Distributed Systems Programming F29NM1

Promela I

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Overview

- Basic building blocks of Promela programs.
- Structured data types.
- Process definition, instantiation & execution.
- Concurrency and Promela programs.
- Non-deterministic behaviour & basic synchronization.

Promela Programs

- The basic building blocks of Promela programs are:
  - processes
  - channels
  - variables
- Processes model the behaviour of components of a system and are by definition **global** objects.
- Channels and variables define the environment in which processes exist and can be either **local** of **global**.

Executability of Statements

- Promela does not make a distinction between a **condition** and a **statement**, *e.g.* the simple boolean condition `a == b` represents a statement in Promela.
- Promela statements are either **executable** or **blocked**. The execution of a statement is conditional on it not being blocked.
- Promela's notion of statement executability provides the basic means by which process synchronization can be achieved.

```
while (a != b) skip /* conventional busy wait */

(a == b)            /* Promela equivalent */
```

Variables and Basic Data Types

- Promela variables provide the means of storing information about the system being modelled.
- A variable may hold global information on the system or information that is local to a particular component (process).
- Promela supports five basic data types:

Name	Size (bits)	Usage	Range
`bit`	1	unsigned	$0 \ldots 1$
`bool`	1	unsigned	$0 \ldots 1$
`byte`	8	unsigned	$0 \ldots 255$
`short`	16	signed	$-2^{15} - 1 \ldots 2^{15} - 1$
`int`	32	signed	$-2^{31} - 1 \ldots 2^{31} - 1$

Variable Declarations

- Like all well-structured programming languages, Promela requires that variables must be declared before they can be used.
- Variable declarations follow the style of the C programming language, *i.e.* a basic data type followed by one or more identifiers and optional initializer:

  ```
  byte count, total = 0;
  ```

  An initializer must be an expression of the appropriate basic type.
- By default all variables of the basic types are initialized to 0. Note that as in C, 0 (zero) is interpreted as false while any non-zero value is interpreted as true.

Structured Data Types

- Arrays – an array type is declared as follows:

  `int table[max]`

  Note that this generates an array of `max-1` integers, *i.e.* `table[0], table[1], ...  table[max-1]`

- Enumerated Types – a set of symbolic constants is declared as follows:

  `mtype = {LINE_CLEAR, TRAIN_ON_LINE, LINE_BLOCKED}`

  Note: a program can only contain one `mtype` declaration which must be global.

- Structures – a record data type is declared as follows:

  `typdef msg {byte data[4], byte checksum}`

  Note: Structure access is as in C:

  `msg message; ... message.data[0]`

Identifiers, Constants & Expressions

- Identifiers: An identifier is a single letter, a period symbol, or underscore followed by zero or more letters, digits, periods or underscores.

- Constants: A constant is a sequence of digits that represents a decimal integer. Symbolic constants can be defined by means of `mtype` or via a C-style macro definition, *e.g.*

  `#define MAX 999`

- Expressions: An expression is built up from variables, identifiers and constants using the following operators:

`+, -, *, /, %, --, ++,`	arith
`>, >=, <, <=, ==, !=,`	relational
`&&, ||, !,`	logicals
`&, |, ~, ^, >>, <<,`	bits
`!, ?,`	channels
`(), [],`	group/index

Process Types

- A process declaration begins with the keyword `proctype` and contains:
  - process identifier;
  - formal parameter list;
  - sequence of local variable declarations & statements
- Syntactically a process declaration has the following form:

```
proctype name( /* formal parameter list */ )
{
    /* local declarations and statements */
}
```

  Note: `/*` and `*/` delimit comments in Promela.

The `init` Process

- All Promela programs must contain an `init` process which is similar to the `main()` function within a C program, *i.e.* the execution of a Promela program begins with the `init` process.
- An `init` process takes the form:

```
init { /* local declarations and statements */ }
```

  The simplest and may be one of the least useful of Promela programs takes the form:

```
init { skip }
```

  Note: `skip` denotes the null statement.
- While a `proctype` definition declares the behaviour of a process, the instantiation and execution of a process definition is co-ordinated via the `init` process.

Hello World

- A simple two process system:

```
proctype hello(){ printf("Hello") }
proctype world(){ printf("World\n") }
init { run hello(); run world () }
```

- The `init` process initiates the execution of an instance of the `hello` process and the `world` process.
- The `run` operator is executable only if process instantiation is possible. A process instantiation may be blocked if too many processes are already running.
- If a `run` is executable then a `pid` or run-time process identification number is returned. The `pid` for a process can be accessed via the predefined local variable `_pid`.
- The execution of `run` does not wait for the associated process to terminate, *i.e.* further applications of `run` will be executed concurrently.

Active Proctypes

- A refinement to our simple two process system:

```
active proctype hello(){ printf("Hello") }
active proctype world(){ printf("World\n") }
```

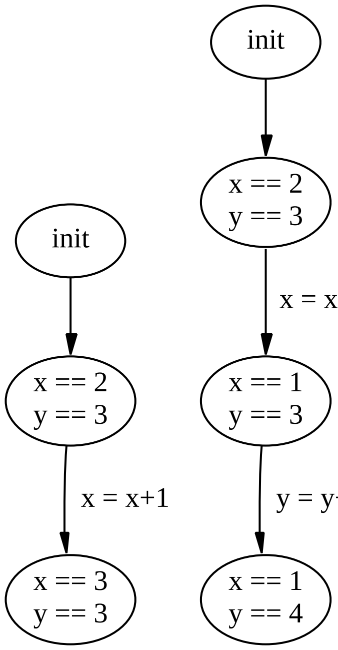
- The keyword `active` can prefix any `proctype` declaration.
- The effective of `active` is to create an instance of the associated `proctype` within the initial system state.
- Multiple instances of the same `proctype` declaration can be generated using an optional array suffix, *e.g.*

```
active [4] proctype hello(){ printf("Hello") }
active [7] proctype world(){ printf("World\n") }
```

  Note: the above will generate 4 instances of `hello` and 7 instances of `world`.

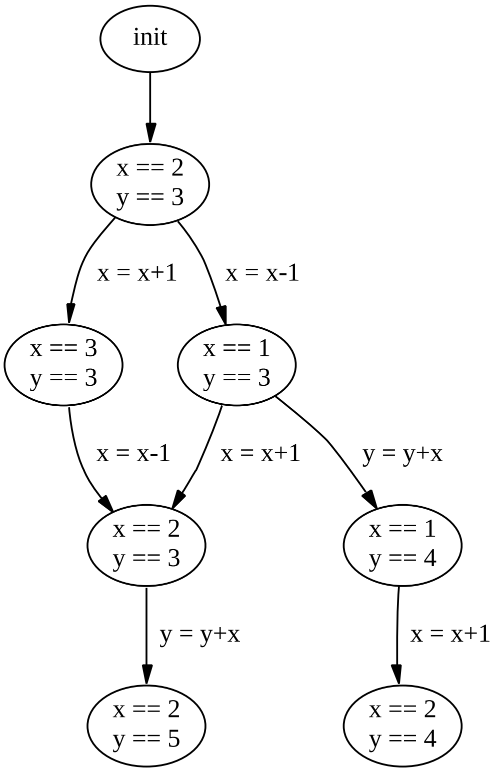
Processes as Automata

```
byte x = 2, y = 3;
proctype A(){x = x + 1}
proctype B(){x = x - 1; y = y + x}
```



Concurrency via Interleaving

```
init { run A(); run B() }
```



Deterministic & Non-Deterministic Behaviour

- **Deterministic behaviour:** a process is deterministic if for a given start state it behaves in exactly the same way if supplied with the same stimuli from its environment.
- **Non-deterministic behaviour:** a process is non-deterministic if it need not always behave in exactly the same way each time it executes from a given start state with the same stimuli from its environment.

More Non-Deterministic Behaviour

- Consider the following two process system:

  ```
  byte state = 1;
  proctype A() { (state == 1) -> state = state + 1 }
  proctype B() { (state == 1) -> state = state - 1 }
  init { run A(); run B() }
  ```

  note that `S1 -> S2` and `S1; S2` are equivalent.
- Note that if process `A` (`B`) terminates before process `B` (`A`) begins execution then `B` (`A`) will be blocked forever on the initial condition, *i.e.* `(state == 1)`.
- Note that if both `A` and `B` pass the condition simultaneously then both processes can terminate but the final value of `state` is unpredictable, *i.e.* 0, 1 or 2.

Dekker's Solution

```
#define true    1
#define false   0
#define Aturn   false
#define Bturn   true
bool Aruns, Bruns, t;

proctype A()
{Aruns = true;
 t = Bturn;
 (Bruns == false || t == Aturn); /* S1 */
 /* critical section */
 Aruns = false
}

proctype B()
{Bruns = true;
 t = Aturn;
 (Aruns == false || t == Bturn); /* S2 */
 /* critical section */
 Bruns = false
}

init { run A(); run B() }
```


Observations on Dekker's Solution

- Statements `S1` and `S2` ensure synchronization between `A` and `B` on **critical section** access.
- Consider the case of `S1` which occurs within the definition of process `A`: `(Bruns == false || t == Aturn)`
  - If the left disjunct holds then process `B` is not executing so it is safe for `A` to enter the critical section.
  - Else if the right disjunct holds `t` must be `false` so it is safe for `A` to enter the critical section because both disjuncts of `S2` must be false, *i.e.* process `B` is blocked.
  - Else process `A` is blocked. However, the right disjunct of `S2` must hold so it is safe for `B` to enter the critical section.
  - On exiting the critical section process `A` sets `Aruns` to `false` which has the effect of unblocking process `B`.

Atomic Sequences

- Promela provides another means of avoiding the undesirable interleaving problem illustrated above via the `atomic` operator.
- Consider the following refinement to the two process system:

```
byte state = 1;
proctype A()
{ atomic{ (state == 1) -> state = state + 1 } }
proctype B()
{ atomic{ (state == 1) -> state = state - 1 } }
init { run A(); run B() }
```

- The final value of the global variable `state` will be either 2 or 0, depending upon which process executes.
- Note that an atomic sequence restricts the level of interleaving so reduces the complexity when it comes to validating a Promela model.

Summary

Learning outcomes:

- To be able to understand and construction simple Promela programs exploiting both local and global data objects;
- To understand the Promela model for concurrent process execution;
- To be able to model synchronous behaviour between processes;

Recommended reading:

- "Concise Promela Reference" — see course homepage
- "Basic Spin Manual" — see course homepage