UNIVERSITY OF WATERLOO
CS 350 MIDTERM :: SPRING 2012

Date: Monday, June 25, 2012
Time: 7:00 – 8:50 pm
Instructor: Dave Tompkins
Exam Type: Closed book
Additional Materials Allowed: none

Last Name: SOLUTION

First Name: ______________________________

Student #: __ __ __ __ __ __ __ __

UW Login: __ __ __ __ __ __ __ __

Signature: ______________________________

Question	Out Of	AVG
1	10	6.2
2	15	9.5
3	5	4.1
4	16	9.0
5	12	10.6
6	4	2.4
7	18	5.8
8	20	11.6
Bonus		0.9
Total	100	60.0

INSTRUCTIONS

1. Before you begin, make certain that you have one exam booklet with 8 pages (double sided)
2. All solutions must be placed in this booklet.
3. If you need to make an assumption to answer a question, state your assumption clearly.
4. When writing code, you should use C or C-like pseudocode. You do not have to worry about `#include` statements or semi-colons.
5. If you need more space, use the last page, and indicate that you have done so in the original question.
6. A big gap after a question does not necessarily mean that a long answer is expected.
7. Did you see in the marking guide there's a bonus question? woo-hoo! Make sure you answer it at the end.
8. Relax! Read this instruction as often as needed.

Question 1 [10 Marks]

(a) [3 Marks] In OS/161 there is a `struct thread` to represent a thread context and a `struct trapframe` to represent a trap frame. Describe something that is contained in both structures, and then for each of the structures describe something that it contains that the other does not. Briefly explain why each of the 3 things you describe appears where it does.

Almost ALL registers are stored in a trap frame when a trap occurs (interrupt/syscall/exception), but only a subset are backed up when a thread context switch occurs. So (for example) s1 would be in both, but temp register t0 would only be in the trapframe. The thread context also has thread-specific information, such as the base of the kernel stack, the thread name, cwd, etc.

(b) [2 Marks] On the MIPS + OS/161 system, explain why `a++` is not considered an atomic operation, yet `V(s)` is.

a++ is really 3 separate assembler instructions (load, add, store) and an interrupt could occur in-between them. Within V(), interrupts are disabled so it cannot be interrupted.

(c) [3 Marks] What behaviour does a lock have that a binary semaphore does not? Briefly describe a situation where you would prefer a lock and a situation where you would prefer a binary semaphore.

```
* a lock ensures that it can only be released by the thread
that acquired it.
* Use a lock to surround a critical section of code and you
want a guarantee that no other thread can unlock.
* You can use a semaphore for much more.  For example you can
enforce 2 threads execute in a specific order (eg: thread A
waits for thread B).
```

(d) [2 Marks] Explain what this line of code is doing and why:

```
mips_syscall(struct trapframe *tf) {
  ...
  tf->tf_epc += 4;       <---- explain this line
  ...
}
```

```
* when a system call occurs, the program counter (PC) is
stored in the trap frame (tf->tf_epc).
* when the kernel returns to user mode, it must increment the
PC to the next instruction after the syscall, otherwise it
will repeat the syscall.
```

Question 2 [15 Marks]

(a) [4 Marks] There are three different ways a thread can transition from user mode to kernel mode. Write a small user program for OS/161 that ensures that all three would occur during its execution and identify how each would occur. If you cannot ensure a transition will occur, explain why.

```
int main() {
  int i = 1;
  int *ptr = 0;
  printf("system call");
  while (i > 0) i++;  // long loop to ensure timer interrupt
  i = *ptr; // exception
}
```

```
(note: partial marks for saying it's impossible for a user
prog. to cause an interrupt.)
```

(b) [5 Marks] In class, 5 different sections of an ELF file were described:

```
text   rodata   data   bss   sbss
```

Write a small user program for OS/161 that would have elements in each of the 5 section types and identify where each appears in your program.
(pro tip: you can simply have variable names that use the appropriate section name).

```
int data = 1;
int sbss;
int bss[4096];
void textsection () { // all code goes into text
  printf("rodata");
}
```

(c) [6 Marks] Write a single user program for OS/161 that will generate one child process, which in turn will generate a grandchild process (3 processes in total). The output should be the sum of the three `pid`s. For simplicity, assume that `pid_t` is an `int`.

The following functions might be helpful:

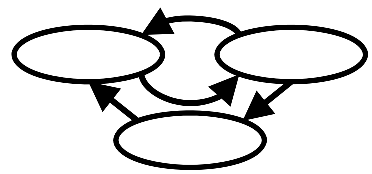
```
int   printf(const char *format, ...);
pid_t getpid(void);
pid_t fork(void);
pid_t waitpid(pid_t pid, int *status, int options); // opt=0
void  _exit(int exitcode);
```

```
int main() {
  int parent, child, grandchild;
  parent = (int) getpid();
  child = (int) fork();
  if (child == 0) {
    grandchild = (int) fork();
    _exit(grandchild);
  } else {
    waitpid(child,&grandchild,0);
    printf("%d\n", parent + child + grandchild);
  }
}

/********************
 another fun example:
 ********************/

int main() {
  int sum = (int) getpid();
  if (fork() == 0) {
    sum += (int) getpid();
    if (fork() == 0) {
      sum += (int) getpid();
      printf("%d\n",sum);
    }
  }
}
```

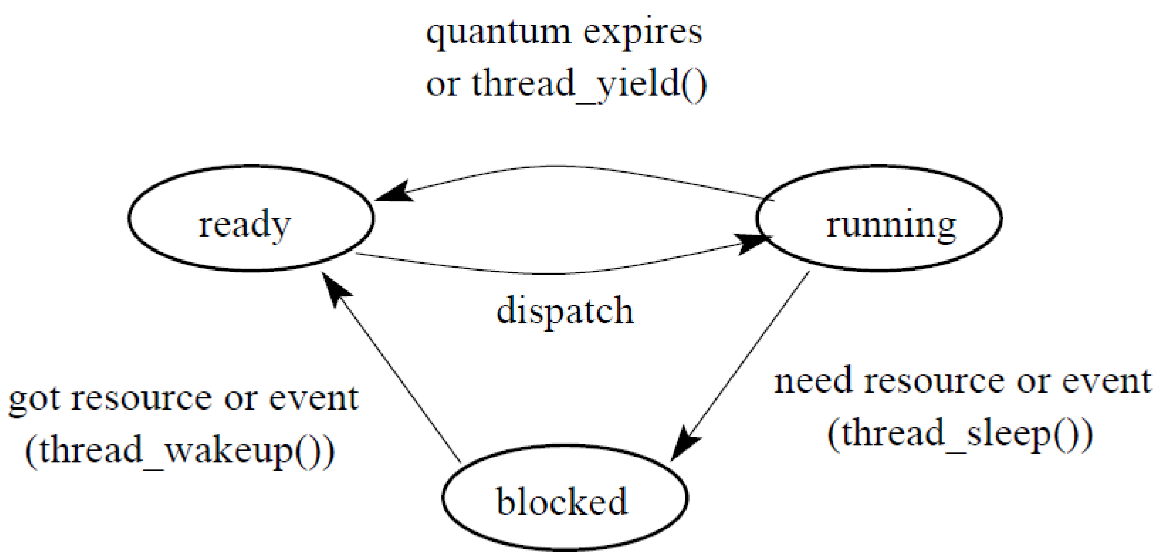
Question 3 [5 Marks]



(a) Re-draw the thread state transition diagram shown in class, and label each of the 3 states and all 4 transitions.

(b) In OS/161 there is a fourth state: S_ZOMB. Add this state to your diagram and label the new transition(s).

(a) [figure from notes]



(b) A single arrow from "running" to "zombie", arrow labeled with thread_exit.

Question 4 [16 Marks]

You are given the first 25 pages of an execution string for a process:

A B C D E B D B C D B C D B C B D E B D E B C B A

There are 5 unique pages, but it is to be run on a system that has only 4 frames of physical memory allocated to the process (and there will always be 4). None of the pages are resident at the beginning of the execution (ie: all frames are uninitialized).

(a) [8 Marks] For each of the following page replacement algorithms, state which page(s) would <u>NOT</u> be in resident memory at the end of the execution. If you cannot answer, state your reason (eg: "not enough information" or " a tie between X and Y")

FIFO (First In, First Out): B

OPT (Theoretically Optimal): cannot determine / tie for BCDE

LFU (Least Frequently Used): E

LRU (Least Recently Used): D

(b) [3 Marks] For the following two algorithms, how many page <u>hits</u> would there be?

OPT: 19

LRU: 19

(c) [2 Marks] What is WS(25,4)? (In other words, what is the working set (WS) at the end of the execution if $\Delta = 4$)?

{A,B,C}

(c) [3 Marks] At the beginning of the execution none of the pages were resident. Explain what policy the O/S would likely have in place and why that is often a good policy.

O/S is likely using demand paging, a policy that avoids over-allocating memory and ensures pages are loaded only when required.

Question 5 [12 Marks]

For all parts of this question, you should assume a virtual memory system based on simple paging. All parts of this question refer to the following two page tables, one for process P1 and one for process P2. Note that the frame numbers are specified in hexadecimal, as are all virtual and physical addresses used in this question.

P1

Page #	Frame #
0	0x8d10
1	0x1004
2	0x3008
3	0x5500
4	0x2220
5	0x2221
6	0x2222
7	0x222a
8	0x5558

P2

Page #	Frame #
0	0x222b
1	0x010a
2	0x010b
3	0x3008
4	0x3001
5	0x222c

(a) [4 marks] For each of the following virtual addresses from P1's virtual address space, indicate the physical address to which it corresponds. For the purpose of this part of the question, assume that the page size is 4096 (2^{12}) bytes. Give your answers in hexadecimal. If the specified virtual address is not part of the virtual address space of P1, write "NO TRANSLATION" instead.

0x0000022 0x8d10022

0x00005ff 0x8d105ff

0x0001004 0x1004004

0x0006072 0x2222072

(b) [4 marks] Repeat part(a), but this time for P2 and under the assumption that the page size is 256 (2^8) bytes.

0x0000022 0x222b22

0x00003a8 0x3008a8

0x00005ff 0x222cff

0x0001004 NO TRANSLATION

(c) [4 marks] For each of the following physical addresses, indicate which process's virtual address space maps to that physical address, and indicate which specific virtual address maps there. If you cannot answer the question, explain why not. For the purposes of this question, assume that the page size is 4096 (2^{12}) bytes.

```
0x010abcd      P2: 0x1bcd

0x2222ffa      P1: 0x6ffa

0x222d002      NO MAPPING (no pages map to frame 0x222d)

0x3008888      NO SPECIFIC VIRTUAL ADDRESS
               (shared memory for P1 & P2)
               P1: 0x2888  & P2: 0x3888
```

Question 6 [4 Marks]

The following function has a critical section that should only be accessed by one thread at a time:

```
int myFunction () {
  struct semaphore *s = sem_create("my semaphore", 0);
  /* ... */
   V(s);
  /* ... critical section ... */
   P(s);
  /* ... */
}
```

Is this a good design? Briefly justify your answer

```
No, This is a bad design.  The critical section is not
protected as the semaphore is declared as a local variable and
so _each_ thread has its own semaphore.

partial marks for observing:
* P & V are in the wrong order, and the sem should init to 1.
```

Question 7 [18 Marks]

(a) [3 Marks] The cat & mouse simulation in assignment 1 was run entirely in the kernel. Explain why it could not be run as a user process.

To solve the cat and mouse problem, we require basic synchronization primitives (semaphores are sufficient) and shared memory.

In user space, we have neither: The semaphore interface is entirely implemented in kernel space, and user processes each have their own virtual address space and only support single threads.

(b) [15 Marks] How would you modify OS/161 to enable users to run multi-threaded applications that can use semaphores for synchronization?

Notes: Use point form. You must provide sufficient functionality so that an application such as the cat & mouse simulation could be implemented (with semaphores). There are many different strategies available to solve this problem. You may assume that assignment 2 has been completed. You do not have to provide any code, just describe your changes and new features and briefly motivate them.

Note: there are many approaches.

The most straightforward is to export the use of semaphores via new system calls to user space (eg: sys_P, sys_V, sys_sem_create/destroy). The OS could create a user space handle for each semaphore similar to file handlers.

continued...

Question 7 (more space)

The system would also require user threads to have shared memory.

This could be done by adding shared memory syscalls (such as shmget) so that separate processes could share memory. The OS would map virtual pages from two processes to the same physical memory.

Alternatively, we could enhance the OS to allow a process to have multiple threads (each thread would share the same address space). The OS would have a new process structure that could contain several threads, each with a separate thread context (stack, etc.). The OS would still have to add new syscalls for a process to create a new thread.

Question 8 [20 Marks]

In this question we are running a modified cat & mouse simulation that can accommodate an arbitrary number of animal types, and an arbitrary number of each type of animal.

Once they are created, animals repeat the following steps until they die: they wait to eat, they eat, and then they nap. Animals are continuously being created (it's the circle of life). Animals eat at bowls. There are a fixed number of bowls; each bowl can be occupied by at most one animal at a time, and all of the animals eating at the same time must be of the same type (otherwise there is chaos).

You must implement the function:

```
void bowlfree() {...} // called whenever bowls are available
```

You should try to implement the most **efficient** solution you can and keep *as many bowls occupied as possible*. You should **not** worry about starvation or fairness.

You may assume the following global variables and functions are available:

```
const int numbowls      // total number of bowls
const int N             // number of animal types
volatile int numfree    // number of currently free bowls
volatile int curtype    // type of animal currently eating

struct animal {...}     // data structure for an animal

void assign(*a)         // Assign animal a to a free bowl

struct queue {...}      // FIFO queue for managing animals
void qadd(*q, *a)       // Add animal a to queue q
animal* qnext(*q)       // Get & remove the next animal from the queue q
int qsize(*q)           // Return the number of animals in q

queue *waiting[]        // waiting queues for each type of animal
int maxtype()           // animal type with the largest waiting[] queue
```

- You do not have to worry about initializing any global variables you create.
- The animal "types" are integers 0..(N-1). (eg: 0=mice, 1=cats, 2=dogs, etc.)
- Assume all animals behave the same: they eat & nap for the same duration.
- When `bowlfree()` is called you can assume there is at least one bowl free and at least one animal waiting to eat. The function `bowlfree()` may be called by multiple threads simultaneously. Do not concern yourself over how or when `bowlfree()` is called or the mechanics of `assign()`.
- You do not have to track *which* bowls are free or update `numfree`. If there is a free bowl `assign()` will work properly and update `numfree` for you. If `assign()` is called and there are no free bowls, or there is a different type of animal currently eating, the system will panic (crash).
- The queues and queue functions are not synchronized. You should use a synchronization mechanism for each queue. You do not have to worry about how the `waiting[]` queues are populated and can assume they are populated using your synchronization mechanism.

(a) [15 marks]

```
// YOUR GLOBAL VARIABLES GO HERE

struct lock *qlock[N];  // one lock per queue

struct lock *bflock;   // (one master lock was acceptable)

void bowlfree() {   // at least one bowl is free

  // obviously many solutions possible

  int qmax, nummax, numwait;
  int numeating = numbowls – numfree;

  lock_acquire(bflock);

    qmax = maxtype();

    lock_acquire(qlock[qmax]);
      nummax = qsize(waiting[qmax]);
    lock_release(qlock[qmax]);

    if (numeating == 0) {
      curtype = qmax;
    }

    lock_acquire(qlock[curtype]);

     numwait = qsize(waiting[curtype]);

     // Only let the current animal keep eating if
     // it can fill all the bowls, OR
     // it's capacity (eating + waiting) is larger than
     // all other animals.

     if ((numwait >= numfree)
          || ((numeating + numwait) >= nummax) {

      // this is some sample code: you can use it if you wish
      while ((numfree > 0) && (qsize(waiting[curtype]) > 0)) {
        assign(qnext(waiting[curtype]));
      }
     }
    lock_release(qlock[curtype]);
  lock_release(bflock);

}
```

(b) [5 marks] Justify why your solution is efficient, and describe any sacrifices in fairness you made to achieve that efficiency.

If there are enough of the "current" animal C to keep the bowls completely full at all times, we will achieve ~100% efficiency. We completely sacrifice fairness and let C continue to eat, possibly starving all other animals.

The lower bound on efficiency is when (naptime >> eattime) and another animal D could keep all the bowls completely full at all times, but C keeps control of the bowls. This occurs when and the number of C's is (numbowls + epsilon) such that the bowls can be mostly empty for a naptime duration but will be completely refilled with C's before all of the bowls become empty. The efficiency is ~(eattime/naptime).

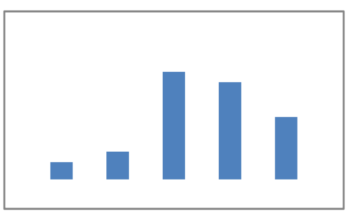
If C cannot fill the bowls, and another animal D continues to have more capacity to fill the bowls than C, then C will stop being assigned bowls and it will switch to D.

Bonus Question [1 Mark]

Please answer the following 3 questions ***honestly*** at the end of the exam:

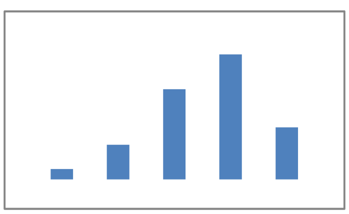
This exam was too long:

a) Strongly disagree
b) Disagree
c) Neutral
d) Agree
e) Strongly agree



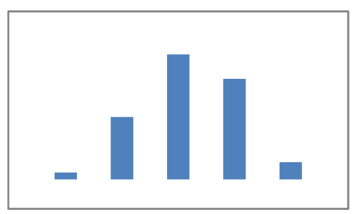
This exam was too hard:

a) Strongly disagree
b) Disagree
c) Neutral
d) Agree
e) Strongly agree



This exam was fair:

a) Strongly disagree
b) Disagree
c) Neutral
d) Agree
e) Strongly agree



Draw a picture of an operating system thrashing