Recap of the Last Class

- System protection and kernel mode
- System calls and the interrupt interface
- Processes
  - Process concept
  - A process's image in a computer
  - Operations on processes
  - Context switches and the scheduling process

Process and Its Image

- An operating system executes a variety of programs:
  - A program that browses the Web
  - A program that serves Web requests
- Process - a program in execution.
- A process's state/image in a computer includes:
  - User-mode address space
  - Kernel data structure
  - Registers (including program counter and stack pointer)
- Address space and memory protection
  - Physical memory is divided into user memory and kernel memory
  - Kernel memory can only be accessed when in the kernel mode
  - Each process has its own exclusive address space in the user-mode memory space (sort-of)

Process Management

- A process is a program in execution
  - Unit of work - A process needs certain resources, including CPU time, memory, files, and I/O devices, to accomplish its task
  - Protection domain
- OS responsibilities for process management:
  - Process creation and deletion
  - Process scheduling, suspension, and resumption
  - Process synchronization, inter-process communication

Private Address Spaces

- Each process has its own private address space.

Diagram:

- Kernel virtual memory
  - (code, data, heap, stack)
- User stack
  - (created at runtime)
- Memory mapped region for shared libraries
- Run-time heap
  - (managed by malloc)
- Read/write segment
  - (.data, .bss)
- Read-only segment
  - (.init, .text, .rodata)
- Unused
- Memory invisible to user code
- %esp (stack pointer)
- brk
- Loaded from the executable file
User-mode Address Space

User-mode address space for a process:
- **Text**: program code, instructions
- **Data**: initialized global and static variables (those data whose size is known before the execution)
- **BSS**: block started by symbol: uninitialized global and static variables
- **Heap**: dynamic memory (those being malloc-ed)
- **Stack**: local variables and other stuff for function invocations

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<tr>
<th>Stack</th>
<th>Heap</th>
<th>BSS</th>
<th>Data</th>
<th>Text</th>
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Process Control Block (PCB)

OS data structure (in kernel memory) maintaining information associated with each process:
- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- Information about open files
- maybe kernel stack?

Queues for PCBs

- **Ready queue**: set of all processes ready for execution.
- **Device queues**: set of processes waiting for an I/O device.
- Process migration between the various queues.

Process State

As a process executes, it changes state:
- **new**: The process is being created
- **ready**: The process is waiting to be assigned to a process
- **running**: Instructions are being executed
- **waiting**: The process is waiting for some event to occur
- **terminated**: The process has finished execution
Process Creation

- When a process (parent) creates a new process (child)
  - Execution sequence?
  - Address space sharing?
  - Open files inheritance?
  - ... ...
- UNIX examples
  - `fork` system call creates new process with a duplicated copy of everything.
  - `exec` system call used after a `fork` to replace the process' memory space with a new program.
  - child and parent compete for CPU like two normal processes.
- Copy-on-write

Today

- Context switches and the scheduling process
- Inter-process communication
  - Shared memory
- Thread
  - Thread concept
  - Multithreading models
  - Types of threads

Context Switching

- Processes are managed by a shared chunk of OS code called the `kernel`
  - Important: the kernel is not a separate process, but rather runs as part of some user process
- Control flow passes from one process to another via a `context switch`.

Scheduling: Transferring Context Blocks

Coroutines

```
transfer(other)
```

save all callee-saves registers on stack, including ra and fp

```
*current := sp
current := other
sp := *current
pop all callee-saves registers (including ra, but NOT sp!)
return (into different coroutine!)
```
Uniprocessor Scheduling

- Use Ready List to reschedule voluntarily (cooperative threading)

  reschedule:
  - t : cb := dequeue(ready_list)
  - transfer(t)

  yield:
  - enqueue(ready_list, current)
  - reschedule

sleep_on(q):
  - enqueue(q, current)
  - reschedule

Preemption

- Use timer interrupts or signals to trigger involuntary yields
- Protect scheduler data structures by disabling/reenabling prior to/after rescheduling

  yield:
  - disable_signals
  - enqueue(ready_list, current)
  - reschedule
  - re-enable_signals

CPU Switch From Process to Process

- When can the OS switch the CPU from one process to another?
- Which one to switch to? - scheduling

Process Termination

- Process executes last statement and gives the control to the OS (exit)
  - Notify parent if it is waiting
  - Deallocate process's resources
- The OS may forcefully terminate a process
  - Software exceptions
  - Receiving certain signals
Interprocess Communication

- Reasons for processes to cooperate
  - Information sharing (e.g., files)
  - Computation speedup
  - Modularity and protection
  - Convenience - multitasking

Mechanisms for Interprocess Communication

- Shared memory
- Message passing
  - Pipes, sockets, remote procedure calls

Shared Memory: POSIX interface

- shm_get – returns the identifier of a shared memory segment
- shmat – attaches the shared memory segment to the address space
- shmdt – detaches the segment located at the specified address
- shmctl – control of shared memory segments, including deletion
- Other possibilities: mmap (file sharing with preserved properties)

Message Passing

- Direct or indirect communication – processes or ports
- Fixed or variable size
- Send by copy or reference
- Automatic or explicit buffering
- Blocking or non-blocking (send or receive)

- Examples: client-server sockets, Mach ports, Windows 2000 local procedure call (LPC), remote procedure call (RPC, RMI)
Processes or Threads

- A process or thread is a potentially-active execution context
- Processes/threads can come from
  - Multiple CPUs
  - Kernel-level multiplexing of single physical CPU (kernel-level threads or processes)
  - Language or library-level multiplexing of kernel-level abstraction (user-level threads)
- Threads can run
  - Truly in parallel (on multiple CPUs)
  - Unpredictably interleaved (on a single CPU)
  - Run-until-block (coroutine-style)

Processes and Threads

- Thread - a program in execution; without a dedicated address space.
- OS memory protection is only applied to processes.

Processes Vs. Threads

- Process
  - Single address space
  - Single thread of control for executing program
  - State information
    - Page tables, swap images, file descriptors, queued I/O requests, saved registers
- Threads
  - Separate notion of execution from the rest of the definition of a process
  - Other parts potentially shared with other threads
  - Program counter, stack of activation records, control block (e.g., saved registers/state info for thread management)
  - Kernel-level (lightweight process) handled by the system scheduler
  - User-level handled in user mode

Why Use Threads?

- Multithreading is used for parallelism/concurrency. But why not multiple processes?
  - Memory sharing.
  - Efficient synchronization between threads
  - Less context switch overhead
User/Kernel Threads

- User threads
  - Thread data structure is in user-mode memory
  - scheduling/switching done at user mode
- Kernel threads
  - Thread data structure is in kernel memory
  - scheduling/switching done by the OS kernel

User/Kernel Threads (cont.)

- Benefits of user threads
  - lightweight - less context switching overhead
  - more efficient synchronization??
  - flexibility - allow application-controlled scheduling
- Problems of user threads
  - can’t use more than one processor
  - oblivious to kernel events, e.g., all threads in a process are put to wait when only one of them does I/O

Mixed User/Kernel Threads

- M user threads run on N kernel threads (M≥N)
  - N=1: pure user threads
  - M=N: pure kernel threads
  - M>N>1: mixed model

Solaris/Linux Threads

- Solaris
  - supports mixed model
- Linux
  - No standard user threads on Linux
  - Processes and threads treated in a similar manner (both called tasks)
  - Processes are tasks with exclusive address space
  - Tasks can also share the address space, open files, …
Pthreads

- Each OS has its own thread package with different Application Programming Interfaces ⇒ poor portability.
- Pthreads
  - A POSIX standard API for thread management and synchronization.
  - API specifies behavior of the thread library, not the implementation.
  - Commonly supported in UNIX operating systems.

Issues with the Threading Model

- Thread-local storage – what about globals?
- Stack management
- Interaction with fork and exec system calls
  - Two versions of fork?
- Signal handling – which thread should the signal be delivered to?
  - Synchronous
  - All
  - Assigned thread
  - Unix: could assign a specific thread to handle signals
  - Windows: asynchronous procedure calls, which are thread-specific

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