CSCI 360
Introduction to Operating Systems

Process Management

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Outline

- Inter Process Communications (IPC)
  - Pipes
  - Message Passing
  - Shared Memory
- Process Synchronization
  - Race Condition
  - Critical Region Problem: Peterson's Solution
  - Producer Consumer Problem
  - Semaphore
  - Mutex
  - The Dinning Philosophers Problem
  - The Readers and Writers Problem

Inter Process Communication

- **Processes** within a system may be ***independent*** or ***cooperating***
- An ***Independent*** process cannot affect or be affected by the execution of the other processes
- A ***Cooperating*** process can affect or be affected by the other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes need **interprocess communication** (**IPC**)

Inter Process Communication

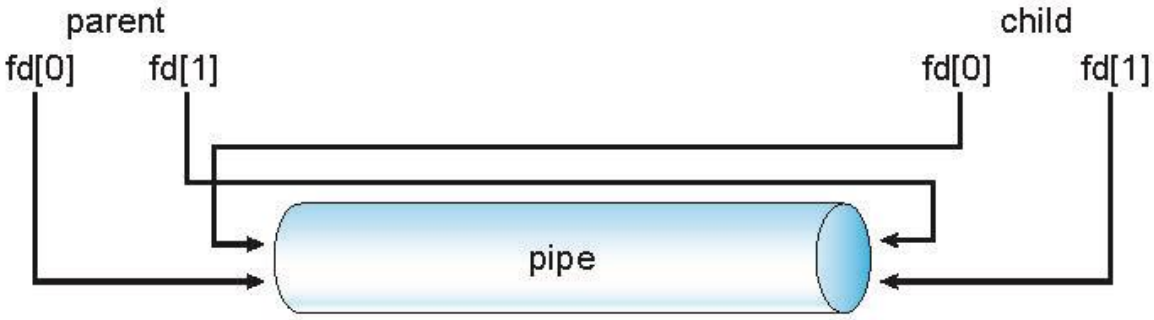
- Three models of IPC
  - **Pipe**
  - **Message Queue**
  - **Shared Memory**

IPC: Pipe

- Pipe acts as a conduit allowing two processes to communicate
- **Ordinary pipes** – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- **Named pipes** – can be accessed without a parent-child relationship.

IPC: Pipe

- Ordinary Pipes allow communication in standard **producer-consumer** style
- **Producer** writes to one end (the **write-end** of the pipe)
- **Consumer** reads from the other end (the **read-end** of the pipe)
- Ordinary pipes are therefore **unidirectional**
- Require **parent-child** relationship between communicating processes

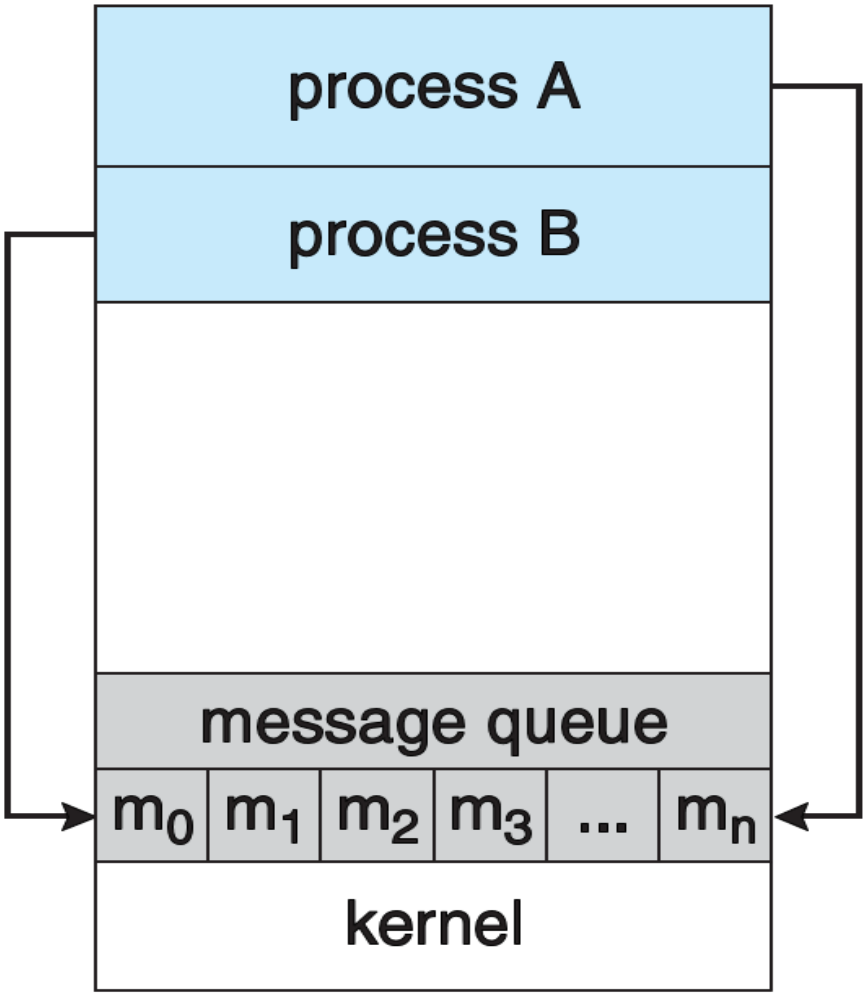


- Windows calls these **anonymous pipes**

IPC: Pipe

- Named Pipes are more powerful than ordinary pipes
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Communication is unidirectional in most of the systems
- Provided on both UNIX and Windows systems

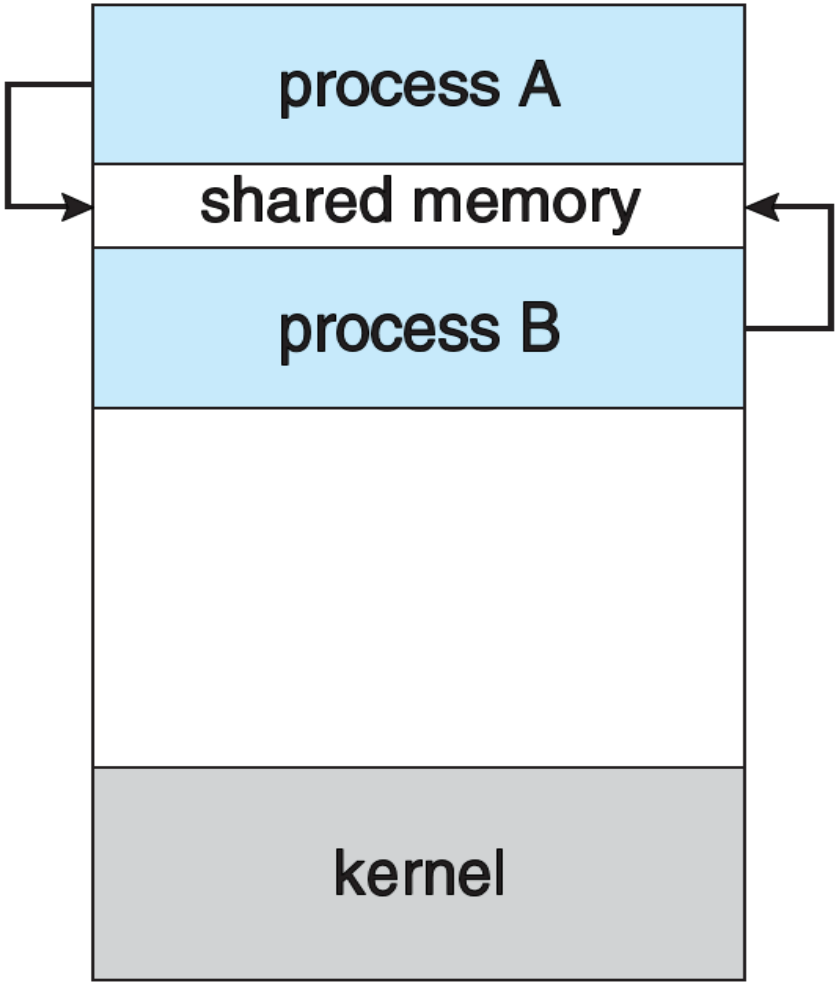
Message Queue



Message Queue

- **Message queue** has **configurable** internal structure
  - **size** of each message
  - **size** of the queue
- Provides **two operations** to the communicating processes
  - **`send`**(*message*)
  - **`receive`**(*message*)
- More than two processes can **send** and **receive**
- **Send** operation assigns a **priority** to each message
- **Oldest message** with the **highest priority** goes to the **front** of the queue
- **Receive** operation gets and **removes** the **front message** from the queue.
- A process can check the **status** of the queue.

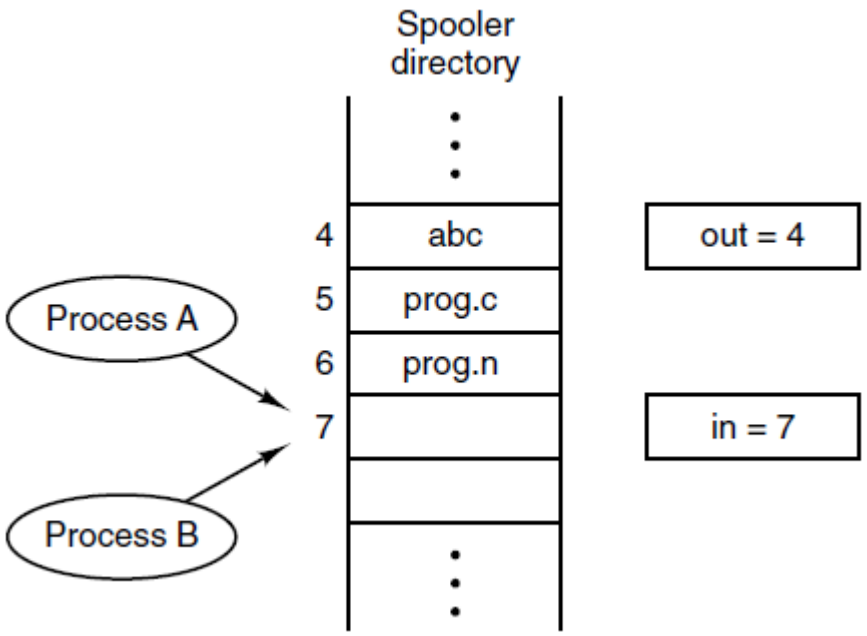
Shared Memory



Shared Memory

- An **area** of **memory shared** among the processes that wish to communicate
- The communication is under the **control** of the **users processes** not the operating system.
- Major issues is to provide mechanism that will allow the user processes to **synchronize** their actions when they access shared memory to avoid **race condition**.

Race Condition

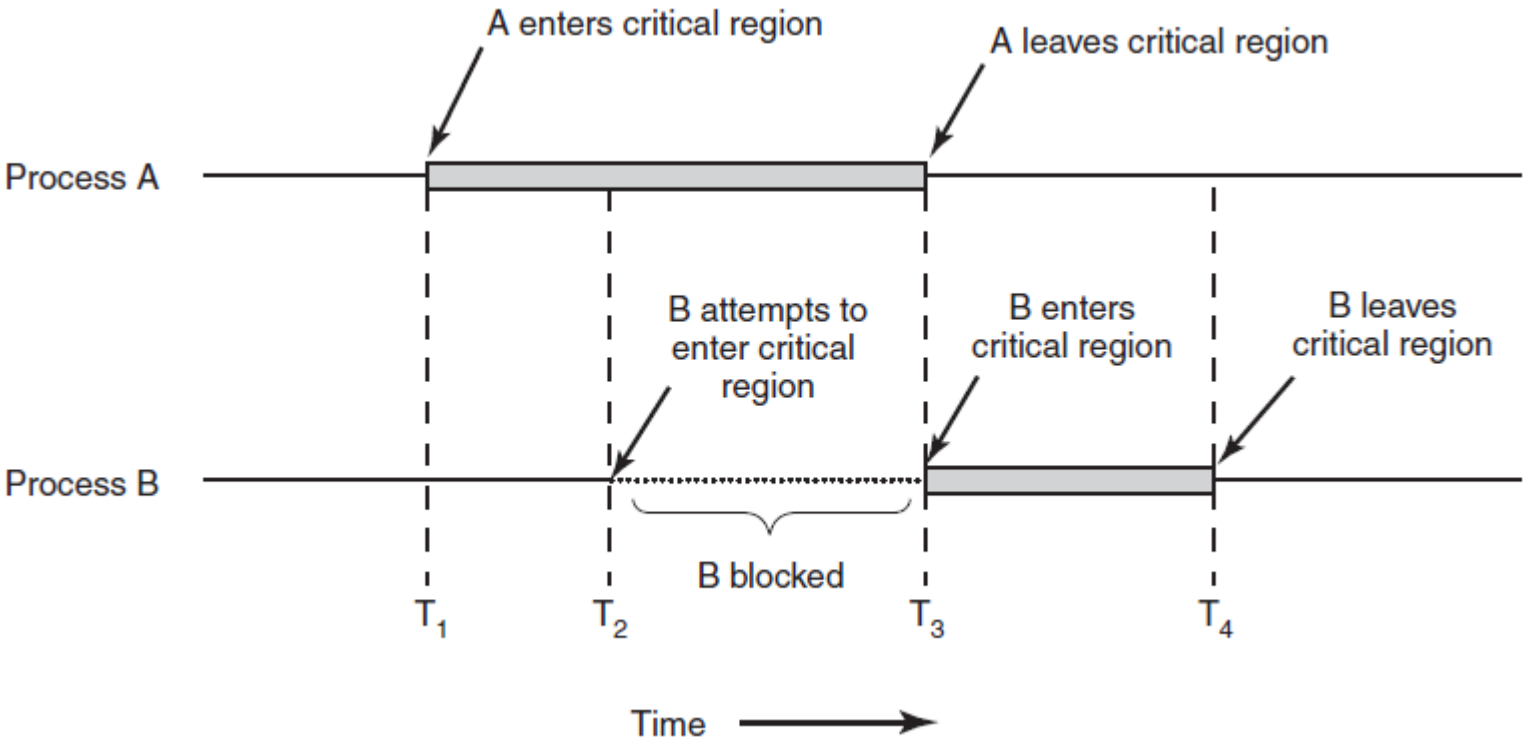


- **Race Condition**: Undesirable **data inconsistency** in a shared memory due to its simultaneous access by two or more processes.
- **Critical Region**: The **code segment** that causes race condition, i.e., that accesses shared memory.

Requirements to avoid Race Conditions

- No two processes may be simultaneously inside their **critical regions**.
- No assumptions may be made about **speeds** or the **number of CPUs**.
- A process running **outside** its **critical region** must **not block** other processes.
- A process must **not** have to **wait forever** to enter its **critical region**.

Critical Region Mutual Exclusion



Mutual Exclusion with Busy Waiting:
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 proposed solution to the critical region problem.

(a) Process 0. (b) Process 1.

Mutual Exclusion with Busy Waiting: Peterson's Solution

```
#define FALSE  0
#define TRUE  1
#define N  2
int turn = 0;
int interested[N] = {FALSE, FALSE};
void enter_region(int process) {
        int other = 1 – process;
        interested[process] = TRUE;
        turn = process;
        while (turn == process && interested[other] == TRUE); //busy wait
}
void leave_region(int process) {
        interested[process] = FALSE;
}
```

```
int process = 0;
while(TRUE) {
        enter_region(0);   //busy wait prcess 0
        critical_region();
        leave_region(0);
        noncritical_region();
}
```

```
int process = 1;
while(TRUE) {
        enter_region(1);   //busy wait process 1
        critical_region();
        leave_region(1);
        noncritical_region();
}
```

Mutual Exclusion with Busy Waiting

Entering and leaving a critical region using a lock variable.

```
#define LOCKED 1
#define UNLOCKED 0

int lock = UNLOCKED;

void enter_region(int process) {
      while(lock == LOCKED);                    //busy wait while  LOCKED
      lock = LOCKED;
}

void leave_region (int process) {
     lock = UNLOCKED;                           //UNLOCK
}
```

Does not work, lock variable itself suffers from race condition.

Mutual Exclusion with Busy Waiting:
The TSL Instruction

```
enter_region:
        TSL REGISTER,LOCK       | copy lock to register and set lock to 1
        CMP REGISTER,#0         | was lock zero?
        JNE enter_region        | if it was nonzero, lock was set, so loop
        RET                     | return to caller; critical region entered

leave_region:
        MOVE LOCK,#0            | store a 0 in lock
        RET                     | return to caller
```

Entering and leaving a critical region using the TSL instruction.

Mutual Exclusion with Busy Waiting:
The XCHG Instruction

```
enter_region:
        MOVE REGISTER,#1          | put a 1 in the register
        XCHG REGISTER,LOCK        | swap the contents of the register and lock variable
        CMP REGISTER,#0           | was lock zero?
        JNE enter_region          | if it was non zero, lock was set, so loop
        RET                       | return to caller; critical region entered

leave_region:
        MOVE LOCK,#0              | store a 0 in lock
        RET                       | return to caller
```

Entering and leaving a critical region using the XCHG instruction

Sleep and Wakeup

The Producer-Consumer Problem: Producer

```
#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)
{
```

- Race condition: **count** is shared with consumer but not mutually excluded. **insert_item**() critical region not mutually excluded.
- Deadlock: **wakeup** signal from consumer gets lost if producer is rescheduled before it executes **sleep**() function.

Sleep and Wakeup

The Producer-Consumer Problem: Consumer

```
        }
    }


    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 */
        }
    }
```

- Race condition: **count** is shared with producer but not mutually excluded. **remove_item**() critical region not mutually excluded.
- Deadlock: **wakeup** signal from producer gets lost if consumer is rescheduled before it executes **sleep**() function.

Semaphores

The Producer-Consumer Problem: Producer

```
#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) {                          /* TRUE is the constant 1 */
                item = produce_item( );         /* generate something to put in buffer */
                down(&empty);                   /* decrement empty count */
                down(&mutex);                   /* enter critical region */
                insert_item(item);              /* put new item in buffer */
                up(&mutex);                     /* leave critical region */
                up(&full);                      /* increment count of full slots */
        }
}
```

void consumer(void)

- No Race condition: no shared count with consumer. **insert_item**() critical region is mutually excluded by semaphore **mutex**.
- Deadlock: **up** signal from consumer on semaphore **empty** is held if producer is rescheduled before it executes **down**(&empty) function.

Semaphores

The Producer-Consumer Problem: Consumer

```
            up(&full);                          /* increment count of full slots */
        }
}

void consumer(void)
{
        int item;

        while (TRUE) {                          /* infinite loop */
            down(&full);                        /* decrement full count */
            down(&mutex);                       /* enter critical region */
            item = remove_item( );              /* take item from buffer */
            up(&mutex);                         /* leave critical region */
            up(&empty);                         /* increment count of empty slots */
            consume_item(item);                 /* do something with the item */
        }
}
```

- No Race condition: no shared count with producer. **remove_item**() critical region is mutually excluded by semaphore **mutex**.
- Deadlock: **up** signal from producer on semaphore **full** is held if producer is rescheduled before it executes **down**(&full) function.

Mutexes: The TSL Instruction

```
mutex_lock:
        TSL REGISTER,MUTEX      | copy mutex to register and set mutex to 1
        CMP REGISTER,#0         | was mutex zero?
        JZE ok                  | if it was zero, mutex was unlocked, so return
        CALL thread_yield       | mutex is busy; schedule another thread
        JMP mutex_lock          | try again
ok:     RET                     | return to caller; critical region entered

mutex_unlock:
        MOVE MUTEX,#0           | store a 0 in mutex
        RET                     | return to caller
```

Implementation of *mutex_lock* and *mutex_unlock*.

Mutexes in Pthread

Function	Description
pthread_mutex_init()	Create a mutex
pthread_mutex_destroy()	Destroy an existing mutex
pthread_mutex_lock()	Acquire lock on a mutex or block yourself until succeed
pthread_mutex_trylock()	Acquire a lock on a mutex or return immediately with an error
pthread_mutex_unlock()	Release a locked from a mutex.

Some of the pthreads calls relating to mutexes.

Conditions in Pthread

Function	Description
pthread_cond_init()	Create a condition variable
pthread_cond_destroy()	Destroy an existing condition variable
pthread_cond_wait()	Wait until a wake up signal is received
pthread_cond_signal()	Signal a waiting thread to wake it up
pthread_cond_broadcast()	Broadcast a signal to multiple waiting threads and wake them up.

Some of the Pthreads calls relating to condition variables.

Pthread Mutexes and Conditions

The Producer-Consumer Problem: Producer

```
#include <stdio.h>
#include <pthread.h>
#define MAX 1000000000                  /* how many numbers to produce */
pthread_mutex_t the_mutex;
pthread_cond_t condc, condp;            /* used for signaling */
int buffer = 0;                         /* buffer used between producer and consumer */

void *producer(void *ptr)               /* produce data */
{       int i;

        for (i= 1; i <= MAX; i++) {
                pthread_mutex_lock(&the_mutex);    /* get exclusive access to buffer */
                while (buffer != 0) pthread_cond_wait(&condp, &the_mutex);
                buffer = i;                        /* put item in buffer */
                pthread_cond_signal(&condc);       /* wake up consumer */
                pthread_mutex_unlock(&the_mutex); /* release access to buffer */
        }
        pthread_exit(0);
}
```

Pthread Mutexes and Conditions

The Producer-Consumer Problem: Consumer

```
        pthread_exit(0);
}

void *consumer(void *ptr)                       /* consume data */
{       int i;

        for (i = 1; i <= MAX; i++) {
                pthread_mutex_lock(&the_mutex);    /* get exclusive access to buffer */
                while (buffer ==0 ) pthread_cond_wait(&condc, &the_mutex);
                buffer = 0;                        /* take item out of buffer */
                pthread_cond_signal(&condp);       /* wake up producer */
                pthread_mutex_unlock(&the_mutex); /* release access to buffer */
        }
        pthread_exit(0);
}

int main(int argc, char **argv)
```

Pthread Mutexes and Conditions

The Producer-Consumer Problem

```
        pthread_exit(0);
}

int main(int argc, char **argv)
{
        pthread_t pro, con;
        pthread_mutex_init(&the_mutex, 0);
        pthread_cond_init(&condc, 0);
        pthread_cond_init(&condp, 0);
        pthread_create(&con, 0, consumer, 0);
        pthread_create(&pro, 0, producer, 0);
        pthread_join(pro, 0);
        pthread_join(con, 0);
        pthread_cond_destroy(&condc);
        pthread_cond_destroy(&condp);
        pthread_mutex_destroy(&the_mutex);
}
```

Message Queue

The Producer-Consumer Problem: Producer

```
#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)
```

The producer-consumer problem with *N* messages.

Message Queue

The Producer-Consumer Problem: Consumer

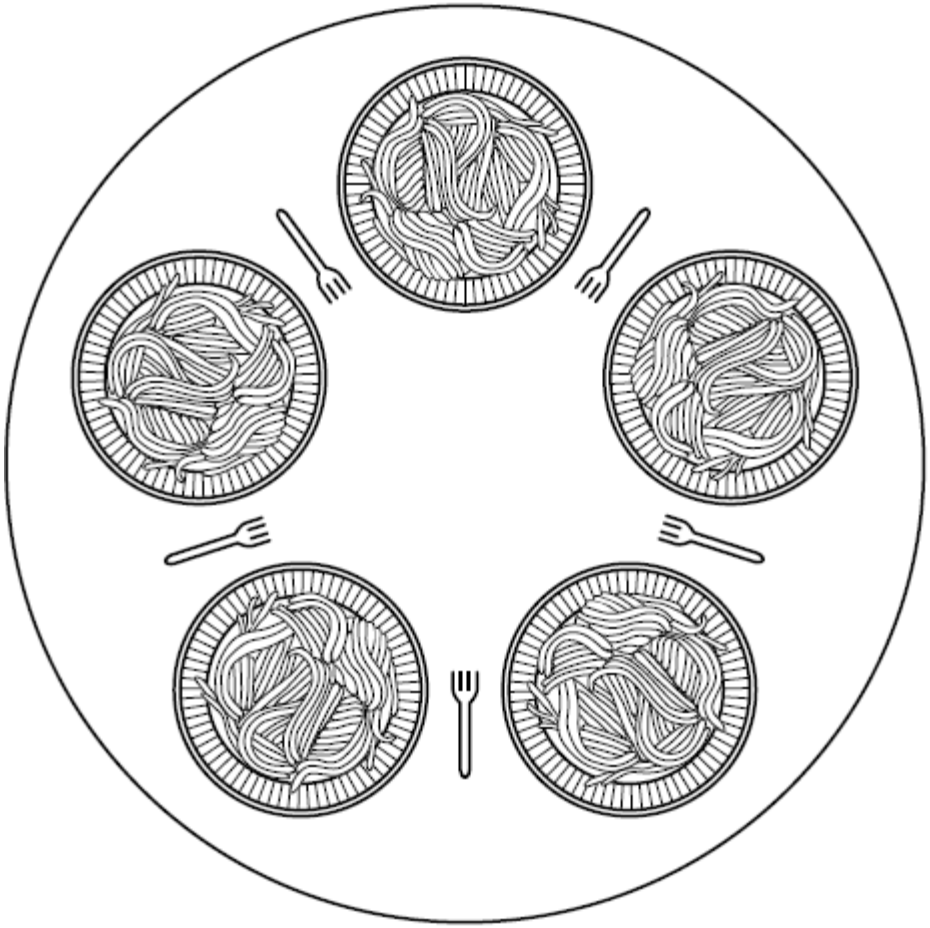
```
            send(consumer, &m);                 /* send item to consumer */
        }
}

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.

The Dining Philosophers Problem



Lunch time in the Philosophy Department.

The Dining Philosophers Problem

```
#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 */
        }
}
```

A nonsolution to the dining philosophers problem.

The Dining Philosophers Problem

```
#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 */
    }
}
```

A solution to the dining philosophers problem.

The Dining Philosophers Problem

```
            put_forks(i);                    /* put both forks back on table */
        }
    }

    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 */
```

A solution to the dining philosophers problem.

The Dining Philosophers Problem

```
}

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]);
        }
}
```

A solution to the dining philosophers problem.

The Readers and Writers Problem

```
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)
```

A solution to the readers and writers problem.

The Readers and Writers Problem

```
            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 */
        }
}
```

A solution to the readers and writers problem.

Summary

- Pipe
- Message Passing
- Shared Memory
- Race Condition
- Critical Region Problem: Peterson's Solution
- Producer Consumer Problem
- Semaphore
- Mutex
- The Dinning Philosophers Problem
- The Readers and Writers Problem

Next

Memory Management

- Address Space
- Memory allocation algorithms
- Swapping and compaction
- Virtual Memory
- Paging