Table 3.1   Reasons for Process Creation

New batch job	The operating system is provided with a batch job control stream, usually on tape or disk. When the operating system is prepared to take on new work, it will read the next sequence of job control commands.
Interactive logon	A user at a terminal logs on to the system.
Created by OS to provide a service	The operating system can create a process to perform a function on behalf of a user program, without the user having to wait (e.g., a process to control printing).
Spawned by existing process	For purposes of modularity or to exploit parallelism, a user program can dictate the creation of a number of processes.

Table 3.2 Reasons for Process Termination

Normal completion	The process executes an OS service call to indicate that it has completed running.
Time limit exceeded	The process has run longer than the specified total time limit. There are a number of possibilities for the type of time that is measured. These include total elapsed time ("wall clock time"), amount of time spent executing, and, in the case of an interactive process, the amount of time since the user last provided any input.
Memory unavailable	The process requires more memory than the system can provide.
Bounds violation	The process tries to access a memory location that it is not allowed to access.
Protection error	The process attempts to use a resource or a file that it is not allowed to use, or it tries to use it in an improper fashion, such as writing to a read-only file.
Arithmetic error	The process tries a prohibited computation, such as division by zero, or tries to store numbers larger than the hardware can accommodate.
Time overrun	The process has waited longer than a specified maximum for a certain event to occur.
I/O failure	An error occurs during input or output, such as inability to find a file, failure to read or write after a specified maximum number of tries (when, for example, a defective area is encountered on a tape), or invalid operation (such as reading from the line printer).
Invalid instruction	The process attempts to execute a nonexistent instruction (often a result of branching into a data area and attempting to execute the data).
Privileged instruction	The process attempts to use an instruction reserved for the operating system.
Data misuse	A piece of data is of the wrong type or is not initialized.
Operator or OS intervention	For some reason, the operator or the operating system has terminated the process (for example, if a deadlock exists).
Parent termination	When a parent terminates, the operating system may automatically terminate all of the offspring of that parent.
Parent request	A parent process typically has the authority to terminate any of its offspring.

Table 3.3 Reasons for Process Suspension

Swapping	The operating system needs to release sufficient main memory to bring in a process that is ready to execute.
Other OS reason	The operating system may suspend a background or utility process or a process that is suspected of causing a problem.
Interactive user request	A user may wish to suspend execution of a program for purposes of debugging or in connection with the use of a resource.
Timing	A process may be executed periodically (e.g., an accounting or system monitoring process) and may be suspended while waiting for the next time interval.
Parent process request	A parent process may wish to suspend execution of a descendent to examine or modify the suspended process, or to coordinate the activity of various descendents.

Table 3.4 Typical Elements of a Process Image

User Data

The modifiable part of the user space. May include program data, a user stack area, and programs that may be modified.

User Program

The program to be executed.

System Stack

Each process has one or more last-in-first-out (LIFO) system stacks associated with it. A stack is used to store parameters and calling addresses for procedure and system calls.

Process Control Block

Data needed by the operating system to control the process (see Table 3.6).

Table 3.5   Typical Elements of a Process Control Block (page 1 of 2)

Process Identification

Identifiers

Numeric identifiers that may be stored with the process control block include

- Identifier of this process
- Identifier of the process that created this process (parent process)
- User identifier

Processor State Information

User-Visible Registers

A user-visible register is one that may be referenced by means of the machine language that the processor executes. Typically, there are from 8 to 32 of these registers, although some RISC implementations have over 100.

Control and Status Registers

These are a variety of processor registers that are employed to control the operation of the processor. These include

- *Program counter:* Contains the address of the next instruction to be fetched
- *Condition codes:* Result of the most recent arithmetic or logical operation (e.g., sign, zero, carry, equal, overflow)
- *Status information:* Includes interrupt enabled/disabled flags, execution mode

Stack Pointers

Each process has one or more last-in-first-out (LIFO) system stacks associated with it. A stack is used to store parameters and calling addresses for procedure and system calls. The stack pointer points to the top of the stack.

Table 3.5 Typical Elements of a Process Control Block (page 2 of 2)

Process Control Information
Scheduling and State Information This is information that is needed by the operating system to perform its scheduling function. Typical items of information: •*Process state:* defines the readiness of the process to be scheduled for execution (e.g., running, ready, waiting, halted). •*Priority:* One or more fields may be used to describe the scheduling priority of the process. In some systems, several values are required (e.g., default, current, highest-allowable) •*Scheduling-related information:* This will depend on the scheduling algorithm used. Examples are the amount of time that the process has been waiting and the amount of time that the process executed the last time it was running. •*Event:* Identity of event the process is awaiting before it can be resumed.
Data Structuring A process may be linked to other process in a queue, ring, or some other structure. For example, all processes in a waiting state for a particular priority level may be linked in a queue. A process may exhibit a parent-child (creator-created) relationship with another process. The process control block may contain pointers to other processes to support these structures.
Interprocess Communication Various flags, signals, and messages may be associated with communication between two independent processes. Some or all of this information may be maintained in the process control block.
Process Privileges Processes are granted privileges in terms of the memory that may be accessed and the types of instructions that may be executed. In addition, privileges may apply to the use of system utilities and services.
Memory Management This section may include pointers to segment and/or page tables that describe the virtual memory assigned to this process.
Resource Ownership and Utilization Resources controlled by the process may be indicated, such as opened files. A history of utilization of the processor or other resources may also be included; this information may be needed by the scheduler.

Table 3.7 Typical Functions of an Operating System Kernel

Process Management

•Process creation and termination
•Process scheduling and dispatching
•Process switching
•Process synchronization and support for interprocess communication
•Management of process control blocks

Memory Management

•Allocation of address space to processes
•Swapping
•Page and segment management

I/O Management

•Buffer management
•Allocation of I/O channels and devices to processes

Support Functions

•Interrupt handling
•Accounting
•Monitoring

Table 3.8 Mechanisms for Interrupting the Execution of a Process

Mechanism	Cause	Use
Interrupt	External to the execution of the current instruction	Reaction to an asynchronous external event
Trap	Associated with the execution of the current instruction	Handling of an error or an exception condition
Supervisor call	Explicit request	Call to an operating system function

Table 3.9 UNIX Process States

User Running	Executing in user mode.
Kernel Running	Executing in kernel mode.
Ready to Run, in Memory	Ready to run as soon as the kernel schedules it.
Asleep in Memory	Unable to execute until an event occurs; process is in main memory (a blocked state).
Ready to Run, Swapped	Process is ready to run, but the swapper must swap the process into main memory before the kernel can schedule it to execute.
Sleeping, Swapped	The process is awaiting an event and has been swapped to secondary storage (a blocked state).
Preempted	Process is returning from kernel to user mode, but the kernel preempts it and does a process switch to schedule another process.
Created	Process is newly created and not yet ready to run.
Zombie	Process no longer exists, but it leaves a record for its parent process to collect.

Table 3.10 UNIX Process Image

	User-Level Context
Process Text	Executable machine instructions of the program
Process Data	Data accessible by the program of this process
User Stack	Contains the arguments, local variables, and pointers for functions executing in user mode
Shared Memory	Memory shared with other processes, used for interprocess communication
	Register Context
Program Counter	Address of next instruction to be executed; may be in kernel or user memory space of this process
Processor Status Register	Contains the hardware status at the time of preemption; contents and format are hardware dependent
Stack Pointer	Points to the top of the kernel or user stack, depending on the mode of operation at the time or preemption
General-Purpose Registers	Hardware dependent
	System-Level Context
Process Table Entry	Defines state of a process; this information is always accessible to the operating system
U (user) Area	Process control information that needs to be accessed only in the context of the process
Per Process Region Table	Defines the mapping from virtual to physical addresses; also contains a permission field that indicates the type of access allowed the process: read-only, read-write, or read-execute
Kernel Stack	Contains the stack frame of kernel procedures as the process executes in kernel mode

Table 3.11 UNIX Process Table Entry

Process Status	Current state of process.
Pointers	To U area and process memory area (text, data, stack).
Process Size	Enables the operating system to know how much space to allocate the process.
User Identifiers	The **real user ID** identifies the user who is responsible for the running process. The **effective user ID** may be used by a process to gain temporary privileges associated with a particular program; while that program is being executed as part of the process, the process operates with the effective user ID.
Process Identifiers	ID of this process; ID of parent process. These are set up when the process enters the Created state during the fork system call.
Event Descriptor	Valid when a process is in a sleeping state; when the event occurs, the process is transferred to a ready-to-run state.
Priority	Used for process scheduling.
Signal	Enumerates signals sent to a process but not yet handled.
Timers	Include process execution time, kernel resource utilization, and user-set timer used to send alarm signal to a process.
P_link	Pointer to the next link in the ready queue (valid if process is ready to execute).
Memory Status	Indicates whether process image is in main memory or swapped out. If it is in memory, this field also indicates whether it may be swapped out or is temporarily locked into main memory.

Table 3.12 UNIX U Area

Process Table Pointer	Indicates entry that corresponds to the U area.
User Identifiers	Real and effective user IDs. Used to determine user privileges.
Timers	Record time that the process (and its descendants) spent executing in user mode and in kernel mode.
Signal-Handler Array	For each type of signal defined in the system, indicates how the process will react to receipt of that signal (exit, ignore, execute specified user function).
Control Terminal	Indicates login terminal for this process, if one exists.
Error Field	Records errors encountered during a system call.
Return Value	Contains the result of system calls.
I/O Parameters	Describe the amount of data to transfer, the address of the source (or target) data array in user space, and file offsets for I/O.
File Parameters	Current directory and current root describe the file system environment of the process.
User File Descriptor Table	Records the files the process has open.
Limit Fields	Restrict the size of the process and the size of a file it can write.
Permission Modes Fields	Mask mode settings on files the process creates.

Table 3.13 VAX/VMS Process States

Process State	Process Condition
Currently Executing	Running process.
Computable (resident)	Ready and resident in main memory.
Computable (outswapped)	Ready, but swapped out of main memory.
Page Fault Wait	Process has referenced a page not in main memory and must wait for the page to be read in.
Collided Page Wait	Process has referenced a shared page that is the cause of an existing page fault wait in another process, or a private page that is in the process of being read in or written out.
Common Event Wait	Waiting for shared event flag (event flags are single-bit interprocess signaling mechanisms).
Free Page Wait	Waiting for a free page in main memory to be added to the collection of pages in main memory devoted to this process (the working set of the process).
Hibernate Wait (resident)	Process puts itself in a wait state.
Hibernate Wait (outswapped)	Hibernating process is swapped out of main memory.
Local Event Wait (resident)	Process in main memory and waiting for local event flag (usually I/O completion).
Local Event Wait (outswapped)	Process in local event wait is swapped out of main memory.
Suspended Wait (resident)	Process is put into a wait state by another process.
Suspended Wait (outswapped)	Suspended process is swapped out of main memory.
Resource Wait	Process waiting for miscellaneous system resource.