UNIVERSITY OF WATERLOO

Final Examination

Term: Winter Year: 2017

CS343
Concurrent and Parallel Programming
Sections 001
Instructor: Peter Buhr

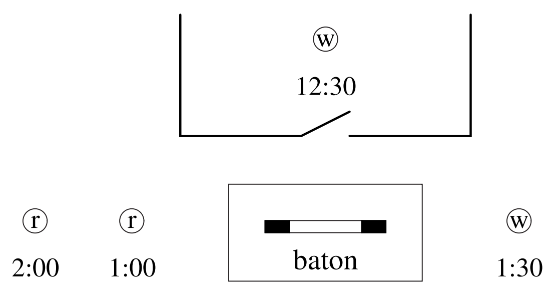
Thursday, April 20, 2017
Start Time: 12:30 End Time: 15:00
Duration of Exam: 2.5 hours
Number of Exam Pages (including cover sheet): 6
Total number of questions: 6
Total marks available: 104
CLOSED BOOK, NO ADDITIONAL MATERIAL ALLOWED

1. (a) **7 marks** The following is an implementation of a binary semaphore. Indicate where the *conceptual baton* is picked up, put down, passed and received. Use the line numbers on the left to indicate where the baton actions occur.

```
1   class BinSem {
2       queue<Task> blocked;
3       bool inUse;
4       SpinLock lock;
5     public:
6       BinSem( bool usage = false ) : inUse( usage ) {}
7       void P() {
8           lock.acquire();
9           if ( inUse ) {
10              // add self to lock' s blocked list
11              yieldNoSchedule( lock ); // atomically block and release lock
12          }
13          inUse = true;
14          lock.release();
15      }
16      void V() {
17          lock.acquire();
18          if ( ! blocked.empty() ) {
19              // remove task from blocked list and make ready
20          } else {
21              inUse = false;
22              lock.release();
23          }
24      }
25  };
```

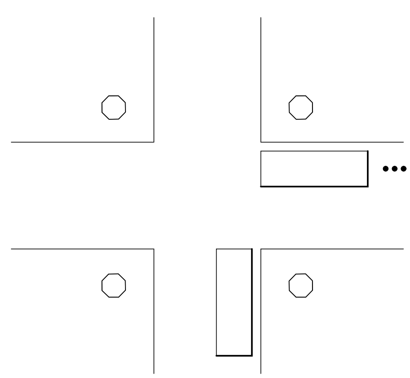
(b) **3 marks** Explain the difference between barging *avoidance* and *prevention*. Does question 1a use avoidance or prevention?

(c) **2 marks** Given the following readers/writer snapshot:



and the 12:30 writer exits the critical section at 2:30, explain a scenario resulting in *staleness* and one resulting in *freshness*.

(d) **2 marks** Given this 4-way stop, where for simultaneous arrival, the person on the right has the right-of-way (otherwise, the first arriver has the right-of-way), explain how starvation can occur.



(e) **6 marks** Consider a system in which there is a single resource with 11 identical units. The system uses the banker's algorithm to avoid deadlock. Suppose there are four processes P_1, P_2, P_3, P_4 with maximum resource requirements of 2, 5, 8, and 8 units, respectively. A system state is denoted by $(a_1 a_2 a_3 a_4)$, where a_i is the number of resource units held by $P_i, i = 1,2,3,4$. Which of the following states are safe? Justify your answers.

i. (1 2 4 2)

ii. (1 1 5 3)

(f) **2 marks** For deadlock detection-and-recovery, give two reasons why *preemption* is difficult?

2. (a) **2 marks** Explain the two aspects of the *dating-service problem* preventing a straightforward implementation by *external scheduling*.

(b) **2 marks** Explain two situations where a *public* **_Nomutex** member is useful and give an example of each.

(c) **5 marks** Using μC++, write the shortest possible *external-scheduling* monitor using the following interface that implements a counting semaphore (you may add code anywhere).

```
_Monitor semaphore {
  public:
    semaphore( int cnt = 1 );
    void P();
    void V();
};
```

(d) **2 marks** Explain why *automatic-signal monitors* are easier to use than *explicit-signal monitors* but more expensive in terms of execution time.

(e) **1 mark** Independent of any performance benefit, why do many concurrent locks and monitors allow barging?

(f) **2 marks** Explain why it is impossible to construct a condition lock using a separate monitor.

3. (a) **2 marks** What purpose does the **_When** clause provide on an **_Accept** clause?

(b) **2 marks** Explain why the **_When** clause cannot be easily replaced by the **if** statement.

(c) **2 marks** On assignment 6, is the vending machine a *server* or an *administrator*? Justify your answer.

(d) **3 marks** A *future* can have 3 outcomes. Name each kind of outcome.

(e) **2 marks** What is *cache thrashing*?

(f) **2 marks** What does the C/C++ qualifier **volatile** do, and give an example where it prevents a problem in a concurrent program.

4. (a) **2 marks** Why are operations on lock-free data-structures deadlock-free?

(b) **1 mark** Which aspect of mutual exclusion do lock-free data-structures violate?

(c) **4 marks** When pushing a node on a lock-free stack there is problem. Give the name of the problem and describe it.

(d) **1 mark** State the main hardware architectural difference between CPUs and GPUs that makes GPUs difficult to program.

(e) **2 marks** In the programming language Go, name the mechanism used for thread communication and explain how the communication mechanism is implemented.

5. A *barrier lock* performs synchronization on a group of N threads so they all proceed at the same time. A barrier is accessed by any number of threads. The barrier makes the first $N-1$ threads wait until the Nth thread arrives at the barrier and then all N threads continue. After a group of N threads continue, the barrier resets and begins synchronization for the next group of N threads. A barrier is used in the following way by client tasks:

```
Barrier b;     // global declaration or passed to the client
. . .
b.block();     // each client synchronizes, possibly multiple times
```

Write a barrier using μC++ monitors that implements a barrier lock using:

(a) **4 marks** external scheduling,
(b) **4 marks** internal scheduling,
(c) **4 marks** implicit (automatic) signalling,
(d) **7 marks** internal scheduling with barging.

The barrier class has the following interface (you may add a public destructor and private members):

```
_Monitor Barrier {
    const unsigned int N;        // number in group
    unsigned int count;          // number of arrived tasks
    // ANY ADDITIONAL VARIABLES NEEDED FOR EACH IMPLEMENTATION
  public:
    Barrier( int N ) : N( N ), count( 0 ) {
        // ANY ADDITIONAL INITIALIZATION NEEDED FOR EACH IMPLEMENTATION
    }
    void block(); // WRITE A VERSION FOR EACH IMPLEMENTATION
}
```

The group size, N, is passed to the constructor. **Do not write or create the client tasks.**

Assume the existence of the following preprocessor macros for implicit (automatic) signalling:

```
#define AUTOMATIC_SIGNAL . . .
#define WAITUNTIL( cond ) . . .
#define RETURN( expr. . . ) . . .   // gcc variable number of parameters
```

Macro AUTOMATIC_SIGNAL is placed only once in an automatic-signal monitor as a private member, and contains any private variables needed to implement the automatic-signal monitor. Macro WAITUNTIL is used to delay until the cond evaluates to true. Macro RETURN is used to return from a public routine of an automatic-signal monitor, where expr is optionally used for returning a value.

Assume the existence of the following routines for internal scheduling with barging:

```
void wait() {
    bench.wait();                              // wait until signalled
    while ( rand() % 5 == 0 ) {                // multiple bargers allowed
        _Accept( block ) {                     // accept barging callers
        } _Else {                              // do not wait if no callers
        } // Accept
    }
}
void signalAll() {
    while ( ! bench.empty() ) bench.signal();  // drain the condition
}
```

```
_Task Echo {
  public:
    _Task Guide {                             // created by Echo
      public:
        Guide( Echo &employer );
    };
    typedef Future_ISM<Guide *> FLGuide;  // future lead guide
    _Event Closed {};                         // indicate Echo closed
  private:
    enum { NoOfGuides = 10 };
    const unsigned int R, G;                  // number of rafters/guides per raft
    uCondition guides;                        // guides waiting for trip
    list<FLGuide> rafters;                    // rafters waiting for lead guide
    Guide *leadGuide;                         // communication variable
    // ADD PRIVATE MEMBERS
  public:
    Echo( const unsigned int R ) : R( R ), G( 2 ) {}

    FLGuide hire() {                          // called by rafters
        FLGuide fl;
        rafters.push_back( fl );              // store future
        return fl;                            // return future for lead guide
    }
    Guide *onduty() {                         // called by guides
        guides.wait( (uintptr_t)&uThisTask() ); // wait for a full raft
        return leadGuide;                     // return lead guide
    }
  private:
    void main();                              // WRITE ONLY THIS ROUTINE!!!!
};
```

Figure 1: Echo-River Rafting-Administrator

6. **26 marks** Write an administrator task for the Echo-River Rafting-Company, which offers rafting trips on the Tuolumne River composed of 2 guides and R rafters. The company has ten guides with a sufficient number of rafts available for hire. Once a group of 2 guides and R rafters form, a rafting trip can occur.

   Figure 1 contains the starting code for the Echo-River Rafting-Administrator (you may add only a public destructor and private members). **(Do not copy the starting code into your exam booklet.)**

   The administrator's members are as follows:

   hire: is called by rafters to indicate their desire to take a rafting trip. A future lead-guide is immediately returned to the rafter so they do not have to wait for the lead-guide (e.g., they can get ready for the rafting trip). Eventually, the rafter accesses the lead-guide future to start the trip, which may block until a pair of guides and $R-1$ other rafters are available.

   onduty: is called by guides to indicate their desire to supervise a rafting trip. The call blocks immediately until another guide and R rafters are available; when this call returns it specifies the *lead guide* for the pair of guides.

   The company administrator assigns R rafters and two guides (on a first-come-first-served basis) to a raft, releases both guides indicating which is the lead guide, and informs the R rafters about the lead guide via their future. The lead guide can be either of the two guides. (Then the non-lead guide would contact the lead guide to select a raft, and the rafters would contact the lead guide to learn which raft to assemble at, which you do not have to write.)

When the administrator's destructor is called, the administrator may assume no new calls occur from rafters. However, the administrator must unblock rafters waiting for a lead guide by inserting exception Closed as the future value, and unblock any guides waiting for *R* rafters, returning nullptr as the address of the lead guide.

Ensure the administrator task does as much administration works as possible; a monitor-style solution will receive little or no marks. Write only the code for Echo::main based on the given outline, **do not write a rafter or guide or uMain::main**. Assume uMain::main creates the rafter.

μC++ future server operations are:

- delivery(T result) - copy result to be returned to the client(s) into the future, unblocking clients waiting for the result.
- exception(uBaseEvent *cause) - copy a server-generated exception into the future, and the exception cause is thrown at clients accessing the future.

μC++ wait statement allows an integer/pointer value to be stored with a waiting task on a condition queue. The integer value can be accessed through the uCondition member routine front, e.g.:

```
x = guides.front();
```

C++ list operations are:

int size()	list size
bool empty()	size() == 0
T front()	first element
T back()	last element
void push_front(**const** T &x)	add x before first element
void push_back(**const** T &x)	add x after last element
void pop_front()	remove first element
void pop_back()	remove last element
void clear()	erase all elements