Interprocess Communication

Interprocess Communication

- Consider shell pipeline
  - *cat* chapter1 chapter2 chapter3 | *grep* tree
  - 2 processes
  - Information sharing
  - Order of execution

Interprocess Communication

- Processes within a system may be **independent** or **cooperating**
- Cooperating process can affect or be affected by other processes
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes require a mechanism to exchange data and information

IPC issues

1. How one process passes information to another ?
2. How to make sure that two or more processes do not get into each other’s way when engaging in critical activities?
3. How to do proper sequencing when dependencies are present?

- Ans 1: easy for threads, for processes different approaches (e.g., message passing, shared memory)
- Ans 2 and Ans 3: same problems and same solutions apply for threads and processes
  - Mutual exclusion & Synchronization

Spooling Example: Correct

Process 1

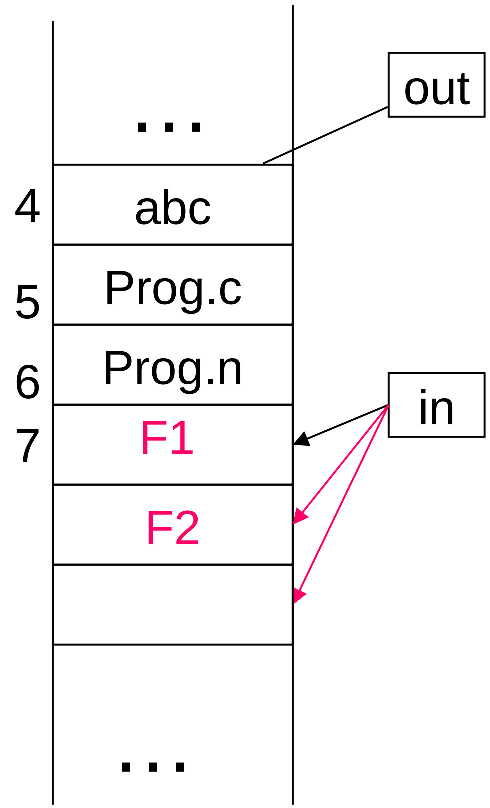
int next_free;

1 next_free = in;

2 Stores F1 into next_free;

3 in=next_free+1

Shared memory



Process 2

int next_free;

4 next_free = in

5 Stores F2 into next_free;

6 in=next_free+1

Spooling Example: Races

Process 1

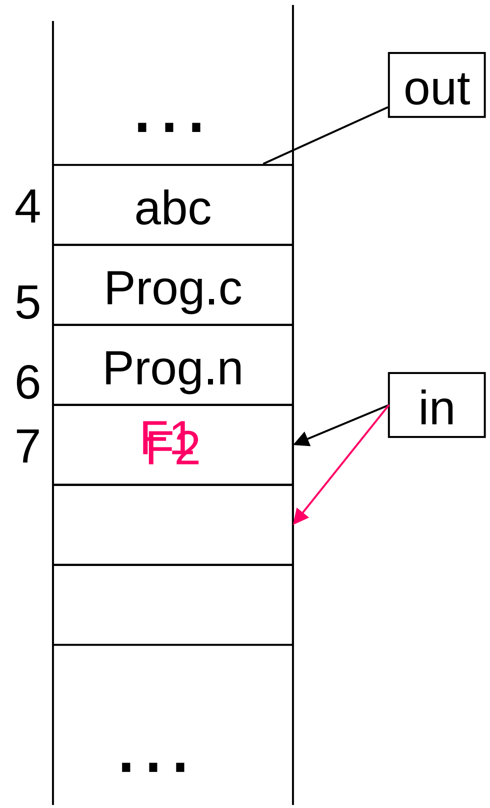
int next_free;

1 next_free = in;

3 Stores F1 into next_free;

4 in=next_free+1

Shared memory



Process 2

int next_free;

2 next_free = in
/* value: 7 */

5 Stores F2 into next_free;

6 in=next_free+1

Better Coding?

- In previous code

```
for(;;){
   int next_free = in;
   slot[next_free] = file;
   in = next_free+1;
}
```

- What if we use one line of code?

```
for(;;){
   slot[in++] = file
}
```

When Can process Be switched?

- After each machine instruction!
- `in++` is a C/C++ statement, translated into three machine instructions:
  - load mem, R
  - inc R
  - store R, mem
- Interrupt (and hence process swichting) can happen in between.

Race condition

- Two or more processes are reading or writing some shared data and the final result depends on who runs precisely when
- Very hard to Debug

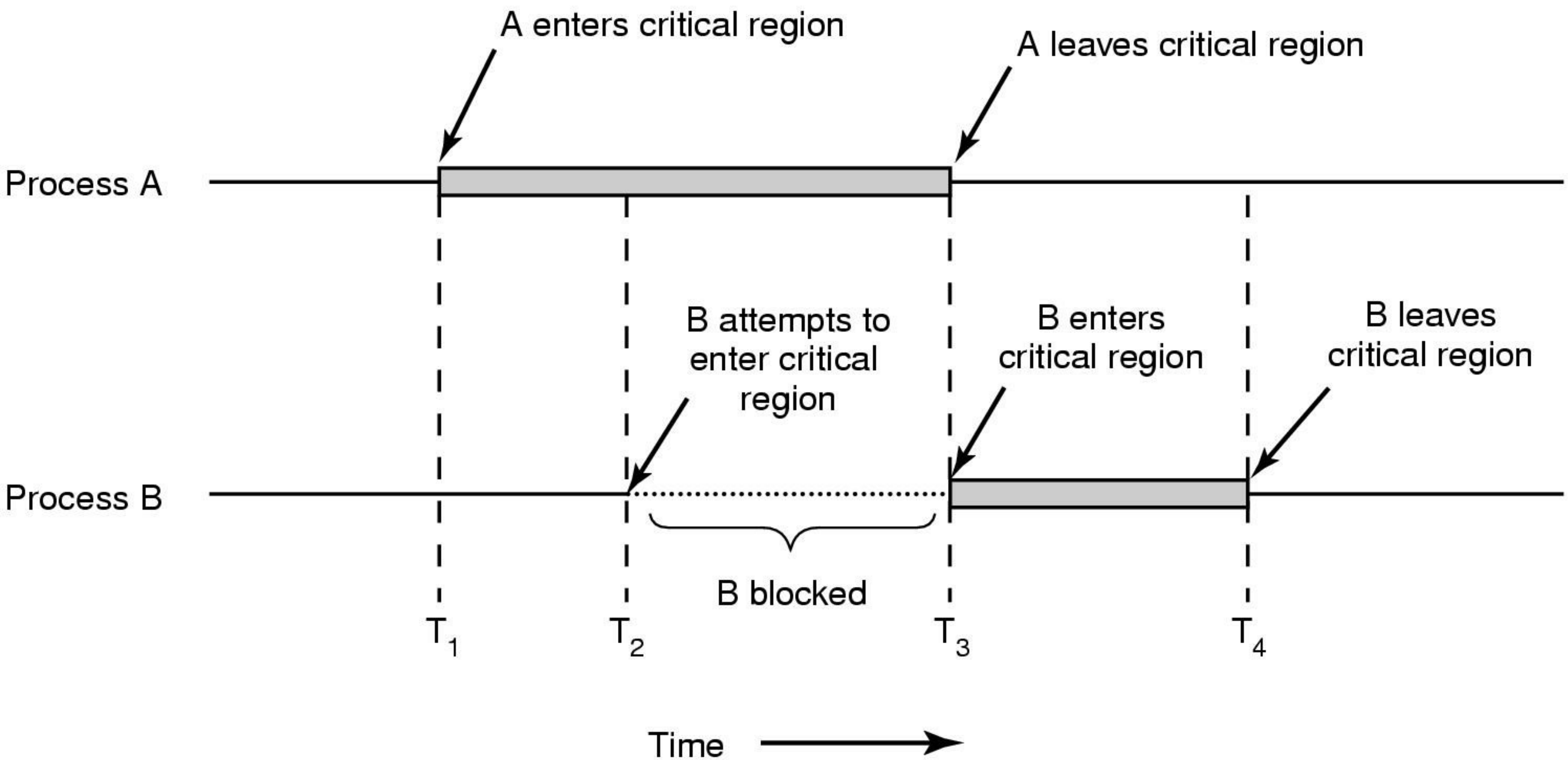
Critical Region

- That part of the program that do critical things such as accessing shared memory
- Can lead to race condition

Solution Requirement

1) No two processes simultaneously in critical region
2) No assumptions made about speeds or numbers of CPUs
3) No process running outside its critical region may block another process
4) No process must wait forever to enter its critical region

Solution Requirement



Mutual exclusion With Busy Waiting

- Possible Solutions
  - Disabling Interrupts
  - Lock Variables
  - Strict Alternation
  - Peterson's solution
  - TSL

Disabling Interrupts

- How does it work?
  - Disable all interrupts just after entering a critical section
  - Re-enable them just before leaving it.

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

- Why does it work?
  - With interrupts disabled, no clock interrupts can occur
  - No switching can occur
- Problems:
  - What if the process forgets to enable the interrupts?
  - Multiprocessor? (disabling interrupts only affects one CPU)

Lock Variables

```
int lock = 0;
while (lock);
lock = 1;
//EnterCriticalSection;
  access shared variable;
//LeaveCriticalSection;
lock = 0;
```

Does the above code work?

Lock Variables

```
int lock = 0;
while (lock);
Check again here?
lock = 1;
//EnterCriticalSection;
   access shared variable;
//LeaveCriticalSection;
lock = 0;
```

Still doesn't work!

Strict Alternation

```
while (TRUE) {
    while (turn != 0)        /* loop */ ;
    critical_region( );
    turn = 1;
    noncritical_region( );
}
```

(a)

```
while (TRUE) {
    while (turn != 1)        /* loop */ ;
    critical_region( );
    turn = 0;
    noncritical_region( );
}
```

(b)

(a)Process 0 **(b) Process 1**

Proposed solution to critical region problem

Problem

- Busy waiting: Continuously testing a variable until some value appear
  - Wastes CPU time
- Violates condition 3
  - When one process is much slower than the other

Peterson's solution

- Consists of 2 procedures
- Each process has to call
  - `enter_region` with its own process # before entering its C.R.
  - And `Leave_region` after leaving C.R.

```
do{

    enter_region(process#)
        critical section

    leave_region(process#)
        remainder section

} while (TRUE);
```

Peterson's solution (for 2 processes)

```
#define FALSE  0
#define TRUE   1
#define N      2                          /* number of processes */

int turn;                                 /* whose turn is it? */
int interested[N];                        /* all values initially 0 (FALSE) */

void enter_region(int process);           /* process is 0 or 1 */
{
     int other;                           /* number of the other process */

     other = 1 – process;                 /* the opposite of process */
     interested[process] = TRUE;          /* show that you are interested */
     turn = process;                      /* set flag */
     while (turn == process && interested[other] == TRUE) /* null statement */ ;
}

void leave_region(int process)            /* process: who is leaving */
{
     interested[process] = FALSE;         /* indicate departure from critical region */
}
```

Peterson’s Solution: Analysis(1)

- Let Process 1 is not interested and Process 0 calls enter_region with 0
- So, turn = 0 and interested[0] = true and Process 0 is in CR
- Now if Process 1 calls enter_region, it will hang there until interested[0] is false. Which only happens when Process 0 calls leave_region i.e. leaves the C.R.

Peterson’s Solution: Analysis(2)

- Let both processes call enter_region simultaneously
- Say turn = 1. (i.e. Process 1 stores last)
- Process 0 enters critical region: while (turn = = 0 && …) returns false since turn = 1.
- Process 1 loops until process 0 exits: while (turn = = 1 && interested[0] = = true) returns true.
- It works fine!!

Busy Waiting: Problems

- Waste CPU time since it sits on a tight loop
- May have unexpected effects:
  - **Priority Inversion Problem**

Example:

- 2 Cooperating Processes: H (high priority) and L (low priority)
- *Scheduling rule:* H is run whenever it is ready
- Let L in C. R. and H is ready and wants to enter C.R.
- Since H is ready it is given the CPU and it starts busy waiting
- L will never gets the chance to leave its C.R.
- H loops forever

Sleep & wakeup

- When a process has to wait, change its state to **BLOCKED**
- Switched to **READY** state, when it is OK to retry entering the critical section
- Sleep is a system call that causes the caller to block
  - be suspended until another process wakes it up
- Wakeup system call has one parameter, the process to be awakened.
- Let's illustrate the use of sleep & wakeup with an example: The producer consumer problem

Producer Consumer Problem

- Also called bounded-buffer problem
- Two (or *m*+*n*) processes share a common buffer
- One (or *m*) of them is (are) **producer**(s): put(s) information in the buffer
- One (or *n*) of them is (are) **consumer**(s): take(s) information out of the buffer
- Trouble and solution
  - Producer wants to put but buffer full- Go to **sleep** and **wake up** when consumer takes one or more
  - Consumer wants to take but buffer empty- go to sleep and wake up when producer puts one or more

Sleep and Wakeup

```
#define N 100                                  /* number of slots in the buffer */
int count = 0;                                 /* number of items in the buffer */

void producer(void)
{
      int item;

      while (TRUE) {                           /* repeat forever */
            item = produce_item( );            /* generate next item */
            if (count == N) sleep( );          /* if buffer is full, go to sleep */
            insert_item(item);                 /* put item in buffer */
            count = count + 1;                 /* increment count of items in buffer */
            if (count == 1) wakeup(consumer);  /* was buffer empty? */
      }
}


void consumer(void)
{
      int item;

      while (TRUE) {                           /* repeat forever */
            if (count == 0) sleep( );          /* if buffer is empty, got to sleep */
            item = remove_item( );             /* take item out of buffer */
            count = count − 1;                 /* decrement count of items in buffer */
            if (count == N − 1) wakeup(producer); /* was buffer full? */
            consume_item(item);                /* print item */
      }
}
```

Sleep and Wakeup

```
#define N 100                              /* number of slots in the buffer */
int count = 0;                             /* number of items in the buffer */
```

```
void producer(void)
{
      int item;

      while (TRUE) {
            item = produce_item( );
            if (count == N) sleep( );
            insert_item(item);
            count = count + 1;
            if (count == 1) wakeup(consumer);
      }
}
```

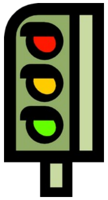
```
void consumer(void)
{
      int item;

      while (TRUE) {                                          /
            if (count == 0) sleep( );                         /
            item = remove_item( );                            /
            count = count − 1;                                /
            if (count == N − 1) wakeup(producer);
            consume_item(item);                               /
      }
}
```

Producer-consumer problem

Sleep and Wakeup: Race condition

- **Busy waiting problem is resolved but the following** race condition **exists**
- Unconstrained access to *count*
  - CPU is given to P just after C has read count to be 0 but not yet gone to sleep.
  - P calls wakeup
  - Result is lost wake-up signal
  - Both will sleep forever

Semaphores



- A new variable type
- A kind of generalized lock
  - First defined by Dijkstra in late 60s
  - Main synchronization primitive used in original UNIX
- Semaphores are like integers, except
  - No negative values
  - Only operations allowed are *up* and *down* – can't read or write value, except to set it initially

Semaphores: Types

- **Counting semaphore**.
  - The value can range over an unrestricted domain
- **Binary semaphore**
  - The value can range only between 0 and 1.
  - On some systems, binary semaphores are known as mutex locks as they provide mutual exclusion

Semaphores: Operation

- Operation “down”:
  - if value > 0; value-- and then continue.
  - if value = 0; process is put to sleep without completing the down for the moment
    - Checking the value, changing it, and possibly going to sleep, is all done as an ***atomic*** *action*.
- Operation “up”:
  - increments the value of the semaphore addressed.
  - If one or more process were sleeping on that semaphore, one of them is chosen by the system (e.g. at random) and is allowed to complete its *down*
    - The operation of incrementing the semaphore and waking up one process is also indivisible
  - No process ever blocks doing an *up*.

Semaphores: Atomicity

- Operations must be atomic
  - Two *down*’s together can’t decrement value below zero
  - Similarly, process going to sleep in *down* won’t miss wakeup from *up* – even if they both happen at same time

Producer & consumer

```
#define N 100                          /* number of slots in the buffer */
typedef int semaphore;                 /* semaphores are a special kind of int */
semaphore mutex = 1;                   /* controls access to critical region */
semaphore empty = N;                   /* counts empty buffer slots */
semaphore full = 0;                    /* counts full buffer slots */
```

```
void producer(void)
{
    int item;

    while (TRUE) {
        item = produce_item( );
        down(&empty);
        down(&mutex);
        insert_item(item);
        up(&mutex);
        up(&full);
    }
}
```

```
void consumer(void)
{
    int item;

    while (TRUE) {
        down(&full);
        down(&mutex);
        item = remove_item( );
        up(&mutex);
        up(&empty);
        consume_item(item);
    }
}
```

Semaphores in Producer Consumer Problem: Analysis

- 3 semaphores are used
  - *full* (initially 0) for counting occupied slots
  - *Empty* (initially *N*) for counting empty slots
  - *mutex* (initially 1) to make sure that Producer and Consumer do not access the buffer at the same time.
- Here 2 uses of semaphores
  - Mutual exclusion (mutex)
  - Synchronization (full and empty)
    - To guarantee that certain event sequences do or do not occur

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

Semaphores: Usage

1. Mutual exclusion
2. Controlling access to limited resource
3. Synchronization

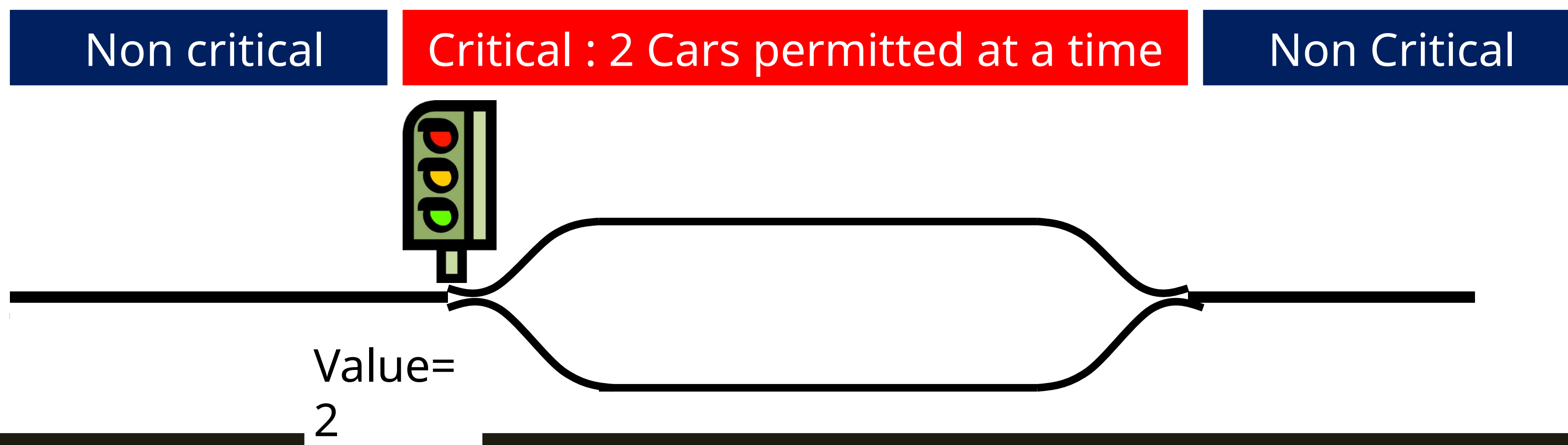
Mutual exclusion

- How to ensure that only one process can enter its C.R.?
- Binary semaphore initialized to 1
- Shared by all collaborating processes
- If each process does a *down* just before entering CR and an *up* just after leaving then mutual exclusion is guaranteed

```
do {
      down(mutex);
      // critical section
      up(mutex);
      // remainder section
} while (TRUE);
```

Controlling access to a resource

- What if we want maximum **m** process/thread can use a resource simultaneously ?
- Counting semaphore initialized to the number of available resources
- Semaphore from railway analogy
  - Here is a semaphore **initialized to 2** for resource control:



Synchronization

- How to resolve dependency among processes
- Binary semaphore initialized to 0
- consider 2 concurrently running processes:
  - P1 with a statement S1 and
  - P2 with a statement S2.
  - Suppose we require that S2 be executed only after S1 has completed.

```
S1;
up(synch);
```

```
down(synch)
;
S2;
```

Semaphores: “Be Careful”

- Suppose the following is done in Producer’s code

```
…
down(&empty)
down(&mutex)
…
```

```
…
down(&mutex)
down(&empty)
…
```

Just the order is reversed

- If buffer full P would block due to down(&empty) with mutex = 0.
- So now if C tries to access the buffer, it would block too due to its down(&mutex).
- Both processes would stay blocked forever: DEADLOCK

Monitors

- A higher level synchronization primitive
- A collection of procedures, variables and data structures grouped in a special kind of module or package.

monitor *example*
    integer *i*;
    condition *c*;

    procedure *producer*( );
    .
    .
    .
    end;

    procedure *consumer*( );
    .
    .
    .
    end;
end monitor;

Example of a monitor

Monitors

- Only one process can be active in a monitor at any instant
- Monitors are programming language construct, so the compiler knows they are special and can handle calls to monitor procedures differently from other calls.
- Because the compiler, not the programmer, is arranging the mutual exclusion, it is **safer**
- We also need a way to block and wakeup: Wait and Signal (done on a condition variables)

Monitors

- *wait* is called on some condition variables:
  - Calling process is blocked
  - another process that had been previously prohibited from entering the monitor is allowed to enter now.
- *signal* is called on some condition variable:
  - A process waiting on *that CV* is given the chance to get up.
  - Who should run? Caller or awakened one?

Alternative#1: Let newly awakened process to run suspending the caller.

Alternative#2: Process doing a signal must exit the monitor immediately i.e. signal statement may appear only as the final statement in a monitor procedure.

Alternative#3: Let the caller run and when it exits the monitor then the waiting process is allowed to start.

Note: If more than one processes are waiting on *full*, one of them is scheduled.

Outline of producer-consumer using Monitors

```
monitor ProducerConsumer
    condition full, empty;
    integer count;
    procedure insert(item: integer);
    begin
        if count = N then wait(full);
        insert_item(item);
        count := count + 1;
        if count = 1 then signal(empty)
    end;
    function remove: integer;
    begin
        if count = 0 then wait(empty);
        remove = remove_item;
        count := count − 1;
        if count = N − 1 then signal(full)
    end;
    count := 0;
end monitor;
```

```
procedure producer;
begin
    while true do
    begin
        item = produce_item;
        ProducerConsumer.insert(item)
    end
end;
procedure consumer;
begin
    while true do
    begin
        item = ProducerConsumer.remove;
        consume_item(item)
    end
end;
```

- Outline of producer-consumer problem with monitors
  - only one monitor procedure active at one time
  - buffer has N slots

Producer-consumer solution in Java

```
public class ProducerConsumer {
      static final int N = 100;      // constant giving the buffer size
      static producer p = new producer( );    // instantiate a new producer thread
      static consumer c = new consumer( );  // instantiate a new consumer thread
      static our_monitor mon = new our_monitor( );      // instantiate a new monitor

      public static void main(String args[ ]) {
         p.start( );      // start the producer thread
         c.start( );      // start the consumer thread
      }

      static class producer extends Thread {
         public void run( )  {// run method contains the thread code
            int item;
            while (true) {      // producer loop
               item = produce_item( );
               mon.insert(item);
            }
         }
         private int produce_item( ) { ... }      // actually produce
      }

      static class consumer extends Thread {
         public void run( )  { run method contains the thread code
            int item;
            while (true) {      // consumer loop
               item = mon.remove( );
               consume_item (item);
            }
         }
         private void consume_item(int item) { ... }// actually consume
      }
```

```
static class our_monitor {   // this is a monitor
    private int buffer[ ] = new int[N];
    private int count = 0, lo = 0, hi = 0;   // counters and indices

    public synchronized void insert(int val) {
        if (count == N) go_to_sleep( );     // if the buffer is full, go to sleep
        buffer [hi] = val; // insert an item into the buffer
        hi = (hi + 1) % N;        // slot to place next item in
        count = count + 1;        // one more item in the buffer now
        if (count == 1) notify( );         // if consumer was sleeping, wake it up
    }

    public synchronized int remove( ) {
        int val;
        if (count == 0) go_to_sleep( );     // if the buffer is empty, go to sleep
        val = buffer [lo]; // fetch an item from the buffer
        lo = (lo + 1) % N;        // slot to fetch next item from
        count = count – 1;        // one few items in the buffer
        if (count == N – 1) notify( ); // if producer was sleeping, wake it up
        return val;
   }
   private void go_to_sleep( ) { try{wait( );} catch(InterruptedException exc) {};}
  }
}
```

Problems with monitors and semaphores

- **Semaphores are too low level**
- **Monitors are not usable except in a few programming languages**
- **Designed to work in an environment having access to a** common **memory**
- **Doesn't allow information exchange among machines**
- **None of them would work in a distributed systems (why?) consisted of multiple CPUs, each with its** own **private memory connected by a LAN.**

Message Passing

- solution to the problem of semaphores and monitors w.r.t distributed systems
- A method of IPC that uses two primitives
  - send and receive: system calls.
  - send(destination, &message)
  - receive(source, &message)
  - If no message is available:
    - The receiver can block until one arrives
    - Return immediately with an error code

Message Passing

- Challenges (Study of Computer Networks)
  - Messages can be lost by the network.
  - Acknowledgement and retransmission issue.
  - Process naming.
  - Authentication.
  - Performance issue.

Producer Consumer with Message Passing

Assumptions:

- All messages are of same size
- Messages sent but not yet received are automatically buffered

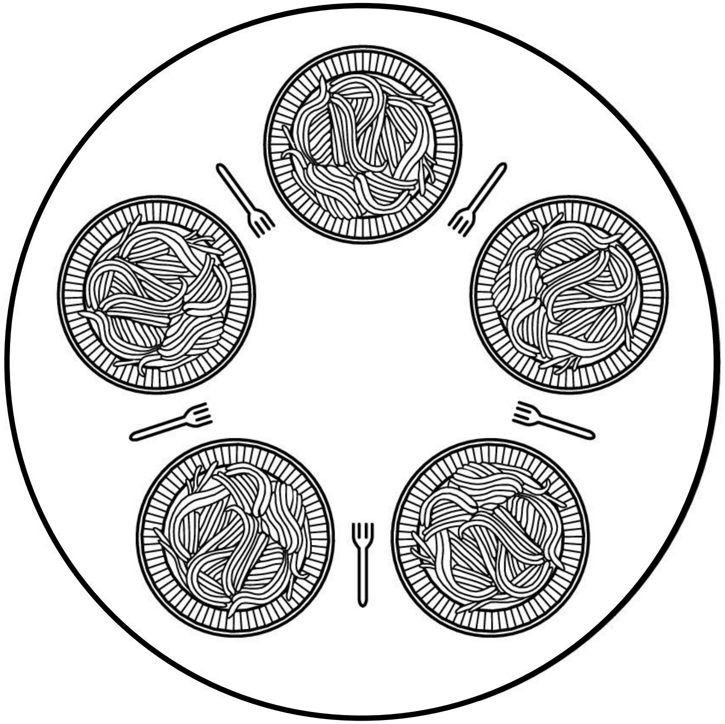
```
#define N 100                               /* number of slots in the buffer */

void producer(void)
{
     int item;
     message m;                             /* message buffer */

     while (TRUE) {
          item = produce_item( );           /* generate something to put in buffer */
          receive(consumer, &m);            /* wait for an empty to arrive */
          build_message(&m, item);          /* construct a message to send */
          send(consumer, &m);               /* send item to consumer */
     }
}

void consumer(void)
{
     int item, i;
     message m;

     for (i = 0; i < N; i++) send(producer, &m);  /* send N empties */
     while (TRUE) {
          receive(producer, &m);            /* get message containing item */
          item = extract_item(&m);          /* extract item from message */
          send(producer, &m);               /* send back empty reply */
          consume_item(item);               /* do something with the item */
     }
}
```

The producer-consumer problem with N messages

Dining Philosophers

An example problem for process synchronization

- Philosophers spend their lives thinking and eating
- Don’t interact with their neighbors
- When get hungry try to pick up 2 chopsticks (one at a time in either order) to eat
- Need both to eat, then release both when done
- How to program the scenario avoiding all concurrency problems?

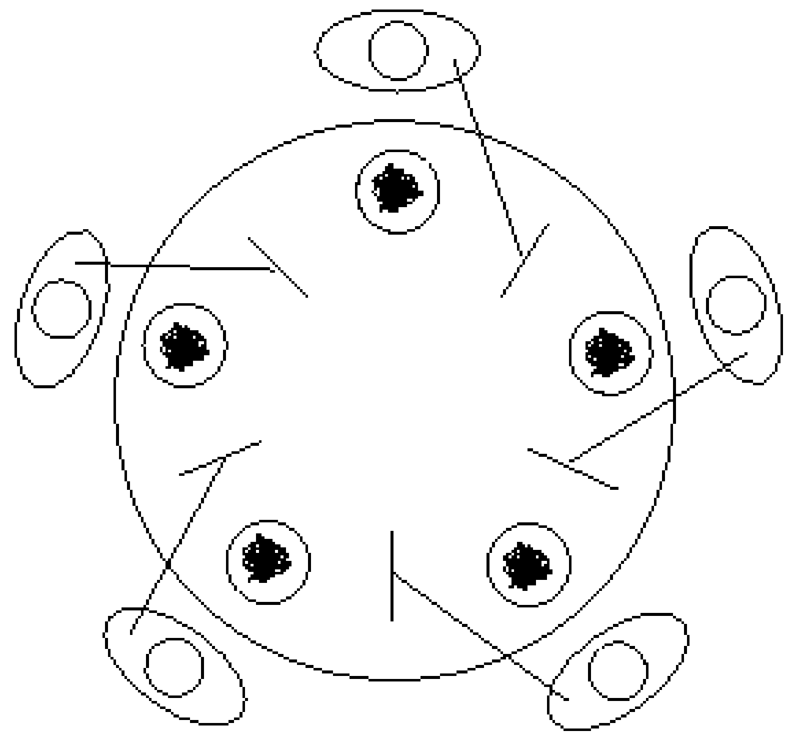


Dining Philosophers: A Solution

```
#define N 5                          /* number of philosophers */

void philosopher(int i)              /* i: philosopher number, from 0 to 4 */
{
     while (TRUE) {
          think( );                  /* philosopher is thinking */
          take_fork(i);              /* take left fork */
          take_fork((i+1) % N);      /* take right fork; % is modulo operator */
          eat( );                    /* yum-yum, spaghetti */
          put_fork(i);               /* put left fork back on the table */
          put_fork((i+1) % N);       /* put right fork back on the table */
     }
}
```

Dining Philosophers: Problems with Previous Solution

- Deadlock may happen
- Does this solution prevents any such thing from happening ?
  - Everyone takes the left
    fork simultaneously



Dining Philosophers: Problems with Previous Solution

Tentative Solution:

- After taking left fork, check whether right fork is available.
- If not, then return left one, wait for some time and repeat again.

Problem:

- All of them start and do the algorithm synchronously and simultaneously:
- STARVATION (A situation in which all the programs run indefinitely but fail to make any progress)
- Solution: Random wait; but what if the most unlikely of same random number happens?

Another Attempt, Successful!

```
void philosopher(int i)
{
  while (true)
  {
      think();
      down(&mutex);
      take_fork(i);
      take_fork((i+1)%N);
      eat();
      put_fork(i);
      put_fork((i+1)%N);
      up(&mutex);
  }
}
```

- Theoretically solution is OK- no deadlock, no starvation.
- Practically with a performance bug:
  - Only one philosopher can be eating at any instant: absence of parallelism

Final Solution part 1

```
#define N           5            /* number of philosophers */
#define LEFT        (i+N−1)%N    /* number of i's left neighbor */
#define RIGHT       (i+1)%N      /* number of i's right neighbor */
#define THINKING    0            /* philosopher is thinking */
#define HUNGRY      1            /* philosopher is trying to get forks */
#define EATING      2            /* philosopher is eating */
typedef int semaphore;           /* semaphores are a special kind of int */
int state[N];                    /* array to keep track of everyone's state */
semaphore mutex = 1;             /* mutual exclusion for critical regions */
semaphore s[N];                  /* one semaphore per philosopher */

void philosopher(int i)          /* i: philosopher number, from 0 to N−1 */
{
    while (TRUE) {               /* repeat forever */
        think( );                /* philosopher is thinking */
        take_forks(i);           /* acquire two forks or block */
        eat( );                  /* yum-yum, spaghetti */
        put_forks(i);            /* put both forks back on table */
    }
}
```

Final Solution Part 2

```
void take_forks(int i)              /* i: philosopher number, from 0 to N–1 */
{
    down(&mutex);                   /* enter critical region */
    state[i] = HUNGRY;              /* record fact that philosopher i is hungry */
    test(i);                        /* try to acquire 2 forks */
    up(&mutex);                     /* exit critical region */
    down(&s[i]);                    /* block if forks were not acquired */
}

void put_forks(i)                   /* i: philosopher number, from 0 to N–1 */
{
    down(&mutex);                   /* enter critical region */
    state[i] = THINKING;            /* philosopher has finished eating */
    test(LEFT);                     /* see if left neighbor can now eat */
    test(RIGHT);                    /* see if right neighbor can now eat */
    up(&mutex);                     /* exit critical region */
}

void test(i)                        /* i: philosopher number, from 0 to N–1 */
{
    if (state[i] == HUNGRY && state[LEFT] != EATING && state[RIGHT] != EATING) {
        state[i] = EATING;
        up(&s[i]);
    }
}
```

The Readers and Writers Problem

- Dining Philosopher Problem: Models processes that are competing for exclusive access to a limited resource
- Readers Writers Problem: Models access to a database

Example: An airline reservation system- many competing process wishing to read and write-

  - Multiple readers simultaneously- acceptable
  - Multiple writers simultaneously- not acceptable
  - Reading, while write is writing- not acceptable

The Readers and Writers Problem

- *First* variation – no reader kept waiting unless writer has permission to use shared object
- *Second* variation – once writer is ready, it performs write ASAP

```
typedef int semaphore;            /* use your imagination */
semaphore mutex = 1;              /* controls access to 'rc' */
semaphore db = 1;                 /* controls access to the database */
int rc = 0;                       /* # of processes reading or wanting to */

void reader(void)
{
     while (TRUE) {               /* repeat forever */
          down(&mutex);           /* get exclusive access to 'rc' */
          rc = rc + 1;            /* one reader more now */
          if (rc == 1) down(&db); /* if this is the first reader ... */
          up(&mutex);             /* release exclusive access to 'rc' */
          read_data_base( );      /* access the data */
          down(&mutex);           /* get exclusive access to 'rc' */
          rc = rc − 1;            /* one reader fewer now */
          if (rc == 0) up(&db);   /* if this is the last reader ... */
          up(&mutex);             /* release exclusive access to 'rc' */
          use_data_read( );       /* noncritical region */
     }
}


void writer(void)
{
     while (TRUE) {               /* repeat forever */
          think_up_data( );       /* noncritical region */
          down(&db);              /* get exclusive access */
          write_data_base( );     /* update the data */
          up(&db);                /* release exclusive access */
     }
}
```

Issue regarding the solution

- Inherent priority to the readers
- Say a new reader arrives every 2 seconds and each reader takes 5 seconds to do its work. What will happen to a writer?

Issue regarding second variation

- Writer don’t have to wait for readers that came along after it
- Less concurrency, lower performance

Thanks for your sincerity