COS 318: Operating Systems

Processes and Threads

Jaswinder Pal Singh
Computer Science Department
Princeton University

(http://www.cs.princeton.edu/courses/cos318/)
Today’s Topics

- Concurrency
- Processes
- Threads

Reminder:
- Hope you’re all busy working on your implementations
Concurrenty and Processes

- Concurrency
  - Hundreds of jobs going on in a system
  - CPU is shared, as are I/O devices

- Concurrency via Processes
  - Decompose complex problems into simple ones
  - Make each simple one a process
  - Processes run ‘concurrently’ but each process feels like it has its own computer

- Example: gcc (via “gcc –pipe –v”) launches the following
  - /usr/libexec/cpp | /usr/libexec/cc1 | /usr/libexec/as | /usr/libexec/elf/ld
  
  - Each instance of cpp, cc1, as and ld running is a process
Process Concurrency

- **Virtualization**
  - Processes interleaved on CPU

- **I/O concurrency**
  - I/O for P1 overlapped with CPU for P2
  - Each runs almost as fast as if it has its own computer
  - Reduce total completion time

- **CPU parallelism**
  - Multiple CPUs (such as SMP)
  - Processes running in parallel
  - Speedup
Parallelism

- Parallelism is common in real life
  - A single sales person sells $1M annually
  - Hire 100 sales people to generate $100M revenue

- Speedup
  - Ideal speedup is factor of N
  - Reality: bottlenecks + coordination overhead reduce speedup

- Questions
  - Can you speed up by working with a partner?
  - Can you speed up by working with 20 partners?
  - Can you get super-linear (more than a factor of N) speedup?
Simplest Process

- Sequential execution
  - No concurrency inside a process
  - Everything happens sequentially
  - Some coordination may be required

- Process state
  - Registers
  - Main memory
  - I/O devices
    - File system
    - Communication ports
  - …
Program and Process

main()
{
  ...
  foo()
  ...
}

bar()
{
  ...
}

Program

main()
{
  ...
  foo()
  ...
}

bar()
{
  ...
}

Process

heap

stack

registers

PC
Process vs. Program

- **Process > program**
  - Program is just the code; just part of process state
  - Example: many users can run the same program

- **Process < program**
  - A program can invoke more than one process
  - Example: Fork off processes
  - Many processes can be running the same program
Managing Processes: Process Control Block (PCB)

- Process management info
  - Identification
  - State
    - Ready: ready to run.
    - Running: currently running.
    - Blocked: waiting for resources
  - Registers, EFLAGS, EIP, and other CPU state
  - Stack, code and data segment
  - Parents, etc

- Memory management info
  - Segments, page table, stats, etc

- I/O and file management
  - Communication ports, directories, file descriptors, etc.

- Resource allocation and accounting information
API for Process Management

- Creation and termination
  - Exec, Fork, Wait, Kill

- Signals
  - Action, Return, Handler

- Operations
  - Block, Yield

- Synchronization
  - We will talk about this a lot more later
Create A Process

- **Creation**
  - Load code and data into memory
  - Create an empty call stack
  - Initialize state
  - Make the process ready to run

- **Cloning a process**
  - Save state of current process
  - Make copy of current code, data, stack and OS state
  - Make the process ready to run
Unix Example

- Methods to make processes:
  - fork clones a process
  - exec overlays the current process

```c
pid = fork();
if (pid == 0)
    /* child process */
    exec("foo"); // does not return
Else
    /* parent */
    wait(pid);    // wait for child to die */
```
Fork and Exec in Unix

```c
pid = fork();
if (pid == 0)
    exec("foo");
else
    wait(pid);

Main()
{
    ...
}

pid = fork();
if (pid == 0)
    exec("foo");
else
    wait(pid);

foo:
    pid = fork();
    if (pid == 0)
        exec("foo");
    else
        wait(pid);
    ...
```

Wait
More on Fork

- Parent process has a PCB and an address space
- Create and initialize PCB
- Create an address space
- Copy the content of the parent address space to the new address space
- Inherit the execution context of the parent

New process is ready
Process Context Switch

- Save a context (everything that a process may damage)
  - All registers (general purpose and floating point)
  - All co-processor state
  - Save all memory to disk?
  - What about cache and TLB?

- Start a context
  - Does the reverse

- Challenge
  - OS code must save state without changing any state
  - E.g. how should OS run without touching any registers?
    - CISC machines have a special instruction to save and restore all registers on stack
    - RISC: reserve registers for kernel or have way to carefully save one and then continue
(Reduced) Process State Transition

- **Running**
  - Scheduler dispatch
  - Wait for resource
  - Create
  - Terminate

- **Ready**
  - Resource becomes available

- **Blocked**
Threads

- Thread
  - A sequential execution stream within a process (also called lightweight process)
  - Threads in a process share the same address space

- Thread concurrency
  - Easier to program overlapping I/O and CPU with threads than with signals
  - Human being likes to do several things at a time
  - A server (e.g. file server) serves multiple requests
  - Multiple CPUs sharing the same memory
Thread Control Block (TCB)

- **State**
  - Ready: ready to run
  - Running: currently running
  - Blocked: waiting for resources

- **Registers**
- **Status (EFLAGS)**
- **Program counter (EIP)**
- **Stack**
- **Code**
Typical Thread API

- **Creation**
  - Fork, Join

- **Mutual exclusion**
  - Acquire (lock), Release (unlock)

- **Condition variables**
  - Wait, Signal, Broadcast

- **Alert**
  - Alert, AlertWait, TestAlert
Revisit Process

- Process
  - Threads
  - Address space
  - Environment for the threads to run on OS (open files, etc)

- Simplest process has 1 thread
Thread Context Switch

- Save a context (everything that a thread may damage)
  - All registers (general purpose and floating point)
  - All co-processor state
  - Need to save stack?
  - What about cache and TLB?

- Start a context
  - Does the reverse

- May trigger a process context switch
Procedure Call

- Caller or callee save some context (same stack)
- Caller saved example:

```plaintext
save active caller registers
call foo

foo() {
    do stuff
}
restore caller regs
```
Threads vs. Procedures

- Threads may resume out of order
  - Cannot use LIFO stack to save state
  - Each thread has its own stack

- Threads switch less often
  - Do not partition registers
  - Each thread “has” its own CPU

- Threads can be asynchronous
  - Procedure call can use compiler to save state synchronously
  - Threads can run asynchronously

- Multiple threads
  - Multiple threads can run on multiple CPUs in parallel
  - Procedure calls are sequential
Process vs. Threads

- **Address space**
  - Processes do not usually share memory (address space)
  - Process context switch page table and other memory mechanisms
  - Threads in a process share the entire address space

- **Privileges**
  - Processes have their own privileges (file accesses, e.g.)
  - Threads in a process share all privileges

- **Question**
  - Do you really want to share the “entire” address space?
Real Operating Systems

- One or many address spaces
- One or many threads per address space

<table>
<thead>
<tr>
<th>Address Space Type</th>
<th>One Address Space</th>
<th>Many Address Spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 thread per address space</td>
<td>MSDOS, Macintosh</td>
<td>Traditional Unix</td>
</tr>
<tr>
<td>Many threads per address spaces</td>
<td>Embedded OS, Pilot</td>
<td>VMS, Mach (OS-X), OS/2, Windows NT/XP/Vista/7, Solaris, HP-UX, Linux</td>
</tr>
</tbody>
</table>
Summary

- Concurrency
  - CPU and I/O
  - Among applications
  - Within an application

- Processes
  - Abstraction for application concurrency

- Threads
  - Abstraction for concurrency within an application