Silberschatz and Galvin

Chapter 4

Processes

Chapter overview

- Introduction to processes, process control blocks
- Introduction to process scheduling
- Operations on processes
- Cooperating processes; threads; interprocess communication

Processes: Review of Terminology

- **Multiprogramming**: several users share system at same time
  - batched: keep CPU busy by switching in other work when idle (e.g., waiting for I/O)
- Multitasking (timesharing): frequent switches to permit interactive use (extension of multiprogramming)
- **Multiprocessing**: several processors are used on a single system

Multiprocessing

- Multiprocessor systems: multiple CPUs, generally MIMD
  - Symmetric: identical copy of OS; communicate as necessary
    - Tightly coupled: share main memory
    - Loosely coupled: connected via communications links
  - Asymmetric: each processor has specific task
    - e.g., master/slave, channels, etc.

Terminology

- Opposite terms
  - multiprogramming and uniprogramming
  - multiprocessor and uniprocessor
- Orthogonal terms
  - multiprogramming and multiprocessor

Process

- **Process**: (Sequential) process is a program in execution. Sequential because at any time at most one instruction is in execution for a process.
- **Program**: passive entity. Static. Code.
- Process: active entity. Dynamic.
- Program and sequential process similar but not identical since one program can require multiple processes.

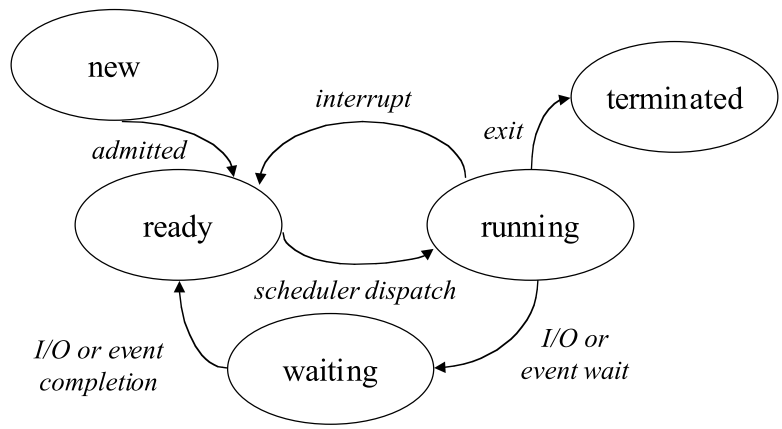
Sequential Process Characteristics

- Sequential
- Formed from running code plus environment
- Environment encoded in
  - Program counter
  - Process stack
  - Global data section
- Execution stream
  - Sequence of instructions performed by a process+environment

Process States

- **New**: the process is being created
- **Running**: instructions are being executed
- **Waiting**: the process is waiting for some event to occur (*such as?*). Sometimes called **blocked**.
- **Ready**: Waiting to be assigned to a processor.
- **Terminated**: Finished execution

Process State Diagram



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Notes on Process States

- In uniprocessor, at most one process can be running.
- Many can be ready or waiting (or new or terminated).
- (Short term) **scheduler** (also called **dispatcher**) figures out which process is to be moved from ready to running states.
- Timer can cause process to move from running to ready states when time slice (quantum) expires.
- Process requests transfer from running to waiting by for example invoking I/O system call. Remaining transitions are OS-invoked. Wakeup occurs when request is satisfied (transfer from waiting to ready queues).

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Process Control Block (PCB)

- Information associated with each process
  - **Process state**
  - **Program counter**: next instruction to be executed
  - **CPU registers**: accumulators, index registers, stack pointers, general purpose registers, condition codes
  - **CPU scheduling information**: priorities, queue pointers, etc.
  - **Memory-management information**: base and limit registers, page/segment tables
  - **Accounting information**: resources used, account numbers, etc.
  - **I/O status information**: allocated devices, open files, etc.
  - Other information: process id, parent's id, configuration info., etc.

Process Control Block

- Process Control Block (PCB) also called "process descriptor" or "task control block"
- "Record" that serves as repository for descriptive information varying from process to process.
- Represents process to Operating System
- One implementation: entry in linked list where the list is associated with a particular queue (e.g., ready, running, devices, etc.)
- As process moves from queue to queue this is represented by moving the PCB from list to list

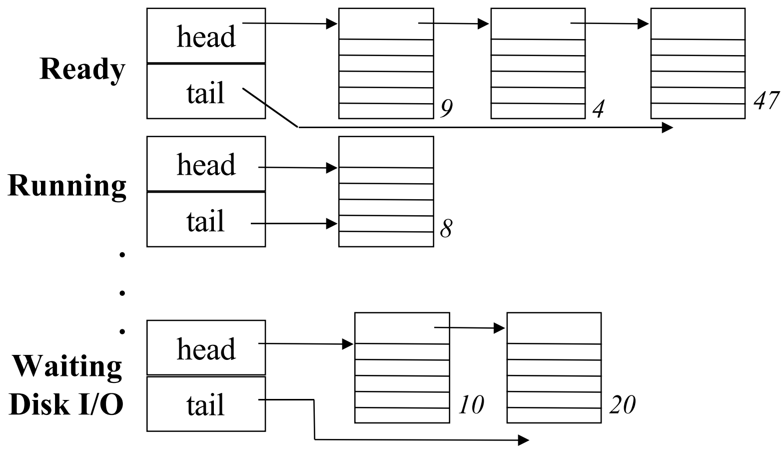
PCB Contents (examples of possible fields)

- Process unique identifier
- current state of process
- pointer to process' parent
- space to save needed values like program counter, CPU registers, current addressing mode (user/supervisor) when process is swapped
- CPU scheduling information (e.g., priority, scheduler data structures)
- memory management information (e.g., limit registers, page tables)
- pointers to allocated resources. I/O status information (e.g., devices, list of open files)
- accounting information (CPU time used, wall clock time used, time limits, account numbers, etc.)
- Configuration information (e.g., processor process is running on, etc.)

Process scheduling queues

- Job queue--set of all processes 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

PCBs and Queues



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Process Scheduling

- How is process state implemented?
  - PCB moves between queues
    - State: new — Queue: job queue
    - State: ready — Queue: ready queue
    - State: waiting — Queues: device queues
      waiting for process termination
- How do processes move from state to state?
  - Schedulers
    - Part of the OS
    - implement a *scheduling strategy* (a *policy*)

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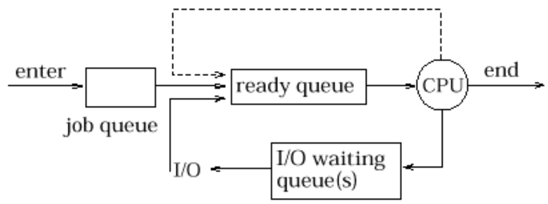
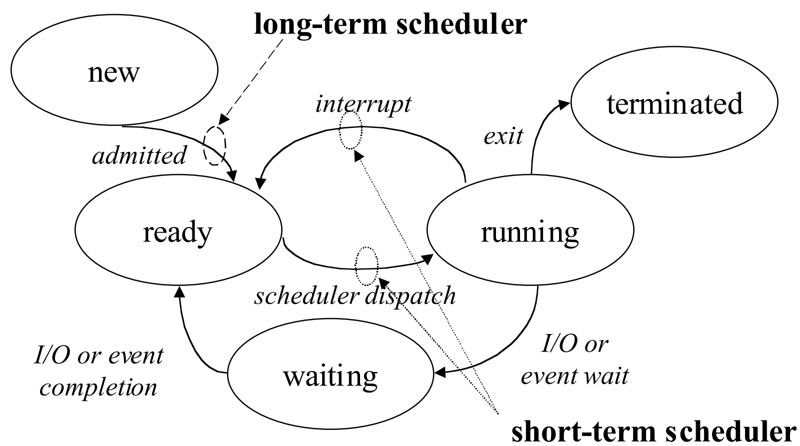
Queuing diagram representation of process scheduling



Process Scheduling

- **Long-term scheduler** (*job scheduler*): selects processes from the pool of available processes and loads them into memory for execution
  - Which jobs should be allowed to compete actively for the resources of the system?
- **Short-term scheduler** (*CPU scheduler*): selects from among the ready processes and allocates the CPU to one of them
  - Which ready process should be assigned to the CPU?

Process State Diagram



Process Scheduling

- Short-term scheduler
  - may be executed frequently (every 100 milliseconds or so)
  - must be very fast
- Long-term scheduler
  - executes infrequently (perhaps minutes between executions)
  - can afford to take longer to make decisions
  - can take characteristics of process into account (I/O bound or CPU bound)
  - Goal: to obtain a good *process mix* of I/O and CPU bound processes
  - controls degree of multiprogramming
- **Degree of multiprogramming**: number of processes in memory

Possible Scheduling Objectives

- Fairness
- CPU efficiency
- Response time
- Predictability
- Turnaround
- Throughput
- Degrade gracefully
- Minimize overhead

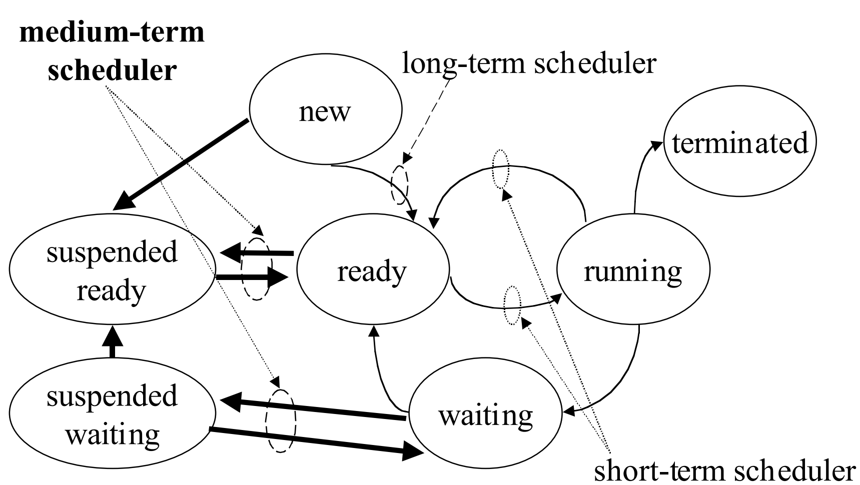
Context Switch

- Context switch: required to move a process from or to "running" state
  - save state of old process
  - load saved state for new process
  - 1 to 1000 microseconds typically
  - time depends highly on degree of hardware support
- Expensive; scheduler must be designed taking cost into consideration

Process Scheduling

- **Medium-term scheduler**: Which processes should be allowed to compete for CPU (given that the other resources they need are available)
  - Swapping (swap in and out): remove processes from memory and active contention for CPU. (Later restore them to memory and permit execution to proceed.)

Process State Diagram



Operating System Process Management Functions

- Process management provides services for
  - process creation and termination
  - process suspension and resumption
  - process synchronization
  - process communication
  - CPU scheduling

Process creation

- Parent process creates child processes; forms tree of processes
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources

Process creation

- Execution options
  - Concurrent execution
  - Parent waits until children terminate
- Address space options
  - Child is duplicate of parent
  - Child has separate program loaded into it

Steps in Process Creation

- Load code and data into memory
- Create (empty) call stack
- Create (or assign) and initialize PCB
- Make process known to dispatcher
  - Dispatcher: portion of the OS that manages the running of processes. Responsible for deciding which process to run, when to start another, etc.

Steps in Process Creation Second Approach (fork)

- Make sure current process is not running
- Update information in PCB if necessary
- Make *copy* of existing process. Do not copy pid, ppid, locks, pending interrupts, etc.). Do copy code, data, stack.
- Copy PCB of source into new process
- Make process known to dispatcher

UNIX fork() Distinguishing Parent and Child

```
if(childpid=fork()) {
   /* this is the parent (fork returned child's PID
   which is nonzero or "true" */
}
else {
   /* this is the child (fork returned 0, which
   is "false" */
}
```

Unix fork() example

```
#include <stdio.h>
main()
{
   int pid;  char ch;  int i, j;
   pid = fork();
   if(pid) ch = 'a'; else ch = 'b';
   for(i=1;i<=25;i++)  {
        fputc(ch,stdout); fflush(stdout);
        for(j=1;j<100000;j++)  ;
   }
   if(pid)  {
        wait();
        fputc('\n', stdout);
   }
}
```


Unix fork() example

```
bbbabbaabbbaaabaabbaabbabbbaaabbaabbbaaabaaabbaaba
bbbbbbbaaaaaaabbbabaaabbbaabbbabbaabbaaabababaaaba
bbaaaaaaaaaaaaaabbbbbbbbbbaaabbbabbbaabbaabaaabbbb
aaaaaaaaaaaaaabbbbbbabbbaababab bbaaabbbaaabbbbbbbb
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bbbbbaaaabbaaabbbaabbbaaabaabaabbbabbaabbaaabbaaba
bbbbbbbbaaaaaabbbaabbaaabaaabbababbaaabbaabbbaaaba
```

Process Creation via fork() Some Options

- parent and child execute concurrently (as in example)
- parent waits for all children to terminate via `wait()`
- child executes copy of parent's code (as in example)
- child loads a new program and runs it via, e.g., `execve(path,argv,envp)`
- In some other systems (VMS, e.g.) the OS creates new process, loads specified program into process, and starts it running instead of the user program doing this. Unix `system()` call simulates this.

Process Termination

- Process termination via own volition or as a result of system call from parent or root (e.g., exception)
  - Examples of exceptions?
  - What does parent need to know to accomplish this?
- Process may return information to parent on termination
- Deallocate process resources (physical and virtual memory, open files, I/O buffers, etc.). Who gets them?
- Cascading termination
- Orphan processes
- Zombie processes

Waiting Processes

- When process transfers from “running” state, information about it must be saved
- Save anything process might need to reuse (that might be damaged by another process)
  - Program counter
  - Processor status word (PSW)
  - Registers
- Must take care not to damage information in the process of saving it
- How about memory?

Waiting Processes

- Memory alternatives (three of many possible)
  - Trust the next process
  - World swap (move everything to disk)
  - Rely on memory protection to make sure that the other processes use different segments
- How expensive is the job of saving PCB and memory information?

Independent Processes

- **Independent process**: cannot affect or be affected by the other processes executing in the system
  - – no shared state with other processes
  - – execution is deterministic
    - depends only on input state
    - reproducible; given same input get same results
    - hence execution can be stopped and restarted without ill effects

Cooperating Processes

- **Cooperating processes**: processes can affect or be affected by other processes executing in system
  - – state shared among other processes
  - – result of execution cannot be predicted in advance because it depends on relative execution sequence
  - – result of execution in nondeterministic. can vary with same input!

Why have Cooperating Processes?

- Information sharing (concurrent access)
- Computational speedup (parallel subtasks)
- Modularity (organizational reasons)
- Convenience (multitasking the individual)
- *Supporting cooperating processes requires Operating Systems synchronization and communication mechanisms*

Producer-Consumer problem

- Paradigm for cooperating processes
  - *Producer* process produces information that is consumed by a *consumer* process
- Variants
  - Unbounded buffer: places no practical limit on size of buffer
  - Bounded buffer: assumes there is a fixed buffer size

Bounded buffer/Shared memory

- Shared data

var *n*;

type *item* = …;

var *buffer*: **array** [0..*n*-1] **of** *item*;

in, *out*: 0..*n*-1;

Bounded buffer/Shared memory

- Producer process

repeat

---produce an item in *nextp*

while *in*+1 **mod** *n* = *out* **do** *no-op;*

buffer[*in*] := *nextp;*

in := *in*+1 **mod** *n;*

until *false;*

Bounded buffer/Shared memory

- Consumer process

  repeat

  > **while** *in* = *out* **do** *no-op*;
  >
  > nextc := *buffer*[*out*];
  >
  > *out* := *out* + 1 **mod** *n;*
  >
  > ---consume the item in *nextc*

  until *false*;

Note that this solution only can fill up n-1 buffers

Threads

- Traditional processes
  - operate independently of other processes
  - significant overhead in creation
  - significant overhead in switching
  - hence called "heavyweight processes"
- Wish to make it easy to share and access resources concurrently
- Wish to reduce overhead in "process" creation and in switching among processes

Threads

- Thread (also called a *lightweight process*, or *LWP*)
  - Has own
    - program counter
    - register set
    - stack space
  - Shares with peer threads
    - code section
    - data section
    - operating-system resources (open files, signals)
  - **Task**: name for the collective

Lightweight vs Heavyweight Processes

- Switching between threads is inexpensive due to the extensive sharing
  - Requires register set switch but no memory management
- Heavyweight process==task with only one thread
- LWP can be implemented at user level (*user-level threads*), at kernel level, or both.
- User-level threads fast because no OS involvement
  - but scheduling can be unfair because OS doesn't know about multiple threads
  - entire process may have to wait if kernel not multi-threaded

Thread Scheduling

- States: ready, blocked, running, terminated
- Share CPU, only one thread at a time is running
- Thread executes sequentially
- Thread has own stack and PC
- Thread can create child threads
- If one thread blocked for system call, another can run
- Threads not independent because can access any address in task. No protection between threads because they are assumed to be cooperating, not hostile (as with traditional processes).
- Process synchronization mechanisms still required

Example applications

- Producer-consumer (shared buffer)
- Shared file system (block waiting for disk)
  - if threaded can continue onward acquiring work rather than having CPU idle
- Kernel operations--without threads only one task can be executing code in kernel at a time

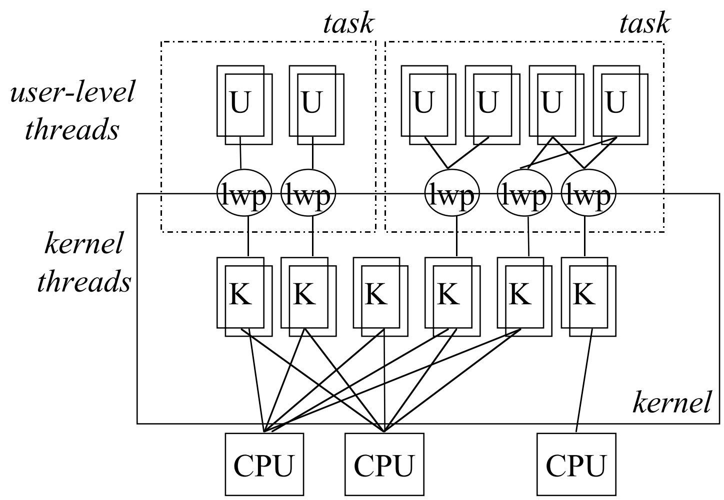
Threads in Solaris 2

- Solaris 2 thread categories
  - User-level threads (kernel has no knowledge of these)
  - Lightweight processes (LWP)
    - One or more user-level threads associated with a LWP
    - User-level thread cannot accomplish work if not connected to LWP
    - Others either are blocked or waiting for a LWP
  - Kernel-level threads
    - Exactly one kernel-level thread associated with each LWP
    - Other kernel-level threads as well for other kernel functions
    - On request, kernel-level thread can be *pinned* to a specific processor (only that thread runs on processor and the processor is allocated to that thread)

Threads in Solaris 2

- **Task** (Solaris 2 *process*): consists of at least one LWP and associated threads
- Tasks, user-level threads, LWP manipulated by the thread library
- Kernel-level threads scheduled by kernel's scheduler
- CPU free to run something else when kernel-level thread blocks

Threads in Solaris 2



Solaris 2 Threads

- Kernel thread: small data structure and stack. Switching is fast (no memory access information needs to change)
- LWP: PCB, register data, accounting information, memory information. Switching requires a fair amount of work and is slow
- User-level thread: stack and PC, no kernel resources. Switching among them is fast since kernel not involved. May be thousands of user-level threads but kernel only sees the LWP supporting them.

Interprocess Communication (IPC)

- Communication between two processes without resorting to shared variables
- Operations
  – Send(message)
  – Receive(message)
- Implementation issues include how links are established, whether more than two can participate, capacity of links, size limits on messages, link direction unidirectional or bidirectional

Why use messages?

- many applications fit sequential flow of information model naturally
- keeps processes totally separate except for messages
  – less error prone implementation
    - no invisible side effects
    - processes can't mess with each others' memory (also added security)
    - permits separation of implementation and enforcement of well-defined interfaces
  – separation especially appropriate when proceses cannot "trust" each other (e.g., OS and user process)
  – permits distribution of processes, even across different kinds of processors on a network

IPC can be direct or indirect

- Direct: processes explicitly name each other
  - Send(P, message)
  - Receive(Q, message)
- Indirect: communication through intermediary of mailbox

Direct Communication Producer/Consumer example

- Producer

```
while(true) {
        produce data in nextp
        send(consumer, nextp);

}
```

- Consumer

```
while(true) {

        receive(producer, nextc);
        consume data in nextc
}
```

Indirect Communication

- Messages are sent to and received from mailboxes (ports)
  - send(A, message): deposit a message into mailbox A
  - receive(A, message): extract a message from mailbox A
- Each mailbox has an unique id
- Two processes can communicate only if they have a shared mailbox
- A mailbox may be owned by a process or by the system

IPC Buffering

- Queue of messages attached to a link
  - Zero capacity: queue is of maximum length 0. Sender must wait for receiver (*rendezvous*)
  - Bounded capacity: finite length of *n* messages. Sender must wait if link full
  - Unbounded capacity: infinite length. Sender never waits
- Variants: sender never waits but message lost if receiver doesn't process it before another is sent.
- Sender delays until receives a reply (synchronous)

IPC exception conditions

- Sender or receiver terminates before message is processed
- Message lost. Options include
  - OS detects and resends message
  - Sender detects and resends
  - OS detects, notifies sender; sender takes appropriate action
- Scrambled messages

Remote Procedure Calls (RPC)

- High-level concept for process communication
- Programmer's view is the same as for regular procedure calls
- Each RPC is implemented as a pair of synchronous send and receive statements
  - first pair transmits (and acknowledges) input parameters
  - second pair acquires (and acknowledges) corresponding results
- Another view of same process: remote procedure in implementation
  - begins with a receive to acquire actual parameters
  - ends with a send to provide results to caller
- Sun RPC encapsulates these in an event-driven structure
  - Remote procedures are implemented as set of handlers that are executed as called