CSE 451: Operating Systems
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Module 6
Review of Processes,
Kernel Threads, User-Level Threads

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What's "in" a process?

- A process consists of (at least):
  - An address space, containing
    - the code (instructions) for the running program
    - the data for the running program (static data, heap data, stack)
  - CPU state, consisting of
    - The program counter (PC), indicating the next instruction
    - The stack pointer
    - Other general purpose register values
  - A set of OS resources
    - open files, network connections, sound channels, …
- In other words, it's all the stuff you need to run the program
  - or to re-start it, if it's interrupted at some point

The OS gets control because of …

- Trap: Program executes a syscall
- Exception: Program does something unexpected (e.g., page fault)
- Interrupt: A hardware device requests service

PCBs and CPU state

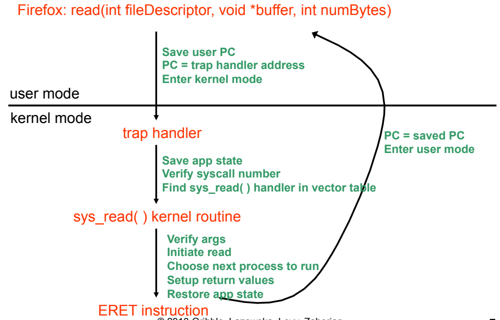
- When a process is running, its CPU state is inside the CPU
  - PC, SP, registers
  - CPU contains current values
- When the OS gets control (trap, exception, interrupt), the OS saves the CPU state of the running process in that process's PCB
  - when the OS returns the process to the running state, it loads the hardware registers with values from that process's PCB – general purpose registers, stack pointer, instruction pointer
- This is called a context switch

The syscall

- How do user programs do something privileged?
  - e.g., how can you write to a disk if you can't execute an I/O instructions?
- User programs must call an OS procedure – that is, get the OS to do it for them
  - OS defines a set of system calls
  - User-mode program executes system call instruction with a parameter indicating the specific function desired
- Syscall instruction
  - Like a protected procedure call

- The syscall instruction atomically:
  - Saves the current PC
  - Sets the execution mode to privileged
  - Sets the PC to a handler address
- With that, it's a lot like a local procedure call
  - Caller puts arguments in a place callee expects (registers or stack)
    - One of the args is a syscall number, indicating which OS function to invoke
  - Callee (OS) saves caller's state (registers, other control state) so it can use the CPU
  - OS function code runs
    - OS must verify caller's arguments (e.g., pointers)
  - OS returns using a special instruction
    - Automatically sets PC to return address and sets execution mode to user

A kernel crossing illustrated



Interrupts and exceptions work the same way as traps

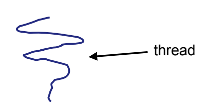
- Transition to kernel mode
- Save state of running process in PCB
- Handler routine deals with whatever occurred
- Choose a next process to run
- Restore that process's CPU state from its PCB
- Execute an instruction that returns you to user mode at the appropriate instruction

The OS kernel is not a process

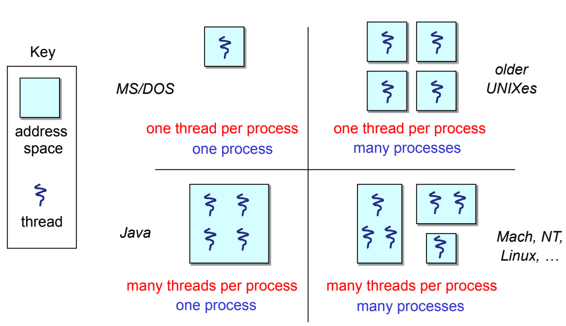
- It's just a block of code!
- (In a microkernel OS, many things that you normally think of as the operating system execute as user-mode processes. But the OS kernel is just a block of code.)

Threads

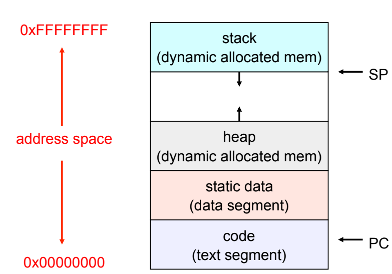
- Key idea:
  - separate the concept of a process (address space, OS resources)
  - … from that of a minimal "thread of control" (execution state: stack, stack pointer, program counter, registers)
- This execution state is usually called a thread, or sometimes, a lightweight process



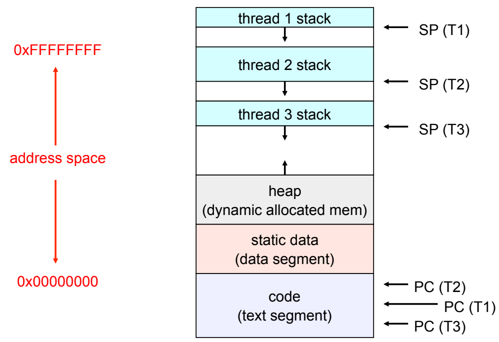
The design space



(old) Process address space



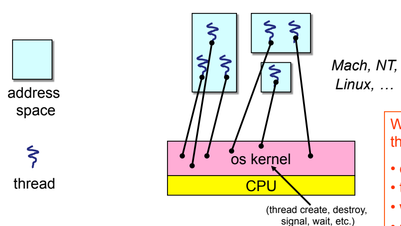
(new) Address space with threads



Kernel threads

- OS now manages threads *and* processes / address spaces
  - all thread operations are implemented in the kernel
  - OS schedules all of the threads in a system
    - if one thread in a process blocks (e.g., on I/O), the OS knows about it, and can run other threads from that process
    - possible to overlap I/O and computation inside a process
- Kernel threads are cheaper than processes
  - less state to allocate and initialize
- But, they're still pretty expensive for fine-grained use
  - orders of magnitude more expensive than a procedure call
  - thread operations are all system calls
    - context switch
    - argument checks

Kernel threads

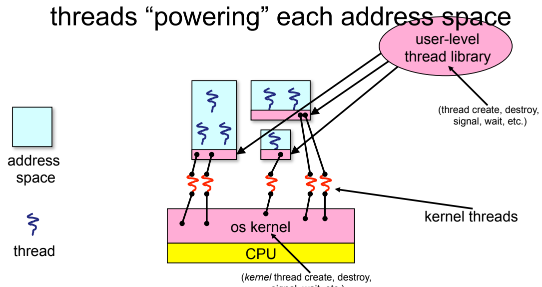


What happens when a thread wants to:
- create another thread?
- terminate itself?
- wait for some condition?
- signal some condition?
- do I/O?

User-level threads

- There is an alternative to kernel threads
- Threads can also be managed at the user level (that is, entirely from within the process)
  - a library linked into the program manages the threads
    - because threads share the same address space, the thread manager doesn't need to manipulate address spaces (which only the kernel can do)
    - threads differ (roughly) only in hardware contexts (PC, SP, registers), which can be manipulated by user-level code
    - the thread package multiplexes user-level threads on top of kernel thread(s)
    - each kernel thread is treated as a "virtual processor"
  - we call these user-level threads

User-level threads with multiple kernel threads "powering" each address space



Getting started …

- Fork a process (one kernel thread, one or more user-level threads)
  - Creates an address space that's a clone of the parent
  - In the kernel, there's a new PCB that describes the child's address space and OS resources
  - A kernel thread is created – there's a new kernel TCB that's "linked" to the new PCB, so the OS knows which set of page tables to use when scheduling a particular thread
  - Because the address space is cloned, the child has as many user-level threads as the parent did
  - In both parent and child, next instruction is the one after the fork
  - Child can exec
  - Child or parent can create additional threads for itself, etc.

Getting started …

- Fork a process (multiple kernel threads)
  - The child gets only one kernel thread - the one that issued the fork
  - So in the child, the next instruction to be executed is the one after the fork

Summary

- You really want multiple threads per address space
- Kernel threads are much more efficient than processes, but they're still not cheap
  - all operations require a kernel call and parameter validation
- User-level threads are:
  - really fast/cheap
  - great for common-case operations
    - creation, synchronization, destruction
  - can suffer in uncommon cases due to kernel obliviousness
    - I/O
    - preemption of a lock-holder
- Scheduler activations are an answer
  - return control to the user-level scheduler upon blockage
- "Optimize the common case" is a key design principle