CS370 Operating Systems

Midterm Review

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Safe State, Safe Sequence

System must decide if immediate allocation leaves the system in a safe state

System is in **safe state** if there exists a sequence <P_1, P_2, …, P_n> of ALL the processes such that

- for each P_i, the resources that P_i can still request can be satisfied by
  - currently available resources +
  - resources held by all the P_j, with $j < i$
  - That is
    - If P_i resource needs are not immediately available, then P_i can wait until all P_j have finished and released resources
    - When P_i terminates, P_{i+1} can obtain its needed resources, and so on
- If no such sequence exists: system state is **unsafe**

Example A: Assume 12 Units in the system

	Max need	Current holding
av		3
P0	10	5
P1	4	2
P2	9	2

At time T0 (shown):
9 units allocated
3 (12-9) units available

A unit could be a drive,
a block of memory etc.

- Is the system at time **T0** in a safe state?
  - Try sequence <P1, P0 , P2>
  - P1 can be given 2 units
  - When P1 releases its resources; there are now 5 available units
  - P0 uses 5 and subsequently releases them (10 available now)
  - P2 can then proceed.
- Thus <P1, P0 , P2> is a safe sequence, and at T0 system was in a safe state

More detailed look

Example A: Assume 12 Units in the system (timing)

Is the state at T0 safe? Detailed look for instants T0, T1, T2, etc..

Time

	Max need	Current holding	+2 allo to P1	P1 releases all	..	..	..
		T0	T1	T2	T3	T4	T5
av		**3**	1	5	0	10	3
P0	10	**5**	5	5	10 done	0	0
P1	4	**2**	4 done	0	0	0	0
P2	9	**2**	2	2	2	2	9 done

Thus the state at T0 is safe.

Example B: 12 Units initially available in the system

	Max need	T0	T1 safe?
Av		3	2
P0	10	5	5
P1	4	2	2
P2	9	2	3 Is that OK?

Before T1:
3 units available

At T1:
2 units available

- At time **T1,** P2 is allocated 1 more units. Is that a good decision?
  - Now only P1 can proceed (already has 2, and given be given 2 more)
  - When P1 releases its resources; there are 4 units
  - P0 needs 5 more, P2 needs 6 more. Deadlock.
    - **Mistake** in granting P2 the additional unit.
- The state at **T1** is not a safe state. Wasn't a good decision.

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Review for Midterm

Closed book, closed notes, no cheat sheets. Respondus Lockdown Browser, Calculator in browser itself.

- Sec 001
  - 2-3:15 PM Tuesday Oct 8 in Biology 136 usual room
  - One scratch sheet, must be handed in before leaving.
- Sec 801 (non-local):
  - 1 hr 15 min. Wed Oct 9 12:10 AM - 11:50 PM window.
  - One scratch sheet, must be destroyed before camera
- SDC students: You should have made arrangements with SDC already.

How to prepare for the Midterm

What you have been doing already

- Attend classes, listen actively, review slides
  - Consult text, TAs as needed
- Quizzes: Review things before and during quizzes spending more time is better
- Self Exercises and Homework: Understand objectives & constructs, design approach, review & test code
- Study before exams. Why?

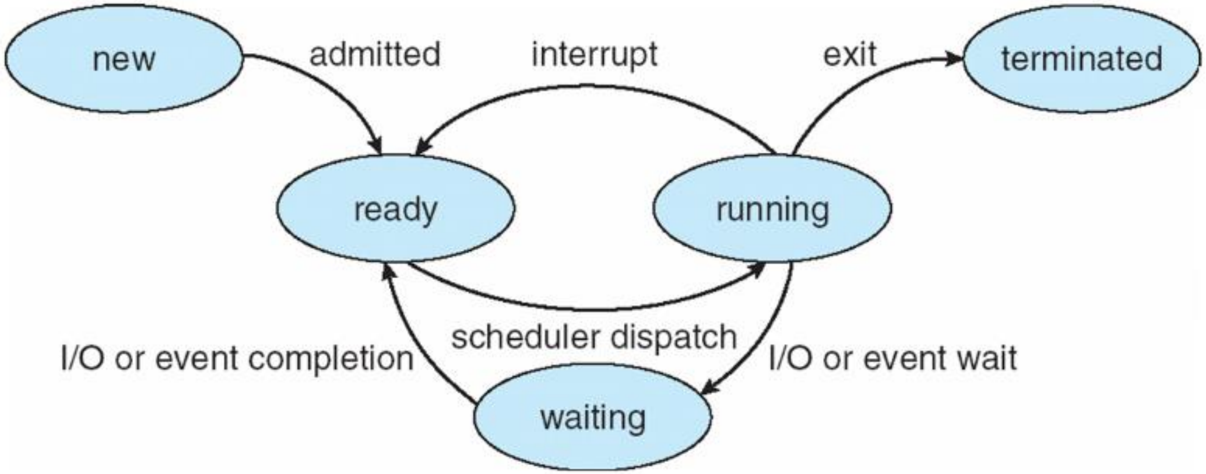
Course Overview

Computer System Structures

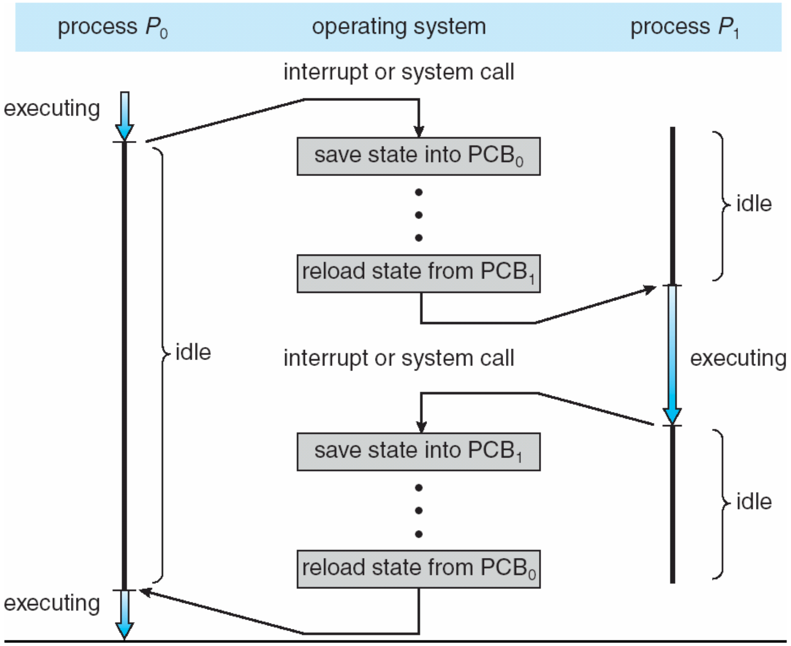
- Computer System Operation
  - Stack for calling functions (subroutines)
- I/O Structure: polling, interrupts, DMA
- Storage Structure
  - Storage Hierarchy
- System Calls and System Programs
- Command Interpreter

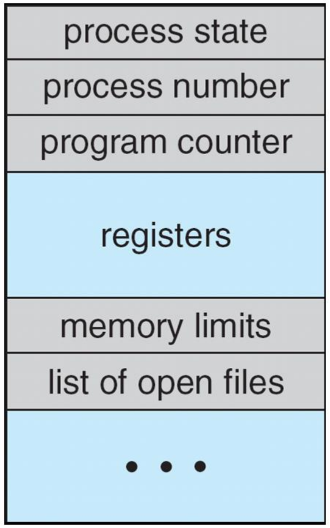
The Concept of a Process

- 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.



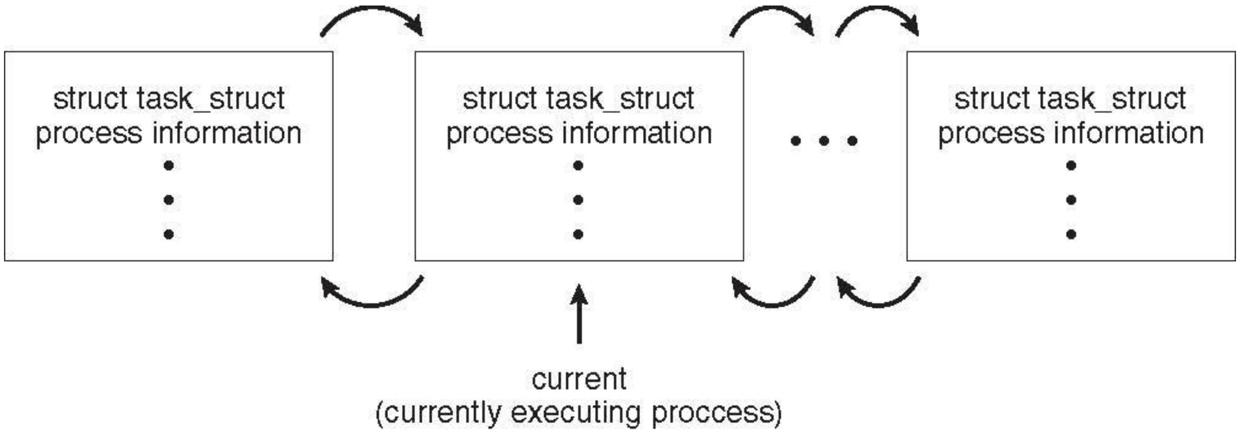
CPU Switch From Process to Process





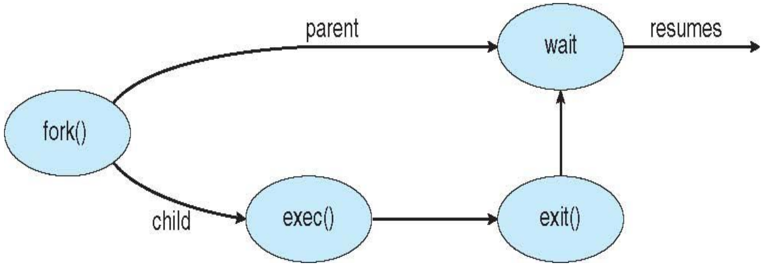
C structure

`task_struct`



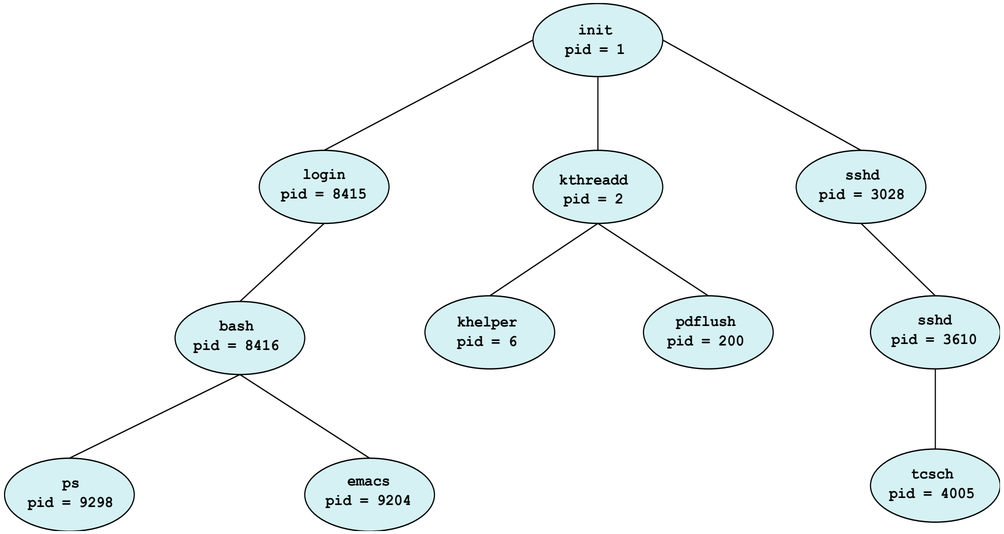
Process Creation

- 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.



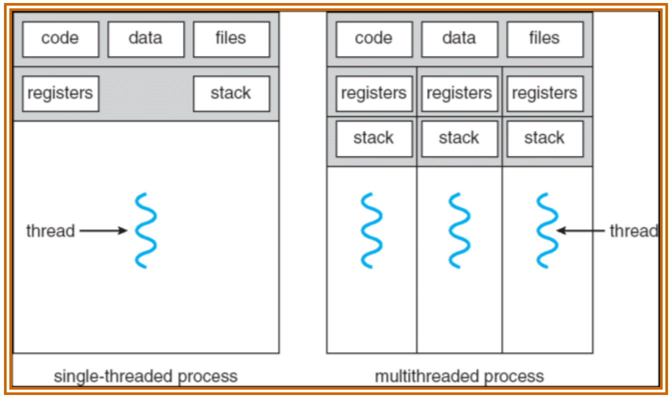
```
cid = fork();
if (cid < 0) { /* error occurred */
    fprintf(stderr, "Fork Failed\n");
      return 1;
}
  else if (cid == 0) { /* child process */
      execlp("/bin/ls","ls",NULL);
  }
   else { /* parent process, will wait for child to complete */
       wait(NULL);

  }
```



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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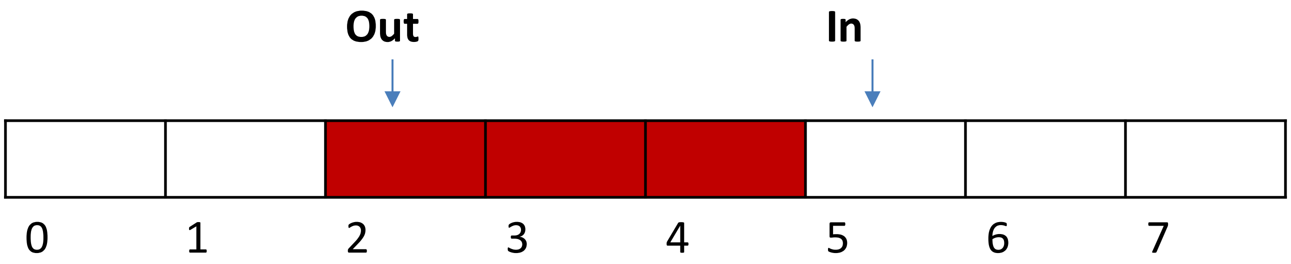
Producer-Consumer Problem

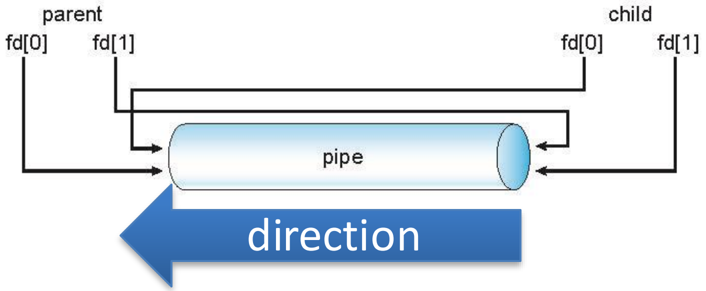
- Paradigm for cooperating processes;
  - producer process produces information that is consumed by a consumer process.
- We need buffer of items that can be filled by producer and emptied by consumer.
  - Unbounded-buffer
  - Bounded-buffer
- Producer and Consumer must synchronize.

```
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)

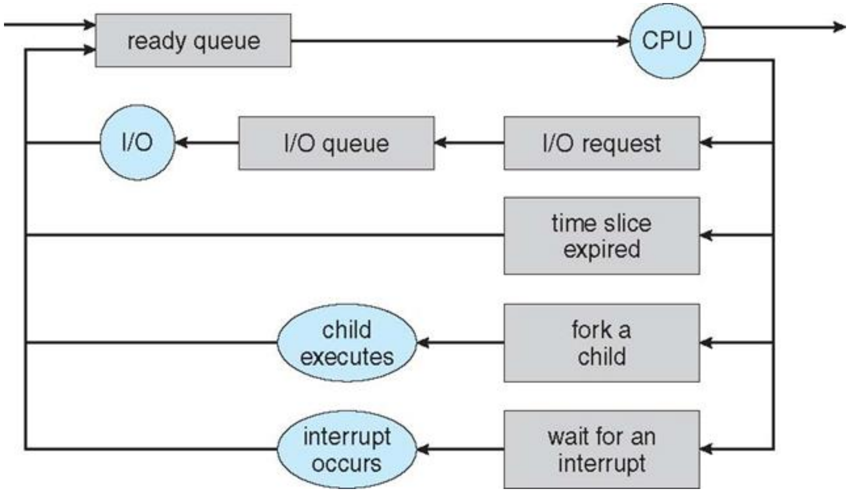
- Mechanism for processes to communicate and synchronize their actions.
  - Via shared memory
  - Pipes
  - Sockets
  - Via Messaging system - processes communicate without resorting to shared variables.



```
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]);
child process:
      ….
```

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



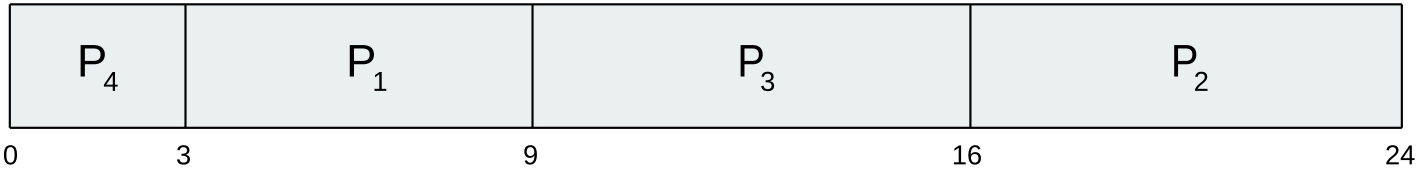
Scheduling Policies

- 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
  - Variable time-slice based on number and priority of the tasks in the queue.
  - virtual run time is the weighted run-time

Example: SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

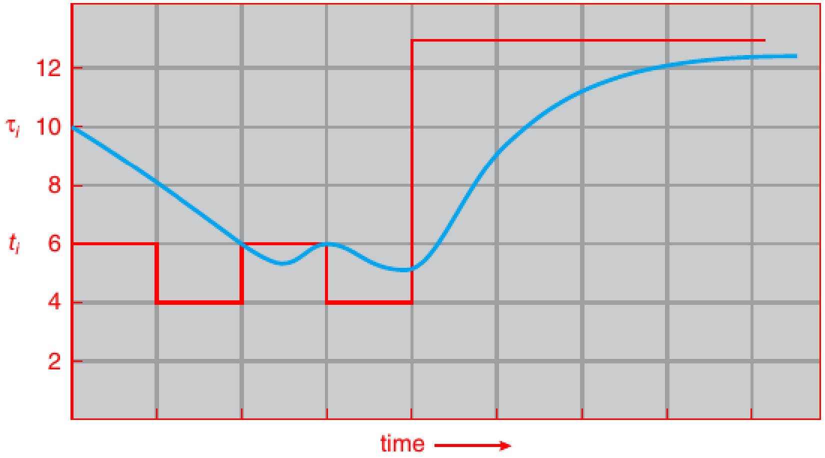
- All arrive at time 0.
- SJF scheduling chart



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

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. $\alpha, 0 \leq \alpha \leq 1$
  4. Define: $\tau_{n=1} = \alpha\, t_n + (1 - \alpha)\tau_n .$
- Commonly, α set to ½

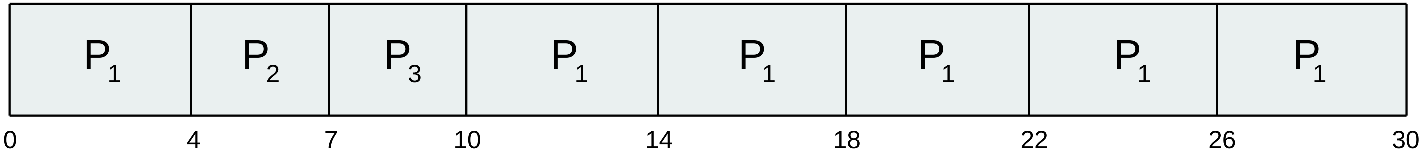


CPU burst (t_i)		6	4	6	4	13	13	13	…
"guess" (τ_i)	10	8	6	6	5	9	11	12	…

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**

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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.

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!

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

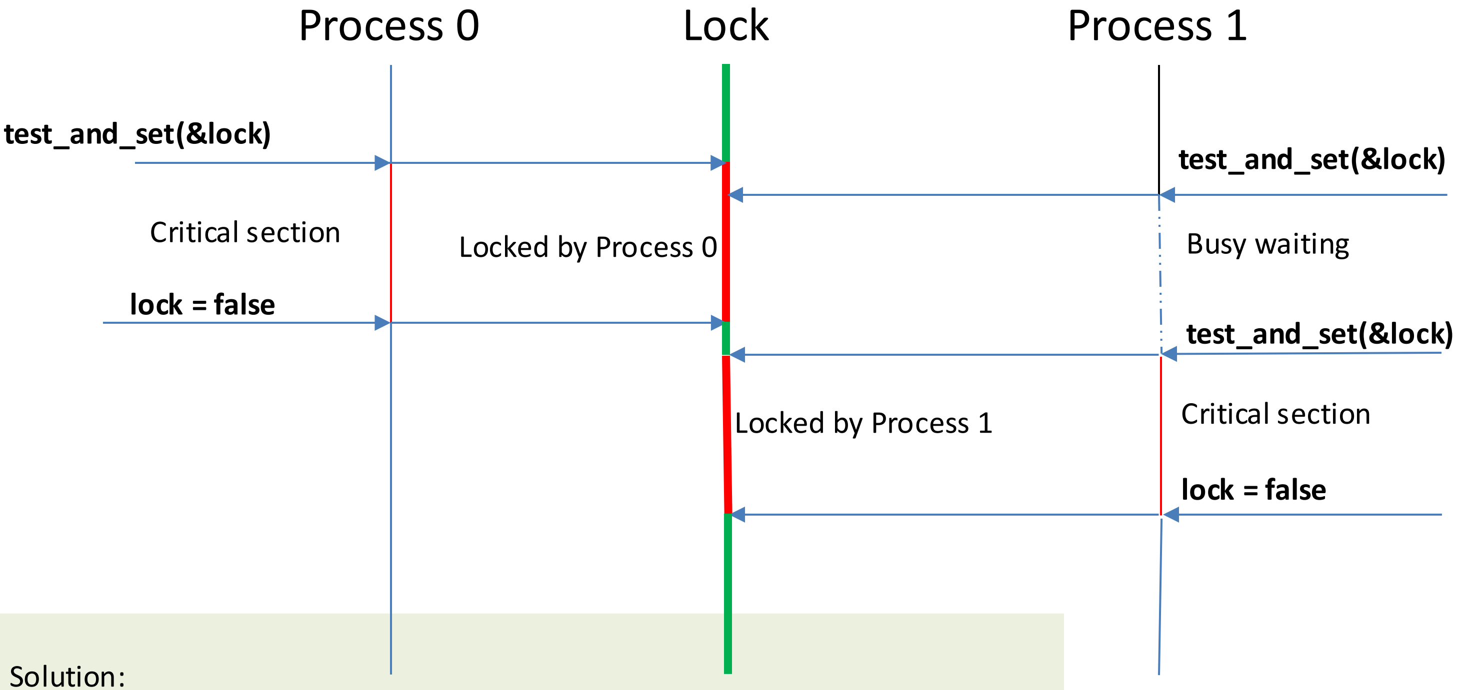
Being nice!

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

- 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 variable lock is initially FALSE



- Solution:

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

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;
    }
```

Semaphore

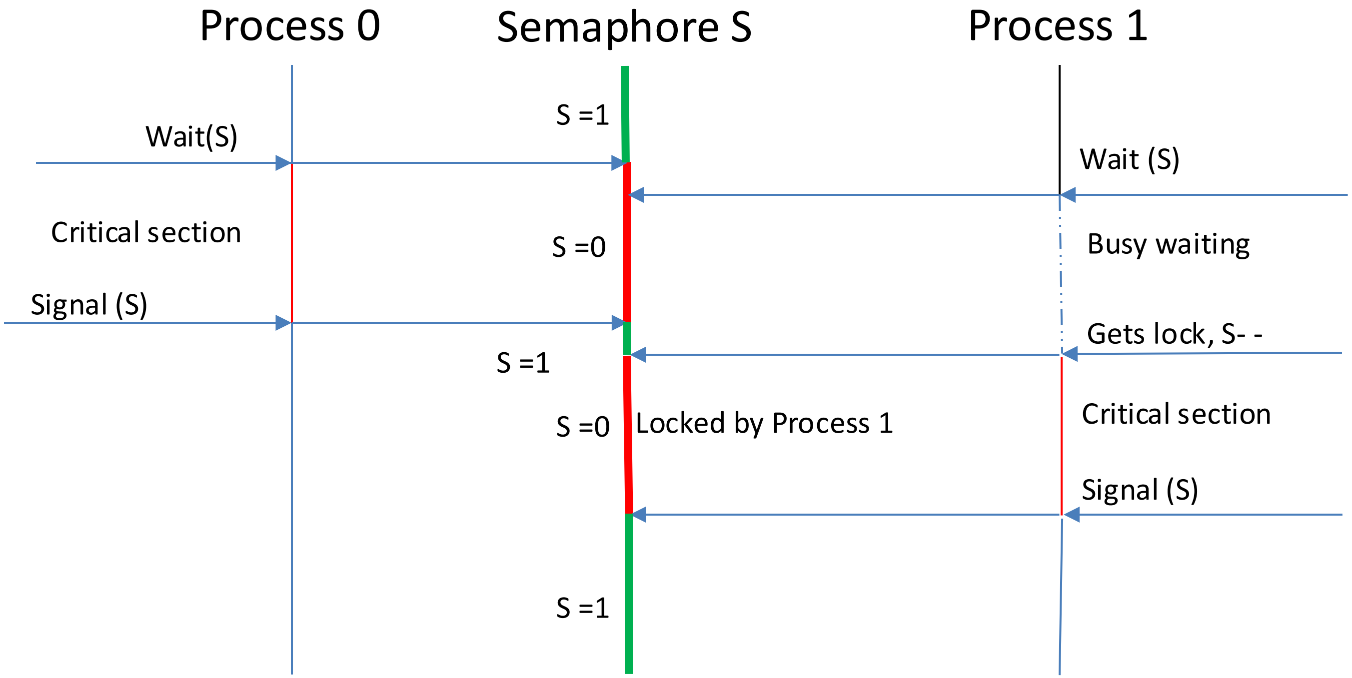
- Synchronization tool that provides more sophisticated ways (than Mutex locks) for process to synchronize their activities.
- Semaphore ***S*** – integer variable
- Can only be accessed via two indivisible (atomic) operations
  - `wait()` and `signal()`
    - Originally called `P()` and `V()`
- Definition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



Process 0

Semaphore S

Process 1

S =1

Wait(S)

Wait (S)

Critical section

S =0

Busy waiting

Signal (S)

Gets lock, S- -

S =1

Critical section

S =0

Locked by Process 1

Signal (S)

S =1

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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

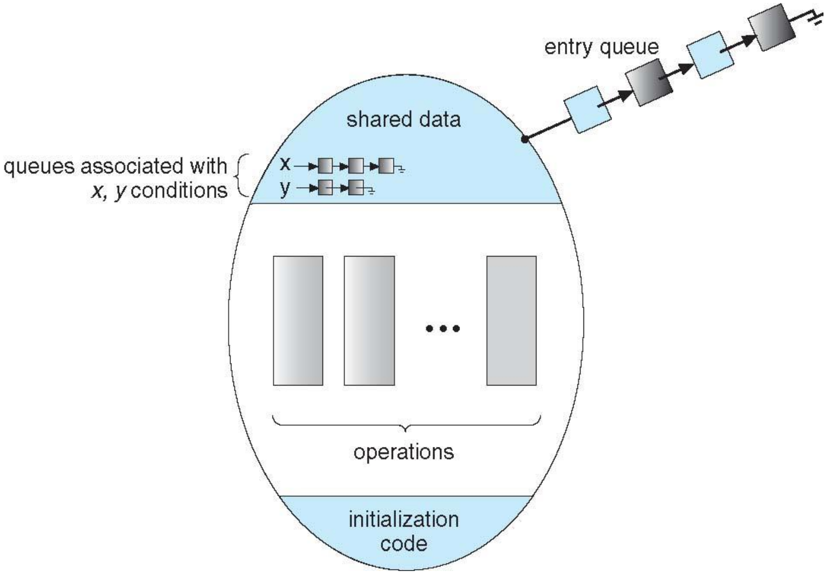
When:
writer in critical section
and if n readers waiting
1 is queued on rw_mutex
(n-1) queued on mutex

The structure of a writer process

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

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.*

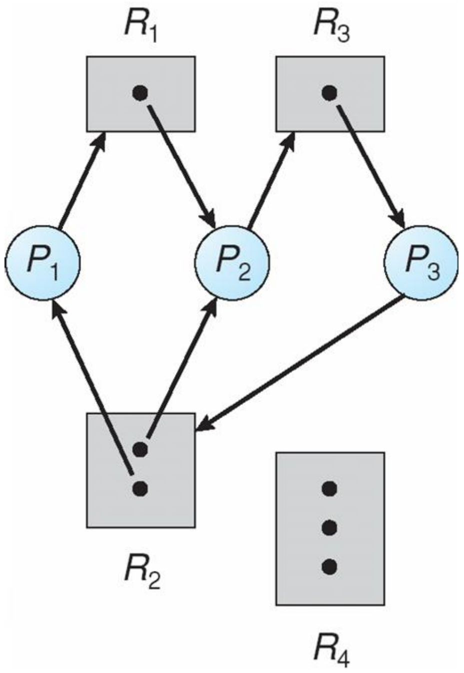
The pickup() and putdown() operations

```
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

Midterm Rules

- You need to bring a laptop with Respondus Lockdown Browser *installed and tested*.
- You *may not* sit in your usual place , or next to the usual neighbors or team members/friends. Spread evenly in the room.
- Your cell phone and smart watch should be inside your bag.
- One sheet of paper will be provided for scratch work. You need to write your name and student-id on it and *hand in at the end* to the TAs/instructor.
- The TAs are *not permitted* to define terms, explain concepts, provide hints, or help in any way that will benefit a specific student. Questions on typos and language can be asked but none during the first 15 minutes.
- You *cannot leave* the room without permission.

That’s it for today.