

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

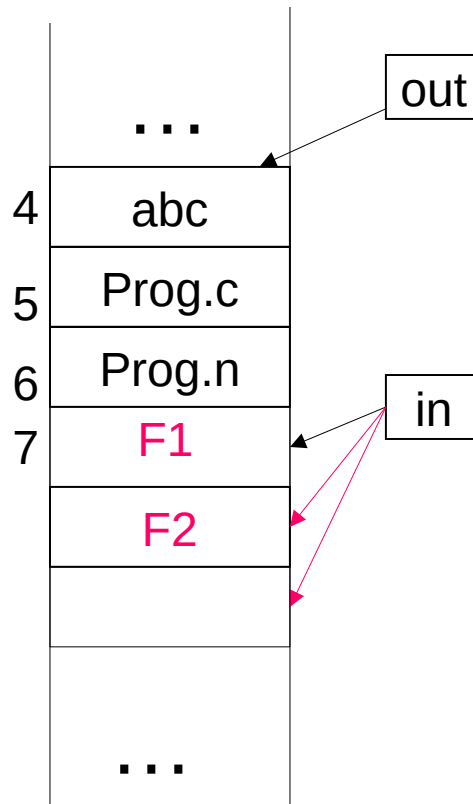
1. How one process **passes** information to another ?
2. How to make sure that two or more processes do not get into each other's way when engaging in **critical** activities?
3. How to do proper **sequencing** when **dependencies** are present?
 - Ans 1: easy for threads, for processes different approaches (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

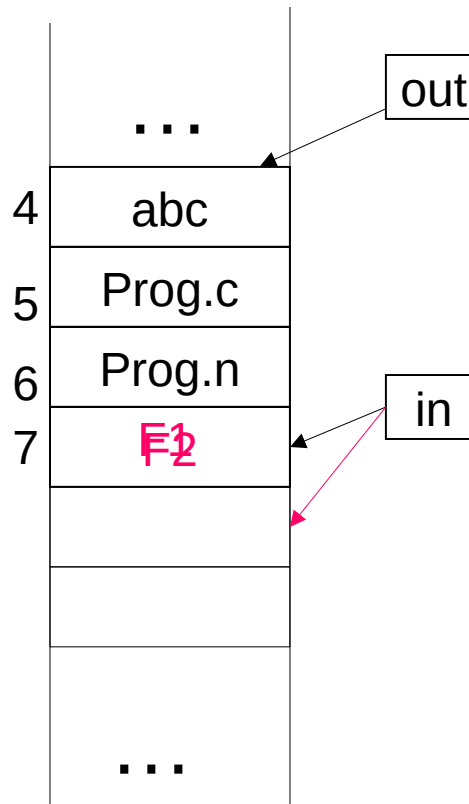
Process 1
int next_free;

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

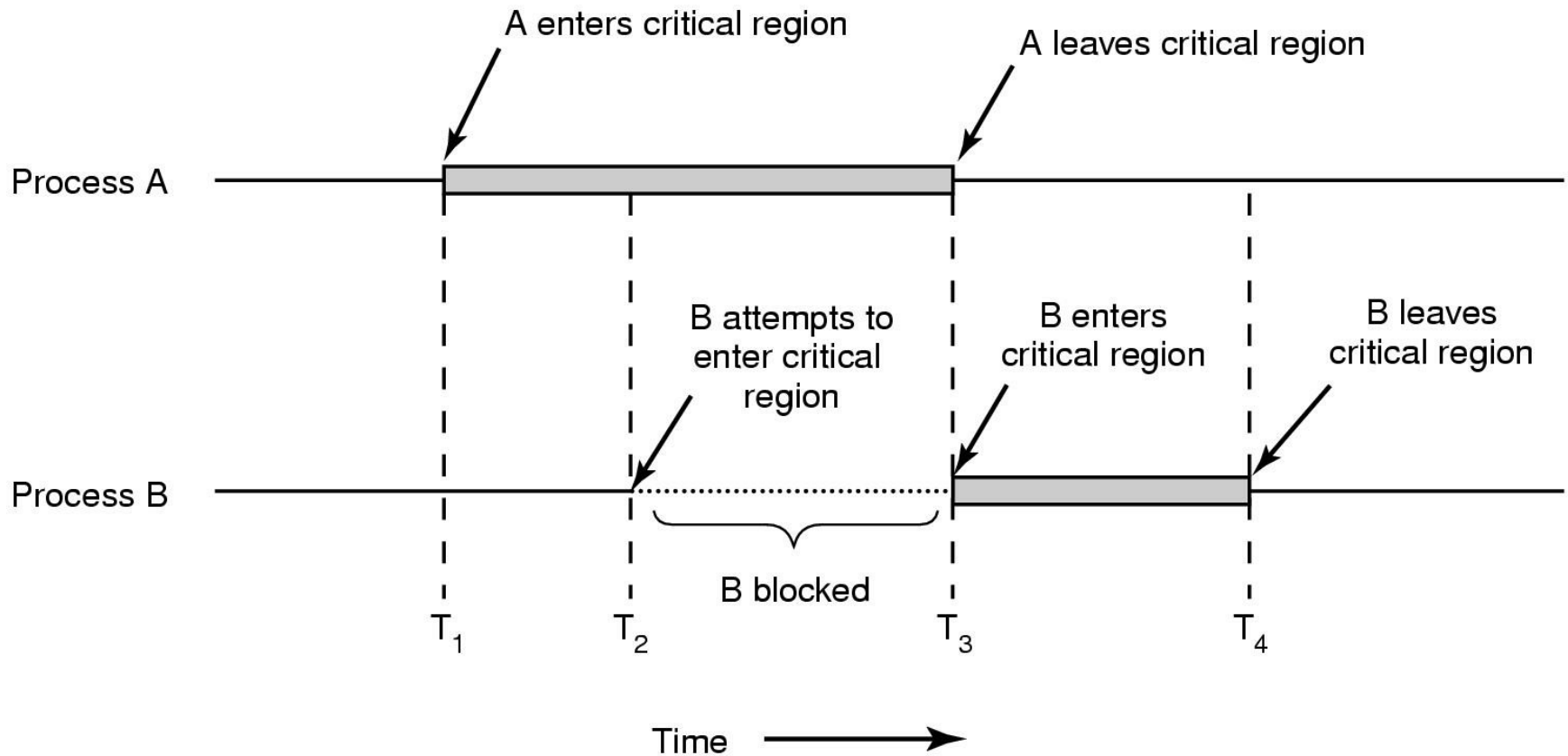
Critical Region

- 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)
- Only used **inside** OS

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)

(a) Process 0
Process 1

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

(b)

(b)

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(proce
ss#)

critical section

leave_region(proce
ss#)

remainder section

} while (TRUE);

Peterson's solution (for 2

```
#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
int count = 0;
```

```
/* number of slots in the buffer */
/* 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);
```

```
    }
```

```
}
```

```
/* repeat forever */
```

```
/* generate next item */
```

```
/* if buffer is full, go to sleep */
```

```
/* put item in buffer */
```

```
/* increment count of items in buffer */
```

```
/* was buffer empty? */
```

```
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);
```

```
    }
```

```
}
```

```
/* repeat forever */
```

```
/* if buffer is empty, got to sleep */
```

```
/* take item out of buffer */
```

```
/* decrement count of items in buffer */
```

```
/* was buffer full? */
```

```
/* print item */
```

Sleep and Wakeup

```
#define N 100
int count = 0;
```

```
/* number of slots in the buffer */
/* 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
typedef int semaphore;
semaphore mutex = 1;
semaphore empty = N;
semaphore full = 0;
```

```
void producer(void)
```

```
{
    int item;
```

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

```
}
```

```
}
```

```
/* number of slots in the buffer */
/* semaphores are a special kind of int */
/* controls access to critical region */
/* counts empty buffer slots */
/* counts full buffer slots */
```

```
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

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

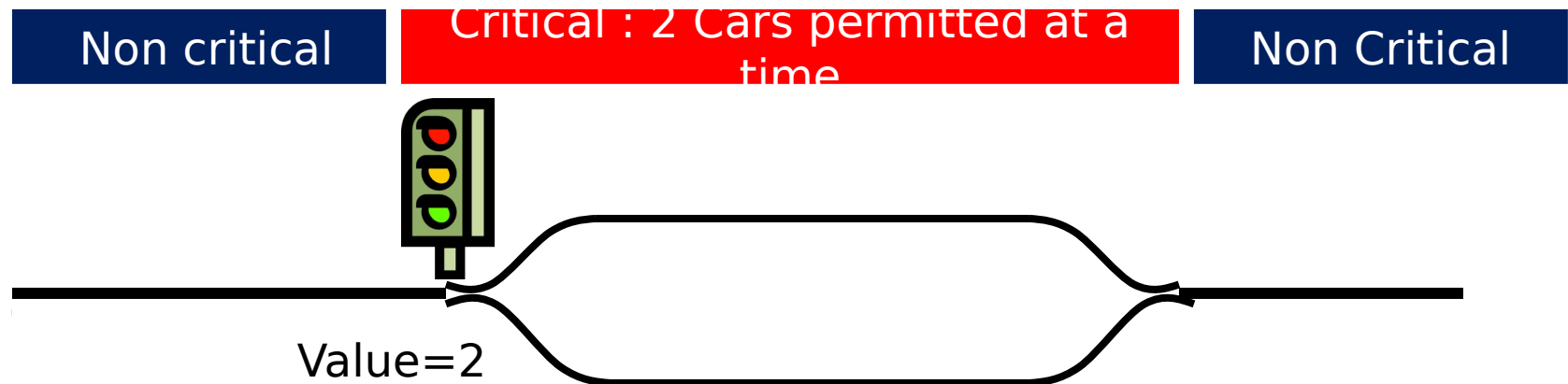
Mutual exclusion

- 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 on S1;
has completed
down(sync
h);
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.

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;
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 less item 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

```
#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 */
    }
}
```

Assumptions:

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

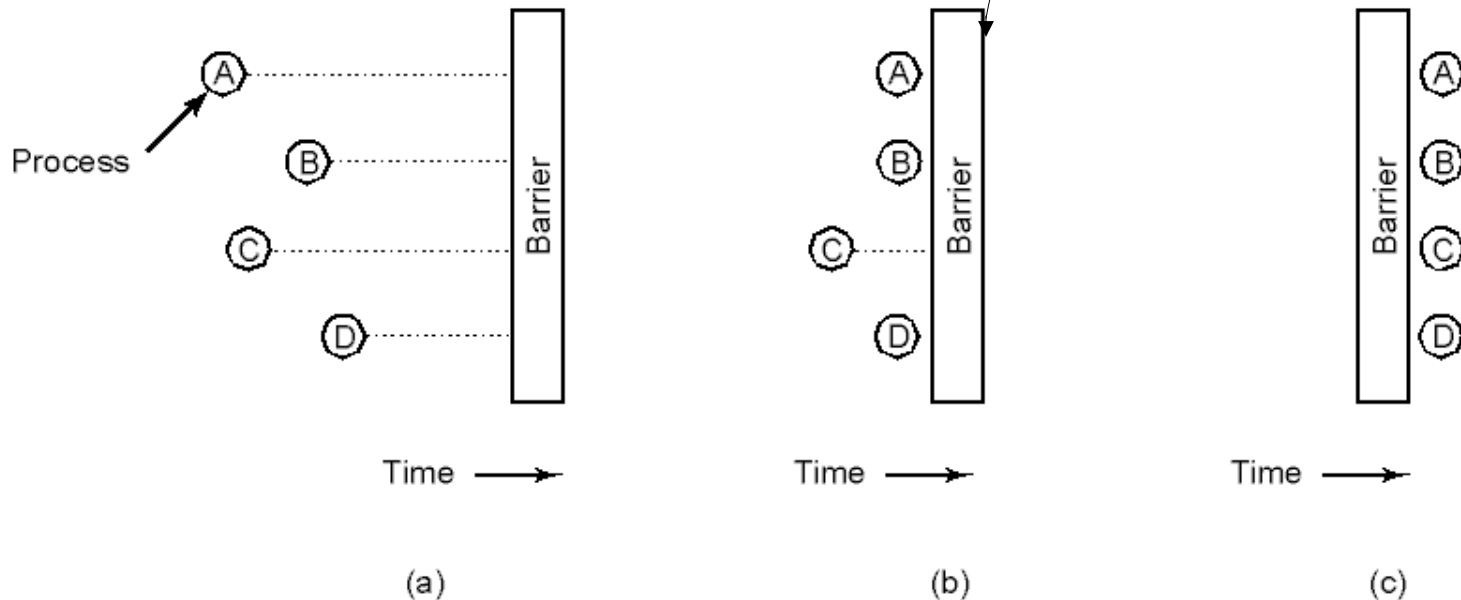
The producer-consumer problem with N messages

Barriers

- A synchronizing mechanism intended for **groups** of processes
- Some applications are divided into **phases** and have the rule that no process may proceed into the next phase until **all** processes are ready to proceed to the next phase.
- This can be done by placing a barrier at the end of each phase.
- When a process reaches the barrier, it is blocked until all processes have reached the barrier.

Barriers

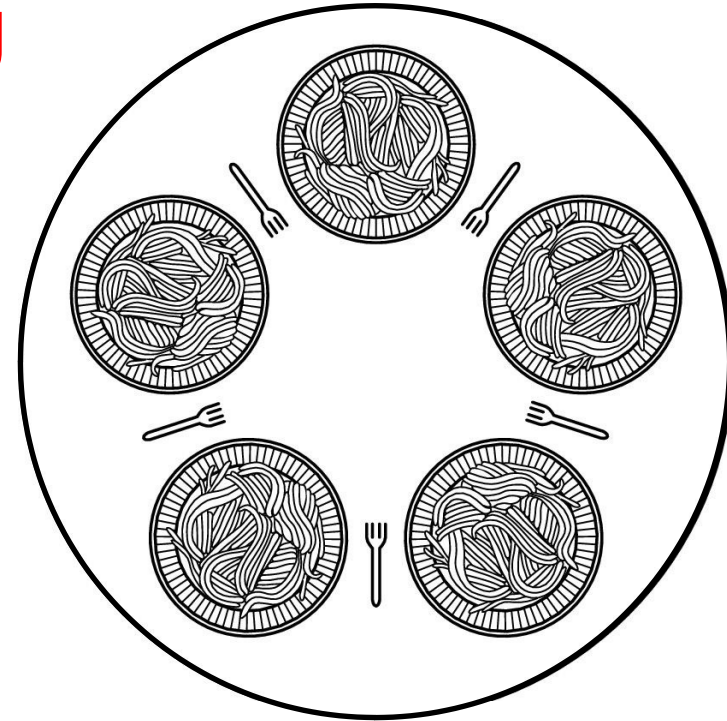
Executes a barrier
primitive



- Use of a barrier
 - processes approaching a barrier
 - all processes but one blocked at barrier
 - last process arrives, all are let through

Dining Philosophers

- 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?



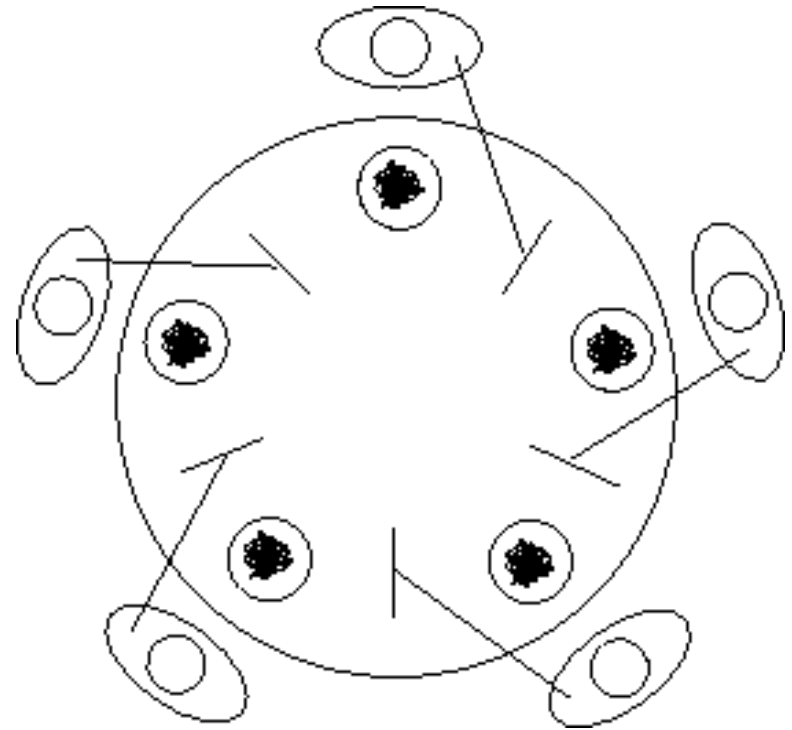
Dining Philosophers: A Solution

```
#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)
```

```
{
```

```
    down(&mutex);  
    state[i] = HUNGRY;  
    test(i);  
    up(&mutex);
```

```
    down(&s[i]);
```

```
}
```

```
void put_forks(i)
```

```
{
```

```
    down(&mutex);  
    state[i] = THINKING  
    test(LEFT);  
    test(RIGHT);  
    up(&mutex);
```

```
}
```

```
void test(i)
```

```
{
```

```
    if (state[i] == HUNGRY && state[LEFT] != EATING && state[RIGHT] != EATING) {  
        state[i] = EATING;  
        up(&s[i]);
```

```
    }
```

```
}
```

```
/* i: philosopher number, from 0 to N-1 */
```

```
/* enter critical region */
```

```
/* record fact that philosopher i is hungry */
```

```
/* try to acquire 2 forks */
```

```
/* exit critical region */
```

```
/* block if forks were not acquired */
```

```
/* i: philosopher number, from 0 to N-1 */
```

```
/* enter critical region */
```

```
/* philosopher has finished eating */
```

```
/* see if left neighbor can now eat */
```

```
/* see if right neighbor can now eat */
```

```
/* exit critical region */
```

```
/* i: philosopher number, from 0 to N-1 */
```

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;  
semaphore mutex = 1;  
semaphore db = 1;  
int rc = 0;
```

```
void reader(void)  
{
```

```
    while (TRUE) {  
        down(&mutex);  
        rc = rc + 1;  
        if (rc == 1) down(&db);  
        up(&mutex);  
        read_data_base();  
        down(&mutex);  
        rc = rc - 1;  
        if (rc == 0) up(&db);  
        up(&mutex);  
        use_data_read();  
    }
```

```
}
```

```
void writer(void)
```

```
{  
    while (TRUE) {  
        think_up_data();  
        down(&db);  
        write_data_base();  
        up(&db);  
    }  
}
```

```
/* use your imagination */  
/* controls access to 'rc' */  
/* controls access to the database */  
/* # of processes reading or wanting to */
```

```
/* repeat forever */  
/* get exclusive access to 'rc' */  
/* one reader more now */  
/* if this is the first reader ... */  
/* release exclusive access to 'rc' */  
/* access the data */  
/* get exclusive access to 'rc' */  
/* one reader fewer now */  
/* if this is the last reader ... */  
/* release exclusive access to 'rc' */  
/* noncritical region */
```

```
/* repeat forever */  
/* noncritical region */  
/* get exclusive access */  
/* update the data */  
/* 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