CS 3204 Sample Midterm

Answers are shown in this style. This exam was given in Fall 2007.

1. Semaphores (20 pts)

a) (20 pts) Semaphores.
Write a program using 2 threads that will ***always deadlock*** (independent of which scheduling policy is in effect). Your program should ***use only semaphores*** (that is, no timer_sleep() or thread_yield() or similar functions).

The idea is to use two semaphores l1 and l2 as resources (initialized to 1), which the two threads acquire in a different order. To ensure that deadlock always happens, the threads each must know that the other has acquired its resource, which can be easily accomplished by using a rendezvous after acquiring the first resource acquire. This rendezvous requires the use of two additional semaphores s1 and s2, initialized to 0.

// Insert your definitions here (show initial values for your semaphores!) *semaphore s1(0), s2(0), l1(1), l2(1);*	
// Thread 1 *l1.down();* *s1.up();* *s2.down();* *l2.down();*	// Thread 2 *l2.down();* *s2.up();* *s1.down();* *l1.down();*

This question ended up being somewhat ambiguous.

The difficulty revolves around the meaning of "deadlock." What I had intended was a deadlock that is a (static) resource deadlock, which is a situation that arises due to a sequence of requests, acquisitions and subsequent releases of static, identifiable resources by processes. Only this type of deadlock can be described by the 4 necessary conditions discussed in class. If I were to create a similar question again, I would explicitly specify such a static deadlock.

However, in lecture (as well in the example exams and even in the OS literature), the term deadlock is often used more informally to describe a number of situations in which progress is prevented because (static or dynamic) resources will not become available to the processes waiting for them.

An interesting discussion of this topic can be found in Levine's paper on "Defining Deadlock" http://doi.acm.org/10.1145/881775.881781.See in particular Sections 1 and 2, where Levine points out that even OS textbooks sometimes contain examples that don't strictly follow (their own)

definition of deadlock. For instance, our textbook (pg 243) gives the example of two trains meeting at a crossing, and a Kansas law that requires each train to give preference to the other. Obviously, this example is not a deadlock – there is no hold-and-wait, for instance. Instead, it is a simultaneous request for a single resource which can be handled by arbitrating the request in some way.

2. Process States and Priorities (24 pts)

a) (14 pts) Assume a preemptive, strictly priority-based scheduler that implements priority inheritance. Under this assumption, write down the output of the following program. You may assume that thread_create and lock_* functions work as in Pintos.

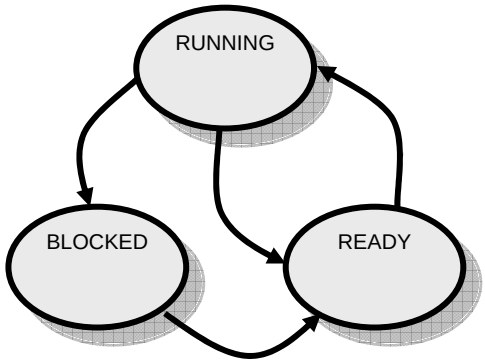
```
void
test_priority (void)
{
  struct lock lock;

  /* Make sure our priority is the default. */
  ASSERT (thread_get_priority () == PRI_DEFAULT);

  lock_init (&lock);
  lock_acquire (&lock);
  thread_create ("thread1", PRI_DEFAULT + 1, thread1_func, &lock);
  msg ("A");

  thread_create ("thread2", PRI_DEFAULT + 2, thread2_func, &lock);
  msg ("B");

  lock_release (&lock);
  msg ("C");
}

static void
thread1_func (void *lock_)
{
  struct lock *lock = lock_;

  lock_acquire (lock);
  msg ("D");
  lock_release (lock);
  msg ("E");
}

static void
thread2_func (void *lock_)
{
  struct lock *lock = lock_;

  lock_acquire (lock);
  msg ("F");
  lock_release (lock);
  msg ("G");
}
```

The output is:

A B F G D E C

(You should already be familiar with this program as priority-donate-one)

b) (6 pts) Recall the simple 3-state process diagram:



Explain why there are no arrows from BLOCKED to RUNNING and from READY to BLOCKED!

i. (3 pts) BLOCKED → RUNNING is missing because:

Blocked processes first transition into the READY state because this model separates unblocking a process from scheduling that process. The former is dictated by the occurrence of an event – the latter is a policy decision that is under the purview of the scheduler.

ii. (3 pts) READY → BLOCKED is missing because:

A process blocks if it encounters a situation in which it cannot continue execution. Ready processes do not currently execute, therefore, they cannot block.

c) (4 pts) Suppose that there are only two threads in a system, and suppose both are in the READY or RUNNING state. Is there a need for priority inheritance in such a system?
Say why or why not!

There is no need for priority inheritance, because priority inversion cannot occur since even if the higher-priority thread blocked on a resource held by the lower-priority thread, the lower-priority thread would be run as the only READY thread.

3. Deadlock (20 pts)

a) (4 pts) While debugging your Pintos kernel, you notice that it's getting stuck. Your teammate says that Pintos must have deadlocked. Is his inference correct? Justify your answer!

No, this inference is incorrect. "Getting stuck" could happen for any number of reasons that do not indicate deadlock: processes could loop infinitely, processes could sleep, could wait for I/O, or you may have a bug in your scheduler in which you incorrectly manage your ready queue.

See also question 1 a). However, even under an extended view of deadlock that includes static and dynamic resources, not all reasons for getting stuck will qualify as deadlock.

b) (8 pts) The following comment can be found in a file that is part of the Linux kernel (linux/mm/rmap.c):

```
/*
 * Lock ordering in mm:
 *
 * inode->i_mutex  (while writing or truncating, not reading or faulting)
 *   inode->i_alloc_sem (vmtruncate_range)
 *   mm->mmap_sem
 *     page->flags PG_locked (lock_page)
 *       mapping->i_mmap_lock
 *         anon_vma->lock
 *           mm->page_table_lock or pte_lock
 *             zone->lru_lock (in mark_page_accessed, isolate_lru_page)
 *             swap_lock (in swap_duplicate, swap_info_get)
 *               mmlist_lock (in mmput, drain_mmlist and others)
 *               mapping->private_lock (in __set_page_dirty_buffers)
 *               inode_lock (in set_page_dirty's __mark_inode_dirty)
 *                 sb_lock (within inode_lock in fs/fs-writeback.c)
 *                 mapping->tree_lock (widely used, in set_page_dirty,
 *                           in arch-dependent flush_dcache_mmap_lock,
 *                           within inode_lock in __sync_single_inode)
 */
```

i. (4 pts) Was the intention of the developer when writing this comment related to deadlock recovery, deadlock avoidance, or deadlock prevention? Define the term you choose as an answer.

The intention is deadlock prevention. Deadlock prevention removes one of the four necessary conditions for deadlock to occur.

ii. (4 pts) Depending on your answer in i., explain how this comment can help recover from deadlocks, avoid deadlocks, or prevent deadlocks. Be specific.

Specifying a locking order avoids circularities in the resource allocation graph, removing one of the necessary conditions for deadlock.

c) (8 pts) Generally, a better method to convey information about the assumptions that underlie a correct program is the use of assertions (e.g. ASSERT()). Could the information that is conveyed in the comment given

in part b) of this question also have been expressed as assertions? If so, sketch how by example. If not, justify why not. Be precise.

*In theory, yes. In **all** places where a lock is acquired, place an assertion that the current thread does not already hold **any** of the locks that are lower in the locking order. In practice, this is less practical because a) there may be many objects, b) not all objects that are sources of deadlock have a notion of ownership, or implement ownership, and c) because not all objects may be easily accessible in the current scope.*
Example:

```
/* [ would have to place assertions that none of the locks that could be
acquired following inode->i_mutex are already held, for instance: ] */
assert(!lock_held_by_current_thread(inode->i_alloc_sem));
/* and many more, which likely makes this approach impractical. */
lock_acquire (inode->i_mutex);
```

Note that locking order does not mean that all lower-order locks must be acquired before a higher-order lock is requested. Rather, it means that a lower-order lock cannot be requested once a higher-order lock is held. It would be wrong to assert() you're holding a lower-order lock before acquiring a higher-order lock.

4. System Calls and Protection (36 pts)

a) (8 pts) Virtual machine monitors (VMM) such as VMware ESX are a software layer that can multiplex the simultaneous execution of multiple operating systems, along with the user processes running inside them, on a single physical machine. VMM virtualize physical hardware components, such as the CPU, memory, or I/O devices for the guest operating systems running inside them, very much like ordinary operating systems virtualize such resources for their user processes.
To provide isolation between different virtual machines, a technique called deprivileging is being used in which the kernel code of each guest operating system is run in user mode.
As a specific example, assume that the guest OS contains an idle thread which it schedules when there are no other process to run. The idle thread executes the x86 "hlt" instruction in a loop, which suspends the CPU in a low-power state until an interrupt arrives.

i. (4 pts) What would happen, specifically, if a guest OS's idle thread were run in user mode? Explain why!

The hlt instruction is a privileged instruction because ordinary user process must not allow a machine to be halted. If such a privileged instruction is executed while the CPU is in user mode, a trap or exception will occur. (I demoed this in class.)

ii. (4 pts) How could the underlying virtual machine monitor make it so that the guest OS that has scheduled an idle thread would still

function as designed (that is, the guest must not be aware that it is running deprivileged inside a virtual machine)?
Sketch what the VMM would have to do! Consider also how the guest OS regains control eventually.

When the trap occurs, the hypervisor will realize that this guest machine is idle, and it will stop assigning the real CPU to it; it may then move on to schedule another guest machine. When an interrupt occurs for this guest machine, the hypervisor will resume execution in that virtual machine after the hlt instruction, then deliver the interrupt. To the guest, it will appear that the hlt instruction had the same effect as on real hardware.

b) (20 pts, 4 pts each.) In Unix-like OS, processes are usually terminated when they access virtual memory addresses that are either not mapped or that are mapped as being accessible in kernel-mode only. If these processes are started from a shell, you then see a message that says "Segmentation Fault." Typically, such invalid memory accesses are the results of a programming error.
Based on your knowledge of a typical runtime environment, state, for each of the following erroneous programs, under which conditions they would be terminated with a segmentation fault! State your assumptions if necessary. You may use C-style short-hand notation.

		Would be terminated if:

i)	`int overflow1(void) {`
	`  int buf[10];`
	`  return buf[20000];`
	`}`
		*buf + 20000 * sizeof(int) > PHYS_BASE (or upper end of stack segment)*

ii)	`int underflow1(void) {`
	`  int buf[10];`
	`  return *(buf - 20000);`
	`}`
		*buf – 20000 * sizeof(int) < Current lower end of stack segment*

iii)	`int overflow2(void) {`
	`  int *b = malloc(80);`
	`  return b[20000];`
	`}`
		*b + 20000 * sizeof(int) > Current upper end of heap segment*

iv)	`static int buf1[20];`
	`int overflow3(void) {`
	`  return buf1[20000];`
	`}`
		*b + 20000 * sizeof(int) > Current upper end of heap segment (assuming data segments and heap segments are adjacent.)*

v)	`int arbitrary(void) {`
	`  return *(int*)0x9000000;`
	`}`
		0x9000000 is not in any valid segment.

c) (8 pts) In a previous offering of CS 3204, a student criticized Pintos for not being a real OS because unlike “real OS,” Pintos does not pass system call arguments in registers. By comparison, Linux passes arguments to system calls in registers: %eax is the syscall number on entry; %ebx, %ecx, %edx, %esi, %edi and %ebp are the six generic registers used as parameters 0 to 5. The return value is also transferred in register %eax.

Sketch what your syscall handler function would look like if Pintos used this method of passing system call parameters!

Assuming that at most 3 parameters are used, the system call handler could look as simple as:

```
static void
syscall_handler (struct intr_frame *f)
{
      if ((unsigned)f->eax >= SYS_CALLNO_MAX)
            thread_exit();
      f->eax = syscall_table[f->eax](f->ebx, f->ecx, f->edx);
}
```

Note that since the stack is not used, no checking on f->esp needs to be done.