Semaphore

A variable that has an integer value upon which only three operations are defined:

- There is no way to inspect or manipulate semaphores other than these three operations

1) A semaphore may be initialized to a nonnegative integer value
2) The semWait operation decrements the semaphore value
3) The semSignal operation increments the semaphore value

Consequences

There is no way to know before a process decrements a semaphore whether it will block or not

There is no way to know which process will continue immediately on a uniprocessor system when two processes are running concurrently

You don't know whether another process is waiting so the number of unblocked processes may be zero or one

```
struct semaphore {
     int count;
     queueType queue;
};
void semWait(semaphore s)
{
     s.count--;
     if (s.count < 0) {
          /* place this process in s.queue */;
          /* block this process */;
     }
}
void semSignal(semaphore s)
{
     s.count++;
     if (s.count <= 0) {
          /* remove a process P from s.queue */;
          /* place process P on ready list */;
     }
}
```

Figure 5.6 A Definition of Semaphore Primitives

```
struct binary semaphore {
     enum {zero, one} value;
     queueType queue;
};
void semWaitB(binary semaphore s)
{
     if (s.value == one)
          s.value = zero;
     else {
               /* place this process in s.queue */;
               /* block this process */;
     }
}
void semSignalB(semaphore s)
{
     if (s.queue is empty())
          s.value = one;
     else {
               /* remove a process P from s.queue */;
               /* place process P on ready list */;
     }
}
```

Figure 5.7 A Definition of Binary Semaphore Primitives

Strong/Weak Semaphores

😐 A queue is used to hold processes waiting on the semaphore

Strong Semaphores

- The process that has been blocked the longest is released from the queue first (FIFO)

Weak Semaphores

- The order in which processes are removed from the queue is not specified

Monitors

- Programming language construct that provides equivalent functionality to that of semaphores and is easier to control
- Implemented in a number of programming languages
  - Concurrent Pascal, Pascal-Plus, Modula-2, Modula-3, Java
- Has also been implemented as a program library
- Software module consisting of one or more procedures, an initialization sequence, and local data

Monitor Characteristics

Local data variables are accessible only by the monitor's procedures and not by any external procedure

Process enters monitor by invoking one of its procedures

Only one process may be executing in the monitor at a time

Synchronization

- A monitor supports synchronization by the use of **condition variables** that are contained within the monitor and accessible only within the monitor
  - Condition variables are a special data type in monitors which are operated on by two functions:
    - `cwait(c)`: suspend execution of the calling process on condition `c`
    - `csignal(c)`: resume execution of some process blocked after a `cwait` on the same condition

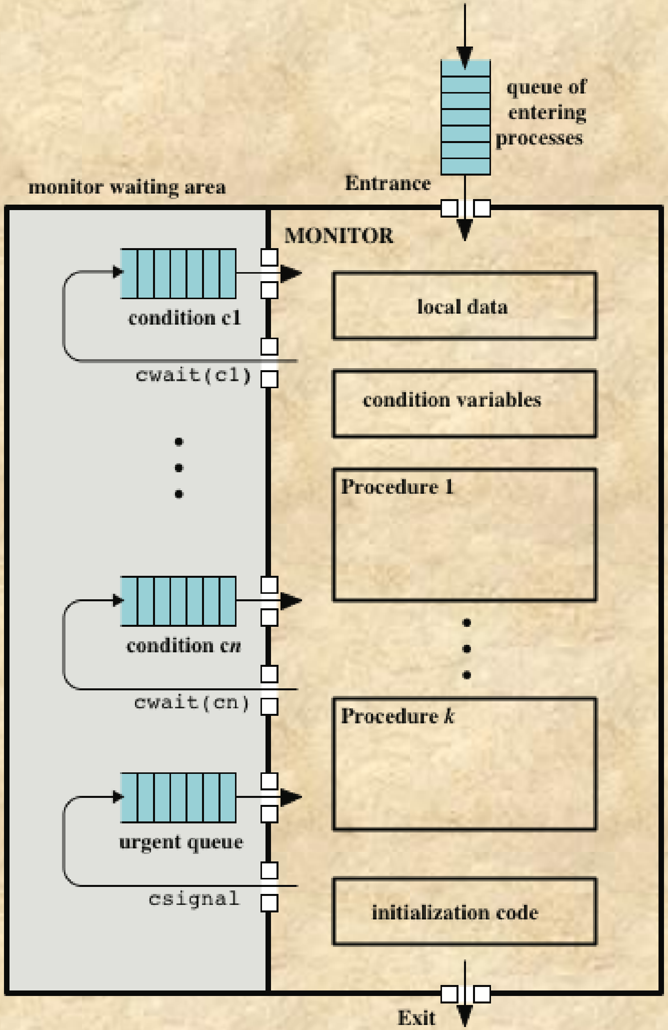


Figure 5.18 Structure of a Monitor

```
/* program producerconsumer */
monitor boundedbuffer;
char buffer [N];                                          /* space for N items */
int nextin, nextout;                                      /* buffer pointers */
int count;                                                /* number of items in buffer */
cond notfull, notempty;              /* condition variables for synchronization */

void append (char x)
{
    if (count == N) cwait(notfull);        /* buffer is full; avoid overflow */
    buffer[nextin] = x;
    nextin = (nextin + 1) % N;
    count++;
    /* one more item in buffer */
    csignal(notempty);                            /* resume any waiting consumer */
}
void take (char x)
{
    if (count == 0) cwait(notempty);     /* buffer is empty; avoid underflow */
    x = buffer[nextout];
    nextout = (nextout + 1) % N;
    count--;                                         /* one fewer item in buffer */
    csignal(notfull);                              /* resume any waiting producer */
}
{                                                                /* monitor body */
    nextin = 0; nextout = 0; count = 0;               /* buffer initially empty */
}
```

```
void producer()
{
    char x;
    while (true) {
    produce(x);
    append(x);
    }
}
void consumer()
{
    char x;
    while (true) {
      take(x);
      consume(x);
    }
}
void main()
{
    parbegin (producer, consumer);
}
```

Figure 5.19 A Solution to the Bounded-Buffer Producer/Consumer Problem Using a Monitor

```
void append (char x)
{
    while(count == N) cwait(notfull);    /* buffer is full; avoid overflow */
    buffer[nextin] = x;
    nextin = (nextin + 1) % N;
    count++;                                       /* one more item in buffer */
    cnotify(notempty);                       /* notify any waiting consumer */
}

void take (char x)
{
    while(count == 0) cwait(notempty); /* buffer is empty; avoid underflow */
    x = buffer[nextout];
    nextout = (nextout + 1) % N;
    count--;                                      /* one fewer item in buffer */
    cnotify(notfull);                        /* notify any waiting producer */
}
```

Figure 5.20 Bounded Buffer Monitor Code for Mesa Monitor

Dining Philosophers Problem

- No two philosophers can use the same fork at the same time (mutual exclusion)
- No philosopher must starve to death (avoid deadlock and starvation)

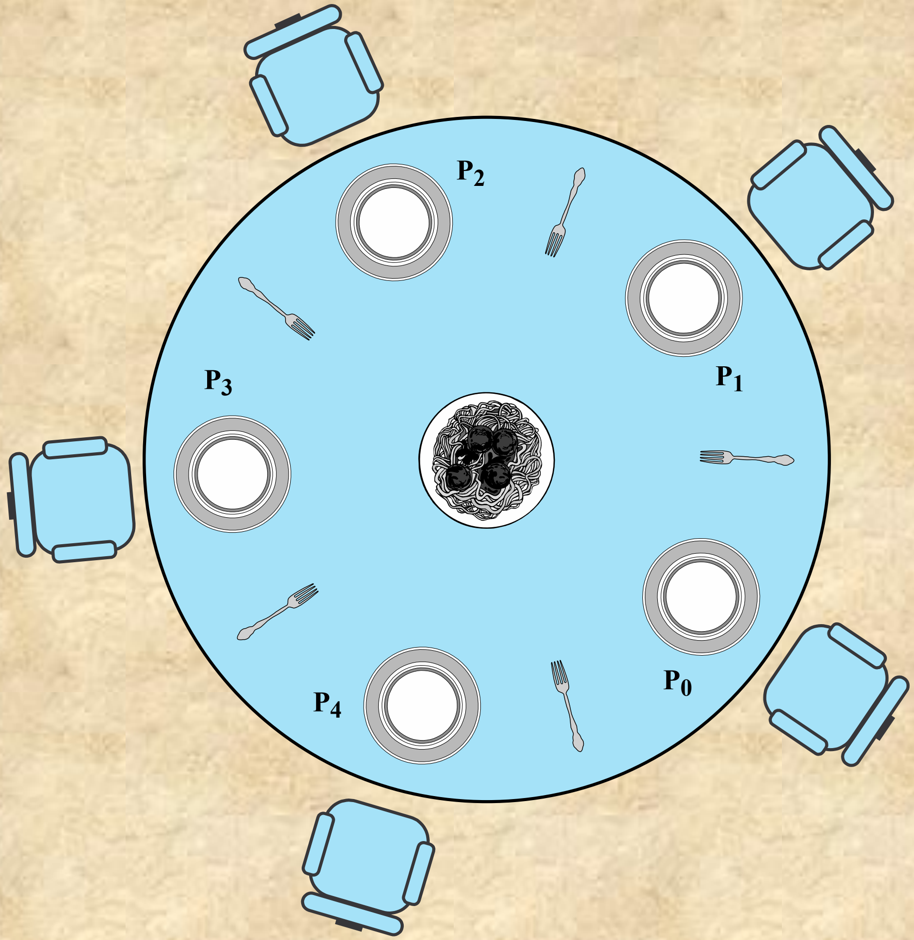


Figure 6.11 Dining Arrangement for Philosophers

```
/* program     diningphilosophers */
semaphore fork [5] = {1};
int i;
void philosopher (int i)
{
     while (true) {
          think();
          wait (fork[i]);
          wait (fork [(i+1) mod 5]);
          eat();
          signal(fork [(i+1) mod 5]);
          signal(fork[i]);
     }
}
void main()
{
     parbegin (philosopher (0), philosopher (1), philosopher
(2),
          philosopher (3), philosopher (4));
     }
```

Figure 6.12 A First Solution to the Dining Philosophers Problem

```
/* program diningphilosophers */
semaphore fork[5] = {1};
semaphore room = {4};
int i;
void philosopher (int i)
{
    while (true) {
     think();
     wait (room);
     wait (fork[i]);
     wait (fork [(i+1) mod 5]);
     eat();
     signal (fork [(i+1) mod 5]);
     signal (fork[i]);
     signal (room);
    }

}
void main()
{
    parbegin (philosopher (0), philosopher (1), philosopher (2),
          philosopher (3), philosopher (4));
}
```

Figure 6.13 A Second Solution to the Dining Philosophers Problem

```
monitor dining_controller;
cond ForkReady[5];        /* condition variable for synchronization */
boolean fork[5] = {true};        /* availability status of each fork */

void get_forks(int pid)          /* pid is the philosopher id number */
{
   int left = pid;
   int right = (++pid) % 5;
   /*grant the left fork*/
   if (!fork[left])
      cwait(ForkReady[left]);         /* queue on condition variable */
   fork[left] = false;
   /*grant the right fork*/
   if (!fork[right])
      cwait(ForkReady[right]);        /* queue on condition variable */
   fork[right] = false:
}
void release_forks(int pid)
{
   int left = pid;
   int right = (++pid) % 5;
   /*release the left fork*/
   if (empty(ForkReady[left])       /*no one is waiting for this fork */
      fork[left] = true;
   else                        /* awaken a process waiting on this fork */
      csignal(ForkReady[left]);
   /*release the right fork*/
   if (empty(ForkReady[right])      /*no one is waiting for this fork */
      fork[right] = true;
   else                        /* awaken a process waiting on this fork */
      csignal(ForkReady[right]);
}
```

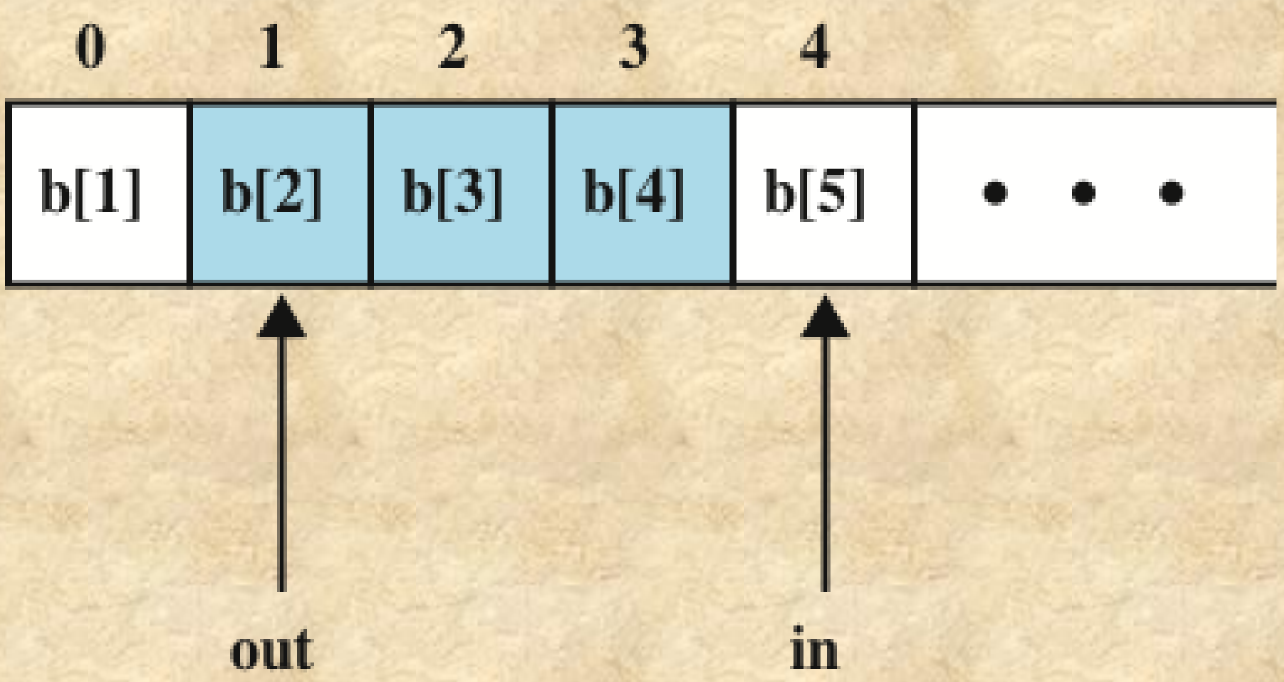
```
void philosopher[k=0 to 4]          /* the five philosopher clients */
{
   while (true) {
      <think>;
      get_forks(k);          /* client requests two forks via monitor */
      <eat spaghetti>;
      release_forks(k);     /* client releases forks via the monitor */
   }
}
```

Figure 6.14

A Solution to the Dining Philosophers Problem Using a Monitor

Producer/Consumer Problem

General Statement:	One or more producers are generating data and placing these in a buffer
	A single consumer is taking items out of the buffer one at a time
	Only one producer or consumer may access the buffer at any one time
The Problem:	Ensure that the producer won't try to add data into the buffer if its full, and that the consumer won't try to remove data from an empty buffer



Note: shaded area indicates portion of buffer that is occupied

Figure 5.11 Infinite Buffer for the Producer/Consumer Problem

```
/* program producerconsumer */
int n;
binary_semaphore s = 1, delay = 0;
void producer()
{
     while (true) {
          produce();
          semWaitB(s);
          append();
          n++;
          if (n==1) semSignalB(delay);
          semSignalB(s);
     }
}
void consumer()
{
     semWaitB(delay);
     while (true) {
          semWaitB(s);
          take();
          n--;
          semSignalB(s);
          consume();
          if (n==0) semWaitB(delay);
     }
}
void main()
{
     n = 0;
     parbegin (producer, consumer);
}
```

Figure 5.12 An Incorrect Solution to the Infinite-Buffer Producer/Consumer Problem Using Binary Semaphores

Table 5.4
Possible Scenario for the Program of Figure 5.12

	Producer	Consumer	s	n	Delay
1			1	0	0
2	`semWaitB(s)`		0	0	0
3	`n++`		0	1	0
4	`if (n==1) (semSignalB(delay))`		0	1	1
5	`semSignalB(s)`		1	1	1
6		`semWaitB(delay)`	1	1	0
7		`semWaitB(s)`	0	1	0
8		`n--`	0	0	0
9		`semSignalB(s)`	1	0	0
10	`semWaitB(s)`		0	0	0
11	`n++`		0	1	0
12	`if (n==1) (semSignalB(delay))`		0	1	1
13	`semSignalB(s)`		1	1	1
14		`if (n==0) (semWaitB(delay))`	1	1	1
15		`semWaitB(s)`	0	1	1
16		`n--`	0	0	1
17		`semSignalB(s)`	1	0	1
18		`if (n==0) (semWaitB(delay))`	1	0	0
19		`semWaitB(s)`	0	0	0
20		`n--`	0	–1	0
21		`semSignalB(s)`	1	–1	0

Note: White areas represent the critical section controlled by semaphore s.

```
/* program producerconsumer */
int n;
binary_semaphore s = 1, delay = 0;
void producer()
{
     while (true) {
          produce();
          semWaitB(s);
          append();
          n++;
          if (n==1) semSignalB(delay);
          semSignalB(s);
     }
}
void consumer()
{
     int m; /* a local variable */
     semWaitB(delay);
     while (true)  {
          semWaitB(s);
          take();
          n--;
          m = n;
          semSignalB(s);
          consume();
          if (m==0) semWaitB(delay);
     }
}
void main()
{
     n = 0;
     parbegin (producer, consumer);
}
```

Figure 5.13 A Correct Solution to the Infinite-Buffer Producer/Consumer Problem Using Binary Semaphores

```
/* program  producerconsumer */
semaphore n = 0, s = 1;
void producer()
{
     while (true) {
          produce();
          semWait(s);
          append();
          semSignal(s);
          semSignal(n);
     }
}
void consumer()
{
     while (true) {
          semWait(n);
          semWait(s);
          take();
          semSignal(s);
          consume();
     }
}
void main()
{
     parbegin (producer, consumer);
}
```

Figure 5.14 A Solution to the Infinite-Buffer Producer/Consumer Problem Using Semaphores

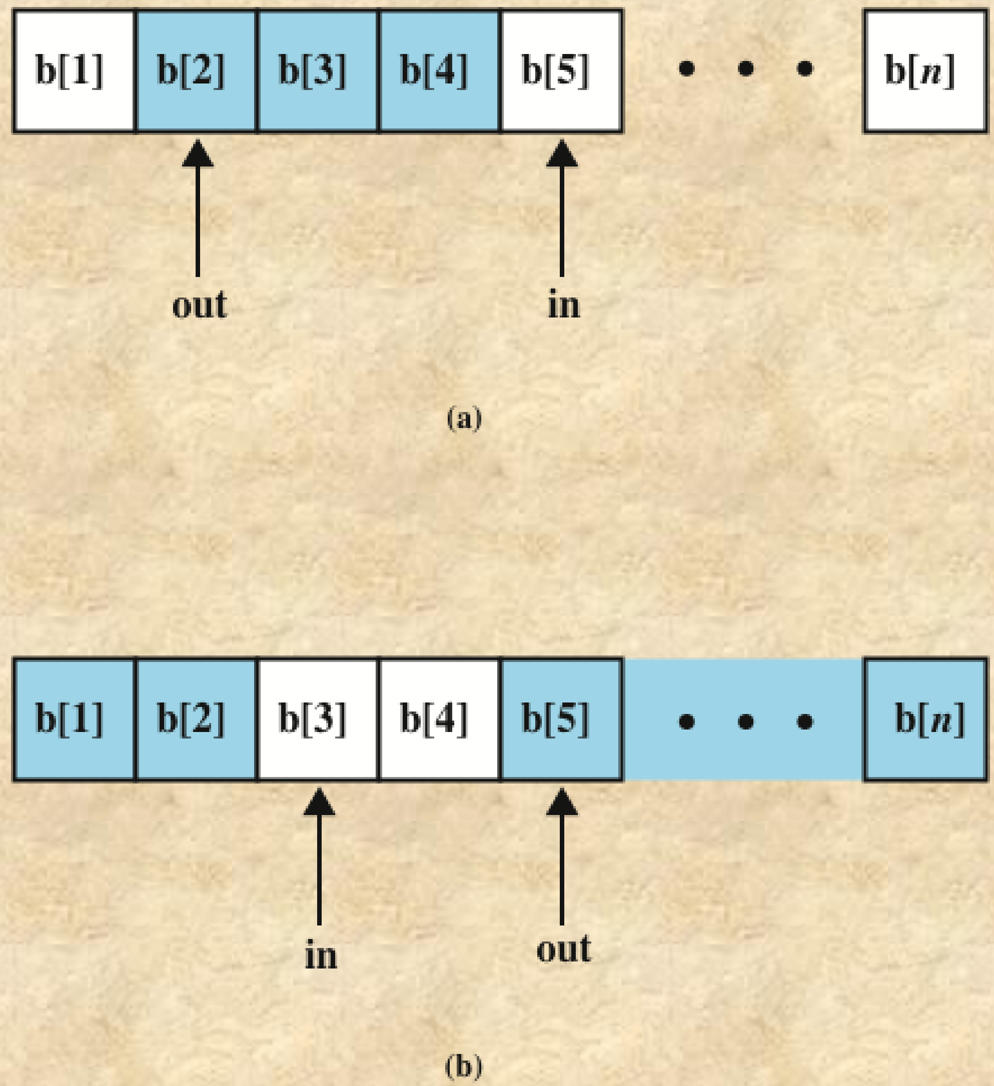


Figure 5.15 Finite Circular Buffer for the Producer/Consumer Problem

```
/* program boundedbuffer */
const int sizeofbuffer = /* buffer size */;
semaphore s = 1, n= 0, e= sizeofbuffer;
void producer()
{
     while (true) {
          produce();
          semWait(e);
          semWait(s);
          append();
          semSignal(s);
          semSignal(n);
     }
}
void consumer()
{
     while (true) {
          semWait(n);
          semWait(s);
          take();
          semSignal(s);
          semSignal(e);
          consume();
     }
}
void main()
{
     parbegin (producer, consumer);
}
```

Figure 5.16 A Solution to the Bounded-Buffer Producer/Consumer Problem Using Semaphores

Readers/Writers Problem

- A data area is shared among many processes
  - Some processes only read the data area, (readers) and some only write to the data area (writers)
- Conditions that must be satisfied:
  - Any number of readers may simultaneously read the file
  - Only one writer at a time may write to the file
  - If a writer is writing to the file, no reader may read it

```
/* program readersandwriters */
int readcount;
semaphore x = 1, wsem = 1;
void reader()
{
    while (true) {
      semWait (x);
      readcount++;
      if (readcount == 1) semWait (wsem);
      semSignal (x);
      READUNIT();
      semWait (x);
      readcount--;
      if (readcount == 0) semSignal (wsem);
      semSignal (x);
    }
 }
void writer()
{
    while (true) {
      semWait (wsem);
      WRITEUNIT();
      semSignal (wsem);
    }
}

void main()
{
    readcount = 0;
    parbegin (reader, writer);
}
```

Figure 5.25 A Solution to the Readers/Writers Problem Using Semaphores: Readers Have Priority

```
/* program readersandwriters */
int  readcount, writecount;
semaphore x = 1, y = 1, z = 1, wsem = 1, rsem = 1;
void reader()
{
    while (true) {
     semWait (z);
          semWait (rsem);
               semWait (x);
                    readcount++;
                    if (readcount == 1) semWait (wsem);
               semSignal (x);
          semSignal (rsem);
     semSignal (z);
     READUNIT();
     semWait (x);
          readcount--;
          if (readcount == 0) semSignal (wsem);
     semSignal (x);
    }
}
void writer ()
{
    while (true) {
     semWait (y);
          writecount++;
          if (writecount == 1) semWait (rsem);
     semSignal (y);
     semWait (wsem);
     WRITEUNIT();
     semSignal (wsem);
     semWait (y);
          writecount--;
          if (writecount == 0) semSignal (rsem);
     semSignal (y);
    }
}
void main()
{
    readcount = writecount = 0;
    parbegin (reader, writer);
}
```

Figure 5.26 A Solution to the Readers/Writers Problem Using Semaphores: Writers Have Priority

Readers only in the system	•*wsem* set •no queues
Writers only in the system	•*wsem* and *rsem* set •writers queue on *wsem*
Both readers and writers with read first	•*wsem* set by reader •*rsem* set by writer •all writers queue on *wsem* •one reader queues on *rsem* •other readers queue on *z*
Both readers and writers with write first	•*wsem* set by writer •*rsem* set by writer •writers queue on *wsem* •one reader queues on *rsem* •other readers queue on *z*

Table 5.6

State of the Process Queues for Program of Figure 5.26