Operating Systems:
Internals and Design Principles, 6/E
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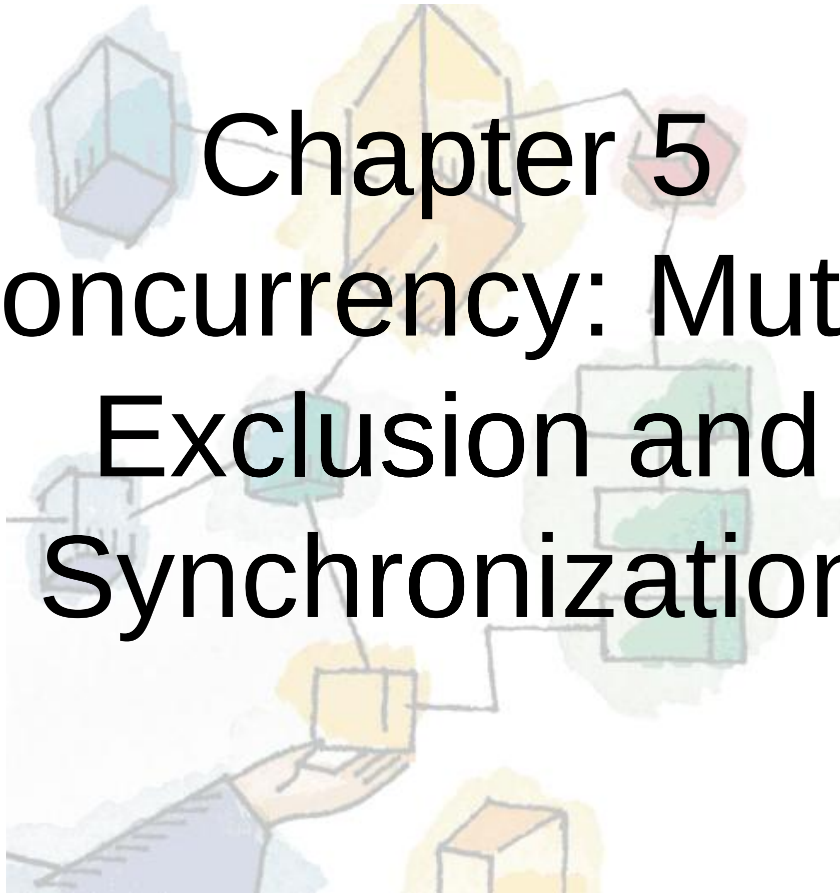


Chapter 5
Concurrency: Mutual Exclusion and Synchronization

Multiple Processes

- Central to the design of modern Operating Systems is managing multiple processes
  - Multiprogramming
  - Multiprocessing
  - Distributed Processing
- Big Issue is Concurrency
  - Managing the interaction of all of these processes

Difficulties of Concurrency

- **Sharing of global resources**
  - If P1 and P2 are sharing common variable, then care should be taken with read and write operations
- **Optimally managing the allocation of resources**
  - If P1 is given access to I/O channel and it gets suspended before using I/O, then performance will suffer
- **Difficult to locate programming errors as results are not deterministic and reproducible**
  - Due to overwriting of values

A Simple Example

```
void echo()
{
   chin = getchar();
   chout = chin;
   putchar(chout);
}
```

- Consider that we have a single-processor multiprogramming system supporting a single user.
  - The user can jump from one application to another, and each application uses the same keyboard for input and the same screen for output.

A Simple Example

- Each application needs to use the procedure echo,
  - So it makes sense for it to be a shared procedure that is loaded into a portion of memory global to all applications.
  - Thus, only a single copy of the echo procedure is used, saving space.

A Simple Example: Single Processor, Multiprogramming System

- P1 calls echo, but interrupted after first line (chin=x)
- P2 activated, calls echo and runs till end (chin=chout=y)
- P1 resumes, but the value is overwritten (prints y!!)

- **Problem:**
  – Shared global variables / procedure

- **Solution:**
  – Permit only one process to access the procedure at a time (works for multiprocesssing systems as well)

A Simple Example: On a Multiprocessor

Process P1

```
        .
chin = getchar();
        .
chout = chin;
putchar(chout);
        .
        .
```

Process P2

```
        .
        .
chin = getchar();
chout = chin;
        .
putchar(chout);
        .
```

Enforce Single Access

- If we enforce a rule that only one process may enter the function at a time then:
  - P1 & P2 run on separate processors
  - P1 enters echo first
  - P2 tries to enter but is blocked
  - P1 completes execution
  - P2 resumes and executes echo

Race Condition

- A **race condition** occurs when
  - “Multiple processes or threads read and write data items hence the final result depends on the order of execution of the processes”
  - The output depends on who finishes the race last.
- E.g. Consider that a global variable “a” is accessed by Processes P1 and P2
  - P1 writes a=1
  - P2 writes a=2
  - The loser wins!

Operating System Concerns

- What design and management issues are raised by the existence of concurrency?

- The OS must
  - Keep track of various processes
  - Allocate and de-allocate resources
  - Protect the data and resources against interference by other processes
  - Manage concurrency properly

Process Interaction Scenarios

- Can be divided in three categories:
  - Processes unaware of each other
    - Competition
  - Processes indirectly aware of each other
    - Co-operation by sharing
  - Processes directly aware of each other
    - Co-operation by communication

Process Interaction: Unaware

- Example: Multiprogramming
  - Each process has different goal
- OS needs to be concerned about the competition for resources
  - P1 and P2 may compete for Printer

- **Potential Control Problems:**
  - Mutual Exclusion
  - Deadlock
  - Starvation

Process Interaction: Unaware

- **Mutual Exclusion:**
  - If P1 and P2 both need printer
    - Mutual exclusion should be enforced
  - Only one process should be allowed to use printer at a time
- Critical Resource:
  - Printer can be called a critical resource for this case
- Critical Section:
  - The part of code where printer is being accessed can be called critical section

Process Interaction: Unaware

- **Deadlock:**
  - Occurs due to enforcement of mutual exclusion

  - Consider two processes (P1,P2) and two resources (R1,R2)
  - Process P1 is allocated R1 and P2 is allocated R2
  - P1 requires R2 to complete and P2 requires R1 to complete --- Deadlock!

Process Interaction: Unaware

- **Starvation:**
  - Occurs due to enforcement of mutual exclusion

  - Consider that three processes P1,P2 and P3 need periodic access to resource R
  - If P1 is allotted R --- P2, P3 get delayed
  - When P1 exits critical section, either P2 or P3 will be allowed to enter critical section
    - Suppose P3 is granted access
    - After P3, if P1 gets access to R again, P2 might suffer from starvation

Process Interaction: Unaware

- Hence, the general structure for each process should be as follows:

```
void P1 {
  while(true) {
        //Preceding Code
        enterCritical(Ra);
        //critical section
        exitcritical(Ra);
        //following Code
        }
  }
```

Process Interaction: Indirect Awareness

- Multiple processes may have access to shared variables / files / databases

- Integrity needs to be ensured

- Data is held on resources e.g. memory or other storage
  - Same control problems occur – Mutual Exclusion, Deadlock, Starvation
  - Difference here is we need only write operations to be mutually exclusive

Process Interaction: Indirect Awareness

- One more requirement: Data Coherence
- Consider the code given which has to make sure that a=b. (a and b are initialized with same value)

```
P1:
        a = a + 1;
        b = b + 1;
P2:
        b = 2 * b;
        a = 2 * a;
```

Process Interaction: Indirect Awareness

- Assume that mutual exclusion is done on a and b (If P1 is updating a, P2 can not update a)
- If the processes execute as given below, then a=b will not hold

```
a = a + 1;
b = 2 * b;
b = b + 1;
a = 2 * a;
```

- So we need to put entire execution sequence in critical section

Process Interaction: Direct Awareness

- Processes co-operate by communication
- When processes cooperate by communication, they participate in a common effort that links all of the processes.
- The communication provides a way to synchronize, or coordinate, the various activities.

Process Interaction: Direct Awareness

- Because nothing is shared between processes in the act of passing messages, mutual exclusion is not a control requirement for this sort of cooperation.

- However, the problems of deadlock (P1 & P2 waiting for messages from each other) and starvation (P1 and P2 keep communicating, starving P3) are still present.

Process Interaction

Table 5.2 Process Interaction

Degree of Awareness	Relationship	Influence That One Process Has on the Other	Potential Control Problems
Processes unaware of each other	Competition	• Results of one process independent of the action of others • Timing of process may be affected	• Mutual exclusion • Deadlock (renewable resource) • Starvation
Processes indirectly aware of each other (e.g., shared object)	Cooperation by sharing	• Results of one process may depend on information obtained from others • Timing of process may be affected	• Mutual exclusion • Deadlock (renewable resource) • Starvation • Data coherence
Processes directly aware of each other (have communication primitives available to them)	Cooperation by communication	• Results of one process may depend on information obtained from others • Timing of process may be affected	• Deadlock (consumable resource) • Starvation

Requirements for Mutual Exclusion

- Only one process at a time is allowed in the critical section for a resource
- A process that halts in its noncritical section must do so without interfering with other processes
- No deadlock or starvation
- A process must not be delayed access to a critical section when there is no other process using it
- No assumptions are made about relative process speeds or number of processes
- A process remains inside its critical section for a finite time only

How to achieve the Requirements of Mutual Exclusion?

- Three ways possible

1. Leave the responsibility to the processes
   - High overhead
2. Use special purpose machine instructions (hardware support)
   - Reduces overhead
3. Support of OS
   - Most popular

Hardware Support for Mutual Exclusion

- Two methods:

  1. Interrupt Disabling

  2. Special Machine Instructions

Disabling Interrupts

- Uniprocessors only allow interleaving
- A process runs until it invokes an operating system service or until it is interrupted
- Disabling interrupts guarantees mutual exclusion

- **Issues:**
  - – Execution efficiency is degraded as interleaving gets limited.
  - – Will not work in multiprocessor architecture

Pseudo-Code

```
while (true) {
   /* disable interrupts */;
   /* critical section */;
   /* enable interrupts */;
   /* remainder */;
}
```

Special Machine Instructions

- Compare&Swap Instruction
  - also called a “compare and exchange instruction”
- Exchange Instruction

Compare&Swap Instruction

```
int compare_and_swap (int *word,
  int testval, int newval)
{
   int oldval;
   oldval = *word;
   if (oldval == testval) *word = newval;
   return oldval;
}
```

Compare&Swap Instruction

- This version of the instruction checks a memory location (*word) against a test value (testval).

- If the memory location's current value is testval, it is replaced with newval;
  - otherwise it is left unchanged.

- The old memory value is always returned;
  - thus, the memory location has been updated if the returned value is the same as the test value.
- This is an atomic instruction

Mutual Exclusion

```
/* program mutualexclusion */
const int n = /* number of processes */;
int bolt;
void P(int i)
{
   while (true) {
     while (compare_and_swap(bolt, 0, 1) == 1)
          /* do nothing */;
      /* critical section */;
      bolt = 0;
      /* remainder */;
   }
}
void main()
{
   bolt = 0;
   parbegin (P(1), P(2), ... ,P(n));

}
```

(a) Compare and swap instruction

Mutual Exclusion

- Bolt is initialized to 0
- First call (P1) would be C&S(0,0,1)
  - Word and testval same so word gets updated
  - Return value is 0, hence P1 can enter critical section (while condition false)

- P2 calls C&S(1,0,1)
  - No change
  - Return value is 1, hence P2 waits (while condition true)

Exchange instruction

```
void exchange (int register, int
  memory)
{
   int temp;
   temp = memory;
   memory = register;
   register = temp;
}
```

- Exchange the contents of register with the content of memory location

Mutual Exclusion

```
    /* program mutualexclusion */
int const n = /* number of processes**/;
int bolt;
void P(int i)
{
    int keyi = 1;
    while (true) {
        do exchange (keyi, bolt)
        while (keyi != 0);
        /* critical section */;
        bolt = 0;
        /* remainder */;
    }
}
void main()
{
    bolt = 0;
    parbegin (P(1), P(2), . . ., P(n));
}
```

(b) Exchange instruction

Mutual Exclusion

- For process P1,
  - keyi=1, exchange(1,0) is called
  - keyi=0, bolt=1
  - P1 enters critical section

- For process P2,
  - keyi=1, exchange(1,1) is called
  - No change, P2 waits

Hardware Mutual Exclusion: Advantages

- Applicable to any number of processes on either a single processor or multiple processors sharing main memory
- It is simple and therefore easy to verify
- It can be used to support multiple critical sections

Hardware Mutual Exclusion: Disadvantages

- Busy-waiting consumes processor time
- Starvation is possible when a process leaves a critical section and more than one process is waiting.
  - Some process could indefinitely be denied access.
- Deadlock is possible
  - P1 runs and calls C&S
  - Interrupted due to high priority process P2
  - P2 runs but needs the resource occupied by P1

Semaphore

- OS and Programming language based mechanism
- Two or more processes co-operate using signals
  - A process has to stop at a place until it receives a signal
  - Special variables – Semaphores are used for this purpose
- Operations on Semaphores (all of which are atomic):
  - initialize,
  - Decrement (`semWait`)
  - increment. (`semSignal`)

Operations on Semaphores

- A semaphore may be initialized to a nonnegative integer value.

- The semWait operation decrements the semaphore value.
  - If the value becomes negative, then the process executing the semWait is blocked.
  - Otherwise, the process continues execution.

Operations on Semaphores

- The semSignal operation increments the semaphore value.
  - If the resulting value is less than or equal to zero, then a process blocked by a semWait operation, if any, is unblocked.

- This type of semaphores are called Counting / General semaphores

Semaphore Primitives

```
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 5.3 A Definition of Semaphore Primitives

Binary Semaphores

- Restricted version of counting semaphores
- Operations on Semaphores (all of which are atomic):
  - Initialize
  - Decrement (`semWaitB`)
  - increment. (`semSignalB`)

Binary Semaphores

- A binary semaphore may be initialized to either zero or one.

- The semWaitB operation checks the semaphore value
  - If the value is zero, process is blocked
  - Otherwise, value is changed to zero and the process continues execution.

Binary Semaphores

- The semSignalB operation checks if any processes are blocked (semaphore value zero)
  - If blocked, one process is unblocked
  - If no processes are blocked, value is set to One.

Binary 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 5.4 A Definition of Binary Semaphore Primitives

Strong/Weak Semaphore

- A queue is used to hold processes waiting on the semaphore
  - In what order are processes removed from the queue?

- ***Strong Semaphores*** use FIFO

- ***Weak Semaphores*** don't specify the order of removal from the queue

Mutual Exclusion Using Semaphores

```
/* program mutualexclusion */
const int n = /* number of processes  */;
semaphore s = 1;
void P(int i)
{
     while (true) {
          semWait(s);
          /* critical section   */;
          semSignal(s);
          /* remainder   */;
     }
}
void main()
{
     parbegin (P(1), P(2), . . ., P(n));
}
```

Figure 5.6 Mutual Exclusion Using Semaphores

Mutual Exclusion Using Semaphores

- All processes need the same resource, hence each process contains a critical section to access the resource
- First process executing semWait will be allowed to enter critical section, rest of the processes will be blocked
- When a process exits critical section, semaphore value is incremented, so any one blocked process will be allowed to enter critical section

- Can the same solution work for multiple critical sections?

Mutual Exclusion Using Semaphores

- If the value of s is positive,
  - Equal to number of processes that can issue semWait and access critical section

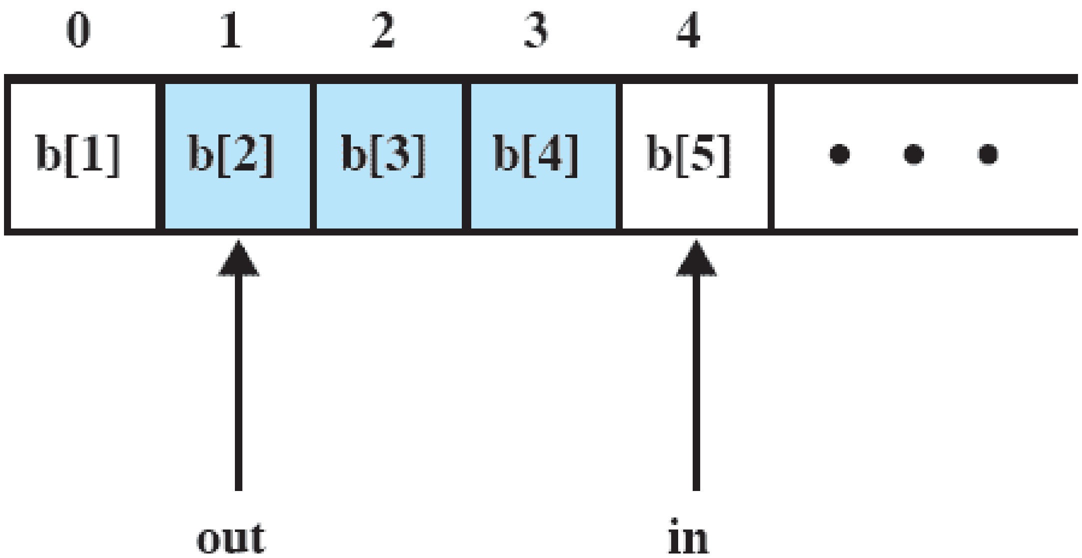
- If the value of s is zero,
  - Next process that issues semWait will be blocked

- If the value of s is negative,
  - Equal to the number of processes waiting

Producer/Consumer Problem

- **General Situation:**
  - 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 time
  - Only one producer or consumer may access the buffer at any one time
- **The Problem:**
  - Ensure that the Producer can’t add data into full buffer and consumer can’t remove data from empty buffer

Buffer



Note: shaded area indicates portion of buffer that is occupied

Figure 5.8 Infinite Buffer for the Producer/Consumer Problem

Functions

- Assume an infinite buffer ***b*** with a linear array of elements

Producer	Consumer

while (true) {
    /* produce item v */
    b[in] = v;
    in++;
}
	while (true) {
	    while (in <= out)
	    /*do nothing */;
	    w = b[out];
	    out++;
	    /* consume item w */
	}

Incorrect Solution

```
/* 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);
}
```

Possible Scenario

Table 5.4 Possible Scenario for the Program of Figure 5.9

	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		semiSignlaB(s)	1	–1	0

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

Solution?

- What will happen if the conditional statement is moved inside critical section?
  - Deadlock!
    - Consumer would block in critical section
    - Producer can't enter critical section to unblock consumer

Correct Solution

```
/* 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);
}
```

Using Counting 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 5.11 A Solution to the Infinite-Buffer Producer/Consumer Problem Using Semaphores

Cases to consider

- To check the working of solution, we can test the following scenarios:
  – Producer runs before consumer
  – Consumer runs before producer
  – Multiple producers run and then consumer runs

- Will the interchange of first two lines in consumer code create any issue?

Bounded Buffer

Block on:	Unblock on:
Producer: insert in full buffer	Consumer: item inserted
Consumer: remove from empty buffer	Producer: item removed

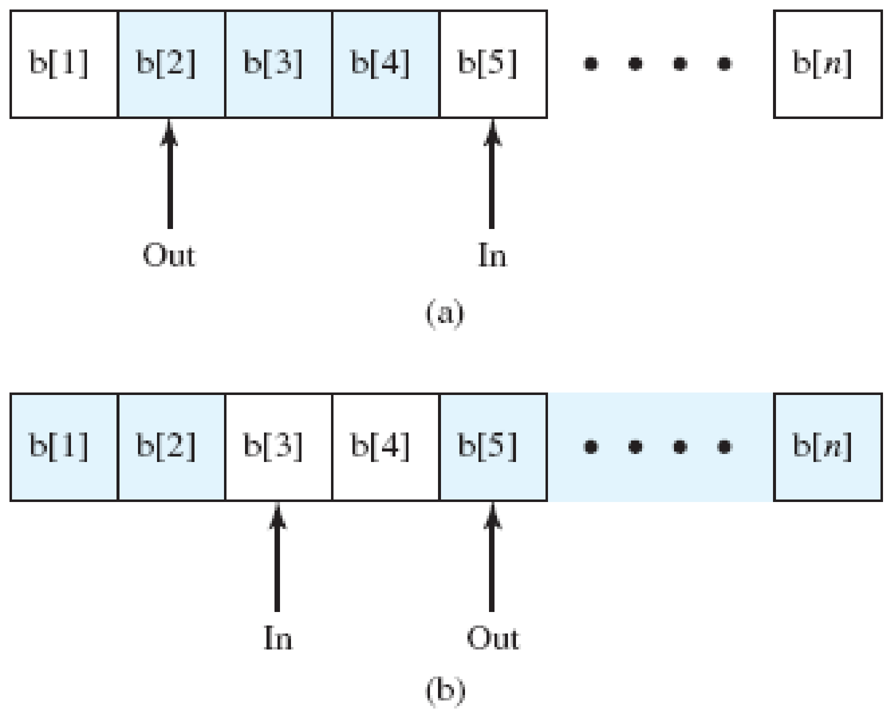


Figure 5.12 **Finite Circular Buffer for the Producer/Consumer Problem**

Bounded Buffer

- Three semaphores needed:
  - S: Mutual Exclusion
  - E: Keep track of empty spaces
  - N: Number of items
- What should be the initial values for semaphores?

Bounded Buffer

```
/* 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);
}
```

Functions in a Bounded Buffer

Producer	Consumer

while (true) {
    /* produce item v */
    while ((in + 1) % n == out) /* do nothing */;
    b[in] = v;
    in = (in + 1) % n
}
	while (true) {
	    while (in == out)
	        /* do nothing */;
	    w = b[out];
	    out = (out + 1) % n;
	    /* consume item w */
	}

Monitors

- Semaphores are difficult to control as semWait and SemSignal calls can be scattered throughout the program.
- The Monitor is a programming-language construct that provides equivalent functionality to that of semaphores and that is easier to control.

- Monitor contains:
  - One or more procedures
  - Initialization sequence
  - Local data

Chief characteristics

1. Local data variables are accessible by monitor's procedures
2. A process enters monitor by invoking one of its procedures
3. Only one process may be executing in the monitor at a time
   – Any other process invoking monitor is blocked

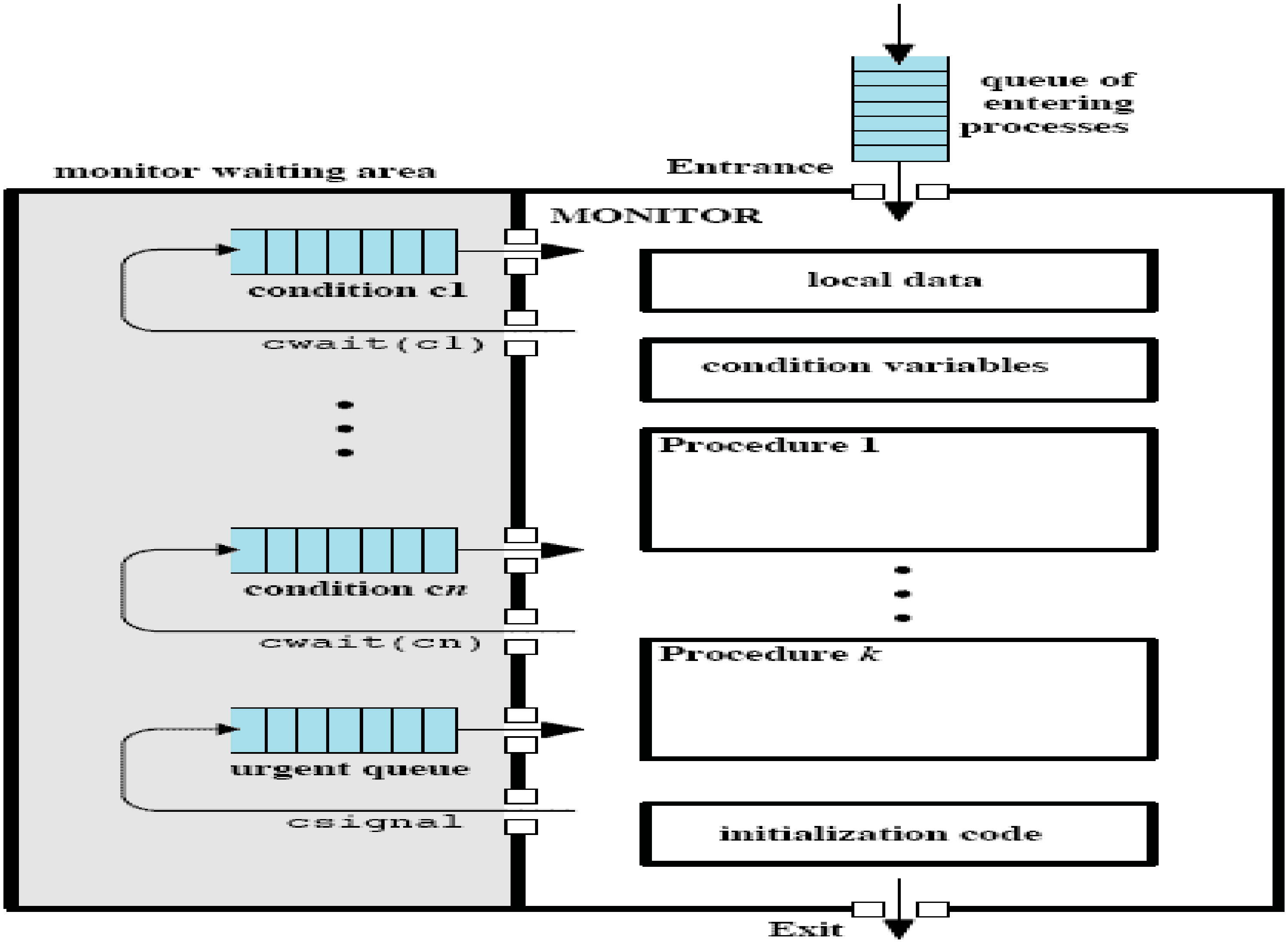
- 1^{st} and 2^{nd} are like OOP
- 3^{rd} provides mutual exclusion

Synchronization

- Synchronisation achieved by condition variables within a monitor

- **Monitor 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
- **Difference with Semaphores:**
  - If a process in monitor signals and no task is waiting on condition variable, the signal is lost

Structure of a Monitor



Structure of a Monitor

- Although a process can enter the monitor by invoking any of its procedures, we can think of the monitor as having a single entry point that is guarded so that only one process may be in the monitor at a time.
  - Other processes that attempt to enter the monitor join a queue of processes blocked waiting for monitor availability.
- Once a process is in the monitor, it may temporarily block itself on condition x by issuing cwait(x)

Structure of a Monitor

- It is then placed in a queue of processes waiting to re-enter the monitor when the condition changes, and resume execution at the point in its program following the cwait(x) call.

- If a process that is executing in the monitor detects a change in the condition variable x, it issues csignal(x), which alerts the corresponding condition queue that the condition has changed.

Bounded Buffer Solution Using 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 */
}
```

Bounded Buffer Solution Using Monitor

- Notfull is true when there is a room to add at least once character to the buffer
- Notempty is true when there is at least one character in the buffer
- Producer can add characters to the buffer by means of append procedure only
- Consumer can remove characters from the buffer by means of take procedure only
- **“Monitor itself enforces mutual exclusion, programmer has to manage synchronization only”**
- “Semaphores require programmer to manage both”

Solution Using Monitor

```
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);
}
```

Message Passing

- When processes interact with one another, two fundamental requirements must be satisfied:
  - synchronization and
  - communication.

- The actual function of message passing is normally provided in the form of a pair of primitives:
  - send (destination, message)
  - receive (source, message)

Synchronization

- “Communication requires synchronization”
  - Sender must send before receiver can receive

- What happens to a process after it issues a send or receive primitive?
  - Sender and receiver may or may not be blocking (waiting for message)

Message Passing

- Using these functions, three useful combinations are commonly used:

1. Blocking Send, Blocking Receive
2. Non Blocking Send, Blocking Receive
3. Non Blocking Send, Non Blocking Receive

Blocking send, Blocking receive

- Both sender and receiver are blocked until message is delivered
- Known as a *rendezvous*
- Allows for tight synchronization between processes.

Non-blocking Send

- More natural for many concurrent programming tasks

- Nonblocking send, blocking receive
  - Sender continues on
  - Receiver is blocked until the requested message arrives

- Nonblocking send, nonblocking receive
  - Neither party is required to wait

Addressing

- Sending process need to be able to specify which process should receive the message

- Two Types:
  - Direct addressing
  - Indirect Addressing

Direct Addressing

- Send primitive includes a specific identifier of the destination process
- Receive primitive could know ahead of time which process a message is expected OR
- Receive primitive could use source parameter to return a value when the receive operation has been performed

Indirect addressing

- Messages are sent to a shared data structure consisting of queues
- Queues are called *mailboxes*

- One process sends a message to the mailbox and the other process picks up the message from the mailbox

- **Advantage:**
  – Decoupling of sender and receiver

Indirect addressing

- **Four Types:**

1. One to One -- e.g. private communication
2. One to Many – e.g. broadcast
3. Many to One – e.g. client-server
4. Many to Many – e.g. multiple clients, multiple servers

Indirect Process Communication

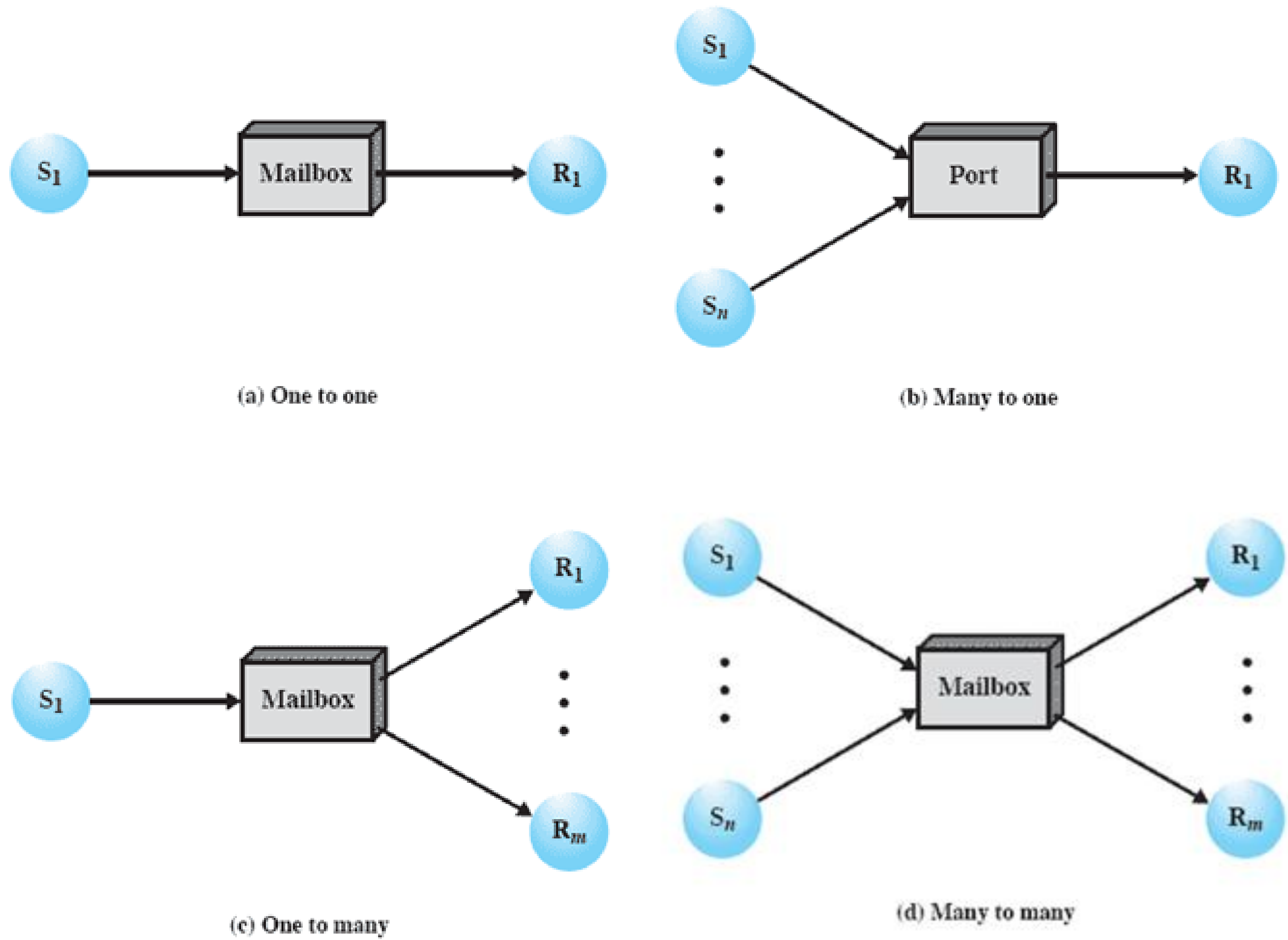


Figure 5.18 Indirect Process Communication

General Message Format

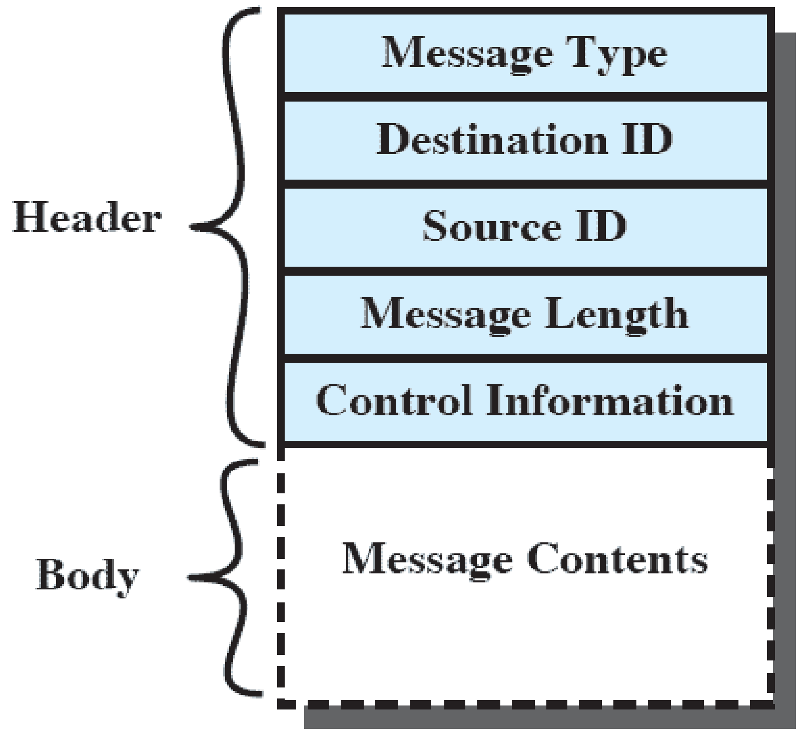


Figure 5.19 General Message Format

Mutual Exclusion Using Messages

- The approach can be designed as follows:
  - Attempt to receive the message
  - If MailBox is empty
    - block the process
  - Else
    - Enter Critical Section
    - Extract Message
    - Place Message in box for other processes
- Nonblocking send, blocking receive approach

Mutual Exclusion Using Messages

```
/* program mutualexclusion */
const int n = /* number of processes  */;
void P(int i)
{
    message msg;
    while (true) {
     receive (box, msg);
     /* critical section   */;
     send (box, msg);
     /* remainder   */;
    }
}
void main()
{
    create mailbox (box);
    send (box, null);
    parbegin (P(1), P(2), . . ., P(n));
}
```

Figure 5.20 Mutual Exclusion Using Messages

Mutual Exclusion Using Messages

- We assume the use of the blocking receive primitive and the non-blocking send primitive.

- This assumes that if more than one process performs the receive operation concurrently, then
  - If there is a message, it is delivered to only one process and the others are blocked, or
  - If the message queue is empty, all processes are blocked; when a message is available, only one blocked process is activated and given the message.

Producer/Consumer Messages

```
const int
    capacity = /* buffering capacity */ ;
    null =/* empty message */ ;
int i;
void producer()
{   message pmsg;
    while (true) {
     receive (mayproduce, pmsg);
     pmsg = produce();
     send (mayconsume, pmsg);
    }
}
void consumer()
{   message cmsg;
    while (true) {
     receive (mayconsume, cmsg);
     consume (cmsg);
     send (mayproduce, null);
    }
}

void main()
{
    create_mailbox (mayproduce);
    create_mailbox (mayconsume);
    for (int i = 1; i <= capacity; i++) send (mayproduce, null);
    parbegin (producer, consumer);
}
```

Producer/Consumer Messages

- Two mailboxes are used.
  - As the producer generates data, it is sent as messages to the mailbox mayconsume.
  - As long as there is at least one message in that mailbox, the consumer can consume.

- Hence mayconsume serves as the buffer; the data in the buffer are organized as a queue of messages.

Producer/Consumer Messages

- The “size” of the buffer is determined by the global variable capacity.
- Initially, the mailbox mayproduce is filled with a number of null messages equal to the capacity of the buffer.
- The number of messages in mayproduce shrinks with each production and grows with each consumption.

Readers/Writers Problem

- A data area is shared among many processes
  - Some processes only read the data area, some only write to the area
- Conditions to satisfy:
  1. Multiple readers may read the file at once.
  2. Only one writer at a time may write
  3. If a writer is writing to the file, no reader may read it.

Readers have Priority

```
/* 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);
}
```

Writers 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);
    }
}
```

Writers have Priority

```
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);
}
```