

MIT OpenCourseWare  
<http://ocw.mit.edu>

6.004 Computation Structures  
Spring 2009

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.

**6.004 Computation Structures**  
**Lab #8**

**Instructions**

1. Make a private copy of /mit/6.004/bsim/lab8.uasm
2. Run lab8.uasm and look through the code to figure out how it works
3. Modify lab8.uasm as described below and test your changes
4. There is no automated check-in for the lab. When you are ready for checkoff, schedule a short meeting with a TA during his or her lab hours (preferably during the less hectic times early in the week). **Bring along a copy of the Lab 8 Writeup** which will be filled out during your meeting. If you work from home, **remember to upload your program onto Athena** so you can demonstrate its operation during the meeting.

**Step 0: Run lab8.uasm and look through the code**

Lab8.uasm is a program that implements a simple timesharing system. When you use BSim to load, assemble and then run lab8.uasm, the following prompt should appear in the console pane of the Bsim Display Window:

```
Start typing, Bunky.
```

```
00000000>
```

As you type, each character is echoed to the console and when you hit return the whole sentence is translated into Pig Latin and written to the console:

```
00000000> 6.004 is a fun course  
6.004AY ISAY AAY UNFAY OURSECAY
```

```
00001F61>
```

The hex number written out as part of the prompt is a count of the number of times one of the user-mode processes has been scheduled while you typed in the sentence.

Lab8.uasm implements the following functionality:

- Kernel-mode interrupt routine for handling input from the keyboard. Incoming characters are stored in a kernel buffer for subsequent use by user-mode programs (see the GetKey() supervisor call).
- Kernel-mode supervisor call dispatching and a repertoire of call handlers that provide simple I/O services to user-mode programs. Handlers include
  - Halt() – stop a user-mode process
  - WrMsg() – write a null-terminated ASCII string to the console. The string immediately follows the WrMsg() instruction; execution resumes with the instruction following the string. For example:

```
WrMsgC
.text "This text is sent to the console...\n"
...next instruction...
```
  - WrCh() – write the ASCII character found in R0 to the console
  - GetKey() – return the next ASCII character from the keyboard in R0; this call does not return to the user until there is a character available.
  - HexPrt() – convert the value passed in R0 to a hexadecimal string and output it to the console.
  - Wait() – implement atomic WAIT operation on the integer semaphore whose address is passed in R3.
  - Signal() – implement atomic SIGNAL operation on the integer semaphore whose address is passed in R3.
  - Yield() – immediately schedule the next user-mode program for execution. Execution will resume in the usual fashion when the round-robin scheduler chooses this process again.
- A round-robin scheduler and the necessary kernel data structures to support multiple user-mode programs. The scheduler is invoked by periodic clock interrupts or when a user-mode program makes a Yield() supervisor call.

Lab8.uasm also contains code for three programs each of which runs in a separate user-mode process:

- Process 0: prompts the user for new lines of input. Reads lines from the keyboard using the GetKey() supervisor call and sends them to Process 1 using the Send() procedure. Send() implements a bounded buffer synchronized through the use of semaphores.
- Process 1: reads lines of inputs from the bounded buffer (using the Rcv() procedure), translates them into Pig Latin and types them out on the console (using the WrMsg() and WrCh() supervisor calls).
- Process 2: Each time this process is executed, it simply increments a counter and uses the Yield() supervisor call to give up the remainder of its quantum. This count is used as part of the prompt displayed by Process 0.

### Step 1: Add mouse interrupt handler (3 points)

When you click the mouse over the console pane, BSim generates an interrupt, forcing the PC to 0x80000010 and saving PC+4 of the interrupted instruction in the XP register. Note that BSim implements a “vectored interrupt” scheme where different types of interrupts force the PC to different addresses (rather than having all interrupts for the PC to 0x80000008). The following table shows how different exceptions are mapped to PC values:

0x80000000	reset
0x80000004	illegal opcode
0x80000008	clock interrupt (must specify “.options clk” to enable)
0x8000000C	keyboard interrupt (must specify “.options tty” to enable)
0x80000010	mouse interrupt (must specify “.options tty” to enable)

Recall that only user-mode programs can be interrupted. Interrupts signaled while in the Beta is running in kernel-mode (e.g., handling another interrupt or servicing a supervisor call) have no effect until the processor returns to user-mode.

The original lab8.uasm prints out “Illegal interrupt” and then halts if a mouse interrupt is received. Change this behavior by adding an interrupt handler that stores the click information in a new kernel memory location and then returns to the interrupted process. You might find the keyboard interrupt handler a good model to follow.

We’ve added a new Beta instruction your interrupt handler can use to retrieve information about the last mouse click:

CLICK()

This instruction can only be executed when in kernel mode (e.g., from inside an interrupt handler). It returns a value in R0: -1 if there hasn’t been a mouse click since the last time CLICK() was executed, or a 32-bit integer with the X coordinate of the click in the high-order 16 bits of the word, and the Y coordinate of the click in the low-order 16 bits. The coordinates are non-negative and relative to the upper left hand corner of the console pane. In our scenario, CLICK() is only called after a mouse click, so we should never see -1 as a return value.

Testing your implementation: insert a “.breakpoint” before the JMP(XP) at the end of your interrupt handler, run the program and click the mouse over the console pane. If things are working correctly the simulation should stop at the breakpoint and you can examine the kernel memory location where the mouse info was stored to verify that it’s correct. Continuing execution (click the “Run” button in the toolbar at the top of the window) should return to the interrupted program. When you’re done remember to remove the breakpoint.

### Step 2: Add Mouse() supervisor call (3 points)

Implement a Mouse() supervisor call that returns the coordinate information from the most recent mouse click (i.e., the information stored by the mouse interrupt handler). Like GetKey() supervisor call, a user-mode call to Mouse() should consume the available click information. If no mouse click has occurred since the previous call to Mouse(), the supervisor call should “hang” until new click information is available. “Hang” means that the supervisor call should back up the saved PC so that the next user-mode instruction to be executed is the Mouse() call and then

branch to the scheduler to run some other user-mode program. Thus when the calling program is rescheduled for execution at some later point, the Mouse() call is re-executed and the whole process repeated. From the user's point of view, the Mouse() call completes execution only when there is new click information to be returned. The GetKey() supervisor call is a good model to follow.

Notes: Supervisor calls are actually unimplemented instructions that cause the expected trap when executed. The illegal instruction trap handler looks for illegal instructions it knows to be supervisor calls and calls the appropriate handler – look at SVC\_UUO for details. To define a new supervisor call, add the following definition just after the definition for Yield():

```
.macro Mouse() SVC(8)
```

This is the ninth supervisor call and the current code at SVC\_UUO was tailored for processing exactly eight supervisor calls, so you'll need to make the appropriate modifications.

Testing your implementation: Once your Mouse() implementation is complete, add a Mouse() instruction just after P2Start. If things are working correctly, this user-mode process should now hang and Count3 should not be incremented even if you type in several sentences (i.e., the prompt should always be "00000000>"). Now click the mouse once over the console pane and then type more sentences. The prompt should read "00000001>". When you're done, remember to remove the Mouse() instruction you added.

### **Step 3: Add fourth user-mode process that reports mouse clicks (6 points)**

Modify the kernel to add support for a fourth user-mode process. Add user-mode code for the new process that calls Mouse() and then prints out a message of the form:

```
Click at x=0000000EE, y=00000041
```

Each click message should appear on its own line (i.e., it should be preceded and followed by a newline character). You can use WrMsg() and HexPrt() to send the message; see the code for Process 0 for an example of how this is done.

Testing your implementation: If all three parts are working correctly the appropriate message should be printed out whenever you click the mouse over the console pane. You may find it necessary to use ".breakpoint" commands to debug your user-mode code.

### **Step 4: Synchronize mouse reporting with other I/O (3 points)**

Using semaphores, coordinate the operation of the user-mode processes so that click messages only appear after the prompt has been output but before you've started typing in a sentence to be translated. In other words, once you start typing in a sentence, click messages should be delayed until after the next prompt. If the user clicks multiple times after they have started typing, a typical implementation displays two messages: one for the first click whose coords have already been read, and one for the last click – the intervening click coords having been overwritten by each subsequent click.

Testing your implementation: Start typing in a sentence, then click the mouse. The click message should be printed *after* the translation and the following prompt have been printed.