University of Waterloo
CS350 Midterm Examination

Fall 2017

Student Name: ______________________________

Closed Book Exam
No Additional Materials Allowed

1. (13 total marks)

a. (2 marks)

Is it possible to have more than one trapframe in one kernel stack? Explain why or why not.

b. (3 marks)

Explain why the following implementation of semaphore P is incorrect. Provide an example interaction between two threads that illustrates the problem.

```
void P(struct semaphore *sem) {
    spinlock_acquire(&sem->sem_lock);
    while (sem->sem_count == 0) {
        spinlock_release(&sem->sem_lock);
        wchan_lock(sem->sem_wchan);
        wchan_sleep(sem->sem_wchan);
        spinlock_acquire(&sem->sem_lock);
    }
    sem->sem_count--;
    spinlock_release(&sem->sem_lock);
}
```

c. (2 marks)

When an exception occurs, the CPU saves the contents of the `PC` to the `EPC`, turns off interrupts, and performs two other actions. List those two other actions.

d. (2 marks)

For what reasons would `waitpid` return an error?

e. (2 marks)

A trapframe contains more information than a switchframe. Why?

f. (2 marks)

Why does `thread_fork` require a function for the thread to call, while `fork` is able to simply return in both processes?

2. (8 total marks)

Suppose we want to count the number of times the word "the" appears in Wikipedia. After downloading all the articles, the following program is written to perform this task:

```
char **articles;
int counts[NUMARTICLES];
struct lock *mutex;

void Count(char *word, int articleNum)
{
    int wordCount;
    [ ... find word count ... ]
    counts[articleNum] = wordCount;
}

int CountWord(char **articles, int articleCount)
{
    int i;
    for (i = 0; i < articleCount; i++)
        thread_fork([...], Count, word, i);

    int sum = sum(counts);
    printf("Number of words: %d\n", sum );
}
```

However, when this program is run, the number printed is incorrect.

a. (2 marks)

Why is the sum incorrect?

}

b. (6 marks)

Fix the code.

```
char **articles;
int counts[NUMARTICLES];
struct lock *mutex;




void Count(char *word, int articleNum)
{
    int wordCount;




    [ ... find word count ... ]




}

int CountWord(char **articles, int articleCount)
{
    int i;




    for (i = 0; i < articleCount; i++)
        thread_fork([...], Count, word, i);




    int sum = sum(counts);
    printf("Number of words: %d\n", sum );
}
```

3. (8 total marks)

A system uses 64-bit physical addresses and 48-bit virtual addresses. The page size is 2^{32} bytes. The system uses a single-level page table as its implementation of virtual memory.

a. (1 mark) How many page table entries does the page table contain?

b. (1 mark) How many bits are used for the page number?

c. (1 mark) How many bits are used for the page offset?

d. (1 mark) If each page table entry is 128 bits ($2^4 = 16$ bytes), how big is a page table?

e. (2 marks) Process P has a 256KB (2^{28} byte) contiguous address space, starting at the beginning of a page. How many pages are valid?

f. (2 marks) How much memory on the pages assigned to process P is unused?

4. (6 marks)

An OS/161 process P is in `sys_write`, from a `write` system call, when a timer interrupt fires. Draw the relevant stack frames for P's user and kernel stack, during the call to `mips_trap` caused by the timer interrupt. The application source code is as follows:

```
int main() {
    write(1, "Hello, world!\n", 8);
}
```

User stack

Kernel stack

5. (8 total marks)

a. (2 marks)

Consider a single-level paging-based virtual memory system. Explain the consequence of having two valid page table entries from two different page tables store the same frame number.

b. (4 marks)

At this point in the course, a parent and child process can only communicate with each other through the exit code of the child process. For this question, explain in detail what changes you would need to make to the `fork` system call such that, in addition to its normal function, fork would allocate a shared region of memory that is readable but not writeable by the parent, and readable and writeable by the child. You can assume the kernel is using a paging-based virtual memory system. The interface to this modified fork system call is as follows:

```
pid_t fork(size_t size, void **retval);
```

Example code that allocates 4 KB of shared memory using this modified system call:

```
void *shared_memory;
rc = fork(4096, &shared_memory);
```

We are only interested in the changes that you need to make inside the kernel.

c. (2 marks)

When would it be safe for the child process to write data to the shared memory region, and for the parent process to read data from the shared memory region? Explain your reasoning.

6. (8 total marks)

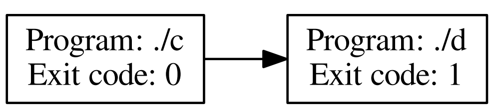
Draw the tree of processes for the following programs, in which `a.c` is compiled into `./a` and `b.c` is compiled into `./b`, and the root process starts by running `./a`. Include arrows from parents to children. For each process, indicate which program it's running at exit and its exit code.

a.c:

```
int main() {
    char buf[32];
    int p = fork();
    if (p != 0) {
        char *args[3];
        sprintf(buf, "%d", p);
        args[0] = "./b";
        args[1] = buf;
        args[2] = NULL;
        execv("./b", args);
    } else {
        if (fork() == 0)
            _exit(1);
        else
            _exit(2);
    }
    _exit(3);
}
```

b.c:

```
int main(int argc, char **argv) {
    int r = 0;
    int p = fork();
    if (p != 0) {
        int e;
        waitpid(p, &e, 0);
        if (WIFEXITED(e))
            r = WEXITSTATUS(e);
        waitpid(atoi(argv[1]), &e, 0);
        if (WIFEXITED(e))
            r += WEXITSTATUS(e);
    }
    _exit(r);
}
```

Example: 

7. (16 total marks)

As part of Assignment 1, you implemented locks and condition variables using spinlocks and wait channels. In this problem, you must use locks and condition variables to build a Readers-Writer lock, a synchronization primitive that allows multiple concurrent readers to simultaneously read from shared data, or one writer to write to shared data.

A reader acquires and releases a Readers-Writer lock by passing READ as the first argument to `rwlock_acquire` and `rwlock_release`. Similarly, a writer passes WRITE as the first argument to `rwlock_acquire` and `rwlock_release`. Multiple readers must be able to simultaneously acquire the same lock if a writer does not already own (having acquired but not yet released) the lock, and no writers are waiting to acquire the lock. A writer must be able to acquire a lock if no readers or other writers currently own the lock. Only one writer can acquire the lock at a time. Waiting readers and writers must block; they cannot just spin until the lock becomes available.

Note that this Readers-Writer lock specification provides **write priority**. If there are both readers and writers waiting to acquire the lock, a waiting writer must be allowed to acquire the lock before the waiting readers. As a concrete example, if a reader R_1 currently owns the lock, a new writer W_1 must block when it tries to acquire the lock. If reader R_2 arrives while W_1 is blocked and R_1 is still holding the lock, R_2 must also block. When R_1 releases the lock, W_1 must be unblocked and allowed to acquire the lock before R_2.

Implement the following four functions. Structures and global variables can be defined in the provided space.

```
// Define your structures and global variables here.
enum LockTypes {
    READ = 0, WRITE = 1
};
typedef enum LockTypes LockType;

struct rwlock {
    char *lk_name;
    // Add other fields here









};
```

```c
struct rwlock *rwlock_create(const char *name)
{
    struct rwlock *lk = kmalloc(sizeof(struct rwlock));
    if (lk == NULL) {
        return NULL;
    }
    lk->lk_name = kstrdup(name);
    if (lk->lk_name == NULL) {
        kfree(lk);
        return NULL;
    }
    // You are allowed to omit error checking code in this function.












}

void rwlock_destroy(struct rwlock *lk)
```

```
void rwlock_acquire(LockType lt, struct rwlock *lk)
```

```
void rwlock_release(LockType lt, struct rwlock *lk)
```