CS370 Operating Systems
Midterm Review

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Spring 2022

Review for Midterm

Closed book, closed notes, no cheat sheets. Calculator in browser available.

- Sec 002 and local 801 students
  - 12:30-1:45 PM Tuesday March 8 in Clark A 201 usual room
- Sec 801 (non-local):
  - 1 hr 15 min. Tuesday March 8 12:30- Wed March 9 1:45 PM window.
- SDC students: You should have made arrangements with SDC already.
- Sec 002: Respondus lockdown browser, Sec 801 Honorlock

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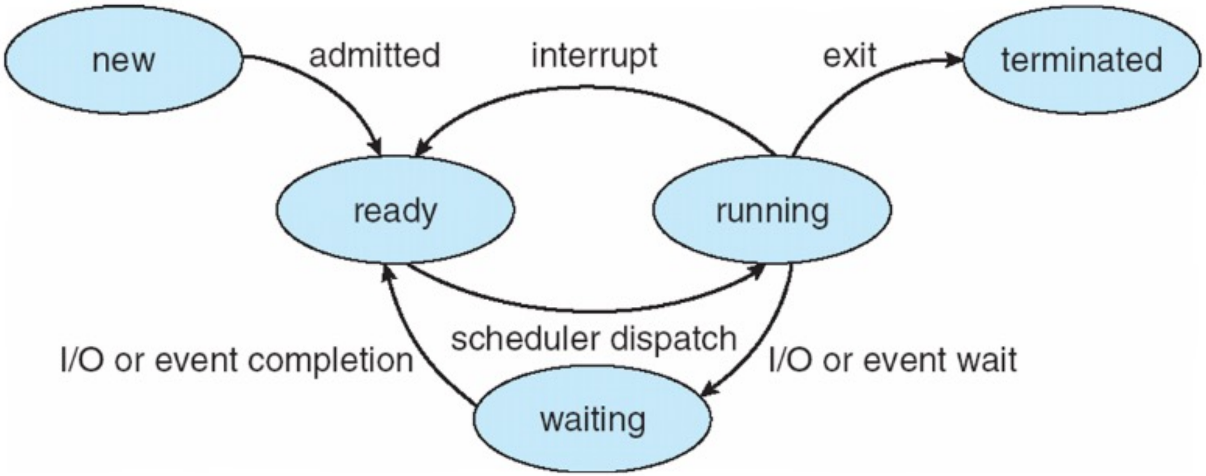
Course Overview

Computer System Structures

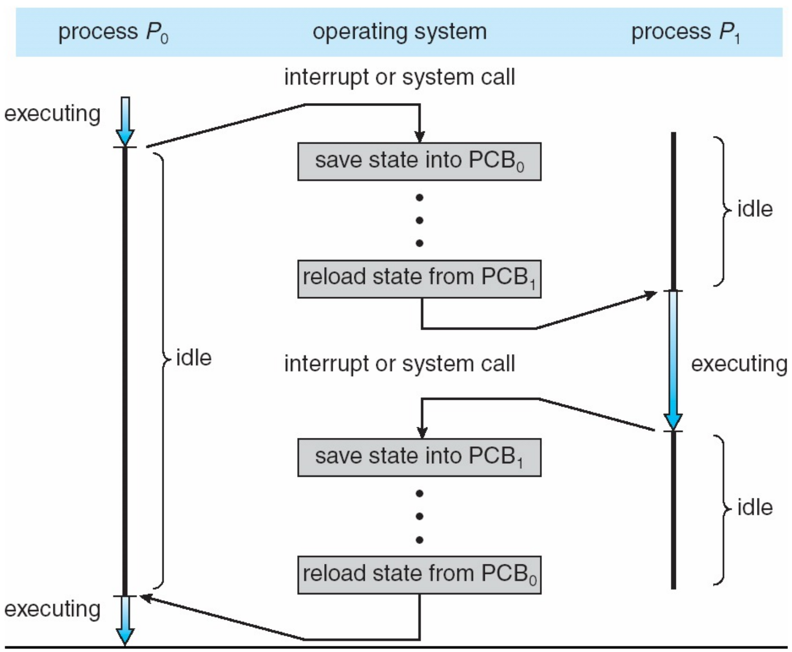
- Computer System Operation
  - Stack for calling functions (subroutines)
- I/O Structure: polling, interrupts, DMA
- Storage Structure
  - Storage Hierarchy
- System Calls and System Programs
- Command Interpreter

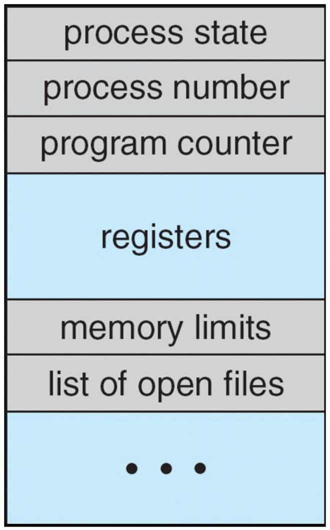
The Concept of a Process

- Process - a program in execution
  - process execution proceeds in a sequential fashion
- Multiprogramming: several programs apparently executing “concurrently”.
- Process States
  - e.g. new, running, ready, waiting, terminated.

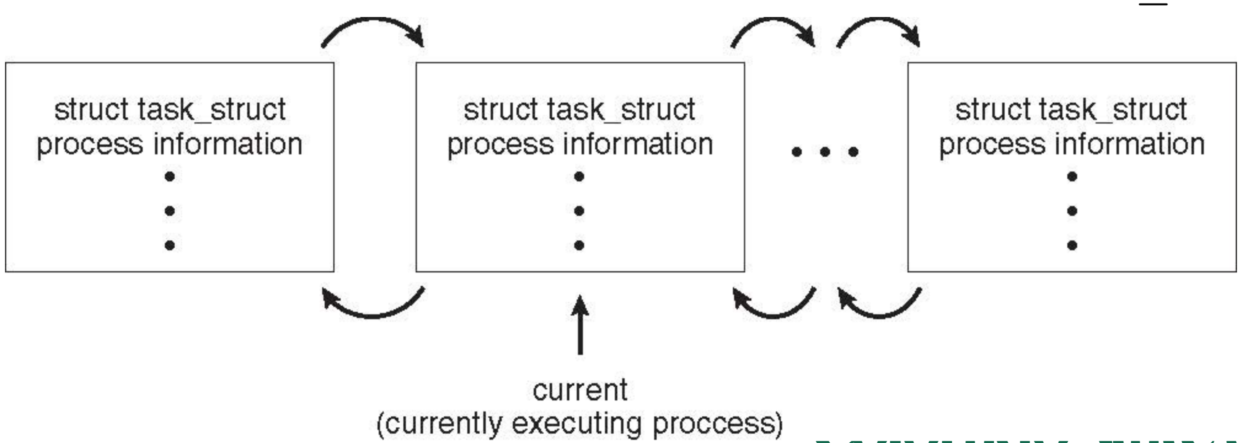


CPU Switch From Process to Process



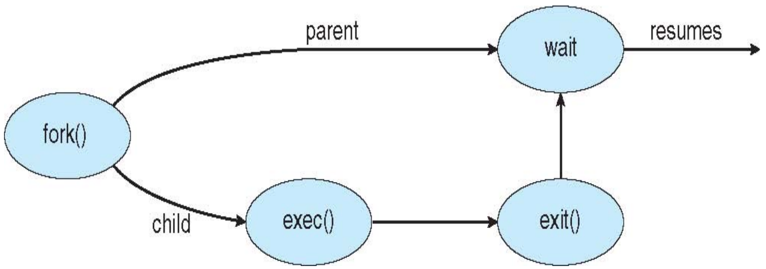


C structure
`task_struct`



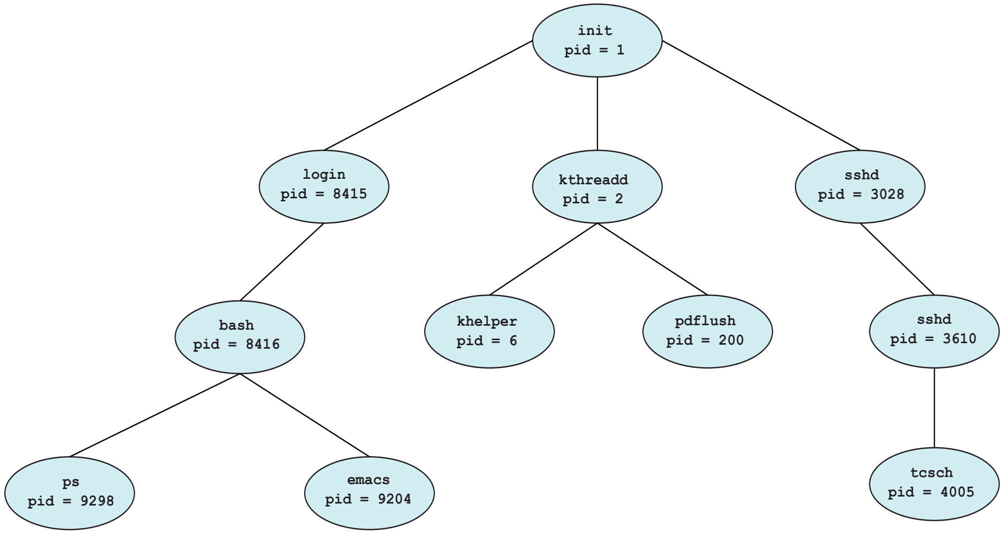
Process Creation

- Processes are created and deleted dynamically
- Process which creates another process is called a *parent* process; the created process is called a *child* process.
- Result is a tree of processes
  - e.g. UNIX - processes have dependencies and form a hierarchy.
- Resources required when creating process
  - CPU time, files, memory, I/O devices etc.



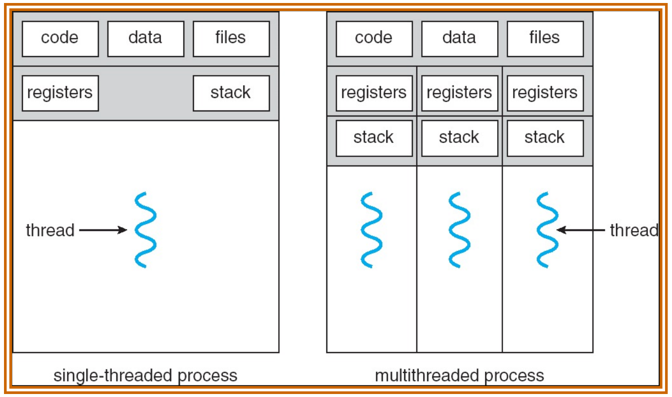

```
cid = fork();
if (cid < 0) { /* error occurred */
   fprintf(stderr, "Fork Failed\n");
    return 1;
}
 else if (cid == 0) { /* child process */
    execlp("/bin/ls","ls",NULL);
 }
  else { /* parent process, will wait for child to complete */
     wait(NULL);

 }
```



Threads

- A thread (or lightweight process)
    - basic unit of CPU utilization; it consists of:
        - program counter, register set and stack space
  - A thread shares the following with peer threads:
    - code section, data section and OS resources (open files, signals)
  - Collectively called a task.
- Thread support in modern systems
  - User threads vs. kernel threads, lightweight processes
  - 1-1, many-1 and many-many mapping
- Implicit Threading (e.g. OpenMP)
- Hardware support in newer processors



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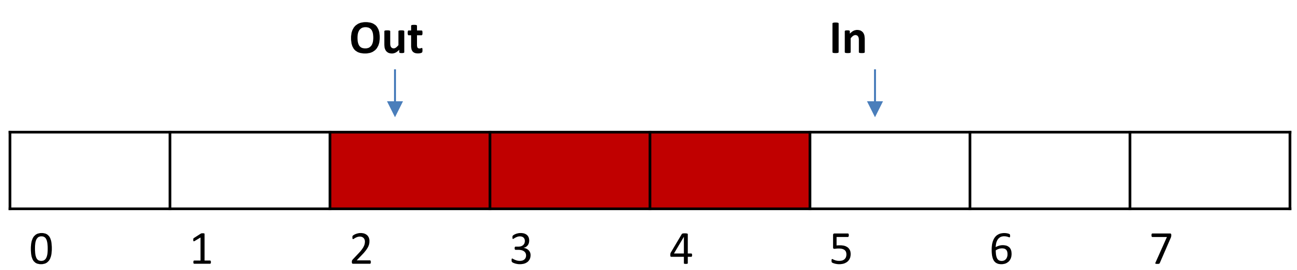
Producer-Consumer Problem

- Paradigm for cooperating processes;
  - producer process produces information that is consumed by a consumer process.
- We need buffer of items that can be filled by producer and emptied by consumer.
  - Unbounded-buffer
  - Bounded-buffer
- Producer and Consumer must synchronize.

```
item next_produced;
while (true) {
        /* produce an item in next produced */
        while (((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
}
```



Interprocess Communication (IPC)

- Mechanism for processes to communicate and synchronize their actions.
  - Via shared memory
  - Pipes
  - Sockets
  - Via Messaging system - processes communicate without resorting to shared variables.

```
int fd[2];

create the pipe:
  if (pipe(fd) == -1) {
    fprintf(stderr,"Pipe failed");
    return 1;
fork a child process:
     pid = fork();

parent process:
      /* close the unused end of the pipe */
       close(fd[READ_END]);

       /* write to the pipe */
         write(fd[WRITE_END], write_msg, strlen(write_msg)+1);

       /* close the write end of the pipe */
      close(fd[WRITE_END]);
```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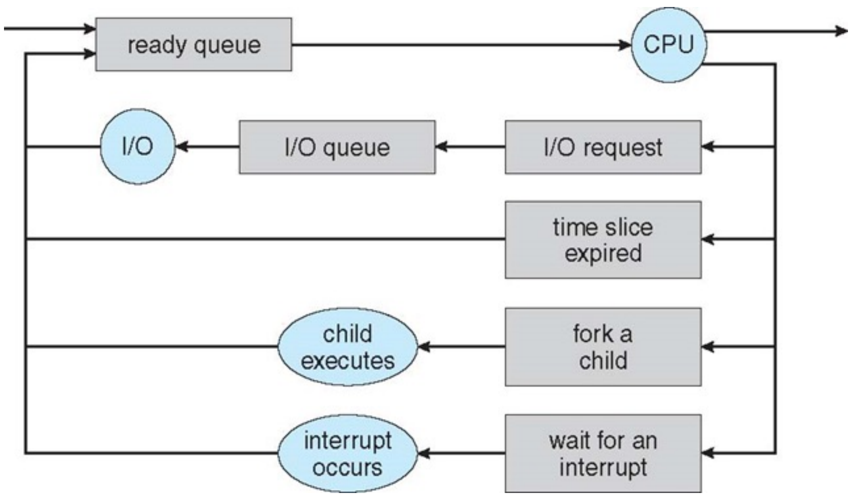
CPU Scheduling

- **CPU utilization** – keep the CPU as busy as possible: Maximize
- **Throughput** – # of processes that complete their execution per time unit: Maximize
- **Turnaround time** –time to execute a process from submission to completion: Minimize
- **Waiting time** – amount of time a process has been waiting in the ready queue: Minimize
- **Response time** –time it takes from when a request was submitted until the first response is produced, not output (for time-sharing environment): Minimize



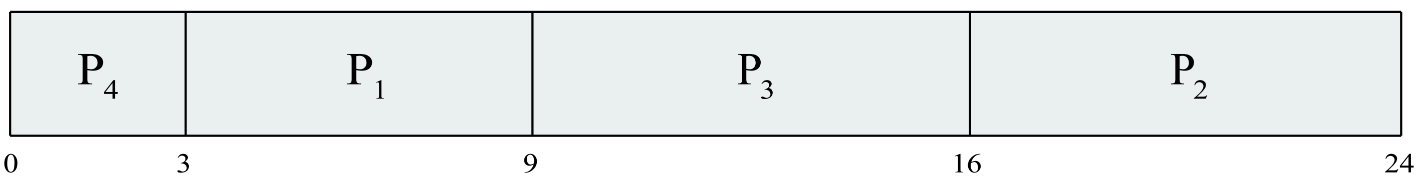
Scheduling Policies

- FCFS (First Come First Serve)
  - Process that requests the CPU *FIRST* is allocated the CPU *FIRST.*
- SJF (Shortest Job First)
  - Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time.
- Shortest-remaining-time-first (preemptive SJF)
  - A process preempted by an arriving process with shorter remaining time
- Priority
  - A priority value (integer) is associated with each process. CPU allocated to process with highest priority.
- Round Robin
  - Each process gets a small unit of CPU time
- MultiLevel
  - ready queue partitioned into separate queues
  - Variation: Multilevel Feedback queues: priority lower or raised based on history
- Completely Fair

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- All arrive at time 0.
- SJF scheduling chart



- Average waiting time for P_1,P_2,P_3,P_4 = (3 + 16 + 9 + 0) / 4 = 7

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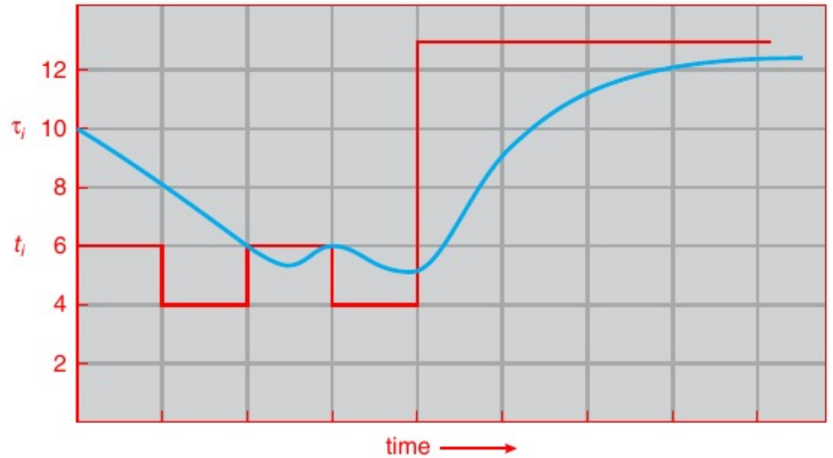
Determining Length of Next CPU Burst

- Can be done by using the length of previous CPU bursts, using *exponential averaging*
  1. $t_n =$ actual length of n^{th} CPU burst
  2. $\tau_{n+1} =$ predicted value for the next CPU burst
  3. $\alpha, 0 \le \alpha \le 1$
  4. Define: $\tau_{n=1} = \alpha\, t_n + (1-\alpha)\tau_n.$
- Commonly, α set to ½

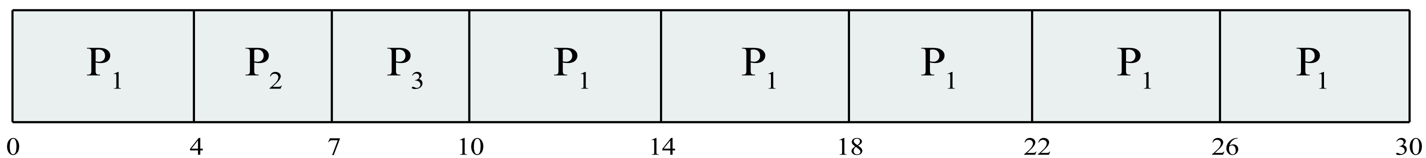


CPU burst (t_i)		6	4	6	4	13	13	13	…
"guess" (τ_i)	10	8	6	6	5	9	11	12	…

Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Arrive a time 0 in order P1, P2, P3: The Gantt chart is:



- Waiting times: P1:10-4 =6, P2:4, P3:7, average 17/3 = 5.66 units
- Typically, higher average turnaround than SJF, but better ***response***
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch overhead < 1%

Response time: Arrival to beginning of execution: P2: 4
Turnaround time: Arrival to finish of execution: P2: 7

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- **Assume Homogeneous processors** within a multiprocessor
- **Asymmetric multiprocessing** – only one processor accesses the system data structures, alleviating the need for data sharing
- **Symmetric multiprocessing** **(SMP)** – each processor is self-scheduling,
  - all processes in common ready queue, or
  - each has its own private queue of ready processes
    - Currently, most common
- **Processor affinity** – process has affinity for processor on which it is currently running because of info in cache
  - **soft affinity: try but no guarantee**
  - **hard affinity can specify processor sets**

Consumer-producer problem

Producer

```
while (true) {
        /* produce an item*/
  while (counter == BUFFER_SIZE) ;
                /* do nothing */
  buffer[in] = next_produced;
  in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

Consumer

```
while (true) {
  while (counter == 0);
        /* do nothing */
   next_consumed = buffer[out];
   out = (out + 1) % BUFFER_SIZ
   counter--;
        /* consume the item in
        next consumed */
}
```

They run “concurrently” (or in parallel), and are subject to context switches at unpredictable times.

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Race Condition

`counter++` **could be compiled as**

```
register1 = counter
register1 = register1 + 1
counter = register1
```

`counter--` **could be compiled as**

```
register2 = counter
register2 = register2 - 1
counter = register2
```

They run concurrently, and are subject to context switches at unpredictable times.

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` {counter = 6 }
S5: consumer execute `counter = register2` {counter = 4}

Overwrites!

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The Critical Section Problem

- Requirements
  - Mutual Exclusion
  - Progress
  - Bounded Waiting
- Solution to the critical section problem

```
do {
     acquire lock
          critical section
     release lock
          remainder section
} while (TRUE);
```

Peterson's Algorithm for Process P_i

```
do {
     flag[i] = true;
     turn = j;
     while (flag[j] && turn = = j);   /*Wait*/
             critical section
     flag[i] = false;
             remainder section
 } while (true);
```

Being nice!

- The variable `turn` indicates whose turn it is to enter the critical section
- `flag[i] = true` implies that process P_i is ready!
- Proofs **for Mutual Exclusion, Progress, Bounded Wait**

Solution using test_and_set()

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

```
do {
     while (test_and_set(&lock)) ; /* do nothing */
            /* critical section */
      …. .
     lock = false;
            /* remainder section */
    …   ..
  } while (true);
```


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Bounded-waiting Mutual Exclusion with test_and_set

For process i:

```
do {
   waiting[i] = true;
   key = true;
   while (waiting[i] && key)
      key = test_and_set(&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);
```

Shared Data structures initialized to FALSE

- `boolean waiting[n];`
- `boolean lock;`

The entry section for process i :

- First process to execute TestAndSet will find key == false ; ENTER critical section,
- EVERYONE else must wait

The exit section for process i:

Part I: Finding a suitable waiting process j and enable it to get through the while loop,

or if thre is no suitable process, make lock FALSE.

Mutex Locks

- Protect a critical section by first **`acquire()`** a lock then **`release()`** the lock
  - Boolean indicating if lock is available or not
- Calls to **`acquire()`** and **`release()`** must be atomic
  - Usually implemented via hardware atomic instructions
- But this solution requires **busy waiting**
  - This lock therefore called a **spinlock**

•**Usage**

```
do {
    acquire lock
        critical section
    release lock
        remainder section
} while (true);
```

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

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

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

Semaphore

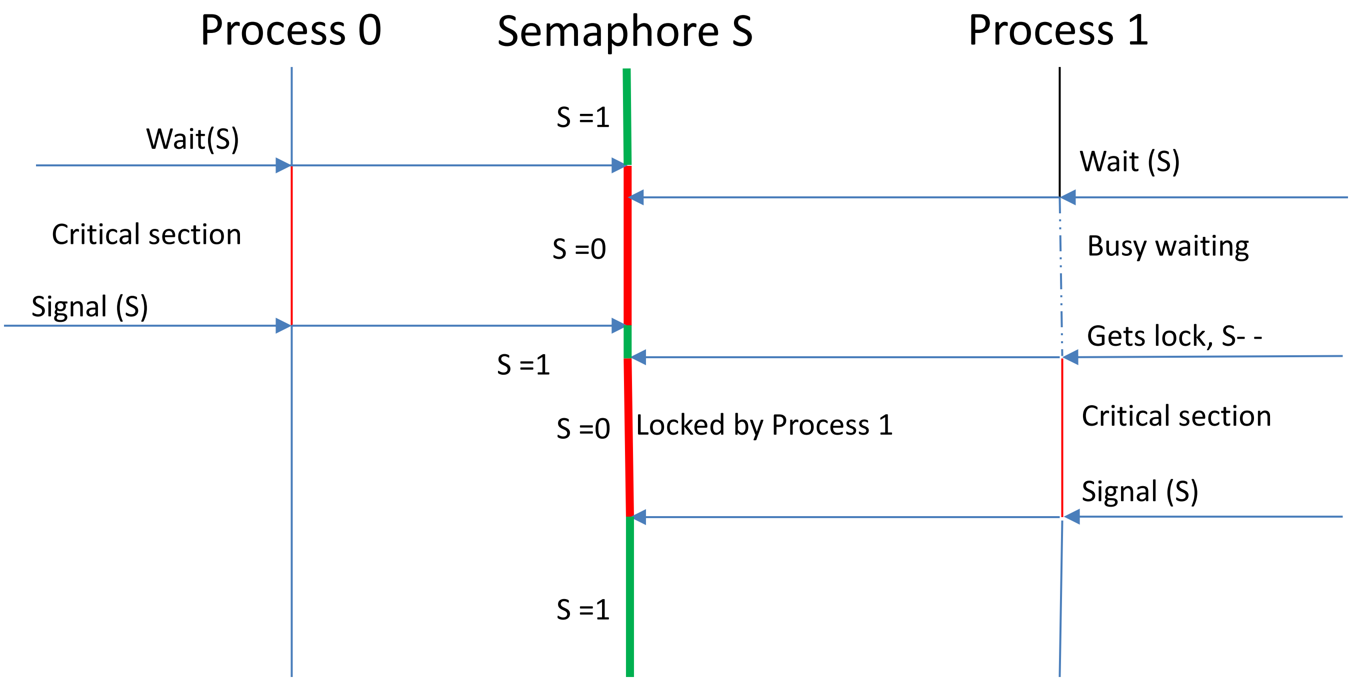
- Synchronization tool that provides more sophisticated ways (than Mutex locks) for process to synchronize their activities.
- Semaphore ***S*** – integer variable
- Can only be accessed via two indivisible (atomic) operations
  - **`wait()`** and **`signal()`**
    - Originally called **`P()`** and **`V()`**
- Definition of the **`wait() operation`**

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

- Definition of the **`signal() operation`**

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

Wait(S) and Signal (S)



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Readers-Writers Problem (Cont.)

- The structure of a reader process

```
do {
     wait(mutex);
        read_count++;
        if (read_count == 1)
              wait(rw_mutex);
     signal(mutex);
         ...
        /* reading is performed */
         ...
     wait(mutex);
        read count--;
        if (read_count == 0)
             signal(rw_mutex);
     signal(mutex);
} while (true);
```

mutex for mutual exclusion to readcount

When:
writer in critical section
and if n readers waiting
1 is queued on rw_mutex
(n-1) queued on mutex

The structure of a writer process

```
do {
 wait(rw_mutex);
      ...
/* writing is performed */
      ...
   signal(rw_mutex);
} while (true);
```

Implementation with no Busy waiting (Counting Sema)

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

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

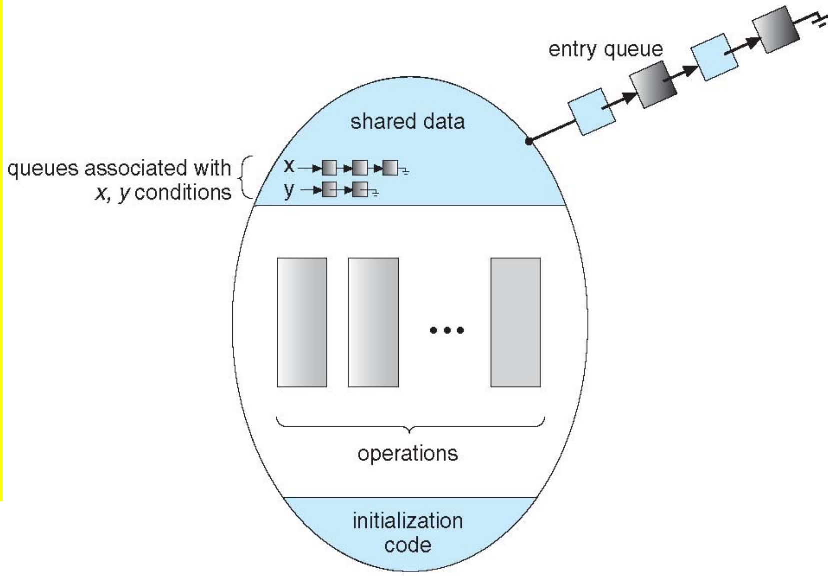
```
typedef struct{
    int value;
    struct process *list;
    } semaphore;
```

Monitors and Condition Variables

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

   procedure Pn (…) {……}

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



The **condition** construct

- **`condition x, y;`**
- Two operations are allowed 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()`**
    - If no **`x.wait()`** on the variable, then it has no effect on the variable. *Signal is lost.*

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The pickup() and putdown() operations

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

    void pickup (int i) {
           state[i] = HUNGRY;
           test(i);   //on next slide
           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);
   }
```

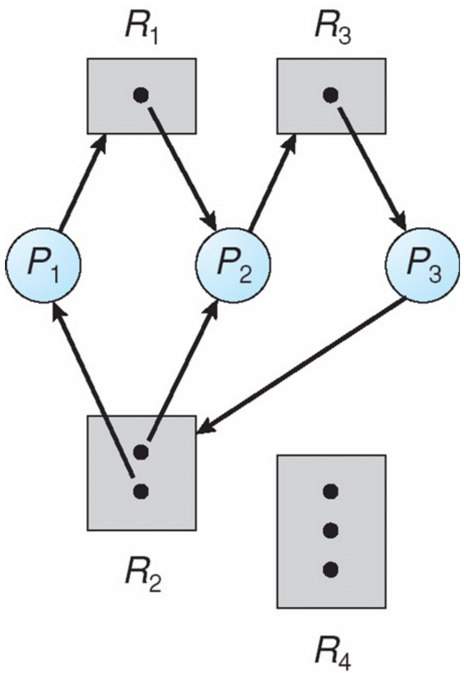
```
    void test (int i) {
            if ((state[(i + 4) % 5] != EATING) &&
            (state[i] == HUNGRY) &&
            (state[(i + 1) % 5] != EATING) ) {
                 state[i] = EATING ;
               self[i].signal () ;
            }
   }

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

Deadlocks

- System Model
  - Resource allocation graph, claim graph (for avoidance)
- Deadlock Characterization
  – Conditions for deadlock - mutual exclusion, hold and wait, no preemption, circular wait.
- Methods for handling deadlocks
  - Deadlock Prevention
  - Deadlock Avoidance
  - Deadlock Detection
  - Recovery from Deadlock

  – Combined Approach to Deadlock Handling



At this point, two minimal cycles exist in the system:
P1→ R1→ P2→ R3→ P3→ R2→ P1
P2→ R3→ P3→ R2→ P2
Processes *P1, P2,* and *P3* are deadlocked.

Deadlock Prevention

- If any one of the conditions for deadlock (with reusable resources) is denied, deadlock is impossible.
- Restrain ways in which requests can be made
  - Mutual Exclusion - cannot deny (important)
  - Hold and Wait - guarantee that when a process requests a resource, it does not hold other resources.
  - No Preemption
    - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, the process releases the resources currently being held.
  - Circular Wait
    - Impose a total ordering of all resource types.

Deadlock avoidance: Safe states

- If the system can:
  - Allocate resources to each process in some order
    - Up to the maximum for the process
  - Still avoid deadlock
  - Then it is in a **safe state**
- A system is safe ONLY IF there is a safe sequence
- A safe state is not a deadlocked state
  - Deadlocked state is an unsafe state
  - Not all unsafe states are deadlock

Questions

Various types of questions:

- Easy, hard, middle

Question types (may be similar to quiz questions):

- Problem solving/analyzing: Gantt charts, tables, e.g., scheduling
- True/False, Multiple choice
- Match things
- Identifying things in diagrams or complete them
- Concepts: define/explain/fill in blanks
- Code fragments: fill missing code, values of variables
- How will you achieve something?
- Others

How to prepare for the Midterm

- What you have been doing already
  - Listen to the lectures carefully, connecting terms, concepts and approaches
  - Think while answering quizzes, reviewing material as needed
  - Understanding, designing, coding and testing of programs
- Review course materials
  - Slides
  - HWs
  - Quizzes. There will be one this weekend.
  - Textbook

That’s it for today.