CHAPTER 7

Synchronization Examples

7.1 Classic Problems of Synchronization

In this section, we present a number of synchronization problems as examples of a large class of concurrency-control problems. These problems are used for testing nearly every newly proposed synchronization scheme. In our solutions to the problems, we use semaphores for synchronization, since that is the

```
while (true) {
    . . .
   /* produce an item in next_produced */
    . . .
   wait(empty);
   wait(mutex);
    . . .
   /* add next_produced to the buffer */
    . . .
   signal(mutex);
   signal(full);
}
```

Figure 7.1 The structure of the producer process.

traditional way to present such solutions. However, actual implementations of these solutions could use mutex locks in place of binary semaphores.

7.1.1 The Bounded-Buffer Problem

The *bounded-buffer problem* was introduced in Section 6.1; it is commonly used to illustrate the power of synchronization primitives. Here, we present a general structure of this scheme without committing ourselves to any particular implementation. We provide a related programming project in the exercises at the end of the chapter.

In our problem, the producer and consumer processes share the following data structures:

```
int n;
semaphore mutex = 1;
semaphore empty = n;
semaphore full = 0
```

We assume that the pool consists of `n` buffers, each capable of holding one item. The `mutex` binary semaphore provides mutual exclusion for accesses to the buffer pool and is initialized to the value 1. The `empty` and `full` semaphores count the number of empty and full buffers. The semaphore `empty` is initialized to the value `n`; the semaphore `full` is initialized to the value 0.

The code for the producer process is shown in Figure 7.1, and the code for the consumer process is shown in Figure 7.2. Note the symmetry between the producer and the consumer. We can interpret this code as the producer producing full buffers for the consumer or as the consumer producing empty buffers for the producer.

7.1.2 The Readers–Writers Problem

Suppose that a database is to be shared among several concurrent processes. Some of these processes may want only to read the database, whereas others may want to update (that is, read and write) the database. We distinguish

```
while (true) {
   wait(full);
   wait(mutex);
      . . .
   /* remove an item from buffer to next_consumed */
      . . .
   signal(mutex);
   signal(empty);
      . . .
   /* consume the item in next_consumed */
      . . .
}
```

Figure 7.2 The structure of the consumer process.

between these two types of processes by referring to the former as ***readers*** and to the latter as ***writers***. Obviously, if two readers access the shared data simultaneously, no adverse effects will result. However, if a writer and some other process (either a reader or a writer) access the database simultaneously, chaos may ensue.

To ensure that these difficulties do not arise, we require that the writers have exclusive access to the shared database while writing to the database. This synchronization problem is referred to as the **readers–writers problem**. Since it was originally stated, it has been used to test nearly every new synchronization primitive.

The readers–writers problem has several variations, all involving priorities. The simplest one, referred to as the *first* readers–writers problem, requires that no reader be kept waiting unless a writer has already obtained permission to use the shared object. In other words, no reader should wait for other readers to finish simply because a writer is waiting. The *second* readers–writers problem requires that, once a writer is ready, that writer perform its write as soon as possible. In other words, if a writer is waiting to access the object, no new readers may start reading.

A solution to either problem may result in starvation. In the first case, writers may starve; in the second case, readers may starve. For this reason, other variants of the problem have been proposed. Next, we present a solution to the first readers–writers problem. See the bibliographical notes at the end of the chapter for references describing starvation-free solutions to the second readers–writers problem.

In the solution to the first readers–writers problem, the reader processes share the following data structures:

```
semaphore rw_mutex = 1;
semaphore mutex = 1;
int read_count = 0;
```

The binary semaphores `mutex` and `rw_mutex` are initialized to 1; `read_count` is a counting semaphore initialized to 0. The semaphore `rw_mutex`

```
while (true) {
   wait(rw mutex);
      . . .
   /* writing is performed */
      . . .
   signal(rw mutex);
}
```

Figure 7.3 The structure of a writer process.

is common to both reader and writer processes. The `mutex` semaphore is used to ensure mutual exclusion when the variable `read count` is updated. The `read count` variable keeps track of how many processes are currently reading the object. The semaphore `rw mutex` functions as a mutual exclusion semaphore for the writers. It is also used by the first or last reader that enters or exits the critical section. It is not used by readers that enter or exit while other readers are in their critical sections.

The code for a writer process is shown in Figure 7.3; the code for a reader process is shown in Figure 7.4. Note that, if a writer is in the critical section and n readers are waiting, then one reader is queued on `rw mutex`, and $n - 1$ readers are queued on `mutex`. Also observe that, when a writer executes `signal(rw mutex)`, we may resume the execution of either the waiting readers or a single waiting writer. The selection is made by the scheduler.

```
while (true) {
   wait(mutex);
   read count++;
   if (read count == 1)
      wait(rw mutex);
   signal(mutex);
      . . .
   /* reading is performed */
      . . .
   wait(mutex);
   read count--;
   if (read count == 0)
      signal(rw mutex);
   signal(mutex);
}
```

Figure 7.4 The structure of a reader process.

7.1.3 The Dining-Philosophers Problem

Consider five philosophers who spend their lives thinking and eating. The philosophers share a circular table surrounded by five chairs, each belonging to one philosopher. In the center of the table is a bowl of rice, and the table is laid with five single chopsticks (Figure 7.5). When a philosopher thinks, she does not interact with her colleagues. From time to time, a philosopher gets hungry and tries to pick up the two chopsticks that are closest to her (the chopsticks that are between her and her left and right neighbors). A philosopher may pick up only one chopstick at a time. Obviously, she cannot pick up a chopstick that is already in the hand of a neighbor. When a hungry philosopher has both her chopsticks at the same time, she eats without releasing the chopsticks. When she is finished eating, she puts down both chopsticks and starts thinking again.

The **dining-philosophers problem** is considered a classic synchronization problem neither because of its practical importance nor because computer scientists dislike philosophers but because it is an example of a large class of concurrency-control problems. It is a simple representation of the need

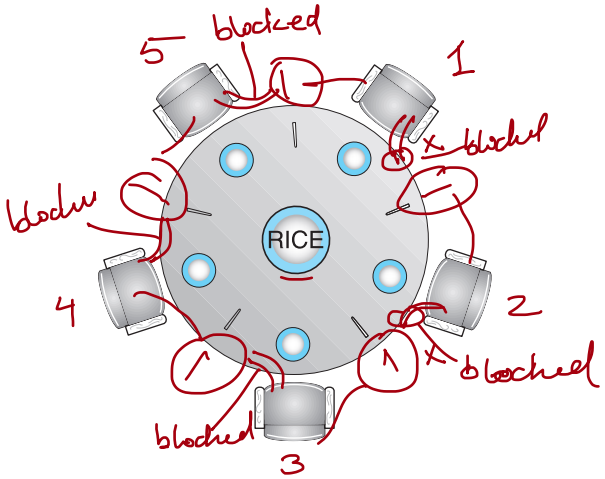

Figure 7.5 The situation of the dining philosophers.

```
while (true) {
   wait(chopstick[i]);
   wait(chopstick[(i+1) % 5]);
      . . .
   /* eat for a while */
      . . .
   signal(chopstick[i]);
   signal(chopstick[(i+1) % 5]);
      . . .
   /* think for awhile */
      . . .
}
```

Figure 7.6 The structure of philosopher *i*.

to allocate several resources among several processes in a deadlock-free and starvation-free manner.

7.1.3.1 Semaphore Solution

One simple solution is to represent each chopstick with a semaphore. A philosopher tries to grab a chopstick by executing a `wait()` operation on that semaphore. She releases her chopsticks by executing the `signal()` operation on the appropriate semaphores. Thus, the shared data are

```
semaphore chopstick[5];
```

where all the elements of `chopstick` are initialized to 1. The structure of philosopher *i* is shown in Figure 7.6.

Although this solution guarantees that no two neighbors are eating simultaneously, it nevertheless must be rejected because it could create a deadlock. Suppose that all five philosophers become hungry at the same time and each grabs her left chopstick. All the elements of `chopstick` will now be equal to 0. When each philosopher tries to grab her right chopstick, she will be delayed forever.

Several possible remedies to the deadlock problem are the following:

- Allow at most four philosophers to be sitting simultaneously at the table.
- Allow a philosopher to pick up her chopsticks only if both chopsticks are available (to do this, she must pick them up in a critical section).
- Use an asymmetric solution—that is, an odd-numbered philosopher picks up first her left chopstick and then her right chopstick, whereas an even-numbered philosopher picks up her right chopstick and then her left chopstick.