國立陽明交通大學
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Institute of Artificial Intelligence Innovation
Department of Computer Science

Operating System

Lecture 06: Process Synchronization

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Wed. 10:10 - 12:00 EC115 +
Fri. 11:10 – 12:00 Online

Course Schedule

W	Date	Lecture	Online	Homework
1	Sept. 4	Lec00: Couse Overview & Historical Prospective		
2	Sept. 11	Lec01: Introduction	V	
3	Sept. 18	Lec02: OS Structure	V	HW01 Due 10/5
4	Sept. 25	Lec03: Processes Concept	X	
5	Oct. 2	Typhoon – No class	V	
6	Oct. 9	Lec07: Memory Management	V	
7	Oct. 16	Lec08: Virtual Memory Management	V	HW02 Due 11/2
8	Oct. 23	Lec04: Multithreaded Programming	V	
9	Oct. 30	Midterm Exam		
10	Nov. 6	Lec05: Process Scheduling	V	Let's take a breath
11	Nov. 13	Lec06: Process Synchronization & Deadlocks	X	HW03
12	Nov. 20	School Event – No class		
13	Nov. 27	Lec09: File System Interface	V	
14	Dec. 4	Lec10: File System Implementation	V	HW04
15	Dec. 11	Lec11: Mass Storage System & Lec12: IO Systems	V	
16	Dec. 18	School Final Exam		

Overview

- Background
- Critical Section
- Synchronization Hardware
- Semaphores
- Classical Problems of Synchronization
- Monitors
- Atomic Transactions

Background

- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanism to ensure the orderly execution of cooperating processes

Consumer & Producer Problem

- Determine whether buffer is empty or full
  - Previously: use in, out position
  - Now: use count value

```
/*producer*/
while (1) {
   nextItem = getItem( );
   while (counter == BUFFER_SIZE) ;
   buffer[in] = nextItem;
   in = (in + 1) % BUFFER_SIZE;
   counter++;
}
```

```
/*consumer*/
while (1) {
   while (counter == 0) ;
   item = buffer[out];
   out = (out + 1) % BUFFER_SIZE;
   counter--;
}
```

Concurrent Operations on counter

- The statement “counter++” may be implemented in machine language as:

```
move ax, counter
add  ax, 1
move counter, ax
```

- The statement “counter--” may be implemented as:

```
move    bx, counter
sub     bx, 1
move    counter, bx
```

Instruction Interleaving

- Assume counter is initially 5. One interleaving of statement is:

producer: move ax, counter → ax = 5
producer: add ax, 1 → ax = 6
context switch
consumer: move bx, counter → bx = 5
consumer: sub bx, 1 → bx = 4
context switch
producer: move counter, ax → counter = 6
context switch
consumer: move counter, bx → counter = 4

- The value of counter may be either 4, 5, or 6, where the correct result should be 5

Race Condition

- Race condition: the situation where several processes access and manipulate shared data concurrently. The final value of the shared data depends upon which process finishes last
- To prevent race condition, concurrent processes must be synchronized
  - On a single-processor machine, we could disable interrupt or use non-preemptive CPU scheduling
- Commonly described as critical section problem

Critical Section

The Critical-Section Problem

- Purpose: a protocol for processes to cooperate
- Problem description:
  - N processes are competing to use some shared data
  - Each process has a code segment, called critical section, in which the shared data is accessed
  - Ensure that when one process is executing in its critical section, no other process is allowed to execute in its critical section -> mutually exclusive

The Critical-Section Problem

- General code section structure
  - Only one process can be in a critical section

```
do {
        entry section          Get entry permission
            critical section   Modify shared data
        exit section           Release entry permission
        remainder section
} while (1);
```

Critical Section Requirements

1. Mutual Exclusion: if process P is executing in its CS, no other processes can be executing in their CS
2. Progress: if no process is executing in its CS and there exist some processes that wish to enter their CS, these processes cannot be postponed indefinitely
3. Bounded Waiting: A bound must exist on the number of times that other processes are allowed to enter their CS after a process has made a request to enter its CS

- -> How to design entry and exist section to satisfy the above requirement?

Review Slides (1)

- Race condition?
- Critical-Section (CS) problem? 4 sections?
  - entry, CS, exit, remainder
- 3 requirements for solutions to CS problems?
  - mutual exclusion
  - progress
  - bounded waiting

Critical Section Solutions & Synchronization Tools

- Software Solution
- Synchronization Hardware
- Semaphore
- Monitor

Algorithm for Two Processes

- Only 2 processes, P0 and P1
- Shared variables
  - int turn; //initially turn = 0
  - turn = i -> Pi can enter its critical section

```
/* Process 0 */
do {
  while (turn != 0) ;
    critical section
  turn = 1;
    remainder section
} while (1)
```

entry section

exit section

```
/* Process 1 */
do {
  while (turn != 1) ;
    critical section
  turn = 0;
    remainder section
} while (1)
```

➔ Mutual exclusion? Yes   Progress? No

Bounded-Wait? Yes

Peterson's Solution for Two Processes

- Shared variables
  - int turn; //initially turn = 0
  - turn = i -> Pi can enter its critical section
  - Boolean flag[2]; //initially flag [0] = flag [1] = false
  - Flag [i] = true -> Pi ready to enter its critical section

```
//Pi:
do {
    flag[ i ] = TRUE;
    turn = j ;
    while (flag [ j ] &&
               turn == j ) ;
      critical section
    flag [ i ] = FALSE ;
      remainder section
}   while (1) ;
```

Enter CS when either:

1. a process gets its turn
2. the other process is not ready

Proof of Peterson's Solution

- Mutual exclusion:
  - If P0 CS -> flag[1] == false || turn == 0
  - If P1 CS -> flag[0] == false || turn == 1
- Assume both processes in CS -> flag[0] == flag[1] == true
  - -> turn==0 for P0 to enter, turn==1 for P1 to enter
  - However, "turn" will be either 0 or 1 because its value will be set for both processes, but only one value will last
  - Therefore, P0 ,P1 can't in CS at the same time!

```
/* process 0 */
do {
  flag[ 0 ] = TRUE;
  turn = 1 ;
  while (flag [ 1 ] && turn == 1 ) ;
     critical section
  flag [ 0 ] = FALSE ;
     remainder section
}  while (1) ;
```

```
/* process 1 */
do {
  flag[ 1 ] = TRUE;
  turn = 0 ;
  while (flag [ 0 ] && turn == 0 ) ;
     critical section
  flag [ 1 ] = FALSE ;
     remainder section
}  while (1) ;
```

Proof of Peterson's Solution

- Progress (e.g., P0 wishes to enter its CS):
  1. If P1 is not ready -> flag[1] = false -> P0 can enter
  2. If both are ready -> flag[0] == flag[1] == true

     If trun ==0 then P0 enters, otherwise P1 enters
  - **Either cases, some waiting process can enter CS!**

```
/* process 0 */
do {
  flag[ 0 ] = TRUE;
  turn = 1 ;
  while (flag [ 1 ] && turn == 1 ) ;
    critical section
  flag [ 0 ] = FALSE ;
    remainder section
}  while (1) ;
```

(2)

(1)

```
/* process 1 */
do {
  flag[ 1 ] = TRUE;
  turn = 0 ;
  while (flag [ 0 ] && turn == 0 ) ;
    critical section
  flag [ 1 ] = FALSE ;
    remainder section
}  while (1) ;
```

Proof of Peterson's Solution

- Bounded waiting (e.g., P0 wishes to enter its CS):
  1. Once P1 exits CS -> flag[1]==false -> P0 can enter
  2. If P1 exits CS && reset flag[1]=true

     -> turn==0 (overwrite P0 setting) -> P0 can enter

  - **P0 won't wait indefinitely!**

```
/* process 0 */
do {
  flag[ 0 ] = TRUE;
  turn = 1 ;
→ while (flag [ 1 ] && turn == 1 ) ;
    critical section
  flag [ 0 ] = FALSE ;
    remainder section
}  while (1) ;
```

```
/* process 1 */
do {
  flag[ 1 ] = TRUE;
  turn = 0 ;
(2) → while (flag [ 0 ] && turn == 0 ) ;
    critical section
  flag [ 1 ] = FALSE ;
(1) →    remainder section
}  while (1) ;
```

Producer/Consumer Problem

- Producer process

```
while (TRUE) {
    entry-section( );
    nextItem = getItem( );
    while (counter ==BUFFER_SIZE);
    buffer[in] = nextItem;
    in = (in + 1) % BUFFER_SIZE;
    counter++;
    computing();
    exit-section( );
}
```

- Consumer process

```
while (TRUE) {
    entry-section( );
    while (counter == 0) ;
    item = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    counter--;
    computing();
    exit-section( );
}
```

➔ Incorrect: deadlock, if consumer enters the CS first.

Producer/Consumer Problem

- Producer process

```
while (TRUE) {
    nextItem = getItem( );
    while (counter ==BUFFER_SIZE);
    buffer[in] = nextItem;
    in = (in + 1) % BUFFER_SIZE;
    entry-section( );
    counter++;
    computing();
    exit-section( );
}
```

- Consumer process

```
while (TRUE) {
    while (counter == 0) ;
    item = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    entry-section( );
    counter--;
    computing();
    exit-section( );
}
```

➔ Correct but poor performance

Producer/Consumer Problem

- Producer process

```
while (TRUE) {
    nextItem = getItem( );
    while (counter ==BUFFER_SIZE);
    buffer[in] = nextItem;
    in = (in + 1) % BUFFER_SIZE;
    entry-section( );
    counter++;
    exit-section( );
    computing();
}
```

- Consumer process

```
while (TRUE) {
    while (counter == 0) ;
    item = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    entry-section( );
    counter--;
    exit-section( );
    computing();
}
```

➔ Correct & Maximize concurrent performance

Bakery Algorithm (n processes)

- Before enter its CS, each process receives a #
- Holder of the smallest # enters CS
- The numbering scheme always generates # in non-decreasing order; i.e., 1,2,3,3,4,5,5,5
- If processes Pi and Pj receive the same #, if i < j, then Pi is served first
- Notation:
  - (a, b) < (c, d) if a < c or if a == c && b < d

Bakery Algorithm (n processes)

```
//Process i: do {
        choosing [ i ] = TRUE ;
        num[ i ] = max(num[0],num[1],…,num[n-1]) + 1;
        choosing [ i ] = FALSE ;
        for (j = 0; j < n; j++) {
            while (choosing [ j ] ) ;
            while ((num[ j ] != 0) &&
                    ((num[ j ], j) < (num[ i ], i))) ;
        }
            critical section
        num[ i ] = 0 ;
            reminder section
} while (1) ;
```

Get ticket

FCFS

Cannot compare when num is being modified

release ticket

- Bounded-waiting because processes enter CS on a First-Come, First Served basis

Bakery Algorithm (n processes)

- Why cannot compare when num is being modified?
- Without locking…
    1. Let 5 be the current maximum number
    2. If P1 and P4 take number together, but P4 finishes before P1
        - P1 = 0; P4 = 6 -> P4 will enter the CS
    3. After P1 takes the number
        - P1 = P4 = 6 -> P1 will enter the CS as well!!!
- With locking…
    - P4 will have to wait until P1 finish taking the number
    - Both P1 & P4 will have the new number "6" before comparison

Pthread Lock/Mutex Routines

- To use mutex, it must be declared as of type pthread_mutex_t and initialized with pthread_mutex_init()
- A mutex is destroyed with pthread_mutex_destory()
- A critical section can then be protected using pthread_mutex_lock() and pthread_mutex_unlock()
- Example:

```
#include "pthread.h"                          specify default
pthread_mutex   mutex;                        attribute for the mutex
pthread_mutex_init (&mutex, NULL);
pthread_mutex_lock(&mutex);                   // enter critical section

       Critical Section

pthread_mutex_unlock(&mutex);                 // leave critical section
pthread_mutex_destory(&mutex);
```

Condition Variables (CV)

- CV represent some condition that a thread can:
  - Wait on, until the condition occurs; or
  - Notify other waiting threads that the condition has occurred
- Three operations on condition variables:
  - wait() --- Block until another thread calls signal() or broadcast() on the CV
  - signal() --- Wake up one thread waiting on the CV
  - broadcast() --- Wake up all threads waiting on the CV
- In Pthread, CV type is a pthread_cond_t
  - Use pthread_cond_init() to initialize
  - pthread_cond_wait (&theCV, &somelock)
  - pthread_cond_signal (&theCV)
  - pthread_cond_broadcast (&theCV)

Using Condition Variable

- Example:
  - A threads is designed to take action when x=0
  - Another thread is responsible for decrementing the counter

```
pthread_cond_t    cond;                       pthread_mutex_t    mutex;
pthread_cond_init (cond, NULL);               pthread_mutex_init (mutex, NULL);
```

```
action() {
   pthread_mutex_lock (&mutex)
   if (x != 0)
      pthread_cond_wait (cond, mutex);
   pthread_mutex_unlock (&mutex);
   take_action();
}
```

```
counter() {
  pthread_mutex_lock (&mutex)
  x--;
  if (x==0)
     pthread_cond_signal (cond);
  pthread_mutex_unlock (&mutex);
}
```

- All condition variable operation MUST be performed while a mutex is locked!!!

Using Condition Variable

```
action() {
  pthread_mutex_lock (&mutex)
  whild (x != 0)
    pthread_cond_wait (cond, mutex);
  pthread_mutex_unlock (&mutex);
  take_action();
}
```

```
counter() {
  pthread_mutex_lock (&mutex)
  x--;
  if (x==0)
    pthread_cond_signal (cond);
  pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex

Using Condition Variable

```
action() {
   pthread_mutex_lock (&mutex)
   whild (x != 0)
      pthread_cond_wait (cond, mutex);
   pthread_mutex_unlock (&mutex);
   take_action();
}
```

```
counter() {
   pthread_mutex_lock (&mutex)
   x--;
   if (x==0)
      pthread_cond_signal (cond);
   pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex
2. Wait()
   - Put the thread into sleep & releases the lock

1. Lock mutex

Using Condition Variable

```
action() {
   pthread_mutex_lock (&mutex)
   whild (x != 0)
      pthread_cond_wait (cond, mutex);
   pthread_mutex_unlock (&mutex);
   take_action();
}
```

```
counter() {
  pthread_mutex_lock (&mutex)
  x--;
  if (x==0)
     pthread_cond_signal (cond);
  pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex
2. Wait()
   - Put the thread into sleep & releases the lock
   - Waked up, but the thread is locked

1. Lock mutex
2. Signal()

Using Condition Variable

```
action() {
   pthread_mutex_lock (&mutex)
   whild (x != 0)
      pthread_cond_wait (cond, mutex);
   pthread_mutex_unlock (&mutex);
   take_action();
}
```

```
counter() {
  pthread_mutex_lock (&mutex)
  x--;
  if (x==0)
     pthread_cond_signal (cond);
  pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex
2. Wait()
   - Put the thread into sleep & releases the lock
   - Waked up, but the thread is locked
   - Re-acquire lock and resume execution

1. Lock mutex
2. Signal()
3. Releases the lock

Using Condition Variable

```
action() {
    pthread_mutex_lock (&mutex)
    whild (x != 0)
        pthread_cond_wait (cond, mutex);
    pthread_mutex_unlock (&mutex);
    take_action();
}
```

```
counter() {
    pthread_mutex_lock (&mutex)
    x--;
    if (x==0)
        pthread_cond_signal (cond);
    pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex
2. Wait()
   - Put the thread into sleep & releases the lock
   - Waked up, but the thread is locked
   - Re-acquire lock and resume execution
3. Release the lock

1. Lock mutex
2. Signal()
3. Releases the lock

Using Condition Variable

```
action() {
   pthread_mutex_lock (&mutex)
   whild (x != 0)
      pthread_cond_wait (cond, mutex);
   pthread_mutex_unlock (&mutex);
   take_action();
}
```

```
counter() {
  pthread_mutex_lock (&mutex)
  x--;
  if (x==0)
     pthread_cond_signal (cond);
  pthread_mutex_unlock (&mutex);
}
```

- What really happens…

1. Lock mutex
2. Wait()
   - Put the thread into sleep & releases the lock
   - Waked up, but the thread is locked
   - Re-acquire lock and resume execution
3. Release the lock

1. Lock mutex
2. Signal()
3. Releases the lock

Another reason why condition variable op. MUST within mutex lock

ThreadPool Implementation

Task structure

```
typedef struct {
    void (*function)(void *);
    void *argument;
} threadpool_task_t;
```

Threadpool structure

```
struct threadpool_t {
    pthread_mutex_t lock;
    pthread_cond_t notify;
    pthread_t *threads;
    threadpool_task_t *queue;
    int thread_count;
    int queue_size;
    int head;
    int tail;
    int count;
    int shutdown;
    int started;
};
```

Allocate thread and task queue

```
/* Allocate thread and task queue */
pool->threads = (pthread_t *) malloc(sizeof(pthread_t) * thread_count);
pool->queue = (threadpool_task_t *) malloc(sizeof(threadpool_task_t) * queue_size);
```

Source: http://swind.code-life.info/posts/c-thread-pool.html

ThreadPool Implementation

```
static void *threadpool_thread(void *threadpool)
 {
     threadpool_t *pool = (threadpool_t *)threadpool;
     threadpool_task_t task;

     for(;;) {
         /* Lock must be taken to wait on conditional variable */
         pthread_mutex_lock(&(pool->lock));

         /* Wait on condition variable, check for spurious wakeups.
            When returning from pthread_cond_wait(), we own the lock. */
         while((pool->count == 0) && (!pool->shutdown)) {
             pthread_cond_wait(&(pool->notify), &(pool->lock));
         }
```

ThreadPool Implementation

```
    /* Grab our task */
    task.function = pool->queue[pool->head].function;
    task.argument = pool->queue[pool->head].argument;
    pool->head += 1;
    pool->head = (pool->head == pool->queue_size) ? 0 : pool->head;
    pool->count -= 1;

    /* Unlock */
    pthread_mutex_unlock(&(pool->lock));

    /* Get to work */
    (*(task.function))(task.argument);
}
```

Synchronization HW

Hardware Support

- The CS problem occurs because the modification of a shared variable may be interrupted
- If disable interrupts when in CS…
  - not feasible in multiprocessor machine
  - clock interrupts cannot fire in any machine
- HW support solution: atomic instructions
  - atomic: as one uninterruptible unit
  - examples: TestAndSet(var), Swap(a,b)

Atomic TestAndSet()

```
boolean TestAndSet ( bool   &lock) {
    bool  value = lock ;
    lock = TRUE ;
    return value ;
}
```

execute atomically: return the value of "lock" and set "lock" to TRUE

Mutual exclusion? Yes   Progress? Yes   Bounded-Wait? No!

Shared data: boolean lock; //initially lock = FALSE;

```
do {   // P0
  while (TestAndSet (lock) ) ;
     critical section
  lock = FALSE;
     remainder section
} while (1) ;
```

```
do {   // P1
  while (TestAndSet (lock) ) ;
     critical section
  lock = FALSE;
     remainder section
} while (1) ;
```

obtain lock

release lock

Atomic Swap()

- Idea: enter CS if lock==false:

Shared data: boolean **lock**; //initially **lock = FALSE**;

```
do {  // P0
    key0 = TRUE;
    while (key0 == TRUE)
        Swap (lock, key0) ;
    critical section
    lock = FALSE;
    remainder section
} while (1) ;
```

```
do {  // P1
    key1 = TRUE;
    while (key1 == TRUE)
        Swap (lock, key1) ;
    critical section
    lock = FALSE;
    remainder section
} while (1) ;
```

Mutual exclusion? Yes   Progress? Yes   Bounded-Wait? No!

Review Slide (2)

- Use software solution to solve CS?
  - Peterson’s and Bakery algorithms
- Use HW support to solve CS?
  - TestAndTest(), Swap()

Semaphores

Semaphore

- A tool to generalize the synchronization problem (easier to solve, but no guarantee for correctness)
- More specifically…
  - a record of how many units of a particular resource are available
    - If #record = 1 -> binary semaphore, mutex lock
    - If #record > 1 -> counting semaphore
  - accessed only through 2 atomic ops: wait & signal
- Spinlock implementation:
  - Semaphore is an integer variable

```
wait (S) {
   while (S <= 0) ;   busy waiting
   S--;
}
```

```
signal (S) {
   S++;
}
```

POSIX Semaphore

- Semaphore is part of POSIX standard BUT it is not belonged to Pthread
  - It can be used with or without thread
- POSIX Semaphore routines:
  - sem_init(sem_t *sem, int pshared, unsigned int value)
  - sem_wait(sem_t *sem)
  - sem_post(sem_t *sem)
  - sem_getvalue(sem_t *sem, int *valptr)
  - sem_destory(sem_t *sem)

Initial value of the semaphore

Current value of the semaphore

- Example:

```
#include <semaphore.h>
sem_t  sem;
sem_init(&sem);
sem_wait(&sem);
// critical section
sem_post(&sem);
 sem_destory(&sem);
```

n-Process Critical Section Problem

- shared data:

```
semaphore mutex ;   // initially mutex = 1
```

- Process Pi:

```
do {
    wait (mutex) ;      // pthread_mutex_lock(&mutex)
            critical section
    signal (mutex); // pthread_mutex_unlock(&mutex)
            remainder section
} while (1) ;
```

- Progress? Yes
- Bounded waiting? Depends on the implementation of wait()

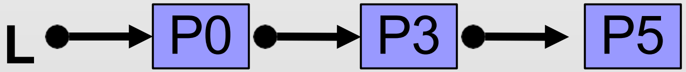
Non-busy waiting Implementation

- Semaphore is data struct with a queue
  - may use any queuing strategy (FIFO, FILO, etc)

```
typedef struct {
   int value; // init to 0
   struct process *L ;
   //  "PCB"  queue
} semaphore ;
```

E.g.,:

Value = -3



- wait() and signal()
  - use system calls: sleep() and wakeup()
  - must be executed atomically

```
void wait (semaphore S) {
   S.value--; // subtract first
   if (S.value < 0) {
      add this process to S.L ;
      sleep( );
   }
}
```

```
void signal (semaphore S) {
   S.value++;
   if (S.value <= 0) {
      remove a process P from S.L ;
      wakeup(P);
   }
}
```

Atomic Operation

- How to ensure atomic wait & signal ops?
  - Single-processor: disable interrupts
  - Multi-processor:
    - HW support (e.g. Test-And-Set, Swap)
    - SW solution (Peterson's solution, Bakery algorithm)

Semaphore with Critical Section

```
void wait (semaphore S) {
    entry-section( );
    S.value--;
    if (S.value < 0) {
        add this process to S.L ;
        exit-section( );
        sleep( );
    }
    else {
        exit-section( );
    }
}
```

```
void signal (semaphore S) {
    entry-section( );
    S.value++;
    if (S.value <= 0)
        remove a process P from S.L;
        exit-section( );
        wakeup(P);
    }
    else {
        exit-section( );
    }
}
```

- Busy waiting for entry-section()?
  - limited to only the CS of wait & signal (~10 instructions) -> very short period of time

Cooperation Synchronization

- P1 executes S1 ; 2 executes S2
  - S2 be executed only after S1 has completed
- Implementation:
  - shared var:

    semaphore sync ; // initially sync = 0

P1:

```
S1 ;
signal (sync) ;
```

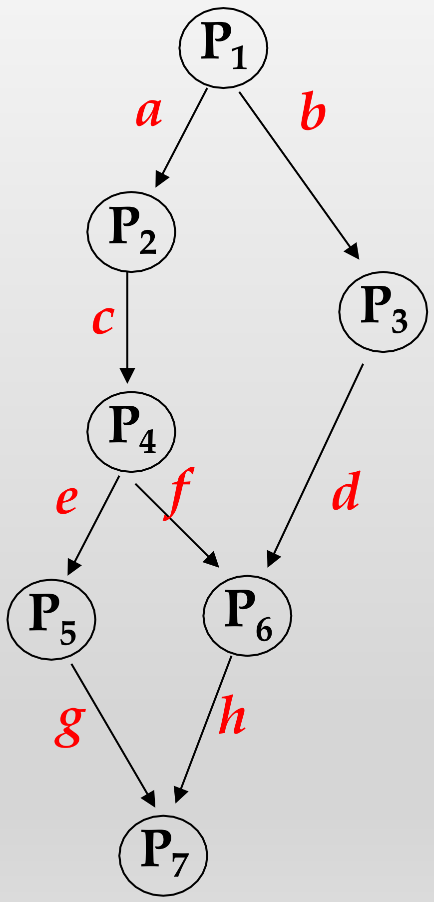
P2:

```
wait (sync) ;
S2 ;
```

A More Complicated Example

(Initially, all semaphores are 0)

```
begin
    P1: S1; signal(a); signal(b);
    P2: wait(a); S2; signal(c);
    P3: wait(b); S3; signal(d);
    P4: wait(c); S4; signal(e); signal(f);
    P5: wait(e); S5; signal(g);
    P6: wait(f); wait(d); S6; signal(h);
    P7: wait(g); wait(h); S7;
end
```



Deadlocks & Starvation

- Deadlocks: 2 processes are waiting indefinitely for each other to release resources
- Starvation: example: LIFO queue in semaphore process queue

P_0	P_1
wait(S);	*wait(Q);*
wait(Q);	*wait(S);*
⋮	⋮
signal(S);	*signal(Q);*
signal(Q)	*signal(S);*

Review Slide (3)

- What’s semaphore? 2 operations?
- What’s busy-waiting (spinlock) semaphore?
- What’s non-busy-waiting (non-spinlock) semaphore?
- How to ensure atomic wait & signal ops?
- Deadlock? starvation?

Classical Synchronization Problems

Listing & Purpose

- Purpose: used for testing newly proposed synchronization scheme
- Bounded-Buffer (Producer-Consumer) Problem
- Reader-Writers Problem
- Dining-Philosopher Problem

Bounded-Buffer Problem

- A pool of n buffers, each capable of holding one item
- Producer:
  - grab an empty buffer
  - place an item into the buffer
  - waits if no empty buffer is available
- Consumer:
  - grab a buffer and retracts the item
  - place the buffer back to the free pool
  - waits if all buffers are empty

Readers-Writers Problem

- A set of shared data objects
- A group of processes
  - reader processes (read shared objects)
  - writer processes (update shared objects)
  - a writer process has exclusive access to a shared object
- Different variations involving priority
  - first RW problem: no reader will be kept waiting unless a writer is updating a shared object
  - second RW problem: once a writer is ready, it performs the updates as soon as the shared object is released

    writer has higher priority than reader

    once a writer is ready, no new reader may start reading

First Reader-Writer Algorithm

```
// mutual exclusion for write
semaphore wrt=1
// mutual exclusion for readcount
semaphore mutex=1
int readcount=0;

Writer(){
    while(TRUE){
        wait(wrt);

          // Writer Code

        signal(wrt);
    }
}
```

- Readers share a single wrt lock
- Writer may have starvation problem

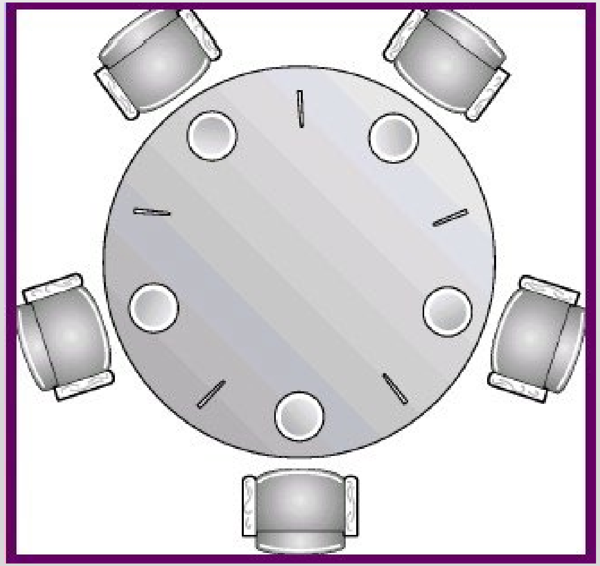
```
Reader(){
  while(TRUE){
    wait(mutex);
      readcount++;
      if(readcount==1)
        wait(wrt);
    signal(mutex);

        // Reader Code

    wait(mutex);
      readcount--;
      if(readcount==0)
        signal(wrt);
    signal(mutex);
  }
}
```

Acquire write lock if reads haven't

release write lock if no more reads

Dining-Philosophers Problem

- 5 persons sitting on 5 chairs with 5 chopsticks
- A person is either thinking or eating
  - thinking: no interaction with the rest 4 persons
  - eating: need 2 chopsticks at hand
  - a person picks up 1 chopstick at a time
  - done eating: put down both chopsticks
- deadlock problem
  - one chopstick as one semaphore
- starvation problem



Monitors

Motivation

- Although semaphores provide a convenient and effective synchronization mechanism, its correctness is depending on the programmer
  - All processes access a shared data object must execute wait() and signal() in the right order and right place
  - This may not be true because honest programming error or uncooperative programmer

Monitor --- A high-level language construct

- The representation of a monitor type consists of
  - declarations of variables whose values define the state of an instance of the type
  - Procedures/functions that implement operations on the type
- The monitor type is similar to a class in O.O. language
  - A procedure within a monitor can access only local variables and the formal parameters
  - The local variables of a monitor can be used only by the local procedures
- But, the monitor ensures that only one process at a time can be **active** within the monitor
- Similar idea is incorporated to many prog. language:
  - concurrent pascal, C# and Java

Monitor

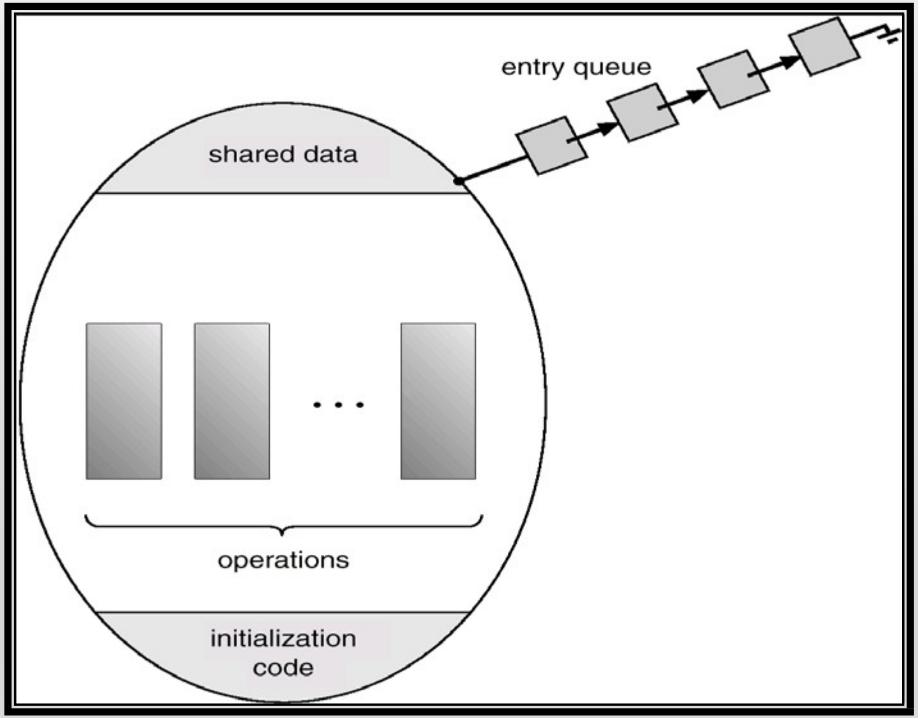
- High-level synchronization construct that allows the safe sharing of an abstract data type among

concurrent processes

Syntax

```
monitor monitor-name {
        // shared variable declarations
        procedure body P1 (…) {
                . . .
        }
        procedure body P2 (…) {
                . . .
        }
        procedure body Pn (…) {
                . . .
        }
        initialization code {
        }
}
```

Schematic View



Monitor Condition Variables

- To allow a process to wait within the monitor, a condition variable must be declared, as

  condition x, y;

- Condition variable can only be used with the operations wait() and signal()
  - x.wait();

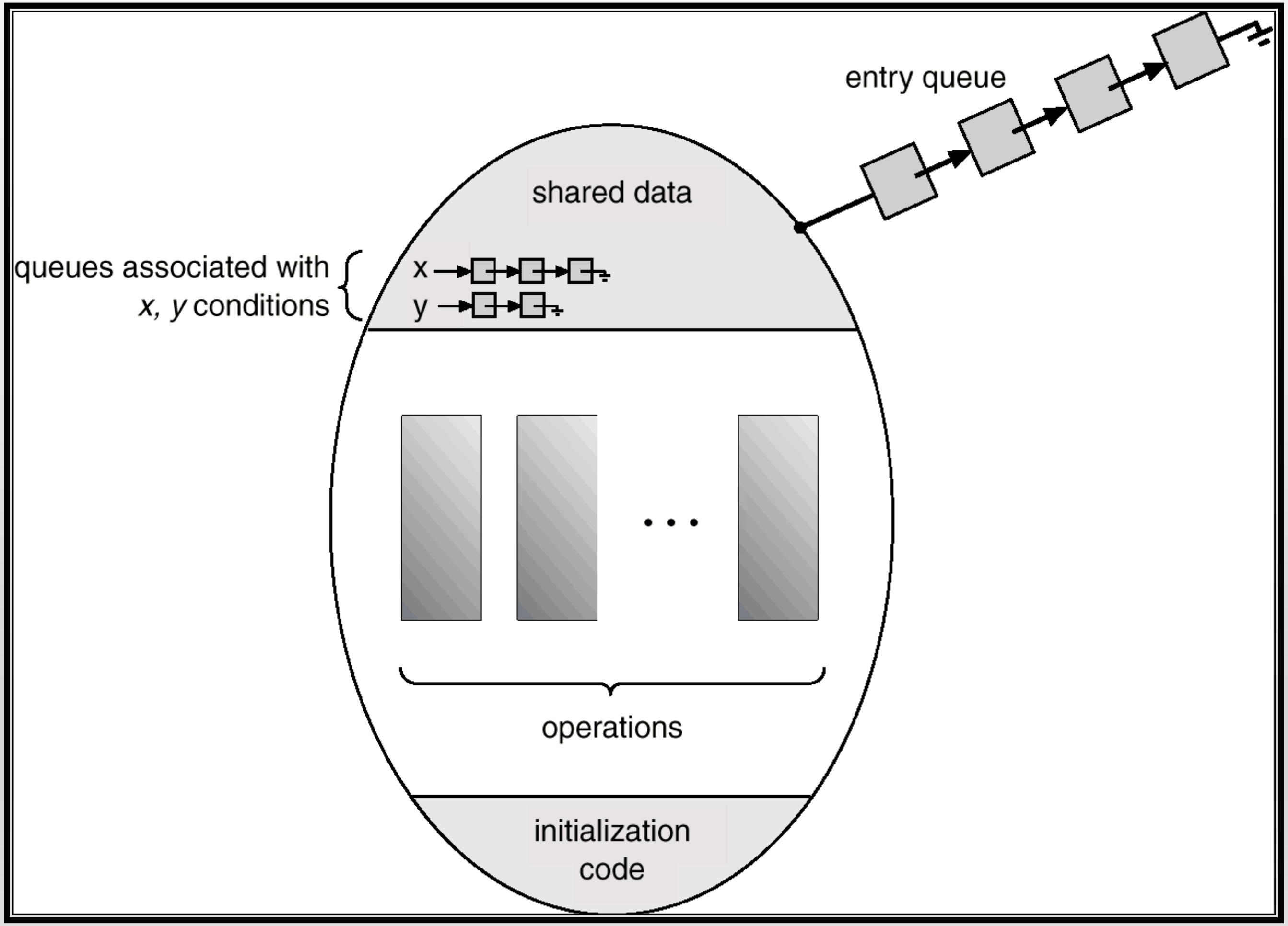
    means that the process invoking this operation is suspended until another process invokes

  - x.signal();

    resumes exactly one suspended process. If no process is suspended, then the signal operation has no effect

    (In contrast, signal always change the state of a semaphore)

Monitor With Condition Variables



Dining Philosophers Example

```
monitor dp {
  enum {thinking, hungry, eating} state[5];  //current state
  condition self[5];  //delay eating if can't obtain chopsticks
  void pickup(int i)        // pickup chopsticks
  void putdown(int i)       // putdown chopsticks
  void test(int i)          // try to eat
  void init() {
      for (int i = 0; i < 5; i++)
          state[i] = thinking;
  }
}
```

```
void pickup(int i) { state[i] =
    hungry; test(i); //try to
    eat
    if (state[i] != eating)
        self[i].wait();//wait to eat
}
```

```
void putdown(int i) {
    state[i] = thinking;
    // check if neighbors
    // are waiting to eat
    test((i+4) % 5);
    test((i+1) % 5);
}
```

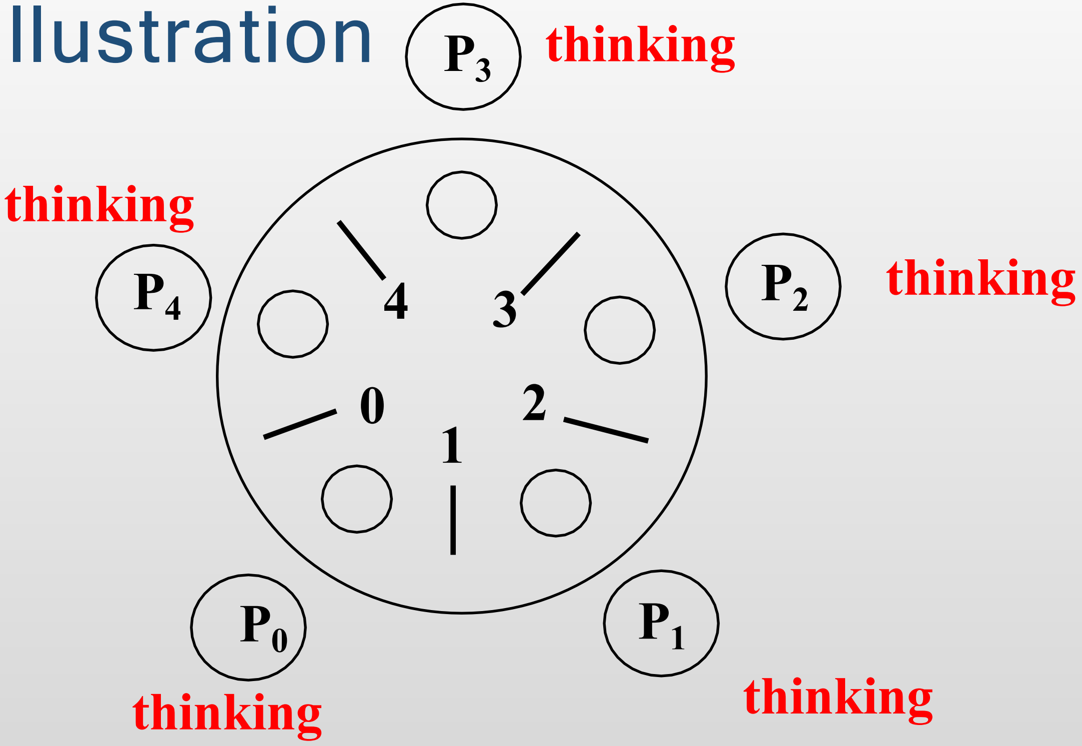
//try to let P_i eat (if it is hungry)

```
void test(int i) {
    if ( (state[(i + 4) % 5] != eating) &&(state[(i + 1) % 5] != eating) && (state[i]
        == hungry) ) {
        //No neighbors are eating and Pi is hungry
        state[i] = eating;
        self[i].signal();
    }
}
```

If P_i is suspended, resume it

If P_i is not suspended, **no effect**

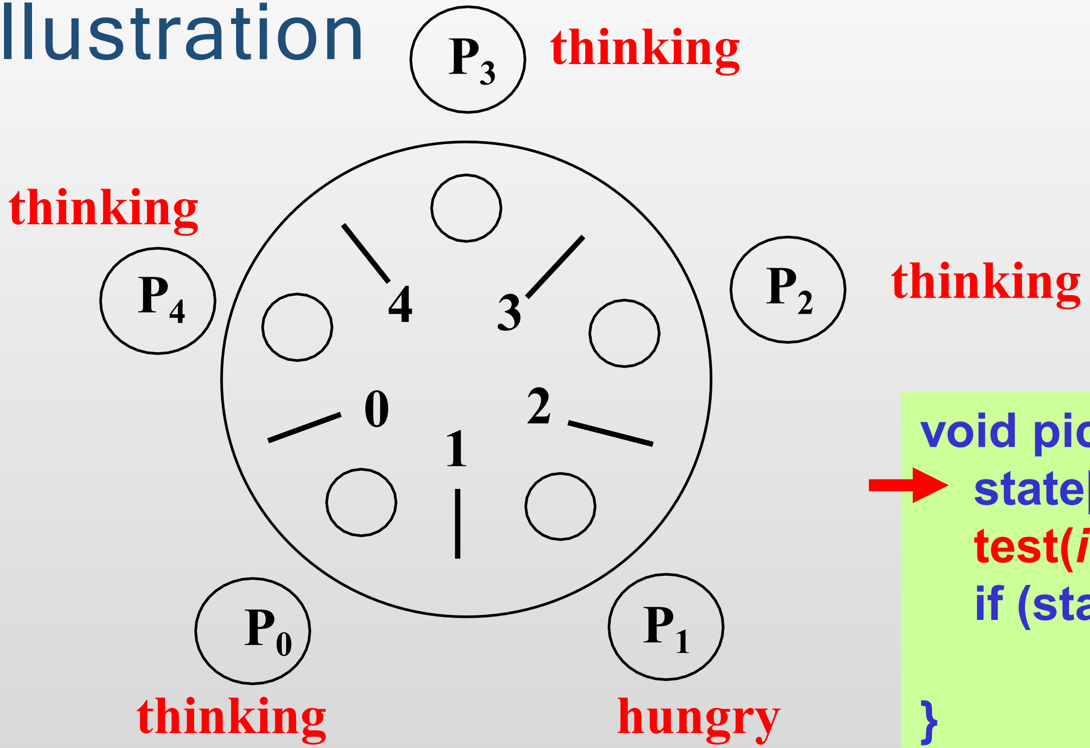
An illustration



P1:
DiningPhilosophers.pickup(1)
eat
DiningPhilosophers.putdown(1)

P2:
DiningPhilosophers.pickup(2)
eat
DiningPhilosophers.putdown(2)

An illustration

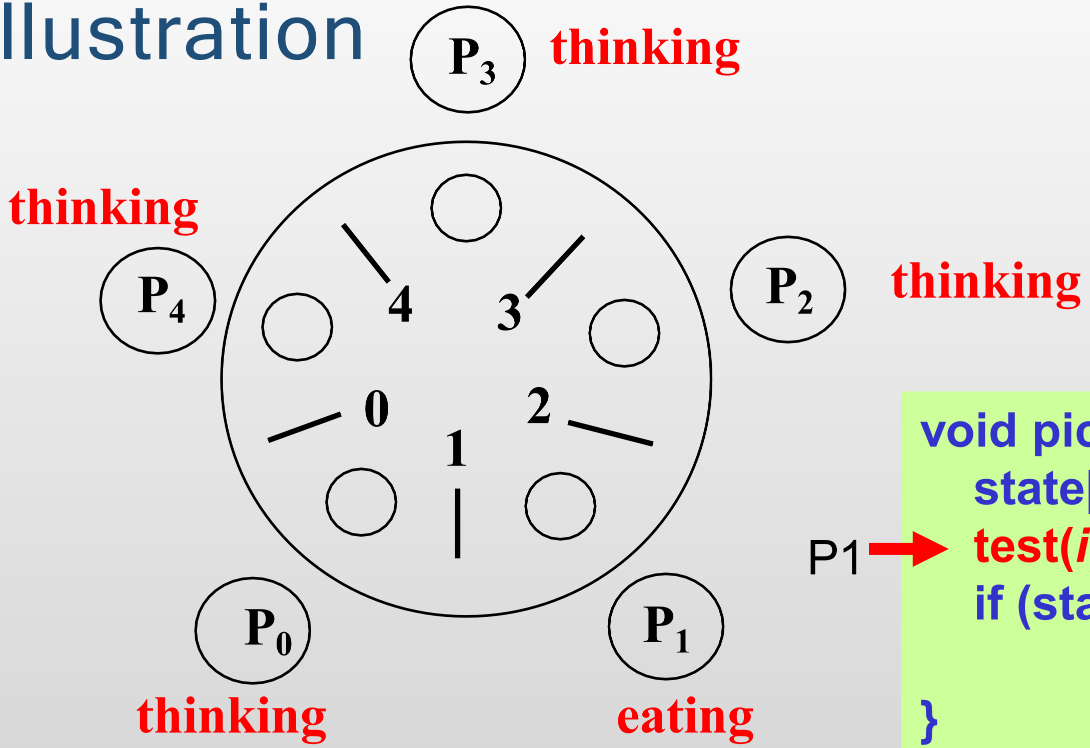



```
void pickup(int i) {
    state[i] = hungry;
    test(i); //try to eat
    if (state[i] != eating)
            self[i].wait();//wait to eat
}
```

```
P1:
DiningPhilosophers.pickup(1)
        eat
DiningPhilosophers.putdown(1)
```

```
P2:
DiningPhilosophers.pickup(2)
        eat
DiningPhilosophers.putdown(2)
```

An illustration



P1 →

```
void pickup(int i) {
   state[i] = hungry;
   test(i); //try to eat
   if (state[i] != eating)
         self[i].wait();//wait to eat
}
```

P1:

→ DiningPhilosophers.pickup(1)

eat

DiningPhilosophers.putdown(1)

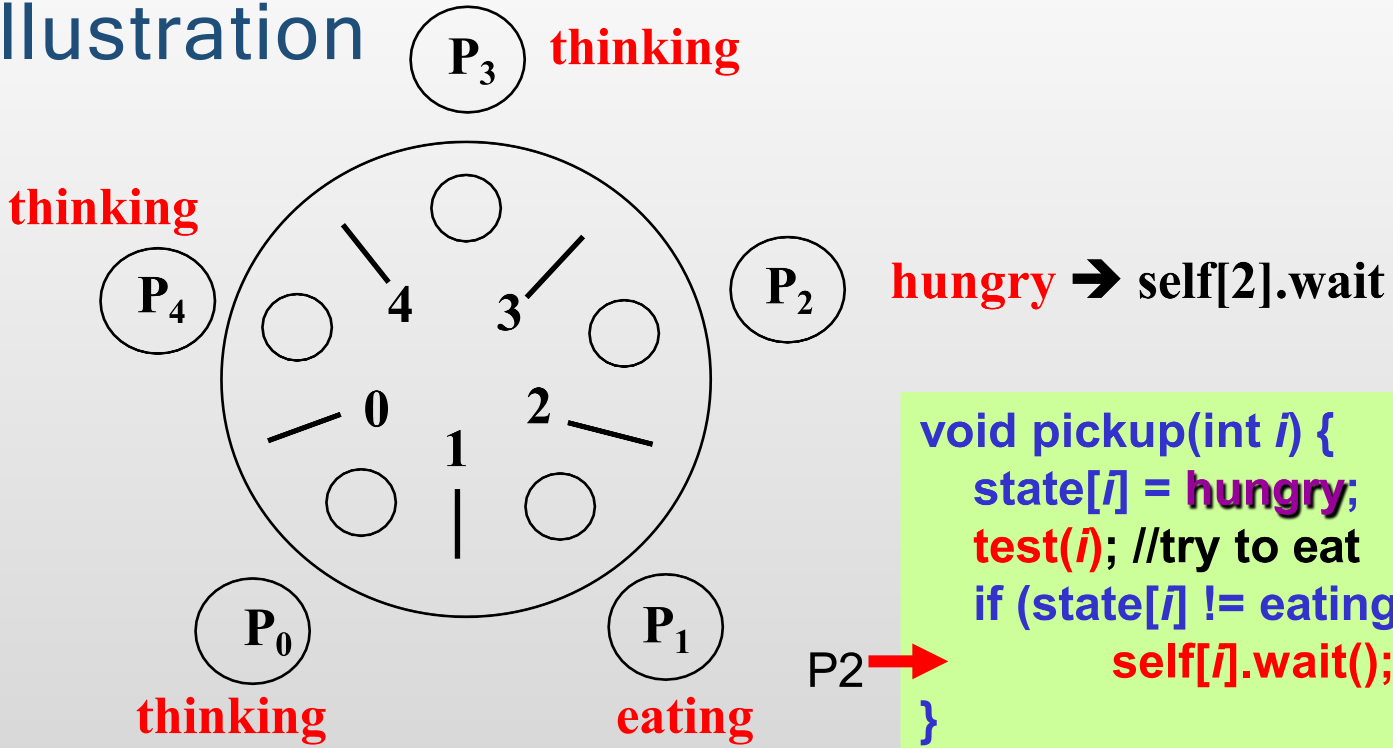
P2:

DiningPhilosophers.pickup(2)

eat

DiningPhilosophers.putdown(2)

An illustration



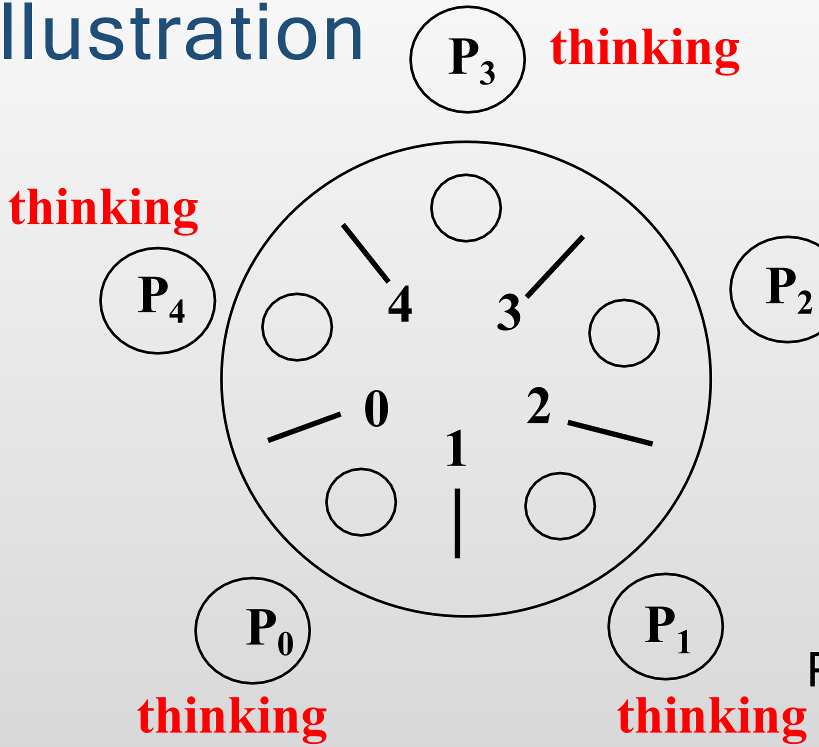

```
void pickup(int i) {
    state[i] = hungry;
    test(i); //try to eat
    if (state[i] != eating)
            self[i].wait();//wait to eat
}
```

P2 →

P1:
DiningPhilosophers.pickup(1)
        eat
DiningPhilosophers.putdown(1)

P2:
DiningPhilosophers.pickup(2)
        eat
DiningPhilosophers.putdown(2)

An illustration

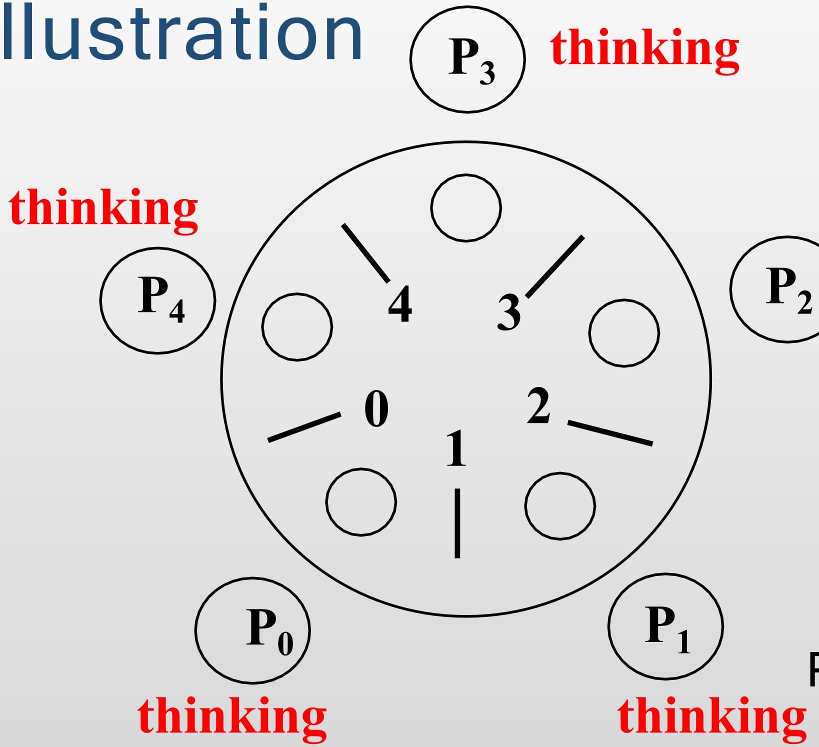



```
void putdown(int i) {
   state[i] = thinking;
   // check if neighbors
   // are waiting to eat
P1 ➔ test((i+4) % 5); test((i+1) % 5);
}
```

```
P1:
DiningPhilosophers.pickup(1)
        eat
➔ DiningPhilosophers.putdown(1)
```

```
P2:
➔ DiningPhilosophers.pickup(2)
        eat
DiningPhilosophers.putdown(2)
```

An illustration



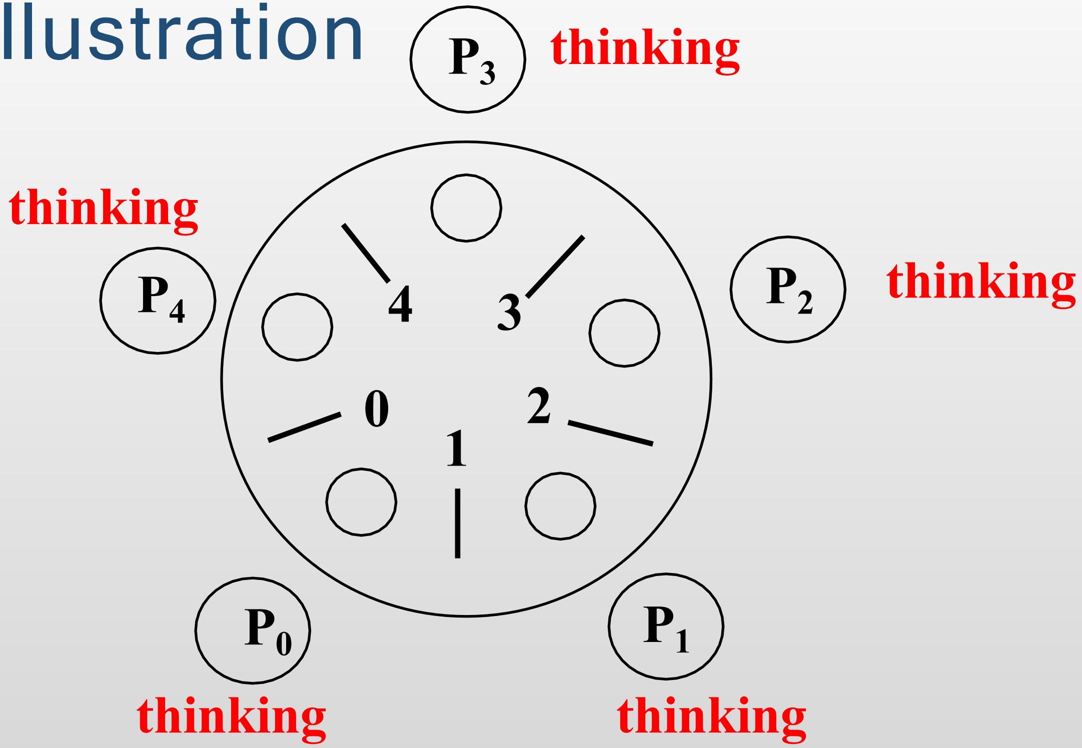
eating ➔ self[2].signal

```
void putdown(int i) {
    state[i] = thinking;
    // check if neighbors
    // are waiting to eat
P1 ➔ test((i+4) % 5); test((i+1) % 5);
}
```

P1:
DiningPhilosophers.pickup(1)
eat
➔ DiningPhilosophers.putdown(1)

P2:
➔ DiningPhilosophers.pickup(2)
eat
DiningPhilosophers.putdown(2)

An illustration



P1:
DiningPhilosophers.pickup(1)
eat
DiningPhilosophers.putdown(1)

P2:
DiningPhilosophers.pickup(2)
eat
DiningPhilosophers.putdown(2)

Synchronized Tools in JAVA

- Synchronized Methods (Monitor)
  - Synchronized method uses the method receiver as a lock
  - Two invocations of synchronized methods cannot interleave on the same object
  - When one thread is executing a synchronized method for an object, all other threads that invoke synchronized methods for the same object block until the first thread exist the object

```
public class SynchronizedCounter {
        private int c = 0;
        public synchronized void increment() { c++; }
        public synchronized void decrement() { c--; }
        public synchronized int value() { return c; }
```

Synchronized Tools in JAVA

- Synchronized Statement (Mutex Lock)
  - Synchronized blocks uses the expression as a lock
  - A synchronized Statement can only be executed once the thread has obtained a lock for the object or the class that has been referred to in the statement
  - useful for improving concurrency with fine-grained

```
public void run()
{
    synchronized(p1)
    {
          int i = 10; // statement without locking requirement
          p1.display(s1);
     }
```

Review Slides (4)

- Bounded-buffer problem?
- Reader-Writer problem?
- Dining Philosopher problem?
- What is monitor and why need monitor?

Atomic Transactions

System Model

- Transaction: a collection of instructions

  (or instructions) that performs a single logic function
- Atomic Transaction: operations happen as a single logical unit of work, in its entirely, or not at all
- Atomic transaction is particular a concern for database system
  - Strong interest to use DB techniques in OS

File I/O Example

- Transaction is a series of read and write operations
- Terminated by commit (transaction successful) or abort (transaction failed) operation
- Aborted transaction must be rolled back to undo any changes it performed
- It is part of the responsibility of the system to ensure this property

Log-Based Recovery

- Record to stable storage information about all modifications by a transaction
  - Stable storage: never lost its stored data
- Write-ahead logging: Each log record describes single transaction write operation
  - Transaction name
  - Data item name
  - Old & new values
  - Special events: <Ti starts>, <Ti commits>
- Log is used to reconstruct the state of the data items modified by the transactions
  - Use undo (Ti), redo(Ti) to recover data

Checkpoints

- When failure occurs, must consult the log to determine which transactions must be re-done
    - Searching process is time consuming
    - Redone may not be necessary for all transactions
- Use checkpoints to reduce the above overhead:
    - Output all log records to stable storage
    - Output all modified data to stable storage
    - Output a log record <checkpoint> to stable storage

Review Slides (5)

- What is atomic transaction?
- Purpose of commit, abort, rolled-back?
- How to use log and checkpoints?

Reading Material & HW

- Chap 6
- HWs
  - 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.9, 6.14, 6.20

Backup

Case Study:

- Solaris 2
- Windows XP

Solaris 2 Synchronization

- Implements a variety of locks to support multitasking, multithreading (including real-time threads), and multiprocessing.
- Uses adaptive mutexes for efficiency when protecting data from short code segments.
  - Mutex and semaphore always serialize data accesses
- Uses condition variables and readers-writers locks when longer sections of code need access to data.
  - Efficient for data that is accessed frequently, but in a read- only manner

Solaris 2 Adaptive Mutex

- Multiprocessor system
    - Data locked (i.e. in use)
        - Locking thread is running -> requesting thread spins on the mutex (spinlock)
        - Locking thread is not in run state -> requesting thread blocks on the mutex (waiting lock)
- Uniprocessor system
    - Requesting thread always blocks

Solaris 2 Turnstile

- Uses turnstiles to order the list of threads waiting to acquire either an adaptive mutex or reader-writer lock
  - A turnstile is a queue structure containing threads blocked on a lock
- To prevent a priority inversion, turnstiles are organized according to a *priority-inheritance protocol*
  - Temporarily inherit the priority of the high-priority thread (blocked on this lock)

XP Synchronization

- Use interrupt masks to protect access to global resources on uniprocessor systems (disable interrupt)
- Uses spinlocks on multiprocessor system
- Dispatcher objects: either in signaled or nonsignaled state
  - Signaled: object is available immediately
  - Nonsignaled: object is not available
  - Thread queue associated with each object
  - WaitForSingleObject or WaitForMultipleObjects

Q & A

Thank you for your attention