CS 3204
Operating Systems

Lecture 4

Godmar Back

Announcements

- Project 0 due this Sunday Sep 3, 11:59pm
- Project 1 help sessions next week:
  - Tuesday Sep 5, 7-9pm MCB 129
  - Wednesday Sep 6, 7-9pm MCB 209
- Group formation: please everybody send me email indicating
  - who your group members are or
  - if you are still looking for a group
- Announcements:
  - Microsoft "Meet The Company" Sep 7, 7-9pm Pamplin 2030
- Reading assignment is Chapter 3

ACM Programming Contest

- Tryout for regional contest
- Sep 9, 10am-5:30pm MCB 124

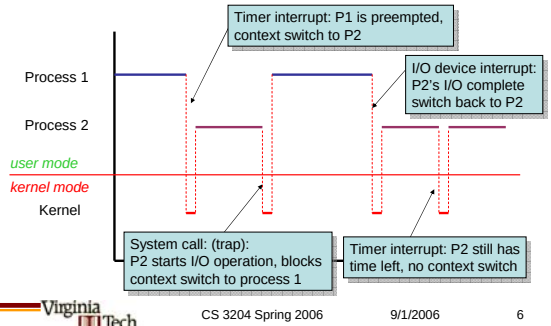
Processes & Threads

Continued

Overview

- Definitions
- How does OS execute processes?
  - How do kernel & processes interact
  - How does the kernel switch between processes
  - How do interrupts fit in
- Process States
- Priority Scheduling

Context Switching



Implementing Processes

- To maintain illusion, must remember a process's information when not currently running
- Process Control Block (PCB)
  - Identifier (*)
  - Value of registers, including stack pointer (*)
  - Information needed by scheduler: process state (whether blocked or not) (*)
  - Resources held by process: file descriptors, memory pages, etc.

(*) applies to TCB (thread control block) as well

PCB vs TCB

- In 1:1 systems (Pintos), TCB==PCB
  - **`struct thread`**
  - add information as projects progresses
- In 1:n syst
  - TCB cont
    scheduli
    process t
  - PCB cont
    about res

```
struct thread
  {
    tid_t tid;                  /* Thread identifier. */
    enum thread_status status;  /* Thread state. */
    char name[16];              /* Name. */
    uint8_t *stack;             /* Saved stack pointer. */
    int priority;               /* Priority. */
    struct list_elem elem;      /* List element. */
    /* others you'll add as needed. */
};
```


Steps in context switch: high-level

- Save the current process's execution state to its PCB
- Update current's PCB as needed
- Choose next process N
- Update N's PCB as needed
- Restore N's PCB execution state
  - May involve reprogramming MMU

Execution State

- Saving/restoring execution state is highly tricky:
  - Must save state without destroying it
- Registers
  - On x86: eax, ebx, ecx, …
- Stack
  - Special area in memory that holds activation records: e.g., the local (automatic) variables of all function calls currently in progress
  - Saving the stack means retaining that area & saving a pointer to it ("stack pointer" = esp)

The Stack, seen from C/C++

```
int a;
static int b;
int c = 5;
struct S
  {
    int t;
  } s;
```

```
void func(int d)
{
  static int e;
  int f;
  struct S w;
  int *g = new int[10];
}
```

A.: On stack: d, f, w (including w.t), g
Not on stack: a, b, c, s (including s.t), e, g[0]…g[9]

Switching Procedures

- Inside kernel, context switch is implemented in some procedure (function) called from C code
  - Appears to caller as a procedure call
- Must understand how to switch procedures (call/return)
- Procedure calling conventions
  - Architecture-specific
  - Defined by ABI (application binary interface), implemented by compiler
  - Pintos uses SVR4 ABI

x86 Calling Conventions

- Caller saves caller-saved registers as needed
- Caller pushes arguments, right-to-left on stack via push assembly instruction
- Caller executes CALL instruction: save address of next instruction & jump to callee
- Callee executes:
  - Saves callee-saved registers if they'll be destroyed
  - Puts return value (if any) in eax
- Callee returns: pop return address from stack & jump to it
- Caller resumes: pop arguments off the stack
- Caller restores caller-saved registers, if any

Example

```
int globalvar;

int
callee(int a, int b)
{
   return a + b;
}

int
caller(void)
{
   return callee(5, globalvar);
}
```

```
callee:
        pushl   %ebp
        movl    %esp, %ebp
        movl    12(%ebp), %eax
        addl    8(%ebp), %eax
        leave
        ret

caller:
        pushl   %ebp
        movl    %esp, %ebp
        pushl   globalvar
        pushl   $5
        call    callee
        popl    %edx
        popl    %ecx
        leave
        ret
```


Pintos Context Switch (1)

```
static void
schedule (void)
{
  struct thread *cur = running_thread ();
  struct thread *next = next_thread_to_run ();
  struct thread *prev = NULL;
  if (cur != next)
    prev = switch_threads (cur, next);
retlabel:  /* not in actual code */
  schedule_tail (prev);
}

uint32_t thread_stack_ofs = offsetof (struct thread, stack);
```

- threads/thread.c, threads/switch.S

Pintos Context Switch (2)

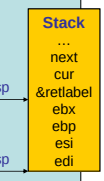
```
switch_threads:  // switch_thread (struct thread *cur, struct thread *next)
        # Save caller's register state.
        # Note that the SVR4 ABI allows us to destroy %eax, %ecx, %edx,
        # but requires us to preserve %ebx, %ebp, %esi, %edi.
        pushl %ebx; pushl %ebp; pushl %esi; pushl %edi

        # Get offsetof (struct thread, stack).
        mov thread_stack_ofs, %edx

        # Save current stack pointer to old thread's stack.
        movl SWITCH_CUR(%esp), %eax
        movl %esp, (%eax,%edx,1)        } cur->stack = esp

        # Restore stack pointer from new thread's stack.
        movl SWITCH_NEXT(%esp), %ecx
        movl (%ecx,%edx,1), %esp        } esp = next->stack

        # Restore caller's register state.
        popl %edi; popl %esi; popl %ebp; popl %ebx
        ret
```




```
#define SWITCH_CUR 20
#define SWITCH_NEXT 24
```


Famous Quote For The Day

```
2230    /*
2231    * If the new process paused because it was
2232    * swapped out, set the stack level to the last call
2233    * to savu(u_ssav).  This means that the return
2234    * which is executed immediately after the call to aretu
2235    * actually returns from the last routine which did
2236    * the savu.
2237    *
2238    * You are not expected to understand this.
2239    */
```

If the new process paused because it was swapped out, set the stack level to the last call to savu(u_ssav). This means that the return which is executed immediately after the call to aretu actually returns from the last routine which did the savu.

You are not expected to understand this.

- Source: Dennis Ritchie, Unix V6 slp.c (context-switching code) as per The Unix Heritage Society (tuhs.org); gif by Eddie Koehler.

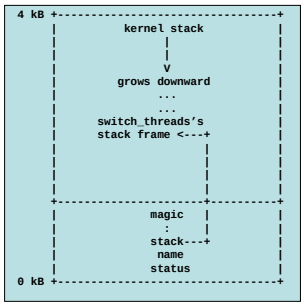
Pintos Context Switch (3)

- All state is stored on outgoing thread's stack, and restored from incoming thread's stack
  - Each thread has a 4KB page for its stack
  - Called "kernel stack" because it's only used when thread executes in kernel mode
  - Mode switch automatically switches to kernel stack
    - x86 does this in hardware, curiously.
- switch_threads assumes that the thread that's switched in was suspended in switch_threads as well.
  - Must fake that environment when switching to a thread for the first time.
- Aside: none of the thread switching code uses privileged instructions:
  - that's what makes user-level threads (ULT) possible

Pintos Kernel Stack

- One page of memory captures a process's kernel stack + PCB
- Don't allocate large objects on the stack:

```
void
kernel_function(void)
{
    char buf[4096]; // DON'T
    // KERNEL STACK OVERFLOW
    // guaranteed
}
```



External Interrupts & Context Switches

```
intr_entry:
      /* Save caller's registers. */
      pushl %ds; pushl %es; pushl %fs; pushl %gs; pushal

      /* Set up kernel environment. */
      cld
      mov $SEL_KDSEG, %eax          /* Initialize segment registers. */
      mov %eax, %ds; mov %eax, %es
      leal 56(%esp), %ebp           /* Set up frame pointer. */

      pushl %esp
      call intr_handler    /* Call interrupt handler. Context switch happens in there*/
      addl $4, %esp
      /* FALL THROUGH */
intr_exit:                  /* Separate entry for initial user program start */
      /* Restore caller's registers. */
      popal; popl %gs; popl %fs; popl %es; popl %ds
      iret  /* Return to current process, or to new process after context switch. */
```


Context Switching: Summary

- Context switch means to save the current and restore next process's execution context
- Context Switch != Mode Switch
  - Although mode switch often precedes context switch
- Asynchronous context switch happens in interrupt handler
  - Usually last thing before leaving handler
- Have ignored so far when to context switch & why → next