cse

Threads and Events

THE UNIVERSITY OF NEW SOUTH WALES

cse

System Building

- General purpose systems need to deal with
  - Many activities
    - potentially overlapping
    - may be interdependent
  - Activities that depend on external phenomena
    - may requiring waiting for completion (e.g. disk read)
    - reacting to external triggers (e.g. interrupts)
- Need a systematic approach to system structuring

THE UNIVERSITY OF NEW SOUTH WALES

cse

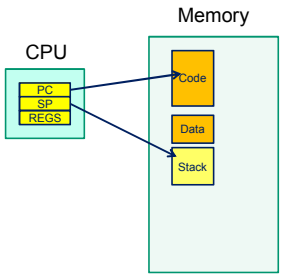
One Approach - Threads

- What are threads?
- How do we implement them?

THE UNIVERSITY OF NEW SOUTH WALES

cse

A Thread

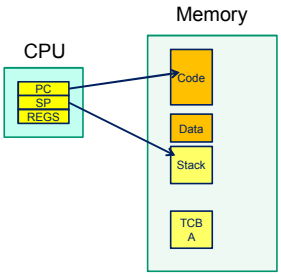


- Thread attributes
  - processor related
    - memory
    - program counter
    - stack pointer
    - registers (and status)
  - OS/package related
    - state (running/blocked)
    - identity
    - scheduler (queues, priority)
    - etc…

THE UNIVERSITY OF NEW SOUTH WALES

cse

Thread Control Block

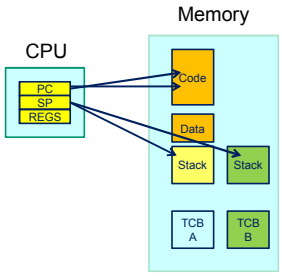


- To support more than a single thread we to need store thread state and attributes
- Stored in thread control block
  - also indirectly in stack

THE UNIVERSITY OF NEW SOUTH WALES

cse

Thread A and Thread B



- Thread A state currently loaded
- Thread B state stored in TCB B
- Thread switch from A → B
  - saving state of thread a
    - regs, sp, pc
  - restoring the state of thread B
    - regs, sp, pc
- Note: registers and PC can be stored on the stack, and only SP stored in TCB

THE UNIVERSITY OF NEW SOUTH WALES

cse

Approx thread switch

```
mi_switch()
{
  struct thread *cur, *next;
  next = scheduler();

/* update curthread */
  cur = curthread;
  curthread = next;

/*
 * Call the machine-dependent code that actually does the
 * context switch. How?
 */
  md_switch(&cur->t_pcb, &next->t_pcb);

/* back running in same thread */

}
```

Note: global variable curthread

cse

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
```


cse

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

cse

OS/161 mips_switch

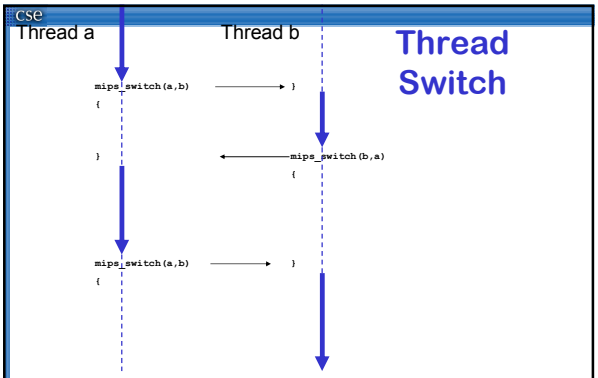
```
/* Get the new stack pointer from the new pcb */
   lw    sp, 0(a1)
   nop             /* delay slot for load */

/* 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
```

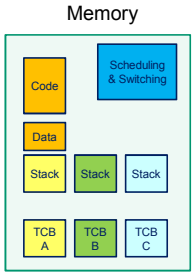

cse

Thread Switch



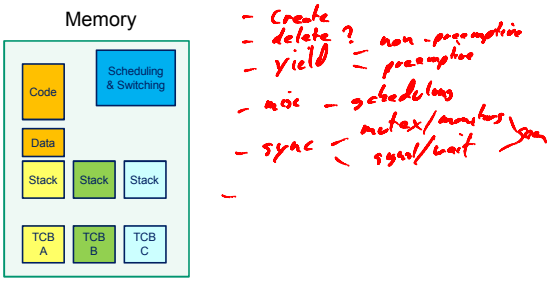
cse

Threads on simple CPU



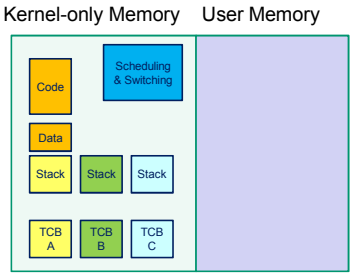
cse

Discussion: What operations are in a thread package?



cse

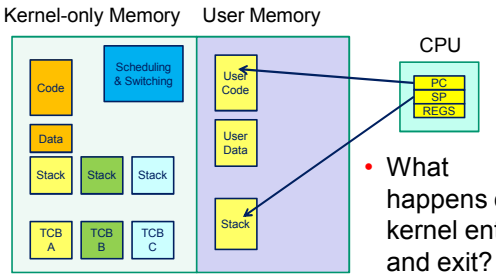
Threads on CPU with protection



- What is missing?

cse

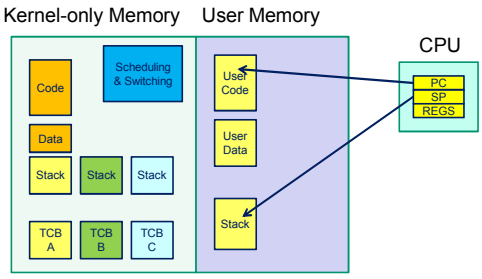
Threads on CPU with protection



- What happens on kernel entry and exit?

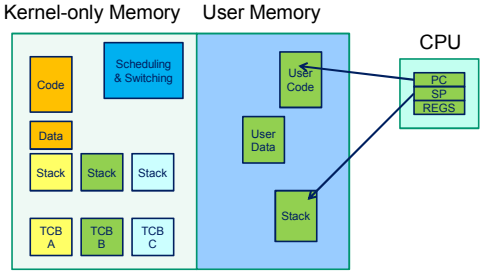
cse

Switching Address Spaces on Thread Switch = Processes



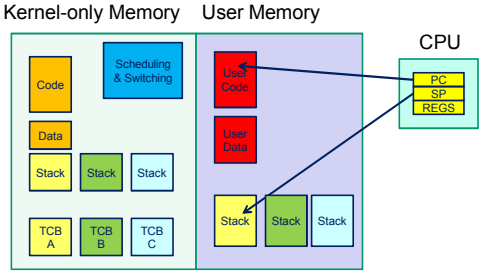
cse

Switching Address Spaces on Thread Switch = Processes



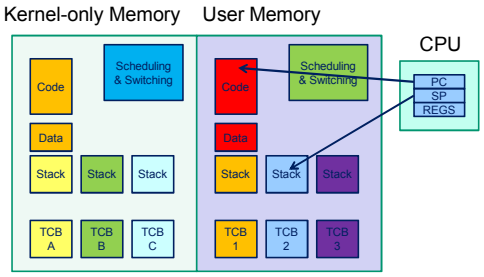
cse

What is this?



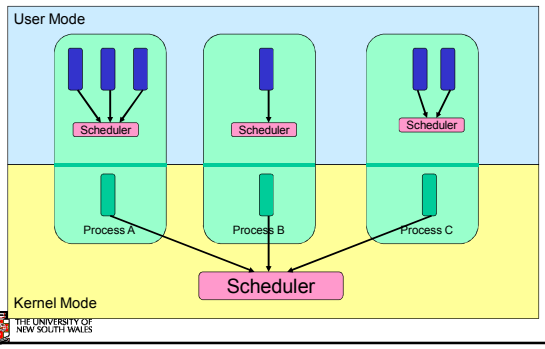
cse

What is this?



cse

User-level Threads



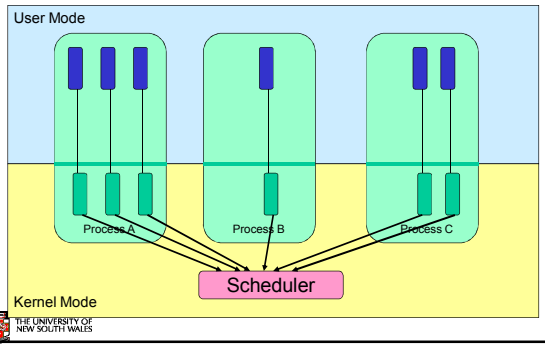
cse

User-level Threads

- ✓ Fast thread management (creation, deletion, switching, synchronisation…)
- × Blocking blocks all threads in a process
  - Syscalls
  - Page faults
- × No thread-level parallelism on multiprocessor

cse

Kernel-Level Threads



cse

Kernel-level Threads

- × Slow thread management (creation, deletion, switching, synchronisation…)
  - System calls
- ✓ Blocking blocks only the appropriate thread in a process
- ✓ Thread-level parallelism on multiprocessor

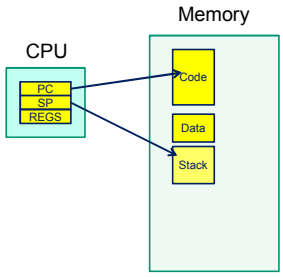
cse

Thread Alternative - Events

- External entities generate (post) events.
  - keyboard presses, mouse clicks, system calls
- *Event loop* waits for events and calls an appropriate *event handler.*
  - common paradigm for GUIs
- *Event handler* is a function that runs until completion and returns to the *event loop.*

cse

Event Model

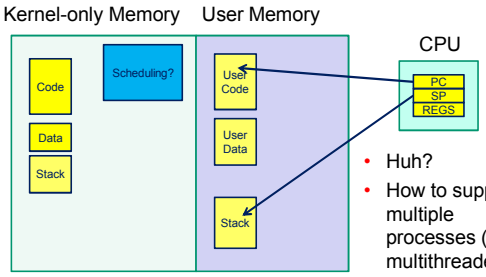


- The event model only requires a single stack
  - All event handlers must return to the event loop

THE UNIVERSITY OF NEW SOUTH WALES

cse

Event-based kernel on CPU with protection

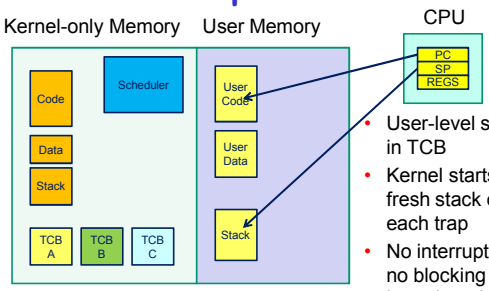


- Huh?
- How to support multiple processes (or multithreaded apps)?

THE UNIVERSITY OF NEW SOUTH WALES

cse

Event-based kernel on CPU with protection



- User-level state in TCB
- Kernel starts on fresh stack on each trap
- No interrupts, no blocking in kernel mode

THE UNIVERSITY OF NEW SOUTH WALES

cse

The two alternatives

From the view of the designer there are two alternatives.

Single Kernel Stack	**Per-Thread Kernel Stack**
Only one stack is used all the time to support all user threads.	Every user thread has a kernel stack.

THE UNIVERSITY OF NEW SOUTH WALES

cse

Per-Thread Kernel Stack

- A thread's kernel state is implicitly encoded in the kernel activation stack
  - If the thread must block in-kernel, we can simply switch from the current stack, to another threads stack until thread is resumed
  - Resuming is simply switching back to the original stack
  - Preemption is easy
  - no conceptual difference between kernel mode and user mode

Processes Model

```
example(arg1, arg2) {
   P1(arg1, arg2);
   if (need_to_block) {
        thread_block();
        P2(arg2);
   } else {
        P3();
   }
   /* return control to user */
   return SUCCESS;
}
```

THE UNIVERSITY OF NEW SOUTH WALES

cse

Single Kernel Stack

"Event" or "Interrupt" Model

- How do we use a single kernel stack to support many threads?
  - Issue: How are system calls that block handled?

⇒ either *continuations*

- Using Continuations to Implement Thread Management and Communication in Operating Systems. [Draves *et al.*, 1991]

⇒ or *stateless kernel* (interrupt model)

- Interface and Execution Models in the Fluke Kernel. [Ford *et al.*, 1999]

THE UNIVERSITY OF NEW SOUTH WALES

cse

Continuations

- State required to resume a blocked thread is explicitly saved in a TCB
  - A function pointer
  - Variables
- Stack can be discarded and reused to support new thread
- Resuming involves discarding current stack, restoring the continuation, and continuing

```
example(arg1, arg2) {
    P1(arg1, arg2);
    if (need_to_block) {
        save_arg_in_TCB;
        thread_block(example_continue);
        /* NOT REACHED */
    } else {
        P3();
    }
    thread_syscall_return(SUCCESS);
}
example_continue() {
    recover_arg2_from_TCB;
    P2(recovered arg2);
    thread_syscall_return(SUCCESS);
}
```

THE UNIVERSITY OF NEW SOUTH WALES

cse

Stateless Kernel

- System calls can not block within the kernel
  - If syscall must block (resource unavailable)
    - Modify user-state such that syscall is restarted when resources become available
    - Stack content is freed (functions all return)
- Preemption within kernel difficult to achieve.
  - ⇒ Must (partially) roll syscall back to a restart point
- Avoid page faults within kernel code
  - ⇒ Syscall arguments in registers
    - Page fault during roll-back to restart (due to a page fault) is fatal.

THE UNIVERSITY OF NEW SOUTH WALES

cse

IPC examples – Per thread stack

Send and Receive system call implemented by a non-blocking send part and a blocking receive part.

```
msg_send_rcv(msg, option,
        send_size, rcv_size, ...) {

   rc = msg_send(msg, option,
        send_size, ...);

   if (rc != SUCCESS)
   return rc;

   rc = msg_rcv(msg, option, rcv_size, ...);
   return rc;
}
```

Block inside msg_rcv if no message available

THE UNIVERSITY OF NEW SOUTH WALES

cse

IPC examples - Continuations

```
msg_send_rcv(msg, option,
        send_size, rcv_size, ...) {
   rc = msg_send(msg, option,
        send_size, ...);
   if (rc != SUCCESS)
        return rc;
   cur_thread->continuation.msg = msg;
   cur_thread->continuation.option = option;
   cur_thread->continuation.rcv_size = rcv_size;
        ...
   rc = msg_rcv(msg, option, rcv_size, ...,
        msg_rcv_continue);
   return rc;
}
msg_rcv_continue() {
   msg = cur_thread->continuation.msg;
   option = cur_thread->continuation.option;
   rcv_size = cur_thread->continuation.rcv_size;
        ...
   rc = msg_rcv(msg, option, rcv_size, ...,
   );
   return rc;
}
```

The function to continue with if blocked

Note: we don't get here if msg_rcv blocked

THE UNIVERSITY OF NEW SOUTH WALES

cse

IPC Examples – stateless kernel

```
msg_send_rcv(……) {
   rc = msg_send(dest);
   if (rc != SUCCESS)
        return rc;

   rc = msg_rcv(cur_thread);
   if (rc == WOULD_BLOCK) {
        set_args(cur_thread, ……);
        set_pc(cur_thread, msg_rcv_entry);
        return BLOCKED;
   }
   return rc;
}
```

Set user-level PC to restart msg_rcv only

BLOCKED changes (away from) curthread on exiting the kernel

THE UNIVERSITY OF NEW SOUTH WALES

cse

Single Kernel Stack

- either *continuations* — per Processor, event model
  - complex to program
  - must be conservative in state saved (any state that *might* be needed)
  - Mach (Draves), L4Ka::Strawberry, NICTA Pistachio, OKL4
- or *stateless kernel*
  - no kernel threads, kernel not interruptible, difficult to program
  - request all potentially required resources prior to execution
  - blocking syscalls must always be re-startable
  - Processor-provided stack management can get in the way
  - system calls need to be kept simple "atomic".
  - e.g. the fluke kernel from Utah
- low cache footprint
  - always the same stack is used !
  - reduced memory footprint

THE UNIVERSITY OF NEW SOUTH WALES

Per-Thread Kernel Stack

- simple, flexible
  - kernel can always use threads, no special techniques required for keeping state while interrupted / blocked
  - no conceptual difference between kernel mode and user mode
  - e.g. traditional L4, Linux, Windows, OS/161
- but larger cache footprint
- and larger memory consumption