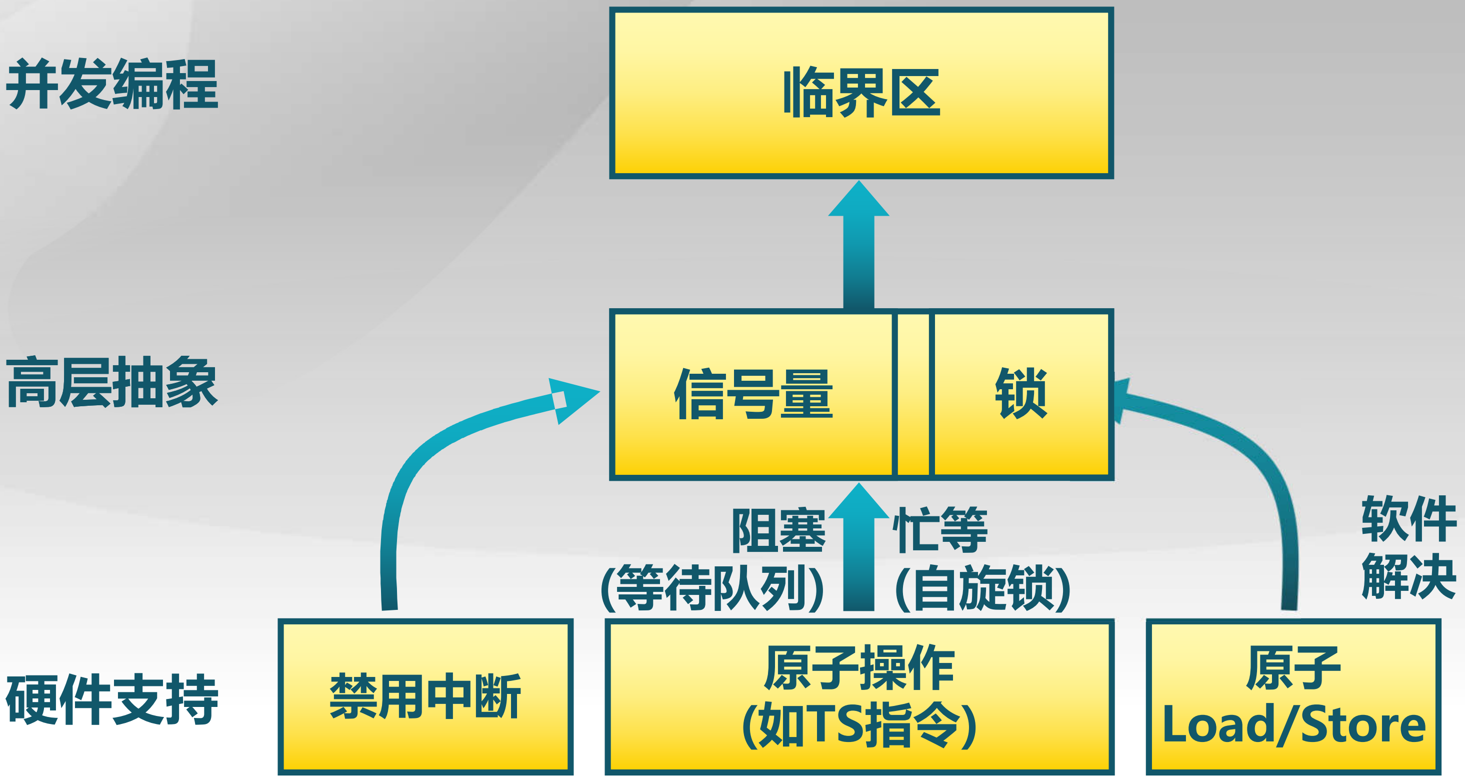
操作系统
Operating Systems

回顾

- 并发问题
  - 多线程并发导致资源竞争
- 同步概念
  - 协调多线程对共享数据的访问
  - 任何时刻只能有一个线程执行临界区代码
- 确保同步正确的方法
  - 底层硬件支持
  - 高层次的编程抽象

基本同步方法

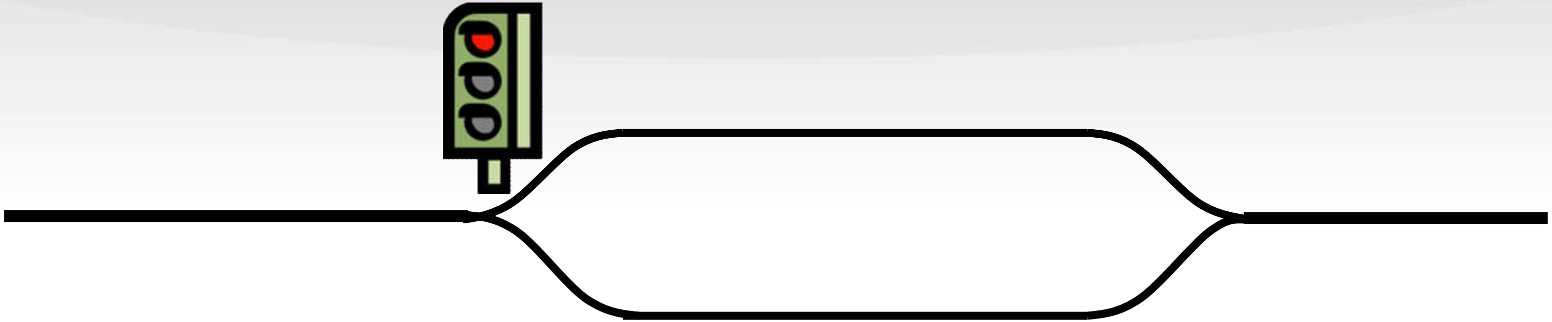

并发编程
高层抽象
硬件支持
临界区
信号量
锁
阻塞
(等待队列)
忙等
(自旋锁)
软件
解决
禁用中断
原子操作
(如TS指令)
原子
Load/Store

信号量(semaphore)

- 信号量是操作系统提供的一种协调共享资源访问的方法
  - 软件同步是平等线程间的一种同步协商机制
  - OS是管理者，地位高于进程
  - 用信号量表示系统资源的数量
- 由Dijkstra在20世纪60年代提出
- 早期的操作系统的主要同步机制
  - 现在很少用（但还是非常重要在计算机科学研究）

信号量(semaphore)

- 信号是一种抽象数据类型
  - 由一个整形 (sem)变量和两个原子操作组成
  - P()（Prolaag （荷兰语尝试减少））
    - sem减1
    - 如sem<0, 进入等待, 否则继续
  - V()（Verhoog （荷兰语增加））
    - sem加1
    - 如sem≤0, 唤醒一个等待进程
- 信号量与铁路的类比
  - 2个站台的车站
  - 2个资源的信号量



信号量的特性

- 信号量是**被保护**的**整数**变量
  - 初始化完成后，只能通过P()和V()操作修改
  - 由操作系统保证，PV操作是原子操作
- **P() 可能阻塞**，V()不会阻塞
- 通常假定信号量是“公平的”
  - 线程不会被无限期阻塞在P()操作
  - 假定信号量等待按先进先出排队

自旋锁能否实现先进先出?

信号量的实现

```
classSemaphore {
int sem;
WaitQueue q;
}
```

```
Semaphore::P() {
    sem--;
    if (sem < 0) {
         Add this thread t to q;
         block(p);
      }
}
```

```
Semaphore::V() {
     sem++;
     if (sem<=0) {
          Remove a thread t from q;
          wakeup(t);
     }
}
```

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信号量分类

- 可分为两种信号量
  - 二进制信号量：资源数目为0或1
  - 资源信号量:资源数目为任何非负值
  - 两者等价
    - 基于一个可以实现另一个
- 信号量的使用
  - 互斥访问
    - 临界区的互斥访问控制
  - 条件同步
    - 线程间的事件等待

用信号量实现临界区的互斥访问

每个临界区设置一个信号量，其初值为1

```
mutex = new Semaphore(1);
```

```
mutex->P();
Critical Section;
mutex->V();
```

- 必须**成对使用**P()操作和V()操作
  - P()操作保证互斥访问临界资源
  - V()操作在使用后释放临界资源
  - PV操作**不能次序错误、重复或遗漏**

用信号量实现条件同步

每个条件同步设置一个信号量，其初值为0

```
condition = new Semaphore(0);
```

线程A

```
… M …
condition->P();
… N …
```

线程B

```
… X …
condition->V();
… Y …
```

生产者-消费者问题

生产者 → 缓冲区 → 消费者

- 有界缓冲区的生产者-消费者问题描述
  - 一个或多个**生产者**在生成数据后放在一个缓冲区里
  - 单个**消费者**从缓冲区取出数据处理
  - 任何时刻**只能有一个**生产者或消费者可访问缓冲区

用信号量解决生产者-消费者问题

- 问题分析
  - 任何时刻只能有一个线程操作缓冲区（互斥访问）
  - 缓冲区空时，消费者必须等待生产者（条件同步）
  - 缓冲区满时，生产者必须等待消费者（条件同步）
- 用信号量描述每个约束
  - 二进制信号量mutex
  - 资源信号量fullBuffers
  - 资源信号量emptyBuffers

用信号量解决生产者-消费者问题

```
Class BoundedBuffer {
    mutex = new Semaphore(1);
    fullBuffers = new Semaphore(0);
    emptyBuffers = new Semaphore(n);
}
```

```
BoundedBuffer::Deposit(c) {
    emptyBuffers->P();
    mutex->P();
    Add c to the buffer;
    mutex->V();
    fullBuffers->V();
}
```

```
BoundedBuffer::Remove(c) {
    fullBuffers->P();
    mutex->P();
    Remove c from buffer;
    mutex->V();
    emptyBuffers->V();
}
```

- P、V操作的顺序有影响吗?

使用信号量的困难

- 读/开发代码比较困难
  - 程序员需要能运用信号量机制
- 容易出错
  - 使用的信号量已经被另一个线程占用
  - 忘记释放信号量
- 不能够处理死锁问题

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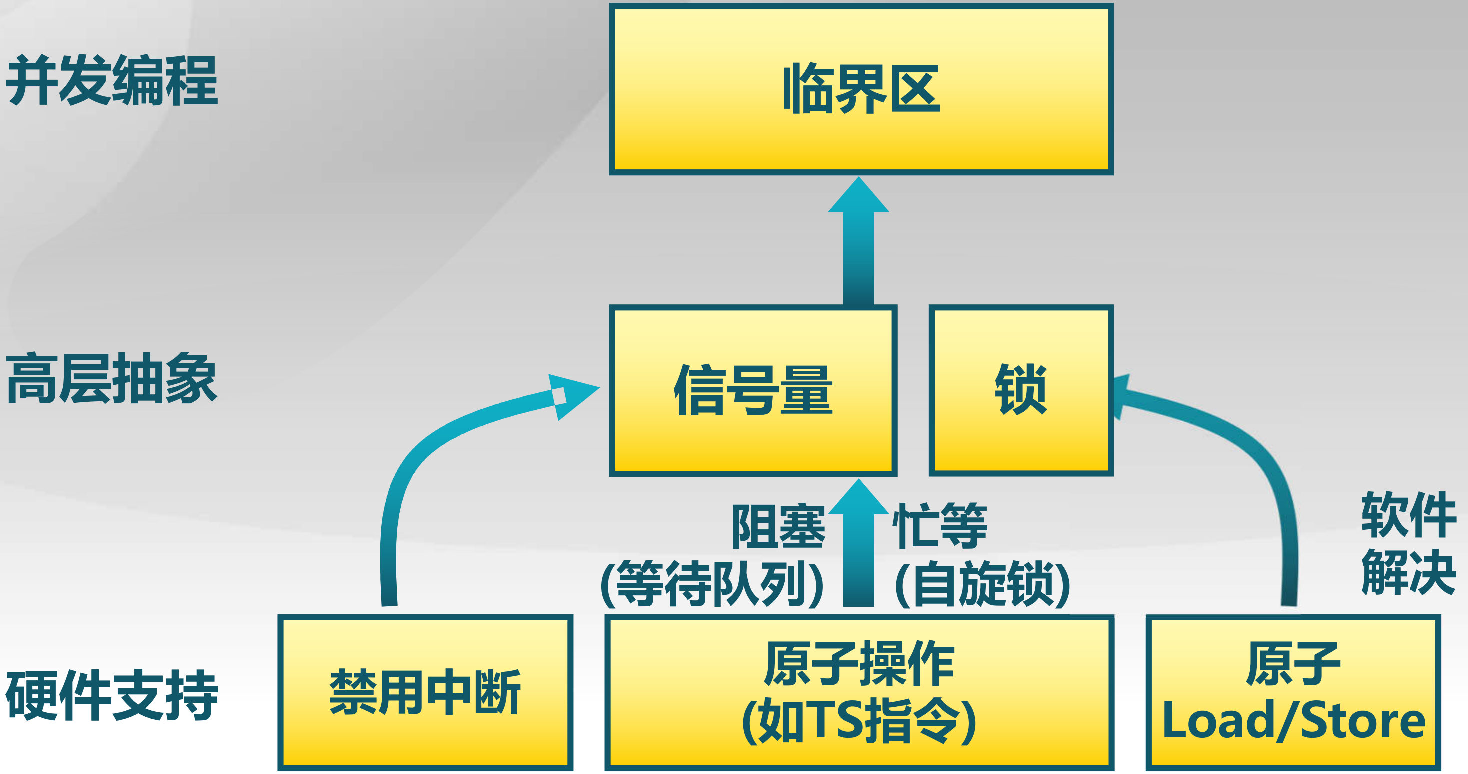
基本同步方法



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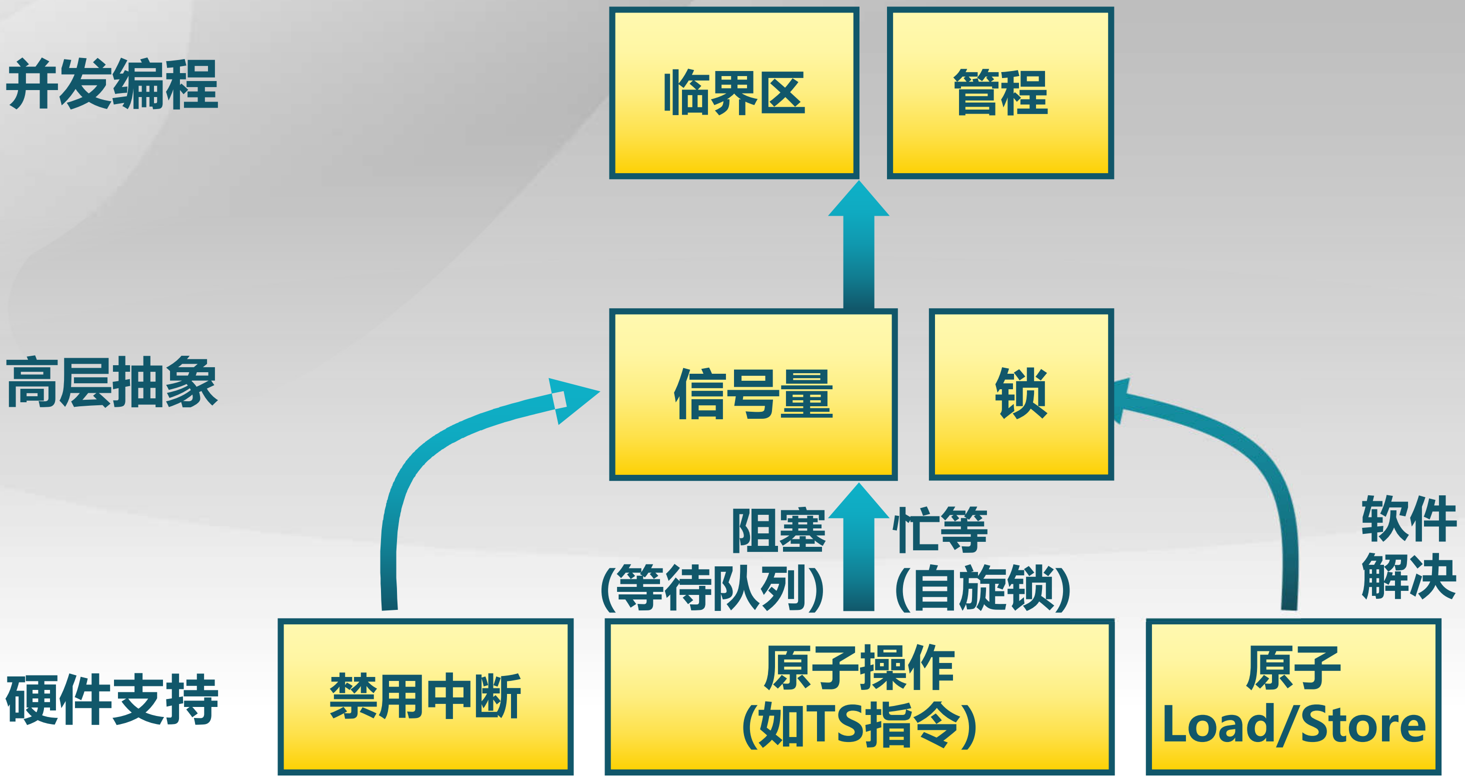
基本同步方法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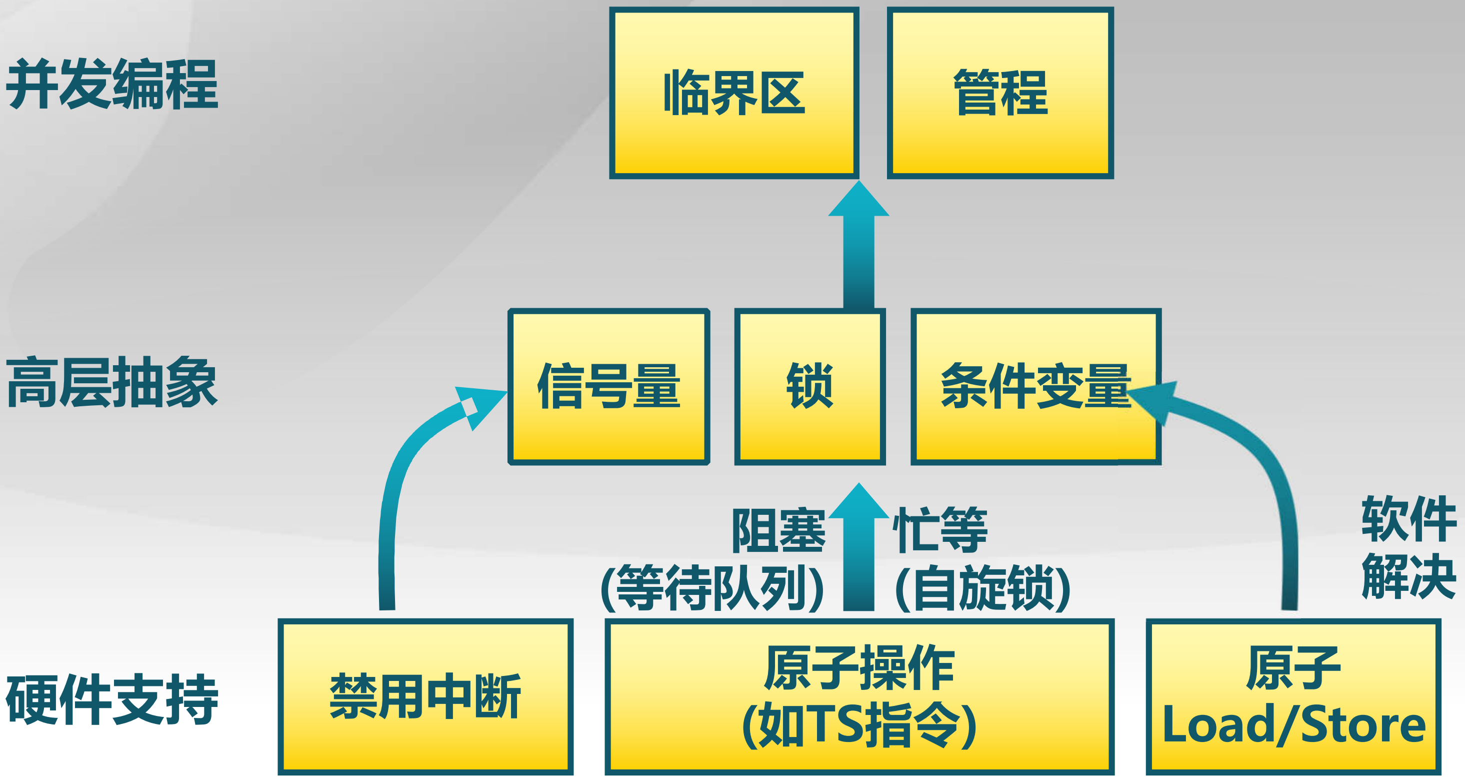
基本同步方法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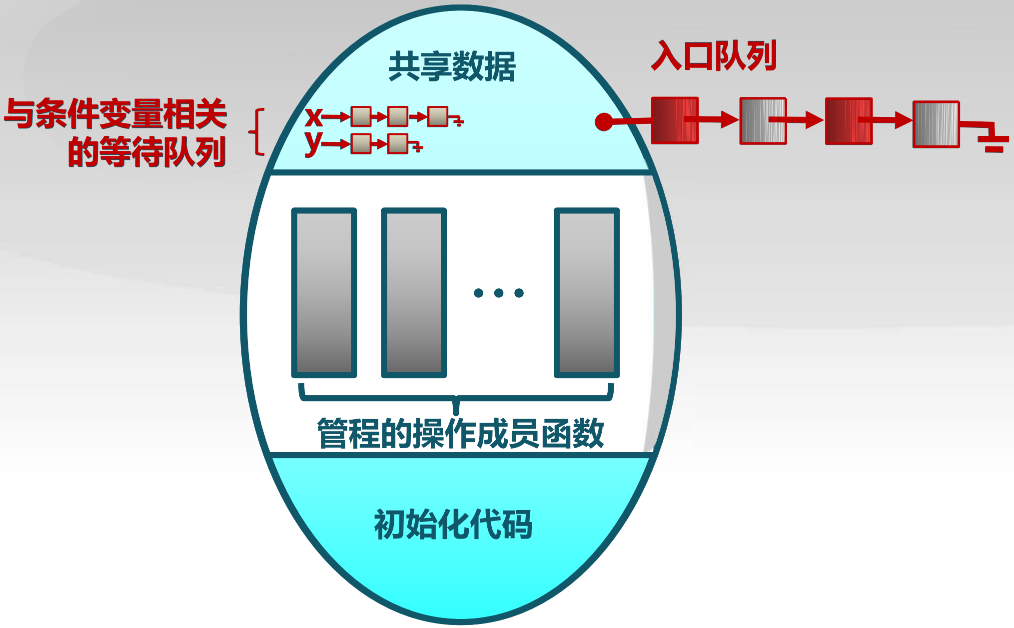
管程（Moniter）

- 管程是一种用于多线程互斥访问共享资源的程序结构
  - 采用面向对象方法，简化了线程间的同步控制
  - 任一时刻最多只有一个线程执行管程代码
  - 正在管程中的线程可临时放弃管程的互斥访问，等待事件出现时恢复
- 管程的使用
  - 在对象/模块中，收集相关共享数据
  - 定义访问共享数据的方法

管程的组成

- 一个锁
  - 控制管程代码的互斥访问
- 0或者多个条件变量
  - 管理共享数据的并发访问



条件变量（Condition Variable）

- 条件变量是管程内的等待机制
  - 进入管程的线程因资源被占用而进入等待状态
  - 每个条件变量表示一种等待原因，对应一个等待队列
- Wait()操作
  - 将自己阻塞在等待队列中
  - 唤醒一个等待者或释放管程的互斥访问
- Signal()操作
  - 将等待队列中的一个线程唤醒
  - 如果等待队列为空，则等同空操作

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){



}
```

```
Condition::Signal(){



}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;

}
```

```
Condition::Signal(){

}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;



}
```

```
Condition::Signal(){





}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex

}
```

```
Condition::Signal(){

}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex
    require(lock);
}
```

```
Condition::Signal(){



}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex
    require(lock);
}
```

```
Condition::Signal(){
    if (numWaiting > 0) {



    }
}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex
    require(lock);
}
```

```
Condition::Signal(){
    if (numWaiting > 0) {
        Remove a thread t from q;


    }
}
```

条件变量实现

```
Class Condition {
    int numWaiting = 0;
    WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex
    require(lock);
}
```

```
Condition::Signal(){
    if (numWaiting > 0) {
        Remove a thread t from q;
        wakeup(t); //need mutex

    }
}
```

条件变量实现

```
Class Condition {
     int numWaiting = 0;
     WaitQueue q;
}
```

```
Condition::Wait(lock){
    numWaiting++;
    Add this thread t  to q;
    release(lock);
    schedule(); //need mutex
    require(lock);
}
```

```
Condition::Signal(){
    if (numWaiting > 0) {
        Remove a thread t from q;
        wakeup(t); //need mutex
        numWaiting--;
    }
}
```

用管程解决生产者-消费者问题

```
classBoundedBuffer {
    …
    Lock lock;
    int count = 0;
    Condition notFull, notEmpty;
}
```

```
BoundedBuffer::Deposit(c) {


    Add c to the buffer;
    count++;


}
```

```
BoundedBuffer::Remove(c) {


    Remove c from buffer;
    count--;


}
```

用管程解决生产者-消费者问题

```
classBoundedBuffer {
    …
    Lock lock;
    int count = 0;
    Condition notFull, notEmpty;
}
```

```
BoundedBuffer::Deposit(c) {
    lock->Acquire();


    Add c to the buffer;
    count++;

    lock->Release();
}
```

```
BoundedBuffer::Remove(c) {
    lock->Acquire();


    Remove c from buffer;
    count--;

    lock->Release();
}
```

用管程解决生产者-消费者问题

```
classBoundedBuffer {
    …
    Lock lock;
    int count = 0;
    Condition notFull, notEmpty;
}
```

```
BoundedBuffer::Deposit(c) {
    lock->Acquire();
    while (count == n)
        notFull.Wait(&lock);
    Add c to the buffer;
    count++;

    lock->Release();
}
```

```
BoundedBuffer::Remove(c) {
    lock->Acquire();


    Remove c from buffer;
    count--;
    notFull.Signal();
    lock->Release();
}
```

用管程解决生产者-消费者问题

```
classBoundedBuffer {
    …
    Lock lock;
    int count = 0;
    Condition notFull, notEmpty;
}
```

```
BoundedBuffer::Deposit(c) {
    lock->Acquire();
    while (count == n)
        notFull.Wait(&lock);
    Add c to the buffer;
    count++;
    notEmpty.Signal();
    lock->Release();
}
```

```
BoundedBuffer::Remove(c) {
    lock->Acquire();
    while (count == 0)
      notEmpty.Wait(&lock);
    Remove c from buffer;
    count--;
    notFull.Signal();
    lock->Release();
}
```

管程条件变量的释放处理方式

- Hansen管程
  - 主要用于真实OS和Java中

```
l.acquire()
…
x.wait()
```

T1进入等待

T2进入管程

```
l.acquire()
…
x.signal()
…
l.release()
```

T2退出管程

```
…
l.release()
```

T1恢复管程执行

- Hoare管程
  - 主要见于教材中

```
l.acquire()
…
x.wait()
```

T1进入等待

T2进入管程

```
l.acquire()
…
x.signal()
```

T2进入等待

```
…
l.release()
```

T1恢复管程执行

T1 结束

T2恢复管程执行

```
…
l.release()
```

Hansen 管程与 Hoare 管程

```
Hansen-style :Deposit(){
   lock->acquire();
   while (count == n) {
        notFull.wait(&lock);
   }
   Add  thing;
   count++;
   notEmpty.signal();
   lock->release();
}
```

```
Hoare-style: Deposit(){
   lock->acquire();
   if (count == n) {
        notFull.wait(&lock);
   }
   Add thing;
   count++;
   notEmpty.signal();
   lock->release();
}
```

- Hansen管程
  - 条件变量释放仅是一个提示
  - 需要重新检查条件
- 特点
  - 高效

- Hoare管程
  - 条件变量释放同时表示放弃管程访问
  - 释放后条件变量的状态可用
- 特点
  - 低效

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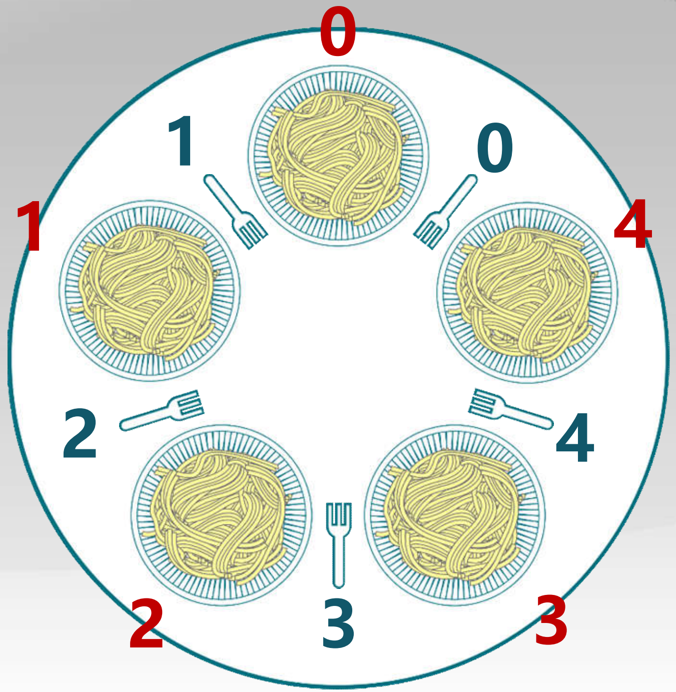
哲学家就餐问题

问题描述：

- 5个哲学家围绕一张圆桌而坐
  - 桌子上放着5支叉子
  - 每两个哲学家之间放一支
- 哲学家的动作包括思考和进餐
  - 进餐时需同时拿到左右两边的叉子
  - 思考时将两支叉子放回原处
- 如何保证哲学家们的动作有序进行？
  如：不出现有人永远拿不到叉子



方案1

```
#define N 5                           // 哲学家个数
semaphore fork[5];                    // 信号量初值为1
void   philosopher(int   i)           // 哲学家编号：0 - 4

    while(TRUE)
    {
      think( );                       // 哲学家在思考
      P(fork[i]);                     // 去拿左边的叉子
      P(fork[(i + 1) % N]);           // 去拿右边的叉子

      eat( );                         // 吃面条中....
      V(fork[i]);                     // 放下左边的叉子
      V(fork[(i + 1) % N ]);          // 放下右边的叉子

    }
```

不正确，可能导致死锁

方案2

```
#define    N    5                          // 哲学家个数
semaphore fork[5];                         // 信号量初值为1
semaphore   mutex;                         // 互斥信号量，初值1
```

方案2

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
semaphore   mutex;                       // 互斥信号量，初值1
void   philosopher(int   i)              // 哲学家编号：0 - 4
    while(TRUE){
        think( );                        // 哲学家在思考



        eat( );                          // 吃面条中….



    }
```

方案2

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
semaphore   mutex;                       // 互斥信号量，初值1
void   philosopher(int   i)              // 哲学家编号：0 - 4
    while(TRUE){
        think( );                        // 哲学家在思考
        P(mutex);                        // 进入临界区


        eat( );                          // 吃面条中….


        V(mutex);                        // 退出临界区
    }
```

方案2

```
#define   N   5                                // 哲学家个数
semaphore fork[5];                             // 信号量初值为1
semaphore   mutex;                             // 互斥信号量，初值1
void   philosopher(int   i)                    // 哲学家编号：0 - 4
    while(TRUE){
        think( );                              // 哲学家在思考
        P(mutex);                              // 进入临界区
        P(fork[i]);                            // 去拿左边的叉子
        P(fork[(i + 1) % N]);                  // 去拿右边的叉子
        eat( );                                // 吃面条中….


        V(mutex);                              // 退出临界区
    }
```

方案2

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                        // 信号量初值为1
semaphore   mutex;                        // 互斥信号量，初值1
void   philosopher(int   i)               // 哲学家编号：0 - 4
    while(TRUE){
        think( );                         // 哲学家在思考
        P(mutex);                         // 进入临界区
        P(fork[i]);                       // 去拿左边的叉子
        P(fork[(i + 1) % N]);             // 去拿右边的叉子
        eat( );                           // 吃面条中….
        V(fork[i]);                       // 放下左边的叉子
        V(fork[(i + 1) % N]);             // 放下右边的叉子
        V(mutex);                         // 退出临界区
}
```

互斥访问正确，但每次只允许一人进餐

方案3

```
#define    N    5                        // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
```

方案3

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
void   philosopher(int   i)              // 哲学家编号：0 - 4
    while(TRUE)
    {
        think( );                        // 哲学家在思考




        eat( );                          // 吃面条中....


    }
```

方案3

```
#define   N   5                              // 哲学家个数
semaphore fork[5];                           // 信号量初值为1
void   philosopher(int   i)                  // 哲学家编号：0 - 4
    while(TRUE)
    {
        think( );                            // 哲学家在思考
        if (i%2 == 0) {


        } else {


        }
        eat( );                              // 吃面条中….


    }
```

方案3

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
void   philosopher(int   i)              // 哲学家编号：0 - 4
    while(TRUE)
    {
        think( );                        // 哲学家在思考
        if (i%2 == 0) {
            P(fork[i]);                  // 去拿左边的叉子
            P(fork[(i + 1) % N]);        // 去拿右边的叉子
        } else {


        }
        eat( );                          // 吃面条中….
    }
```

方案3

```
#define   N   5                                  // 哲学家个数
semaphore fork[5];                               // 信号量初值为1
void   philosopher(int   i)                      // 哲学家编号: 0 - 4
    while(TRUE)
    {
        think( );                                // 哲学家在思考
        if (i%2 == 0) {
            P(fork[i]);                          // 去拿左边的叉子
            P(fork[(i + 1) % N]);                // 去拿右边的叉子
        } else {
            P(fork[(i + 1) % N]);                // 去拿右边的叉子
            P(fork[i]);                          // 去拿左边的叉子
        }
        eat( );                                  // 吃面条中….
    }
```

方案3

```
#define   N   5                          // 哲学家个数
semaphore fork[5];                       // 信号量初值为1
void   philosopher(int   i)              // 哲学家编号: 0 - 4
    while(TRUE)
    {
        think( );                        // 哲学家在思考
        if (i%2 == 0) {
            P(fork[i]);                  // 去拿左边的叉子
            P(fork[(i + 1) % N]);        // 去拿右边的叉子
        } else {
            P(fork[(i + 1) % N]);        // 去拿右边的叉子
            P(fork[i]);                  // 去拿左边的叉子
        }
        eat( );                          // 吃面条中….
        V(fork[i]);                      // 放下左边的叉子
        V(fork[(i + 1) % N]);            // 放下右边的叉子
    }
```

没有死锁，可有多人同时就餐

操作系统

Operating Systems

操作系统
Operating Systems

读者-写者问题描述

- 共享数据的两类使用者
  - 读者：只读取数据，不修改
  - 写者：读取和修改数据
- 读者-写者问题描述：对共享数据的读写
  - “读 - 读”允许
    - 同一时刻，允许有多个读者同时读
  - “读 - 写”互斥
    - 没有写者时读者才能读
    - 没有读者时写者才能写
  - “写 - 写”互斥
    - 没有其他写者时写者才能写

用信号量解决读者-写者问题

- 用信号量描述每个约束
  - 信号量WriteMutex
    - 控制读写操作的互斥
    - 初始化为1
  - 读者计数Rcount
    - 正在进行读操作的读者数目
    - 初始化为0
  - 信号量CountMutex
    - 控制对读者计数的互斥修改
    - 初始化为1

用信号量解决读者-写者问题

Writer

```
write;
```

Reader

```
read;
```

用信号量解决读者-写者问题

Writer

```
P(WriteMutex);
  write;
V(WriteMutex);
```

Reader

```
    P(WriteMutex);

read;

   V(WriteMutex);
```

用信号量解决读者-写者问题

Writer

```
P(WriteMutex);

  write;

V(WriteMutex);
```

Reader

```
  if (Rcount == 0)
    P(WriteMutex);
  ++Rcount;


read;



    V(WriteMutex);
```

用信号量解决读者-写者问题

Writer

```
P(WriteMutex);

  write;

V(WriteMutex);
```

Reader

```
 if (Rcount == 0)
   P(WriteMutex);
 ++Rcount;


read;


 --Rcount;
 if (Rcount == 0)
  V(WriteMutex);
```

用信号量解决读者-写者问题

Writer

```
P(WriteMutex);

  write;

V(WriteMutex);
```

Reader

```
P(CountMutex);
 if (Rcount == 0)
    P(WriteMutex);
 ++Rcount;
V(CountMutex);

read;


 --Rcount;
 if (Rcount == 0)
   V(WriteMutex);
```

用信号量解决读者-写者问题

Writer

```
P(WriteMutex);

  write;

V(WriteMutex);
```

Reader

```
P(CountMutex);
 if (Rcount == 0)
   P(WriteMutex);
 ++Rcount;
V(CountMutex);

read;

P(CountMutex);
 --Rcount;
 if (Rcount == 0)
   V(WriteMutex);
V(CountMutex)
```

此实现中，读者优先

读者/写者问题：优先策略

- 读者优先策略
  - 只要有读者正在读状态，后来的读者都能直接进入
  - 如读者持续不断进入，则写者就处于饥饿
- 写者优先策略
  - 只要有写者就绪，写者应尽快执行写操作
  - 如写者持续不断就绪，则读者就处于饥饿

如何实现？

用管程解决读者-写者问题

■ 两个基本方法

```
Database::Read() {
        Wait until no writers;
        read database;
        check out - wake up waiting writers;
}
```

```
Database::Write() {
        Wait until no readers/writers;
        write database;
        check out - wake up waiting readers/writers;
}
```

■ 管程的状态变量

```
AR = 0;             // # of active readers
AW = 0;             // # of active writers
WR = 0;             // # of waiting readers
WW = 0;             // # of waiting writers
```

用管程解决读者-写者问题

- 两个基本方法

```
Database::Read() {
        Wait until no writers;
        read database;
        check out – wake up waiting writers;
}
```

```
Database::Write() {
        Wait until no readers/writers;
        write database;
        check out – wake up waiting readers/writers;
}
```

- 管程的状态变量

```
AR = 0;                 // # of active readers
AW = 0;                 // # of active writers
WR = 0;                 // # of waiting readers
WW = 0;                 // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out - wake up waiting writers;
  DoneRead();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();




    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();




    AR++;
    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();
    while (???) {
        WR++;
        okToRead.wait(&lock);
        WR--;
    }
    AR++;
    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();
    while ((AW+WW) > 0) {
        WR++;
        okToRead.wait(&lock);
        WR--;
    }
    AR++;
    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();
    while ((AW+WW) > 0) {
        WR++;
        okToRead.wait(&lock);
        WR--;
    }
    AR++;
    lock.Release();
}
```

```
Private Database::DoneRead() {
    lock.Acquire();
    AR--;



    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();
    while ((AW+WW) > 0) {
        WR++;
        okToRead.wait(&lock);
        WR--;
    }
    AR++;
    lock.Release();
}
```

```
Private Database::DoneRead() {
    lock.Acquire();
    AR--;
    if (???) {
        okToWrite.signal();
    }
    lock.Release();
}
```

解决方案详情：读者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Read() {
  //Wait until no writers;
  StartRead();
  read database;
  //check out – wake up waiting writers;
  DoneRead();
}
```

```
Private Database::StartRead() {
    lock.Acquire();
    while ((AW+WW) > 0) {
        WR++;
        okToRead.wait(&lock);
        WR--;
    }
    AR++;
    lock.Release();
}
```

```
Private Database::DoneRead() {
    lock.Acquire();
    AR--;
    if (AR ==0 && WW > 0) {
        okToWrite.signal();
    }
    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();




    AW++;
    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();
    while (???)  {
        WW++;
        okToWrite.wait(&lock);
        WW--;
    }
    AW++;
    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();
    while ((AW+AR) > 0)  {
        WW++;
        okToWrite.wait(&lock);
        WW--;
    }
    AW++;
    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();
    while ((AW+AR) > 0)  {
        WW++;
        okToWrite.wait(&lock);
        WW--;
    }
    AW++;
    lock.Release();
}
```

```
Private Database::DoneWrite() {
    lock.Acquire();
    AW--;



    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();
    while ((AW+AR) > 0)  {
        WW++;
        okToWrite.wait(&lock);
        WW--;
    }
    AW++;
    lock.Release();
}
```

```
Private Database::DoneWrite() {
    lock.Acquire();
    AW--;
    if (WW > 0) {
        okToWrite.signal();
    }


    lock.Release();
}
```

解决方案详情：写者

```
AR = 0;    // # of active readers
AW = 0;    // # of active writers
WR = 0;    // # of waiting readers
WW = 0;    // # of waiting writers
Lock lock;
Condition okToRead;
Condition okToWrite;
```

```
Public Database::Write() {
  //Wait until no readers/writers;
  StartWrite();
  write database;
  //check out-wake up waiting readers/writers;
  DoneWrite();
}
```

```
Private Database::StartWrite() {
    lock.Acquire();
    while ((AW+AR) > 0)  {
        WW++;
        okToWrite.wait(&lock);
        WW--;
    }
    AW++;
    lock.Release();
}
```

```
Private Database::DoneWrite() {
    lock.Acquire();
    AW--;
    if (WW > 0) {
        okToWrite.signal();
    }
    else if (WR > 0) {
        okToRead.broadcast();
    }
    lock.Release();
}
```

操作系统

Operating Systems