Process Synchronization

Reading:

Silberschatz

chapter 6

Additional Reading:

Stallings

chapter 5

Outline

- Concurrency
  - Competing and Cooperating Processes
- The Critical-Section Problem
  - Fundamental requirements, Attempts
  - Dekker’s algorithm
  - Peterson’s algorithm
  - Bakery algorithm
  - Hardware synchronization
- Semaphores
  - Classical Problems
- Monitors

Concurrency

Motivation: Overlap computation with I/O; simplify programming

- Hardware parallelism: CPU computing, one or more I/O devices are running at the same time

- Pseudo parallelism: rapid switching back and forth of the CPU among processes, pretending to run concurrently

- Real parallelism: can only be achieved by multiple CPUs

Real parallelism $\rightarrow$ not possible in single CPU systems

Concurrent Processes

In a multiprogramming environment, processes executing concurrently are either
competing or cooperating

Responsibilities of OS

Competing processes: Careful allocation of resources, proper isolation of processes from each other

Cooperating processes: Protocols to share some resources, allow some processes to interact with each other; Sharing *or* Communication

Competing Processes

Compete for devices and other resources
Unaware of one another

Example:
Independent processes running on a computer

Properties:
Deterministic - Start/Stop without side effects
Reproducible - Proceed at arbitrary rate

Cooperating Processes

Aware of each other, by communication or by sharing resources, may affect the execution of each other

Example:

Transaction processes in Railways/Airline/Stocks

Properties:

Shares Resources or Information

Non-deterministic

May be irreproducible

Race Condition

Why Cooperation?

- Share Some Resources
  - One checking accounts or res. files → Many tellers
- Speed up
  - Read next block while processing current one
  - Divide jobs into smaller pieces and execute them concurrently
- Modularity
  - Construct systems in modular fashion

Competition for Resources

- Conflicting Demands
  - I/O devices, memory, process time,...
  - Blocked process $\rightarrow$ Slow or never gets access

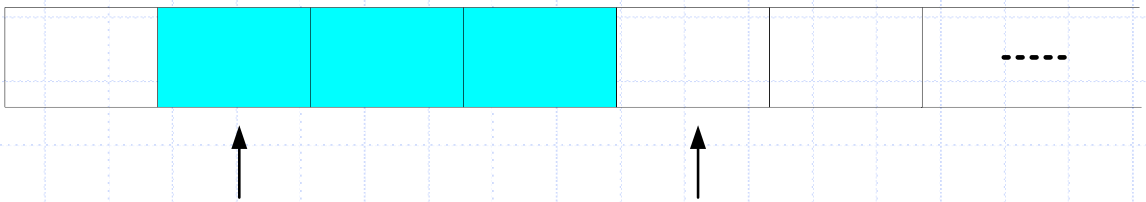
- Problems
  - Mutual exclusion
  - Enforcement of mutual exclusion
    - Deadlock
    - Starvation

Process Cooperation

- Cooperation by Sharing
  - Multiple process → Shared file/database
  - Control problems → Mutual exclusion, deadlock, starv
  - Data items may be accessed in different modes
  - Data Coherence or Racing
- Cooperation by Communication
  - Sync various activities
  - No sharing, No mutual exclusion
  - Starvation and Deadlock

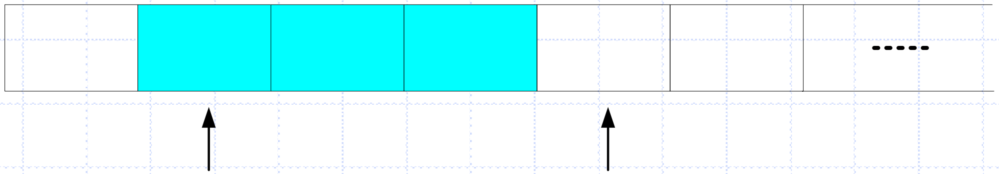
The Producer/Consumer Problem

- Also called as bounded-buffer problem
- A producer produces data that is consumed by a consumer (e.g. spooler and printer)
- A buffer holds the data which is not yet consumed
- There exists several producers and consumers
- Code for the Producer/Consumer Process?



The Producer/Consumer Problem

- Two logical pointers; **in** and **out**
- **in -** next free position in the buffer
- **in == out,** Empty; ((**in +1) % BUFFER_SIZE == out**, Full



- Producer process

```
item nextProduced;

while (1) {
        while ((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = nextProduced;
        in = (in + 1) % BUFFER_SIZE;
}
```

- Consumer process

```
item nextConsumed;

while (1) {
        while (in == out)
                ; /* do nothing */
        nextConsumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;
}
```

Buffer: 1 2 3 4 5

out i

The Potential Problem

Last solution allows BUFFER_SIZE – 1

Remedy → use integer variable, counter = 0

- Shared data
  - **#define BUFFER_SIZE 10**
  - **typedef struct {**
  - **. . .**
  - **} item**;
  - **item buffer[BUFFER_SIZE];**
  - **int in = 0;**
  - **int out = 0;**
  - **int counter = 0;**

A Potential Problem

- Consumer process

```
item nextConsumed;

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

- Producer process

```
item nextProduced;

while (1) {
        while (counter == BUFFER_SIZE)
                ; /* do nothing */
        buffer[in] = nextProduced;
        in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

- The statements

  counter++;
  counter--;

  must be performed *atomically*.

- Atomic operation means an operation that completes in its entirety without interruption.

Race Condition

- **Race condition** → Several processes access and manipulate shared data concurrently.

  Final value of the shared data → Process that finishes last

- To prevent race conditions, concurrent processes must be **synchronized**.

An Example

time	Person A	Person B
8:00	Look in fridge. *Out of milk*	
8:05	Leave for store.	
8:10	Arrive at store.	Look in fridge. *Out of milk*
8:15	Buy milk.	Leave for store.
8:20	Leave the store.	Arrive at store.
8:25	Arrive home, put milk away.	Buy milk.
8;30		Leave the store.
8:35		Arrive home, *OH! OH!*

Someone gets milk, but NOT everyone (*too much milk!*)

Mutual Exclusion

- If cooperating processes are not synchronized, they may face unexpected timing errors $\rightarrow$ *too-much-milk-problem*
- Mutual exclusion is a mechanism to avoid data inconsistency. It ensure that only one process (or person) is doing certain things at one time.

Example: Only one person *buys milk* at a time.

Critical Section

- A section of code or collection of operations in which only one process may be executing at a given time, which we want to make atomic

  Atomic operations are used to ensure that cooperating processes execute correctly

- Mutual exclusion mechanisms are used to solve CS problems

Critical Section

Requirements for the solution to CS problem

- Mutual exclusion – no two processes will simultaneously be inside the same CS
- Progress – processes wishing to enter critical section will eventually do so in finite time
- Bounded waiting – processes will remain inside its CS for a short time only, without blocking

Critical Section Problem - Attempts

- General structure of process

```
do {
        Initialization
    entry protocol
        critical section
    exit protocol
        reminder section
} while (1);
```

- Only two processes (P_i and P_j)

- Process may share some common variables → Sync their actions

Attempt 1: Taking Turns

- Approach → keep a track of CS usage with a shared variable **turn**

- Initialization:

```
*shared* int turn;
...
turn = i ;
```

- Entry protocol: (for process *i*)

```
/* wait until it's our turn */
while (turn != i ) {
}
```

- Exit protocol: (for process *i*)

```
/* pass the turn on */
turn = j ;
```

Problem?

Attempt 2: Using Status Flags

- Approach → Usage of a shared boolean array named as **flags** for each process; flag values – BUSY when in CS or FREE otherwise.
- Initialization:

```
typedef char boolean;
 ... shared boolean flags[n - 1];
 ... flags[i ] = FREE;
 ... flags[j] = FREE;
```

- Entry protocol: (for process *i*)

```
/* wait while the other process is in its CS */
 while (flags[j ] == BUSY) {
 }
-->
/* claim the resource */
flags[i ] = BUSY;
```

Exit protocol: (for process *i*)

```
/* release the resource */
 flags[i ] = FREE;
```

Problem?

Attempt 3: Using Status Flags Again

- Approach → same as attempt 2, but now each process sets its own flag *before* testing others flag to avoid violating mutual exclusion.
- Initialization:

```
typedef char boolean;
 ... shared boolean flags[n – 1];
 ... flags[i ] = FREE;
 ... flags[j ] = FREE;
```

- Entry protocol: (for process *i*)

```
/* claim the resource */
 flags[i ] = BUSY;
                /* wait if the other process is using the resource */
 while (flags[j ] == BUSY) {
}
```

- Exit protocol: (for process *i*)

```
/* release the resource */
 flags[i ] = FREE;
```

Problem?

Attempt 4: Last Try!

- Approach → same as attempt 3, but now we periodically clear and reset our own flag while waiting for other one, to avoid deadlock.
- Initialization:

```
typedef char boolean;
shared boolean flags[n - 1];
... flags[i] = FREE;
... flags[j] = FREE;
```

- Entry protocol: (for process *i*)

```
/* claim the resource */
flags[i] = BUSY;
                /* wait if the other process is using the resource */
while (flags[j] == BUSY) {
flags[i] = FREE;
delay a while ;
flags[i] = BUSY; }
```

- Exit protocol: (for process *i*)

```
/* release the resource */

flags[i] = FREE;
```

Problem?

Dekker's Algorithm

- Approach → same attempt 4, but now we judiciously combine the turn variable (attempt 1) and the status flags.

- Initialization:

```
typedef char boolean;
shared boolean flags[n - 1];
shared int turn;
 ... turn = i ;
 ... flags[i ] = FREE;
 ... flags[j ] = FREE;
```

- Entry protocol: (for process *i*)

Dekker's Algorithm

- Entry protocol: (for process *i*)

```
/* claim the resource */
flags[i] = BUSY;
/* wait if the other process is using the resource */
while (flags[j] == BUSY) {

        /* if waiting for the resource, also wait our turn */
        if (turn != i) {
                /* but release the resource while waiting */
                flags[i] = FREE;
                while (turn != i) {
                }
                flags[i] = BUSY;
        }
}
```

- Exit protocol: (for process *i*)

```
/* pass the turn on, and release the resource */
turn = j;
flags[i] = FREE;
```

Peterson's Algorithm

- Approach → similar to Dekker's algorithm; after setting our flag we immediately give away the turn; By waiting on the **and** of two conditions, we avoid the need to clear and reset the flags.

- Initialization:

```
typedef char boolean;
shared boolean flags[n - 1];
shared int turn;
 ... turn = i ;
 ... flags[i ] = FREE;
 ... flags[j ] = FREE;
```

- Entry protocol: (for process *i*)

Peterson's Algorithm

- Entry protocol: (for process *i*)

```
/* claim the resource */
flags[i] = BUSY;

/* give away the turn */
turn = j;
/* wait while the other process is using the resource *and* has the turn */
while ((flags[j] == BUSY) && (turn != i)) {
}
```

- Exit protocol: (for process *i*)

```
/* release the resource */
flags[i] = FREE;
```

Multi-Process Solutions

Dekker's and Peterson's algorithms → *can* be generalized for N processes, however:

- N must be fixed and known in advance
- Again, the algorithms become too much complicated and expensive

Implementing a mutual exclusion mechanism is difficult!

Bakery Algorithm

- Goal – Solve the CS problem for *n* processes
- Approach – Customers take numbers → lowest number gets service next (*here service means entry to the CS*)

Bakery Algorithm

- Approach → The entering process checks all other processes sequentially, and waits for each one which has a lower number. Ties are possible; these are resolved using process IDs.

- Initialization:

```
typedef char boolean;
...
shared boolean choosing[n]
shared int num[n];
...
for (j=0; j < n; j++) {
num[j] = 0;
}
 ...
```

Bakery Algorithm

- Entry protocol: (for process *i*)

```
/* choose a number */
choosing[i] = TRUE;
num[i] = max(num[0], ..., num[n-1]) + 1;
choosing[i] = FALSE;

/* for all other processes */
for (j=0; j < n; j++) {

        /* wait if the process is currently choosing */
        while (choosing[j]) {}

        /* wait if the process has a number and comes ahead of us */
        if ((num[j] > 0) &&
         ((num[j] < num[i]) ||
         (num[j] == num[i]) && (j < i))) {
                while (num[j] > 0) {}
        }
}
```

- Exit protocol: (for process *i*)

```
/* clear our number */
num[i] = 0;
```

Bakery Algorithm – Why choosing[i]?

- choosing[i] → What happens if you leave it out

- Mutual Exclusion → Violation

  Lets comment choosing[i] to examine the algorithm!

Bakery Algorithm – Why choosing[i]?

- **Entry protocol:** (for process *i*)

```
/* choose a number */
choosing[i] = TRUE;
num[i] = max(num[0], ..., num[n-1]) + 1;
choosing[i] = FALSE;

/* for all other processes */
for (j=0; j < n; j++) {

        /* wait if the process is currently choosing */
        while (choosing[j]) { }

        /* wait if the process has a number and comes ahead of us */
        if ((num[j] > 0) &&
         ((num[j] < num[i]) ||
         (num[j] == num[i]) && (j < i))) {
                while (num[j] > 0) {}
        }
}
```

- **Exit protocol:** (for process *i*)

```
/* clear our number */
num[i] = 0;
```

> - Consider 2 Process → P_0 & P_1
> - Same token P_1 goes to CS after 2 iterations
> - Later P_0 blocked-unblocked → After 2 iterations enters CS!!

Hardware Solutions

- Use of hardware instructions to mask interrupts. The solution for N processes would be as simple as below:

  For Process i

```
while (TRUE) {
        disableInterrupts();

        <Critical Section i>

        enableInterrupts();
        ...
}
```

- Problems
  - Only one system-wide CS active at a time
  - No OS allows *user access* to privileged instructions
  - Not correct solution for multiprocessor machine

Hardware Solutions

- Special Machine Instructions
  - Performed in a single instruction cycle
  - Access to the memory location is blocked for any other instructions

- Test and Set Instruction

```
boolean testset (int i) {
        if (i == 0) {
                i = 1;
                return true;
        }
        else {
                return false;
        }
}
```

Hardware Solutions

- Exchange Instruction

```
void exchange(int register, int memory) {
    int temp;
    temp = memory;
    memory = register;
    register = temp;
}
```

Hardware Solutions

- Sample Program

```
const int n = /* number of processes */;
int bolt;
void P (int i)
{
        while (true);
        {
                while (!testset (bolt))
                        /* do nothing */
        /* critical section */;
        bolt = 0;
        /* remainder */
        }
 }
void main()
{
        bolt = 0;
        parbegin (P(1), P(2), ... , P(n));
}
```

- Test and Set Instruction

```
boolean testset (int i) {
        if (i == 0) {
                i = 1;
                return true;
        }
        else {
                return false;
        }
}
```

Hardware Solutions

- Advantages
  - Applicable to any # processes, single/multiple processors sharing main memory
  - Verification is simple/easy
  - Can be used to support multiple CS
- Disadvantages
  - Busy waiting → Consumes processors time
  - Starvation is possible → Selection of waiting process is arbitrary
  - Deadlock is possible → The flag can only be reset by low priority process but has been preempted by high priority process

Semaphores

PROBERN
Probe/test/wait

VERHOGEN
Release

- *S*, Semaphore (an integer variable) → *Operation* **P** and **V**
  - When a process executes **P**(*S*) , *S* is decremented by one
    - $S \geq 0$ → Process continues execution; or
    - $S < 0$ → Process is stopped and put on a *waiting queue* associated with *S*.
  - When a process executes **V**(*S*), *S* is incremented by one
    - $S > 0$ → Process continues execution; or
    - $S \leq 0$ → Process is removed from the *waiting queue* and is permitted to continue execution; *process which evoked* **V**(S) *can also continue execution*.
- **P** and **V** are indivisible/atomic → Cannot be interrupted in between
- Only one process can execute **P** or **V** at a time on given Semaphore

Implementation

- **Busy Waiting**
  - Two process solutions
  - Loop continuously in entry code
  - Problem → Multiprogramming systems
  - **Spinlock** → Spins while waiting for Lock
  - Useful
    - Multiprocessor System, No context switch time
    - Locks are expected to be held for short time
- **Semaphore Solution**
  - **P**, wait → block itself into a *waiting queue*
  - **V**, signal → *waiting queue* to *ready queue*

Implementation

```
struct semaphore {
        int count;
        queue Type queue
}

void wait(semaphore s)
{
        s.count--;
        if (s.count < 0)
        {
         place this process in the s.queue;
         block this process
        }
}
void signal(semaphore s)
{
        s.count++;
        if (s.count <= 0)
        {
         remove a process p from the s.queue;
         place process p on the ready queue
        }
}
```

Mutual Exclusion

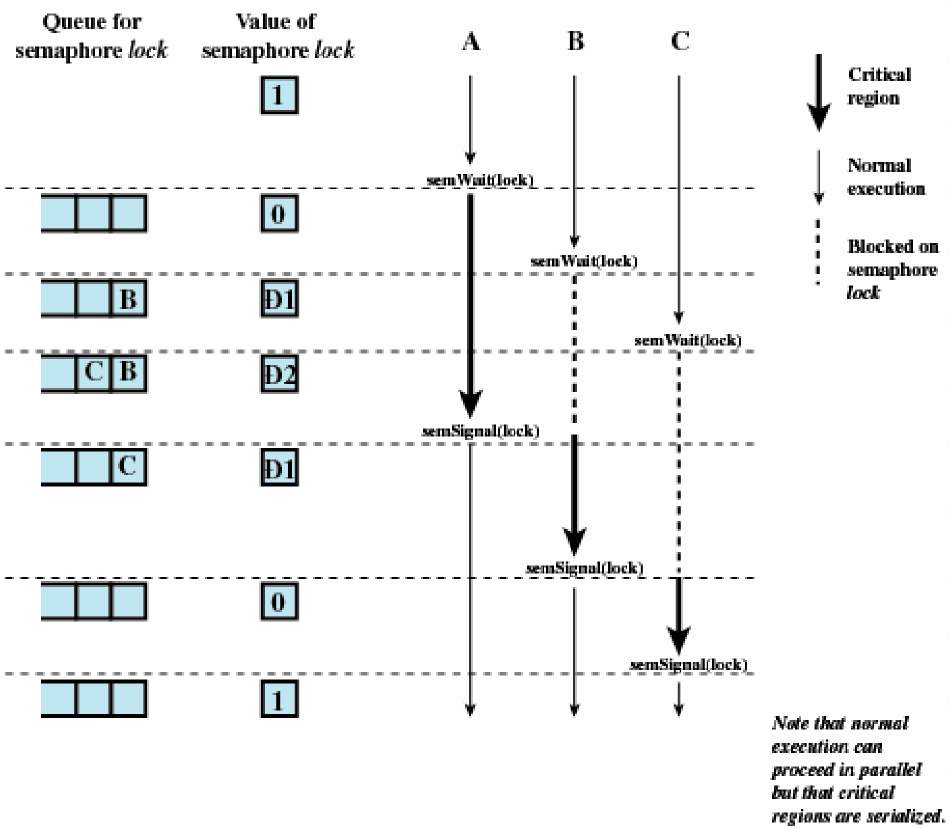
- Sample Program

```
const int n = /* number of processes */
semaphore s=1;
void P (int i)
{
        while (true);
        {
                wait(s);
                /* critical section */;
                signal(s);
                /* remainder */
        }
 }
void main()
{
        parbegin (P(1), P(2), … , P(n));
}
```

Above program can also handle the requirement that more than one process be allowed inside CS at a time, How?

Mutual Exclusion

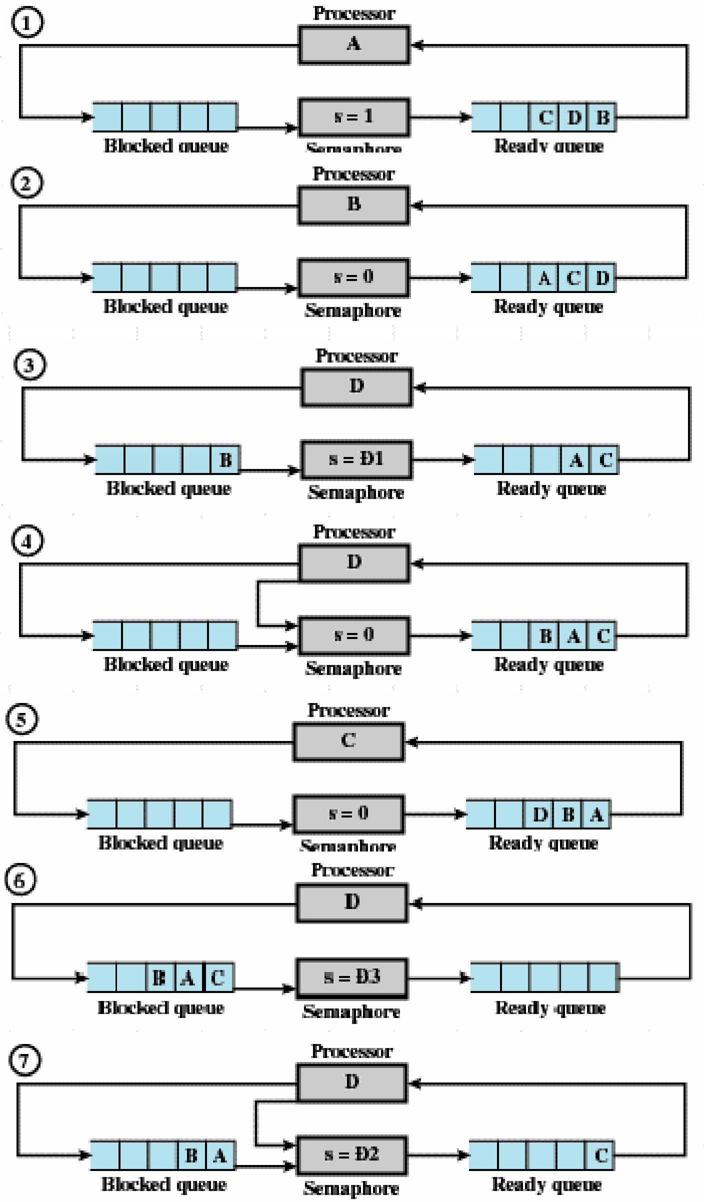
- Example - Three Process Accessing Shared Data using Semaphore



Semaphore Types

- Integer/Counting/General Semaphore
- Binary Semaphore
- Fairest Policy $\rightarrow$ FIFO
- Order of removing process from waiting queue
  - Strong Semaphore $\rightarrow$ Includes policy definition
    - Guarantees freedom from Starvation
    - Typically provided by most OS
  - Weak Semaphore $\rightarrow$ Does not specify the order

Example



1
Processor
A
s = 1
Blocked queue
Semaphore
C D B
Ready queue
2
Processor
B
s = 0
Blocked queue
Semaphore
A C D
Ready queue
3
Processor
D
B
s = Ð1
Blocked queue
Semaphore
A C
Ready queue
4
Processor
D
s = 0
Blocked queue
Semaphore
B A C
Ready queue
5
Processor
C
s = 0
Blocked queue
Semaphore
D B A
Ready queue
6
Processor
D
B A C
s = Ð3
Blocked queue
Semaphore
Ready queue
7
Processor
D
B A
s = Ð2
Blocked queue
Semaphore
C
Ready queue

Possible Implementations

- No existing hardware implements P and V operations directly
- Semaphores → Build up using hardware sync primitives
- Uniprocessor Solution
  - Usually → disable interrupts
- Multiprocessor Solution
  - Use hardware support for atomic operations

Possible Usage

- Mutual Exclusion → Initialize semaphore to one
- Synchronization → Initialize semaphore to zero
- Multiple instances → Initialize semaphore to # of instances

Two Possible Implementations

```
wait(semaphore s)
{
        disable interrupts

        s.count--;
        if (s.count < 0)
        {
         place this process in the s.queue;
         block this process     and enable interrupts
        }
        else
           enable interrupts
}

signal(semaphore s)
{
         disable interrupts

        s.count++;
        if (s.count <= 0)
        {
         remove a process p from the s.queue;
         place process p on the ready queue
        }
         enable interrupts
}
```

The Producer/Consumer Problem

Semaphore freeSpace, **initially n** — % Number of empty buffers

Semaphore availItems, **intiailly 0** — % Number of full buffers

- **Producer process**

```
item nextProduced;

while (1) {
 wait(freeSpace);
 buffer[in] = nextProduced;
 in = (in+1) mod n;
 signal(availItems);
}
```

- **Consumer process**

```
item nextConsumed;

while (1) {
 wait(availItems);
 nextConsumed =buffer[out];
 out = (out+1) mod n;
 signal(freeSpace);
}
```

Deadlock and Starvation

- **Deadlock**

- Let S and Q be two semaphores initialized to 1

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

- **Starvation** – indefinite blocking; A process may never be removed from the semaphore queue in which it is suspended.

Implementing *S* as a Binary Semaphore

- Data structures:

  binary-semaphore S1, S2;

  int C:

- Initialization:

  S1 = 1

  S2 = 0

  C = initial value of semaphore ***S***

Implementing ***S***

- *wait* operation

```
wait(S1);
C--;
if (C < 0) {
        signal(S1);
        wait(S2);
}
signal(S1);
```

- *signal* operation

```
wait(S1);
C ++;
if (C <= 0)
    signal(S2);
else
    signal(S1);
```

Problems with Semaphores

- The **P**(*S*) and **V**(*S*) signals are scattered among several processes. Therefore its difficult to understand their effects.
- Incorrect usage → timing errors (difficult to detect; only with some particular execution sequence which are rare)
- One bad process or programming error can kill the whole system or put the system in deadlock

Solution?

High-level language constructs

Critical Regions, Eventcounts, Sequencers, Path Expressions, Serializsers, Monitors, …

A fundamental high-level synchronization construct → *Monitor* type

Monitor

- **A monitor type** presents a set of *programmer defined operations* which can provide *mutual exclusion within the monitor*
  - **Procedures**
  - **Initialization code**
  - **Shared data**

- **Monitor Properties**
  - Shared data can only be accessed by monitors procedures
  - Only <u>one</u> process at a time can execute in the monitor (executing a monitor procedure)

- Shared data may contain condition variables

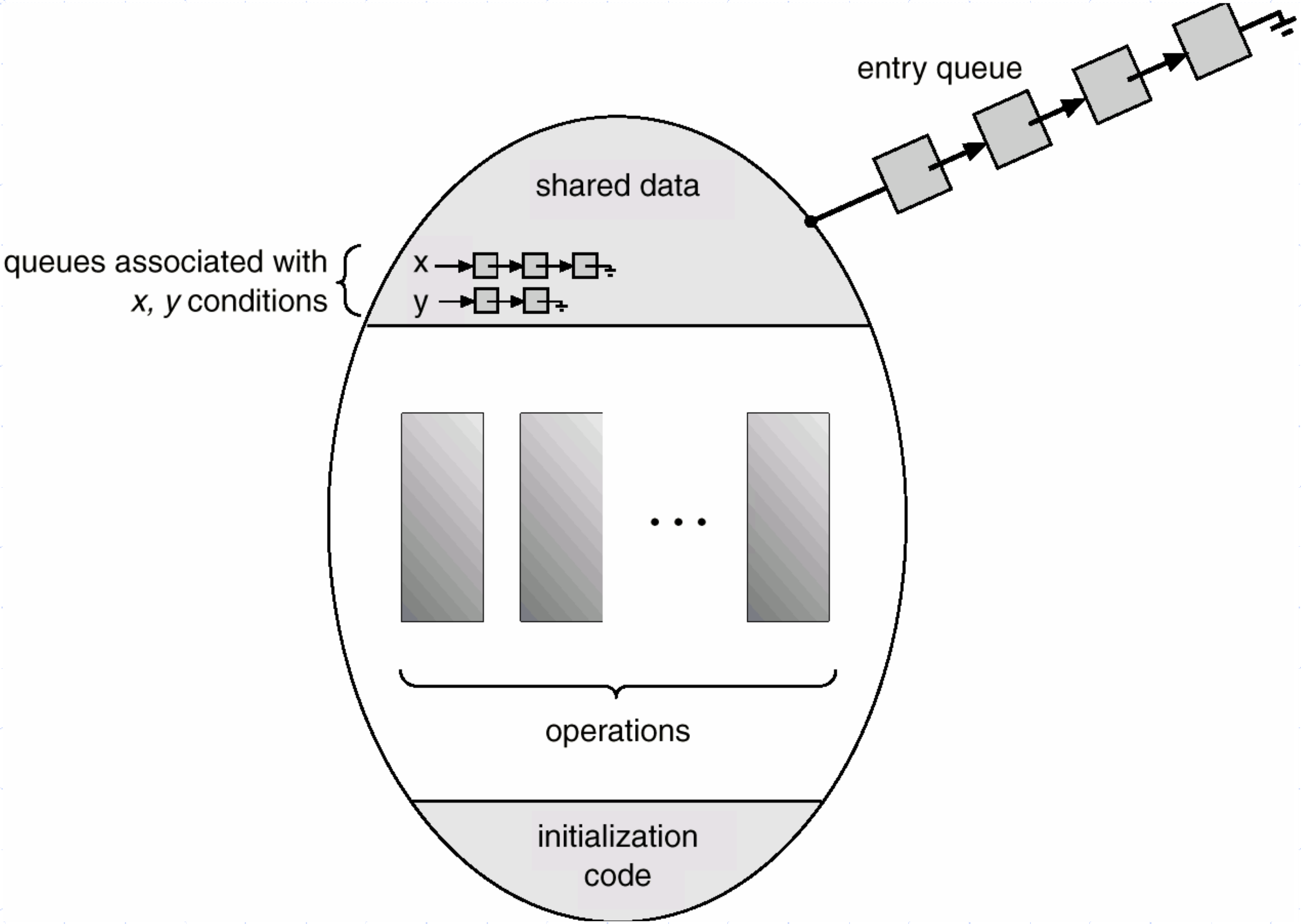
Monitor

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

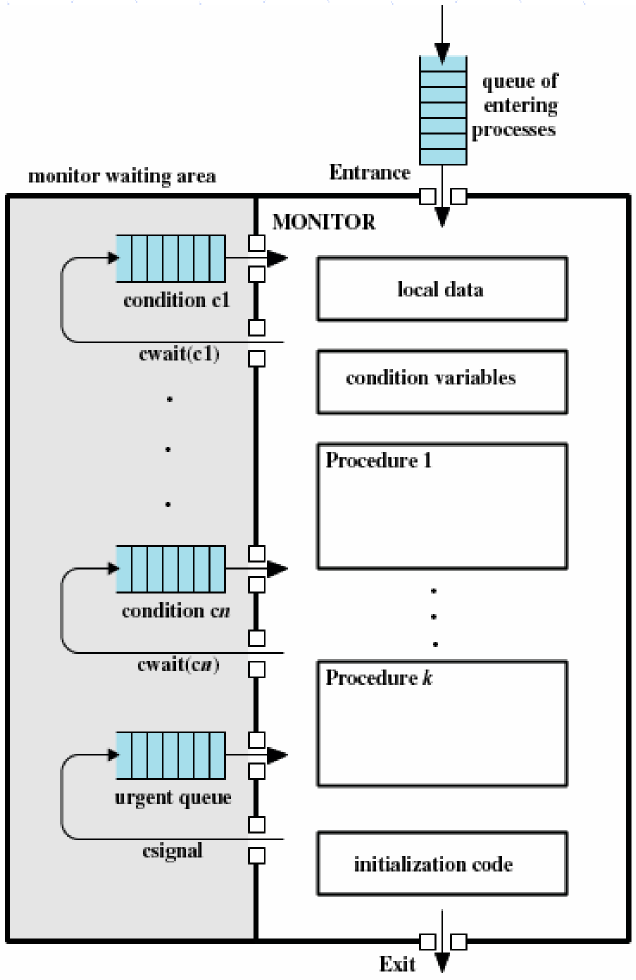
Condition Variables

- Condition variables → To allow a process to wait in a monitor
- Condition variables can only be used with following operations
  - Condition : x, y
    - Declaring a condition variable
  - x.wait
    - Process invoking x.wait is suspended until another process invokes x.signal
  - x.signal
    - Resumes exactly one suspended process. If no process is suspended this operation has no effect
- If x.signal is evoked by a process P, after Q → suspended
  - Signal and Wait
  - Signal and Continue
- Resuming processes within monitor; x.wait(c) → conditional-wait

Monitor Architecture



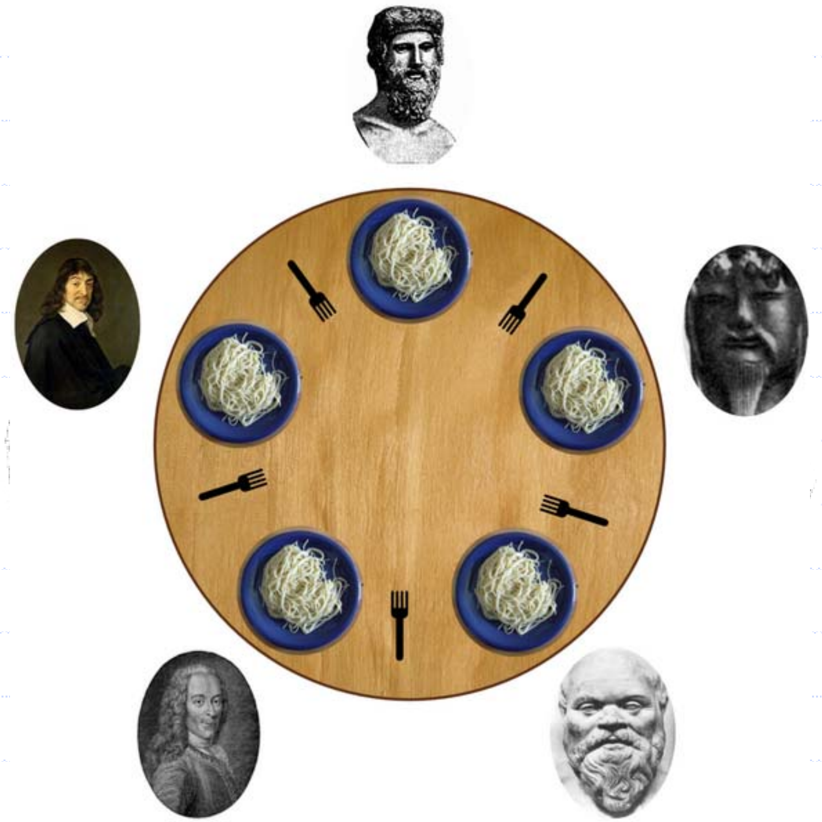
Monitor Architecture



Classical Synchronization Problems

- Bounded-Buffer Problem √
- Dining-Philosophers Problem
- Readers and Writers Problem

Dining-Philosophers Problem



- Example of large class of concurrent-control problems
- Provide deadlock-free and starvation-free solution
- Chopstick → Semaphore
  - `semaphore chopstick[5];`
    - Initially `chopstick` → `1`

Dining-Philosophers Problem

- Philosopher *i*:

```
do {
    wait(chopstick[i])
    wait(chopstick[(i+1) mod 5])
        …
      eat
        …
    signal(chopstick[i]);
    signal(chopstick[(i+1) mod 5]);
        …
      think
        …
    } while (1);
```

- Problem → Deadlock

Dining-Philosophers Problem

- Possible solutions *against* deadlock
  - Allow at most 4 philosophers to sit simultaneously
  - Allow a philosopher to pick chopstick only if both chopsticks are available,
  - Odd philosopher $\rightarrow$ first *left* then *right* chopstick

- Satisfactory solution must guard against *Starvation*

  Deadlock-free solution does not eliminate possible starvation

Dining Philosophers Example

- Deadlock-free solution using monitor
- Chopsticks pick up → Only if both of them are available
  - Distinguish among 3 states of a philosopher

```
monitor dp
{
  enum {thinking, hungry, eating} state[5];
  condition self[5]; /* delay yourself when hungry but unable to obtain chopsticks */
  void pickup(int i)    /* Next Slide */
  void putdown(int i)   /* Next Slide */
  void test(int i)      /* Next Slide */
  void init() {
     for (int i = 0; i < 5; i++)
          state[i] = thinking;
          }
}
```

```
state [i]= eating only if
   state [(i+4) mod 5] != eating &&
   state [(i+1) mod 5] != eating
```

Dining Philosophers Example

```
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) mod 5);
  test((i+1) mod 5);
   }
                         void test(int i) {
                         if ( (state[(i + 4) mod 5] != eating) &&
                         (state[i] == hungry) &&
                         (state[(i + 1) mod 5] != eating)) {
                                   state[i] = eating;
                                   self[i].signal();
                                                        }
                                        }
  void init() {
       for (int i = 0; i < 5; i++)
                 state[i] = thinking;
                    }
}
```

```
dp.pickup(i)
    …
    …
    eat
    …
dp.putdown(i)
```

- Problem?

First Solution - Dining Philosophers

```
/* program diningphilosophers */
semaphore  fork [5] = {1};
int i:
void philosopher (int i)
{
    while (true)
    {
        think ();
        wait (fork[i]);
        wait (fork [(i+1)] mod 5]);
        eat ();
        signal (fork[i]);
        signal (fork [(i+1)] mod 5]);
    }
}
void main()
{
    parbegin (philosopher (0), philosopher (1), philosopher (2), philosopher (3), philosopher
    (4));
}
```

Second Solution - Dining Philosophers

```
    /* program diningphilosophers */
    semaphore  fork [5] = {1};
    semaphore  room = {4};
    int i:
    void philosopher (int i)
{
    while (true)
    {
            think ();
            wait (room);
            wait (fork[i]);
            wait (fork [(i+1)] mod 5]);
            eat ();
            signal (fork[i]);
            signal (fork [(i+1)] mod 5]);
            signal (room);
    }
}
void main()
{
    parbegin (philosopher (0), philosopher (1), philosopher (2), philosopher (3), philosopher (4));
}
```

Readers-Writers Problem

- File/Record is to be shared among several concurrent processes
- Many readers, Exclusively one writer at a time

	Reader	Writer
Readers	✓	×
Writers	×	×

- Several variations
  - No reader should wait for other readers to finish simply because a writer is waiting
  - Once a writer is ready, writer performs its write ASAP
- Possible starvation
- Solution → First variation

```
int readcount = 0;
semaphore mutex,
        initially 1
semaphore wrt,
        initially 1
```

Readers-Writers Problem

Writer:

```
wait(wrt)
   …
writing is performed
   …
signal(wrt)
```

Reader:

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

          …
    reading is performed
          …

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

Readers-Writers Problem

```
/*program readersandwriters*/
int  readcount, writecount;
semaphore x = 1, y = 1, z = 1, wsem = 1, rsem = 1;
void reader()
{
    while (true)
    {
     semWait (z);
          semWait (rsem);
               semWait (x);
                    readcount++;
                    if (readcount == 1)
                         semWait (wsem);
               semSignal (x);
          semSignal (rsem);
     semSignal (z);
     READUNIT();
     semWait (x);
          readcount--;
          if (readcount == 0)
               semSignal (wsem);
     semSignal (x);
    }
}
void writer ()
{
    while (true)
    {
     semWait (y);
          writecount++;
          if (writecount == 1)
               semWait (rsem);
     semSignal (y);
     semWait (wsem);
     WRITEUNIT();
     semSignal (wsem);
     semWait (y);
          writecount--;
          if (writecount == 0)
               semSignal (rsem);
     semSignal (y);
    }
}
void main()
{
    readcount = writecount = 0;
    parbegin (reader, writer);
}
```

Readers only in the system:
- ***wsem*** **set**
- **no queues**

Writers only in the system:
- ***wsem*** **and** ***rsem*** **set**
- **Writers queues on** ***wsem***

Last Solution, Writers → Starvation

No new readers are allowed to access the data once at least one writer has declared a desire to write

Readers-Writers Problem

```
/*program readersandwriters*/
int  readcount, writecount;
semaphore x = 1, y = 1, z = 1, wsem = 1, rsem = 1;
void reader()
{
    while (true)
    {
     semWait (z);
          semWait (rsem);
               semWait (x);
                    readcount++;
                    if (readcount == 1)
                         semWait (wsem);
               semSignal (x);
          semSignal (rsem);
     semSignal (z);
     READUNIT();
     semWait (x);
          readcount--;
          if (readcount == 0)
               semSignal (wsem);
     semSignal (x);
    }
}
void writer ()
{
    while (true)
    {
     semWait (y);
          writecount++;
          if (writecount == 1)
               semWait (rsem);
     semSignal (y);
     semWait (wsem);
     WRITEUNIT();
     semSignal (wsem);
     semWait (y);
          writecount--;
          if (writecount == 0)
               semSignal (rsem);
     semSignal (y);
    }
}
void main()
{
    readcount = writecount = 0;
    parbegin (reader, writer);
}
```

Readers only in the system:
- *wsem* set
- no queues

Writers only in the system:
- *wsem* and *rsem* set
- Writers queues on *wsem*

Both Readers and Writers with *Read First*:
- *wsem* set by reader
- *rsem* set by writer
- all writers queues on *wsem*
- one reader queues on *rsem*
- other readers queues on z

Both Readers and Writers with *write First*
- *wsem* set by writer
- *rsem* set by writer
- writers queues on *wsem*
- one reader queues on *rsem*
- other readers queues on z

Synchronization in Pthreads

- Pthread API
  - Mutex locks, condition variables, read-write locks for thread synchronization
- Pthreads Mutex Locks

Protecting CS using mutex

```
# include <pthread.h>
pthread_mutex_t mutex;

/* create the mutex lock */
pthread_mutex_init(&mutex, NULL);

/* acquire the mutex lock */
pthread_mutex_lock(&mutex);

/**** Critical Section ****/

/* release the mutex lock */
pthread_mutex_unlock(&mutex);
```

Synchronization in Pthreads

- Pthread Semaphores

```
# include <semaphore.h>
sem_t sem;

/* create the semaphore and initialize to 8 */
sem_init(&sem,0,8)
```

  - wait() → sem_wait()
  - signal() → sem_post()

Protecting CS using semaphore

```
# include <semaphore.h>
sem_t mutex;

/* create the semaphore */
sem_init(&mutex, 0, 1);

/* acquire the semaphore */
sem_wait(&mutex);

/**** Critical Section ****/

/* release the semaphore */
sem_post(&mutex);
```

Synchronization using Win32 API

- Win 32 mutex Locks

```
# include <windows.h>
HANDLE Mutex;

/* create a mutex lock*/
Mutex = CreateMutex(NULL, FALSE, NULL);

/* Acquiring a mutex lock created above */
WaitForSingleObject(Mutex, INFINITE);

/* Release the acquired lock */
ReleaseMutex(Mutex);
```

- Win 32 Semaphores

```
# include <windows.h>
HANDLE Sem;

/* create a semaphore*/
Sem = CreateSemaphore(NULL, 1, 5, NULL);

/* Acquiring the semaphore */
WaitForSingleObject(Semaphore, INFINITE);

/* Release the semaphore, signal() */
ReleaseSemaphore(Sem, 1, NULL);
```

Synchronization in Linux

- Current versions → processes running in kernel mode can also be preempted, when higher priority process available

- Linux Kernel → Spinlocks and Semaphores for locking in kernel

- Locking mechanisms
  - Uniprocessor → Enabling and disabling kernel preemption
    - `preempt_disable()`, `preempt_enable()`
  - Multiprocessor → Spinlocks
    - Kernel is designed such that spinlocks are held only for short duration

Synchronization in Linux

- Atomic Operations → Special *data type*, `atomic_t`
  - `ATOMIC_INT (int i), int atomic_read(atomic_t *v)`
  - `void atomic_add(int i, atomic_t *v)`
  - `void atomic_sub(int i, atomic_t *v)`

- Spinlocks → Only one thread at a time can acquire spinlock
  - `void spin_lock(spinlock_t *t)`
  - `void spin_unlock(spinlock_t *lock)`

- Reader-Writer Spinlock → Exclusive access to spinlock that intends to update the data structure, favors readers

- Semaphores → Binary, Counting, Reader-Writer
  - `void sema_init(struct semaphore *sem, int count)`
  - `void init_MUTEX(struct semaphore *sem)`
  - `void init_MUTEX_locked(struct semaphore *sem)`
  - `Void init_rwsem(struct rw_semaphore *sem)`

Synchronization in Windows XP

- Kernel access global resources
  - Uniprocessor → Temporarily *masks interrupts* for all interrupt handlers
  - Multiprocessor
    - Uses spinlocks to protect access to global resources
    - Spinlocks → only to protect short code segment
    - A thread will never be preempted while holding a spinlock
- Thread synchronization outside kernel → *dispatcher objects*
  - Using dispatcher objects, threads synchronize using different mechanisms *(mutexes, semaphores, events, timers)*
  - Singled state, Nonsingled state
- Dispatcher objects may also provide *events* → much like a condition variable

Minor II

- Syllabus → Scheduling, Synchronization, Deadlocks
- Open Book/Notes
  - Can bring your own notes
  - Can also bring class lecture slides
  - Exchange of notes/materials → Strictly prohibited
  - No textbook is allowed
  - No xerox of book(s) is allowed
- Type of questions → Remains Open!

Good Luck!