Chapter 1 Introduction

- System view
    - Resource allocator
    - Control program
- Dual-Mode Operation
    - User mode
    - Kernel mode
        - privileged instruction
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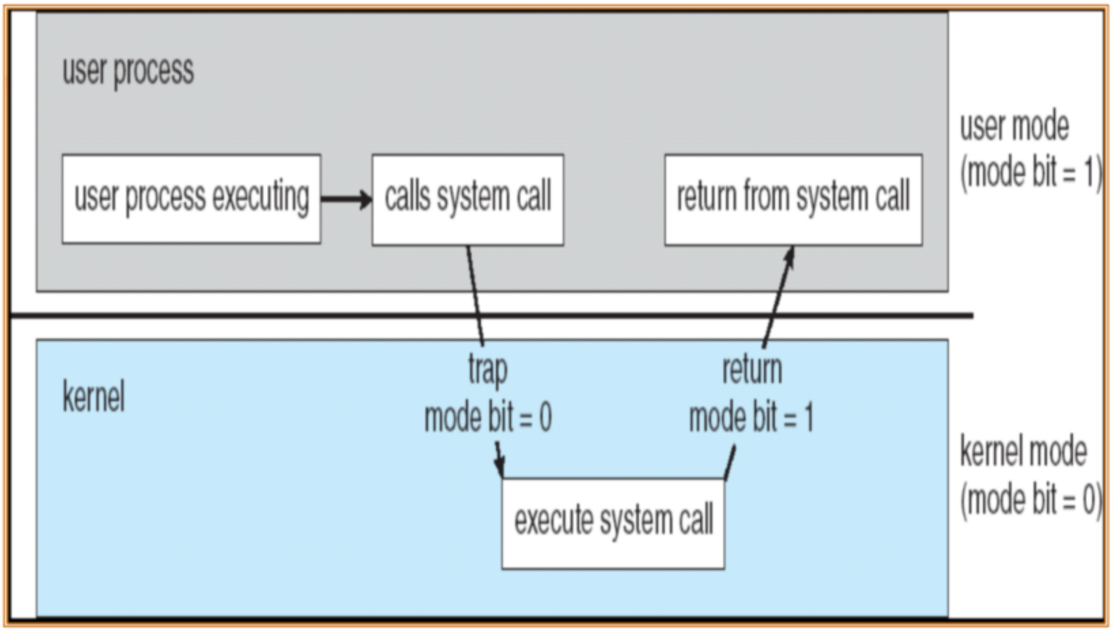
        - 

    - Hardware
    - **CPU protection**
        - **timer**
            - **time sharing**
    - **memory protection**
        - **Base register**
        - **Limit register**
    - **I/O protection**

        - **all I/O instruction are privilege instructions**
- Development of OS
    - mainframe systems
        - NO OS
        - **batch systems**
        - **multiprogramming systems**
        - **time sharing systems**
    - desktop systems
    - multiprocessor systems
    - distributed systems
    - clustered systems
    - real-time systems
    - handheld systems
    - 现代操作系统的特征
        - **并发性Concurrence**
        - **共享性Sharing**
        - **虚拟性Virtual**
        - **异步性Asynchronism**
        - 提高CPU利用率，充分发挥并发性：**程序之间、设备之间、设备与CPU之间**均**并发**
    - Pr：

      批处理系统、多道程序系统和分时系统的技术特性

Chapter 2 Operating-System Structures

- 功能和服务的差别：
    - 对内：自行实现
    - 对外：可以调用其他功能代为实现
- common function of OS
    - process management
        - process synchronization
        - process communication
        - deadlock handling
        - (分布式)
    - main memory management
    - secondary-storage management
    - file management
    - I/O system management
- Operating System Services(Services for **helping users**)
    - Program execution
    - I/O operations
    - File-system manipulation
    - Communications

- Error detection
- Resource allocation
- Accounting(审计)
- Protection

- Operating System Interface
  - Interface to programs
    - **System calls**
      - System-call interface(SCI)
      - Application Programming Interface(API)
        - managed by runtime support library
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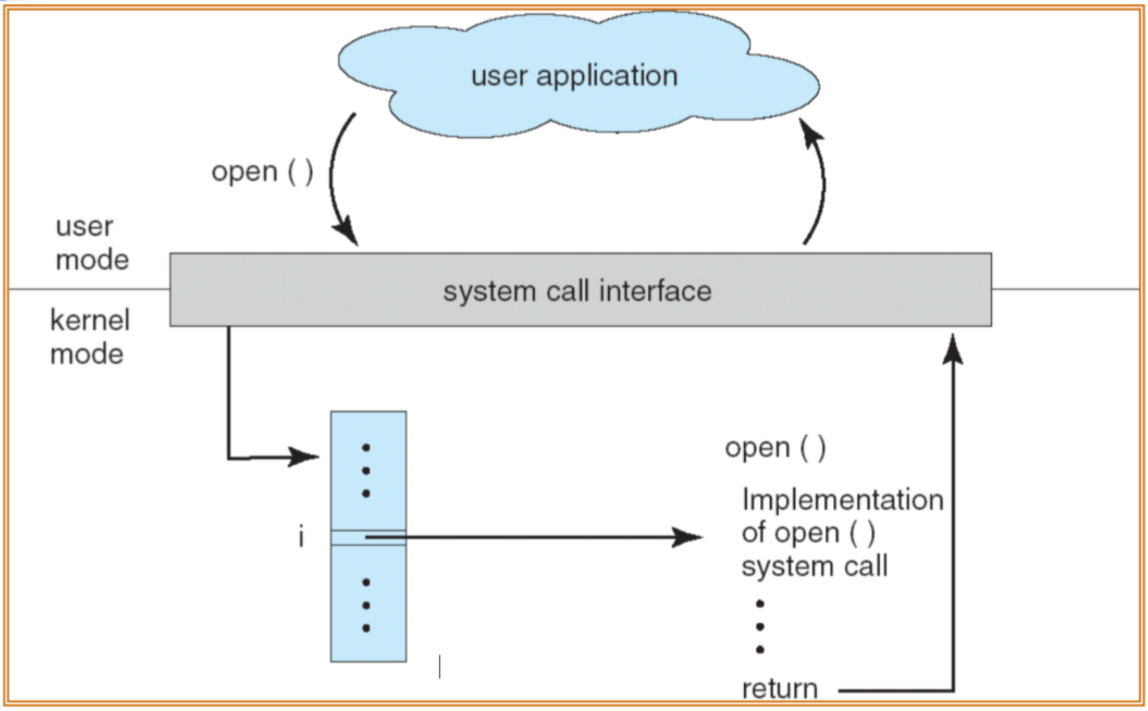
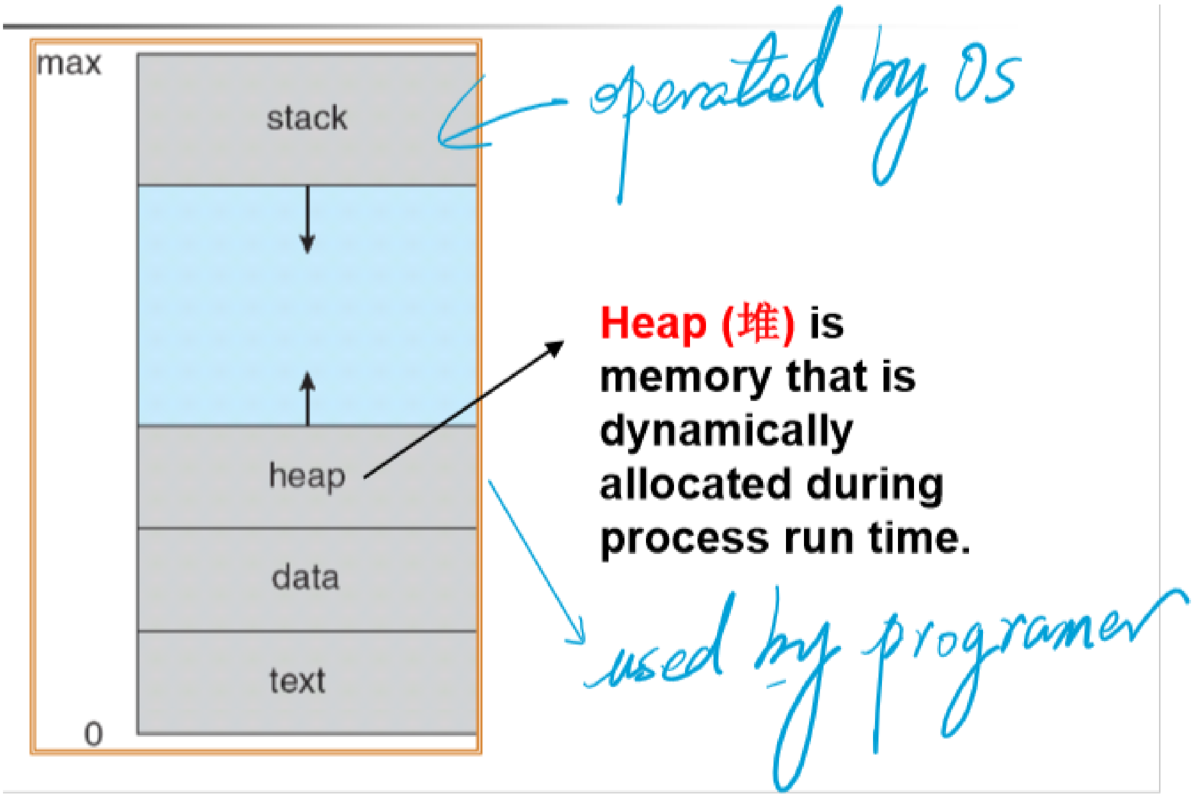
    - 

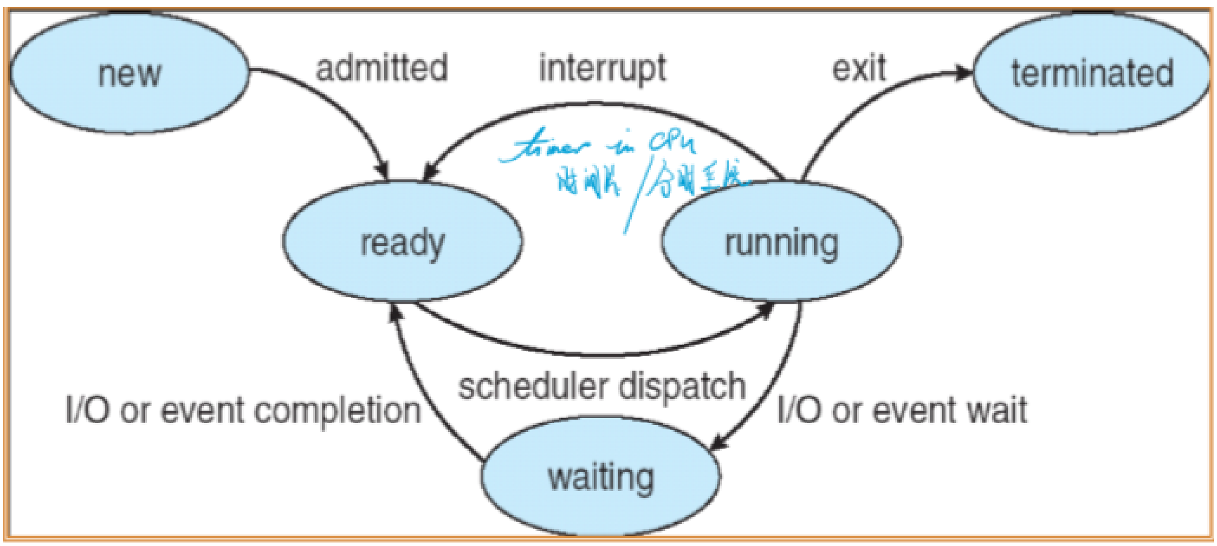
      - Types of System calls
        - Process control
        - File management
        - Device management
        - Information maintenance
        - Communications
  - **PR. Why do user use APIs rather than system calls directory?**
  - **ANS.**
    1. 跨平台能力（提供相同的API封装）移植性好
    2. 模块化封装，可维护性好
    3. 简化了程序编写
    4. 提高了执行效率
- Operating System Structure
  - Simple structure
  - Layered structure

        - virtual machines
    - Microkernel structure
        - Benefis
            - easier to extend
            - easier to port
            - more reliable
            - more secure
    - Modules
    - PR:设计操作系统时采用的模块化内核方法和分层方法在那些方面类似？那些方面不同？
- Operating system design and implementation
- 小结
    - 操作系统概念（管理资源、支持程序运行、方便用户使用的**程序集**）
    - 操作系统的基本目标：**方便性和高效性**
    - 引导程序：**中断、中断处理程序、中断向量**
    - 储存结构：内存（**小、易失**）二级储存（**大、非易失**）、分层结构
    - I/O结构：设备控制器（本地缓冲）、DMA
    - 硬件保护：**双重模式操作、特权指令、I/O保护、内存保护、CPU保护**
    - 操作系统的发展：e.g: 多道程序设计
    - 操作系统的功能：进程（CPU）管理、内存管理、磁盘管理、文件管理、I/O管理、**用户接口**
    - 操作系统服务：**程序执行、I/O操作、文件系统操作、通信、错误检测与处理**、资源分配、统计、保护
    - 操作系统接口：用户接口（CLI、GUI）、程序接口（**系统调用（参数传递、类型）**）、SCI、API
    - 操作系统结构

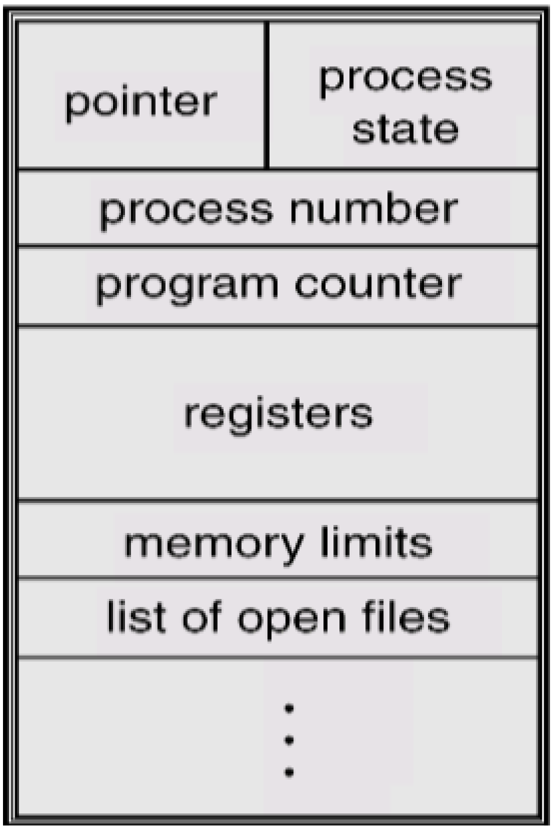
Chapter 3 Process

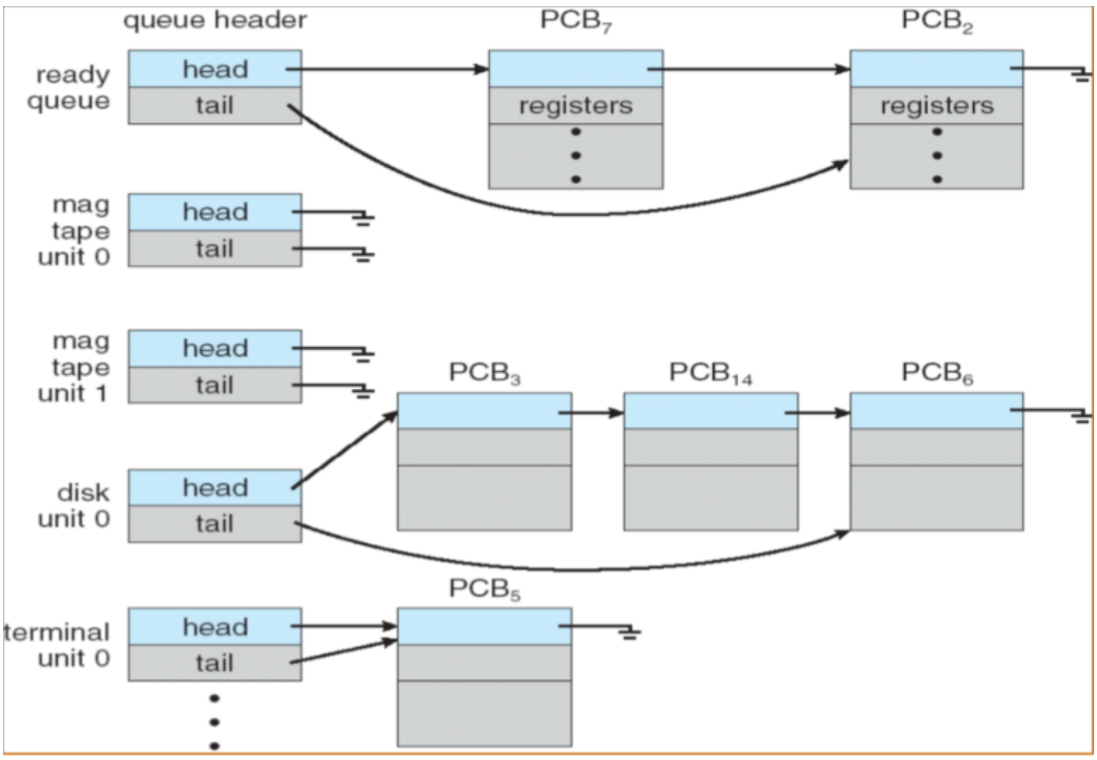
- Process
    - test section(program code)
    - **program counter**
    - **contents of the processer's registers**
    - Heap-stack
    - data section
    -
    -



- **Characteristic of process**
  - **Dynamic动态性**
  - **Independency独立性**
  - **Concurrence并发性**
  - **Structure结构化**
- PR.进程和程序是两个密切相关的概念，请阐述他们之间的区别和联系
- Process state
-
- 

- Process control block(PCB)
-
-



- Process scheduling queues
  - Job queue (in main memory)
    - Ready queue
    - device queues
      - process migration between the various queues
      -
      - 

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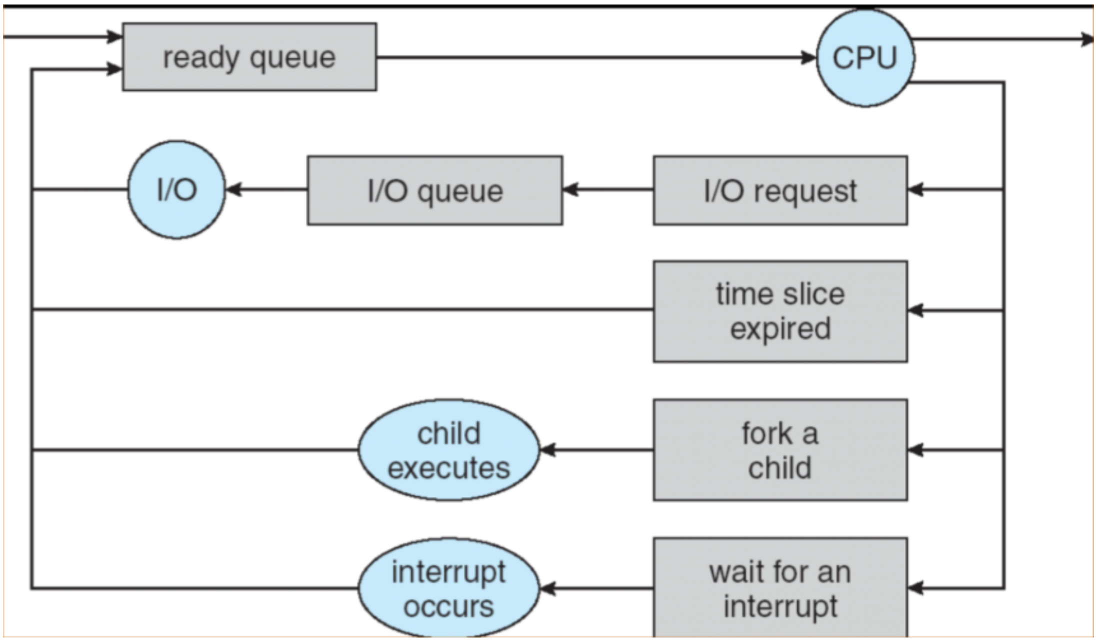
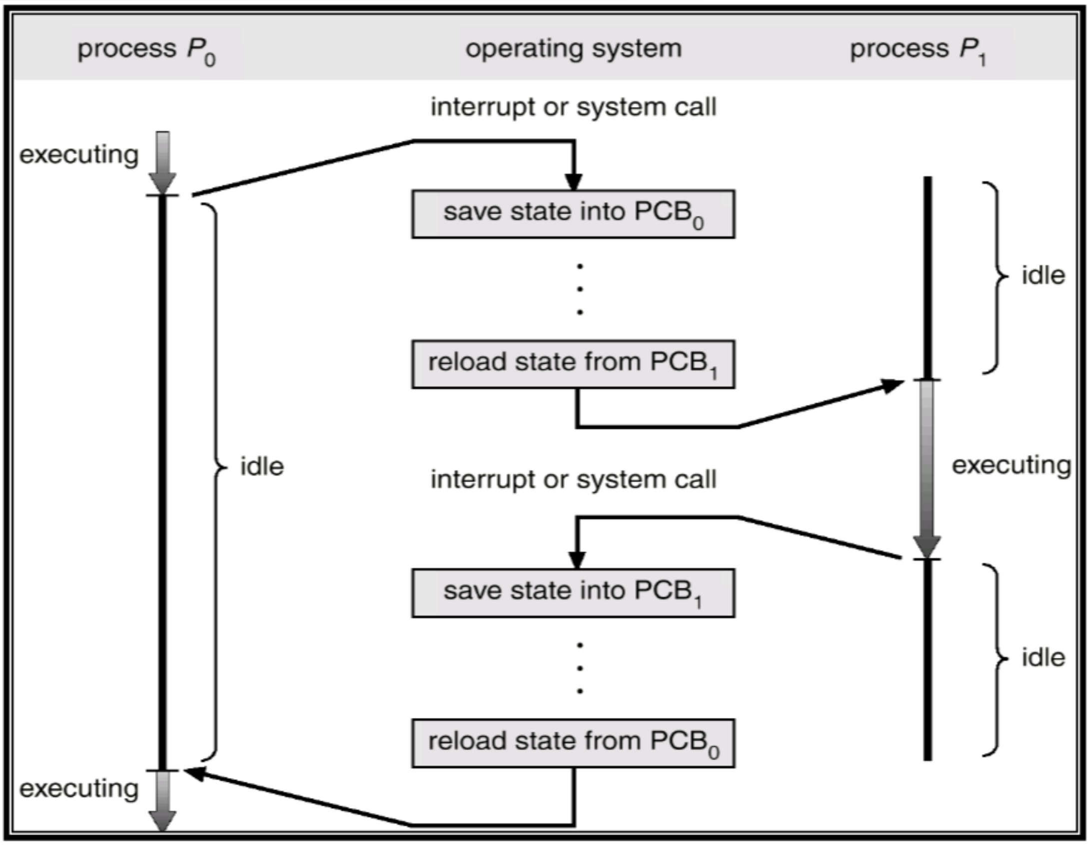
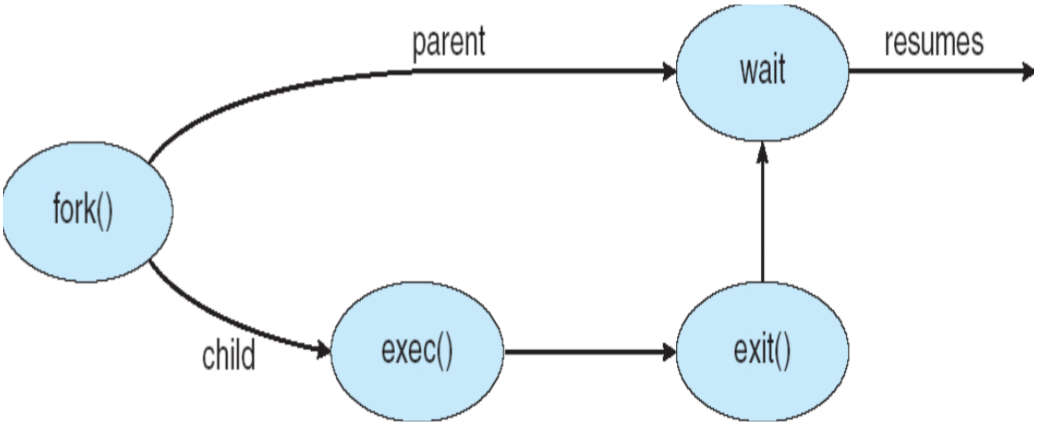
- 

- Schedulers
  - Long-term scheduler(秒级、分钟级，作业调度)
  - Short-term scheduler(毫秒级，CPU调度)
  - Medium-term scheduler(swapping)
- I/O bound process
- CPU bound process
- Context switch
  - The **context** of a process is represented in **PCB** of the process and includes the values of CPU registers.
  - 保存执行后的上下文信息
  - 上下文切换会带来开销
  - 尽量减少上下文切换以减少开销
  -

- 

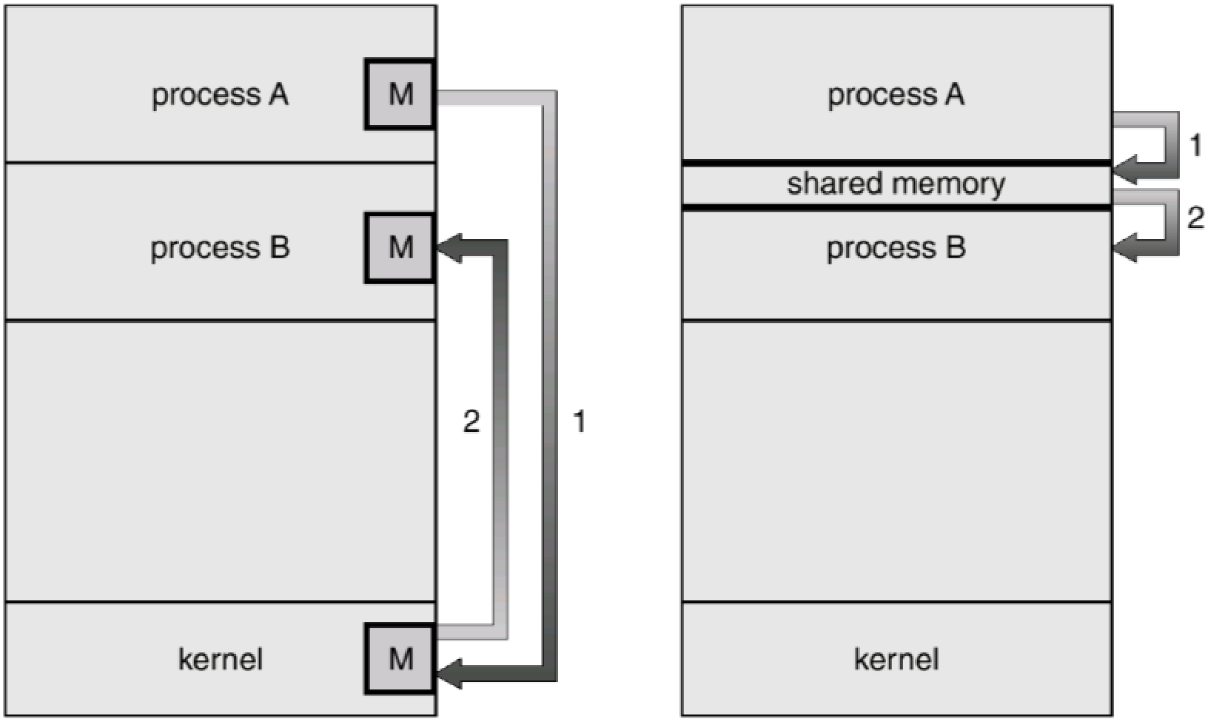
- Operation on Process
    - Process creation
        - child process(unique process identifier(int)), tree of process
        - resource sharing
            - parent and children shall all resources
            - children share subset of parent's resources
            - parent and child share no resources
        - Execution
            - Parent and children execute concurrently
            - Parent waits until children terminate
        - Address space
            - child duplicate of parent
            - child has a program loaded into it (new text section)
            - UNIX examples
                - fork() :create new process
                - exec() :used after a fork to replace the process's memory space with a new program
                -




- ```c
  pid = fork();
  if(pid<0)   /* error occured */
  {
      printf(stderr,"Fork failed");
      exit(-1);
  }
  else if(pid==0) /* child process */
  {
      execlp("/bin/ls","ls",NULL);
  }
  else    /* parent process */
  {
      wait(NULL); /* wait for child process to finish */
      printf("Child complete");
      exit(0);
  }
  ```

- Process Termination
  - exit() process executes last statement and asks the operating system to delete it
    - output data from child to parent (via wait)
    - Process's resources are deallocated by OS
  - abort() parent may terminate execution of children process
    - child has exceeded allocated resources
    - task assigned to child is no longer required
    - parent is exiting *not all of the operation system supports **Cascading termination(级联终止)**

- InterProcess Communication(**IPC**)
  - **Independent** process cannot affect or be effected by the execution of another process
  - **Cooperating** process can affect or be effected by the execution of another process
    - Advantages
      1. Information sharing
      2. Computation speed-up
      3. Modularity
      4. Convenience
  - **Shared memory** & **Message passing**
  ```



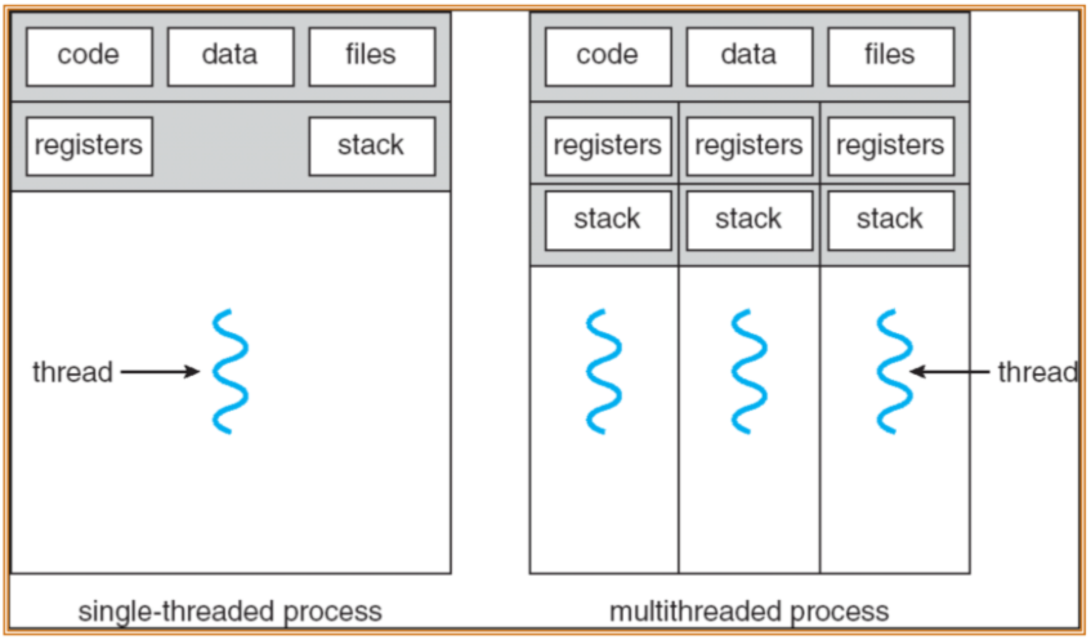
- Shared-memory Systems
  - requiring communication process to establish a region of shared memory
  - a shared memory region resides in the address space of the process creating the shared memory segment
  - the processes are responsible for ensuring that they are not writing to the **same location simultaneously**
    - Producer-Consumer Problem
- Message-passing Systems
  - MPS has two operations
    - send()
    - receive()
  - communication link
    1. link may be unidirectional or bidirectional
    2. a link may be associated with many processes
    - direct communication
      - send(P,message) send a message to process P
      - receive(Q,message) receive a message from process Q
    - indirect communiction
      - mailboxes
        - each mailbox has a unique id
        - two processes can communicate only if the share a mailbox
        - Operations

          > 1. create a new mailbox
          > 2. send and receive messages through mailbox
          > 3. destroy a mail box

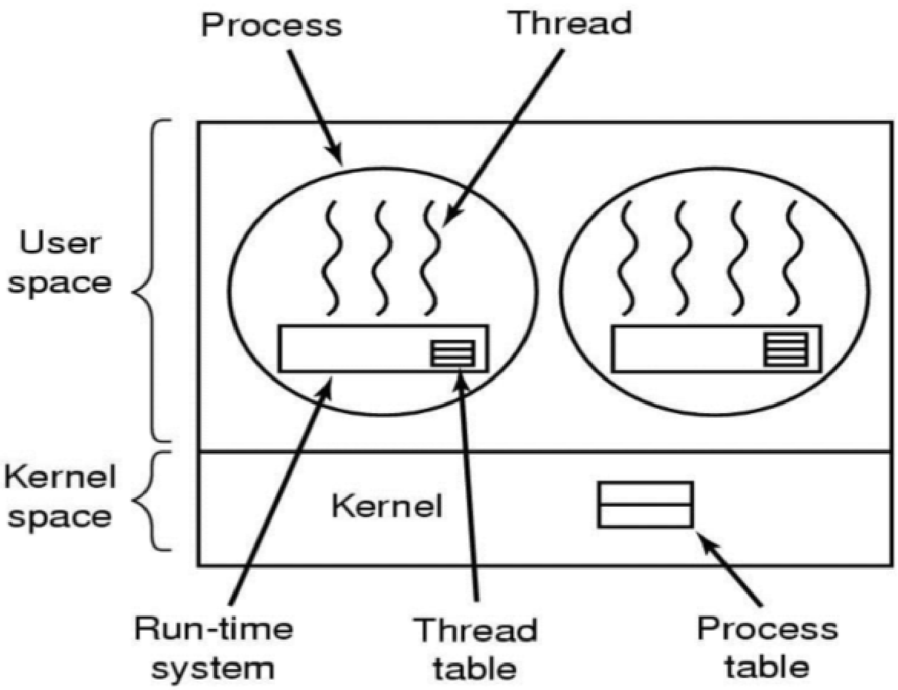
        - Synchronization
            - Blocking: synchronous
            - Non-blocking: asynchronous
        - Buffering
            - **Zero capacity** sender must wait for receiver
            - **Bounded capacity** finite length of n messages, sender must wait if link full
            - **Unbounded capacity** infinite length, sender never blocks
- Communication in Client-Server System
    - **Sockets**
    - **Remote Procedure Calls**
    - **Remote Method Invocation (Java)**

Chapter 4 Threads

- Multithreading Models
    - A thread is a flow of control within a process
    - thread is a **basic** unit of CPU execution (known as LightWeight Process(LWP))
    - process (HeavyWeight process(HWP)) has a **single** thread of control
    - multithreaded process contains several **different** flows of control within the **same** address space
    - Thread
        - has
            - thread ID
            - program counter
            - register set
            - stack
        - share
            - code section
            - data section
            - other OS resources(file and signals)

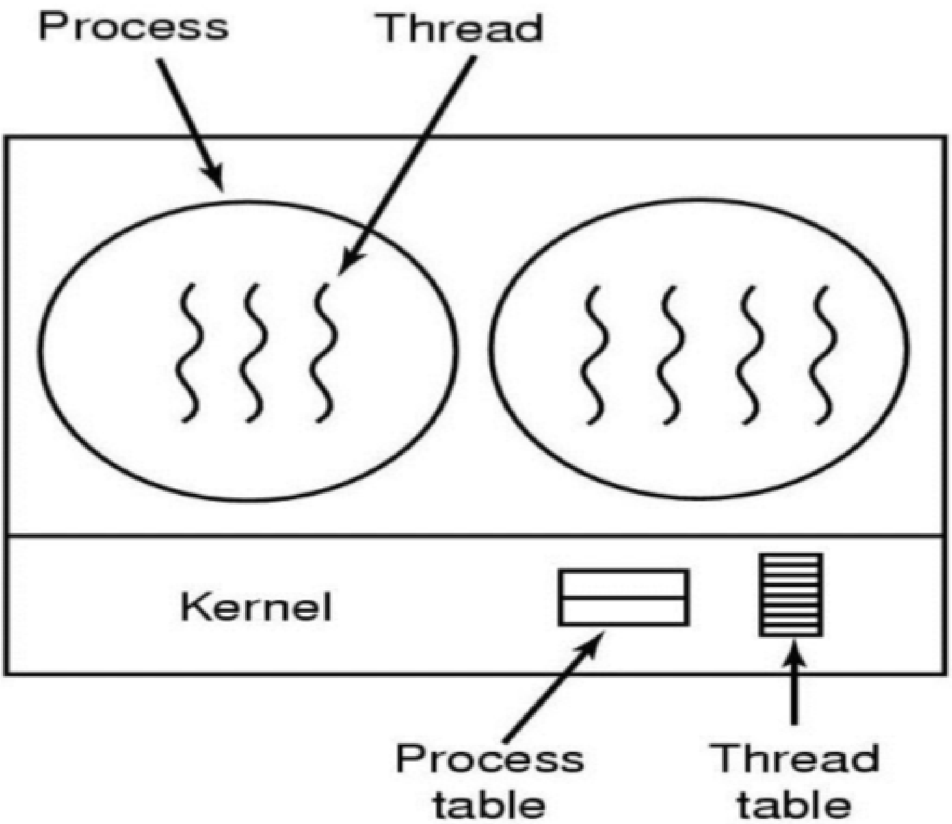


- Benefits
  - responsiveness
  - resource sharing
  - economy(low cost in overhead of creating and context-switch)
  - Utilization of multiprocessor architectures
- User Threads
  - user threads are supported above the kernel. The kernel is **not** aware of user threads
  - Library provides all support for thread creation, termination, joining and scheduling
  - more efficient(no kernel intervention)
  - if one thread is blocked, every other threads of the same process are also blocked(containing process is blocked)



- Kernel Threads

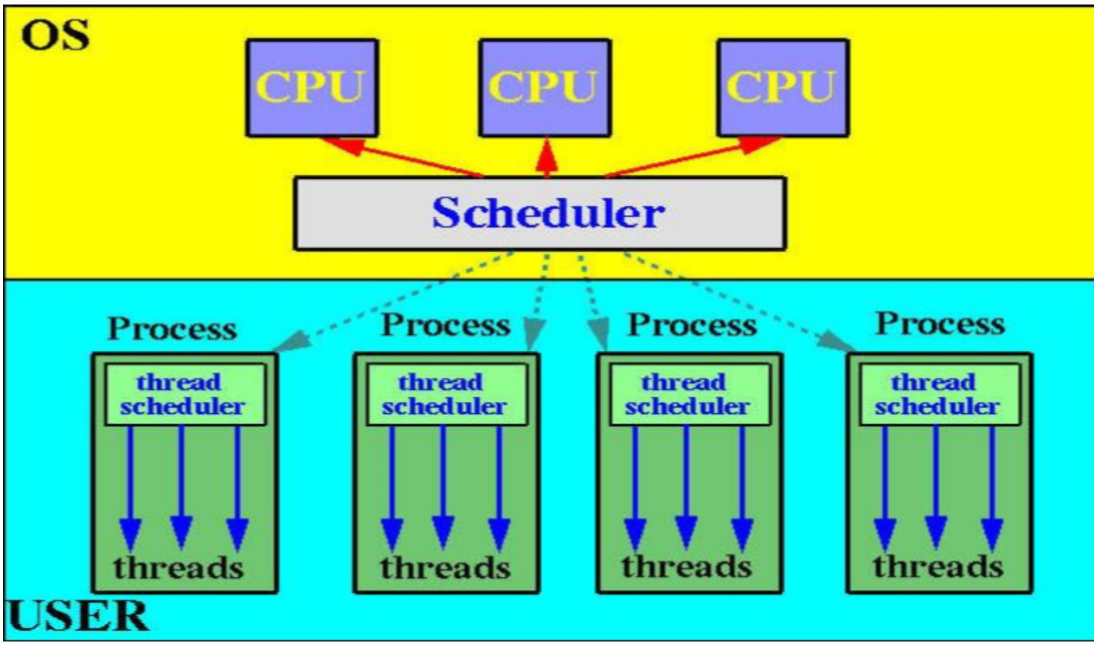
- kernel threads are usually **slower** than the user threads
- blocking one thread will **not** cause other threads of the same process to block
- the kernel can schedule threads on different processors(in a multiprocessor environment)



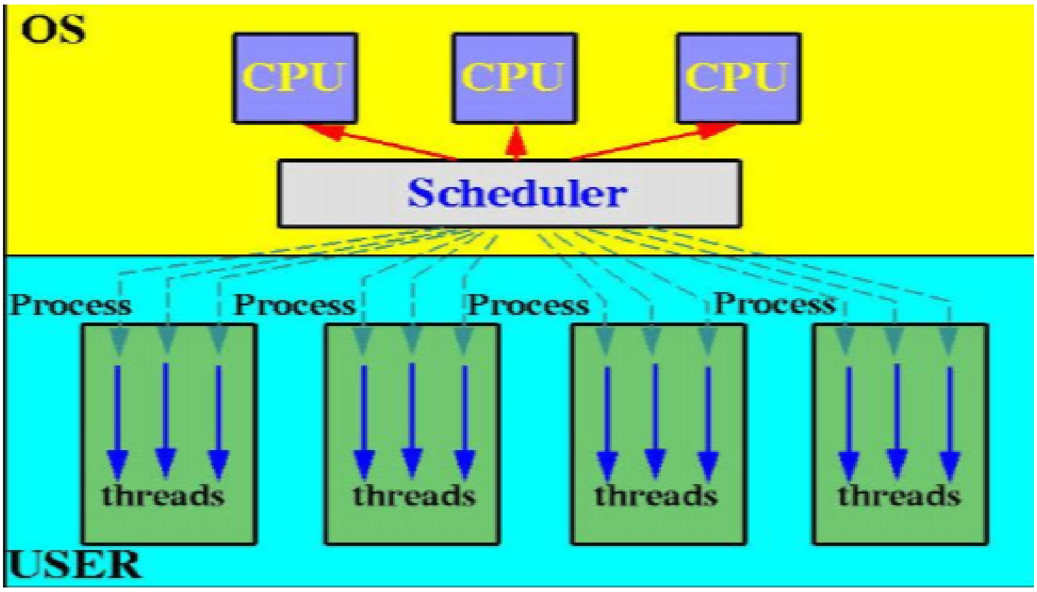
Pr.

1. 进程和线程之间的区别和联系
2. 用户级线程和内核级线程的区别

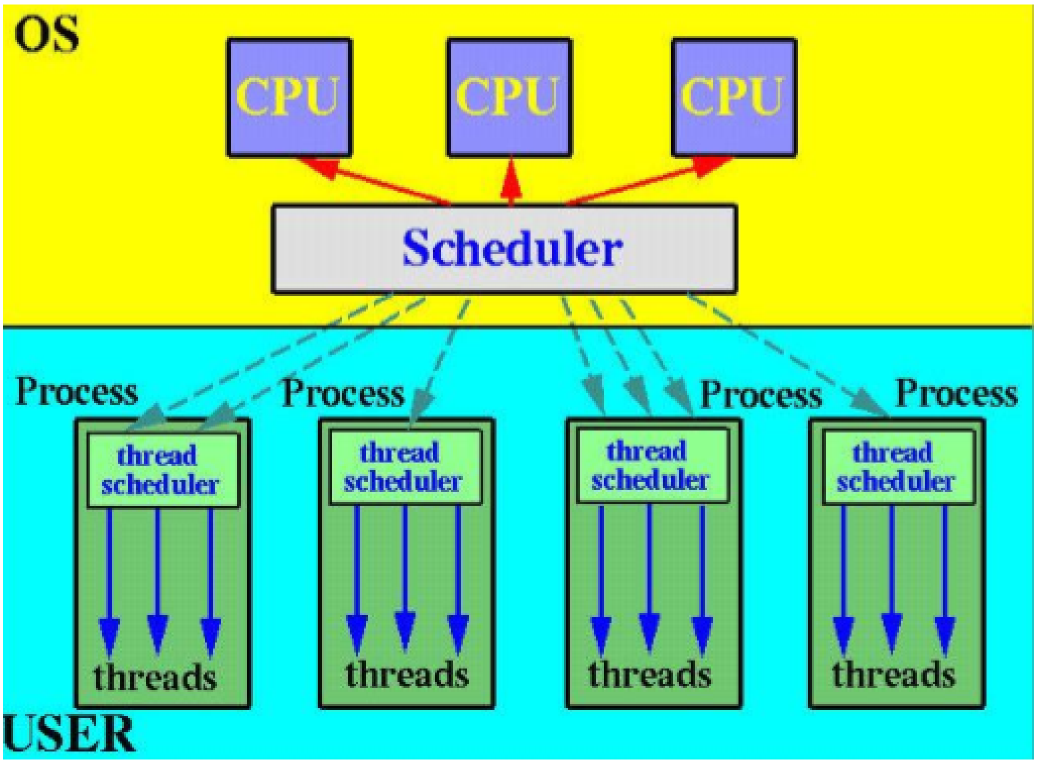
- Multithreading models
  - many to one
    - only one thread in the one process can access the kernel at a time
    - true concurrency is not gained



- one to one
  - each user-level thread maps to kernel thread
  - providing more concurrency
  - restricting the number of threads supported by the system



- many to many
  - allow many user level threads to be mapped to many kernel threads



- Thread Libraries
  - status
  -

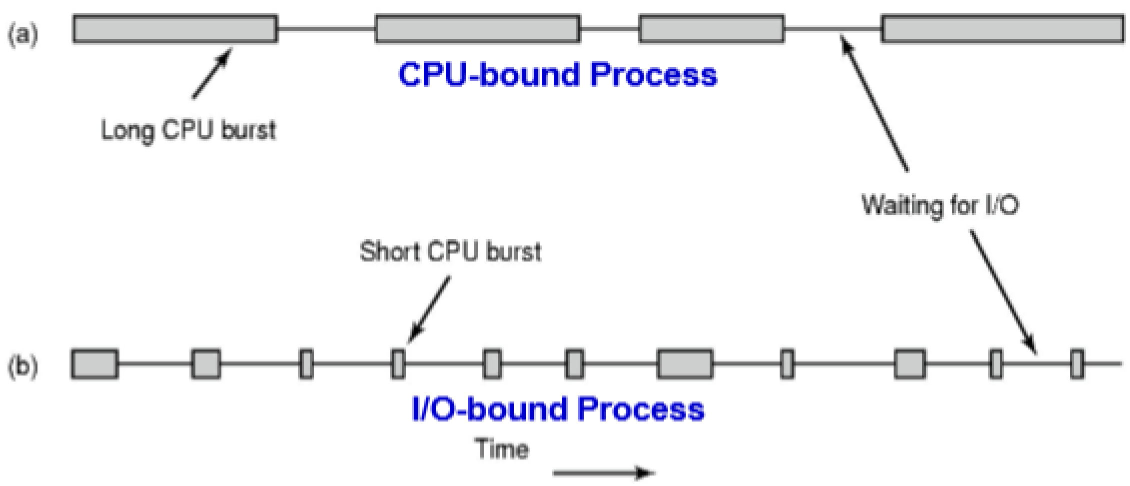
```
int pthread_create(tid,attr,function,arg);
/*
 * pthread_t *tid
     handle of created thread
 * const pthread_attr_t *attr
     attribes of thread to be created
 * void *(*function)(void)
     function to be mapped to thread
 * void * arg
     single argument to function
 */
int pthread_join(tid,val_ptr);
/*
 * pthread_t *tid
     handle of joinable thread
 * void ** var_ptr
     exit value rturn by joined thread
 */
void pthread_exit(void *status);
int pthread_cancel(pthread_t thread);   //terminated immediately
int pthread_kill(pthread_t thread,int sig);
```

  - CreateThread
  - GetCurrentThreadId
  - GetCurrentThread
  - SuspendThread/ResumeTread

    - ExitThread
    - TerminateThread
    - GetExitCodeThread
    - GetThreadTimes
- Threading Issues
- Operating System Examples
- //TODO 关于线程的实现
- **Pr.**
    - 信号机制和中断机制的异同
- Thread Pools
    - advantages
        - faster to service a request(save the time to create new thread)
        - allow the number of threads in the application to be bound to the size of the pool
- Thread specific data
    - threads belonging to a process share the data of the process
    - allows each thread to have its own copy of data
    - when using a thread pool, each thread may be assigned a unique identifier
- Scheduler activations
- **upcalls**

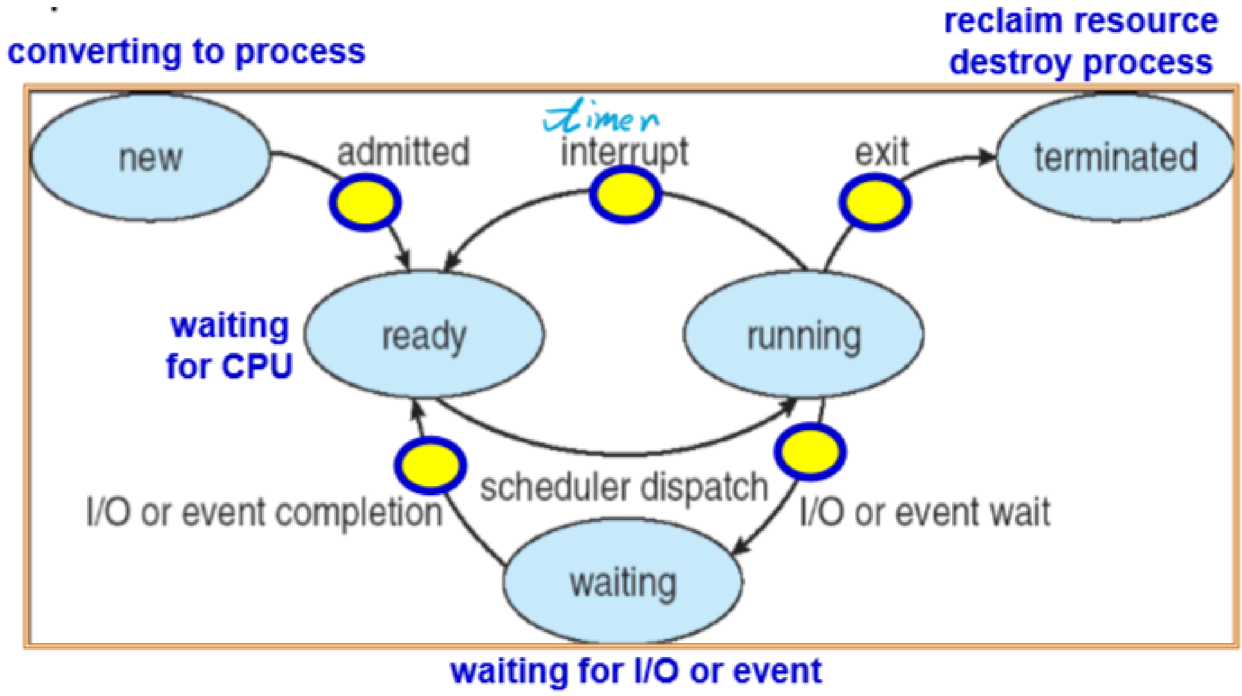
Chapter 5 CPU Scheduling

- Maximum CPU utilization obtained with multiprogramming
- The success of CPU scheduling depends on an property of processes:**CPU-I/O Burst Cycle**
    - process execution consists of a **cycle** of CPU execution and I/O wait.
- CPU-bound
    - a few very long CPU bursts
- I/O-bound
    - many short CPU bursts



- When the CPU is idle, the OS must select another ready process to run

- This selection process is carried out by the **short-term scheduler**
- The CPU scheduler selects a process from **the ready queue** and allocates the CPU to it
- There are many ways to organize the ready queue(e.g. FIFO)



- Circumstances that scheduling may take place
  - A process switches from the running state to the terminated state(finished)
  - A process switches from the running state to the wait state(e.g. IO operation)

    ↑主动操作↑ 非抢占式调度

    ↓被动中止↓ 抢占式调度 → 同步机制
  - A process switched from the running state to the ready state(e.g. a interrupt occurs)
  - A process switches from the wait state to the ready state(e.g. I/O completion)
  - A process switches from the new state to ready state(e.g. a higher priority process ready)
  - Preemptive(抢占式)
    - cost associated with access to **shared data**
    - When the kernel is in its **critical** section modifying some important data .
    - special attention to situation
  - Non-preemptive
    - scheduling occurs when a process **voluntarily terminates**(主动结束) (case1)or enters the wait state(case2)
    - simple but very inefficient

  Pr.

  对于计算中心，抢占式调度和非抢占式调度哪一种比较适合
  - Dispatcher(调度) module
    - switching context

        - switching to user mode
        - jumping to the proper location in the user program to restart that program
    - Dispatch latency
        - the dispatcher should be as fast as possible
- Scheduling criteria
    - CPU utilization
        - keep the CPU as busy as possible
        - lightly|40%|-|90%|heavily
    - Throughput(吞吐)
        - higher throughput means more jobs get done

    吞吐量和CPU利用率有相关性但并没有直接关系

    - Turnaround time
        - The time period from job submission to completion is the turnaround time

    $t_{turnaround} = t_{waitingTimeBeforeEnteringTheSystem} + t_{waitingTImeInTheReadyQueue} + t_{waitingTImeInAllOtherEvents} + t_{timeTheProcessActuallyRunningOnTheCPU}$

- Waiting time
    - time in ready queue
- Response time
    - the time form the submission of a request
- Optimization Criteria
    - MAX CPU utilization
    - MAX throughtput
    - MIN turnaround time(average)
    - MIN waiting time
    - MIN response time
- 为什么需要CPU调度

    大多数任务是CPU和I/O交替使用，

    导致CPU和I/O至少有一个空闲，

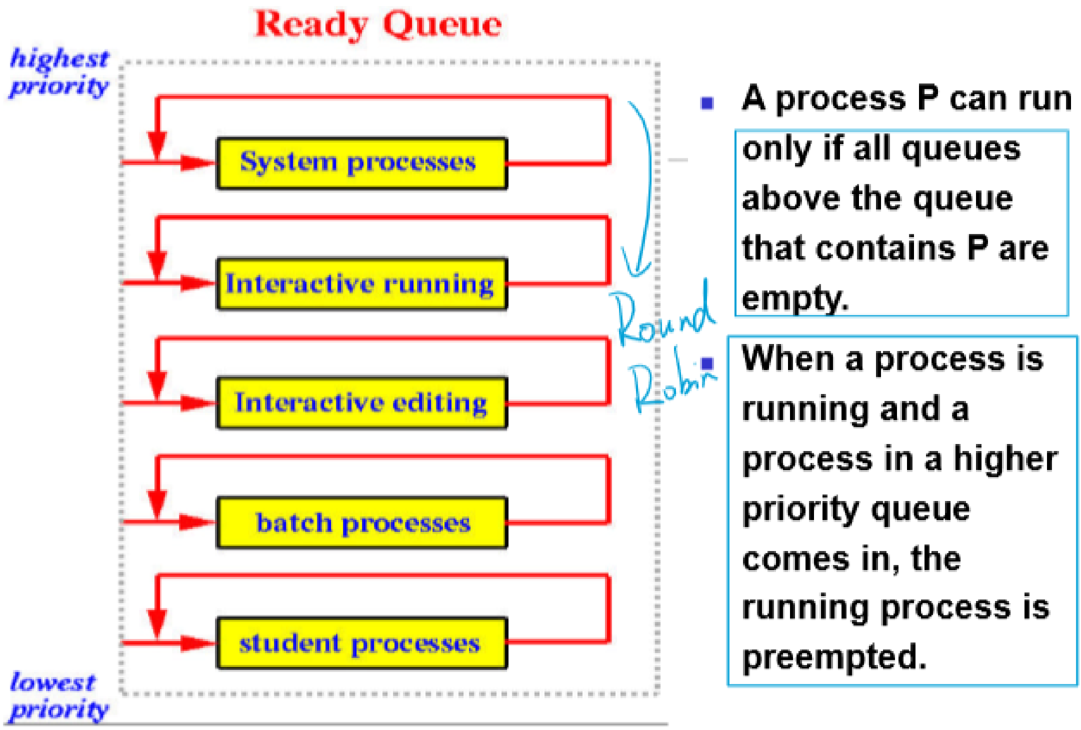
    通过调度让需要执行I/O的任务去执行I/O。

    把CPU给需要CPU的任务运行。

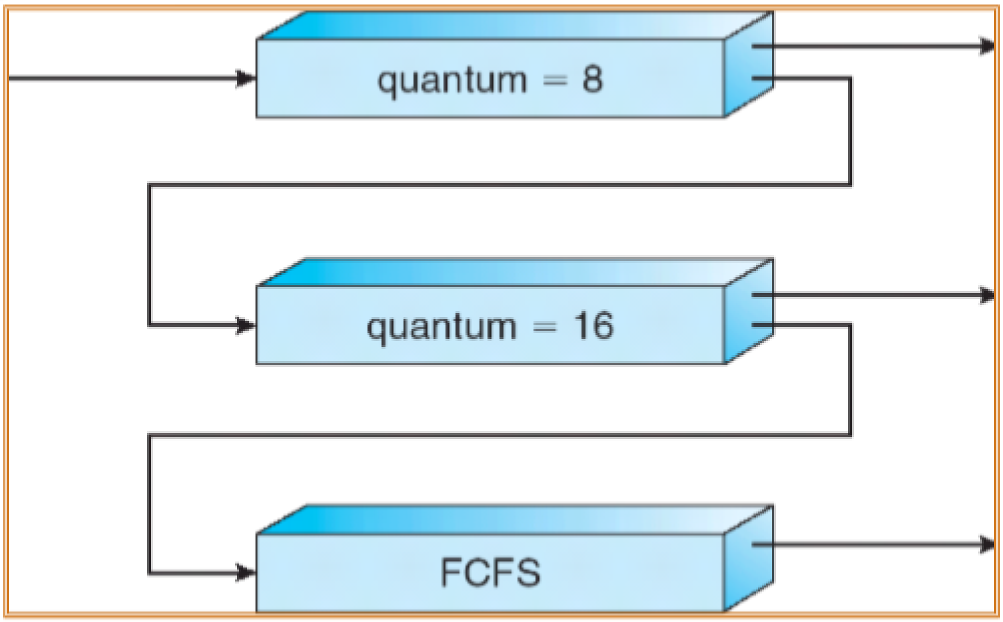
- **Scheduling Algorithms**
    - First-Come-First-Served Scheduling (FCFS)
        - can easily implemented using a queue
        - not preemptive
        - convoy effect (护航效应)
        - troublesome for time-sharing systems
    - Short-Job-First Scheduling (SJF)
        - sorted in next CPU burst length
        - can be nonpreemptive and preemptive

        - **minimum average waiting time for a given set of process**
        - predict CPU burst: exponential averaging
        - long jobs may meet **starvation**!!!
    - Priority Scheduling
        - each process has a **priority**
        - priority may be determined internally or externally
            - internal priority
                - time limits
                - memory requirement
                - number of files
                - etc.
            - external priority
                - importance of the process (not controlled by the OS)
        - starvation/Indefinite block

          a lower priority may never have a chance to run
            - Aging
                - gradually increase the priority of process what wait in the system for a long time
    - Round_Robin Scheduling (RR)(轮询)
        - designed for time-sharing systems
        - each process is assigned a time quantum/slice
        - If the process uses CPU for less than one time quantum, it will release the CPU voluntarily (主动退出)
        - when one time quantum is up , that process is preempted by the scheduler and moved to the tail of the list
        - Typically, higher average time than SJF, better response time
        - time quantum is too large → FCFS
        - time quantum is to small → processor sharing (并发)
            - *shorter time quantum means more context switches*
        - in general, 80% of the CPU bursts should be shorter than the time quantum
        -
    - Multilevel Queue Scheduling (多级队列)
        - partitioned into separate queues
            - foreground (interactive)
            - background (batch)
        - Each process is assigned permanently to one queue based on some properties of the process
        - Each queue has its own scheduling algorithm
            - foreground - RR
            - background -FCFS



        - Scheduling must be done between the queues
            - Fixed priority scheduling (possibility of starvation)
            - Time slice
                - each queue gets a certain amount of CPU time which it can schedule amongst its processes
    - Multilevel Feedback Queue Scheduling
        - allows process to move between queues
        - aging can be implemented this way
        - If a process use more/less CPU time, it is moved to a queue of lower/higher priority → I/O/CPU-bound process will be in higher/lower priority queues
        - exp



- number of queues
- scheduling algorithms for each queue
- method used to determine when to upgrade a process
- method used to determine when to demote a process
- method used to determine which queue a process will enter when that process needs service

- Multiple-Processor Scheduling
  - Homogeneous(同构) processors
  - Load balancing
    - push migration
    - pull migration
  - Asymmetric multiprocessing (非平衡处理)
    - only on processor accesses the system data
      - alleviating(降低) the need for data shring
  - Symmetric multiprocessing (SMP)
    - two processors do **not** choose the same process
  - Processor Affinity (侵核)
    - most SMP systems **try** to avoid migration of processes from one processor to another
      - Soft/Hard Affinity (执行过程中可以/不可以侵核)
- Real-Time Scheduling
  - Hard real-time systems
  - the scheduler either **admits** a process and guarantees that the process will complete on-time, or **reject** the request (resource reservation)
  - secondary storage and virtual memory will cause unavoidable delay
  - Hard real-time systems usually have special software on special hardware
- Soft real-time systems
  - easily doable(可行) within a general system
  - may cause unfair resource allocation and longer delay(starvation) for noncritical tasks.
  - the CPU scheduler must **prevent aging** to occur(critical tasks may have lower priority)

    - **The dispatch latency must be small**
- Priority Inversion
    - a high-priority process needs to access the data that is currently being accessed by a low-priority process → The high-priority process is blocked by the low-priority process
    - priority-inheritance protocol
- Thread Scheduling
    - User-level threads
        - thread library
    - Kernel-level threads
        - scheduled by OS
    - user-level threads must ultimately be mapped to an associated kernel-level thread
    - Local scheduling → User-level Thread
        - Process-contention Scope (PCS)
    - Global Scheduling → Kernel-level Thread
        - System-contention Scope (SCS)
- Algorithm Evaluation
    - Deterministic modeling (Analytic evaluation) 确定情况下 的情形证明
    - Queueing models 队列模型
    - Simulations 仿真
    - Implementation 证明

    从上往下证明力越强，越难证明

- Operating System
    - Scheduling threads using **preemptive** and **priority-based** scheduling algorithms (Real time, system, time sharing, interactive)
    - The default scheduling class for a process is time sharing (multilevel feedback queue)

Chapter 6 Process Synchronization

- Bounded-buffer

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

//Producer process
item nextProduced;
while(1)
```

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

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

- **Atomic operation**
  - counter++
  - counter—
- Race condition
  - two or more processes/thread access and manipulate the same data concurrently
  - the outcome of the execution depends on the particular order in which the access takes place
  - To prevent race conditions, concurrent processes must be synchronized
- The Critical-Section Problem
  - Each process has a code segment, called critical section
  - **Problem**: ensure that when one process is executing in its critical section, no other process is allowed to execute in its critical section
  - The critical-section problem is to design a protocol that processes can use to cooperate

    ┌────────────┐

    | entry section |

    ├────────────┤

    | critical section |

    ├────────────┤

    | exit section |

    ├────────────┤

    |remainder section |

    └────────────┘

    critical section must run in a mutually exclusive way.
- Solution to Critical-Section Problem
  - Mutual Exclusion (互斥、忙等) → 防止冲突
  - Progress (空闲让进) → 进展性

- Bounded Waiting (有限等待) → 进展性
    - 防止饥饿，让权等待，多CPU：死锁
- **the solution cannot depend on relative speed of processes and scheduling policy**
- Mutual Exclusion

- Bakery Algorithm

```
//shared data
boolean choosing[n];    //false
int number[n];          //0
do
{
    choosing[i] = true;
    number[i] = max(number[0],number[1],...,number[n-1])+1;
    choosing[i] = false;
    for(j = 0; j < n; ++j)
    {
        while(choosing[j]);
        while((number[j] != 0)&&((number[j],j)<(number[i],i)));
    }
    //critical section
    number[i] = 0;
    //remainder section
}while(1)
```

- Interrupt Disabling
    - disable interrupts → critical section → enable interrupts
    - When interrupts are disabled, no context switch will occur in a critical section
    - Infeasible in a multiprocessor system because all CPUs must be informed
    - Some feature that depend on interrupts (e.g. clock) may not work properly
- Mutual Exclusion (互斥锁)
    - TestAndSet

```
boolean TestAndSet(boolean &target)
{
    booean rv = &target;
    &target = true;
    return rv;
}
```

```
//shared data
boolean lock = false;
//Process P
do
{
    while(TestAndSet(lock));
    //critical section
    lock = false;
    //remainder section
}
```

- Swap
  - **atomically** swap two variables

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

```
//Global shared data
boolean lock;    //false
//Local variable for each process
boolean key;
Process Pi
do
{
    key = true;
    while(key == true)
    {
        Swap(lock,key);
    }
    //critical section
    lock = false;
    //remainder section
}
```

- Semaphores

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

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

  - Count semaphore
  - Binary semaphore (mutex locks)
- busy waiting (Spinlock)
- block itself (阻塞方法，使用PCB唤醒)
  - Define a semaphore as a record

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

    - block()
    - wakeup(P)

```
wait(S)
{
    S.value--;
    if (s.value < 0)
    {
        //add this process to S.L;
        block();
    }
}
signal(S)
{
    S.value++;
    if(S.value <= 0)
    {
        //remove a process P from S.L;
        wakeup(P);
    }
}
```

    - if the semaphore is negative, its magnitude is the number of process waiting on that semaphore
    - Busy waiting has not been **completely** eliminated
    - furthermore, we have limited busy waiting to the critical sections of the wait() and signal() operations
- Deadlock and Starvation

临界资源、同步关系

  - Bounded-Buffer Problem

```
//Shared data
Semaphore full = 0,empty = n,mutex = 1;
do  //Producer
{
```

```
    //produce an item in nextP
    wait(empty);
    wait(mutex);
    //add nextP to buffer
    signal(mutex);
    signal(full);
}while(1);

do  //Consumer
{
    wait(full);
    wait(mutex);
    //remove an item from buffer to nextC
    signal(mutex);
    signal(empty);
    //consume the item in nextC
}while(1);
```

- Readers and Writers Problem
  - Reader first
  - Writer first

```
//Shared data
int readcount;
semaphore wrt = 1,mutex = 1;
int readcount = 0;
do
{
    wait(wrt);
    //writing
    signal(wrt);
}while(1);
do      //Error: 写者饥饿问题
{
    wait(mutex);
    readcount++;
    if(readcount == 1)
        wait(wrt);
    signal(mutex);
    //reading
    wait(mutex);
    readcount--;
    if(readcount == 0)
        signal(wrt);
    signal(mutex);
}
```

- Dining-Philosophers Problem
- 过独木桥问题

```
//Shared data
int countA = 0; //A方向上已在独木桥上的行人数目
int countB = 0; //B方向上已在独木桥上的新人数目
semaphore MA = 1;   //countA的互斥锁
semaphore MB = 1;   //countB的互斥锁
semaphore mutex = 1;    //实现互斥使用
```

- A方向过桥

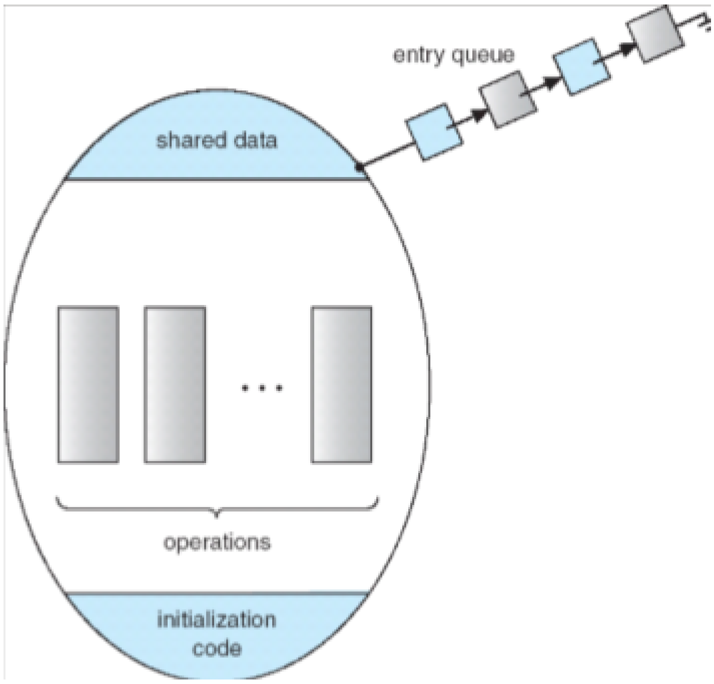
```
do
{
    wait(MA);
    countA++;
    if (count == 1)
    {
        wait(mutex);
    }
    signal(MA);
    //过桥
    wait(MA);
    countA--;
    if(countA == 0)
    {
        signal(mutex);
    }
    signal(MA);
}while(1);
```

- Monitors (管程)
  - High-level synchronization construct that allows the safe sharing of an abstract data type among concurrent processes

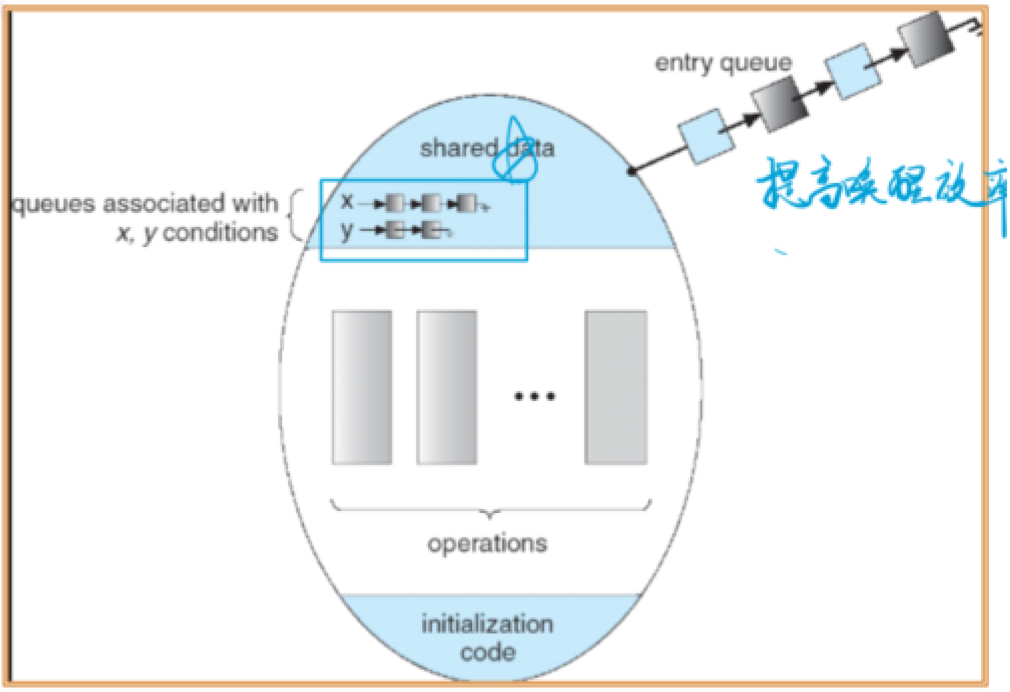
```
monitor monitor-name
{
    shared variable declarations
    proceudre body P1()
    {
        //...
    }
        proceudre body P2()
    {
        //...
    }
    //...
    {//initialization code}
}
```

  - no more than one process can be executing within a monitor
  - when a process calls a monitor procedure and the monitor has a process running, the caller will be blocked outside the monitor

- Mutual exclusion is guaranteed with in a monitor



- Condition variables
    - x,y
        - x.wait() means that the process invoking this operation is suspended until another process invokes x.signal();
        - x.signal() operation resumes exactly one suspended process. If no process is suspended, the signal() operation has no effect



Semaphores	Condition Variables
Can be used anywhere, but not in a monitor	Can only be used in monitors
wait() does **not** always block its caller	wait() **always** blocks its caller
signal() either releases a process, or increase the semaphore counter	signal() either releases a process ,or the signal is **lost** as if it never occurs
If signal() release a process, the caller and the release **both** continue	If signal() release a process, either the caller or the released continues, but **not** both

- 管程是公用数据结构，进程是私有数据结构
- 管程集中管理共享变量上的同步操作，临界区分散在每个进程中
- 管程管理共享资源，进程占用系统资源和实现系统并发性
- 管程被欲使用的共享资源的进程调用，管程和调用它的进程不能并发工作，进程之间能并发工作
- 管程是语言或操作系统的成分，不必创建或撤销，进程有生命周期，有创建有消亡

🚧正在施工中......🚧