

Allen B. Downey

The Little Book of Semaphores

Version 2.2.1

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http://www.greenteapress.com/semaphores/LittleBookOfSemaphores.pdf

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3.7.1 Reusable barrier non-solution (3.7.1a.rebarrier_nonsol.pml)

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3.7.1 Reusable barrier non-solution (3.7.1a.rebarrier_nonsol.pml)

```
$ cat -n 3.7.1a.rebarrier_nonsol.pml | expand
       /* The Little Book of Semaphores (2.2.1)
           by A. Downey
    3
    4
           Chapter 3. Basic synchronization patterns
           3.7 Reusable barrier
    7
           3.7.1 Reusable barrier non-solution
    8
    9
            vk, 2017
   10
       */
   11
       #define THREADS 3
                             /* value for threads number */
   13 #define N
                             /* value for barrier limit */
   14
       #define wait(sem) atomic { sem > 0; sem-- }
   16
       #define signal(sem) sem++
   17
       byte count=0, mutex=1, turnstile=0
                                              /* turnstile is locked */
   19
```

```
proctype Th(byte i) {
        byte temp
22
    rendezvous:
24
        do
25
        :: wait(mutex)
26
                temp=count
27
                count=temp+1
28
            signal(mutex)
29
30
            :: count == N ->
31
                signal(turnstile)
            :: else
32
33
34
            wait(turnstile)
            printf("Th(%d): count = %d\n",i,count)
35
36
            signal(turnstile)
```

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```
3.7.1 Reusable barrier non-solution (3.7.1a.rebarrier_nonsol.pml)
                                                                                   3.7.1 Reusable barrier non-solution (3.7.1a.rebarrier_nonsol.pml)
                                                                                $ spin 3.7.1a.rebarrier_nonsol.pml | expand
                                                                                                   Th(3): count = 3
 37 critical:
 38
              wait(mutex)
                                                                                               Th(2): count = 3
 39
                                                                                           Th(1): count = 3
                  temp=count
 40
                  count=temp-1
                                                                                      turnstile = 0
 41
              signal(mutex)
                                                                                4 processes created
 42
              if
 43
              :: count == 0 ->
 44
                  wait(turnstile)
                                                                                $ spin 3.7.1a.rebarrier_nonsol.pml | expand
 45
                                                                                           Th(1): count = 3
              :: else
 46
              fi
                                                                                                   Th(3): count = 3
 47
              break
                       /* one only iteration */
                                                                                               Th(2): count = 2
 48
         od
                                                                                      turnstile = 0
 49 }
                                                                                4 processes created
 50
                                                                                $ spin 3.7.1a.rebarrier_nonsol.pml | expand
                                                                                                   Th(3): count = 3
                                                                                               Th(2): count = 3
                                                                                           Th(1): count = 1
                                                                                      turnstile = 0
                                                                                4 processes created
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                                                                         5
                                                                                   INF646 Métodos Formales
                                                                                                                                                             6
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                                                                                                             VK, 2017 - The Little Book of Semaphores
3.7.1 Reusable barrier non-solution (3.7.1b.rebarrier_nonsol.pml)
                                                                                   3.7.1 Reusable barrier non-solution (3.7.1b.rebarrier_nonsol.pml)
                                                                                $ spin 3.7.1b.rebarrier_nonsol.pml | expand
                                                                                                   Th(3): count = 3
 51 init {
                                                                                               Th(2): count = 2
 52
         byte i
 53
                                                                                           Th(1): count = 2
 54
         atomic {
                                                                                      turnstile = 0
              for (i: 1 .. THREADS) {
 55
                                                                                4 processes created
 56
                  run Th(i)
 57
 58
                                                                                $ spin 3.7.1b.rebarrier_nonsol.pml | expand
 59
         nr pr == 1 ->
                                                                                               Th(2): count = 3
 60
              assert(turnstile == 0)
                                                                                                   Th(3): count = 3
              printf("turnstile = %d\n",turnstile)
 61
                                                                                           Th(1): count = 3
                                                                                spin: 3.7.1b.rebarrier_nonsol.pml:60, Error: assertion violated
 62 }
                                                                                spin: text of failed assertion: assert((turnstile==0))
                                                                                #processes: 1
                                                                                                 count = 0
                                                                                                 mutex = 1
                                                                                                 turnstile = 1
                                                                                        proc 0 (:init::1) 3.7.1b.rebarrier nonsol.pml:60 (state 12)
                                                                                4 processes created
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                                                                         7
                                                                                   INF646 Métodos Formales
                                                                                                             VK, 2017 - The Little Book of Semaphores
```

```
3.7.1 Reusable barrier non-solution (3.7.1c.rebarrier_nonsol.pml)
                                                                                           3.7.1 Reusable barrier non-solution (3.7.1c.rebarrier_nonsol.pml)
                                                                                        $ spin 3.7.1c.rebarrier_nonsol.pml | expand
                                                                                        pan:1: invalid end state (at depth 55)
    51 init {
    52
             byte i
                                                                                        pan: wrote 3.7.1c.rebarrier_nonsol.pml.trail
    53
    54
             atomic {
                                                                                        (Spin Version 6.4.6 -- 2 December 2016)
                 for (i: 1 .. THREADS) {
    55
                                                                                        Warning: Search not completed
                                                                                                 + Partial Order Reduction
    56
                      run Th(i)
    57
             }
    58
                                                                                        Full statespace search for:
    59
                                                                                                 never claim

    (none specified)

             nr pr == 1 ->
    60
                 assert(turnstile < 3)</pre>
                                                                                                 assertion violations
                 printf("turnstile = %d\n",turnstile)
    61
                                                                                                  cycle checks

    (disabled by -DSAFETY)

                                                                                                  invalid end states
    62 }
                                                                                        State-vector 48 byte, depth reached 61, errors: 1
                                                                                                66 states, stored
                                                                                                 5 states, matched
                                                                                                71 transitions (= stored+matched)
                                                                                                12 atomic steps
                                                                                        hash conflicts:
                                                                                                                   0 (resolved)
                                                                                 9
                                                                                                                                                                         10
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                                                                                           INF646 Métodos Formales
                                                                                                                        VK, 2017 - The Little Book of Semaphores
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  3.7.1 Reusable barrier non-solution (3.7.1c.rebarrier_nonsol.pml)
                                                                                           3.7.1 Reusable barrier non-solution (3.7.1c.rebarrier_nonsol.pml)
                                                                                        $ spin -run (-E)3.7.1c.rebarrier_nonsol.pml | expand
$ spin -t -p -q -l 3.7.1c.rebarrier nonsol.pml | expand
Starting Th with pid 1 ...
                                                                                        (Spin Version 6.4.6 -- 2 December 2016)
Starting Th with pid 2 ...
                                                                                                 + Partial Order Reduction
Starting Th with pid 3 ...
      proc 1 (Th:1) 3.7.1c.rebarrier_nonsol.pml:30 (state 7) [((count==3))]
      proc 1 (Th:1) 3.7.1c.rebarrier nonsol.pml:31 (state 8) [turnstile = (turnstile+1)]
                                                                                        Full statespace search for:
                                                                                                 never claim

    (none specified)

                                                                                                  assertion violations
38: proc 3 terminates
                                                                                                  cycle checks
                                                                                                                             - (disabled by -DSAFETY)
. . .
            Th(2): count = 2
                                                                                                 invalid end states
                                                                                                                             - (disabled by -E flag)
        Th(1): count = 1
                                                                                        State-vector 48 byte, depth reached 63, errors: 0
54: proc 2 terminates
                                                                                             16071 states, stored
                                                                                             20784 states, matched
      proc 1 (Th:1) 3.7.1c.rebarrier_nonsol.pml:41 (state 22)
                                                                [mutex = (mutex+1)]
                                                                                             36855 transitions (= stored+matched)
              mutex = 1
56: proc 1 (Th:1) 3.7.1c.rebarrier_nonsol.pml:43 (state 23)
                                                                                                12 atomic steps
                                                                [((count==0))]
spin: trail ends after 56 steps
                                                                                        hash conflicts:
                                                                                                                   7 (resolved)
#processes: 2
                                                              1 process blocked!
              count = 0
                                                              2 processes blocked?
              mutex = 1
                                                              All 3 processes blocked?
              turnstile = 0
       proc 1 (Th:1) 3.7.1c.rebarrier_nonsol.pml:44 (state 26)
      proc 0 (:init::1) 3.7.1c.rebarrier_nonsol.pml:59 (state 11)
4 processes created
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                                                                                 11
                                                                                           INF646 Métodos Formales
                                                                                                                                                                         12
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                                                                                                                        VK, 2017 - The Little Book of Semaphores
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```
3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
                                                                                      3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
$ cat -n 3.7.3a.rebarrier_nonsol.pml | expand
                                                                                            proctype Th(byte i) {
                                                                                        20
                                                                                        21
                                                                                                byte temp
           The Little Book of Semaphores (2.2.1)
                                                                                       22
                                                                                       23
                                                                                            rendezvous:
            by A. Downey
     3
                                                                                       24
                                                                                                do
                                                                                       25
                                                                                                :: wait(mutex)
     4
            Chapter 3. Basic synchronization patterns
                                                                                       26
                                                                                                        temp=count
            3.7 Reusable barrier
                                                                                       27
     6
                                                                                                        count=temp+1
            3.7.3 Reusable barrier non-solution #2
                                                                                       28
                                                                                                    if
                                                                                       29
                                                                                                                          /* may be true for one thread only */
                                                                                                    :: count == N ->
     9
            vk, 2017
                                                                                        30
                                                                                                        signal(turnstile)
       */
    10
                                                                                       31
                                                                                                    :: else
                                                                                        32
    11
                                                                                        33
                                                                                                    signal(mutex)
    12 #define THREADS 3
                              /* value for threads number */
        #define N
                              /* value for barrier limit */
                                                                                       34
    13
                                                                                        35
                                                                                                    wait(turnstile)
    14
        #define wait(sem) atomic { sem > 0; sem-- }
                                                                                        36
                                                                                                    signal(turnstile)
                                                                                                    printf("Th(%d): count = %d, turnstile = %d\n",
        #define signal(sem) sem++
                                                                                        37
    16
                                                                                                           i,count,turnstile)
    17
                                                /* turnstile is locked */
    18
       byte count=0, mutex=1, turnstile=0
    19
  INF646 Métodos Formales
                                                                            13
                                                                                      INF646 Métodos Formales
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                                                                                                                 VK, 2017 - The Little Book of Semaphores
                                                                                                                                                               14
  3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
                                                                                      3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
                                                                                   . . .
    38 critical:
                                                                                        52 init {
                wait(mutex)
                                                                                                byte i
    39
                                                                                        53
    40
                     temp=count
                                                                                        54
    41
                     count=temp-1
                                                                                        55
                                                                                                atomic {
    42
                if
                                                                                        56
                                                                                                    for (i: 1 .. THREADS) {
                                     /* may be true for one threads only */
    43
                 :: count == 0 ->
                                                                                        57
                                                                                                        run Th(i)
                    wait(turnstile) /* leave turnstile locked */
                                                                                        58
    44
    45
                 :: else
                                                                                        59
    46
                                                                                        60
                                                                                                nr pr == 1 ->
    47
                signal(mutex)
                                                                                                    assert(turnstile == 0)
                                                                                        61
                        /* one only iteration */
                                                                                                    printf("turnstile = %d\n",turnstile)
    48
                break
                                                                                        62
    49
            od
                                                                                        63 }
    50
    51
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            15
                                                                                      INF646 Métodos Formales
                                                                                                                 VK, 2017 - The Little Book of Semaphores
                                                                                                                                                                16
```

```
3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
                                                                                    3.7.3 Reusable barrier non-solution (3.7.3a.rebarrier_nonsol.pml)
$ spin -run 3.7.3a.rebarrier_nonsol.pml | expand
                                                                                 $ spin 3.7.3a.rebarrier_nonsol.pml | expand
                                                                                                Th(2): count = 3, turnstile = 1
(Spin Version 6.4.6 -- 2 December 2016)
                                                                                            Th(1): count = 3, turnstile = 1
        + Partial Order Reduction
                                                                                                    Th(3): count = 2, turnstile = 1
                                                                                        turnstile = 0
                                                                                 4 processes created
Full statespace search for:
                                 - (none specified)
        never claim
        assertion violations
                                                                                 $ spin 3.7.3a.rebarrier_nonsol.pml | expand
        cycle checks
                                 - (disabled by -DSAFETY)
                                                                                                    Th(3): count = 3, turnstile = 1
        invalid end states
                                                                                            Th(1): count = 3, turnstile = 0
                                                                                                Th(2): count = 3, turnstile = 1
State-vector 48 byte, depth reached 61, errors: 0
                                                                                        turnstile = 0
                                                                                 4 processes created
. . .
                                                                                 $ spin 3.7.3a.rebarrier_nonsol.pml | expand
                                                                                                    Th(3): count = 3, turnstile = 0
                                                                                                Th(2): count = 3, turnstile = 0
                                                                                            Th(1): count = 1, turnstile = 0
                                                                                        turnstile = 0
                                                                                 4 processes created
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                                                                          17
                                                                                    INF646 Métodos Formales
                                                                                                                                                            18
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                                                                                                              VK, 2017 - The Little Book of Semaphores
  3.7.3 Reusable barrier non-solution (3.7.3b.rebarrier_nonsol.pml)
                                                                                    3.7.3 Reusable barrier non-solution (3.7.3b.rebarrier_nonsol.pml)
$ cat -n 3.7.3b.rebarrier nonsol.pml | expand
                                                                                      22 proctype Th(byte i) {
        /* The Little Book of Semaphores (2.2.1)
                                                                                              byte temp, j
            by A. Downey
                                                                                      24
     3
                                                                                         rendezvous:
            Chapter 3. Basic synchronization patterns
                                                                                      26
                                                                                              do
                                                                                              :: wait(mutex)
     5
                                                                                      27
     6
            3.7 Reusable barrier
                                                                                      28
                                                                                                      temp=count
            3.7.3 Reusable barrier non-solution #2
                                                                                      29
                                                                                                      count=temp+1
                                                                                      30
     9
                                                                                      31
                                                                                                  :: count == N -> /* may be true for one thread only */
            vk. 2017
       */
    10
                                                                                      32
                                                                                                      signal(turnstile)
                                                                                                  :: else
    11
                                                                                      33
    12 #define THREADS 3
                              /* value for threads number */
                                                                                      34
    13 #define N
                              /* value for barrier limit */
                                                                                      35
                                                                                                  signal(mutex)
    14
                                                                                      36
                                                                                      37
    15 #define wait(sem) atomic { sem > 0; sem-- }
                                                                                                  wait(turnstile)
    16 #define signal(sem) sem++
                                                                                      38
                                                                                                  signal(turnstile)
    17
                                                                                      39
                                                                                                  printf("Th(%d): loop %d\n",i,loop[i])
      byte count=0, mutex=1, turnstile=0 /* turnstile is locked */
                                                                                      40
    19 byte loop[THREADS+1]=1
    20 bool sameloop=true
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                                                                          19
                                                                                    INF646 Métodos Formales
                                                                                                              VK, 2017 - The Little Book of Semaphores
                                                                                                                                                            20
```

```
3.7.3 Reusable barrier non-solution (3.7.3b.rebarrier_nonsol.pml)
                                                                                     3.7.3 Reusable barrier non-solution (3.7.3b.rebarrier_nonsol.pml)
    41 critical:
                                                                                       59
                                                                                                   if
                atomic {
    42
                                                                                       60
                                                                                                   :: loop[i] == 2 ->
    43
                     for (j: 1 .. N-1) {
                                                                                       61
                                                                                                       break
    44
                         sameloop = sameloop && (loop[j] == loop[j+1])
                                                                                       62
                                                                                                   :: else ->
    45
                                                                                       63
                                                                                                       loop[i]++
                                                                                                   fi
    46
                     assert(sameloop)
                                                                                       64
    47
                }
                                                                                       65
                                                                                               od
    48
                                                                                       66
    49
                wait(mutex)
                                                                                       67
    50
                     temp=count
                                                                                       68
                                                                                           init {
    51
                     count=temp-1
                                                                                               byte i
    52
                if
                                                                                       70
    53
                :: count == 0 ->
                                     /* may be true for one threads only */
                                                                                       71
                                                                                               atomic {
                    wait(turnstile) /* leave turnstile locked */
                                                                                                   for (i: 1 .. THREADS) {
    54
                                                                                       72
    55
                :: else
                                                                                       73
                                                                                                       run Th(i)
    56
                fi
                                                                                       74
    57
                signal(mutex)
                                                                                       75
    58
                                                                                       76
                                                                                               nr pr == 1 ->
                                                                                       77
                                                                                                   assert(turnstile == 0)
                                                                                                   printf("turnstile = %d\n",turnstile)
                                                                                       78
                                                                                       79 }
  INF646 Métodos Formales
                                                                           21
                                                                                     INF646 Métodos Formales
                                                                                                                                                              22
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                                                                                                                VK, 2017 - The Little Book of Semaphores
  3.7.3 Reusable barrier non-solution (3.7.3b.rebarrier_nonsol.pml)
                                                                                     3.7.5 Reusable barrier solution (3.7.5.rebarrier.pml)
                                                                                  $ cat -n 3.7.5.rebarrier.pml | expand
                                                                                        1 /* The Little Book of Semaphores (2.2.1)
$ spin 3.7.3b.rebarrier_nonsol.pml | expand
          Th(1): loop 1
                                                                                               by A. Downey
              Th(2): loop 1
                                                                                        3
                  Th(3): loop 1
                                                                                               Chapter 3. Basic synchronization patterns
          Th(1): loop 2
spin: 3.7.3b.rebarrier_nonsol.pml:46, Error: assertion violated
                                                                                               3.7 Reusable barrier
spin: text of failed assertion: assert(sameloop)
                                                                                               3.7.5 Reusable barrier solution
#processes: 4
                                                                                        8
                                                                                               vk, 2017
                count = 1
                                                                                          */
                mutex = 0
                                                                                       10
                turnstile = 1
                                                                                      11
                loop[0] = 1
                                                                                       12 #define THREADS 3
                                                                                                                 /* value for threads number */
                                                                                           #define N
                                                                                                                 /* value for barrier limit */
                loop[1] = 2
                loop[2] = 2
                                                                                      14
                loop[3] = 1
                                                                                      15 #define wait(sem) atomic { sem > 0; sem-- }
                                                                                           #define signal(sem) sem++
                sameloop = 0
128:
        proc 3 (Th:1) 3.7.3b.rebarrier_nonsol.pml:52 (state 38)
                                                                                      17
128:
        proc 2 (Th:1) 3.7.3b.rebarrier nonsol.pml:26 (state 47)
                                                                                       18
                                                                                          byte count=0, mutex=1, turnstile=0, turnstile2=1
        proc 1 (Th:1) 3.7.3b.rebarrier nonsol.pml:46 (state 26)
                                                                                           byte loop[THREADS+1]=1
128:
        proc 0 (:init::1) 3.7.3b.rebarrier_nonsol.pml:76 (state 11)
                                                                                           bool sameloop=true
                                                                                       20
128:
4 processes created
                                                                                       21
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                                                                           23
                                                                                     INF646 Métodos Formales
                                                                                                                VK, 2017 - The Little Book of Semaphores
                                                                                                                                                              24
```

```
3.7.5 Reusable barrier solution (3.7.5.rebarrier.pml)
                                                                                    3.7.5 Reusable barrier solution (3.7.5.rebarrier.pml)
 22 proctype Th(byte i) {
                                                                                      42 critical:
 23
          byte temp, j
                                                                                      43
                                                                                                   atomic {
 24
                                                                                      44
                                                                                                       for (j: 1 .. N-1) {
 25 rendezvous:
                                                                                      45
                                                                                                            sameloop = sameloop && (loop[j] == loop[j+1])
 26
          do
                                                                                      46
 27
                                                                                      47
          :: wait(mutex)
                                                                                                       assert(sameloop)
 28
                                                                                      48
                   temp=count
 29
                   count=temp+1
                                                                                      49
 30
              if
                                                                                      50
                                                                                                   wait(mutex)
 31
              :: count == N ->
                                                                                      51
                                                                                                       temp=count
                                                                                      52
 32
                  wait(turnstile2)
                                        /* lock the second */
                                                                                                       count=temp-1
 33
                                      /* unlock the first */
                                                                                      53
                                                                                                   if
                   signal(turnstile)
                                                                                      54
 34
              :: else
                                                                                                   :: count == 0 ->
 35
                                                                                      55
              fi
                                                                                                       wait(turnstile)
                                                                                                                             /* lock the first */
 36
              signal(mutex)
                                                                                      56
                                                                                                       signal(turnstile2) /* unlock the second */
 37
                                                                                      57
                                                                                                   :: else
 38
              wait(turnstile)
                                        /* first turnstile */
                                                                                      58
                                                                                                   fi
                                                                                      59
                                                                                                   signal(mutex)
 39
              signal(turnstile)
 40
              printf("Th(%d): loop %d\n",i,loop[i])
                                                                                      60
 41
                                                                                      61
                                                                                                   wait(turnstile2)
                                                                                                                             /* second turnstile */
                                                                                      62
                                                                                                   signal(turnstile2)
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                                                                          25
                                                                                     INF646 Métodos Formales
                                                                                                                                                               26
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                                                                                                                VK, 2017 - The Little Book of Semaphores
3.7.5 Reusable barrier solution (3.7.5.rebarrier.pml)
                                                                                    3.7.5 Reusable barrier solution (3.7.5.rebarrier.pml)
                                                                                  $ spin 3.7.5.rebarrier.pml | expand
                                                                                            Th(1): loop 1
                                                                                                     Th(3): loop 1
 63
              :: loop[i] == 3 ->
                                                                                                 Th(2): loop 1
 64
 65
                  break
                                                                                                 Th(2): loop 2
              :: else ->
                                                                                                     Th(3): loop 2
 66
 67
                  loop[i]++
                                                                                            Th(1): loop 2
                                                                                                Th(2): loop 3
              fi
 68
 69
          od
                                                                                            Th(1): loop 3
                                                                                                     Th(3): loop 3
 70
 71
                                                                                  4 processes created
 72 init {
 73
          byte i
                                                                                  $ spin -run 3.7.5.rebarrier.pml | expand
 74
                                                                                  (Spin Version 6.4.6 -- 2 December 2016)
 75
          atomic {
                                                                                          + Partial Order Reduction
 76
              for (i: 1 .. THREADS) {
 77
                  run Th(i)
                                                                                  Full statespace search for:
                                                                                          never claim
 78

    (none specified)

 79
                                                                                          assertion violations
 80
          nr pr == 1 ->
                                                                                          cycle checks

    (disabled by -DSAFETY)

 81
              assert(turnstile == 0)
                                                                                          invalid end states
 82
              assert(turnstile2 == 1)
 83 }
                                                                                  State-vector 48 byte, depth reached 236, errors: 0
INF646 Métodos Formales
                           VK, 2017 - The Little Book of Semaphores
                                                                          27
                                                                                     INF646 Métodos Formales
                                                                                                                VK, 2017 - The Little Book of Semaphores
                                                                                                                                                               28
```

```
3.7.6 Preloaded turnstile (3.7.6.rebarrier_preloaded.pml)
                                                                                       3.7.6 Preloaded turnstile (3.7.6.rebarrier_preloaded.pml)
$ cat -n 3.7.6.rebarrier_preloaded.pml | expand
     1 /* The Little Book of Semaphores (2.2.1)
                                                                                        22
            by A. Downey
                                                                                             proctype Th(byte i) {
     3
                                                                                                 byte temp, j
                                                                                        24
                                                                                        25
     4
            Chapter 3. Basic synchronization patterns
     5
                                                                                        26
                                                                                            rendezvous:
                                                                                        27
            3.7 Reusable barrier
                                                                                                 do
     7
                                                                                        28
                                                                                                 :: wait(mutex)
            3.7.6 Preloaded turnstile
                                                                                        29
     8
                                                                                                         temp=count
     9
            vk, 2017
                                                                                        30
                                                                                                         count=temp+1
        */
                                                                                        31
                                                                                                     if
    10
    11
                                                                                        32
                                                                                                     :: count == N ->
                                                                                        33
    12 #define THREADS 3
                               /* value for threads number */
                                                                                                         signalN(turnstile,N) /* unlock the first */
        #define N
                               /* value for barrier limit */
                                                                                        34
                                                                                        35
    14
                                                                                                     fi
    15 #define wait(sem) atomic { sem > 0; sem-- }
                                                                                        36
                                                                                                     signal(mutex)
        #define signal(sem) sem++
                                                                                        37
    17
        #define signalN(sem,NN) for (j: 1 .. NN) { sem++ } /* no atomic */
                                                                                        38
                                                                                                     wait(turnstile)
                                                                                                                               /* first turnstile */
    18
                                                                                        39
                                                                                                     printf("Th(%d): loop %d\n",i,loop[i])
       byte count=0, mutex=1, turnstile=0, turnstile2=0
                                                                                        40
    19
       byte loop[THREADS+1]=1
    21 bool sameloop=true
  INF646 Métodos Formales
                                                                             29
                                                                                                                                                                 30
                             VK, 2017 - The Little Book of Semaphores
                                                                                       INF646 Métodos Formales
                                                                                                                  VK, 2017 - The Little Book of Semaphores
  3.7.6 Preloaded turnstile (3.7.6.rebarrier_preloaded.pml)
                                                                                       3.7.6 Preloaded turnstile (3.7.6.rebarrier_preloaded.pml)
    41 critical:
                                                                                                     if
                                                                                        60
                                                                                                     :: loop[i] == 3 ->
    42
                 atomic {
                                                                                        61
    43
                     for (j: 1 .. N-1) {
                                                                                        62
                                                                                                         break
                         sameloop = sameloop && (loop[j] == loop[j+1])
                                                                                        63
                                                                                                     :: else ->
    44
    45
                                                                                        64
                                                                                                         loop[i]++
    46
                     assert(sameloop)
                                                                                        65
                                                                                                     fi
    47
                 }
                                                                                        66
                                                                                                 od
    48
                                                                                        67
    49
                 wait(mutex)
                                                                                        68
    50
                     temp=count
                                                                                            init {
                                                                                        69
    51
                     count=temp-1
                                                                                        70
                                                                                                 byte i
    52
                                                                                        71
    53
                                                                                        72
                                                                                                 atomic {
                 :: count == 0 ->
    54
                     signalN(turnstile2,N) /* unlock the second */
                                                                                        73
                                                                                                     for (i: 1 .. THREADS) {
    55
                 :: else
                                                                                        74
                                                                                                         run Th(i)
                                                                                        75
    56
                 fi
    57
                 signal(mutex)
                                                                                        76
    58
                                                                                        77
                                                                                                 nr pr == 1 ->
                                          /* second turnstile */
    59
                 wait(turnstile2)
                                                                                        78
                                                                                                     assert(turnstile == 0)
                                                                                        79
                                                                                                     assert(turnstile2 == 0)
                                                                                        80 }
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                             31
                                                                                       INF646 Métodos Formales
                                                                                                                                                                 32
                                                                                                                  VK, 2017 - The Little Book of Semaphores
```

```
3.7.6 Preloaded turnstile (3.7.6.rebarrier_preloaded.pml)
                                                                                      3.7.7 Barrier objects (3.7.7.barrier_object.pml)
                                                                                   $ cat -n 3.7.7.barrier object.pml | expand
$ spin -run 3.7.6.rebarrier preloaded.pml | expand
                                                                                        1 /* The Little Book of Semaphores (2.2.1)
(Spin Version 6.4.6 -- 2 December 2016)
                                                                                                by A. Downey
        + Partial Order Reduction
                                                                                        3
                                                                                                Chapter 3. Basic synchronization patterns
Full statespace search for:
        never claim
                                 - (none specified)
                                                                                                3.7 Reusable barrier
        assertion violations
                                                                                                3.7.7 Barrier objects
        cycle checks
                                 - (disabled by -DSAFETY)
        invalid end states
                                                                                        9
                                                                                                vk, 2017
                                                                                           */
                                                                                       10
State-vector 48 byte, depth reached 272, errors: 0
                                                                                       11
                                                                                           #include "Semaphore.h"
                                                                                           #include "Barrier.h"
$ spin 3.7.6.rebarrier_preloaded.pml | expand
                                                                                       13
              Th(2): loop 1
                                                                                       14
                                                                                            #define THREADS 3
          Th(1): loop 1
                                                                                                                  /* value for threads number */
                                                                                                                  /* value for barrier limit */
                  Th(3): loop 1
                                                                                           #define N
          Th(1): loop 2
                                                                                       17
                   Th(3): loop 2
                                                                                           Semaphore mutex=1
                                                                                           Barrier barrier
              Th(2): loop 2
                                                                                       19
                  Th(3): loop 3
                                                                                           byte loop[THREADS+1]=1
          Th(1): loop 3
              Th(2): loop 3
                                                                                           unsigned group : 31 = 0
4 processes created
                                                                                        23
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            33
                                                                                      INF646 Métodos Formales
                                                                                                                                                               34
                                                                                                                 VK, 2017 - The Little Book of Semaphores
  3.7.7 Barrier objects (3.7.7.barrier_object.pml)
                                                                                      3.7.7 Barrier objects (3.7.7.barrier_object.pml)
    24
        proctype Th(byte i) {
    25
            do
                                                                                           init {
    26
                                                                                        47
                                                                                                byte i
    27
                printf("Th(%d): loop %d\n",i,loop[i])
                                                                                        48
                                                                                        49
                                                                                                bar init(barrier,N)
        rendezvous:
    29
                bar_wait(barrier)
                                                                                        50
                                                                                        51
    30
        critical:
                                                                                                atomic {
                                                                                        52
                                                                                                    for (i: 1 .. THREADS) {
    31
                group=group*10+loop[i]
                assert(group==1 || group==11 || group==111 ||
                                                                                        53
                                                                                                        run Th(i)
    32
    33
                        group==1112 || group==11122 || group==111222 ||
                                                                                        54
    34
                        group==1112223 || group==11122233 || group==111222333)
                                                                                        55
                printf("Th(%d): loop %d passed with %d\n",i,loop[i],group)
    35
                                                                                        56
                                                                                                nr pr == 1 ->
                                                                                        57
    36
                                                                                                    assert(barrier. turnstile == 0)
    37
                if
                                                                                        58
                                                                                                    assert(barrier. turnstile2 == 0)
    38
                 :: loop[i] == 3 ->
                                                                                        59 }
    39
                     break
    40
                 :: else ->
    41
                     loop[i]++
    42
                fi
    43
            od
    44
    45
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            35
                                                                                      INF646 Métodos Formales
                                                                                                                 VK, 2017 - The Little Book of Semaphores
                                                                                                                                                               36
```

```
3.7.7 Barrier objects (3.7.7.barrier_object.pml)
                                                                                       3.7.7 Barrier objects (3.7.7.barrier_object.pml)
$ cat -n Semaphore.h | expand
                                                                                    $ cat -n Barrier.h | expand
     1
                                                                                          1
        #define Semaphore byte
                                                                                             typedef Barrier {
                                                                                                 byte
                                                                                                            n
        #define wait(sem)
                                  atomic { sem > 0; sem-- }
                                                                                                 bvte
                                                                                          4
                                                                                                            _count
     4
        #define signal(sem)
                                                                                                 Semaphore mutex
        #define signalN(sem,NN) for ( i: 1...NN) { sem++ } /* no atomic */
                                                                                                 Semaphore turnstile
                                                                                                 Semaphore turnstile2
                                                                                          8
     8
        byte _i=0
     9
                                                                                             inline bar_init(bar,n) {
                                                                                         11
                                                                                                 bar._n
                                                                                         12
                                                                                                 bar. count
                                                                                         13
                                                                                                 bar. mutex
                                                                                                                  = 1
                                                                                         14
                                                                                                 bar._turnstile = 0
                                                                                         15
                                                                                                 bar._turnstile2 = 0
                                                                                        16 }
                                                                                         17
  INF646 Métodos Formales
                                                                             37
                                                                                       INF646 Métodos Formales
                                                                                                                                                                  38
                             VK, 2017 - The Little Book of Semaphores
                                                                                                                  VK, 2017 - The Little Book of Semaphores
  3.7.7 Barrier objects (3.7.7.barrier_object.pml)
                                                                                       3.7.7 Barrier objects (3.7.7.barrier_object.pml)
    18 inline bar phase1(bar) {
                                                                                             inline bar phase2(bar) {
    19
            wait(bar._mutex)
                                                                                                 wait(bar._mutex)
                                                                                         31
    20
                 bar._count++
                                  /* atomic here */
                                                                                         32
                                                                                                      bar._count--
                                                                                                                           /* atomic here */
    21
                                                                                         33
                                                                                                      if
    22
                 :: bar._count == bar._n ->
                                                                                         34
                                                                                                      :: bar. count == 0 ->
                     signalN(bar._turnstile,bar._n)
                                                                                                          signalN(bar._turnstile2,bar._n)
    23
                                                                                         35
    24
                 :: else
                                                                                         36
                                                                                                      :: else
    25
                 fi
                                                                                         37
                                                                                                      fi
                                                                                                 signal(bar._mutex)
    26
            signal(bar. mutex)
                                                                                         38
            wait(bar._turnstile)
                                                                                                 wait(bar._turnstile2)
    27
                                                                                         39
    28 }
                                                                                         40
    29
                                                                                         41
                                                                                             inline bar wait(bar) {
                                                                                                 bar_phase1(bar)
                                                                                         43
                                                                                         44
                                                                                                 bar_phase2(bar)
                                                                                         45
                                                                                         46
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                             39
                                                                                       INF646 Métodos Formales
                                                                                                                  VK, 2017 - The Little Book of Semaphores
                                                                                                                                                                  40
```

```
3.7.7 Barrier objects (3.7.7.barrier_object.pml)
                                                                                     3.7.7 Barrier objects (3.7.7.barrier_object.pml)
$ spin (-T) 3.7.7.barrier_object.pml | expand
                                                                                   $ spin -run 3.7.7.barrier object.pml | expand
Th(1): loop 1
                                                                                   (Spin Version 6.4.6 -- 2 December 2016)
Th(2): loop 1
                                                                                           + Partial Order Reduction
Th(3): loop 1
Th(2): loop 1 passed with 1
                                                                                   Full statespace search for:
Th(1): loop 1 passed with 11
                                                                                           never claim

    (none specified)

Th(2): loop 2
                                                                                           assertion violations
Th(3): loop 1 passed with 111
                                                                                           cycle checks
                                                                                                                     - (disabled by -DSAFETY)
Th(1): loop 2
                                                                                           invalid end states
Th(3): loop 2
Th(1): loop 2 passed with 11122
                                                                                   State-vector 52 byte, depth reached 232, errors: 0
Th(2): loop 2 passed with 11122
Th(2): loop 3
Th(3): loop 2 passed with 111222
Th(1): loop 3
Th(3): loop 3
Th(2): loop 3 passed with 1112223
Th(1): loop 3 passed with 11122233
Th(3): loop 3 passed with 111222333
4 processes created
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            41
                                                                                      INF646 Métodos Formales
                                                                                                                                                              42
                                                                                                                VK, 2017 - The Little Book of Semaphores
  3.8.4 Exclusive queue (3.8.4a.exclusive_queue.pml)
                                                                                     3.8.4 Exclusive queue (3.8.4a.exclusive_queue.pml)
$ cat -n 3.8.4a.exclusive_queue.pml | expand
                                                                                           proctype Leader(byte i) {
                                                                                       19
        /* The Little Book of Semaphores (2.2.1)
                                                                                               wait(mutex)
            by A. Downey
                                                                                       21
                                                                                               if
     3
                                                                                       22
                                                                                               :: followers > 0 ->
            Chapter 3. Basic synchronization patterns
                                                                                       23
                                                                                                    followers--
                                                                                                    signal(followerQueue)
     5
                                                                                       24
     6
            3.8 Queue
                                                                                       25
                                                                                               :: else ->
            3.8.4 Exclusive queue solution
                                                                                                   leaders++
                                                                                       26
                                                                                       27
                                                                                                    signal(mutex)
     9
                                                                                       28
                                                                                                    wait(leaderQueue)
            vk. 2017
        */
                                                                                       29
                                                                                               fi
    10
    11
                                                                                       30
    12 #include "Semaphore.h"
                                                                                       31
                                                                                           dance:
                                                                                               printf("leader %d: to dance\n",i)
                                                                                       32
    13
    14 #define N 6
                                                                                       33
                                                                                               wait(rendezvous)
                                                                                               printf("leader %d: dancing\n",i)
    15
                                                                                       34
    16 Semaphore mutex=1, leaderQueue=0, followerQueue=0, rendezvous=0
                                                                                       35
                                                                                               signal(mutex)
    17 byte
                   leaders=0, followers=0
                                                                                       36 }
    18
                                                                                       37
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            43
                                                                                      INF646 Métodos Formales
                                                                                                                VK, 2017 - The Little Book of Semaphores
```

```
3.8.4 Exclusive queue (3.8.4a.exclusive_queue.pml)
                                                                                       3.8.4 Exclusive queue (3.8.4a.exclusive_queue.pml)
        proctype Follower(byte i) {
                                                                                        57 init {
    38
            wait(mutex)
    39
                                                                                         58
                                                                                                 byte i
    40
            if
                                                                                        59
    41
            :: leaders > 0 ->
                                                                                        60
                                                                                                 atomic {
    42
                 leaders--
                                                                                        61
                                                                                                     for (i: 1 .. N) {
    43
                 signal(leaderQueue)
                                                                                        62
                                                                                                         if
    44
             :: else ->
                                                                                                         :: i % 2 -> run Leader(i)
                                                                                        63
    45
                 followers++
                                                                                                         :: else -> run Follower(i)
                                                                                        64
    46
                 signal(mutex)
                                                                                        65
    47
                 wait(followerQueue)
                                                                                        66
    48
            fi
                                                                                        67
                                                                                                 }
    49
                                                                                        68 }
    50
        dance:
    51
            atomic {
    52
                 signal(rendezvous)
    53
                 printf("follower %d: dancing\n",i)
    54
    55 }
    56
  INF646 Métodos Formales
                                                                             45
                                                                                       INF646 Métodos Formales
                                                                                                                                                                 46
                             VK, 2017 - The Little Book of Semaphores
                                                                                                                  VK, 2017 - The Little Book of Semaphores
  3.8.4 Exclusive queue (3.8.4a.exclusive_queue.pml)
                                                                                       3.8.4 Exclusive queue (3.8.4b.exclusive_queue.pml)
$ spin -T 3.8.4a.exclusive_queue.pml | expand
follower 2: dancing
                                                                                             proctype Leader(byte i) {
leader 1: to dance
                                                                                                 wait(mutex)
leader 1: dancing
                                                                                        21
                                                                                                 if
follower 6: dancing
                                                                                        22
                                                                                                 :: followers > 0 ->
leader 3: to dance
                                                                                        23
                                                                                                     followers--
leader 3: dancing
                                                                                        24
                                                                                                     assert(followerQueue == 0)
follower 4: dancing
                                                                                        25
                                                                                                     signal(followerQueue)
leader 5: to dance
                                                                                                 :: else ->
                                                                                        26
leader 5: dancing
                                                                                        27
                                                                                                     leaders++
                                                                                                     signal(mutex)
7 processes created
                                                                                        28
                                                                                        29
                                                                                                     wait(leaderQueue)
$ spin -T 3.8.4a.exclusive_queue.pml | expand
                                                                                        30
                                                                                                 fi
follower 2: dancing
                                                                                        31
leader 5: to dance
                                                                                        32
                                                                                             dance:
leader 5: dancing
                                                                                        33
                                                                                                 printf("leader %d: to dance\n",i)
                                                                                                 wait(rendezvous)
leader 3: to dance
                                                                                        34
                                                                                                 printf("leader %d: dancing\n",i)
follower 6: dancing
                                                                                        35
leader 3: dancing
                                                                                        36
                                                                                                 signal(mutex)
leader 1: to dance
                                                                                        37 }
                                                                                        38
follower 4: dancing
leader 1: dancing
7 processes created
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                             47
                                                                                       INF646 Métodos Formales
                                                                                                                  VK, 2017 - The Little Book of Semaphores
                                                                                                                                                                 48
```

```
3.8.4 Exclusive queue (3.8.4b.exclusive_queue.pml)
                                                                                     3.8.4 Exclusive queue (3.8.4b.exclusive_queue.pml)
        proctype Follower(byte i) {
                                                                                   $ spin -run 3.8.4b.exclusive_queue.pml | expand
    39
            wait(mutex)
    40
            if
                                                                                   (Spin Version 6.4.6 -- 2 December 2016)
    41
    42
            :: leaders > 0 ->
                                                                                           + Partial Order Reduction
    43
                leaders--
    44
                assert(leaderOueue == 0)
                                                                                   Full statespace search for:
    45
                signal(leaderQueue)
                                                                                           never claim
                                                                                                                    - (none specified)
            :: else ->
                                                                                           assertion violations
    46
    47
                followers++
                                                                                           cycle checks
                                                                                                                    - (disabled by -DSAFETY)
    48
                signal(mutex)
                                                                                           invalid end states
                wait(followerQueue)
    49
            fi
    50
                                                                                   State-vector 68 byte, depth reached 77, errors: 0
    51
    52 dance:
    53
            atomic {
    54
                signal(rendezvous)
    55
                printf("follower %d: dancing\n",i)
    56
    57 }
    58
  INF646 Métodos Formales
                                                                           49
                                                                                     INF646 Métodos Formales
                                                                                                                                                              50
                             VK, 2017 - The Little Book of Semaphores
                                                                                                                VK, 2017 - The Little Book of Semaphores
  3.8.4 Exclusive queue (3.8.4c.exclusive_queue.pml)
                                                                                     3.8.4 Exclusive queue (3.8.4c.exclusive_queue.pml)
$ cat -n 3.8.4c.exclusive_queue.pml | expand
                                                                                   $ spin -run 3.8.4c.exclusive_queue.pml | expand
        /* The Little Book of Semaphores (2.2.1)
                                                                                   pan:1: invalid end state (at depth 59)
            by A. Downey
                                                                                   pan: wrote 3.8.4c.exclusive_queue.pml.trail
     3
     4
            Chapter 3. Basic synchronization patterns
                                                                                   (Spin Version 6.4.6 -- 2 December 2016)
                                                                                   Warning: Search not completed
     5
                                                                                           + Partial Order Reduction
     6
            3.8 Oueue
            3.8.4 Exclusive queue solution
                                                                                   Full statespace search for:
     9
            vk. 2017
                                                                                           never claim
                                                                                                                     - (none specified)
       */
    10
                                                                                           assertion violations
    11
                                                                                           cycle checks
                                                                                                                    - (disabled by -DSAFETY)
    12 #include "Semaphore.h"
                                                                                           invalid end states
   13
        #define N(5)
    14
                                                                                   State-vector 60 byte, depth reached 60, errors: 1
    15
    16 Semaphore mutex=1, leaderQueue=0, followerQueue=0, rendezvous=0
    17
        byte
                  leaders=0, followers=0
    18
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                           51
                                                                                     INF646 Métodos Formales
                                                                                                                VK, 2017 - The Little Book of Semaphores
                                                                                                                                                              52
```

```
3.8.4 Exclusive queue (3.8.4c.exclusive_queue.pml)
                                                                                     3.8.4 Exclusive queue (3.8.4d.exclusive_queue.pml)
                                                                                   $ cat -n 3.8.4d.exclusive queue.pml | expand
$ spin -run (-E) 3.8.4c.exclusive_queue.pml | expand
                                                                                           /* The Little Book of Semaphores (2.2.1)
(Spin Version 6.4.6 -- 2 December 2016)
                                                                                        2
                                                                                               by A. Downey
        + Partial Order Reduction
                                                                                        3
                                                                                               Chapter 3. Basic synchronization patterns
Full statespace search for:
        never claim
                                 - (none specified)
                                                                                               3.8 Oueue
                                                                                               3.8.4 Exclusive queue solution
        assertion violations
        cycle checks
                                 - (disabled by -DSAFETY)
        invalid end states
                                 - (disabled by -E flag)
                                                                                        9
                                                                                               vk. 2017
                                                                                           */
                                                                                       10
State-vector 60 byte, depth reached 60, errors: 0
                                                                                       11
                                                                                           #include "Semaphore.h"
. . .
                                                                                       13
                                                                                           #define N(6)
                                                                                       14
                                                                                       15
                                                                                       16
                                                                                           Semaphore mutex=1, leaderQueue=0, followerQueue=0, rendezvous=0
                                                                                                      leaders=0, followers=0
                                                                                       17
                                                                                           byte
                                                                                       18
  INF646 Métodos Formales
                                                                            53
                                                                                      INF646 Métodos Formales
                                                                                                                                                              54
                             VK, 2017 - The Little Book of Semaphores
                                                                                                                VK, 2017 - The Little Book of Semaphores
  3.8.4 Exclusive queue (3.8.4d.exclusive_queue.pml)
                                                                                     3.8.4 Exclusive queue (3.8.4d.exclusive_queue.pml)
                                                                                   $ spin -run 3.8.4d.exclusive_queue.pml | expand
    59 init {
                                                                                   pan:1: invalid end state (at depth 83)
            byte i
    60
    61
                                                                                   pan: wrote 3.8.4d.exclusive_queue.pml.trail
    62
            atomic {
                for (i:(0).. N) {
    63
                                                                                   (Spin Version 6.4.6 -- 2 December 2016)
                                                                                   Warning: Search not completed
    64
                     if
                                                                                           + Partial Order Reduction
    65
                     :: i % 2 -> run Leader(i)
                     :: else -> run Follower(i)
    67
                                                                                   Full statespace search for:
    68
                                                                                           never claim
                                                                                                                     - (none specified)
            }
    69
                                                                                           assertion violations
    70 }
                                                                                           cycle checks
                                                                                                                     - (disabled by -DSAFETY)
                                                                                           invalid end states
                                                                                   State-vector 76 byte, depth reached 84, errors: 1
  INF646 Métodos Formales
                             VK, 2017 - The Little Book of Semaphores
                                                                            55
                                                                                      INF646 Métodos Formales
                                                                                                                VK, 2017 - The Little Book of Semaphores
                                                                                                                                                               56
```

3.8.4 Exclusive queue (3.8.4d.exclusive_queue.pml)

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