

# Semaphores

## Andrews Chapter 04

- Chapter 3 used busy-waiting loops.
- Semaphores are easy to implement.
- Virtually all concurrent libraries include semaphores.
- Make critical sections easy.
- Can be used for signalling and scheduling.

```
sem mutex = 1;  
process CS[i = 1 to n] {  
    while (true) {  
        P(mutex);  
        critical section;  
        V(mutex);  
        noncritical section;  
    }  
}
```

**Figure 4.1** Semaphore solution to the critical section problem.

```

sem arrive1 = 0, arrive2 = 0;
process Worker1 {
    ...
    V(arrive1);    /* signal arrival      */
    P(arrive2);    /* wait for other process */
    ...
}
process Worker2 {
    ...
    V(arrive2);    /* signal arrival      */
    P(arrive1);    /* wait for other process */
    ...
}

```

**Figure 4.2** Barrier synchronization using semaphores.

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- A two-process barrier.
- Can use **count** to generalize (see Downey).
- Can use butterfly or dissemination-barrier.

```

typeT buf;      /* a buffer of some type T */
sem empty = 1, full = 0;
process Producer[i = 1 to M] {
    while (true) {
        ...
        /* produce data, then deposit it in the buffer */
        P(empty);
        buf = data;
        V(full);
    }
}

process Consumer[j = 1 to N] {
    while (true) {
        /* fetch result, then consume it */
        P(full);
        result = buf;
        V(empty);
        ...
    }
}

```

**Figure 4.3** Producers and consumers using semaphores.

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- Split binary semaphores.

```

typeT buf[n];          /* an array of some type T */
int front = 0, rear = 0;
sem empty = n, full = 0; /* n-2 <= empty+full <= n */

process Producer {
    while (true) {
        ...
        produce message data and deposit it in the buffer;
        P(empty);
        buf[rear] = data; rear = (rear+1) % n;
        V(full);
    }
}

process Consumer {
    while (true) {
        fetch message result and consume it;
        P(full);
        result = buf[front]; front = (front+1) % n;
        V(empty);
        ...
    }
}

```

**Figure 4.4** Bounded buffer using semaphores.

- **empty** is initialized to **n**

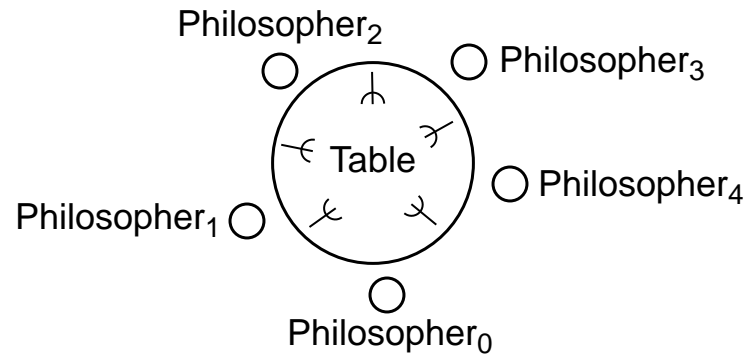
```

typeT buf[n];          /* an array of some type T */
int front = 0, rear = 0;
sem empty = n, full = 0;    /* n-2 <= empty+full <= n */
sem mutexD = 1, mutexF = 1; /* for mutual exclusion */
process Producer[i = 1 to M] {
    while (true) {
        ...
        produce message data and deposit it in the buffer;
        P(empty);
        P(mutexD);
        buf[rear] = data; rear = (rear+1) % n;
        V(mutexD);
        V(full);
    }
}

process Consumer[j = 1 to N] {
    while (true) {
        fetch message result and consume it;
        P(full);
        P(mutexF);
        result = buf[front]; front = (front+1) % n;
        V(mutexF);
        V(empty);
        ...
    }
}

```

**Figure 4.5** Multiple producers and consumers using semaphores.



**Figure 4.6** The dining philosophers.

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```
process Philosopher[i = 0 to 4] {  
    while (true) {  
        think;  
        acquire forks;  
        eat;  
        release forks;  
    }  
}
```

```

sem fork[5] = {1, 1, 1, 1, 1};
process Philosopher[i = 0 to 3] {
    while (true) {
        P(fork[i]); P(fork[i+1]); # get left fork then right
        eat;
        V(fork[i]); V(fork[i+1]);
        think;
    }
}
process Philosopher[4] {
    while (true) {
        P(fork[0]); P(fork[4]);    # get right fork then left
        eat;
        V(fork[0]); V(fork[4]);
        think;
    }
}

```

**Figure 4.7** Dining philosophers solution using semaphores.



```

sem rw = 1;
process Reader[i = 1 to M] {
    while (true) {
        ...
        P(rw);    # grab exclusive access lock
        read the database;
        V(rw);    # release the lock
    }
}
process Writer[j = 1 to N] {
    while (true) {
        ...
        P(rw);    # grab exclusive access lock
        write the database;
        V(rw);    # release the lock
    }
}

```

**Figure 4.8** An overconstrained readers/writers solution.

```

int nr = 0;          # number of active readers
sem rw = 1;          # lock for reader/writer exclusion
process Reader[i = 1 to M] {
    while (true) {
        ...
        < nr = nr+1;
          if (nr == 1) P(rw);  # if first, get lock
        >
        read the database;
        < nr = nr-1;
          if (nr == 0) V(rw);  # if last, release lock
        >
    }
}

process Writer[j = 1 to N] {
    while (true) {
        ...
        P(rw);
        write the database;
        V(rw);
    }
}

```

**Figure 4.9** Outline of readers and writers solution.

```

int nr = 0;          # number of active readers
sem rw = 1;          # lock for access to the database
sem mutexR = 1;      # lock for reader access to nr
process Reader[i = 1 to m] {
    while (true) {
        ...
        P(mutexR);
        nr = nr+1;
        if (nr == 1) P(rw);  # if first, get lock
        V(mutexR);
        read the database;
        P(mutexR);
        nr = nr-1;
        if (nr == 0) V(rw);  # if last, release lock
        V(mutexR);
    }
}
process Writer[j = 1 to n] {
    while (true) {
        ...
        P(rw);
        write the database;
        V(rw);
    }
}

```

**Figure 4.10** Readers and writers exclusion using semaphores.

```

int nr = 0, nw = 0;
## RW:  (nr == 0  $\vee$  nw == 0)  $\wedge$  nw <= 1
process Reader[i = 1 to m] {
    while (true) {
        ...
        <await (nw == 0) nr = nr+1;>
        read the database;
        <nr = nr-1;>
    }
}
process Writer[j = 1 to n] {
    while (true) {
        ...
        <await (nr == 0 and nw == 0) nw = nw+1;>
        write the database;
        <nw = nw-1;>
    }
}

```

**Figure 4.11** A coarse-grained readers/writers solution.

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- Waiting on *two* variables: no simple semaphore works.
- Our implementation of **await** with semaphores uses busy waiting.
- Can we find a *general* solution to **await** with semaphores that doesn't use busy waiting?

```

if (nw == 0 and dr > 0) {
    dr = dr-1; V(r);  # awaken a reader, or
}
elseif (nr == 0 and nw == 0 and dw > 0) {
    dw = dw-1; V(w);  # awaken a writer, or
}
else
    V(e);              # release the entry lock

```

SIGNAL code for Figure 4.12.

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- **e** is a mutex for the readers/writers.
- **e** stands for *entry* into a critical section.
- **r** and **w** stand for the guards.
- Instead of releasing **e**, signal *exactly one* of the semaphores.
- **r**, **w**, and **e** are a split binary semaphore: only one is nonzero.
- A thread is either reading, writing, or nothing.
- The signaller does what the awakened process would do:
  1. keeps the mutex locked
  2. decrements the counter
- **Passing the baton** to one another.

```

int nr = 0,    ## RW: (nr == 0 or nw == 0) and nw <= 1
    nw = 0;
sem e = 1,    # controls entry to critical sections
    r = 0,    # used to delay readers
    w = 0;    # used to delay writers
                # at all times 0 <= (e+r+w) <= 1
int dr = 0,    # number of delayed readers
    dw = 0;    # number of delayed writers
process Reader[i = 1 to M] {
    while (true) {
        # <await (nw == 0) nr = nr+1;>
        P(e);
        if (nw > 0) { dr = dr+1; V(e); P(r); }
        nr = nr+1;
        SIGNAL;    # see text for details
        read the database;
        # <nr = nr-1;>
        P(e);
        nr = nr-1;
        SIGNAL;
    }
}
process Writer[j = 1 to N] {
    while (true) {
        # <await (nr == 0 and nw == 0) nw = nw+1;>
        P(e);
        if (nr > 0 or nw > 0) { dw = dw+1; V(e); P(w); }
        nw = nw+1;
        SIGNAL;
        write the database;
        # <nw = nw-1;>
        P(e);
        nw = nw-1;
        SIGNAL;
    }
}

```

- Some of the **SIGNAL** code can be simplified, resulting in the next figure.

**Figure 4.12** Outline of readers and writers with passing the baton.

```

int nr = 0,    ## RW: (nr==0 or nw==0) and nw<=1
    nw = 0;
sem e = 1,    # controls entry to critical sections
    r = 0,    # used to delay readers
    w = 0;    # used to delay writers
                # at all times 0 <= (e+r+w) <= 1
int dr = 0,    # number of delayed readers
    dw = 0;    # number of delayed writers

process Reader[i = 1 to M] {
    while (true) {
        # <await (nw == 0) nr = nr+1;>
        P(e);
        if (nw > 0) { dr = dr+1; V(e); P(r); }
        nr = nr+1;
        if (dr > 0) { dr = dr-1; V(r); }
        else V(e);
        read the database;
        # <nr = nr-1;>
        P(e);
        nr = nr-1;
        if (nr == 0 and dw > 0) { dw = dw-1; V(w); }
        else V(e);
    }
}

process Writer[j = 1 to N] {
    while (true) {
        # <await (nr == 0 and nw == 0) nw = nw+1;>
        P(e);
        if (nr > 0 or nw > 0) { dw = dw+1; V(e); P(w); }
        nw = nw+1;
        V(e);
        write the database;
        # <nw = nw-1;>
        P(e);
        nw = nw-1;
        if (dr > 0) { dr = dr-1; V(r); }
        elseif (dw > 0) { dw = dw-1; V(w); }
        else V(e);
    }
}

```

## Passing the baton more flexible

- Can give writers precedence by switching the `if` in `Writer`:

```
if (dw > 0) { dw = dw-1; V(w); }  
elseif (dr > 0) { dr = dr - 1; V(r); }  
else V(e);
```

- This change can be made without restructuring the code.
- Can force readers and writers to alternate when both are waiting:
  - delay a new reader when a writer is waiting
  - delay a new writer when a reader is waiting
  - awaken one waiting writer (if any) when a reader finishes
  - awaken all waiting readers (if any) when a writer finishes;  
otherwise awaken one waiting writer (if any)



```

bool free = true;
sem e = 1, b[n] = ([n] 0); # for entry and delay
typedef Pairs = set of (int, int);
Pairs pairs =  $\emptyset$ ;
## SJN: pairs is an ordered set  $\wedge$  free  $\Rightarrow$  (pairs ==  $\emptyset$ )
request(time,id):
    P(e);
    if (!free) {
        insert (time,id) in pairs;
        V(e);          # release entry lock
        P(b[id]);      # wait to be awakened
    }
    free = false;
    V(e);      # optimized since free is false here
release():
    P(e);
    free = true;
    if (P !=  $\emptyset$ ) {
        remove first pair (time,id) from pairs;
        V(b[id]); # pass baton to process id
    }
    else V(e);

```

**Figure 4.14** Shortest-job-next allocation using semaphores.

## Pthreads

```
#include <pthread.h>
pthread_attr_t tattr;          /* thread attributes */
pthread_t tid;                 /* thread descriptor */
void *start_func(void *arg) {
    ...    pthread_exit(value);    ...
}
...
pthread_attr_init(&tattr);
pthread_attr_setscope(&tattr, PTHREAD_SCOPE_SYSTEM);
    /* can use just one of these for all threads */
...
pthread_create(&tid, &tattr, start_func, arg);
...
pthread_join(tid, value_ptr);
```

## Semaphores

```
#include <semaphore.h>
sem_t mutex;
...
sem_init(&mutex, SHARED, 1);
..
sem_wait(&mutex);          /* P(mutex) */
...
sem_post(&mutex);          /* V(mutex) */
```

```

#include <pthread.h>      /* standard lines */
#include <semaphore.h>
#define SHARED 1
#include <stdio.h>

void *Producer(void *); /* the two threads */
void *Consumer(void *);

sem_t empty, full;      /* global semaphores */
int data;               /* shared buffer */
int numIters;

/* main() -- read command line and create threads */
int main(int argc, char *argv[]) {
    pthread_t pid, cid; /* thread and attributes */
    pthread_attr_t attr; /* descriptors */
    pthread_attr_init(&attr);
    pthread_attr_setscope(&attr, PTHREAD_SCOPE_SYSTEM);

    sem_init(&empty, SHARED, 1); /* sem empty = 1 */
    sem_init(&full, SHARED, 0); /* sem full = 0 */

    numIters = atoi(argv[1]);
    pthread_create(&pid, &attr, Producer, NULL);
    pthread_create(&cid, &attr, Consumer, NULL);
    pthread_join(pid, NULL);
    pthread_join(cid, NULL);
}

/* deposit 1, ..., numIters into the data buffer */
void *Producer(void *arg) {
    int produced;
    for (produced = 1; produced <= numIters; produced++) {
        sem_wait(&empty);
        data = produced;
        sem_post(&full);
    }
}

/* fetch numIters items from the buffer and sum them */
void *Consumer(void *arg) {
    int total = 0, consumed;
    for (consumed = 1; consumed <= numIters; consumed++) {
        sem_wait(&full);
        total = total + data;
        sem_post(&empty);
    }
    printf("the total is %d\n", total);
}

```

Figure 4.15 Simple producer/consumer using Pthreads.