Lecture - III

Processes

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Roadmap

• Processes
  - Basic Concepts
  - Process Creation
  - Process Termination
  - Context Switching
  - Process Queues
  - Process Scheduling
  - Interprocess Communication
Process Concept

- A process is a program in execution.

A process image consists of three components:

1. an executable program
2. the associated data needed by the program
3. the execution context of the process, which contains all information the O/S needs to manage the process (ID, state, CPU registers, stack, etc.)

The Process Control Block (PCB)

- is included in the context, along with the stack
- is a “snapshot” that contains all necessary and sufficient data to restart a process where it left off (ID, state, CPU registers, etc.)
- is one entry in the operating system’s process table (array or linked list)
Process Control Block

Example of process and PCB location in memory

Illustrative contents of a process image in (virtual) memory

<table>
<thead>
<tr>
<th>O/S</th>
<th>context</th>
<th>process control block (PCB)</th>
<th>identification</th>
<th>CPU state info</th>
<th>control info</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>data</td>
<td>stack</td>
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</table>

- numeric identifier
- parent identifier
- user identifier
- etc.
- user-visible registers
- control & status registers
- program counter
- stack pointers, etc.
- schedulg & state info
- links to other proc’s
- memory limits
- open files
- etc.

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 processor
  - running: Instructions are being executed
  - waiting: The process is waiting for some event to occur
  - terminated: The process has finished execution
Process Creation

- Some events that lead to process creation (enter)
  - the system boots
    - when a system is initialized, several background processes or “daemons” are started (email, logon, etc.)
  - a user requests to run an application
    - by typing a command in the CLI shell or double-clicking in the GUI shell, the user can launch a new process
  - an existing process spawns a child process
    - for example, a server process (i.e. web server, file server) may create a new process for each request it handles
    - the `init` daemon waits for user login and spawns a shell
  - a batch system takes on the next job in line

Process Creation

- Process creation by spawning

A tree of processes on a typical UNIX system
int main(...) {
  ...
  if ((pid = fork()) == 0) { // create a process
    printf(stdout, "Child pid: %i\n", getpid());
    err = execvp(command, arguments); // execute child
    printf(stderr, "Child error: %i\n", errno);
    exit(err);
  } else if (pid > 0) { // we are in the parent process
    printf(stdout, "Parent pid: %i\n", getpid());
    pid2 = waitpid(pid, &status, 0); // wait for child
    ...
  }
  ...
  return 0;
}
# Fork Example 1

```c
#include <stdio.h>

main()
{
    int ret_from_fork, mypid;

    mypid = getpid();    /* who am i? */
    printf("Before: my pid is %d\n", mypid);    /* tell pid */

    ret_from_fork = fork();

    sleep(1);
    printf("After: my fork returns pid : %d, said %d\n",
           ret_from_fork, getpid());
}
```

# Fork Example 2

```c
#include <stdio.h>

main()
{
    fork();
    fork();
    fork();
    printf("my pid is %d\n", getpid());
}
```

How many lines of output will this produce?
Process Termination

- **Some events that lead to process termination (exit)**
  - regular completion, with or without error code
  - the process voluntarily executes an `exit(err)` system call to indicate to the O/S that it has finished
  - fatal error (uncatchable or uncaught)
    - service errors: no memory left for allocation, I/O error, etc.
    - total time limit exceeded
    - arithmetic error, out-of-bounds memory access, etc.
  - killed by another process via the kernel
    - the process receives a `SIGKILL` signal
    - in some systems the parent takes down its children with it

Process Pause/Dispatch

- **Some events that lead to process pause / dispatch**
  - I/O wait
    - a process invokes an I/O system call that blocks waiting for the I/O device: the O/S puts the process in “Waiting” mode and dispatches another process to the CPU
  - preemptive timeout
    - the process receives a timer interrupt and relinquishes control back to the O/S dispatcher: the O/S puts the process in “Ready” mode and dispatches another process to the CPU
    - not to be confused with “total time limit exceeded”, which leads to process termination
Process “Context” Switching

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process.
- Context-switch time is overhead; the system does no useful work while switching.
- Switching time is dependent on hardware support.

CPU Switch From Process to Process
Process “Context” Switching

How does a full process switch happen, step by step?
1. save CPU context, including PC and registers (*the only step needed in a simple mode switch*)
2. update process state (to “Ready”, “Blocked”, etc.) and other related fields of the PCB
3. move the PCB to the appropriate queue
4. select another process for execution: this decision is made by the CPU scheduling algorithm of the O/S
5. update the PCB of the selected process (state = “Running”)
6. update memory management structures
7. restore CPU context to the values contained in the new PCB

What events trigger the O/S to switch processes?
- **interrupts** — external, asynchronous events, independent of the currently executed process instructions
  - clock interrupt → O/S checks time and may block process
  - I/O interrupt → data has come, O/S may unblock process
  - memory fault → O/S may block process that must wait for a missing page in memory to be swapped in

- **exceptions** — internal, synchronous (but involuntary) events caused by instructions → O/S may terminate or recover process

- **system calls** — voluntary synchronous events calling a specific O/S service → after service completed, O/S may either resume or block the calling process, depending on I/O, priorities, etc.
Process Scheduling Queues

- **Job queue** - set of all jobs in the system
- **Ready queue** - set of all processes residing in main memory, ready and waiting to execute
- **Device queues** - set of processes waiting for an I/O device
- Processes migrate among the various queues

Process Queues

- **The process table can be split into per-state queues**
  - PCBs can be linked together if they contain a pointer field

![Structure of process lists or queues](image)
Ready Queue And Various I/O Device Queues

Representation of Process Scheduling
Three-level CPU Scheduling

- **Long-term scheduler** (or job scheduler) - selects which processes should be brought into the ready queue
- **Short-term scheduler** (or CPU scheduler) - selects which process should be executed next and allocates CPU
Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) ⇒ (must be fast)
- Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow)
- The long-term scheduler controls the *degree of multiprogramming*
- Processes can be described as either:
  - *I/O-bound process* - spends more time doing I/O than computations, many short CPU bursts
  - *CPU-bound process* - spends more time doing computations; few very long CPU bursts
  ➔ *long-term schedulers need to make careful decision*

Addition of Medium Term Scheduling

- In time-sharing systems: remove processes from memory “temporarily” to reduce degree of multiprogramming.
- Later, these processes are resumed ➔ *Swapping*
Cooperating Processes

- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience
- Disadvantage
  - Synchronization issues and race conditions

Interprocess Communication (IPC)

- **Mechanism** for processes to communicate and to synchronize their actions
- **Shared Memory**: by using the same address space and shared variables
- **Message Passing**: processes communicate with each other without resorting to shared variables
Communications Models

Message Passing

- Message Passing facility provides two operations:
  - `send(message)` - message size fixed or variable
  - `receive(message)`

- If $P$ and $Q$ wish to communicate, they need to:
  - establish a *communication link* between them
  - exchange messages via send/receive

- Two types of Message Passing
  - direct communication
  - indirect communication
**Message Passing - direct communication**

- Processes must name each other explicitly:
  - `send (P, message)` - send a message to process P
  - `receive(Q, message)` - receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional
- Symmetrical vs Asymmetrical direct communication
  - `send (P, message)` - send a message to process P
  - `receive(id, message)` - receive a message from any process
- Disadvantage of both: limited modularity, hardcoded

**Message Passing - indirect communication**

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox
- Primitives are defined as:
  - `send(A, message)` - send a message to mailbox A
  - `receive(A, message)` - receive a message from mailbox A
Indirect Communication (cont.)

- **Operations**
  - create a new mailbox
  - send and receive messages through mailbox
  - destroy a mailbox

- **Properties of communication link**
  - Link established only if processes share a common mailbox
  - A link may be associated with many processes
  - Each pair of processes may share several communication links
  - Link may be unidirectional or bi-directional

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Indirect Communication (cont.)

- **Mailbox sharing**
  - $P_1$, $P_2$, and $P_3$ share mailbox $A$
  - $P_1$, sends; $P_2$ and $P_3$ receive
  - Who gets the message?

- **Solutions**
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.
Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
  - **Blocking send** has the sender block until the message is received
  - **Blocking receive** has the receiver block until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking send** has the sender send the message and continue
  - **Non-blocking receive** has the receiver receive a valid message or null

Buffering

- Queue of messages attached to the link; implemented in one of three ways
  1. Zero capacity - 0 messages
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity - finite length of $n$ messages
     Sender must wait if link full
  3. Unbounded capacity - infinite length
     Sender never waits
Summary

• Processes
  - Basic Concepts
  - Process Creation
  - Process Termination
  - Context Switching
  - Process Queues
  - Process Scheduling
  - Interprocess Communication

• Next Lecture: Threads
• Reading Assignment: Chapter 3 from Silberschatz.
• HW 1 will be out next class, due 1 week

Acknowledgements

• “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne

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