JAVA VIRTUAL MACHINE WITH ROLLBACK PROCEDURE ALLOWING SYSTEMATIC AND EXHAUSTIVE TESTING OF MULTI-THREADED JAVA PROGRAMS

Pascal Eugster

<pe@student.ethz.ch>

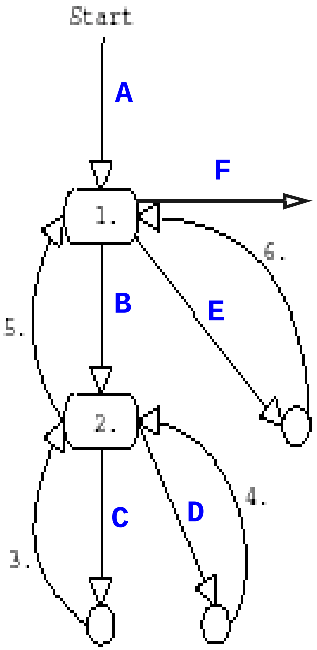
10th April 2003

EXAMPLE 1

❑ rollback procedure

❑ sample sequence of setMilstone, rollback and removeMilestone

```
   - stm sequ A -
1. setMilestone
   - stm sequ B -
2. setMilestone
   - stm sequ C -
3. rollback
   - stm sequ D -
4. rollback
   removeMilestone
5. rollback
   - stm sequ E -
6. rollback
   - stm sequ F -
```

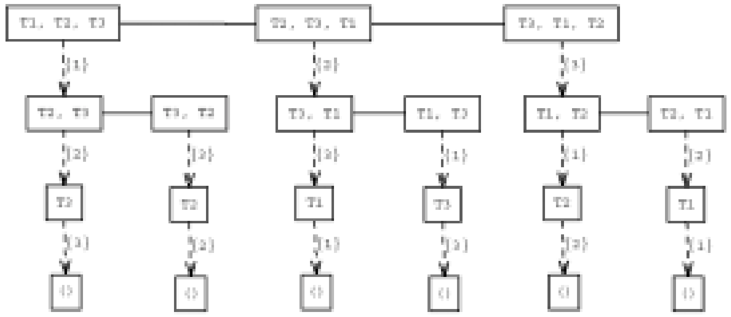


EXAMPLE 2

- ❑ three threads each containing a single synchronized region
- ❑ each thread consists of exactly one atomic block

```
T1:
1: synchronized (x) {}

T2:
2: synchronized (x) {}

T3:
3: synchronized (x) {}
```

EXAMPLE 2, SCHEDULE TREE



EXAMPLE 3

- two threads,
  both containing nested synchronized regions

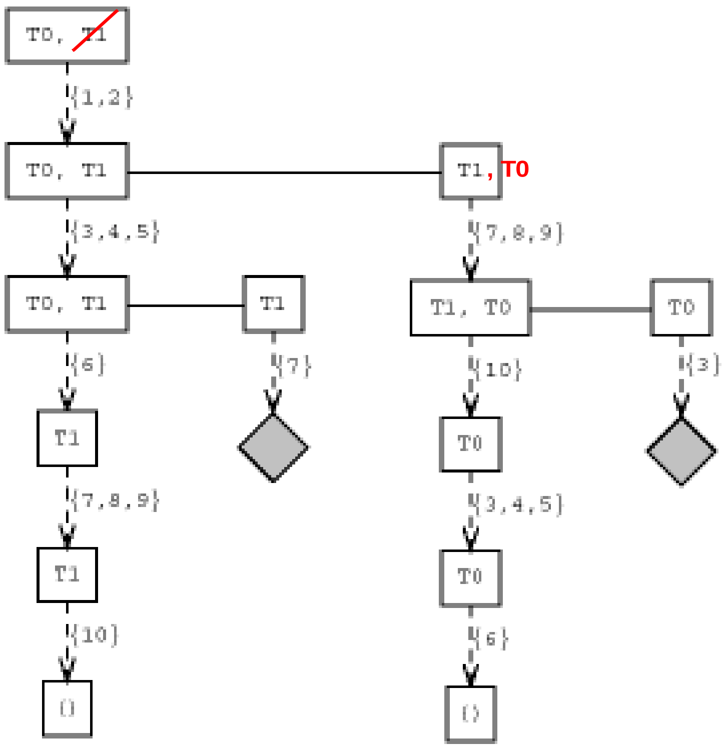
- how does the depth-first-search handle situations,
  where a lock cannot be get

```
T0:
1: t1 = new LockAB (A, B);
2: t1.start();

3: synchronized (B) {
4:   synchronized (A) {
5:   }

6: }


T1:
7: synchronized (A) {
8:   synchronized (B) {
9:   }

10: }
```

- blocked paths are aborted

- lock cycle deadlock detection algorithm started

EXAMPLE 3, SCHEDULE TREE



EXAMPLE 4

- ❑ two threads with a condition deadlock
  occurring when notify is performed prior to wait

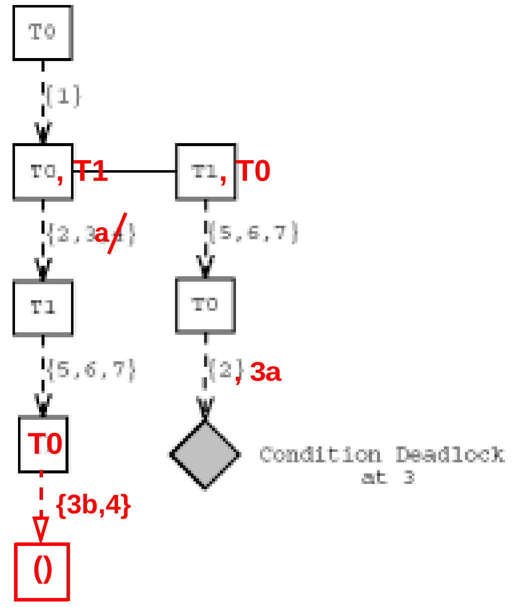
  -> schedule (1, 5, 6, 7, 2)

```
T0:
1: t1.start();

2: synchronized(a) {
3:    a.wait();

4: }


T1:
5: synchronized(a) {
6:    a.notify();

7: }
```

- ❑ to ensure behaviour-complete testing, a milestone has to be created after each thread creation

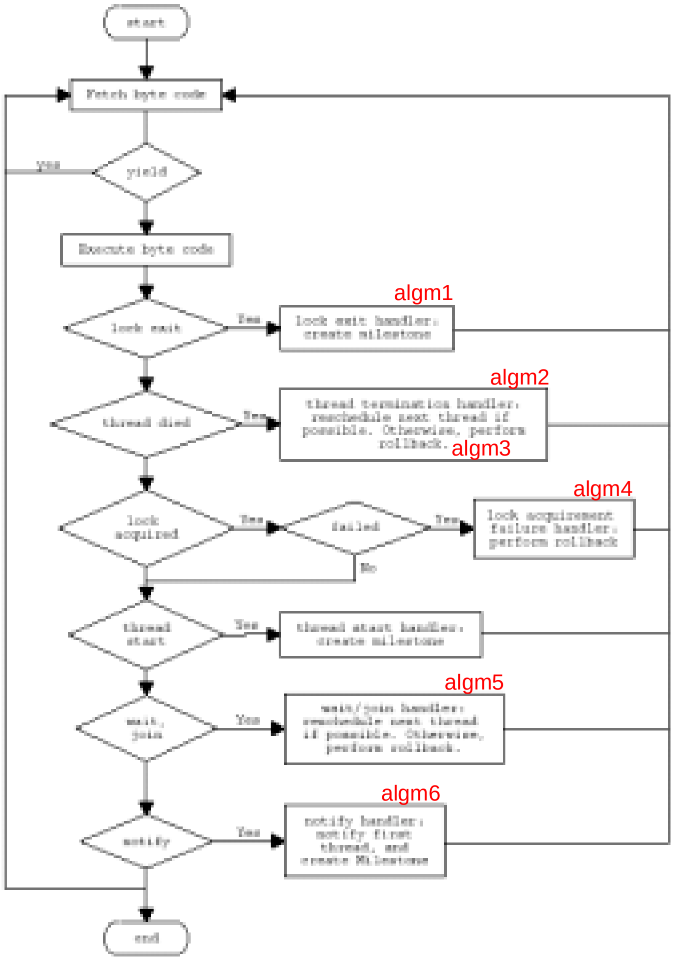
  -> otherwise, only the schedule (1, 2, 5, 6, 7, 3, 4) is executed, where wait and notify are executed in the right order, i. e. deadlock does not occur

EXAMPLE 4, SCHEDULE TREE



- ❑ compare Petri net model and its (reduced) reachability graph

EVENT HANDLER



- ❑ remark: stop, resume, suspend - deprecated

ALGM1
HANDLER TRIGGERED ON A LOCK EXIT

```
handleLockExit() {

   enabled_set = collectEnabledThreads();
   enabled_set = enabled_s{et \ cur_}thread;

   if (number_enabled_threads >= 1)
               /* avoids empty milestones */
      setMilestone( enabled_set );

}
```

- ❑ when a lock exit occurs,
  ExitBlock is notified by the JVM’s lock manager

- ❑ set of enabled threads

  -> runnable threads not scheduled yet from the current milestone

  -> since the current thread continues running, it is not member of the enabled set

  -> used by the rollback

- ❑ on rollback, the state of the whole VM is restored and
  a new branch/schedule is created
  scheduling one thread from the enabled set

ALGM2
HANDLER TRIGGERED ON DEATH OF CURRENT THREAD

```
milestone = getCurrentMilestone();
enabled_set = enable_set \ {cur_thread};
next_thread = reschedule();

if (next_thread == NULL )
   /** rollback continues down the stack,
      selects a next thread there. Returns
      NULL, if stack becomes empty.*/
   next_thread = rollback();

if (next_thread == NULL )
   /** empty stack of milestones */
   terminate();
else
   switchThread (next_thread);
```

- an enabled thread to be scheduled next must be selected
- if there is no enabled thread left, the end of the current schedule is reached

  -> all threads have terminated

  -> rollback to explore next schedule in a new branch

ALGM3
IMPLEMENTATION OF ROLLBACK

```
thread rollback() {

   rollbackVM();

   /** elect thread */
   milestone = getCurrentMilestone();
   next_thread =
      first( milestone->enabled_set );
   milestone->enabled_set =
      milestone->enabled_set \ next_thread;

   if (next_thread == NULL)
   {
      /** no further branch from this
         milestone. So remove this milestone
         and rollback again, continuous down
         the stack.*/
      removeMilestone( milestone );
      next_thread = rollback();
   }

   return next_thread;

}
```

ALGM4

HANDLER TRIGGERED WHEN A LOCK COULD NOT BE OBTAINED

```
next_thread = rollback();
switchThread (next_thread);
```

- lock manager notifies ExitBlock, when
  a lock could not be obtained by the current thread

  -> current thread is aborted by ExitBlock

  -> rollback

ALGM5

HANDLER TRIGGERED FOR *JOIN* AND *WAIT*

```
next_thread = reschedule();

if (next_thread == NULL )
{
   /** condition deadlock detected !!!*/
   next_thread = rollback();
}

if (next_thread == NULL )
   terminate_depth_search();
else
   switchThread(next_thread);
```

- currrent thread falls into sleep, until

  -> occurence of notify
  -> joined thread terminates

- find a new thread that is still enabled

ALGM6

HANDLER TRIGGERED ON INVOCATION OF NOTIFY

```
/** retrieve the wait set of the object on
   which notify was performed */
wait_set = getWaitSet( object );

/** notify first thread which removes
   notified thread from wait set */
notifyNext (wait_set);

/** create a milestone if there are still
   threads waiting on this object that could
   also be notified */
if (count (wait_set) > 0) {

   handleLockExit() /* see Algorithm 1 */
   milestone = getCurrentMilestone();

   /** threads from the wait set needs
      to be notified later. */
   milestone->notify_set = copy(wait_set);

   /** remember enabled set */
   milestone->saved_enabled_set =
         copy(milestone->enabled_set);
}
```

ALGM7

IMPLEMENTATION OF ROLLBACK WITH ADDITIONS FOR NOTIFY HANDLING.

```
thread rollback() {

   milestone = getCurrentMilestone();
   enabled_set = getEnabledSet(milestone );
   next_thread = pop( enabled_set );

   if (isNotifyMilestone( milestone )) {
      milestone->enabled_set =
         copy(milestone->saved_enabled_set);
      thread = first(milestone->notify_set);
      milestone->notify_set =
         milestone->notify_set \ {thread};
      if (thread)
         notify( thread );
         next_thread = cur_thread;
      else
         next_thread = NULL;
   }

   if (next_thread == NULL) {
      removeMilestone( milestone );
      next_thread = rollback();
   }
   return next_thread;

}
```