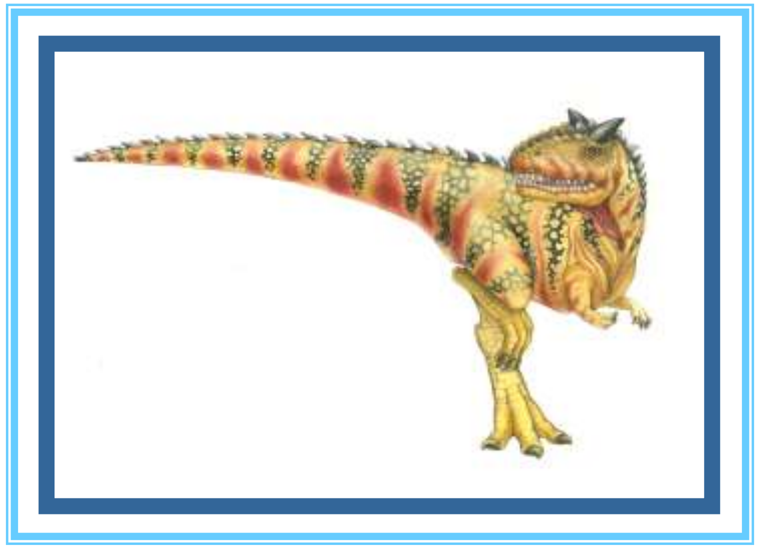
Chapter 6: Process Synchronization



Module 6: Process Synchronization

- Background
- The Critical-Section Problem
- Peterson’s Solution
- Synchronization Hardware
- Semaphores
- Classic Problems of Synchronization
- Monitors
- Synchronization Examples
- Atomic Transactions

Objectives

- To introduce the critical-section problem, whose solutions can be used to ensure the consistency of shared data
- To present both software and hardware solutions of the critical-section problem
- To introduce the concept of an atomic transaction and describe mechanisms to ensure atomicity

Background

- **Process Synchronization** is a technique which is used to coordinate the process that use shared Data.
- **Independent Process –**
  The process that does not affect or is affected by the other process while its execution then the process is called Independent Process. Example The process that does not share any shared variable, database, files, etc.
- **Cooperating Process –**
  The process that affect or is affected by the other process while execution, is called a Cooperating Process. Example The process that share file, variable, database, etc are the Cooperating Process
- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Suppose that we wanted to provide a solution to the consumer-producer problem that fills the buffer. We can do so by having an integer **count** that keeps track of the number of elements in the buffer. Initially, count is set to 0. It is incremented by the producer after it produces a new item into the buffer and is decremented by the consumer after it consumes the item in the buffer.

Producer

```
while (true) {

        /*  produce an item and put in nextProduced  */
         while (counter == BUFFER_SIZE)
                ; // do nothing
             buffer [in] = nextProduced;
             in = (in + 1) % BUFFER_SIZE;
             counter++;
}
```

Consumer

```
while (true)  {
      while (counter == 0)
          ; // do nothing
          nextConsumed =  buffer[out];
           out = (out + 1) % BUFFER_SIZE;
               counter--;

           /*  consume the item in nextConsumed
}
```

Race Condition

- counter++ could be implemented as

  register1 = counter
  register1 = register1 + 1
  counter = register1

- counter-- could be implemented as

  register2 = counter
  register2 = register2 - 1
  count = register2

- Consider this execution interleaving with “count = 5” initially:

  S0: producer execute register1 = counter {register1 = 5}
  S1: producer execute register1 = register1 + 1 {register1 = 6}
  S2: consumer execute register2 = counter {register2 = 5}
  S3: consumer execute register2 = register2 - 1 {register2 = 4}
  S4: producer execute counter = register1 {count = 6 }
  S5: consumer execute counter = register2 {count = 4}

- A situation like this, where several processes access and manipulate the same data concurrently and the outcome of the execution depends on the particular order in which the access takes place, is called a race condition.
- ensure that only one process at a time can be manipulating the variable `counter`
- the problem with critical sections is called a race condition, where the outcome of the program depends on the order in which concurrent processes or threads execute
- Race conditions can result in a wide range of issues, including data corruption, deadlocks, and resource starvation.

Critical Section Problem

- Consider system of n processes $\{p_0, p_1, \ldots p_{n-1}\}$
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc
- When one process is executing in its critical section, no other process is to be allowed to execute in critical section. That is, no two processes are executing in their critical sections at the same time. Critical section problem is to design protocol to solve this.
- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**
- Especially challenging with preemptive kernels

Critical Section

- General structure of process p_i is

```
do {
        entry section
            critical section
        exit section
            remainder section
} while (TRUE);
```

Figure 6.1 General structure of a typical process P_i.

Solution to Critical-Section Problem

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections.
2. **Progress** - If no process is executing in its critical section and some processes wish to enter their critical sections, then only those processes that are not executing in their remainder sections can participate in deciding which will enter its critical section next, and this selection cannot be postponed indefinitely.(decision must be taken within a finite time)
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

First Version of Dekker's Algorithm

- Succeeds in enforcing the mutual exclusion.
- The processor's must enter and exit their critical sections in strict alteration (so inefficient).
- Enforces lockstep synchronization problem.

It means each process depends on other to complete its execution. If one of the two processes completes its execution, then the second process runs.

```
program versionone;
var processnumber: integer;
```

```
procedure processone;
begin
while true do
begin
while processnumber=2
do;
critical_section_one;
processnumber:=2;
otherstuffone
end
end;
```

```
procedure procestwo;
begin
while true do
begin
while processnumber=1
do;
critical_section_two;
processnumber:=1;
otherstufftwo
end
end;
```

```
begin
processnumber:=1;
parbegin
processone;
processtwo;
parend
end;
```

Same process can't enter CS continuously

Second Version of Dekker's Alg

```
program versiontwo;
var p1inside, p2inside : boolean;
```

```
procedure processone;
begin
 while true do
 begin
 while p2inside do;
 p1inside:=true;
 critical_section_one;
 p1inside:=false;
 otherstuffone
 end
end;
```

```
procedure procestwo;
 begin
 while true do
 begin
  while p1inside do;
  p2inside:=true;
  critical_section_two;
  p2inside:=false;
  otherstufftwo
 end
 end;
```

```
begin
p1inside:=false;
p2inside:=false;
parbegin
processone;
processtwo;
parend
end;
```

Lockstep synchronization is removed(but it creates new problem; both enters simultaneously into the CS). Lockstep synchronization is removed by using two flags to indicate its current status and updates them accordingly at the entry and exit section.

statements are generally atomic, but series of statements are not

Mutual exclusion is not guaranteed

```
program versionthree;
var p1wantstoenter, p2wantstoenter:boolean;
procedure processone;
    begin
        while true do
        begin
            p1wantstoenter := true;
            while p2wantstoenter do;
            criticalsectionone;
            p1wantstoenter := false;
            otherstuffone
        end;
    end;
procedure processtwo
    begin
        while true do
        begin
            p2wantstoenter := true;
            while p1wantstoenter do;
            criticalsectiontwo;
            p2wantstoenter := false;
            otherstufftwo
        end;
    end;

begin
    p1wantstoenter := false;
    p2wantstoenter := false;
    parbegin
        processone;
        processtwo;
    parend
end.
```

- Mutual exclusion is guaranteed.
- Introduces two-process deadlock.

Both threads could get flag simultaneously and they will wait for infinite time.

Both threads should not set the flag simultaneously, introduce randomness in the next version(4)

Version 3

```
program versionfour;
var p1wantstoenter, p2wantstoenter:boolean;
procedure processone;
     begin
          while true do
          begin
               p1wantstoenter := true;
               while p2wantstoenter do
                    begin
                         p1wantstoenter := false;
                         delay(random, fewcycles);
                         p1wantstoenter := true;
                    end;
               criticalsectionone;
               p1wantstoenter := false;
               otherstuffone
          end;
     end;
procedure processtwo
     begin
          while true do
          begin
               p2wantstoenter := true;
               while p1wantstoenter do
                    begin
                         p2wantstoenter := false;
                         delay(random, fewcycles);
                         p2wantstoenter := true;
                    end;
               criticalsectiontwo;
               p2wantstoenter := false;
               otherstufftwo
          end;
     end;
```

```
begin
     p1wantstoenter := false;
     p2wantstoenter := false;
     parbegin
          processone;
          processtwo;
     parend
end.
```

- Mutual exclusion is guaranteed.
- Deadlock cannot occur.
- Indefinite postponement could occur.(random delay)
- Version 4 is unacceptable.

Version 4

Dekker's algorithm

```
program dekkersalgorithm;
var favoredprocess: (first, second);
    p1wantstoenter, p2wantstoenter: boolean;
procedure processone;
begin
    while true do
    begin
        p1wantstoenter := true;
        while p2wantstoenter do
        begin
            if favoredprocess = second then
            begin
                p1wantstoenter := false;
                while favoredprocess = second do;
                p1wantstoenter := true
            end;
        end;
        criticalsectionone;
        favoredprocess := second;
        p1wantstoenter := false;
        otherstuffone
    end;
end;
procedure processtwo;
begin
    while true do
    begin
        p2wantstoenter := true;
        while p1wantstoenter do
        begin
            if favoredprocess = first then
            begin
                p2wantstoenter := false;
                while favoredprocess = first do;
                p2wantstoenter := true
            end;
        end;
        criticalsectiontwo;
        favoredprocess := first;
        p2wantstoenter := false;
        otherstufftwo
    end;
end;
begin
    p1wantstoenter := false;
    p1wantstoenter := false;
    favoredprocess := first;
    parbegin
        processone;
        processtwo;
    parend
end.
```

- Mutual exclusion guaranteed.
- Lockstep Synchronization not enforced.
- Deadlock is avoided.
- Resolves possibility of indefinite postponement.

Dekker's algorithm of ME Primitive

- Mutual exclusion guaranteed.
- Lockstep Synchronization not enforced.
- Deadlock is avoided.
- Resolves possibility of indefinite postponement.

Global storage

p1WantsToEnter
p2WantsToEnter
favoredProcess

p1WantsToEnter
p2WantsToEnter
favoredProcess

```
Procedure processOne
begin
   while TRUE do begin
      p1WantsToEnter := TRUE;
      while (p2WantsToEnter) do begin
         if (favoredProcess = 2) then begin
            p1WantsToEnter := FALSE;
            while (favoredProcess = 2) do;
            p1WantsToEnter := TRUE;
         end;
      end;
      // do critical section of 1.
      favoredProcess := 2;
      p1WantsToEnter := FALSE;
      // do remainder sections of 1.
   end;
end;
```

```
Procedure processTwo
begin
   while TRUE do begin
      p2WantsToEnter := TRUE;
      while (p1WantsToEnter) do begin
         if (favoredProcess = 1) then begin
            p2WantsToEnter := FALSE;
            while (favoredProcess = 1) do;
            p2WantsToEnter := TRUE;
         end;
      end;
      // do critical section of 2.
      favoredProcess := 1;
      p2WantsToEnter := FALSE;
      // do remainder sections of 2.
   end;
end;
```

```
p1WantsToEnter := FALSE initially.
p2WantsToEnter := FALSE initially.
favoredProcess := 1 initially.
```

Peterson's Solution

- Two process solution
- The two processes share two variables:
  - int **turn**;
  - Boolean **flag[2]**
- The variable **turn** indicates whose turn it is to enter the critical section
- The **flag** array is used to indicate if a process is ready to enter the critical section. **flag[i]** = true implies that process P_i is ready!

Peterson's Solution-Algorithm for Process P_i

Peterson's solution requires the two processes to share two data items:

```
int turn;
boolean flag[2];
```

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

Algorithm for Process P_j

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

- Provable that

1. Mutual exclusion is preserved
2. Progress requirement is satisfied
3. Bounded-waiting requirement is met

Disadv:

Holds good only for 2 processes

Synchronization Hardware

- Many systems provide hardware support for critical section code

- Uniprocessors – could disable interrupts
  - Currently running code would execute without preemption
  - Generally too inefficient on multiprocessor systems
    - Operating systems using this not broadly scalable

- Modern machines provide special atomic hardware instructions
    - Atomic = non-interruptable
  - Either test memory word and set value
  - Or swap contents of two memory words

TestAndSet Instruction

- Definition:

```
boolean TestAndSet (boolean *target)
{
     boolean rv = *target;
     *target = TRUE;
     return rv:
}
```

Solution using TestAndSet

- Shared boolean variable lock, initialized to FALSE
- Solution:

```
do {
    while ( TestAndSet (&lock ))
            ;   // do nothing

        //    critical section

    lock = FALSE;

        //      remainder section

} while (TRUE);
```

- Definition:

```
boolean TestAndSet (boolean *target)
{
    boolean rv = *target;
    *target = TRUE;
    return rv:
}
```

The Test and Set solution does not satisfy bounded waiting. There is no inherent mechanism in the solution to limit the waiting time for a process trying to acquire the lock.

Swap Instruction

- Definition:

```
void Swap (boolean *a, boolean *b)
{
        boolean temp = *a;
        *a = *b;
        *b = temp:
}
```

Solution using Swap

- Shared Boolean variable lock initialized to FALSE; Each process has a local Boolean variable key
- Solution:

```
do {
        key = TRUE;
        while ( key == TRUE)
              Swap (&lock, &key );

                //    critical section

        lock = FALSE;

                //      remainder section

} while (TRUE);
```

```
void Swap (boolean *a, boolean *b)
        {
                boolean temp = *a;
                *a = *b;
                *b = temp:
        }
```

Bounded-waiting Mutual Exclusion with TestandSet()

every process should get its turn eventually, and no process should be starved indefinitely.

```
do {
    waiting[i] = TRUE;
    key = TRUE;
    while (waiting[i] && key)
            key = TestAndSet(&lock);
    waiting[i] = FALSE;
            // critical section
    j = (i + 1) % n;
    while ((j != i) && !waiting[j])
            j = (j + 1) % n;
    if (j == i)
            lock = FALSE;
    else
            waiting[j] = FALSE;
            // remainder section
} while (TRUE);
```


```
do {
    waiting[i] = TRUE;
    key = TRUE;
    while (waiting[i] && key)
            key = TestAndSet(&lock);
    waiting[i] = FALSE;
            // critical section
    j = (i + 1) % n;
    while ((j != i) && !waiting[j])
            j = (j + 1) % n;
    if (j == i)
            lock = FALSE;
    else
            waiting[j] = FALSE;
            // remainder section
} while (TRUE);
```

- Semaphores are versatile and can be used to control access to multiple resources, not just critical sections. This makes them suitable for scenarios where coordination and synchronization involve more than just protecting shared data.

  Semaphores can be used as counting mechanisms, allowing multiple threads or processes to acquire/release multiple permits. This is useful in scenarios where more than one resource is available, and multiple processes can proceed concurrently.

Mutex Locks

```
do {

    acquire lock

        critical section

    release lock

        remainder section

} while (true);
```

```
acquire() {
    while (!available)
       ; /* busy wait */
    available = false;;
}


release() {
   available = true;
}
```

Problem: spinlock - process "spins" while waiting for the lock.

Semaphore

- Semaphore *S* – integer variable
- Two standard operations modify S: wait() and signal()
  - Originally called P() →P (from the Dutch proberen, "to test");
  - V()→ (from verhogen, "to increment").
- Less complicated
- Can only be accessed via two indivisible (atomic) operations
  - ```
    wait (S) {
        while S <= 0
               ; // no-op
          S--;
     }
    ```
  - ```
    signal (S) {
      S++;
    }
    ```

2 versions of semaphore exists, 1st version with busy waiting, 2nd version with blocking call

Semaphore as General Synchronization Tool

- **Binary** semaphore – integer value can range only between 0 and 1; can be simpler to implement
  - Also known as **mutex locks**
- Mutual-exclusion implementation with **Binary** semaphore
- Semaphore mutex;   // initialized to 1

```
do {
     wait (mutex);
        // Critical Section
     signal (mutex);
          // remainder section
} while (TRUE);
```

- **Use a binary semaphore** when the goal is to protect a critical section. The binary semaphore ensures that only one thread or process can execute in the critical section at any given time.

- **Use a counting semaphore** when you have a fixed number of resources that can be shared among multiple threads or processes, but the access to these resources does not constitute a critical section that requires mutual exclusion.
  - **Managing access to multiple resources**. Counting semaphores allow multiple threads or processes to access shared resources concurrently, up to a specified limit. They are not typically used to enforce mutual exclusion in critical sections, as they allow more than one thread to proceed if the count is greater than 1.
  - Eg: DB connections

- **Counting** semaphore – integer value can range over an unrestricted domain
- **Case 1: To control access to a given resource**

- **Semaphore is initialized to the number of resources**
- **Semaphore Count =0;all resources are utilized**

- **Case 2 : process synchronization**
- **(if we want the restriction on the order of execution: s2 is executed only after s1 completes)**
- **synch=0**

```
S1;
signal(synch);
```

```
wait(synch);
S2;
```

Disadvantage: Busy waiting thus wastes CPU cycles

- While a process is in its critical section, any other process that tries to enter its critical section must loop continuously in the entry code.
- This type of semaphore is also called spinlock a because the process "spins" while waiting for the lock.
- Busy waiting wastes CPU cycles that some other process might be able to use productively.
- To overcome the need for busy waiting, we can modify the definition of the wait() and signal() semaphore operations.
- rather than engaging in busy waiting, the process can *block* itself. The block operation places a process into a waiting queue associated with the semaphore

Semaphore Implementation with no Busy waiting

- With each semaphore there is an associated waiting queue
- Each entry in a waiting queue has two data items:
  - value (of type integer)
  - pointer to next record in the list

```
typedef struct {
      int value;
      struct process *list;
} semaphore;
```

- Two operations:
  - **block** – place the process invoking the operation on the appropriate waiting queue
  - **wakeup** – remove one of processes in the waiting queue and place it in the ready queue

Semaphore Implementation with no Busy waiting (Cont.)

- Synchronization tool that does not require busy waiting

- Implementation of wait:

```
wait(semaphore *S) {
        S->value--;
        if (S->value < 0) {
                add this process to S->list;
                block();
        }
}
```

Entry

Here, semaphore values may be negative, whereas semaphore values are never negative under the classical definition of semaphores with busy waiting.

Semaphore value –ve indicates the processes waiting to acquire that semaphore

- Implementation of signal:

```
signal(semaphore *S) {
        S->value++;
        if (S->value <= 0) {
                remove a process P from S->list;
                wakeup(P);
        }
}
```

Put the processes from the blocked list to ready queue… not into CS

Exit

Deadlock and Starvation

- **Deadlock** – two or more processes are waiting indefinitely for an event
- Let S and Q be two semaphores initialized to 1

P_0		P_1	
wait (S);	S=0	wait (Q);	Q=0
wait (Q);	Q=-1	wait (S);	S=-1
.		.	
.		.	
.		.	
signal (S);		signal (Q);	
signal (Q);		signal (S);	

- **Starvation** – indefinite blocking
  - occur if we remove processes from the list associated with a semaphore in LIFO order

Priority Inversion

- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process
- Solved via **priority-inheritance protocol**
- L and H share/modify kernel data(CS)

L and H(not M) share resource R

- Assume we have three processes, *L*, *M*, and *H*, whose priorities follow the order *L* < *M* < *H*. Assume that process *H* requires resource *R*, which is currently being accessed by process *L*. Ordinarily, process *H* would wait for *L* to finish using resource *R*.
- *M* becomes runnable, thereby preempting process
- a process with a lower priority—process *M*—has affected how long process *H* must wait for *L* to relinquish resource *R*.
- This problem is known as **priority inversion**.
- priority-inheritance protocol would allow process *L* to temporarily inherit the priority of process *H*, thereby preventing process *M* from preempting its execution. When process *L* had finished using resource *R*, it would relinquish its inherited priority from *H* and assume its original priority. Because resource *R* would now be available, process *H*—not *M*—would run next.

Classical Problems of Synchronization

- Classical problems used to test newly-proposed synchronization schemes
  - Bounded-Buffer Problem (When producer is producing an item the consumer must not consume the item)
  - Readers and Writers Problem
  - Dining-Philosophers Problem

Bounded-Buffer Problem

- *N* buffers, each can hold one item
- Semaphore mutex initialized to the value 1
- Semaphore full initialized to the value 0
- Semaphore empty initialized to the value N

Bounded Buffer Problem (Cont.)

- The structure of the producer process

```
do  {

            //   produce an item in next_produced

        wait (empty);
        wait (mutex);

            //  add the item next_produced to the  buffer

        signal (mutex);
        signal (full);
   } while (TRUE);
```

- *N* buffers, each can hold one item
- Semaphore mutex initialized to the value 1
- Semaphore full initialized to the value 0
- Semaphore empty initialized to the value N

Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```
do {
        wait (full);
        wait (mutex);

                //  remove an item from  buffer to next_consumed

        signal (mutex);
        signal (empty);

                //  consume the item in next_consumed

} while (TRUE);
```

Readers-Writers Problem

- A data set is shared among a number of concurrent processes
- Problem – **allow multiple readers to read at the same time**
- **Only one single writer can access the shared data at the same time**
- Shared Data
  - Semaphore mutex initialized to 1
  - Semaphore wrt initialized to 1
  - Integer readcount initialized to 0

Readers-Writers Problem

- **semaphore wrt functions as a mutual-exclusion semaphore for the writers.**
- The structure of a writer process

```
do {
        wait (wrt) ;

            //    writing is performed

        signal (wrt) ;
} while (TRUE);
```

- Semaphore mutex initialized to 1
- Semaphore wrt initialized to 1
- Integer readcount initialized to 0

Readers-Writers Problem (Cont.)

- The structure of a reader process

```
do {
        wait (mutex) ;
        readcount ++ ;
        if (readcount == 1)
              wait (wrt) ;
        signal (mutex)

             // reading is performed

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

- Semaphore **mutex** initialized to 1
- Semaphore **wrt** initialized to 1
- Integer **readcount** initialized to 0

- First reader process will lock the writer process
- Last reader process will enable or allow the writer process to proceed
- Ensure the modification of readcount by only one process

```
do {
        wait (mutex) ;
        readcount ++ ;
        if (readcount == 1)
                    wait (wrt) ;
        signal (mutex)

              // reading is performed

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

Dining-Philosophers Problem

- Philosophers spend their lives thinking and eating
- Don't interact with their neighbors, occasionally try to pick up 2 chopsticks (one at a time) to eat from bowl
  - Need both to eat, then release both when done
- In the case of 5 philosophers
  - Shared data
    - Bowl of rice (data set)
    - Semaphore chopstick [5] initialized to 1

Dining-Philosophers Problem Algorithm

- The structure of Philosopher *i*:

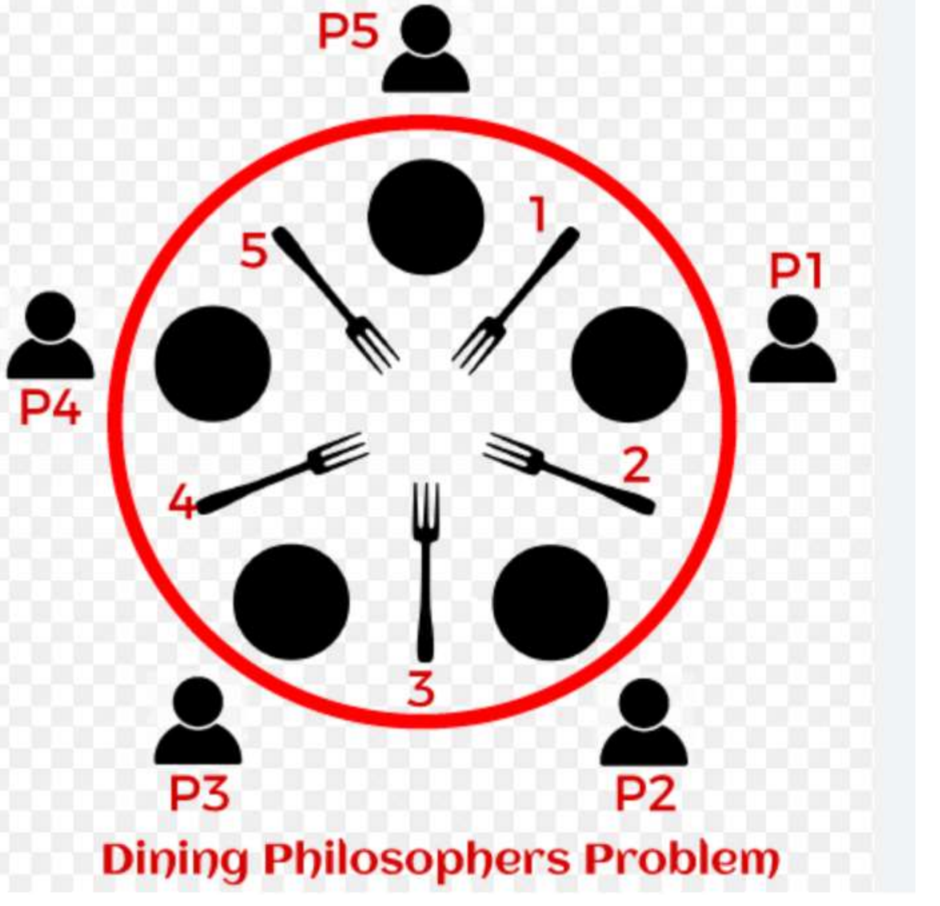
```
do  {
        wait ( chopstick[i] );
        wait ( chopStick[ (i + 1) % 5] );

            //  eat

        signal ( chopstick[i] );
        signal (chopstick[ (i + 1) % 5] );

            //  think

} while (TRUE);
```



- What is the problem with this algorithm?
- If all five philosophers become hungry simultaneously and each grabs her left chopstick. All the elements of chopstick will now be equal to 0.When each philosopher tries to grab her right chopstick, she will be delayed forever.

Several possible remedies to the deadlock problem are listed next.

- Allow at most four philosophers to be sitting simultaneously at the table.
- Allow a philosopher to pick up her chopsticks only if both chopsticks are available .
- Allow odd philosopher picks up first her left chopstick and then her right chopstick, whereas an even philosopher picks up her right chopstick and then her left chopstick.

Monitors

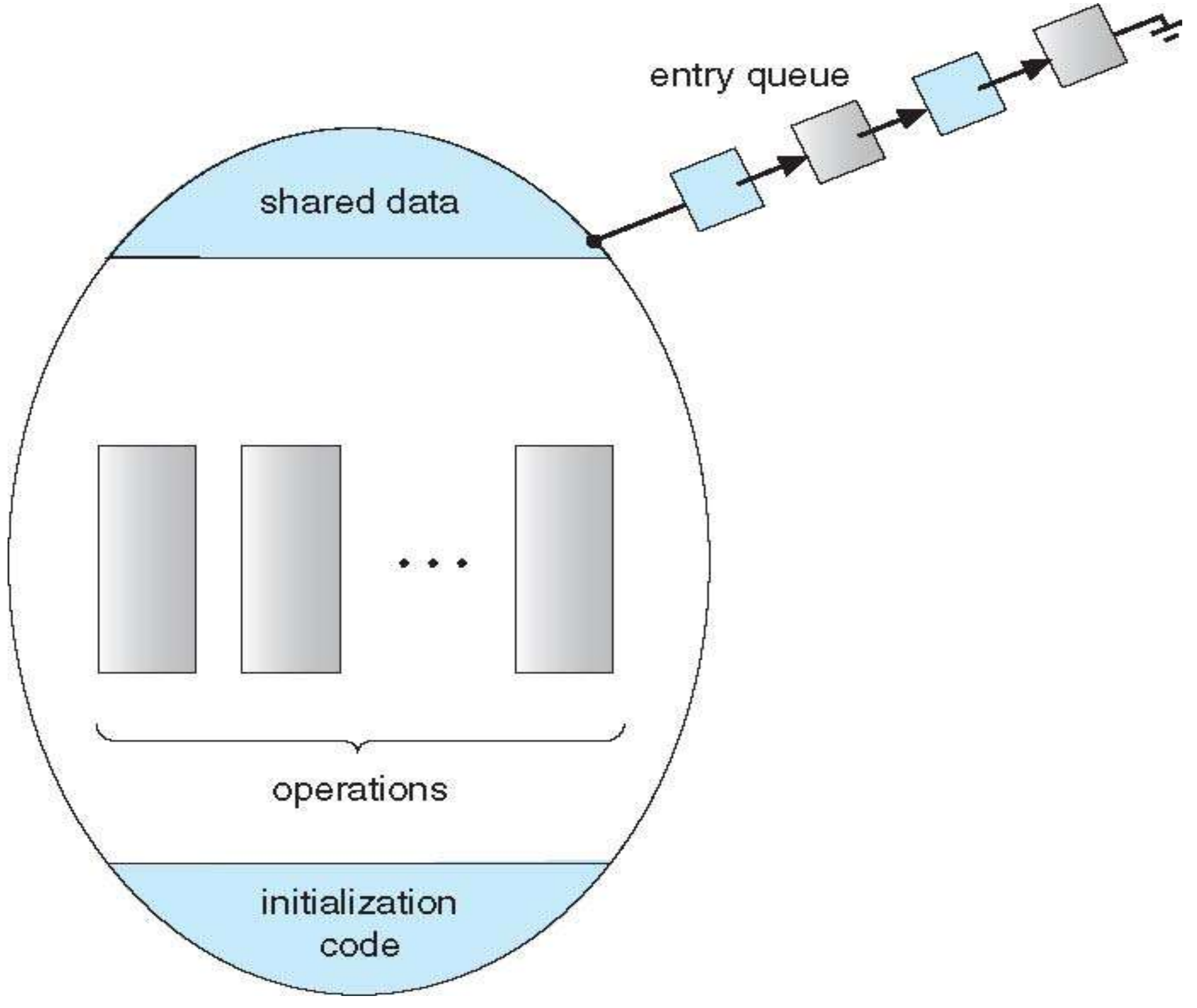
- A high-level abstraction that provides a convenient and effective mechanism for process synchronization
- *Abstract data type*, internal variables only accessible by code within the procedure
- Only one process may be active within the monitor at a time

```
monitor monitor-name
{
    // shared variable declarations
    procedure P1 (…) { …. }

    procedure Pn (…) {……}

    Initialization code (…) { … }
    }
}
```

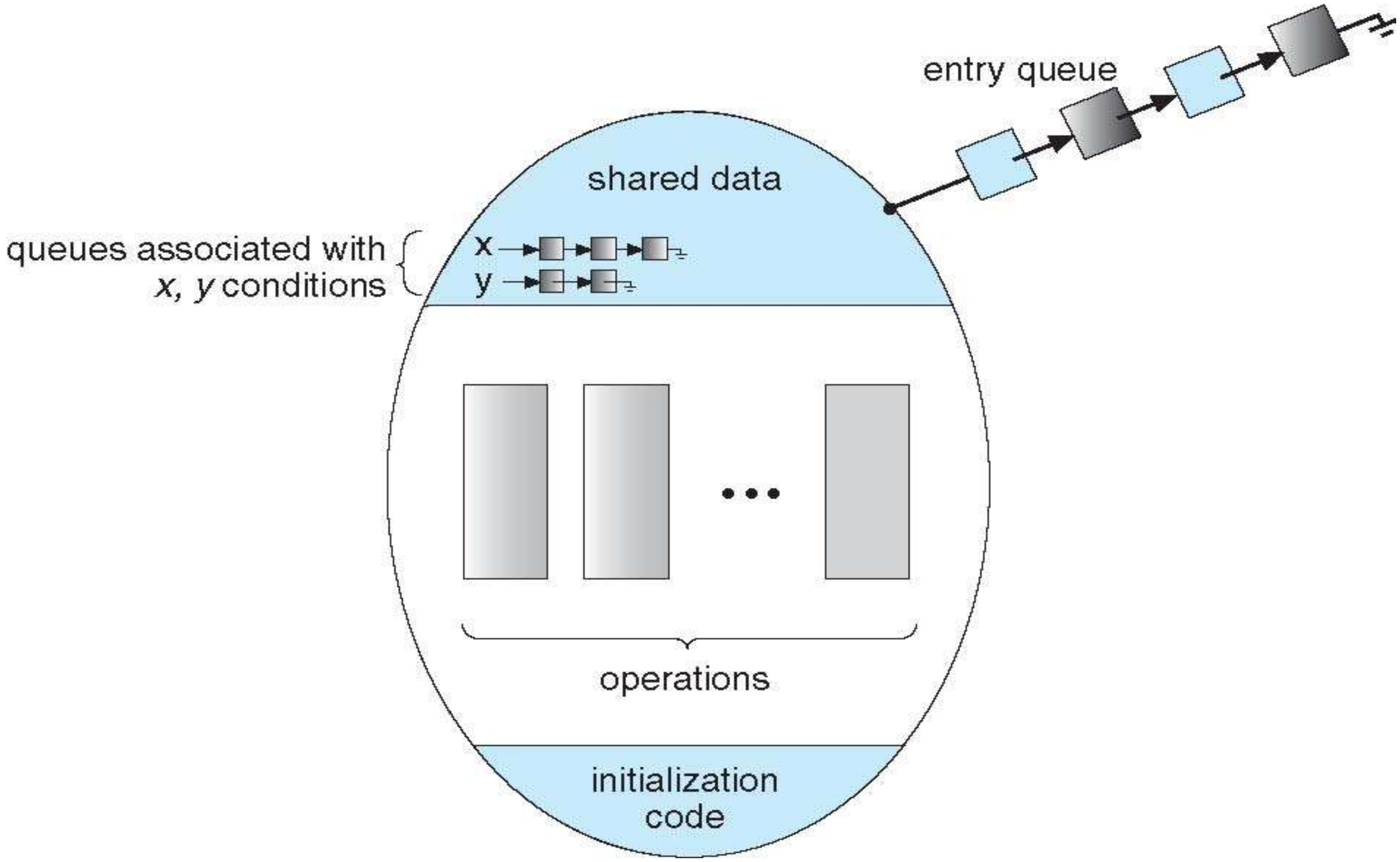
Schematic view of a Monitor

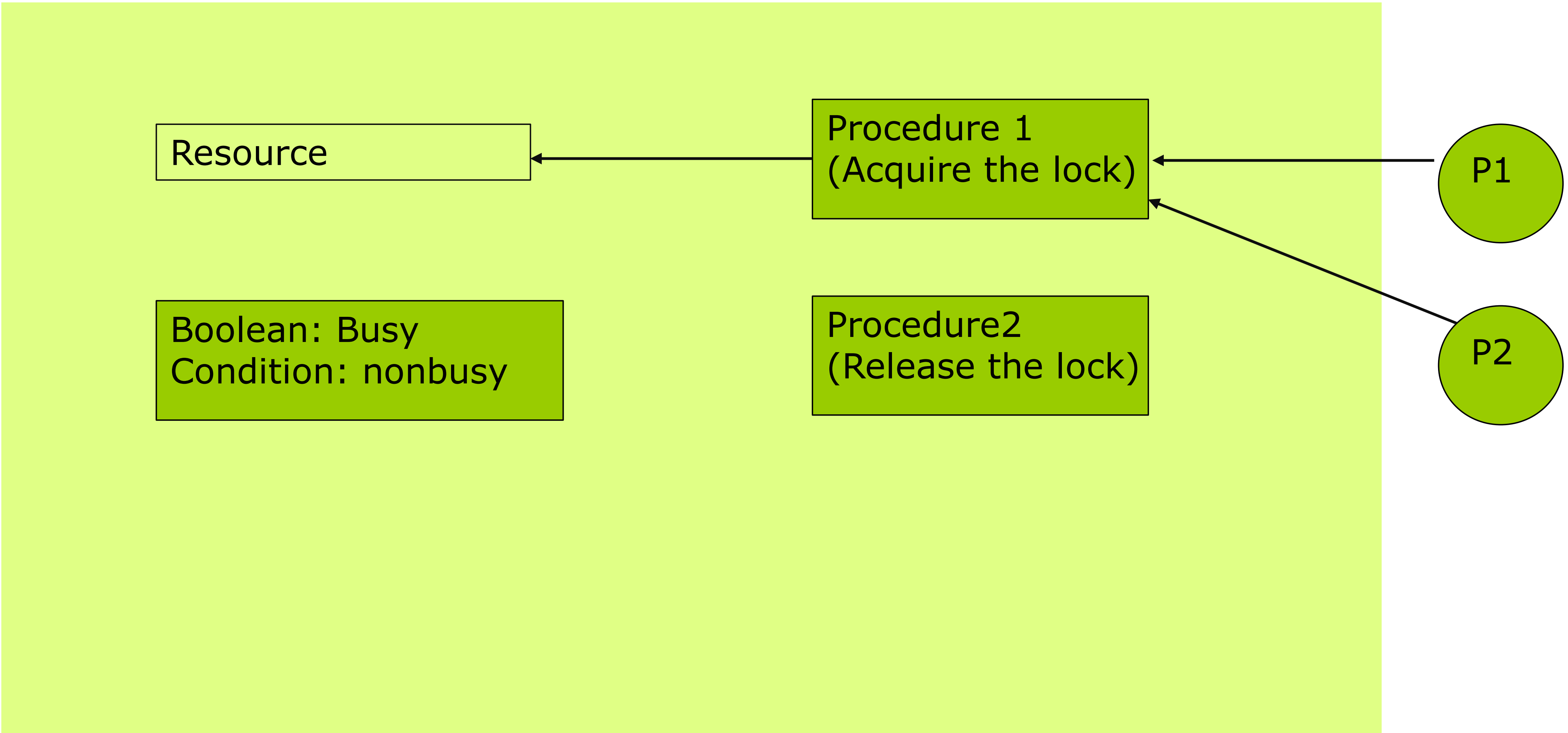


Condition Variables

- condition x, y;
- Two operations on a condition variable:
  - x.wait () – a process that invokes the operation is suspended until x.signal ()
  - x.signal () – resumes one of processes (if any) that invoked x.wait ()

Monitor with Condition Variables






```
if Busy then nonbusy.wait()
Else      Busy=TRUE
```

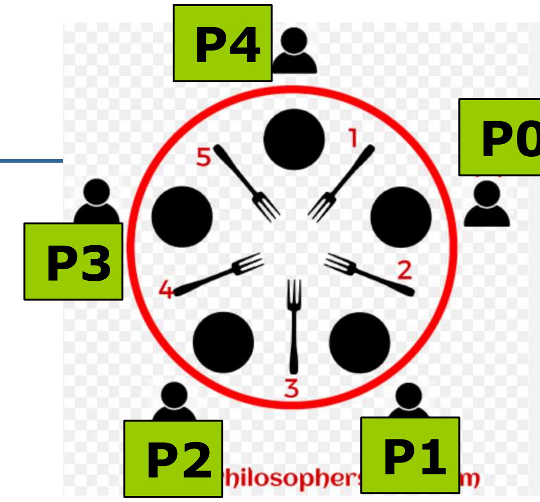
```
Busy=FALSE
nonbusy.signal()
```

Condition Variables Choices

- If process P invokes x.signal (), with Q in x.wait () state, what should happen next?
  - If Q is resumed, then P must wait
- Options include
  - **Signal and wait** – P waits until Q leaves monitor or waits for another condition
  - **Signal and continue** – Q waits until P leaves the monitor or waits for another condition

  - Both have pros and cons – language implementer can decide
  - Monitors implemented in Concurrent Pascal compromise
    - P executing signal immediately leaves the monitor, Q is resumed
  - Implemented in other languages including Mesa, C#, Java

Solution to Dining Philosophers




```
monitor DiningPhilosophers
  {
    enum { THINKING; HUNGRY, EATING} state [5] ;
    condition self [5];

    void pickup (int i) {
           state[i] = HUNGRY;
           test(i);
           if (state[i] != EATING) self [i].wait;
    }

     void putdown (int i) {
           state[i] = THINKING;
                 // test left and right neighbors
            test((i + 4) % 5);
            test((i + 1) % 5);
     }
```

```
void test (int i) {
       if ( (state[(i + 4) % 5] != EATING) &&
       (state[i] == HUNGRY) &&
       (state[(i + 1) % 5] != EATING) )
       {
           state[i] = EATING ;
           self[i].signal () ;
        }
 }

 initialization_code() {
      for (int i = 0; i < 5; i++)
      state[i] = THINKING;
 }
}
```

- **a philosopher moves to his/her eating state only if both neighbors are not in their eating states**
- **if one of my neighbors is eating, and I'm hungry, ask them to signal() me when they're done**

- ***"solution ensures that no two neighbors are eating simultaneously and that no deadlock will occur "***

End of Chapter 6