University of Waterloo
Midterm Examination
Term: Winter Year: 2013

Solution

begin solution

Grade breakdown: Winter 2013

Question	1	2	3	4	5	6	7	Total
Out of	8	12	12	10	10	10	14	76
Average	4.30	7.96	6.00	8.00	5.38	7.13	6.76	45.53
Avg %	53.72	66.37	50.00	80.00	53.76	71.35	48.27	59.91
Maximum	8	12	12	10	10	10	14	75

Grade adjustment add 5% to grade. New average = 65%. Adjusted distribution.

Range	Count
90-105	19
80-89	19
70-79	21
60-69	17
50-59	31
40-49	21
30-39	11
20-29	2
10-19	0
0-9	0

end solution

Problem 1 (8 marks)

a. **(2 mark(s))** You are working on an operating system for a new machine. The processor in this system uses 36 bits for virtual and physical addresses and it has three options for different page sizes:

(a) 4096 bytes (4 KB)
(b) 8192 bytes (8 KB)
(c) 65536 bytes (64 KB)

Each of these choices leaves a different number of bits available for the virtual page number and some team members are arguing about which choice allows the largest amount of virtual memory to be addressed. Explain which option, if any, provides the largest amount of virtual memory to be addressed and why.

————————begin solution————————

Each provides access to exactly the same amount of memory. Each page size leaves a different number of pages but if you multiple the page size by the total number of pages they are the same.
$4096 = 2^{12} * 2^{24} = 2^{36}$
$8096 = 2^{13} * 2^{23} = 2^{36}$
$64\ KB = 2^{16} * 2^{20} = 2^{36}$

————————end solution————————

b. **(2 mark(s))** Can a single thread have more than one address space? **Explain your answer.**

————————begin solution————————

NO. There must be a unique translation of virtual addresses to physical addresses. Otherwise how will the system know which address space to use.
or
YES. If you are executing on a SPARC, the user and kernel address spaces are different but they are used by the same thread.
or
YES. If the process calls execv it starts with one address space and then replaces that address space with the new program.

————————end solution————————

c. **(2 mark(s))** In a system that implements paging, the processor uses 34-bit virtual addresses, 40-bit physical addresses and a page size of 8 KB. How many bits are needed to represent the physical frame? **Explain your answer.**

————————begin solution————————

8 KB = 2^{13}. So 40 - 13 = 27

————————end solution————————

d. **(2 mark(s))** Explain why it is not a good idea to wake up more than one thread when implementing `lock_release`.

————————begin solution————————

It is inefficient.
Because, only one thread can enter the critical section waking up more then one just means that they will all compete for the CPU time only to be denied entry to the critical section. They will waste CPU time running to only find out that they will have to sleep.

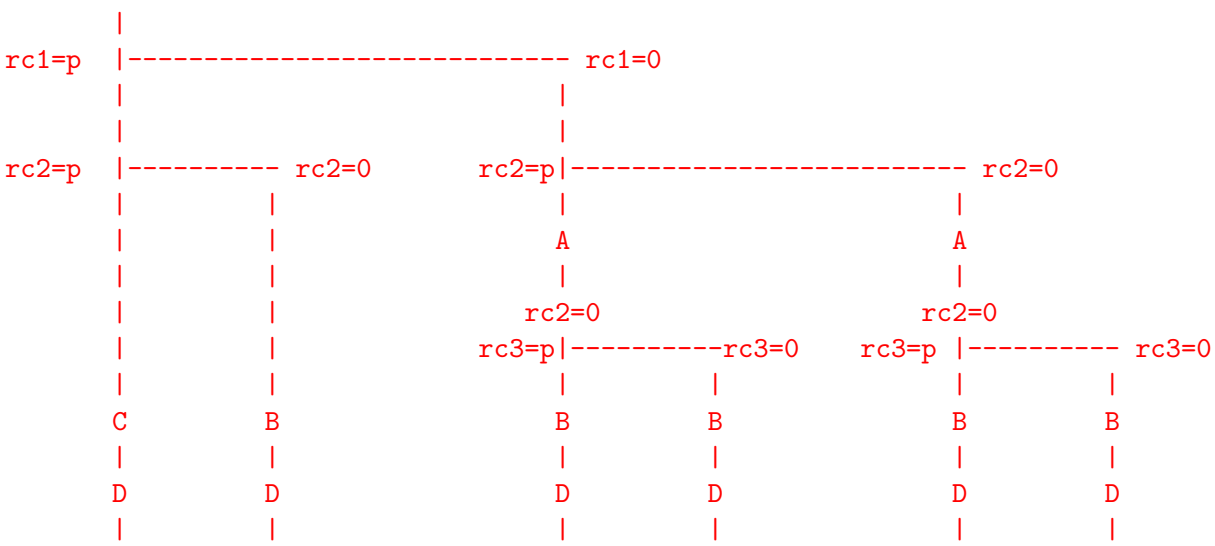
————————end solution————————

Problem 2 (12 marks)
For the program shown below, fill in the blanks at the bottom of the page to indicate how many characters of each letter will be printed in total when the program finishes running. If a range of values is possible, give the range. If it is not possible to determine the number or a range, state so and explain why. Assume that all function, library and system calls are successful. Use the space to the right of the program to draw a diagram of the process hierarchy that results during execution. Use that diagram to explain how you arrived at your answer. **NO MARKS WILL BE GIVEN UNLESS A PROPER DIAGRAM AND EXPLANATION ARE PROVIDED.**

```
#include <stdio.h>
#include <unistd.h>

main()
{
  int rc1, rc2, rc3;

  rc1 = fork();
  rc2 = fork();


  if (rc1 == 0) {
    printf("A");
    rc2 = 0;
    rc3 = fork();
  }

  if (rc2 == 0) {
    printf("B");
  } else {
    printf("C");
  }
  printf("D");
}
```

Total number of printed A's _____ B's _____ C's _____ D's _____

begin solution



Total number of printed A's = 2, B's = 5, C's = 1 D's = 6

NOTE: If you compile and run these on a Linux/Unix machine you may need to insert fflush(stdout); after every printf otherwise you can get strange output (e.g., different numbers of letters because the output may be buffered and copied at the time of a fork.

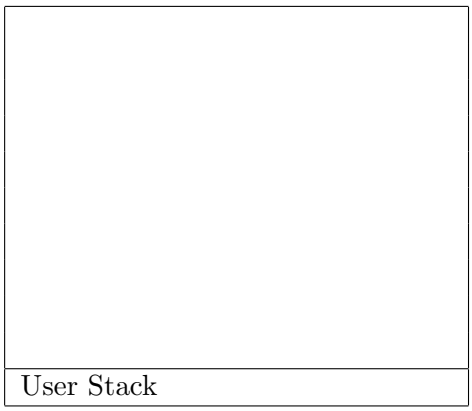
end solution

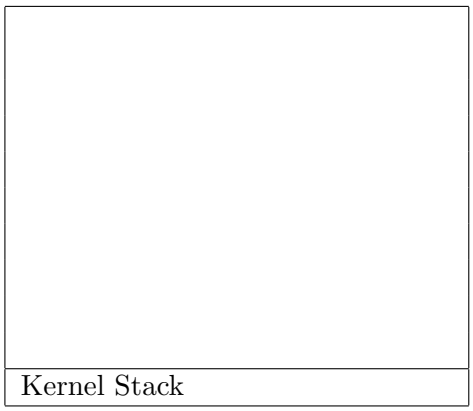
Problem 3 (12 marks)
Assume one **user-level process** (named P1) executes the code shown below on OS161.

```
main()          Q()             R()                    S()
{               {               {                      {
  Q();             S();            S();                   int i, x;
  R();            }               printf("Hello\n");      for (i=0; i<N; i++) {
}                               }                          x = x + i;
                                                        }
                                                       }
```

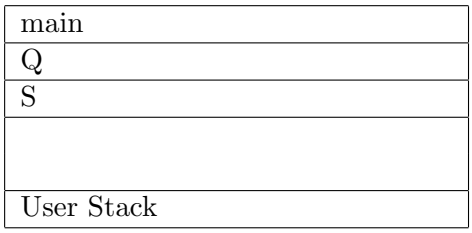
In the rectangles shown for each part of this question below, fill in and label any information about the state of the **user-level stack and the kernel stack** for the executing process (P1) as they would appear at the point in time stated in the question. Do not draw anything that has been popped from the stacks (is no longer active) and use the same level of detail used in class and the course notes. Be sure to show any stack frames, trap frames, and thread contexts, if they are present. 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.

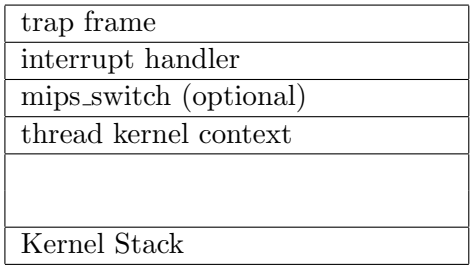
a. **(8 mark(s))** The process P1 calls `main`, `Q`, and `S` at which point it is interrupted (while still executing `S`) and a context switch to another process (P2) occurs. Show the state of the stacks for P1 after the context switch to P2 has completed.





begin solution

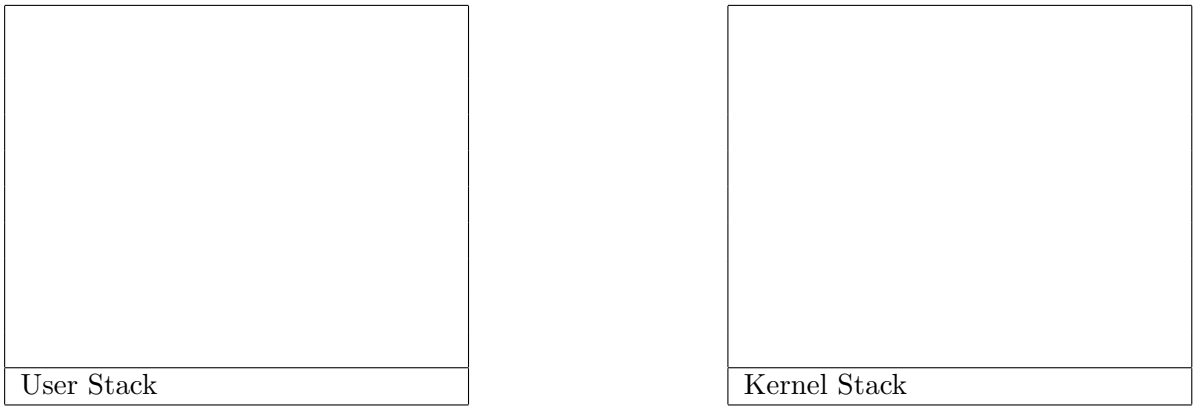




end solution

b. **(4 mark(s))** Now assume that the thread for P1 is later dispatched and it resumes execution. Show the state of the stacks for P1 as they would appear after running to the point in the code just after returning from `S()` but before the call to `printf("Hello")`.

begin solution



end solution

Problem 4 (10 marks)

Consider executing the code below when answering the questions on this page.

```
struct semaphore *sem1, *sem2;
main()
{
   sem1 = sem_create("sem1", 2);
   sem2 = sem_create("sem2", 4);

   for(i=0; i<10; i++) {
      thread_fork("A",NULL,i,A,NULL);
   }
   for(i=0; i<7; i++) {
      thread_fork("B",NULL,i,B,NULL);
   }
}
void A(void *x, unsigned long y)
{
  P(sem1);
  printf("A");
  P(sem2);
  printf("C");
}
```

```
 void B(void *x, unsigned long y)
{
   printf("B");
   P(sem2);
   printf("D");
   V(sem1);
}
```

For each of the substrings of output below indicate, by circling the appropriate response, whether or not the output IS POSSIBLE, IS NOT POSSIBLE, or CAN NOT BE DETERMINED. Assume that the first character shown is the first character printed when the threads start running and that not all of the output is shown (i.e., all threads have not finished executing). If you choose IS NOT POSSIBLE, or CAN NOT BE DETERMINED **briefly explain why**.

ACBDBABBBDCAC [IS POSSIBLE] [IS NOT POSSIBLE] [CAN NOT DETERMINED]

————————begin solution————————

IS NOT POSSIBLE: Before C or D is printed sem2 is decremented so once a total of 4 C's and D's are printed it can't print any more C's or D's.

————————end solution————————

BABABCBBCBB [IS POSSIBLE] [IS NOT POSSIBLE] [CAN NOT DETERMINED]

————————begin solution————————

IS POSSIBLE.

————————end solution————————

BABABCBCBCB [IS POSSIBLE] [IS NOT POSSIBLE] [CAN NOT DETERMINED]

————————begin solution————————

IS NOT POSSIBLE. When the 3rd C is printed there are only 2 A's. A threads must print an A before they print a C.

————————end solution————————

ABAABBBBDD [IS POSSIBLE] [IS NOT POSSIBLE] [CAN NOT DETERMINED]

————————begin solution————————

IS NOT POSSIBLE. The third A could not be printed until at least one D is printed.

————————end solution————————

ABABBCCDBDAA [IS POSSIBLE] [IS NOT POSSIBLE] [CAN NOT DETERMINED]

————————begin solution————————

IS POSSIBLE.

————————end solution————————

Problem 5 (10 marks)
Consider the code below when answering the questions on this page. Assume that the locks are all initialized properly before being used (as shown in the function `init()`) and that `funcA()` and `funcB()` do not do anything that could produce a deadlock. For each of the scenarios in the questions below state whether or not deadlock CAN or CAN NOT occur **and explain why**. Each scenario/question is separate (i.e., the locks and threads are reinitialized for each part of the question).

```
struct lock *A[N],
struct lock *B[N];
void init()
{
  for (i=0; i<N; i++) {
    A[i] = lock_create("NoName");
    B[i] = lock_create("NoName");
  }
}
void ProcB(int i, int j)
{
    assert(i > j);
    assert(i >= 0 && i < N);
    assert(j >= 0 && j < N);
    lock_acquire(A[i]);
      lock_acquire(B[j]);
        funcB(i,j);
      lock_release(B[j]);
    lock_release(A[i]);
}
```

```
void ProcA()
{
  for (i=0; i<N; i++) {
    lock_acquire(A[i]);
      lock_acquire(B[i]);
        funcA();
      lock_release(A[i]);
    lock_release(B[i]);
  }
}
```

a. **(6 mark(s))** A bunch of threads are created and they only call `ProcA()`.

begin solution

CAN NOT DEADLOCK.
Different explanations are possible, here is one.

All A locks are acquired from 0 to N-1 and then all B locks
are acquired from 0 to N-1 so there is a strict ordering
placed on how all locks are acquired.
Since all threads use the same ordering
there can be no deadlocks.

end solution

b. **(4 mark(s))** A bunch of threads are created and they only call `ProcB()`. When they call `ProcB()` the value of `i` is always greater than `j` and both `i` and `j` are always between `0` and `N-1` (inclusive). In other words, the assertions are never triggered.

begin solution

```
CAN NOT DEADLOCK
Different explanations are possible. Here is one.

Since all threads acquire a lock A and then a lock B
there can be no sitation where one of them is holding
a lock that the other needs. So there is no possiblity of deadlock.
```

end solution

Problem 6 (10 marks)

The structure `addrspace` shown below describes the address space of a running process on a 32-bit MIPS processor similar to the `dumbvm` provided in OS161. The virtual page size is 4096 (`0x1000`) bytes. In this implementation, the compiler, linker and operating system use different locations for text, data and stack segments than those used by the version of OS161 and the toolchains you are using this term. 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 = 0x10000000;       /* text segment: virtual base address */
    paddr_t as_pbase1 = 0x00010000;       /* text segment: physical base address */
    size_t as_npages1 = 0x200;            /* text segment: number of pages */
    vaddr_t as_vbase2 = 0x20000000;       /* data segment: virtual base address */
    paddr_t as_pbase2 = 0x80000000;       /* data segment: physical base address */
    size_t as_npages2 = 0x137;            /* data segment: number of pages */
    vaddr_t as_vbase3 = 0x70000000;       /* stack segment: virtual base address */
    paddr_t as_pbase3 = 0x10000000;       /* 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 indicate which segment the address belongs to. Use 32-bit hexadecimal notation for all addresses. Some possibly useful values:

```
  1 * 4096 =    0x1000      2 * 4096 =    0x2000     10 * 4096 =    0xA000
 16 * 4096 =   0x10000     32 * 4096 =   0x20000    100 * 4096 =   0x64000
128 * 4096 =   0x80000    256 * 4096 =  0x100000    512 * 4096 =  0x200000
```

a. **(2 mark(s))** Translate the **Virtual** Address `0x70016429` to a **Physical** Address.

begin solution

`0x70016429 - 0x70000000 = 0x16429+ 0x10000000 = 0x10016429`
`Part of the stack segment.`

end solution

b. **(2 mark(s))** Translate the **Virtual** Address `0x7FFF1289` to a **Physical** Address.

begin solution

`No translation. This is not part of any segment.`
`This address is above the stack's highest address.`

end solution

c. **(2 mark(s))** Translate the **Physical** Address `0x80000080` to a **Virtual** Address.

begin solution

```
0x8000 0080 - 0x8000 0000 = 80 + 0x2000 0000 = 0x2000 0080
Part of the data segment.
```

——————end solution——————

d. **(2 mark(s))** Translate the **Physical** Address `0x10013F39` to a **Virtual** Address.

——————begin solution——————

```
0x1001 3F39 - 0x1000 0000 = 0x  1 3F39 + 0x 7000 0000 = 0x7001 3F39.
Part of the stack segment.
```

——————end solution——————

e. **(2 mark(s))** Translate the **Virtual** Address `0x80000080` to a **Physical** Address.

——————begin solution——————

```
0x80000080  is part of the kernel's address space, so translation can not \\
be performed while running a user application.  An exception would be generated.
```

——————end solution——————

Problem 7 (14 marks)

Consider a processor that uses segmentation and paging (i.e., this is not a MIPS processor). Below is the segment table being used for the currently executing process and below that are pages tables for several processes in the system. Note that some processes may not use all of the available segments. Recall that VPN is the virtual page number, PFN is the physical frame number, V is the valid bit and D is the dirty bit (i.e., the page can be dirtied/modified).

Segment	PT base addr	Max VPN Value
4	70700000	3
3	70200000	3
2	70500000	3
1	70300000	3
0	70100000	3

VPN	PFN	V	D
3	5177	1	0
2	20	0	0
1	77	1	0
0	4251	0	0

Base addr: 70000000

VPN	PFN	V	D
3	1311	1	0
2	12	1	0
1	711	0	0
0	23	1	0

Base addr: 70700000

VPN	PFN	V	D
3	52	1	1
2	41	1	1
1	30	1	1
0	5177	0	1

Base addr: 70400000

VPN	PFN	V	D
3	65	1	1
2	77	1	1
1	567	1	1
0	672	1	1

Base addr: 70300000

VPN	PFN	V	D
3	641	0	1
2	753	1	1
1	2577	1	1
0	517	1	1

Base addr: 70200000

VPN	PFN	V	D
3	5532	0	1
2	5177	1	1
1	336	0	1
0	77	1	1

Base addr: 70600000

VPN	PFN	V	D
3	5177	1	1
2	34	1	1
1	563	1	1
0	1641	1	1

Base addr: 70500000

VPN	PFN	V	D
3	516	1	1
2	37	0	1
1	7731	1	1
0	6341	1	1

Base addr: 70100000

For the first parts of this question (parts a – e) assume that the processor is using 32-bits for virtual and physical addresses, that the page size is 64 KB, that all addresses (virtual and physical) and values shown in the segment table and page tables are expressed in hexadecimal, and that the system uses 4 bits for segments.

a. **(2 mark(s))** Explain how many **bits** of the virtual address will be used to represent the offset?

————————begin solution————————

2^{16} = 64 KB, so 16 bits for the offset

————————end solution————————

b. **(2 mark(s))** What is the **maximum possible size** of a segment in this system in **bytes** (expressed as an equation).

————————begin solution————————

32 virtual address - 4 for segment - 16 bits for page size/offset = 12 bits for a virtual page number and each page is 2^{16} bytes so $2^{12} * 2^{16} = 2^{28}$.
or more simply
32 bit virtual address - 4 bits for the segment = 28 bits. So 2^{28}.

————————end solution————————

c. **(2 mark(s))** Convert the **virtual address** 0x20043751 into a 32-bit physical addresses (also expressed in hexadecimal). Show your work and if the address can not be translated, explain why.

begin solution

```
The first 4 bits are the segment so the segment is 2
and the page table address is 0x70500000 (this is really irrelevant).
12 bits are used for the VPN so the VPN is 4
but the maximum VPN for that segment is 3 so this
does not result in a translation because the program
is accessing memory outside the range of that segment.
```

end solution

d. **(2 mark(s))** Convert the **virtual address** 0x30022267 into a 32-bit physical addresses (also expressed in hexadecimal). Show your work and if the address can not be translated, explain why.

begin solution

The first 4 bits are 0 so the segment is 3.
and the page table address is 0x70200000.
12 bits are used for the VPN so the VPN is 2.
The PFN for that VPN is 753
The last 16 bits are the offset which is 2267.
So the physical address is
0x0753 2267.

end solution

e. **(2 mark(s))** Convert the **physical address** 0x51773721 into a 32-bit virtual addresses (also expressed in hexadecimal). Show your work and if the address can not be translated, explain why.

begin solution

16 bits are used for the offset so 16 bits are used for the frame number.
So the PFN = 5177.
Now find an entry in one of the page tables for the executing process
with PFN = 5177.
The page table with base address 70500000 (segment 2) has PFN = 5177 in VPN 3.
So the VPN is 3 and the the segment is 2.
So the virtual address is 0x20033721.

Note that other Page tables that contain 5177 in the PFN
are not part of the executing process and therefore those
translations are not possible.

end solution

For the remaining part of this question assume that the processor is using 24-bits for virtual and physical addresses, that the page size is 512 bytes, that all values shown in the segment table and the page tables are to be interpreted as octal values (i.e., each character represents 3 bits) and that the system uses 3 bits for segments. Note that some processes may not use all of the available segments.

f. **(4 mark(s))** Convert the **physical address** 00077356 (expressed in octal) into a 24-bit virtual address (also expressed in octal). Show your work and if the address can not be translated, explain why.

begin solution

9 bits are used for the offset so 24-9 = 15 bits
are used for the PFN.
So the PFN = 00077 and the offset is 356.
We look through the page tables for the executing
process for a PFN = 77 and find it in the
pages table located at the base address of 70300000.
This is segment 1.
So the segment is 1 and the VPN for that page is 2.
So that results in the virtual address of
10002356

Note that other Page tables that contain 77 in the PFN
are not part of the executing process and therefore those
translations are not possible.

——————end solution——————