Operating System

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Review

- A system uses FCFS process (arrived_time, duration)
  - $P_1(0,20)$, $P_2(30,10)$, $P_3(20,40)$, $P_4(50,15)$
- Which of the following is the correct running order of the above processes?
  A. P_1, P_2, P_3, P_4
  B. P_1, P_3, P_2, P_4
  C. P_1, P_4, P_2, P_3
  D. P_5, P_2, P_3, P_1

Review

- A system uses SJF process (arrived_time, duration)
  - $P_1(0,20)$, $P_2(30,10)$, $P_3(20,40)$, $P_4(50,15)$
- Which of the following is the correct running order of the above processes?
  A. P_1, P_2, P_3, P_4
  B. P_1, P_4, P_2, P_3
  C. P_1, P_3, P_2, P_4
  D. P_4, P_2, P_3, P_1

Review

- A system uses SRTF process (arrived_time, duration)
  - $P_1(0,20)$, $P_2(30,10)$, $P_3(20,40)$, $P_4(40,15)$
- Which of the following is the correct running order of the above processes?
  A. $P_1, P_3, P_2, P_{4,} P_3$
  B. P_1, P_2, P_3, P_4, P_4
  C. $P_1, P_4, P_2, P_{3,} P_2$
  D. P_1, P_2, P_3, P_1, P_4

Review

- A system uses RR process (arrived_time, duration)
  - $P_1(0,20)$, $P_2(30,10)$, $P_3(20,40)$, $P_4(40,25)$
  - Time quantum = 15
- Which of the following is the correct running order of the above processes?

A. $P_1, P_2, P_3, P_1, P_2, P_3, P_4, P_3$

B. $P_1, P_3, P_1, P_3, P_2, P_3, P_4, P_3$

C. $P_1, P_1, P_2, P_3, P_2, P_3, P_4, P_3$

D. $P_1, P_1, P_3, P_2, P_4, P_3, P_4, P_3$

Review

- A system uses RR process (arrived_time, duration)
  - $P_1(0,20)$, $P_2(30,10)$, $P_3(20,40)$, $P_4(40,25)$
  - Time quantum 15
- Which of the following is the correct total waiting time of the above processes?

A. 40

B. 50

C. 60

D. 70

Inter-process Communication (IPC)

Objectives

- Present what IPC is
- Write a simple IPC program in Linux
- Present why we need synchronization
  - Methods of synchronization
- Write a simple synchronization program

Reference

- Chapter 2, 6 of Operating System Concepts

Introduction

- In some situations, processes need to communicate with each other
  - To send/receive data (web browser – web server)
  - To control the other process
  - To synchronize with each other
- This can be done by IPC
- IPC is implemented differently among OSes
  - Linux: message queue, semaphore, shared segment, …

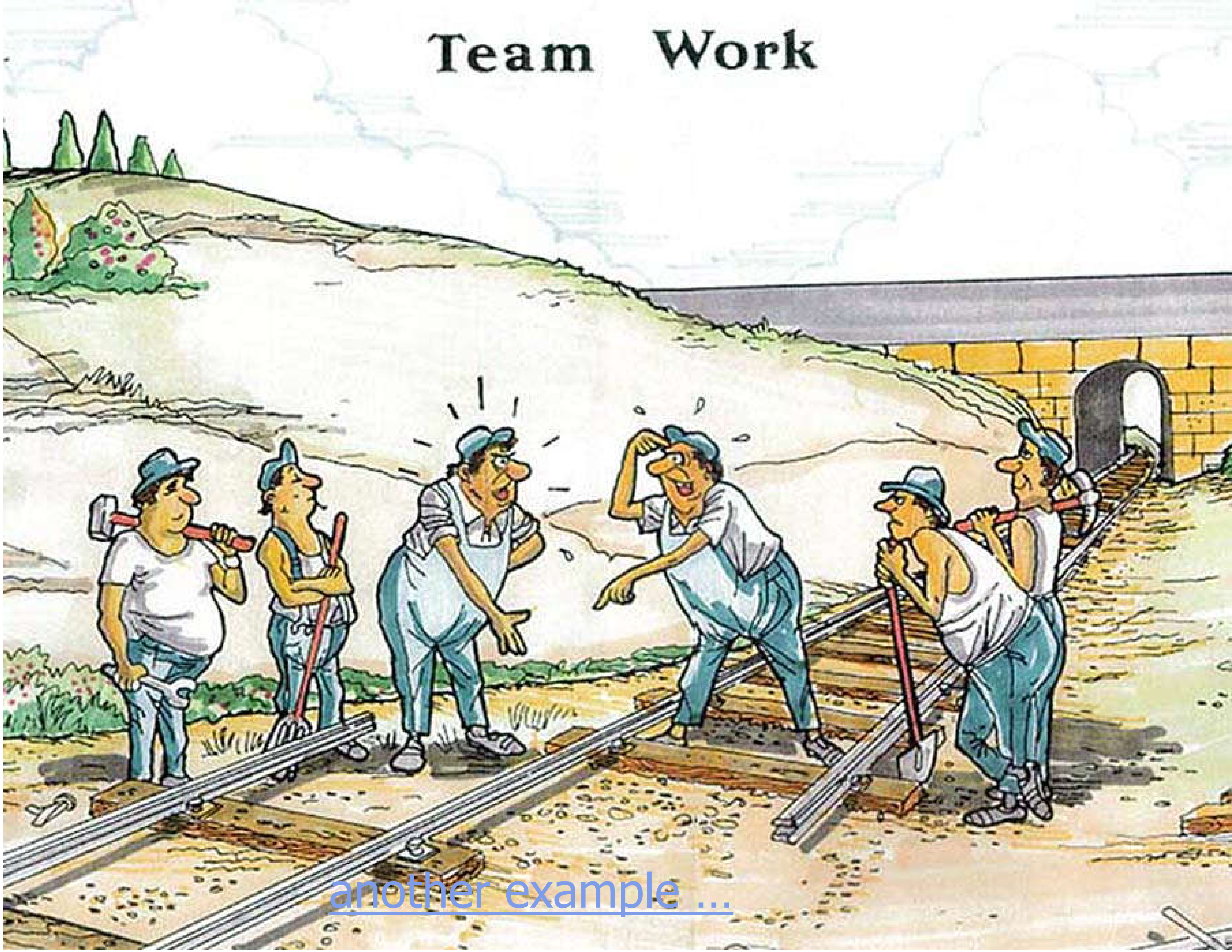
Introduction (cont'd)

- IPC can be divided into 2 categories
  - IPC among processes within the same system
    - Linux: pipe, named pipe, file mapping, …
  - IPC among processes in different systems
    - Remote Procedure Call (RPC), Socket, Remote Method Invocation (RMI), …

Process Synchronization

Synchronization definition

- **Process synchronization** refers to the idea that multiple processes are to join up or handshake at a certain point, in order to reach an agreement or commit to a certain sequence of actions.
  - http://en.wikipedia.org/wiki/Synchronization_(computer_science)



[another example ...]

Problem

Write process *P*:

```
while (true) {
    val=buf;
    val += count();//Take time
    buf=val
}
```

buf: Buffer

UPDATE A SET
    buf=buf+count();

What if more than one P are running?

Problem (cont'd)

- Two concurrent processes

val=buf;
val += count();
buf=val
	val=buf;
	val += count();
	buf=val

Do we always get the expected value of buf? Why?

Problem (cont'd)

- Suppose buf=5

```
val=buf;            //val=5
val+=count();       //val=10
val=buf;            //val=5
val+=count();       //val=10
buf=val             //buf=10
buf=val             //buf=10
```

Problem (cont'd)

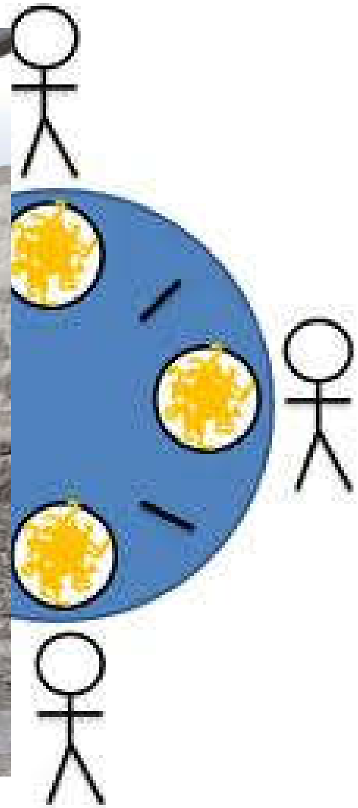
- Cause: *P* and *Q* simultaneously operate on global variable **buf**
- Solution: Let them operate separately

```
val=buf;                //val=5
val+=count();           //val=10
buf=val                 //buf=10

val=buf;                //val=10
val+=count();           //val=15
buf=val                 //buf=15
```

Race condition

- Happen when many processes simultaneously work with shared data



To avoid “trouble”, processes need to be controlled

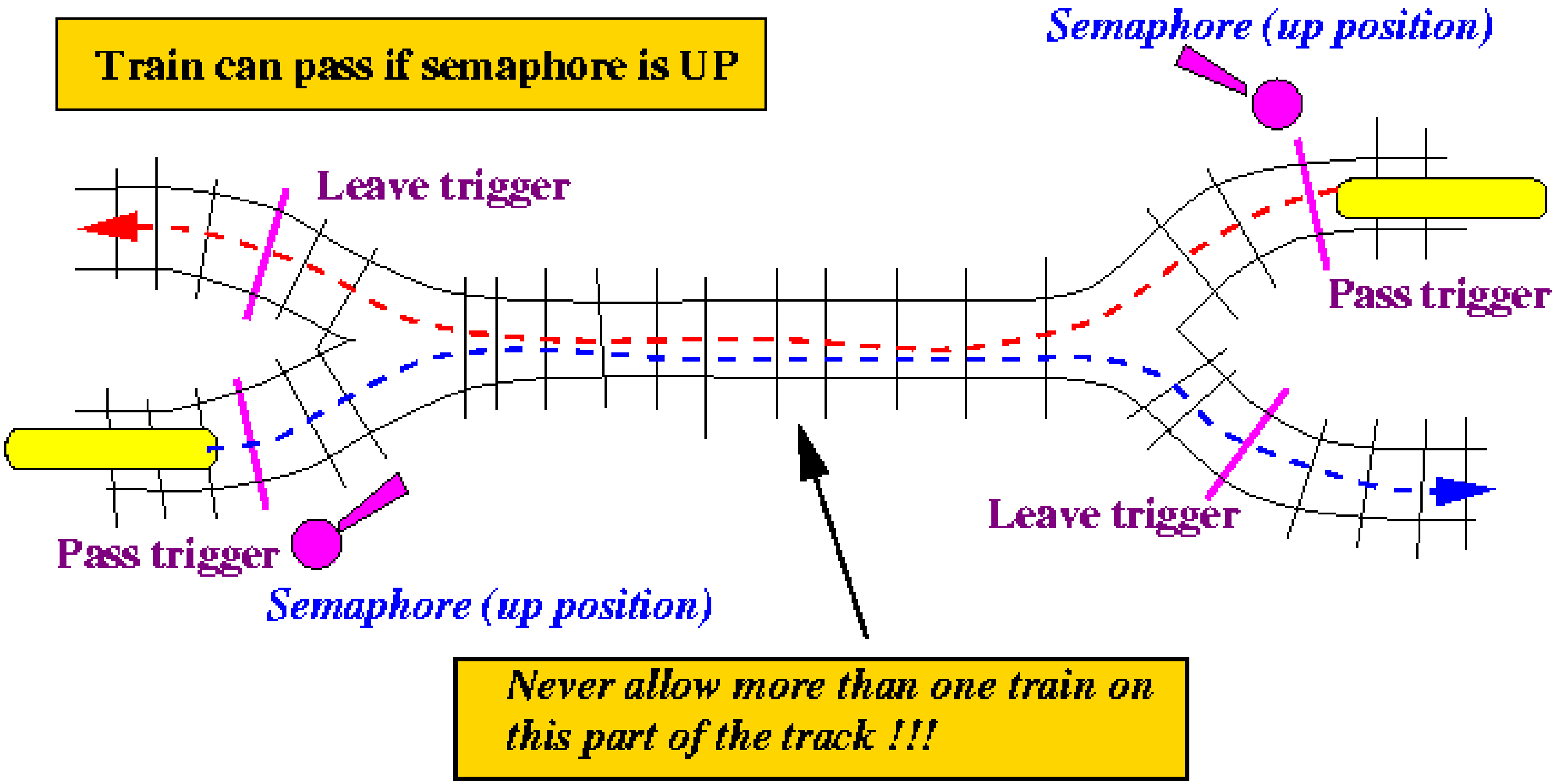
Critical section

- In concurrent programming a **critical section** is a piece of code that accesses a shared resource (data structure or device) that must not be concurrently accessed by more than one thread of execution. A critical section will usually terminate in fixed time, and a thread, task or process will have to wait a fixed time to enter it (aka bounded waiting). Some synchronization mechanism is required at the entry and exit of the critical section to ensure exclusive use, for example a semaphore.
- (http://en.wikipedia.org/wiki/Critical_section)

Critical section

- Suppose *n* processes $P_1, \ldots, P_n$ share a global variable *v*
  - *v* can also be other resource, e.g, file
- Each process has a segment of code CS_i which operates on *v*
  - CS_i is called critical section
  - Because it is critical to prone errors
  - CS_i should be the smallest code segment
- Need to make the critical section safe

Critical section



Question

Process *P*:

```
while (true) {
  waitForNewRequest();
   if(found){
      hit+=1;
      val=hit;
  }
  Respond();
}
```

hit: a global variable

Which is the critical section of the code when multiple processes of P run?

```
while (true) {
  waitForNewRequest();
   if(found){
      hit+=1;
      val=hit;
  }
  Respond();
}
```

Critical section (cont'd)

- Common structure

do {

  Enter_Section (CS_i);

  Run CS_i;

  Exit_Section(CS_i);

  Run ($REMAIN_i$); // Remainder section

} while (TRUE);

Critical section (cont'd)

- Short description

do {

ENTRY$_i$; // Enter section

Run *CS*$_i$; // Critical section

EXIT$_i$; // Exit section

REMAIN$_i$; // Remainder section

} while (TRUE);

Implementation of Critical section

Implementation must satisfy 3 conditions

1. Mutual Exclusion
   - If a process is in its critical section, then no other processes can be in their critical sections
2. Progress
   - If no process is in its critical section
   - other processes waiting to enter their critical section,
   - then the selection of the process to enter the critical section cannot be postponed indefinitely
3. Bounded Waiting
   - No process has to wait indefinitely to enter its critical section

Question

Which is the purpose of the first condition?

A. It supports the priority of process
B. It ensures the correct use of the shared resource
C. It tries to utilize the shared resource effectively
D. It makes the implementation of OS simpler

Question

Which is the consequence of the second condition?

A. It reduces the waiting time of requested processes
B. It ensures the correct use of the shared resource
C. It supports the priority of processes
D. It makes the implementation of OS simpler

Question

Which is the consequence of the second condition?

A. It supports the priority of processes
B. It ensures the correct use of the shared resource
C. It utilizes the shared resource effectively
D. It makes the algorithm complicated to implement

Question

Which is the consequence of the 3rd condition?

A. It supports the priority of processes
B. It ensures the correct use of the shared resource
C. It utilizes the shared resource effectively
D. It makes sure no process can never enter its critical section

Question

Which is the correct conditions of critical section?

A. mutual exclusion, protection, bounded using
B. mutual exclusion, protection, bounded waiting
C. mutual exclusion, progressive, bounded waiting
D. mutual exclusion, bounded waiting, progress

Question

Which is the correct purpose the 2nd condition of critical section?

A. maximize CPU utilization
B. maximize the shared resource utilization
C. maximize disk utilization
D. maximize RAM utilization

Question

Which is the consequence of the 3rd condition?

A. It supports the priority of processes
B. It ensures the correct use of the shared resource
C. It ensures the relative fairness of processes to use the shared resource
D. It utilizes the shared resource effectively

The fairness

The fair exam today is to swim

Critical section (cont'd)

- Each process has to
  - request to run (enter section) its critical section CS_i
  - and announce its completion (exit section) of its CS_i.

Peterson's Solution

- Solution for two processes
- The two processes share two variables:
  - int turn; // with the value of 0 or 1
  - Boolean flag[2]
- The variable turn indicates whose turn it is to enter the critical section
  - If turn==i then P_i is in turn to run its CS_i
- 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 (cont'd)

- Program P_i:

```
do {
   flag[i] = TRUE;
   turn = j;
   while (flag[j] && turn == j) ;
   CS_i;
   flag[i] = FALSE;
   REMAIN_i;
} while (1);
```

Peterson’s solution (cont’d)

- The proof of this solution is provided on page 196 of the textbook
- Comments
  - Complicated when then number of processes increases
  - Difficult to control

Question

- Which code snippet is Enter_Section?

A.
```
flag[i] = TRUE;
turn = j;
while (flag[j] && turn == j) ;
```

B.
```
flag[i] = TRUE;
while (flag[j] && turn == j) ;
```

C.
```
flag[i] = TRUE;
turn = j;
```

D.
```
turn = j;
while (flag[j] && turn == j) ;
```

Semaphore

Reference infomation

- Semaphore is proposed by Edsger Wybe Dijkstra (Dutch) for Computer Science in 1972
- Semaphore was firstly used in his book “The operating system”

Edsger Wybe Dijkstra
(1930-2002)

Semaphore

- Semaphore is an integer, can be only access through two atomic operators wait (or P) and signal (or V).
  - P: proberen – check (in Dutch)
  - V: verhogen – increase (in Dutch)
- Processes can share a semaphore
- Atomic operators guarantee the consistency

wait and signal operators

```
wait(S)      // or P(S)
{
   while (S<=0);
   S--;
}
```

- Wait if semaphore S<=0 else decrease S by 1

```
signal(S)     // or V(S)
{
   S++;
}
```

- Increase S by 1

Using semaphore

- Apply for critical section

```
do {
    wait(s); // s is a semaphore initialized by 1
    CS_i;
    signal(s);
    REMAIN_i;
} while (1);
```

Semaphore

Question

Process *P*:

```
while (true) {
  waitForNewRequest();
   if(found){
      hit+=2;
      val=hit;
  }
  Respond();
}
```

hit: a global variable

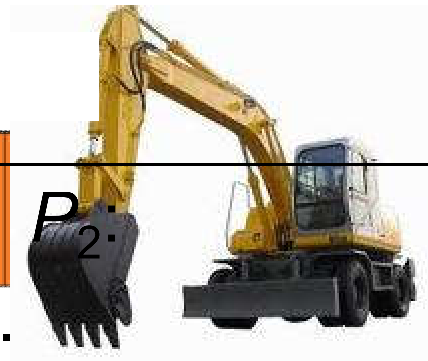
Use semaphore to make the code safe?

```
if(found){
  wait(mutex);
   hit+=2;
   val=hit;
  signal(mutex);
}
```

Using semaphore (cont'd)

- P_1 needs to do O_1; P_2 need to do O_2; O_2 can only be done after O_1
- Solution: use a semaphore *synch* = 0

Producer



Worker

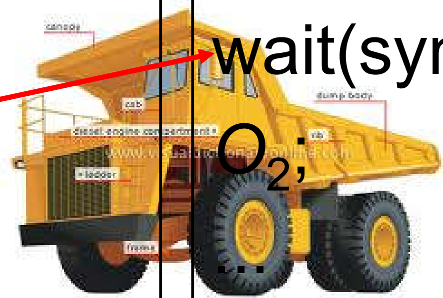
- P_1:

...

O_1;

signal(synch);

...



- P_2:

...

wait(synch);

O_2;

...

Semaphore implementation

- In the above semaphore implementation
  - Use busy waiting (while loop)
  - Resource wasting
- Atomic operators
  - When a process called wait(), it will be blocked if the semaphore is not free
    - This type of semaphore is called *spinlock*
  - Other wait() implementation just returns true/false and does not block the calling process

Semaphore implementation (cont'd)

- Remove the busy waiting loop by using block
- To restored a blocked process, use wakeup
- Semaphore data structure

```
typedef struct {
  int value; // value of semaphore
  struct process *L; //waiting process list
} semaphore;
```

Semaphore implementation (cont'd)

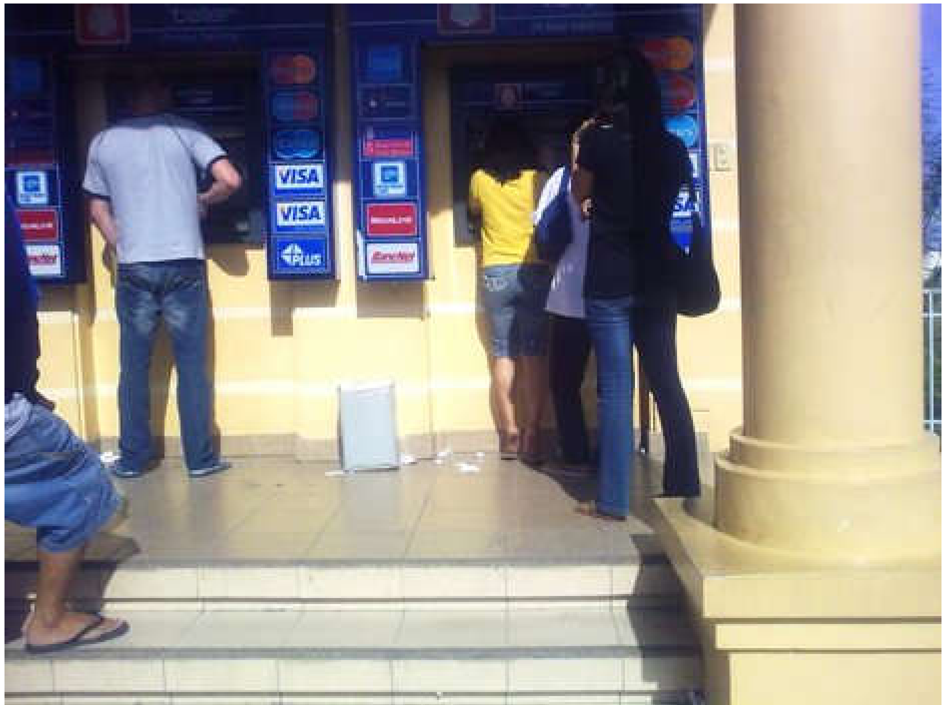
```
void wait(semaphore *S)
{
    S->value--;
    if (S->value<0) {
        Add the requested
    process P into s->L;
        block(P);
    }
}
```

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

Semaphore implementation (cont'd)

Binary semaphore

- Semaphore only has the value of 0 or 1
- Other semaphore type is counting semaphore



Question

- When counting semaphores are suitable to use?
  A. When *2* processes share a single variable/resource
  B. When *3* processes share a single variable/resource
  C. When *n* processes share a single variable/resource
  D. When *n* processes share *m* variables/resources of the same type

Classical synchronization problems

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’d)

Write process *P*:

```
do {
    wait(empty);
    wait(mutex);
    Write (item);
    signal(mutex);
    signal(full);
} while (TRUE);
```

Read process *Q*:

```
do {
    wait(full);
    wait(mutex);
    Read(item);
    signal(mutex);
    signal(empty);
} while (TRUE);
```

Question

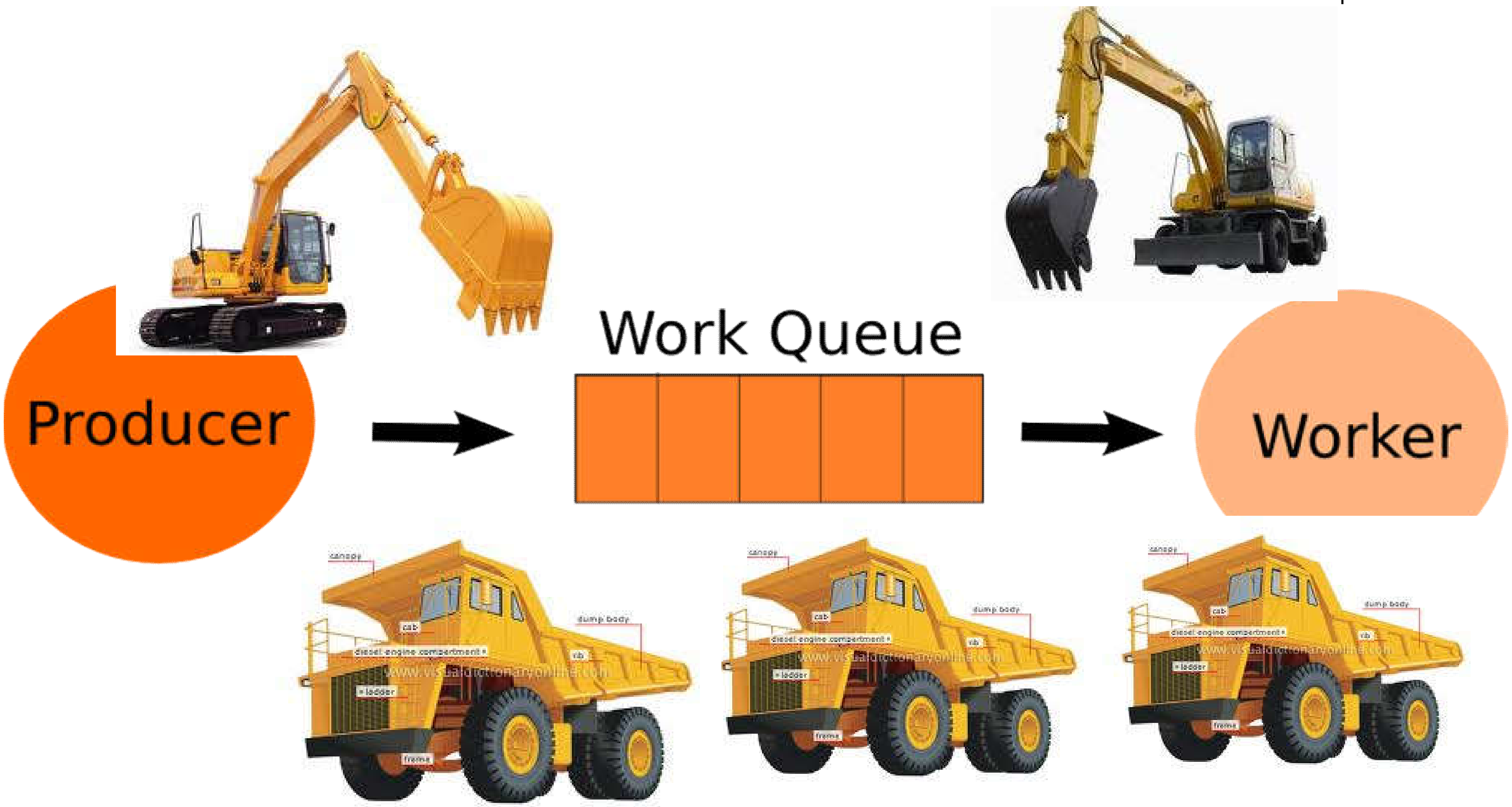
- Which is the initialized value of the *full* variable in the above algorithm?
  A. -1
  B. 0
  C. 1
  D. NULL

Question

What will be the problem if the initialized value of the *full* variable is 1?

A. no problem at all
B. the writer process can not run
C. the reader process can not run
D. the reader can read an invalid value

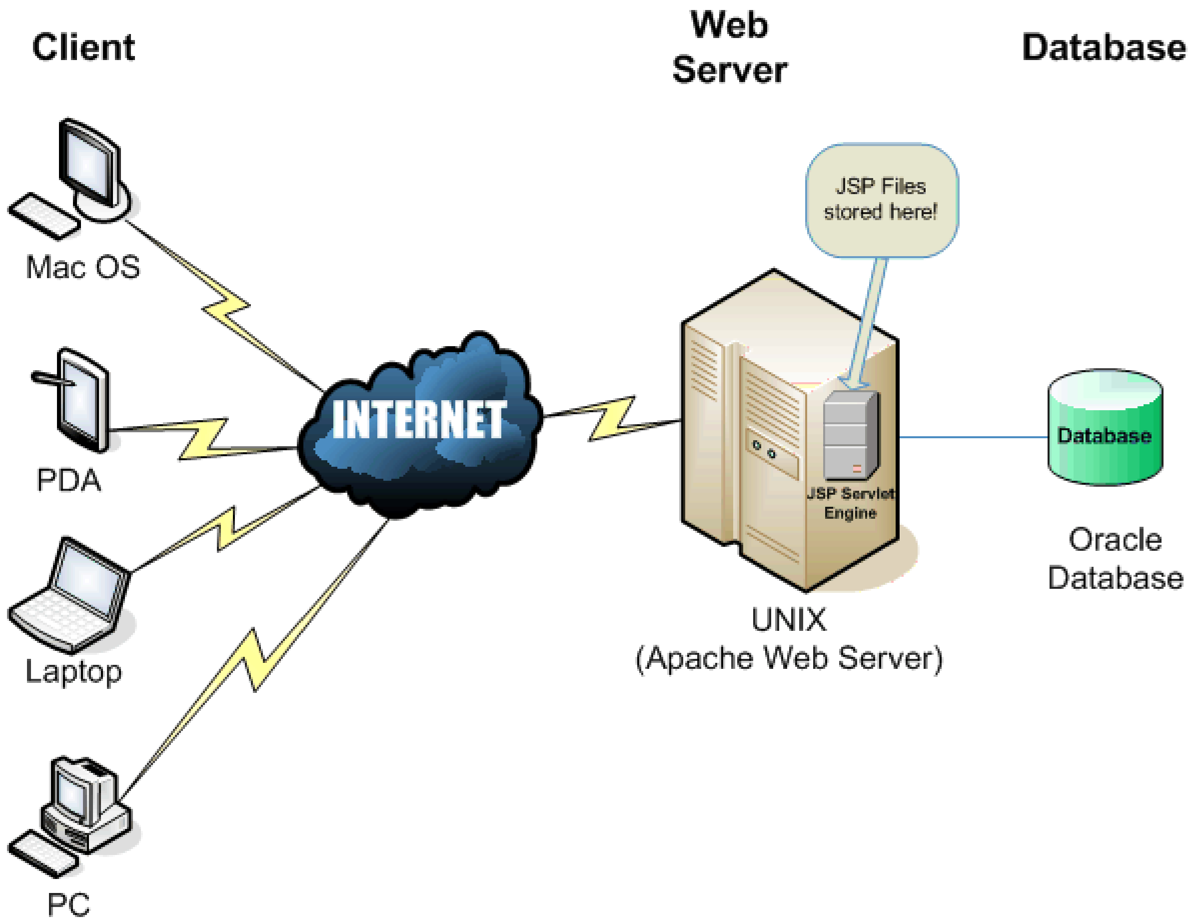
Bounded-buffer problem (cont'd)



Readers-writers problem

- A data set is shared among a number of concurrent processes
  - Readers – only read
  - Writers – can both read and write
- Problem
  - allow multiple readers to read at the same time
  - Only one writer can access the shared data at the a time

Readers-writers problem



Readers-writers problem (cont'd)

- Shared data
  - Data set
  - Semaphore *wrt* initialized by 1
    - Used to manage write access
  - Integer *readcount* initialized by 0 to count the number of readers that are reading
  - Semaphore *mutex* initialized by 1
    - Used to manage readcount access

Readers-writers problem (cont'd)

- **Process writer P_w:**

```
do {
      wait(wrt);
      write(data_set);
      signal(wrt);
}while (TRUE);
```

- **Process reader P_r:**

```
do {
    wait(mutex);
    readcount++;
    if (readcount ==1) wait(wrt);
    signal(mutex);
    read(data_set);
    wait(mutex);
     readcount--;
    if (readcount ==0) signal(wrt);
    signal(mutex);
} while (TRUE);
```

Question

Why do we need *readcount* variable?

A. We may remove this variable
B. To make sure there is one reader at a time
C. To make sure no readers are reading
D. To make sure no readers are reading before writing

Question

Which is the initialized value of the *readcount* variable in the above algorithm?

A. -1
B. 0
C. 1
D. NULL

Question

Which is the purpose of *mutex* variable?

A. To safely access the data_set
B. We may remove this variable without affecting the program
C. To safely access the *readcount* variable
D. To safely access the *wrt* variable

Question

Which is the initialized value of the *mutex* variable in the above algorithm?

A. -1
B. 0
C. 1
D. NULL

Question

Which is the purpose of *wrt* variable?

A. To safely access the *mutex* variable
B. To safely write the *data_set*
C. To safely write the *readcount* variable
D. To safely read the *data_set*

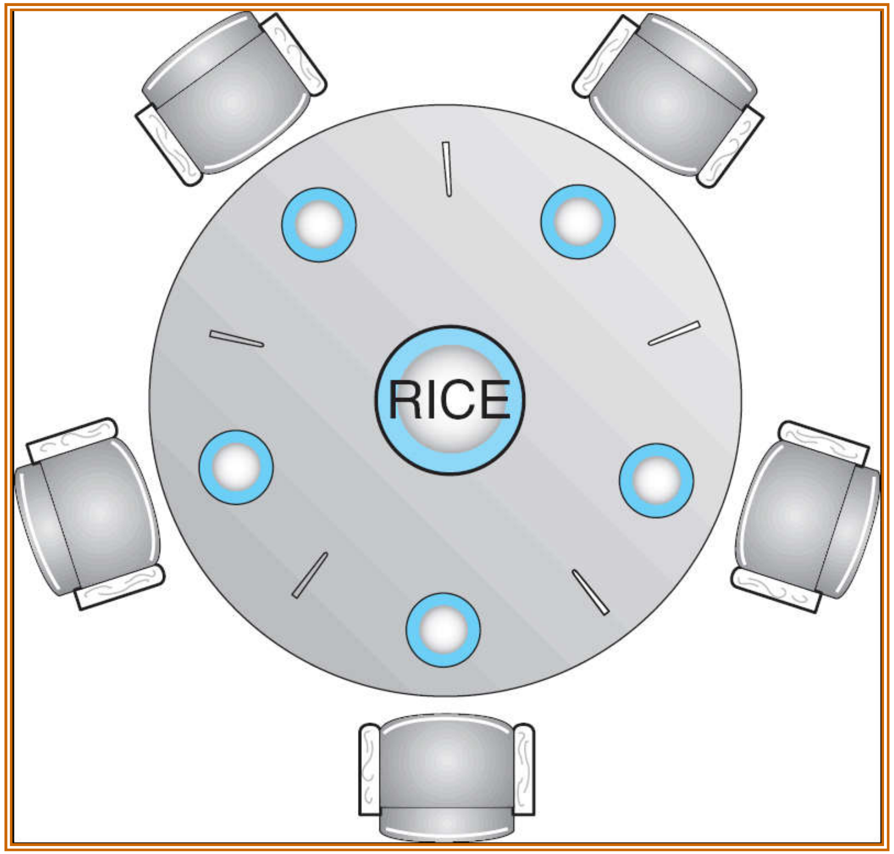
Question

Which is the initialized value of the *wrt* variable in the above algorithm?

A. -1
B. 0
C. 1
D. NULL

Dining-Philosophers Problem

- Five philosophers at a table having 5 chopsticks, 5 bows and a rice cooker
- A philosopher just eats or thinks
- How to make sure philosophers correctly use the "shared data" – the chopsticks



Dining-philosophers problem (cont'd)

- Use semaphore to handle chopstick access
  - semaphore chopstick[5];
- Solution is provided as in the next text box

- Code of philosopher *i*:

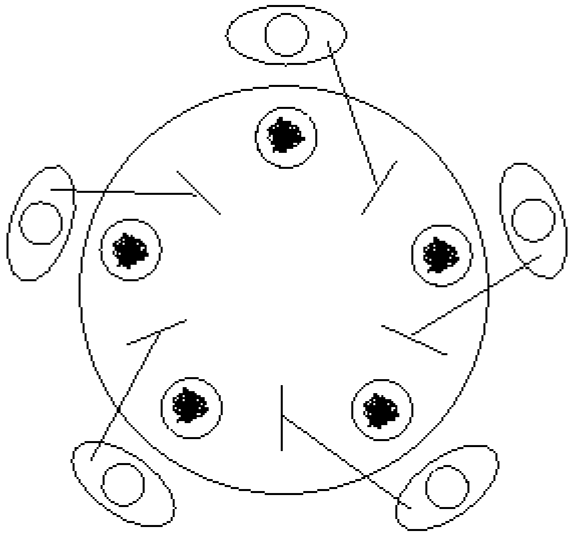
```
do {
    wait(chopstick[i]);
    wait(chopstick[(i+1)%5];
    Eat(i);
    signal(chopstick[i]);
    signal(chopstick[(i+1)%5];
    Think(i);
} while (TRUE);
```

Question

- What value chopstick[i] is initialized?
  A. 1
  B. 2
  C. 0
  D. 5

Question

- Is there any problem with the solution?
  A. No problem
  B. Only one philosopher can eat at a time
  C. Only three philosophers can eat at a time
  D. No philosopher could eat in case each takes a chopstick and waits for the second one



Question

- Which of the following is incorrect about the solution to the above problem?
  A. No solution available
  B. Create an order of philosophers to eat
  C. Create an order of philosophers to think
  D. Allow at most 4 philosophers to request to eat at a time

Limitations of semaphore (cont'd)

- Compare the two code snippets

• Snippet 1	• Snippet 2

Snippet 1

```
...
wait(mutex);
//Critical section
signal(mutex);
...
```

Snippet 2

```
...
signal(mutex);
//Critical section
wait(mutex);
...
```

Question

- What is the problem of the two code snippets?
  A. Snippet 1 has problem
  B. Snippet 2 has problem
  C. Both snippets have problem
  D. No problem at all

Question

- Which is the problem of the incorrect use of semaphore in the above code snippet?
  A. No process can enter its critical section
  B. No problem at all
  C. The mutual exclusion condition may be violated
  D. No process can exit its critical section

Limitations of semaphore

- Semaphores need correct calls to wait and signal
- Incorrect use of semaphore may lead to deadlock
- Even correct use of semaphores may lead to deadlock, in some cases

Limitations of semaphore (cont'd)

- Compare the two code snippets

Snippet 1	Snippet 2
...	...
wait(mutex);	wait(mutex);
CS_1;	CS_2;
wait(mutex);	signal(mutex);
...	...

Question

- Which of the two code snippets has problem?
    A. Snippet 1 has problem
    B. Snippet 2 has problem
    C. Both snippets have problem
    D. No problem at all

Question

- Which is the consequence of the above problem?
  A. One process will be blocked
  B. There will be a deadlock
  C. No consequences if only two processes are involved
  D. No consequences

Limitations of semaphore (cont'd)

• Process P_1	• Process P_2
...	...
wait(S);	wait(Q);
wait(Q);	wait(S);
...	...
signal(S);	signal(Q);
signal(Q);	signal(S);

Question

- What is the problem of the above two processes?
  A. There is deadlock
     - if P_1 got S and waits for Q and
     - P_2 got Q and waits for S
  B. The exclusive condition is violated
  C. The order of semaphore calls is incorrect
  D. No problem at all

Monitor

Reference information

- Per Brinch Hansen (Dennish) proposed the concept and implemented in 1972
- Monitor was firstly used in Concurrent Pascal programming language

Per Brinch Hansen
(1938-2007)

What is monitor?

- Monitor means to supervise
- It is a type of construct in a high level programming language for synchronization purpose
  - C# programming language
    - http://msdn.microsoft.com/en-us/library/hf5de04k.aspx
  - Java programming language
    - http://www.artima.com/insidejvm/ed2/threadsynch.html
    - http://journals.ecs.soton.ac.uk/java/tutorial/java/threads/monitors.html
- Monitor was studied and developed to overcome the limitations of semaphores

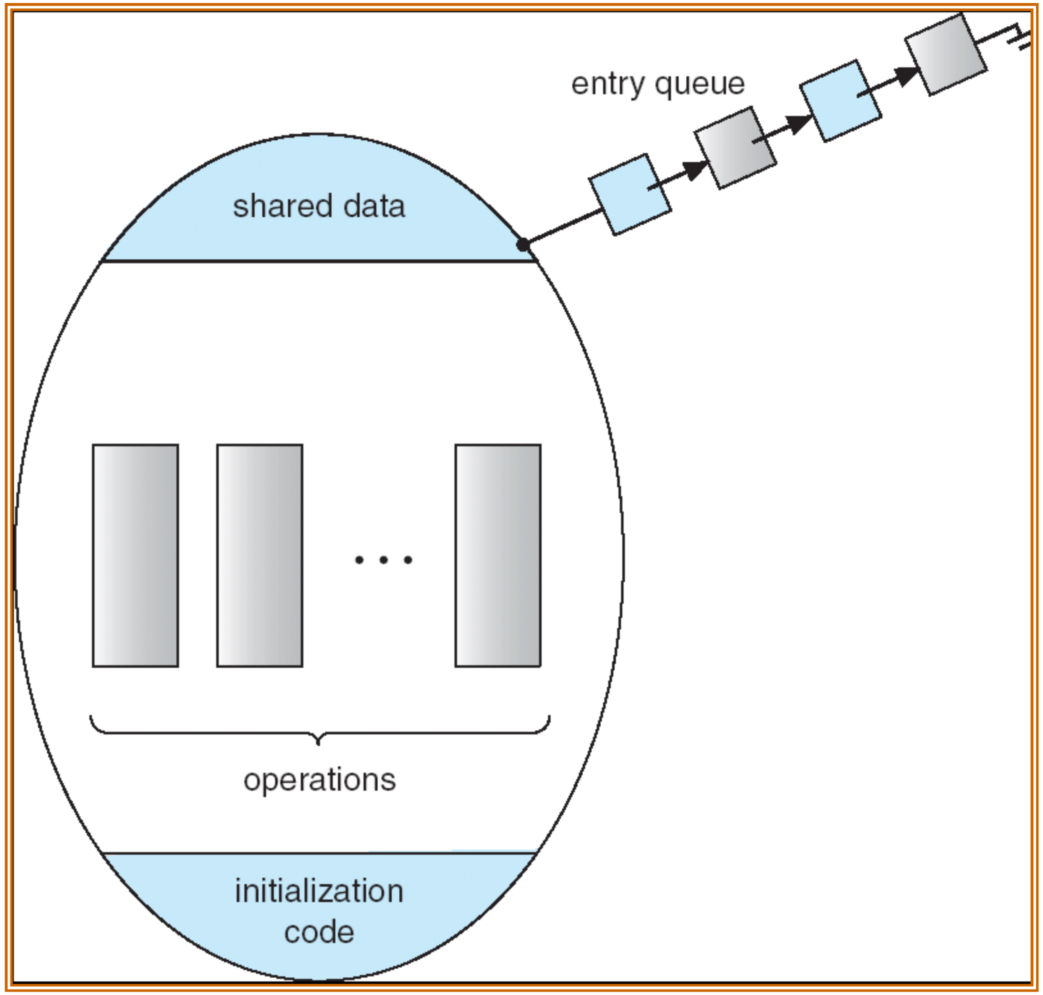
Monitor

- A monitor usually has
  - Member variables as shared resources
  - A set of procedures which operate on the shared resources
  - Exclusive lock
  - Constraints to manage race condition
- This description of monitor is like a class

A sample monitor type

```
monitor monitor_name {
   //Shared resources
   procedure P1(...) { ...
   }
   procedure P2(...) { ...
   }
   ...
   procedure Pn(...) { ...
   }
   initialization_code (..) { ...
   }
}
```

Schematic view of a Monitor



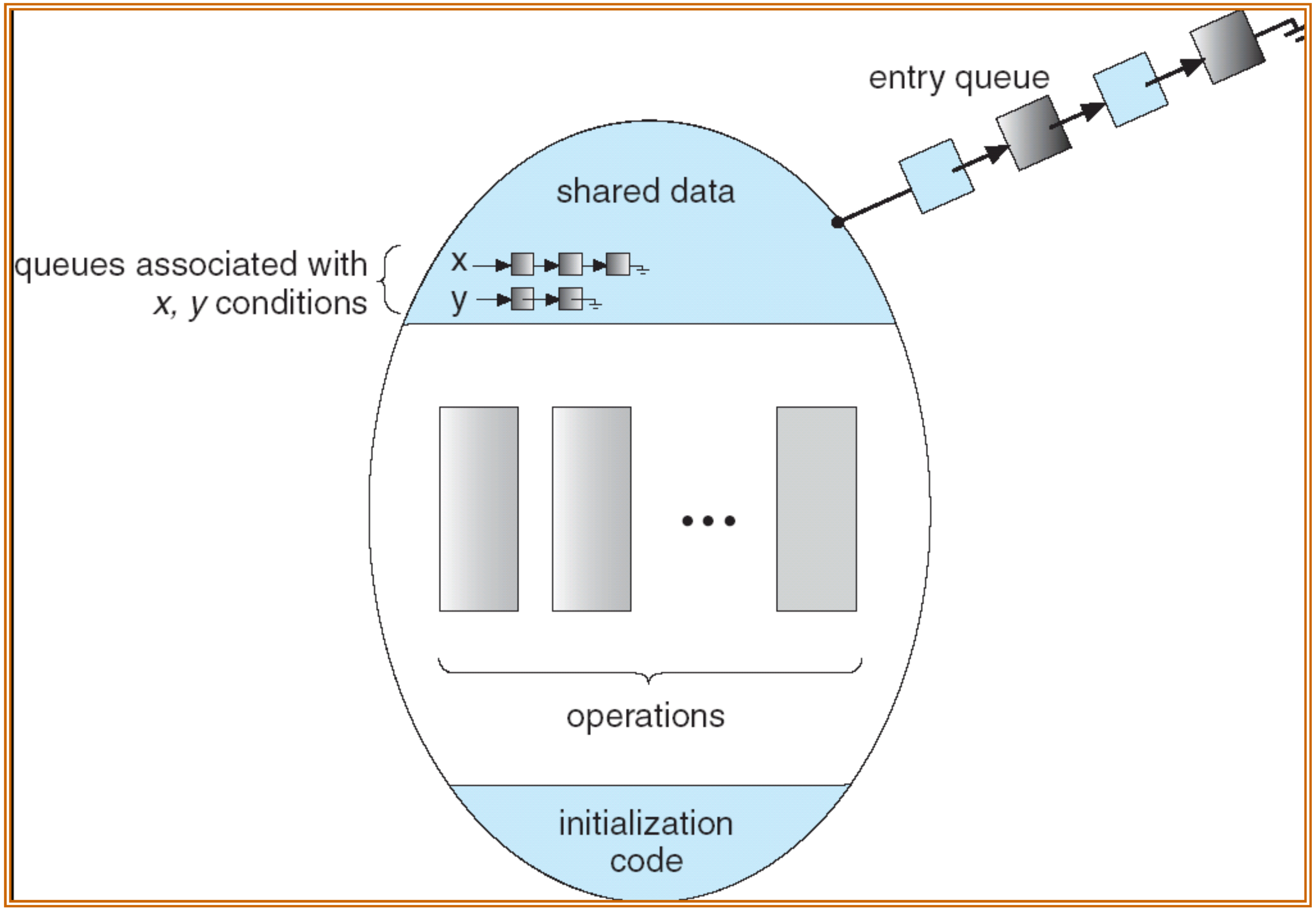
Monitor implementation

- Monitor must be implemented so that
  - only one process can enter the monitor at a time (mutual exclusive)
  - programmer do not need to write code for this
- Other monitor implementation
  - have more synchronization mechanism
  - add *condition variable*

Condition type

- Declaration
  - condition x, y;
- Use condition variable
  - there are two operators: wait and signal
  - x.wait():
    - process calls x.wait() will have to wait or suspend
  - x.signal():
    - process calls x.signal() will wakeup a waiting process – the one that called x.wait()

Monitor with condition



x.signal() characteristics

- x.signal() wakeup only one waiting process
- If no waiting process, it does nothing
- x.signal() is different from that of classical semaphore
  - signal in classical semaphore always change the state (value) of semaphore

Solution to Dining Philosophers

```
monitor DP
  {
   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);
      }
```

Solution to Dining Philosophers (cont)

```
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;
 }
}
```

Solution to Dining Philosophers (cont)

- Each philosopher invokes the operations pickup() and putdown() in the following sequence

dp.pickup (i)

EAT

dp.putdown (i)

Monitor Implementation Using Semaphores

- Variables

```
semaphore mutex;  // (initially  = 1)
semaphore next;   // (initially  = 0)
int next-count = 0;
```

- Each procedure ***F*** will be replaced by

```
wait(mutex);
     …
                    body of F;
     …
if (next-count > 0)
  signal(next)
else
  signal(mutex);
```

- Mutual exclusion within a monitor is ensured.

Monitor Implementation

- For each condition variable ***x***, we have:

```
semaphore x-sem; // (initially  = 0)
int x-count = 0;
```

- The operation x.wait can be implemented as:

```
x-count++;
if (next-count > 0)
    signal(next);
else
    signal(mutex);
wait(x-sem);
x-count--;
```

Monitor Implementation

- The operation x.signal can be implemented as:

```
if (x-count > 0) {
    next-count++;
    signal(x-sem);
    wait(next);
    next-count--;
}
```

Linux Synchronization

- Linux:
  - disables interrupts to implement short critical sections
- Linux provides:
  - semaphores
  - spin locks

Pthreads Synchronization

- pthreads API is OS-independent
- It provides:
  - mutex locks
  - condition variables

- Non-portable extensions include:
  - read-write locks
  - spin locks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Question?