key concepts

threads, concurrent execution, timesharing, context switch, interrupts, preemption

reading

Three Easy Pieces: Chapter 26 (Concurrency and Threads)

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Threads and Concurrency

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What is a Thread?

- Threads provide a way for programmers to express *concurrency* in a program.
- A normal *sequential program* consists of a single thread of execution.
- In threaded concurrent programs there are multiple threads of execution, all occuring at the same time.

OS/161 Threaded Concurrency Examples

- Key ideas from the examples:
 - A thread can create new threads using thread_fork
 - New theads start execution in a function specified as a parameter to thread_fork
 - The original thread (which called thread_fork and the new thread (which is created by the call to thread_fork) proceed concurrently, as two simultaneous sequential threads of execution.
 - All threads *share* access to the program's global variables and heap.
 - Each thread's function activations are *private* to that thread.

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OS/161's Thread Interface

• create a new thread:

• terminate the calling thread:

```
void thread_exit(void);
```

• volutarily yield execution:

```
void thread_yield(void);
```

See kern/include/thread.h

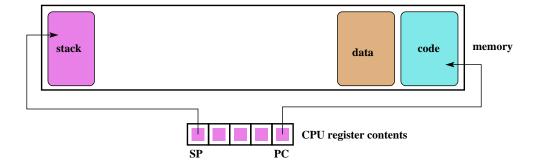
Why Threads?

- **Reason #1**: parallelism exposed by threads enables parallel execution if the underlying hardware supports it.
 - programs can run faster
- Reason #2: parallelism exposed by threads enables better processor utilization
 - if one thread has to block, another may be able to run

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Review: Sequential Program Execution



The Fetch/Execute Cycle

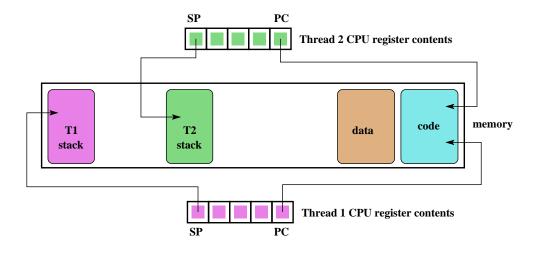
- 1. fetch instruction PC points to
- 2. decode and execute instruction
- 3. advance PC

MIPS Registers

num	name	use	num	name	use
0	z0	always zero	24-25	t8-t9	temps (caller-save)
1	at	assembler reserved	26-27	k0-k1	kernel temps
2	v0	return val/syscall #	28	gp	global pointer
3	v1	return value	29	sp	stack pointer
4-7	a0-a3	subroutine args	30	s8/fp	frame ptr (callee-save)
8-15	t0-t7	temps (caller-save)	31	ra	return addr (for jal)
16-23	s0-s7	saved (callee-save)			

See kern/arch/mips/include/kern/regdefs.h

Concurrent Program Execution (Two Threads)



Conceptually, each thread executes sequentially using its private register contents and stack.

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Implementing Concurrent Threads

- Option 1: multiple processors, multiple cores, hardware multithreading per core
 - P processors, C cores per processor, M multhreading degree per core \Rightarrow PCM threads can execute simultaneously
 - separate register set for each running thread, to hold its execution context
- Option 2: timesharing
 - multiple threads take turns on the same hardware
 - rapidly switch from thread to thread so that all make progress

In practice, both techniques can be combined.

Timesharing and Context Switches

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- When timesharing, the switch from one thread to another is called a *context* switch
- What happens during a context switch:
 - 1. decide which thread will run next (scheduling)
 - 2. save register contents of current thread
 - 3. load register contents of next thread
- Thread context must be saved/restored carefully, since thread execution continuously changes the context

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Context Switch on the MIPS (1 of 2)

```
/* See kern/arch/mips/thread/switch.S */
switchframe_switch:
  /* a0: address of switchframe pointer of old thread. */
  /* al: address of switchframe pointer of new thread. */
   /* Allocate stack space for saving 10 registers. 10*4 = 40 */
   addi sp, sp, -40
        ra, 36(sp)
                   /* Save the registers */
   SW
   SW
        gp, 32(sp)
        s8, 28(sp)
   SW
        s6, 24(sp)
   SW
        s5, 20(sp)
   SW
        s4, 16(sp)
   SW
        s3, 12(sp)
   SW
   SW
        s2, 8(sp)
   SW
        s1, 4(sp)
        s0, 0(sp)
   /* Store the old stack pointer in the old thread */
        sp, 0(a0)
   SW
```

Context Switch on the MIPS (2 of 2)

```
/* Get the new stack pointer from the new thread */
lw
     sp, 0(a1)
              /* delay slot for load */
nop
/* Now, restore the registers */
     s0, 0(sp)
lw
     s1, 4(sp)
lw
     s2, 8(sp)
     s3, 12(sp)
lw
lw
     s4, 16(sp)
     s5, 20(sp)
lw
     s6, 24(sp)
lw
     s8, 28(sp)
lw
lw
     gp, 32(sp)
lw
     ra, 36(sp)
                      /* delay slot for load */
nop
/* and return. */
j ra
addi sp, sp, 40
                      /* in delay slot */
.end switchframe_switch
```

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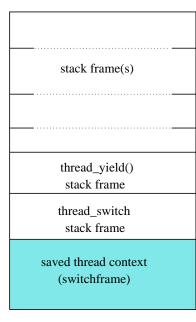
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What Causes Context Switches?

- the running thread calls thread_yield
 - running thread *voluntarily* allows other threads to run
- the running thread calls thread_exit
 - running thread is terminated
- the running thread *blocks*, via a call to **wchan_sleep**
 - more on this later . . .
- the running thread is *preempted*
 - running thread *involuntarily* stops running

OS/161 Thread Stack after Voluntary Context Switch (thread_yield())



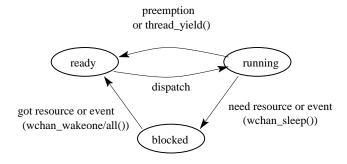
stack growth

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Thread States



running: currently executing

ready: ready to execute

blocked: waiting for something, so not ready to execute.

Preemption

- without preemption, a running thread could potentially run forever, without yielding, blocking, or exiting
- *preemption* means forcing a running thread to stop running, so that another thread can have a chance
- to implement preemption, the thread library must have a means of "getting control" (causing thread library code to be executed) even though the running thread has not called a thread library function
- this is normally accomplished using *interrupts*

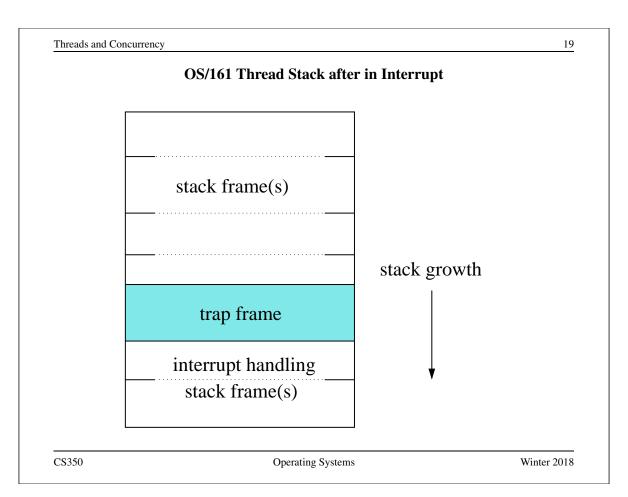
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Review: Interrupts

- an interrupt is an event that occurs during the execution of a program
- interrupts are caused by system devices (hardware), e.g., a timer, a disk controller, a network interface
- when an interrupt occurs, the hardware automatically transfers control to a fixed location in memory
- at that memory location, the thread library places a procedure called an *interrupt handler*
- the interrupt handler normally:
 - 1. create a *trap frame* to record thread context at the time of the interrupt
 - 2. determines which device caused the interrupt and performs device-specific processing
 - 3. restores the saved thread context from the trap frame and resumes execution of the thread



Preemptive Scheduling

- A preemptive scheduler imposes a limit, called the *scheduling quantum* on how long a thread can run before being preempted.
- The quantum is an *upper bound* on the amount of time that a thread can run. It may block or yield before its quantum has expired.
- Periodic timer interrupts allow running time to be tracked.
- If a thread has run too long, the timer interrupt handler preempts the thread by calling thread_yield.
- The preempted thread changes state from running to ready, and it is placed on the *ready queue*.

OS/161 threads use preemptive round-robin scheduling.

