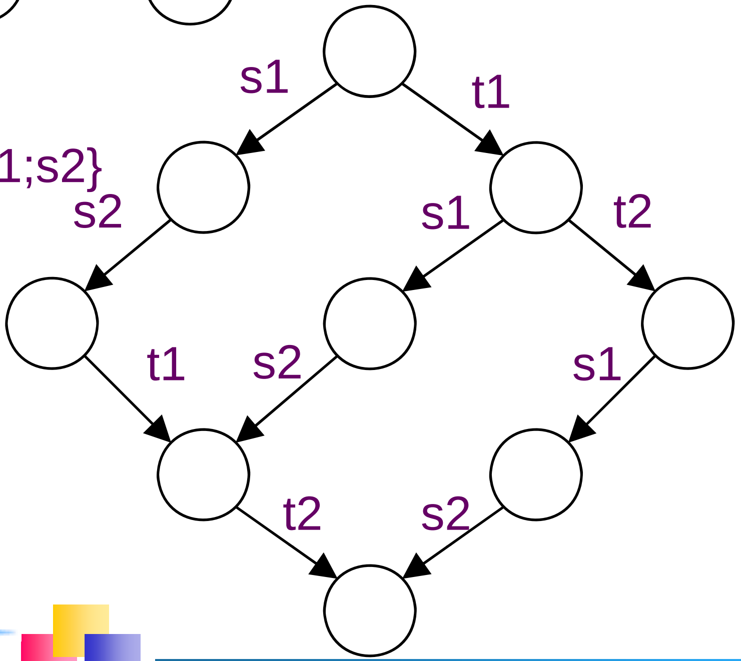
- Atomic and d_step are often used in order to reduce the size of a target model
- Both sequences are executable only when the guard statement is executable
  - **atomic**: if any other statement blocks, atomicity is lost at that point; it can be regained once the statement becomes executable later
  - **d_step**: it is an error if any statement other than the guard statement blocks
- Other differences:
  - **d_step**: the entire sequence is executed as *one* single transition.
  - **atomic**: the sequence is executed step-by-step, but without interleaving, it can make non-deterministic choices
- Caution:
  - infinite loops inside atomic or d_step sequences *are not* detected
  - the execution of this type of sequence models an indivisible step, which means that it cannot be infinite

Examples: atomic v.s. d_step

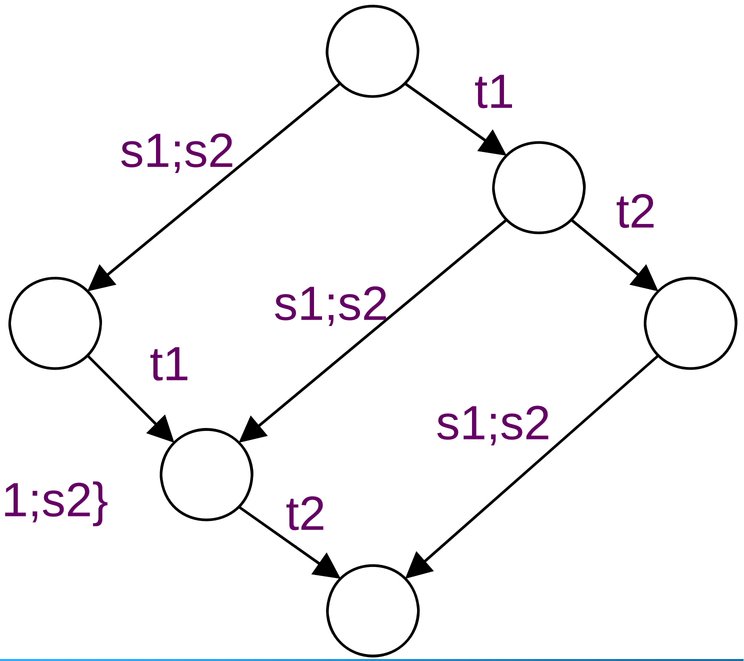




atomic{s1;s2}



d_step{s1;s2}



Rendezvous Comm. within atomic Sequences

- A sender performs a sending operation and a receiver performs a receiving operation at the same time for rendezvous communication
- If a sender has ch!msg in the atomic clause, after the rendezvous handshake, the sender loses its atomicity
- If a receiver has ch?msg in the atomic clause, after the rendezvous handshake, the receiver continues its atomicity
- Therefore, if both operations are in atomic clauses, atomicity moves from a sender to a receiver in a rendezvous handshake

unless

- {guard1; <stmts1>} unless {guard2; <stmts2>}
  - To provide exception handling, or preemption capability
- The unless statement is executable if either
  - the guard statement of the main sequence is executable, or
  - the guard statement of the escape sequence is executable
- <stmts1> can be executed until guard2 becomes true. If then, <stmts2> becomes executable and <stmts1> is not executable anymore
  - Unless clause (<stmts2>) preempts a main clause (<stmts1>) if guard2 is executable, i.e., main clause is stopped.
  - Once unless clause becomes executable, no return to the main clause
- Resembles exception handling in languages like Java and ML

Embedded C Code

- Spin versions 4.0 and later support the inclusion of embedded C code into Promela model
  - `c_expr  :` a user defined boolean guard
  - `c_code  :` a user defined C statement
  - `c_decl  :` declares data types
  - `c_state:` declares data objects
  - `c_track:` to guide the verifier whether it should track the value of data object or not
- Embedded C codes are trusted blindly and copied through from the text of the model into the code of `pan.c`

Example 1

```
c_decl {typedef struct Coord {int x, y;} Coord;}
c_state “Coord pt” “Global” /* goes inside state vector */
int z = 3; /* standard global declaration */
active proctype example() {
   c code { now.pt.x = now.pt.y = 0;};
   do
   :: c_expr {now.pt.x == now.pt.y } ->
      c_code {now.pt.y++}
   :: else -> break
   od;
   c_code {
      printf(“values %d:%d,%d,%d\n”,
      Pexample-> _pid, now.z, now.pt.x, now.pt.y); };
   assert(false);
}
```

Communication between Embedded C and Promela

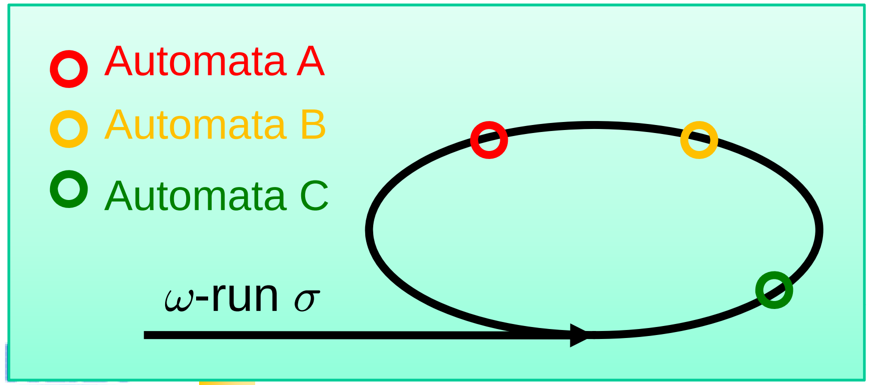
- `c_state` primitive introduces a new global data object pt of `type Coord` into the state vector
  - The object is initialized to zero according to the convention of Promela
- A global data object in a Promela model can be accessed through `now.<var>` in embedded C codes
- A local data object in a Promela model can be accessed through `P<procname>-><var>`

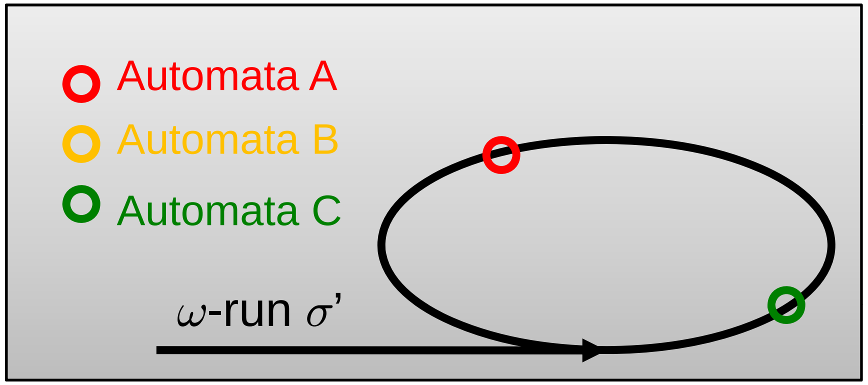
Example 2

```
c_decl {typedef struct Coord {int x, y;} Coord;}
c_code {Coord pt;}  /* Embedded declaration goes inside
   state vector */
int z = 3; /* standard global declaration */
active proctype example() {
   c_code { now.pt.x = now.pt.y = 0;};
   do
   :: c_expr {now.pt.x == now.pt.y } ->
      c_code {now.pt.y++}
   :: else -> break
   od;
   c_code {
      printf(“values %d:%d,%d,%d\n”,
      Pexample-> _pid, now.z, now.pt.x, now.pt.y); };
   assert(false);
}
```

Weak Fairness v.s. Strong Fairness

- Strong fairness
  - An ω-run σ satisfies the strong fairness requirement if it contains infinitely many transitions from every component automaton that is enabled infinitely **often** in σ
    - `FAIRNESS running` in NuSMV
- Weak fairness
  - An ω-run σ satisfies the weak fairness requirement if it contains infinitely many transitions from every component automaton that is enabled infinitely **long** in σ





Examples

```
byte x;
active proctype A() {
do
:: x=2;
:: x=3;
od;}
/* [] <> x==2
F: no fairness
F: weak fairness */
```

```
byte x;
active proctype A() {
do
:: x=2;
od;}
active proctype B() {
do
:: atomic{x==2 -> x=1;}
od;}
/* [] <> (x==1)
F: no fairness
T: weak fairness, thus T
with strong fairness */
```

```
byte x;
active proctype A() {
do
:: x=2;
:: x=3;
od;}

active proctype B() {
do
:: atomic{x==2 -> x=1;}
od;}

/*  [] <> (x==1)
F: if weak fairness is
applied
*/
```