

Processes and Threads

Learning Outcomes

- An understanding of fundamental concepts of processes and threads
- An understanding of the typical implementation strategies of processes and threads
 - Including an appreciation of the trade-offs between the implementation approaches
 - Kernel-threads versus user-level threads
- A detailed understanding of “context switching”

Major Requirements of an Operating System

- Interleave the execution of several processes to maximize processor utilization while providing reasonable response time
- Allocate resources to processes
- Support interprocess communication and user creation of processes

Processes and Threads

- Processes:
 - Also called a task or job
 - Execution of an individual program
 - “Owner” of resources allocated for program execution
 - Encompasses one or more threads
- Threads:
 - Unit of execution
 - Can be traced
 - list the sequence of instructions that execute
 - Belongs to a process

Execution snapshot of three single-threaded processes (No Virtual Memory)

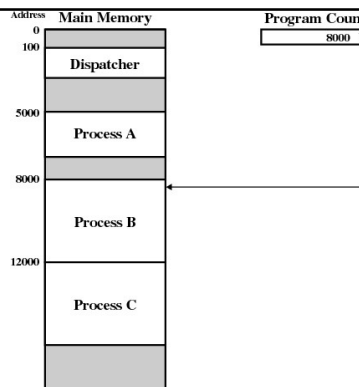


Figure 3.1 Snapshot of Example Execution (Figure 3.1 at Instruction Cycle 13)

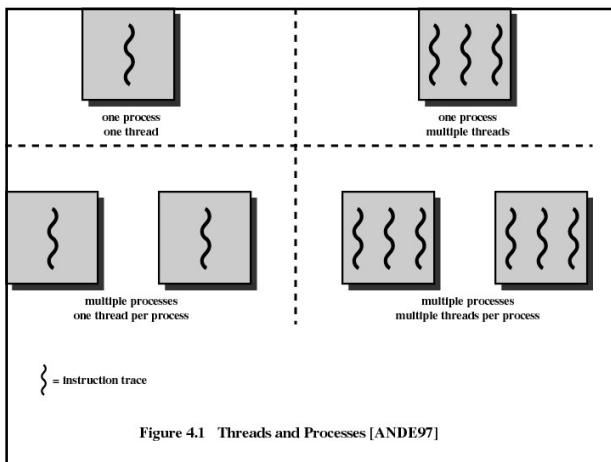
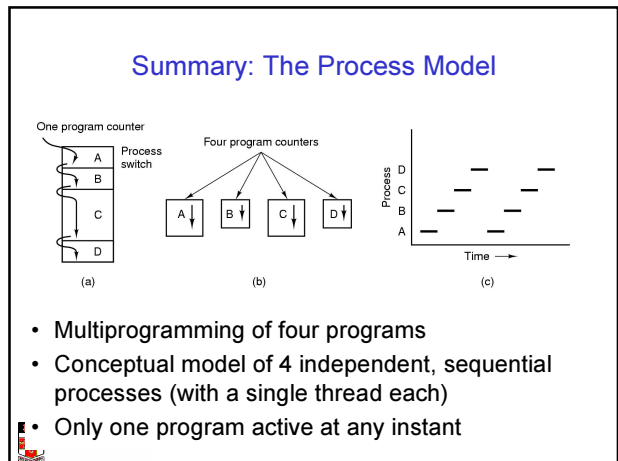
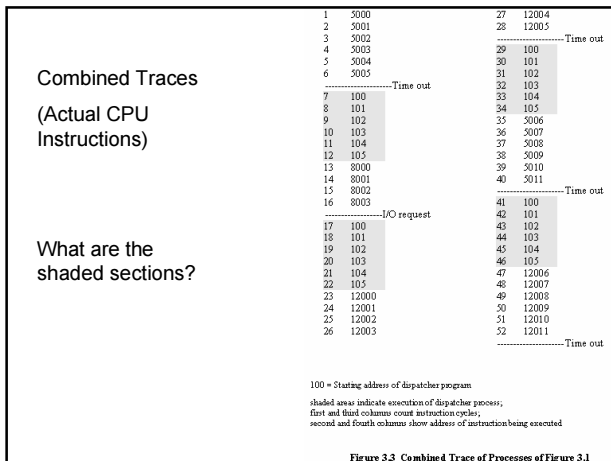
Logical Execution Trace

5000	8000	12000
5001	8001	12001
5002	8002	12002
5003	8003	12003
5004		12004
5005		12005
5006		12006
5007		12007
5008		12008
5009		12009
5010		12010
5011		12011

(a) Trace of Process A (b) Trace of Process B (c) Trace of Process C

5000 = Starting address of program of Process A
8000 = Starting address of program of Process B
12000 = Starting address of program of Process C

Figure 3.2 Traces of Processes of Figure 3.1

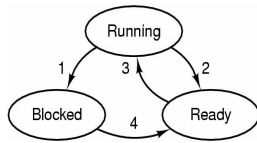


- ### Process and thread models of selected OSes
- Single process, single thread
 - MSDOS
 - Single process, multiple threads
 - OS/161 as distributed
 - Multiple processes, single thread
 - Traditional unix
 - Multiple processes, multiple threads
 - Modern Unix (Linux, Solaris), Windows 2000
- Note: Literature (incl. Textbooks) often do not cleanly distinguish between processes and threads (for historical reasons)
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- ### Process Creation
- Principal events that cause process creation
1. System initialization
 - Foreground processes (interactive programs)
 - Background processes
 - Email server, web server, print server, etc.
 - Called a *daemon* (unix) or *service* (Windows)
 2. Execution of a process creation system call by a running process
 - New login shell for an incoming telnet/ssh connection
 3. User request to create a new process
 4. Initiation of a batch job
- Note: Technically, all these cases use the same system mechanism to create new processes.
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- ### Process Termination
- Conditions which terminate processes
1. Normal exit (voluntary)
 2. Error exit (voluntary)
 3. Fatal error (involuntary)
 4. Killed by another process (involuntary)
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Process/Thread States



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Possible process/thread states
 - running
 - blocked
 - ready
- Transitions between states shown

Some Transition Causing Events

Running \triangleright Ready

- Voluntary `yield()`
- End of timeslice

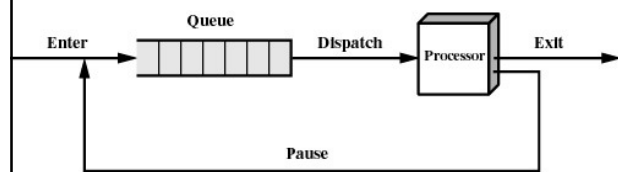
Running \triangleright Blocked

- Waiting for input
 - File, network,
- Waiting for a timer (alarm signal)
- Waiting for a resource to become available

Dispatcher

- Sometimes also called the *scheduler*
 - The literature is also a little inconsistent on this point
- Has to choose a *Ready* process to run
 - How?
 - It is inefficient to search through all processes

The Ready Queue

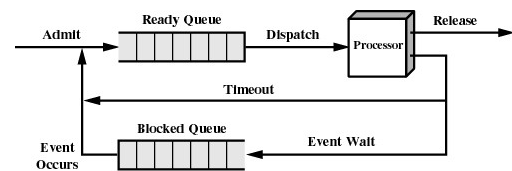


(b) Queuing diagram

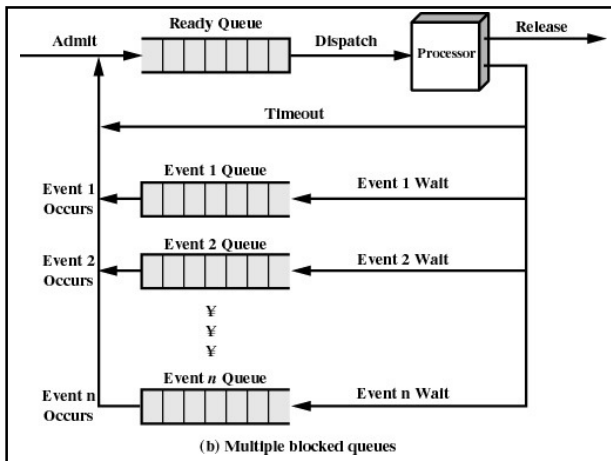
What about blocked processes?

- When an *unblocking* event occurs, we also wish to avoid scanning all processes to select one to make *Ready*

Using Two Queues



(a) Single blocked queue



Implementation of Processes

- A processes' information is stored in a *process control block* (PCB)
- The PCBs form a *process table*
 - Sometimes the kernel stack for each process is in the PCB
 - Sometimes some process info is on the kernel stack
 - E.g. registers in the *trapframe* in OS/161

P7
P6
P5
P4
P3
P2
P1
P0

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Implementation of Processes

Process management Registers Program counter Program status word Stack pointer Process state Priority Scheduling parameters Process ID Parent process Process group Kernel	Memory management Pointer to text segment Pointer to data segment Pointer to stack segment	File management Root directory Working directory File descriptors User ID Group ID
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Example fields of a process table entry

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Threads

The Thread Model

(a) Three processes each with one thread

(b) One process with three threads

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The Thread Model

Per process items Address space Global variables Open files Child processes Pending alarms Signals and signal handlers Accounting information	Per thread items Program counter Registers Stack State
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- Items shared by all threads in a process
- Items private to each thread

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The Thread Model

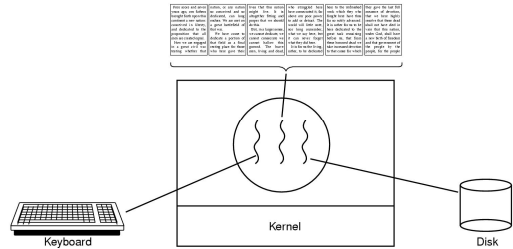
Each thread has its own stack

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Thread Model

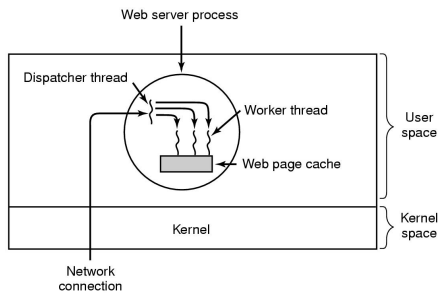
- Local variables are per thread
 - Allocated on the stack
- Global variables are shared between all threads
 - Allocated in data section
 - Concurrency control is an issue
- Dynamically allocated memory (malloc) can be global or local
 - Program defined (the pointer can be global or local)

Thread Usage



A word processor with three threads

Thread Usage



A multithreaded Web server

Thread Usage

```

while (TRUE) {
  get_next_request(&buf);
  handoff_work(&buf);
}
(a)

while (TRUE) {
  wait_for_work(&buf)
  look_for_page_in_cache(&buf, &page);
  if (page_not_in_cache(&page))
    read_page_from_disk(&buf, &page);
  return_page(&page);
}
(b)
    
```

- Rough outline of code for previous slide
 - (a) Dispatcher thread
 - (b) Worker thread

Thread Usage

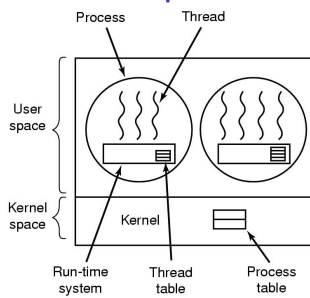
Model	Characteristics
Threads	Parallelism, blocking system calls
Single-threaded process	No parallelism, blocking system calls
Finite-state machine	Parallelism, nonblocking system calls, interrupts

Three ways to construct a server

Summarising “Why Threads?”

- Simpler to program than a state machine
- Less resources are associated with them than a complete process
 - Cheaper to create and destroy
 - Shares resources (especially memory) between them
- Performance: Threads waiting for I/O can be overlapped with computing threads
 - Note if all threads are compute bound, then there is no performance improvement (on a uniprocessor)
- Threads can take advantage of the parallelism available on machines with more than one CPU (multiprocessor)

Implementing Threads in User Space



A user-level threads package

User-level Threads

- Implementation at user-level
 - User-level Thread Control Block (TCB), ready queue, blocked queue, and dispatcher
 - Kernel has no knowledge of the threads (it only sees a single process)
 - If a thread blocks waiting for a resource held by another thread, its state is save and the dispatcher switches to another ready thread
 - Thread management (create, exit, yield, wait) are implemented in a runtime support library

User-Level Threads

- Pros
 - Thread management and switching at user level is much faster than doing it in kernel level
 - No need to trap into kernel and back to switch
 - Dispatcher algorithm can be tuned to the application
 - E.g. use priorities
 - Can be implemented on any OS (thread or non-thread aware)
 - Can easily support massive numbers of threads on a per-application basis
 - Use normal application virtual memory
 - Kernel memory more constrained. Difficult to efficiently support wildly differing numbers of threads for different applications.

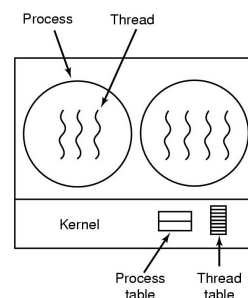
User-level Threads

- Cons
 - Threads have to yield() manually (no timer interrupt delivery to user-level)
 - Co-operative multithreading
 - A single poorly design/implemented thread can monopolise the available CPU time
 - There are work-arounds (e.g. a timer signal per second to enable pre-emptive multithreading), they are coarse grain and a kludge.
 - Does not take advantage of multiple CPUs (in reality, we still have a single threaded process as far as the kernel is concerned)

User-Level Threads

- Cons
 - If a thread makes a blocking system call (or takes a page fault), the process (and all the internal threads) blocks
 - Can't overlap I/O with computation
 - Can use wrappers as a work around
 - Example: wrap the read() call
 - Use select() to test if read system call would block
 - » select() then read()
 - » Only call read() if it won't block
 - » Otherwise schedule another thread
 - Wrapper requires 2 system calls instead of one
 - » Wrappers are needed for environments doing lots of blocking system calls?
 - Can change to kernel to support non-blocking system call
 - Lose "on any system" advantage, page faults still a problem.

Implementing Threads in the Kernel



A threads package managed by the kernel

Kernel Threads

- Threads are implemented in the kernel
 - TCBs are stored in the kernel
 - A subset of information in a traditional PCB
 - The subset related to execution context
 - TCBs have a PCB associated with them
 - Resources associated with the group of threads (the process)
 - Thread management calls are implemented as system calls
 - E.g. create, wait, exit

Kernel Threads

- Cons
 - Thread creation and destruction, and blocking and unblocking threads requires kernel entry and exit.
 - More expensive than user-level equivalent
- Pros
 - **Preemptive** multithreading
 - Parallelism
 - Can overlap blocking I/O with computation
 - Can take advantage of a multiprocessor

Multiprogramming Implementation

1. Hardware saves program counter, etc.
2. Hardware loads new program counter from interrupt vector.
3. Assembly language procedure saves registers.
4. Assembly language procedure sets up new stack.
5. C interrupt service runs (typically reads and buffers input).
6. Scheduler decides which process is to run next.
7. C procedure returns to the assembly code.
8. Assembly language procedure sets up new current process.

Skeleton of what lowest level of OS does when an interrupt occurs – a thread/context switch

Thread Switch

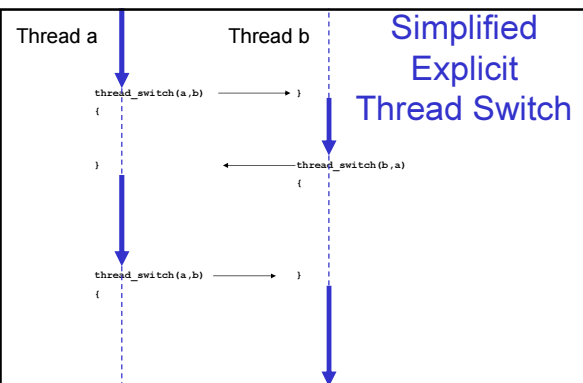
- A switch between threads can happen any time the OS is invoked
 - On a system call
 - Mandatory if system call blocks or on exit();
 - On an exception
 - Mandatory if offender is killed
 - On an interrupt
 - Triggering a dispatch is the main purpose of the *timer interrupt*

A thread switch can happen between any two instructions

Note instructions do not equal program statements

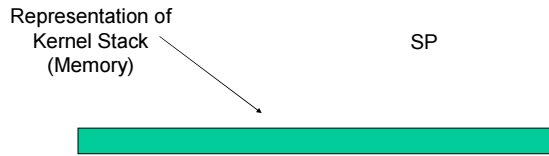
Context Switch

- Thread switch must be *transparent* for threads
 - When dispatched again, thread should not notice that something else was running in the meantime (except for elapsed time)
- ⇒ OS must save all state that affects the thread
- This state is called the *thread context*
- Switching between threads consequently results in a *context switch*.



Example Context Switch

- Running in user mode, SP points to user-level activation stack



Example Context Switch

- Take an exception, syscall, or interrupt, and we switch to the kernel stack



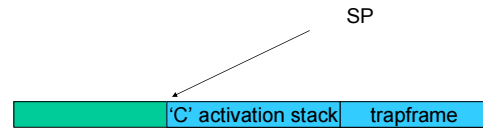
Example Context Switch

- We push a *trapframe* on the stack
 - Also called *exception frame*, *user-level context*...
 - Includes the user-level PC and SP



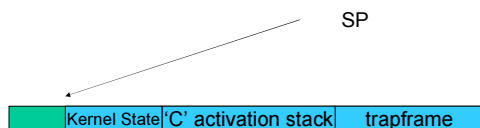
Example Context Switch

- Call 'C' code to process syscall, exception, or interrupt
 - Results in a 'C' activation stack building up



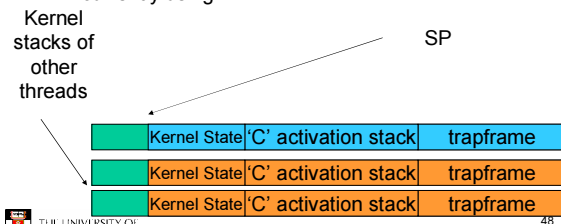
Example Context Switch

- The kernel decides to perform a context switch
 - It chooses a target thread (or process)
 - It pushes remaining kernel context onto the stack



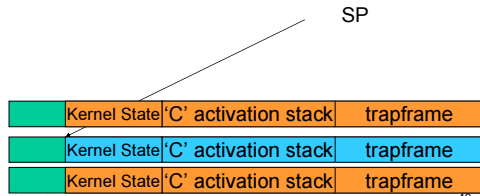
Example Context Switch

- Any other existing thread must
 - be in kernel mode (on a uni processor),
 - and have a similar stack layout to the stack we are currently using



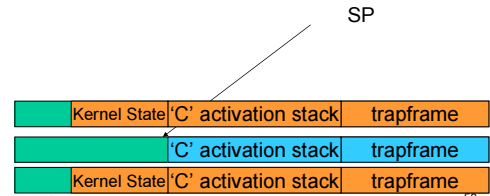
Example Context Switch

- We save the current SP in the PCB (or TCB), and load the SP of the target thread.
- Thus we have *switched contexts*



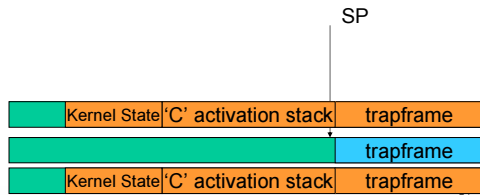
Example Context Switch

- Load the target thread's previous context, and return to C



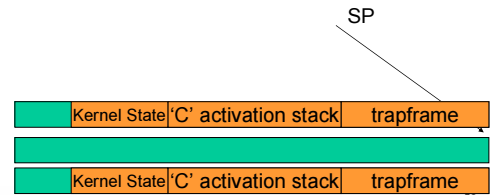
Example Context Switch

- The C continues and (in this example) returns to user mode.



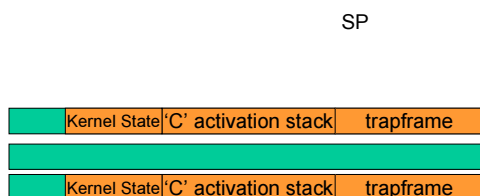
Example Context Switch

- The user-level context is restored



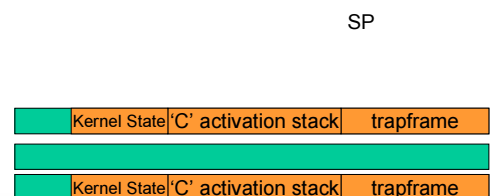
Example Context Switch

- The user-level SP is restored



The Interesting Part of a Thread Switch

- What does the "push kernel state" part do???



OS/161 md_switch

```
md_switch(struct pcb *old, struct pcb *nu)
{
    if (old==nu) {
        return;
    }
    /*
     * Note: we don't need to switch curspl, because splhigh()
     * should always be in effect when we get here and when we
     * leave here.
     */

    old->pcb_kstack = curkstack;
    old->pcb_ininterrupt = in_interrupt;

    curkstack = nu->pcb_kstack;
    in_interrupt = nu->pcb_ininterrupt;

    mips_switch(old, nu);
}
```



OS/161 mips_switch

```
mips_switch:
/*
 * a0 contains a pointer to the old thread's struct pcb.
 * a1 contains a pointer to the new thread's struct pcb.
 *
 * The only thing we touch in the pcb is the first word, which
 * we save the stack pointer in. The other registers get saved
 * on the stack, namely:
 *
 *
 *   s0-s8
 *   gp, ra
 *
 * The order must match arch/mips/include/switchframe.h.
 */

/* Allocate stack space for saving 11 registers. 11*4 = 44 */
addi sp, sp, -44
```



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OS/161 mips_switch

```
/* Save the registers */
sw ra, 40(sp)
sw gp, 36(sp)
sw s8, 32(sp)
sw s7, 28(sp)
sw s6, 24(sp)
sw s5, 20(sp)
sw s4, 16(sp)
sw s3, 12(sp)
sw s2, 8(sp)
sw s1, 4(sp)
sw s0, 0(sp)

/* Store the old stack pointer in the old pcb */
sw sp, 0(a0)
```

Save the registers
that the 'C'
procedure calling
convention
expects preserved



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OS/161 mips_switch

```
/* Get the new stack pointer from the new pcb */
lw sp, 0(a1)
nop /* delay slot for load */

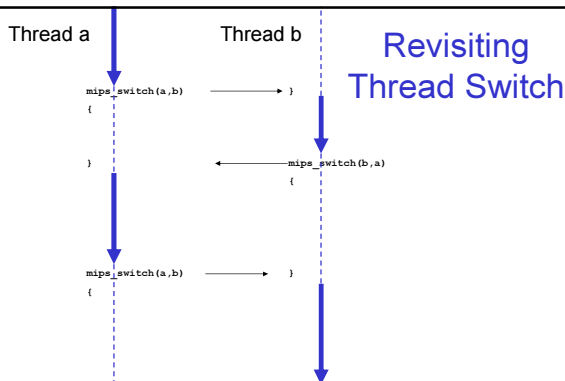
/* Now, restore the registers */
lw s0, 0(sp)
lw s1, 4(sp)
lw s2, 8(sp)
lw s3, 12(sp)
lw s4, 16(sp)
lw s5, 20(sp)
lw s6, 24(sp)
lw s7, 28(sp)
lw s8, 32(sp)
lw gp, 36(sp)
lw ra, 40(sp)
nop /* delay slot for load */

/* and return. */
j ra
addi sp, sp, 44 /* in delay slot */
.end mips_switch
```



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