University of Waterloo
Midterm Examination
Term: Winter Year: 2015

Solution

———begin solution———

Grade breakdown: Winter 2015

Question	1	2	3	4	5	6	7	Total
Out of	9	14	12	10	12	9	9	75
Maximum	9.0	14.0	12.0	10.0	12.0	9.0	9.0	75.0
Average	6.0	9.5	7.4	5.4	8.2	7.1	5.8	49.4
Avg %	66.7	67.9	61.9	53.7	68.2	79.2	64.4	65.9

Range	Count
100-100	2
90-99	10
80-89	25
70-79	37
60-69	37
50-59	28
40-49	15
30-39	12
20-29	1
10-19	1
0-9	0

———end solution———

Problem 1 (9 marks)
For the program shown below, assume that all function, library and system calls are successful. Recall that the prototype/signature for `thread_fork` is:

```
int thread_fork(const char *name, struct proc *proc,
                void (*func)(void *, unsigned long),
                void *data1, unsigned long data2);
```

```
volatile int x = 42;

main()
{
  /* name="1", no process, runs func1 */
  /* parameters 0 and 0, not used */
  thread_fork("1",NULL,func1,0,0);

  /* name="2", no process, runs func2 */
  /* parameters 0 and 0, not used */
  thread_fork("2",NULL,func2,0,0);

  func3(0,0);
}
```

```
void func1(unsigned long notused, void *notused2)
{
    kprintf("A: %d\n", x);
    x = 10;
}
void func2(unsigned long notused, void *notused2)
{
    kprintf("B: %d\n", x);
    x = 20;
}
void func3(unsigned long notused, void *notused2)
{
    kprintf("C: %d\n", x);
    x = 30;
}
```

When consdering each line of output produced by the program above, what would the output be when printing the value of the variable x? If more than one value or a range of values is possible, list all possible values or ranges.

```
/* From func1 */ A:


/* From func2 */ B:


/* From func3 */ C:
```

———————begin solution———————

```
A: 42 | 20 | 30
B: 42 | 10 | 30
C: 42 | 10 | 20
```

———————end solution———————

Problem 2 (14 marks)
For the program shown below, what output would be printed when it runs? If a range or multiple values are possible, give the range or possible values. If it is not possible to determine the value, posssible values or a range, state so and explain why. Assume that all function, library and system calls are successful. If more than one ordering of output is possible choose one of the possible orderings. Recall that `WEXITSTATUS(status)` just gets the exit code portion of the `status` variable.

```
int x = 42;

main()
{
  int rc, status;

  rc = fork();

  if (rc == 0) {
    func1();
    _exit(1);
  } else {
    rc = waitpid(rc, &status, 0);
    printf("R: %d", WEXITSTATUS(status));
    printf("M: %d\n", x);
    x = 100;
    printf("P: %d\n", x);
    _exit(2);
  }

  func2();
}
```

```
void func1()
{
    int rc, status;

    printf("T: %d\n", x);
    x = 10;
    rc = fork();
    if (rc == 0) {
      x = 50;
      printf("Q: %d\n", x);
      _exit(3);
    }
    rc = waitpid(rc, &status, 0)
    printf("A: %d\n", x);
    printf("D: %d", WEXITSTATUS(status));
    _exit(4);
}

void func2()
{
    printf("C: %d\n", x);
}
```

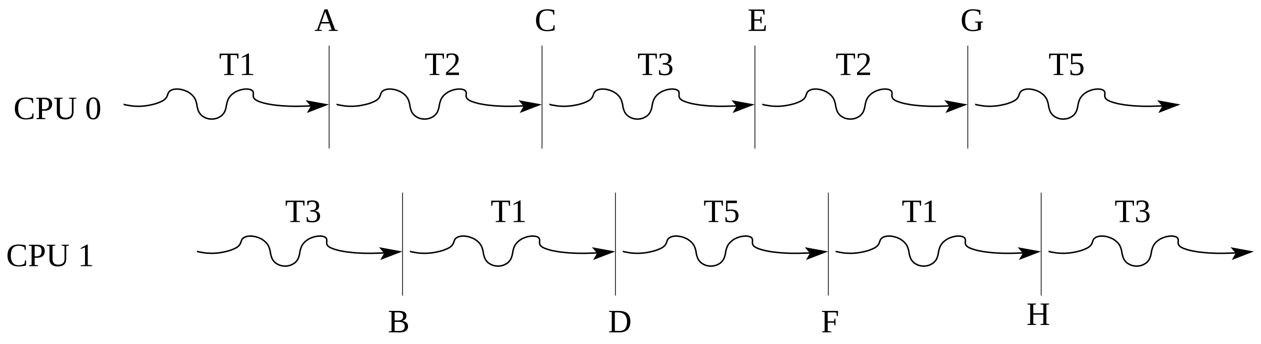
——————begin solution——————

```
T: 42
Q: 50
A: 10
D: 3
R: 4
M: 42
P: 100

NOTE C: never gets printed
```

——————end solution——————

Problem 3 (12 marks)
The diagram below shows a number of threads executing on two different CPUs (the names of each thread are shown). The vertical lines indicate context switches between two threads and the labels at those vertical lines indicate the time at which the context switch occurred.



In OS/161 a context switch is initiated by a call to `thread_switch`. That function determines which thread to run next (pointed to by `next`) and calls `switchframe_switch` which performs the context switch from the current thread (pointed to by `cur`) to the next thread (pointed to by `next`). In the code below we have added two `kprintf` calls to print out the names of the `cur` and `next` thread before and after the context switch.

```
kprintf("Before: cur = %s next = %s\n", cur->t_name, next->t_name);

/* do the switch (in assembler in switch.S) */
switchframe_switch(&cur->t_context, &next->t_context);

kprintf("After: cur = %s next = %s\n", cur->t_name, next->t_name);
```

Using the diagram at the top of the page and the code above fill in the output that would be produced after each call to `switchframe_switch` (the output for the "Before" print statement has been provided). If it is not possible to determine the answer from the information provided in the diagram use the label "UN" (for unknown).

	Before		After	
Time	cur	next	cur	next
A	T1	T2		
E	T3	T2		
G	T2	T5		
H	T1	T3		

———————begin solution———————

	Before		After		Explanation
Time	cur	next	cur	next	(Not part of question)
A	T1	T2	T2	UN	(no info about T2 before time A)
E	T3	T2	T2	T3	(from time C)
G	T2	T5	T5	T1	(from time F)
H	T1	T3	T3	T2	(from time E)

———————end solution———————

Problem 4 (10 marks)

Assume a **user-level process** (named P1) executes the code shown below on OS161.

```
main()         Q()                      R()                      S()
{              {                        {                        {  int i, x;
  Q();            int x = getpid();        int y = getpid();        for (i=0;i<N;i++) {
  R();                                                                x = x + i;
                  S();                                              }
}              }                        }                        }
```

In the rectangles shown for each part of this question below, fill in and label any information about the state of the **kernel stack** for the executing process (P1) as it would appear at the point in time stated in the question. Do not draw anything that has been popped from the stack (is no longer active) and use the same level of detail used in class and the course notes. If they are present, be sure to show trap frames, switch frames, and stack frames. (If you happen to remember some function names for stack frames use them but you don't have to name them or know how many there are just indicate where they are). Draw the stack so that the high addresses are at the top of the diagram and low addresses are at the bottom. Recall that the stack grows from high addresses to low.

a. **(5 mark(s))** The process P1 calls `int y = getpid()` in the funtion `R`. While in the kernel `syscall` function an interrupt occurs. Show what the contents of the stack look like just prior to returning from the interrupt handler and before popping the stack.

Kernel Stack

———————begin solution———————

trap frame [from system call]
/* some stack frames */ interrupt handler (not required) mips_syscall (not required) syscall
trap frame [from interrupt]
interrupt handler (not required)

Kernel Stack

———————end solution———————

Kernel Stack

b. **(5 mark(s))** The process P1 is executing function `S`, an interrupt occurs, the kernel determines that the thread has reached its quantum of CPU time and it context switches to a thread of process P2. Show what the kernel stack looks like for P1 after the context switch to P2.

begin solution

trap frame [from interrupt]
/* some stack frames */ interrupt handler (not required) thread_yield (not required) mips_switch (not required) switchframe_switch
switchframe [from context switch]

Kernel Stack

end solution

Problem 5 (12 marks)
Barrier synchronization can be used to prevent threads from proceeding until a specified number of threads have reached the barrier. Threads reaching the barrier block until the last of the specified number of threads has reached the barrier, at which point all threads can proceed. Below is a partial pseudocode example of how barrier synchronization might be used.

```
/* Used to wait for all mice to be ready to all attack together */
struct barrier *attack_barrier;
/* Used to wait for all mice and the main thread so they can all go to the bar together */
struct barrier *bar_barrier;

main()
{
  unsigned int i;
  attack_barrier = barrier_create(NUM_MICE);
  bar_barrier = barrier_create(NUM_MICE+1);

  for (i=0; i<NUM_MICE; i++) {
    thread_fork("MightyMouse", mouse, NULL, i);
  }

  /* Wait here until all threads are ready to go to the bar */
  barrier_wait(bar_barrier);
  go_to_bar();
}

void
mouse(void *unused, unsigned long mouse_num)
{
   unsigned int i;
   /* Attack the cats a number of times */
   for (i=0; i<ATTACK_COUNT; i++) {
     get_ammo(mouse_num);
     barrier_wait(attack_barrier); /* wait until all mice are ready to attack */
     attack_cats();
   }
   /* Wait here until all threads are ready to go to the bar */
   barrier_wait(bar_barrier);
   go_to_bar();
}
```

Fill in the spaces below (or on the next page) to complete the implementation of a barrier. (You will not implement `barrier_destroy`). You must only use `locks` and `condition variables` for synchronization (as they are defined in OS/161). To simplify the code, assume that all calls to `kmalloc` and to create any required objects always succeed.

```
struct barrier {







};
/* Create a barrier that can be used with thread_count threads */
struct barrier *barrier_create(unsigned int thread_count)
{









}
/* Callers wait here until the number of threads specified have */
/* reached this point, then they all proceed. */
void
barrier_wait(struct barrier *b)
{















}
```

———————begin solution———————

```
struct barrier {
  /* This MUST be volatile */
  volatile unsigned int b_threads_reached;   /* how many have reached the barrier */
  /* This does not need to be volatile, only changed by one thread at init time */
  unsigned int b_threads_expected;           /* num threads to wait for */
  struct lock *b_lock;                       /* lock used to protect count and reached */
  struct cv *b_cv;                           /* cv used to wait when needed */
};

struct barrier *barrier_create(unsigned int thread_count)
{
  struct barrier *b = (struct barrier *) kmalloc(sizeof(barrier));
  b->b_lock = lock_create("barrier");
  b->b_cv = cv_create("barrier");
  b->b_threads_expected = thread_count;
  b->b_threads_reached = 0;
  return b;
}

barrier_wait(struct barrier *b)
{
   lock_acquire(b->b_lock);
     b->b_threads_reached++;
     if (b->b_threads_reached == b->b_threads_expected) {
       /* Must reset number of threads reached to use the barrier more than once */
       /* This could be done before or after broadcast */
       b->b_threads_reached = 0;
       cv_broadcast(b->b_cv, b->b_lock);
     } else {
       cv_wait(b->b_cv, b->b_lock);
     }
   lock_release(b->b_lock);
}

COMMON MISTAKES
Not making the barrier_wait reusable, forgetting to use volatile where needed, using a while loop
/* Common incorrect solution -- with while loop */
barrier_wait(struct barrier *b)
{
  lock_acquire(b->b_lock);
    b->b_threads_reached++;
    while (b->b_threads_reached < b->b_threads_expected) {
      cv_wait(b->b_cv, b->b_lock);
    }
    cv_broadcast(b->b_cv, b->b_lock);
    b->b_threads_reached = 0;
  lock_release(b->b_lock);
}
```

———————end solution———————

Problem 6 (9 marks)

Some possibly useful info: $2^{10} = 1$ KB, $2^{20} = 1$ MB, $2^{30} = 1$ GB.

In this question all addresses, virtual page numbers and physical frame numbers are represented in **octal**. Recall that each octal character represents 3 bits. Note: to make some numbers easier to read, spaces have been added between every 3 octal characters. Please also use this convention when providing your answers.

Consider a machine with *39-bit* virtual addresses, *33-bit* physical addresses and a page size of 262,144 bytes (256 KB). During a program's execution the TLB contains the following entries (all in **octal**). In this example **Dirty** means that the page can be dirtied (i.e., written to).

Virtual Page Num	Physical Frame Num	Valid Bit	Dirty Bit
0 061 252	06 125	1	0
6 125 273	01 234	0	0
0 000 061	30 130	1	1
0 000 612	61 252	1	1

If possible, explain how addresses given below (in **octal**) will be translated and provide the requested translated address. If a translation is not possible, explain what will happen and why. Show and **explain how you derived your answer.** Express the all physical address using **all 33-bits** and all virtual addresses using **all 39-bits**.

a. **(3 mark(s))** The physical address that results from a load from virtual address = 6 125 273 127 604

begin solution

```
THIS DOES NOT NEED TO BE STATED OR REPEATED FOR EACH PART.
$2^{18}$ = 256 KB so 18 bits for offset. 39-18 = 21 for VPN.
18 bits = 6 octal characters for offset, 21 bits = 7 octal characters for VPN.
So the first 7 octal characters are the VPN and the last 6 are the offset.

612 5273 | 127 604
lookup 612 5273 in TLB valid bit is NOT set so exception.
```

end solution

b. **(3 mark(s))** The physical address that results from a store to virtual address = 0 000 061 252 127.

begin solution

```
0 000 061 | 252 127.
0 000 061 is in the TLB and is valid and can be dirtied so translation occurs.
Resulting frame is 30 130.
So resulting address is 30 130 252 127.
```

end solution

c. **(3 mark(s))** Can a store be performed on the **physical** address = 61 252 612 522 If yes, provide the virtual address used to access this physical address and if not explain precisely why not.

begin solution

```
61 252 612 522 frame is 61 252 which is found in the TLB.
The page can be written and is valid so a translation occurs.
The corresponding page is 0 000 612 so we get the virtual address
0 000 612 612 522
```

end solution

Problem 7 (9 marks)

Note: to make some numbers easier to read, spaces have been added between every 4 hexidecimal characters. Please also use this convention when providing your answers.

The structure `addrspace` shown below describes the address space of a running process on a slightly modified MIPS processor. The `addrspace` and modified processor are similar to the `dumbvm` and MIPS processor provided in OS161/SYS161. The key differences are that this processor uses 36-bit virtual and physical addresses and a page size of 64 KB (`0x1 0000`). In a similar fashion to the 32-bit MIPS OS/161 processor the 36-bit virtual address space on this modified processor is divided into two halves. Virtual addresses from `0` to `0x7 FFFF FFFF` are for user programs and virtual address from `0x8 0000 0000` to `0xF FFFF FFFF` can not be accessed while in user mode. Fortunately, this new version of the OS161 kernel now explicitly represents the stack as segment 3 (note the stack size).

```
struct addrspace {
    vaddr_t as_vbase1 = 0x0 5000 0000;      /* text segment: virtual base address */
    paddr_t as_pbase1 = 0x0 0010 0000;      /* text segment: physical base address */
    size_t as_npages1 = 0x200;              /* text segment: number of pages */
    vaddr_t as_vbase2 = 0x3 0000 0000;      /* data segment: virtual base address */
    paddr_t as_pbase2 = 0x8 0000 0000;      /* data segment: physical base address */
    size_t as_npages2 = 0x137;              /* data segment: number of pages */
    vaddr_t as_vbase3 = 0x4 0000 0000;      /* stack segment: virtual base address */
    paddr_t as_pbase3 = 0x1 0000 0000;      /* stack segment: physical base address */
    size_t as_npages3 = 0x18;               /* stack segment: number of pages */
};
```

For an application executing in user space that uses the address space defined above, assume that it is accessing the specified addresses below. When possible you are to translate the provided address. If the translation is not possible, explain why it is not possible and what would happen during translation. If the translation is possible provide the requested translated address and indicate which segment the address belongs to. Use hexadecimal notation for all addresses and show all 36-bits. Show and explain how you arrived at your result.

Some possibly useful values:

```
 1 * 64 KB =  0x1 * 0x1 0000 =  0x1 0000     2 * 64 KB =  0x2 * 0x1 0000 =  0x2 0000
10 * 64 KB =  0xA * 0x1 0000 =  0xA 0000    16 * 64 KB = 0x10 * 0x1 0000 = 0x10 0000
32 * 64 KB = 0x20 * 0x1 0000 = 0x20 0000
```

a. **(3 mark(s))** Translate the **Virtual** Address `0x4 0017 6429` to a **Physical** Address.

——————begin solution——————

```
Part of the stack segment.
0x4 0017 6429 - 0x4 0000 0000 = 0x17 6429 (this is < 0x18 pages, 0x18 0000)
So 0x17 6429 + 0x1 0000 0000 = 0x1 0017 6429
```

——————end solution——————

b. **(3 mark(s))** Translate the **Virtual** Address `0x0 5200 AB25` to a **Physical** Address.

——————begin solution——————

```
No translation. This is not part of ANY segment.
COMMON MISTAKE: saying it is part of text segment but is out of range of that segment.
Or only that it is not part of the text segment, that is insufficient.
It must not be part of ANY segment.
```

——————end solution——————

c. **(3 mark(s))** If possible, determine the user space **Virtual** Address that could be used to access the **Physical** Address `0x8 0128 95FA`.

———————begin solution———————

```
Part of the data segment.
0x8 0128 95FA - 0x8 0000 0000 = 0x128 95FA (0x128 95FA < 0x137 pages = 0x137 0000).
So 0x128 95FA + 0x3 0000 0000 = 0x3 0128 95FA.
```

———————end solution———————