CS477 Formal Software Development Methods

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Slides mostly a reproduction of Theo C. Ruys – SPIN Beginners' Tutorial

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LTL Model Checking

- Model Checking Problem: Given model $\mathcal{M}$ amd logical property φ of $\mathcal{M}$, does $\mathcal{M} \models \varphi$?
- Given transition system with states Q, transition relation δ and inital state state I, say $(Q, \delta, I) \models \varphi$ for LTL formula φ if every run of (Q, δ, I), σ satisfies $\sigma \models \varphi$.

Theorem

The Model Checking Problem for finite transition systems and LTL formulae is decideable.

- Treat states $q \in Q$ as letters in an alphabet.
- Language of (Q, δ, I), $\mathcal{L}(Q, \delta, I)$ (or L(Q) for short) is set of runs in Q
- Language of φ, $\mathcal{L}\varphi = \{\sigma | \sigma \models \varphi\}$
- Question: $\mathcal{L}(Q) \subseteq \mathcal{L}(\varphi)$?
- Same as: $\mathcal{L}(Q) \cap \mathcal{L}(\neg\varphi) = \emptyset$?

How to Decide the Model Checking Problem?

- How to answer $\mathcal{L}(Q) \cap \mathcal{L}(\neg\varphi) = \emptyset$?
- Common approach:
  - Build automaton A such the $\mathcal{L}(A) = \mathcal{L}(Q) \cap \mathcal{L}(\neg\varphi)$
  - Are accepting states of A reachable? (Infinitely often?)
- How to build A?
  - One possible answer: Build a series of automata by recursion on structure of $\neg\varphi$.
  - Another possible answer: Build an automaton B such $\mathcal{L}(B) = \mathcal{L}(\neg\varphi)$; take $A = B \times Q$
- Will do at least one approach if time after Spin

Introduction to SPIN and Promela

- SPIN Background
- Promela processes
- Promela statements
- Promela communication primitives
- Architecture of (X)Spin
- Some SPIN demo's
  - hello world
  - mutual exclusion
  - alternating bit protocol

Slides based heavily on: Theo C. Ruys - SPIN Beginners' Tutorial

SPIN Documentation

- SPIN home page: http://spinroot.com/spin/whatispin.html
- SPIN book: The SPIN Model Checker: Primer and Reference Manual by Gerard J. Holzmann
- On-line Man pages: http://spinroot.com/spin/Man/index.html

SPIN Overview

- Input:
  - (Abstract) model of system
  - Behavior specification
- Output:
  - Says whether model satisfies specification
  - If models fails specification, give a system run that violates requirement (counterexample)
- Focused on correctness of process communications and interactions
- Internal details generally abstracted away

SPIN Introduction

SPIN = Simple Promela Interpreter

- Tool for analyzing logical consistent of concurrent systems
  - specifically data communication protocols
- state-of-the-art model checkers, thousands of users
- Concurrent systems described in modelling language Promela

Promela = Protocol/Process Meta Language

- Resembles C programming language
- Supports dynamic creation of concurrent processes
- limited to describing finite-state systems
- Communication via message channels
  - Synchronous (rendezvous)
  - Asynchronous (buffered)

Promela Models

Promela model consist of:

- type declarations
- channel declarations
- variable declarations
- process declarations
- [init process]

A Promela model corresponds with a (usually very large, but) finite transition system, so

- no unbounded data
- no unbounded channels
- no unbounded processes
- no unbounded process creation

Promela Skeleton Example

```
mtype = {MSG, ACK};
chan toS = ...
chan toP = ...
bool flag;

proctype Sender() {
...    /* process body */
}

proctype Receiver() {
...    /* process body */
}

init {
...    /* creates processes */
}
```


Processes

A process type (proctype) consists of

- a name
- a list of formal parameters
- local variable declarations
- body consisting a sequence of statements

Sample Process Declaration

```
proctype Sender (chan in; chan out) {
    bit sndB, rcvB;      /* local variables */
    do                   /* body beginning */
    :: out ! MSG, sndB ->
           in ? ACK, rcvB;
           if
           :: sndB == rcvB -> sndB = 1-sndB
           :: else -> skip
           fi
    od                   /* body end */
}
```

The body consist of a sequence of statements.

Processes

A process

- is defined by a proctype definition
- executes concurrently with all other processes, independent of speed of behaviour
- communicates with other processes
  - using global (shared) variables
  - using channels

May be several processes of the same type

Each process has own local state:

- process counter (location within the proctype)
- contents of the local variables

Process Creation

- Processes created with run statement
  - Returns process id
- Process createed at any point in exection (of any process)
- Processes start after execution of run statement
- Also created by active keyword before proctype declaration

Sample Proctype Declaration Skeleton

```
proctype Foo(byte x) {
   ...
}

active[3] proctype Bar(byte y) {  /* [3] opt; y init to 0 */
   ...
}

init {
  int pid2 = run Foo(2);
  run Bar(17);
  run Foo (27);
}
```

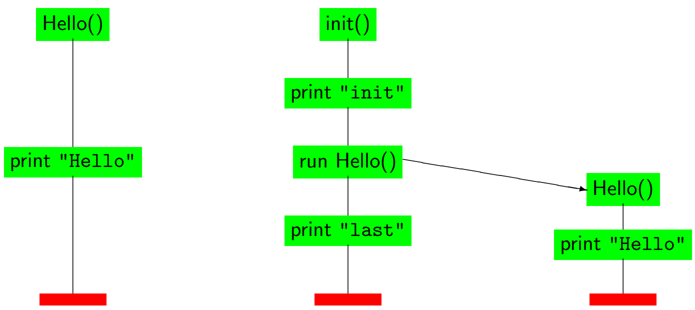

Hello World

```
/* A "Hello World" Promela model for SPIN. */
active proctype Hello() {
printf("Hello process, my pid is: %d\n", _pid);
}
init {
      int lastpid;
      printf("init process, my pid is: %d\n", _pid);
      lastpid = run Hello();
      printf("last pid was: %d\n", lastpid);
}
```

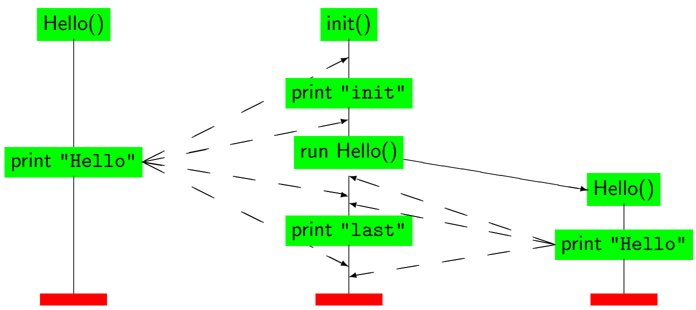

Hello World, Sample Execution

```
bash-3.2$ spin hello.pml
          init process, my pid is: 1
      Hello process, my pid is: 0
              Hello process, my pid is: 2
          last pid was: 2
3 processes created
bash-3.2$ spin hello.pml
      Hello process, my pid is: 0
          init process, my pid is: 1
          last pid was: 2
              Hello process, my pid is: 2
3 processes created
```


Hello Processes



Hello Processes Interleavings



Interleaving Semantics

- Promela processes execute concurrently.
- Non-deterministic scheduling of the processes.
- Processes are interleaved
  - Only one process can execute a statement at each point in time.
  - Exception: rendez-vous communication.
- All statements are atomic
  - Each statement is executed without interleaving it parts with other processes.
- Each process may have several different possible actions enabled at each point of execution.
  - Only one choice is made, non-deterministically (randomly).