

## Programming Problems

- 3.19** Using either a UNIX or a Linux system, write a C program that forks a child process that ultimately becomes a zombie process. This zombie process must remain in the system for at least 10 seconds. Process states can be obtained from the command

```
ps -l
```

The process states are shown below the S column; processes with a state of Z are zombies. The process identifier (pid) of the child process is listed in the PID column, and that of the parent is listed in the PPID column.

Perhaps the easiest way to determine that the child process is indeed a zombie is to run the program that you have written in the background (using the &) and then run the command `ps -l` to determine whether the child is a zombie process. Because you do not want too many zombie processes existing in the system, you will need to remove the one that you have created. The easiest way to do that is to terminate the parent process using the `kill` command. For example, if the process id of the parent is 4884, you would enter

```
kill -9 4884
```

- 3.20** An operating system's **pid manager** is responsible for managing process identifiers. When a process is first created, it is assigned a unique pid by the pid manager. The pid is returned to the pid manager when the process completes execution, and the manager may later reassign this pid. Process identifiers are discussed more fully in Section 3.3.1. What is most important here is to recognize that process identifiers must be unique; no two active processes can have the same pid.

Use the following constants to identify the range of possible pid values:

```
#define MIN_PID 300
#define MAX_PID 5000
```

You may use any data structure of your choice to represent the availability of process identifiers. One strategy is to adopt what Linux has done and use a bitmap in which a value of 0 at position *i* indicates that a process id of value *i* is available and a value of 1 indicates that the process id is currently in use.

Implement the following API for obtaining and releasing a pid:

- `int allocate_map(void)`—Creates and initializes a data structure for representing pids; returns—1 if unsuccessful, 1 if successful
- `int allocate_pid(void)`—Allocates and returns a pid; returns—1 if unable to allocate a pid (all pids are in use)
- `void release_pid(int pid)`—Releases a pid

This programming problem will be modified later on in Chapters 4 and 5.

- 3.21** The Collatz conjecture concerns what happens when we take any positive integer  $n$  and apply the following algorithm:

$$n = \begin{cases} n/2, & \text{if } n \text{ is even} \\ 3 \times n + 1, & \text{if } n \text{ is odd} \end{cases}$$

The conjecture states that when this algorithm is continually applied, all positive integers will eventually reach 1. For example, if  $n = 35$ , the sequence is

35, 106, 53, 160, 80, 40, 20, 10, 5, 16, 8, 4, 2, 1

Write a C program using the `fork()` system call that generates this sequence in the child process. The starting number will be provided from the command line. For example, if 8 is passed as a parameter on the command line, the child process will output 8, 4, 2, 1. Because the parent and child processes have their own copies of the data, it will be necessary for the child to output the sequence. Have the parent invoke the `wait()` call to wait for the child process to complete before exiting the program. Perform necessary error checking to ensure that a positive integer is passed on the command line.

- 3.22** In Exercise 3.21, the child process must output the sequence of numbers generated from the algorithm specified by the Collatz conjecture because the parent and child have their own copies of the data. Another approach to designing this program is to establish a shared-memory object between the parent and child processes. This technique allows the child to write the contents of the sequence to the shared-memory object. The parent can then output the sequence when the child completes. Because the memory is shared, any changes the child makes will be reflected in the parent process as well.

This program will be structured using POSIX shared memory as described in Section 3.5.1. The parent process will progress through the following steps:

- a. Establish the shared-memory object (`shm_open()`, `ftruncate()`, and `mmap()`).
- b. Create the child process and wait for it to terminate.
- c. Output the contents of shared memory.
- d. Remove the shared-memory object.

One area of concern with cooperating processes involves synchronization issues. In this exercise, the parent and child processes must be coordinated so that the parent does not output the sequence until the child finishes execution. These two processes will be synchronized using the `wait()` system call: the parent process will invoke `wait()`, which will suspend it until the child process exits.

- 3.23** Section 3.6.1 describes port numbers below 1024 as being well known—that is, they provide standard services. Port 17 is known as the *quote-of-*