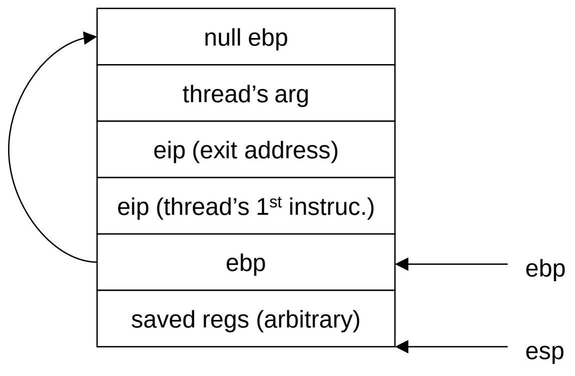
CS167 Homework Assignment 1 Solutions

Spring 2018

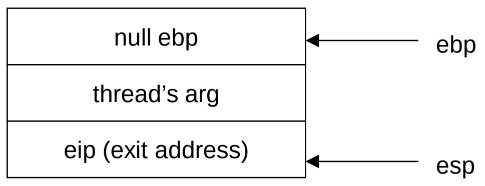
1. *[25%] The text, on page 101, describes how to switch from one thread to another (this also appears in slide II-24). The implicit assumption is that the thread being switched to in thread_switch has sometime earlier yielded the processor by calling thread_switch itself. Suppose, however, that this thread is newly created and is being run for the first time. Thus when its creator calls thread_switch to enter its context, it should start execution as if its first routine had just been called. Show what the initial contents of its stack should be to make this happen (i.e., please draw a diagram showing the stack). Assume an x86-like assembler language, as used in Chapter 3 of the text. Also, assume the IA-32 calling convention, in which arguments are on the stack.*

   We must set up the thread's stack so that when a return instruction is executed in its context, the thread's instruction pointer is set to its first instruction and the now-current stack frame contains the argument to the thread. It's also important (though not necessary for full credit on this problem) that if the thread returns from its first procedure, it returns to code that calls *uthread_exit* (or the equivalent).

   So, the stack should be set up as follows:



   When a return is executed in the context of this stack, the result is the following.



The thread is now executing its first instruction, which will push the frame pointer (ebp) on the stack, save the current registers (whose contents aren't important), and allocate space on the stack for the local variables of its first procedure. If this procedure returns, the instruction pointer will be set to *exit address*, a location that contains a call to *uthread_exit* (what's not shown is setting up the stack to pass an appropriate argument to *uthread_exit*).

2. [25%] To fix implementation of blocking_lock on page 174 (slide III-32) so that it works, the spin lock should remain locked until thread_switch has switched to another thread. Thus blocking_lock should pass a pointer to the spin lock to thread_switch, where it will be unlocked once the context of the next thread has been entered. Show how to modify thread_switch to make this happen. (Note: this is trickier than it might seem at first glance.)

As described in the text, *thread_switch* must be passed a locked spin lock that's protecting the wait queue that the blocking thread has joined. Thus this spin lock is not unlocked in blocking lock, but passed in the locked state to *thread_switch*. Note that *thread_switch* must not unlock the spin lock until the blocking thread is no longer running — otherwise we might still run into the problem that the blocking thread is running on two processors at once. However, the spin lock that's passed to *thread_switch* is on the calling thread's stack. Once that thread is no longer running, *thread_switch* has switched to the new thread's stack and thus the argument spin lock is no longer directly accessible. We might consider copying the argument to a static local variable (it certainly wouldn't improve things to copy it to a non-static local variable). However, since *thread_switch* can be called simultaneously by threads running on different processors, this wouldn't work, since there would be just one copy shared by all processors. So, what we might do is to create a new field within each thread's control block called *wait_spinlock*. The caller of *thread_switch* copies its spinlock into this location of the next thread's control block, and then that thread unlocks it prior to returning from *thread_switch*. The modified code for *thread_switch* is below:

```
void thread_switch(spinlock_t *s) {
  thread_t NextThread, OldCurrent;

  NextThread = dequeue(RunQueue);
  NextThread->wait_spinlock = s;
  OldCurrent = CurrentThread;
  CurrentThread = NextThread;
  swapcontext(&OldCurrent->context, &NextThread->context);

  // We're now in the new thread's context

  spin_unlock(wait_spinlock);

}
```

3. *In this question we explore some of the details of how signals are implemented in Unix. We saw in class what is done to force a thread to call its signal handler after it notices it has been signaled. What we're discussing here is how the thread notices. Assume that when a thread is signaled, a bit is set in its thread control block (in the kernel) indicating it's been signaled. You may also assume the existence of a routine InvokeSignal, called by a thread running in kernel mode, that determines what the thread's response to a signal should be and sets up the thread's user stack, if necessary, to make that response happen. Once InvokeSignal returns, the thread then immediately returns from kernel mode to user mode — its user stack has been set up so the right thing happens. The questions here are: when is this routine called, and how does the thread know to call it? (Don't answer them yet; we'll guide you through them.) Though it's important, in this problem you need not describe how the return values from system calls are set up.*

   a. *[12 %] Since it's important that a signaled thread call InvokeSignal itself, and that it call it while in kernel mode, a signaled thread should check whether it's been signaled at some point when it is running in kernel mode. Assuming the thread is either currently running or is runnable (i.e., on the run queue), describe at what points in the thread's execution it should check if it's been signaled and then call InvokeSignal. You may assume there are periodic clock interrupts. (Hint: there may be a number of places where this could happen, but we want to make things as simple as possible, but still viable.)*

The simplest approach is to check for pending signals when the thread is about to return to user mode, after completing either a system call or interrupt processing.

   b. *[13%] Suppose now the signaled thread is sleeping, i.e., waiting on some wait queue in the kernel, and we'd like to wake it up and force it to deal with the signal. In particular, assume the thread has called wait (from within the kernel). Normally, when the thread returns from wait, it may assume what it's been waiting for has happened (this is not pthread_cond_wait!). However, whoever signals the thread, upon discovering the thread is sleeping, will call unwait to force the thread to wake up and return from the wait call. Thus wait returns some special value indicating that it's returning because of an unwait, rather than returning because what it's waiting for has happened. The thread should, at this point, check to see if it's been signaled. However, this is not a good place to call InvokeSignal — it should be called just before the thread returns to user mode, but the thread may well be deep in nested function calls. Somehow, we must arrange for it to return from all these functions, call InvokeSignal, then return to user mode. Explain how this might be done. (Hint: consider the use of setjmp and longjmp: see slides XXII-25 and XXII-26 from CS 33 where they are called sigsetjmp and siglongjmp (http://cs.brown.edu/courses/csci0330/lecture/22signals1.pdf).*)

To unwind the stack, the thread should call *longjmp*. To establish a point to which the stack should be unwound, it should call *setjmp*. So, when the thread enters a system call, it calls *setjmp*, saving its state in a jmpbuf in its thread control block:

```
if (setjmp(tcb->jmpbuf) == 1) {
   return;
}
/* start processing system call */
```

On return from wait, if it was "unwaited", it longjmps:

```
if (wait(...) == UNWAITED) {
   longjmp(tcb->jmpbuf, 1);
}
```

4. *In the x86 architecture, interrupts are processed using the current thread's kernel stack. However, on the VAX architecture, there was a per-processor interrupt stack on which interrupts were processed. Thus, when an interrupt occurred, the current context was saved on the processor's interrupt stack and the interrupt handler was run on that interrupt stack.*

   a. *[13%] We discussed in class how Windows uses its DPC facility to implement preemption: when the current thread is to be preempted (perhaps because the current thread's time slice has expired) a DPC (deferred procedure call) is requested. When there are no higher-priority interrupts pending or being processes, a DPC interrupt occurs and the interrupt handler simply calls thread_switch to switch from the context of the interrupted thread to the context of the next thread. Explain why this approach doesn't work on the VAX architecture. (Hint: on which stack does the DPC interrupt handler run (and on which it calls thread_switch)? Recall that thread_switch saves the stack context of the caller and restores that of the thread being switched to. You may assume that the value of the interrupt stack pointer is reset to the top of the interrupt stack on return to user mode.)*

Since interrupts are handled on the interrupt stack, the DPC handler would itself be running on the interrupt stack, rather than on the interrupted thread's stack. If it called *thread_switch*, the current stack context (in particular the stack pointer and other relevant registers) would be saved in the interrupted thread's thread control block, and the stack context of the next thread (saved in an earlier call to *thread_switch*) would be restored from its thread control block. But, since there's only one interrupt stack per processor, if the next thread had itself been preempted by a DPC on the same processor as the current interrupted thread, the two contexts would refer to the same stack (the current processor's interrupt stack), and thus one thread would overwrite the stack frames of the other.

   b. *[12%] Instead, the VAX architecture had a feature called asynchronous system traps (ASTs), which is similar, but not identical, to the Windows APC (asynchronous procedure call). Among the processor registers is a special control register containing various flags, one of which is the AST-request flag: when this is set, a trap occurs and the AST handler is called on the kernel stack of the current thread. This register is among those saved when an interrupt occurs and is restored when an interrupted thread is resumed. When an interrupt handler is entered, a copy of this register is loaded that has the AST-request flag cleared. Explain how ASTs might be used to implement preemption on the VAX architecture, achieving the same effect as the DPC approach on the x86 architecture. (Hint: the contents of saved registers can be modified before they are restored.)*

Rather than request a DPC when the current thread is to be preempted, an interrupt handler might set the AST-request flag in the saved copy of the current thread's control register. Then when this register is restored as part of getting back into the context of the interrupted thread, an AST would occur on the thread's stack. The AST handler could then safely call *thread_switch*.