Recap of the Last Class

- **Hardware protection**
  - kernel and user mode

- **System components**
  - process management, memory management, I/O system, file and storage, networking, ...

- **Operating system architectures**
  - monolithic architecture, microkernel
  - ...

Layered Structure

- **Layered structure**
  - The operating system is divided into a number of layers (levels), each built on top of lower layers.
  - The bottom layer (layer 0) is the hardware.
  - The highest (layer N) is the user interface.
  - Decreased privileges for higher layers.

- **Benefits**
  - more reliable
  - more secure
  - more flexibility

- **Disadvantage**
  - Weak integration results in performance penalty (similar to the microkernel structure).

Virtual Machines

- **A virtual machine**
  - **Virtualization:** It is a piece of software that provides an interface identical to the underlying bare hardware.
  - **Multiplexing:** It provides several copies of this interface on top of a single piece of hardware.
  - **Resource management:** The resources of the physical computer are shared to create the virtual machines.
    - e.g., CPU scheduling can create the appearance that each piece of upper-layer software has its own processor.

- **It is not an operating system in the strict sense**
  - It is a resource manager, but not an extended machine
**VM Models**

- **Non-VM**:
  - User programs
  - OS
  - Hardware

- **Native VM**:
  - User programs
  - OS
  - VM monitor
  - Hardware

- **Hosted VM**:
  - User programs
  - OS
  - VM monitor
  - Native OS
  - Hardware

**Usage of Virtual Machines**

- Running several different OSes on a single machine
- Education
- Research and development of operating systems and computer architecture
- Enhanced reliability and security
- Allow general management of “machines” at software level

**Outline**

- **Process**
  - Process concept
  - A process’s image in a computer
  - Operations on processes

- **Thread**
  - Thread concept
  - Multithreading models
  - Types of threads

**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)
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

```
0xffffffff

Stack

Heap

BSS

Data

Text
```

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?

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.

```
new

ready

running

terminated
```

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 CPU like two normal processes.
  - Copy-on-write
Process Tree on a Linux System

- Parent process creates children processes, which, in turn create other processes, forming a tree of processes.

```
init (pid=1)
OS
  daemon x
  daemon y
KDE-init
  user 1
  shell 1a
  shell 1b
  shell 2c
  ssd
  user 2
```

CPU Switch From Process to Process

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

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 Termination

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

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

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

- What is really happening when the execution of one thread switches to another?
  - save the registers (including the SP) of the old thread;
  - restore the registers of the new thread;
  - set the new PC appropriately for the new thread;
- Does this need help from the OS kernel?
- Can you do it in C/Java?
- Does process switching need help from the OS kernel?
- 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

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