计算机操作系统

Operating Systems

田卫东

March, 2014

第2章 进程管理

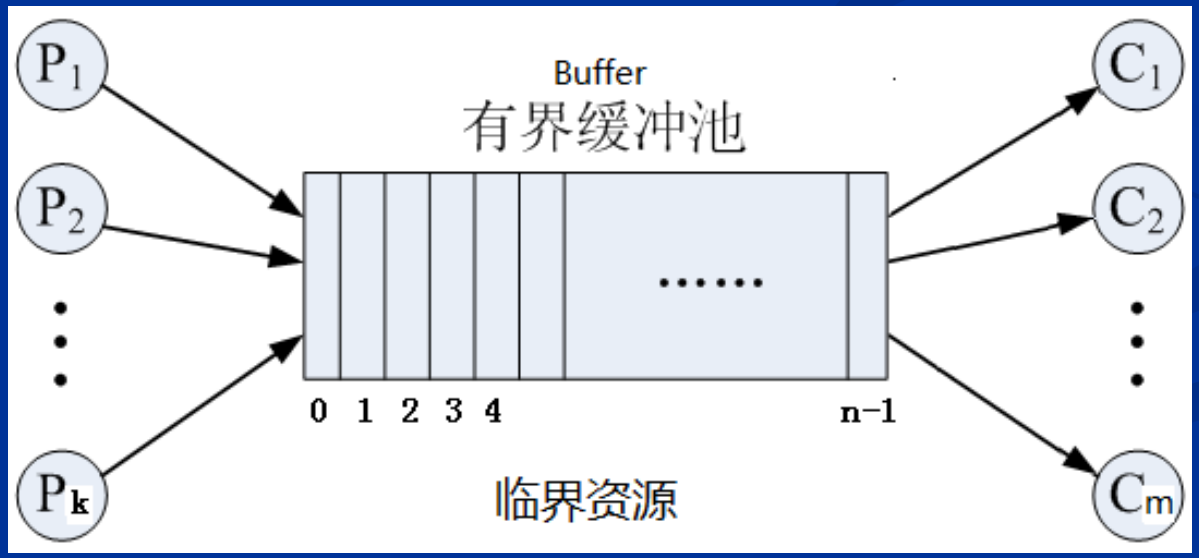
2.4 经典进程同步问题

2.4.1 生产者-消费者问题

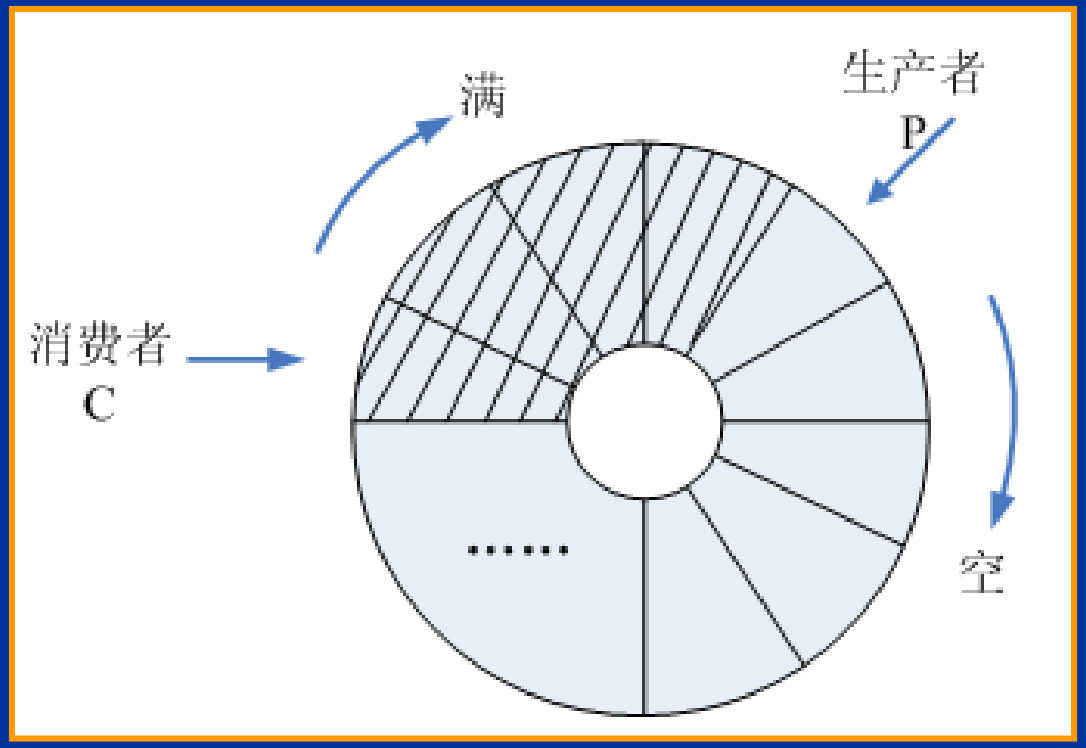
(1) 生产者消费者问题

多个生产者、多个消费者通过共享含n个缓冲区的缓冲池Buffer协作。其中生产者负责生产数据并投入缓冲池，消费者从缓冲池中取数据消费，生产者和消费者，每次生产/消费1个数据，要求每个数据必须且只被消费一次。缓冲池为临界资源。

请用记录型信号量进行同步。

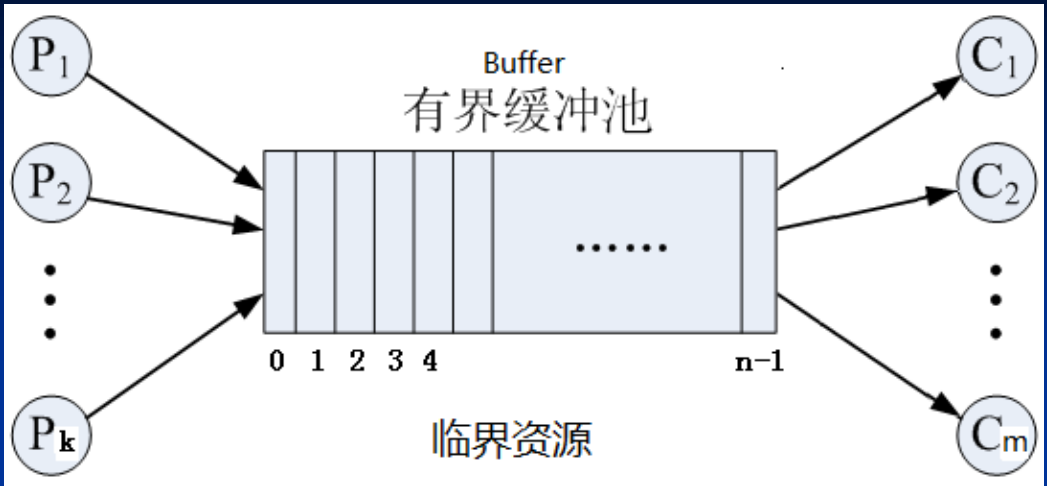


- 有界缓冲池 --> 循环缓冲区



- 循环队列
  - 队列数据结构
  - 入队操作
  - 出队操作

进程资源共享关系和同步关系分析



- 生产者进程：空缓冲区资源
- 消费者进程：满缓冲区资源

```
VAR
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
        repeat
           produce an item in nextp ;

           Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;

       until false
   end

Consumer:
begin
     repeat

        nextc = Buffer(out);
        out := (out + 1 ) mod n ;

        consume the item nextc ;
     until flase
end
Parend
```

数据结构

入队

出队

```
VAR empty, full: semaphore :=  n, 0 ;
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
        repeat
           produce an item in nextp ;
           wait( empty ) ;

           Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;

           signal( full ) ;
       until false
   end

Consumer:
begin
     repeat
        wait( full ) ;

        nextc = Buffer(out);
        out := (out + 1 ) mod n ;

        signal( empty ) ;
        consume the item nextc ;
     until flase
end
Parend
```

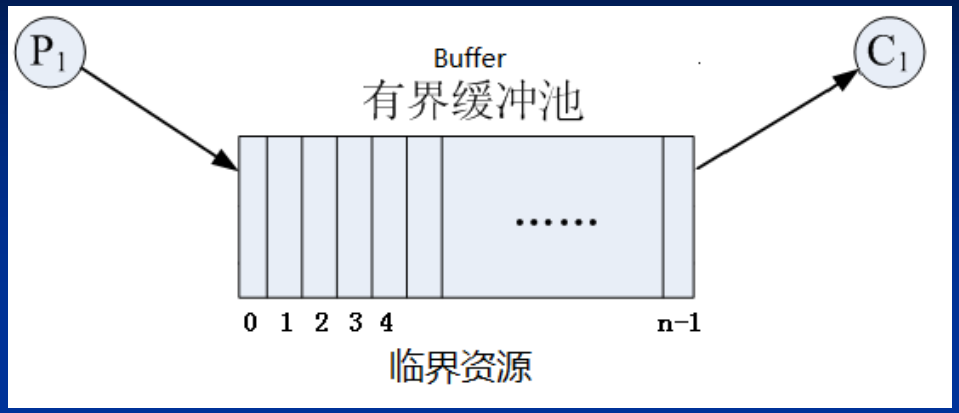
```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
    Producer:
    begin
          repeat
             produce an item in nextp ;
             wait( empty ) ;
             wait( mutex ) ;
             Buffer(in) := nextp ;
             in := (in + 1 ) mod n ;
             signal( mutex ) ;
             signal( full ) ;
          until false
    end

Consumer:
begin
       repeat
          wait( full ) ;
          wait( mutex ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( mutex ) ;
          signal( empty ) ;
          consume the item nextc ;
       until false
end
Parend
```

(2) 问题思考

- 单生产者单消费者、多缓冲时
- 多生产者多消费者、单缓冲时
- 单生产者单消费者、单缓冲时
- 允许生产者写时，消费者可读
- 当缓冲区无限大；
- 每个消息都要每个消费者消费1次
- 调整生产者wait顺序；
- 调整消费者wait顺序；
- 调整signal顺序；

(2) 问题思考

- 单生产者单消费者、多缓冲

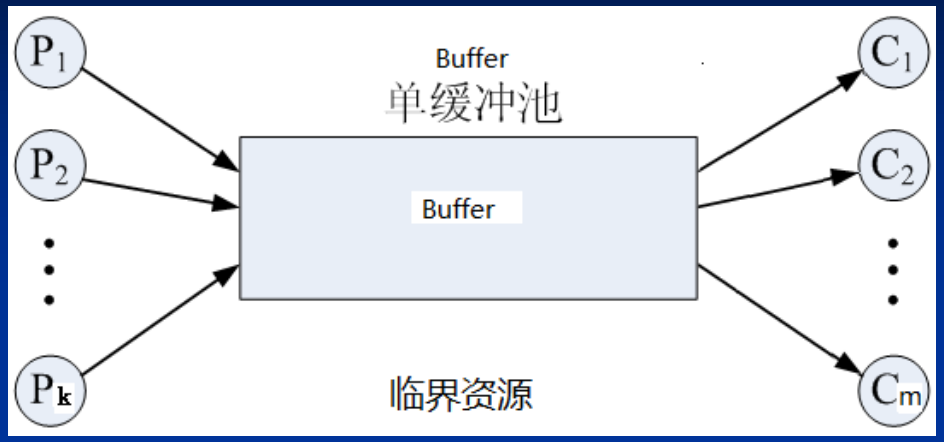


- 生产者-消费者标准程序

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
  Producer:
  begin
     repeat
          produce an item in nextp ;
          wait( empty ) ;
          wait( mutex ) ;
          Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;
           signal( mutex ) ;
           signal( full ) ;
      until false
  end
  Consumer:
  begin
      repeat
          wait( full ) ;
          wait( mutex ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( mutex ) ;
          signal( empty ) ;
          consume the item nextc ;
      until flase
  end
Parend
```

(2) 问题思考

- 多生产者多消费者、单缓冲

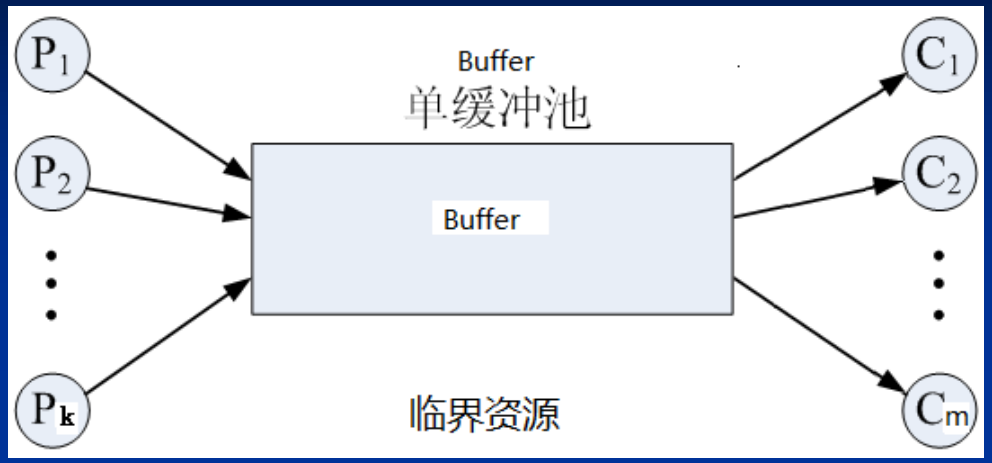


- 生产者-消费者标准程序

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
    repeat
         produce an item in nextp ;
         wait( empty ) ;
         wait( mutex ) ;
         Buffer(in) := nextp ;
          in := (in + 1 ) mod n ;
          signal( mutex ) ;
          signal( full ) ;
    until false
 end
 Consumer:
 begin
     repeat
         wait( full ) ;
         wait( mutex ) ;
         nextc = Buffer(out);
         out := (out + 1 ) mod n ;
         signal( mutex ) ;
         signal( empty ) ;
         consume the item nextc ;
     until flase
 end
Parend
```

(2) 问题思考

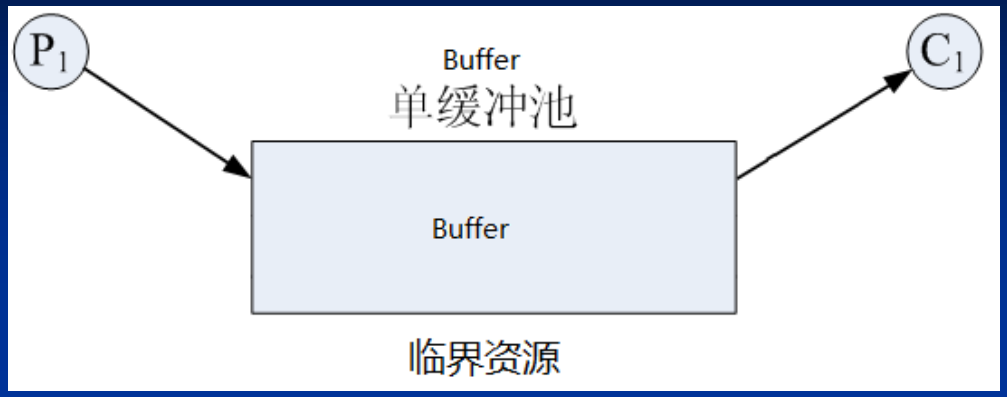
- 多生产者多消费者、单缓冲




```
VAR empty, full: semaphore := 1, 0 ;
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
        repeat
           produce an item in nextp ;
           wait( empty ) ;

           Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;

           signal( full ) ;
        until false
   end

Consumer:
begin
     repeat
        wait( full ) ;

        nextc = Buffer(out);
        out := (out + 1 ) mod n ;

        signal( empty ) ;
        consume the item nextc ;
     until flase
end
Parend
```

(2) 问题思考

- 单生产者单消费者、单缓冲

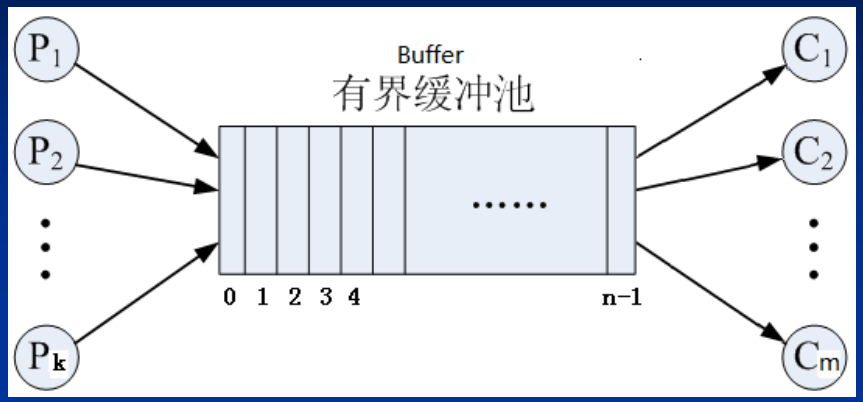


- 同例3

```
VAR empty, full: semaphore := 1, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
          repeat
              produce an item in nextp ;
              wait( empty ) ;
             Buffer(in) := nextp ;
              in := (in + 1 ) mod n ;
              signal( full ) ;
          until false
   end

Consumer:
begin
      repeat
          wait( full ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( empty ) ;
          consume the item nextc ;
      until flase
end
Parend
```

(2) 问题思考

- 允许生产者写时，消费者可读

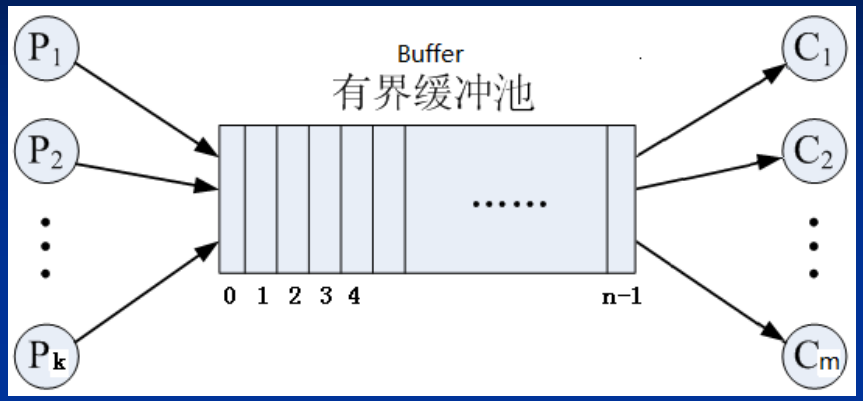


生产者-消费者标准程序

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
   repeat
       produce an item in nextp ;
       wait( empty ) ;
       wait( mutex ) ;
       Buffer(in) := nextp ;
        in := (in + 1 ) mod n ;
        signal( mutex ) ;
        signal( full ) ;
   until false
 end
 Consumer:
 begin
    repeat
       wait( full ) ;
       wait( mutex ) ;
       nextc = Buffer(out);
       out := (out + 1 ) mod n ;
       signal( mutex ) ;
       signal( empty ) ;
       consume the item nextc ;
    until flase
 end
Parend
```

(2) 问题思考

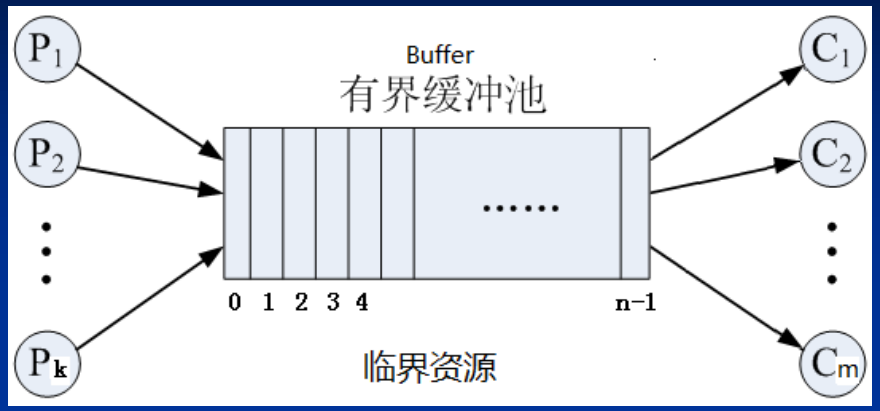
- 允许生产者写时，消费者可读




```
VAR mutexC, mutexP, empty, full: semaphore := 1,1, n, 0 ;
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
        repeat
           produce an item in nextp ;
           wait( empty ) ;
           wait( mutexP ) ;
           Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;
           signal( mutexP ) ;
           signal( full ) ;
        until false
   end

Consumer:
begin
     repeat
        wait( full ) ;
        wait( mutexC ) ;
        nextc = Buffer(out);
        out := (out + 1 ) mod n ;
        signal( mutexC ) ;
        signal( empty ) ;
        consume the item nextc ;
     until false
end
Parend
```

(2) 问题思考

- 缓冲池无限大

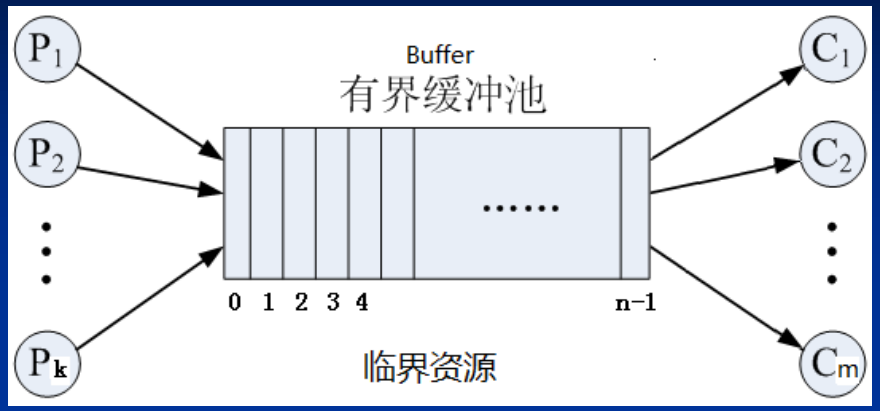


生产者-消费者标准程序

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
      in,out: integer := 0, 0 ;
      Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
    repeat
       produce an item in nextp ;
       wait( empty ) ;
       wait( mutex ) ;
       Buffer(in) := nextp ;
        in := (in + 1 ) mod n ;
        signal( mutex ) ;
        signal( full ) ;
    until false
 end
 Consumer:
 begin
     repeat
       wait( full ) ;
       wait( mutex ) ;
       nextc = Buffer(out);
       out := (out + 1 ) mod n ;
       signal( mutex ) ;
       signal( empty ) ;
       consume the item nextc ;
     until flase
 end
Parend
```

(2) 问题思考

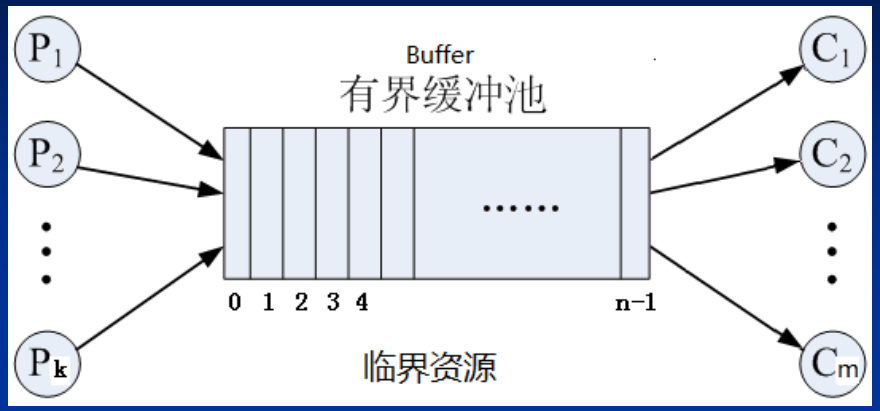
- 缓冲池无限大




```
VAR mutex, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
     repeat
        produce an item in nextp ;
        wait( mutex ) ;
        Buffer(in) := nextp ;
        in := (in + 1 ) mod n ;
        signal( mutex ) ;
        signal( full ) ;
     until false
   end
   Consumer:
   begin
     repeat
        wait( full ) ;
        wait( mutex ) ;
        nextc = Buffer(out);
        out := (out + 1 ) mod n ;
        signal( mutex ) ;

        consume the item nextc ;
     until flase
   end
Parend
```

(2) 问题思考

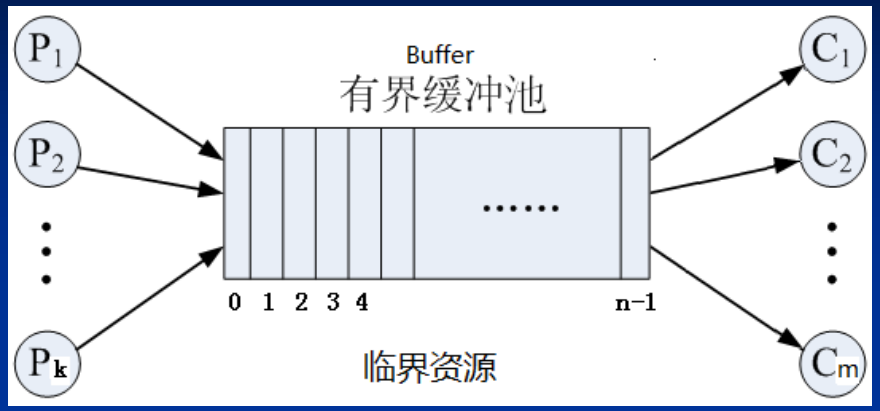
- 调整生产者wait顺序




```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
   Producer:
   begin
     repeat
          produce an item in nextp ;
          wait( mutex ) ;
          wait( empty ) ;
          Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;
           signal( mutex ) ;
           signal( full ) ;
       until false
   end
   Consumer:
   begin
     repeat
          wait( full ) ;
          wait( mutex ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( mutex ) ;
          signal( empty ) ;
          consume the item nextc ;
       until false
   end
Parend
```

(2) 问题思考

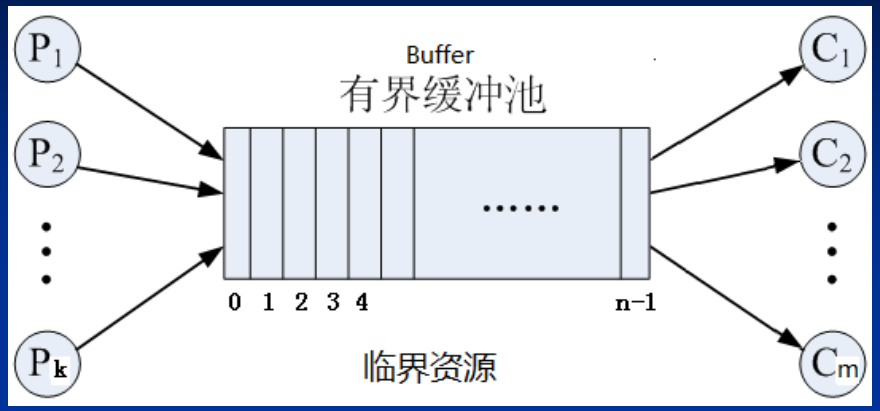
- 调整消费者wait顺序




```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
   repeat
     produce an item in nextp ;
      wait( empty ) ;
      wait( mutex ) ;
      Buffer(in) := nextp ;
      in := (in + 1 ) mod n ;
      signal( mutex ) ;
      signal( full ) ;
    until false
 end
 Consumer:
 begin
    repeat
       wait( mutex ) ;
       wait( full ) ;
       nextc = Buffer(out);
       out := (out + 1 ) mod n ;
       signal( mutex ) ;
       signal( empty ) ;
       consume the item nextc ;
    until flase
 end
Parend
```

(2) 问题思考

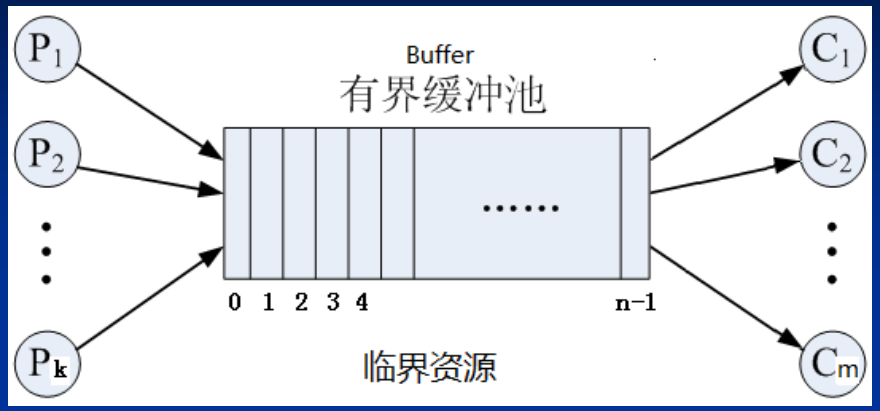
- 调整wait顺序




```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
    repeat
       produce an item in nextp ;
        wait( mutex ) ;
        wait( empty ) ;
        Buffer(in) := nextp ;
         in := (in + 1 ) mod n ;
         signal( mutex ) ;
         signal( full ) ;
     until false
 end
 Consumer:
 begin
     repeat
        wait( mutex ) ;
        wait( full ) ;
        nextc = Buffer(out);
        out := (out + 1 ) mod n ;
        signal( mutex ) ;
        signal( empty ) ;
        consume the item nextc ;
     until flase
 end
Parend
```

(2) 问题思考

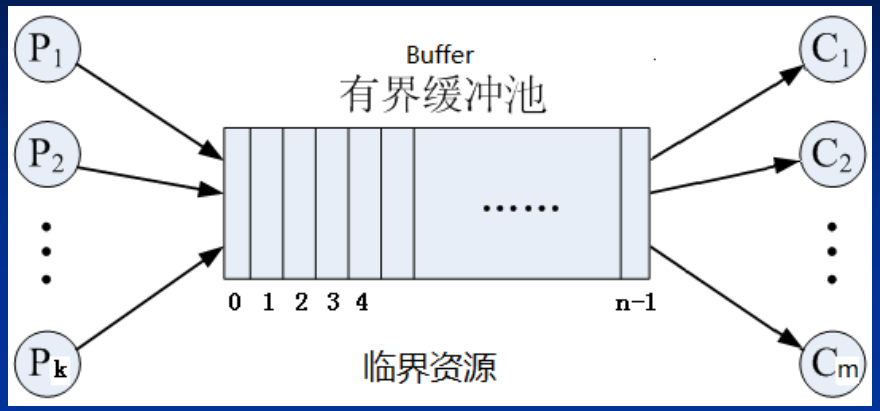
- 调整signal顺序




```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
  Producer:
  begin
      repeat
          produce an item in nextp ;
          wait( empty ) ;
          wait( mutex ) ;
          Buffer(in) := nextp ;
          in := (in + 1 ) mod n ;
          signal( mutex ) ;
          signal( full ) ;
      until false
    end
    Consumer:
    begin
      repeat
          wait( full ) ;
          wait( mutex ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( empty ) ;
          signal( mutex ) ;
          consume the item nextc ;
      until false
     end
Parend
```

(2) 问题思考

- 每个消费者消费每个消息1次



- 如何实现？

留给大家课后解决

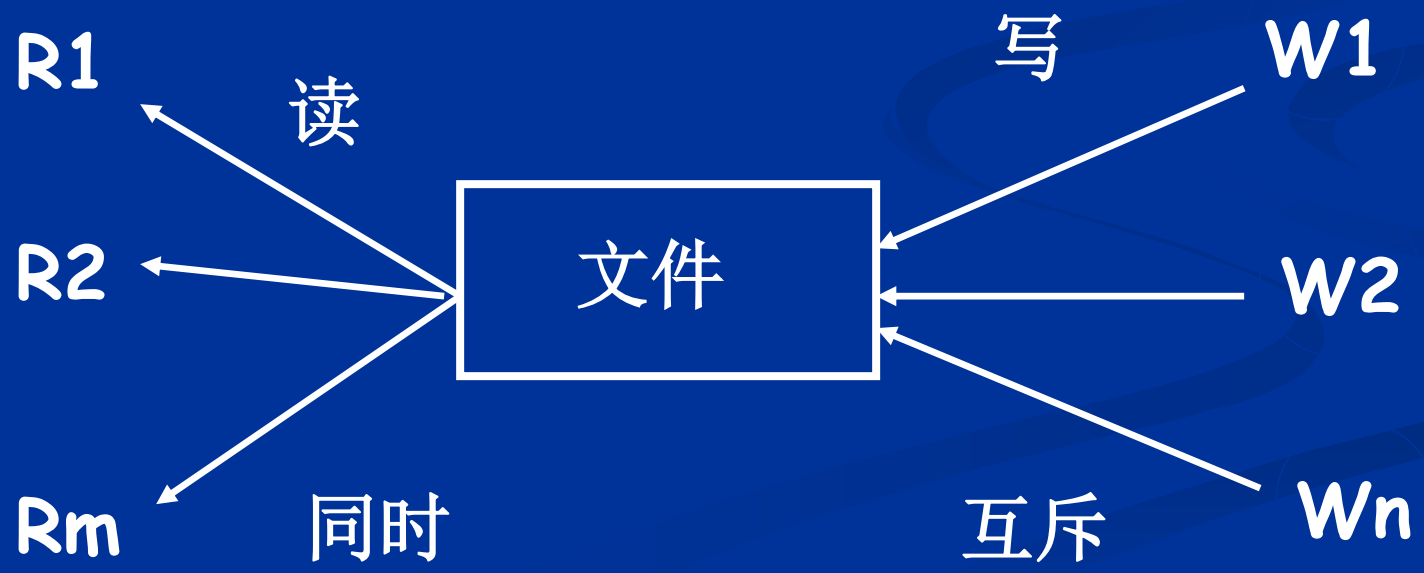
生产者-消费者标准程序

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
  Producer:
  begin
     repeat
          produce an item in nextp ;
          wait( empty ) ;
          wait( mutex ) ;
          Buffer(in) := nextp ;
           in := (in + 1 ) mod n ;
           signal( mutex ) ;
           signal( full ) ;
      until false
  end
  Consumer:
  begin
      repeat
          wait( full ) ;
          wait( mutex ) ;
          nextc = Buffer(out);
          out := (out + 1 ) mod n ;
          signal( mutex ) ;
          signal( empty ) ;
          consume the item nextc ;
       until flase
  end
Parend
```

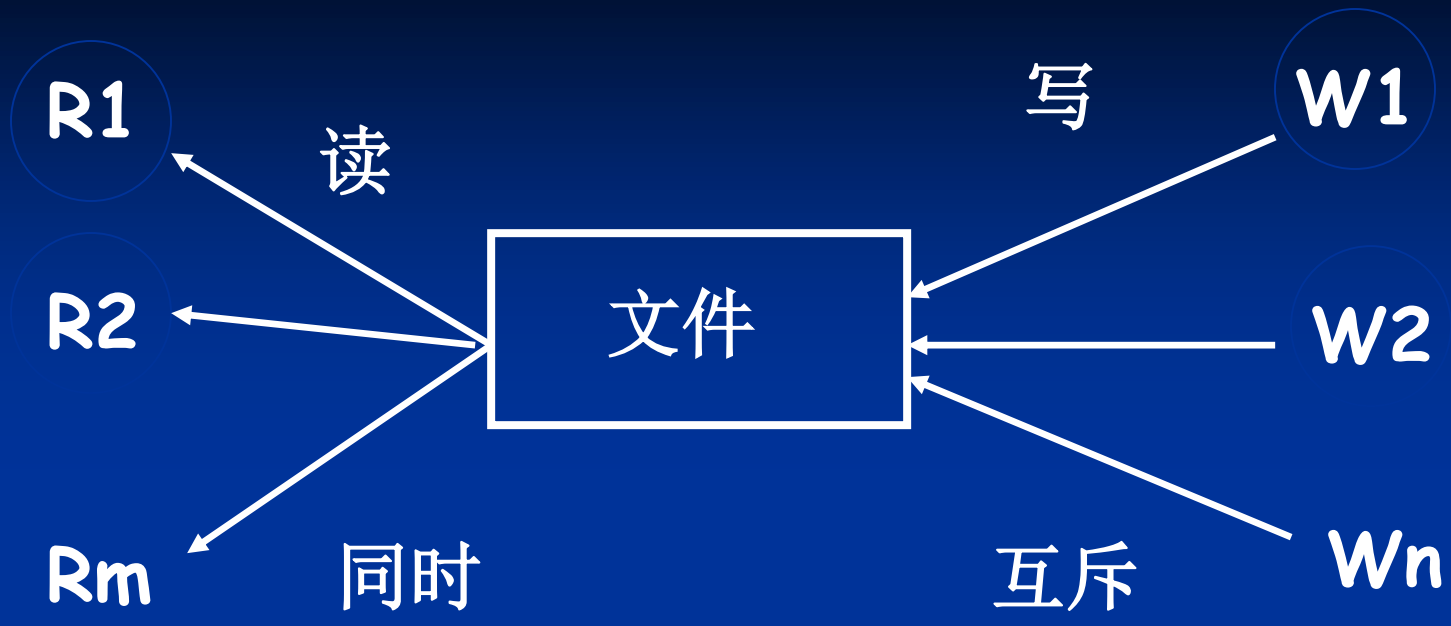
2.4 经典进程同步问题
2.4.2 读者-写者问题

(1) 读者写者问题

多个读者、多个写者共享资源（例如文件、数据等），允许多个读者同时访问资源，写者写时不允许其他进程读或写（互斥访问资源）。请用记录型信号量进行同步。



进程资源共享关系和同步关系分析



- 读者进程：不控制
- 写者进程：互斥
- 读者写者顺序：无

- 读者-写者并发程序实现

```
VAR wmutex: semaphore := 1 ;
Parbegin
 Reader:
 begin
    repeat
        wait( wmutex ) ;
        perform read operation ;
        signal( wmutex ) ;
     until false
 end
 Writer:
 begin
     repeat
        wait( wmutex ) ;
        perform write operation;
        signal( wmutex ) ;
     until false
 end
Parend
```

- 什么问题？

读者-写者并发程序实现

```
VAR wmutex: semaphore := 1 ;
        readcount: integer := 0 ;
Parbegin
  Reader:
  begin
     repeat
          if ( readcount = 0 ) wait( wmutex ) ;
          readcount := readcount + 1 ;
          perform read operation ;
          readcount := readcount - 1 ;
          if ( readcount = 0 ) signal( wmutex ) ;
       until false
  end
  Writer:
  begin
      repeat
          wait( wmutex ) ;
          perform write operation;
          signal( wmutex ) ;
       until flase
  end
Parend
```

什么问题？

读者-写者并发程序实现

```
VAR wmutex: semaphore := 1 ;
        readcount: integer := 0 ;
Parbegin
  Reader:
  begin
     repeat
          if  ( readcount = 0 ) wait( wmutex ) ;
          readcount := readcount + 1 ;
          perform read operation ;
          readcount := readcount - 1 ;
          if ( readcount = 0 ) signal( wmutex ) ;
       until false
  end
  Writer:
  begin
      repeat
          wait( wmutex ) ;
          perform write operation;
          signal( wmutex ) ;
       until flase
  end
Parend
```

读者-写者标准程序

```
VAR rmutex,wmutex: semaphore := 1, 1 ;
        readcount: integer := 0 ;
Parbegin
  Reader:
  begin
     repeat
          wait( rmutex ) ;
          if ( readcount = 0 ) wait( wmutex ) ;
          readcount := readcount + 1 ;
          signal( rmutex ) ;
          perform read operation ;
          wait( rmutex ) ;
          readcount := readcount - 1 ;
          if ( readcount = 0 ) signal( wmutex ) ;
          signal( rmutex ) ;
       until false
  end
  Writer:
  begin
      repeat
          wait( wmutex ) ;
          perform write operation;
          signal( wmutex ) ;
       until flase
  end
Parend
```

读者-写者标准程序

```
VAR rmutex,wmutex: semaphore := 1, 1 ;
        readcount: integer := 0 ;
Parbegin
  Reader:
  begin
     repeat
          wait( rmutex ) ;
          if ( readcount = 0 ) wait( wmutex ) ;
          readcount := readcount + 1 ;
          signal( rmutex ) ;
          perform read operation ;
          wait( rmutex ) ;
          readcount := readcount - 1 ;
          if ( readcount = 0 ) signal( wmutex ) ;
          signal( rmutex ) ;
       until false
  end
  Writer:
  begin
      repeat
          wait( wmutex ) ;
          perform write operation;
          signal( wmutex ) ;
      until false
  end
Parend
```

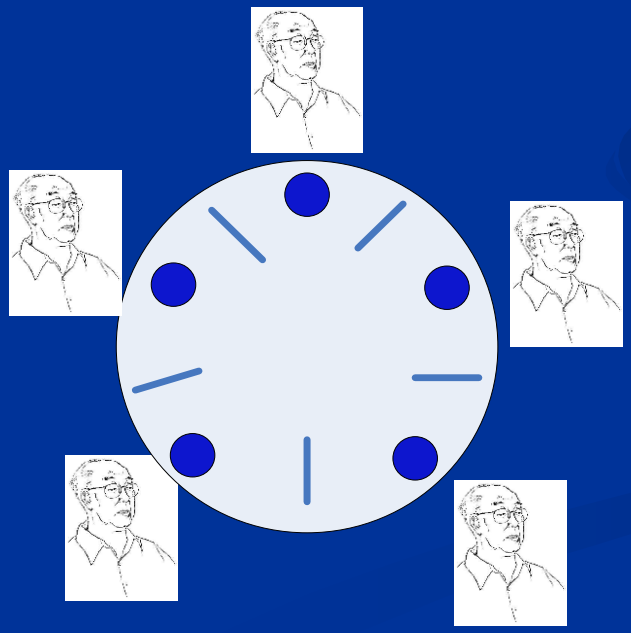
(2) 标准程序的2个问题

- 执行wait和signal的进程
- 临界区设置

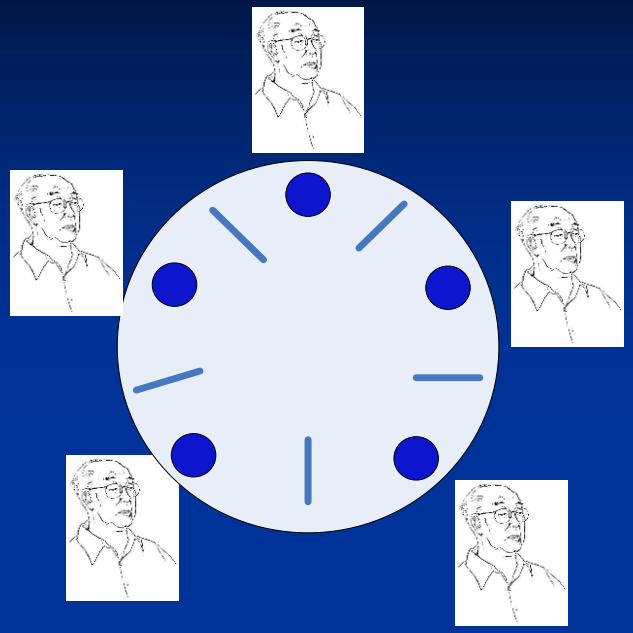
2.4 经典进程同步问题
2.4.3 哲学家进餐问题

(1) 哲学家进餐问题

5位哲学家围绕圆桌而坐，反复思考和进餐。但是只有5只碗和筷子，放置如图所示，只有当哲学家同时拿起碗边的2只筷子时，才能进餐。请用记录型信号量进行同步。

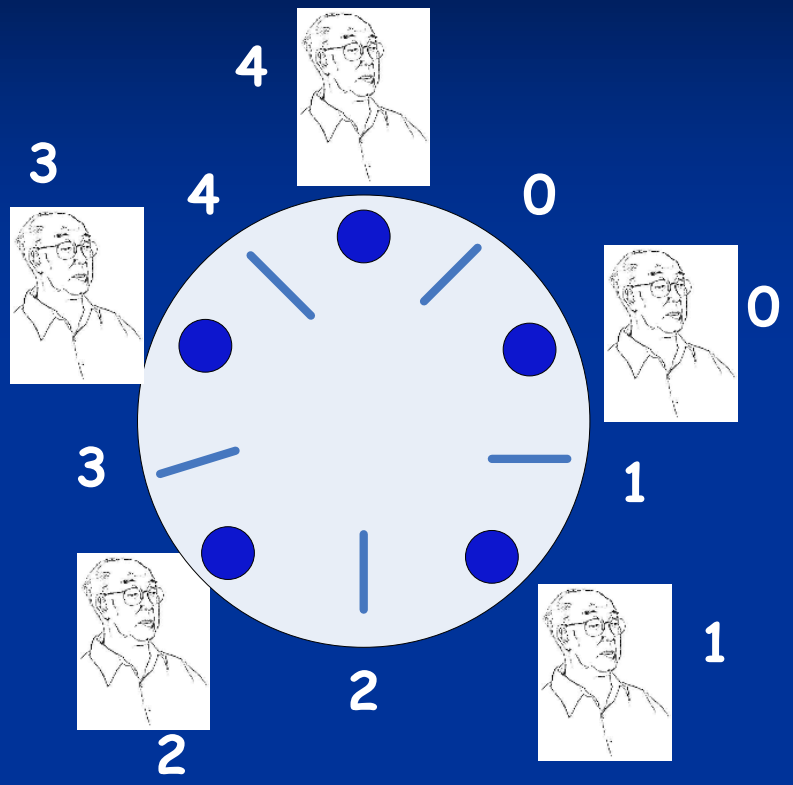


进程资源共享关系和同步关系分析



- 哲学家进程：互斥（筷子）

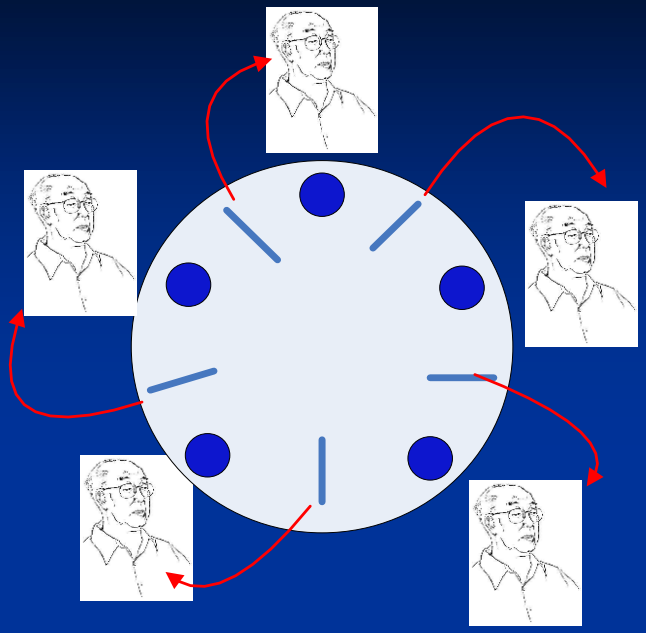
哲学家进餐问题实现

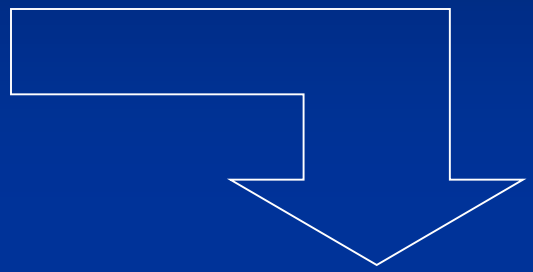


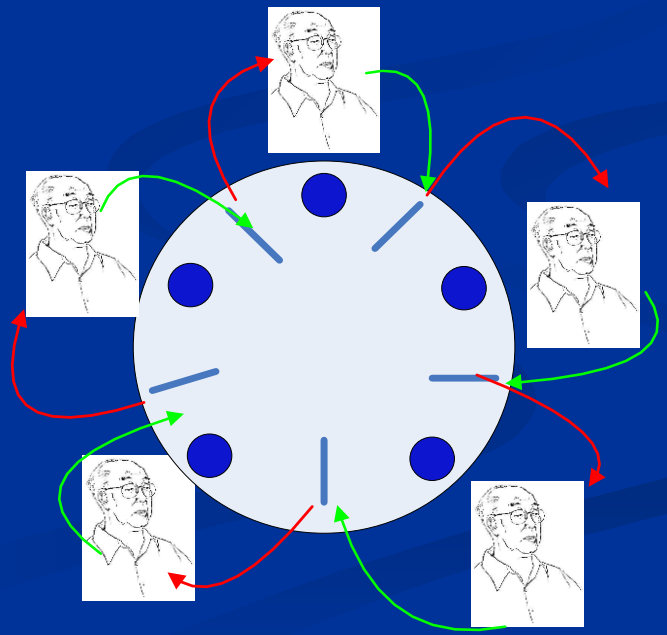

```
VAR chopsticks: array [0..4] of semaphore := 1,1,1,1,1 ;
Parbegin
 philosopher i:
 begin
    repeat
        wait( chopsticks[ i ] ) ;
        wait( chopsticks[ (i+1) mod 5 ] );
        eat ;
        signal( chopsticks[ i ] ) ;
        signal( chopsticks[ (i+1) mod 5 ] );
        think
    until false
 end
Parend
```

- 问题：正确吗？

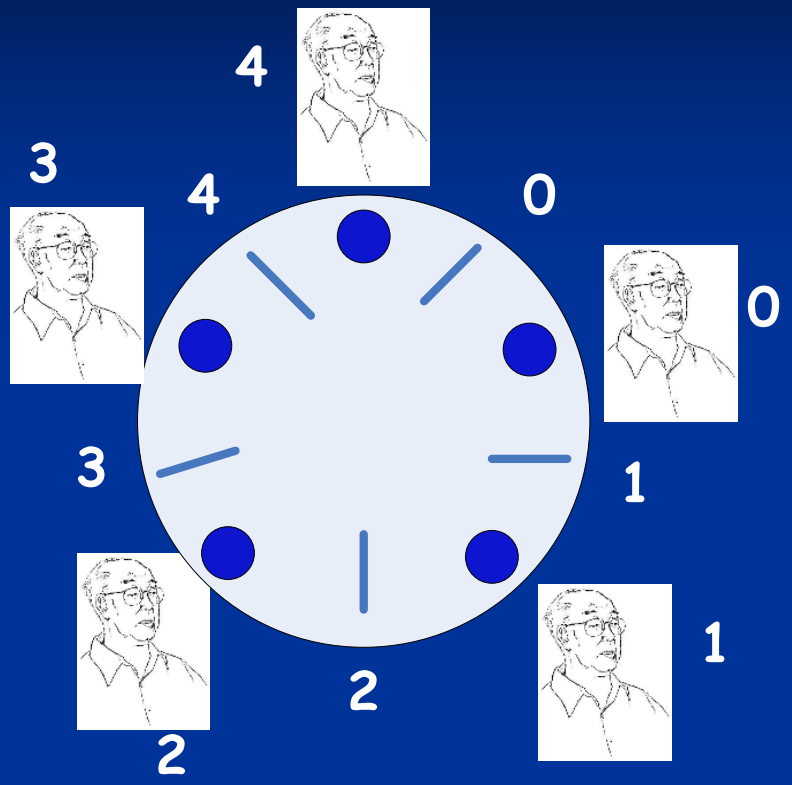
(2) 哲学家进餐程序的问题







哲学家进餐标准程序




```
VAR chopsticks: array [0..4] of semaphore := 1,1,1,1,1 ;
Parbegin
    philosopher0-3:
    begin
       repeat
            wait( chopsticks[ i ] ) ;
            wait( chopsticks[ (i+1) mod 5 ] );
            eat ;
           signal( chopsticks[ i ] ) ;
           signal( chopsticks[ (i+1) mod 5 ] );
        think
         until false
    end
 philosopher4:
 begin
     repeat
        wait( chopsticks[ (i+1) mod 5 ] );
        wait( chopsticks[ i ] ) ;
        eat ;
        signal( chopsticks[ i ] ) ;
        signal( chopsticks[ (i+1) mod 5 ] );
        think
    until false
 end
Parend
```

- 原则：按序申请资源

2.4 经典进程同步问题
2.4.4 理发师问题(课后思考题)

(1) 睡眠理发师问题

理发店有一位理发师，一把理发椅和n把用来等候理发的椅子。如果没有顾客，则理发师便在理发椅上睡觉，顾客到来时，如理发师闲则理发，否则如有空椅则坐等，没有空椅则离开，编写程序实现理发师和顾客程序，实现进程控制。

2.4 经典进程同步问题
2.4.5 信号量集机制

(1) AND型信号量集机制

- 基本思想：
  - 将进程在整个运行过程中需要的所有资源，一次性全部地分配给进程，待进程使用完后再一起释放。
  - 对若干个临界资源的分配，采取原子操作方式要么全部分配到进程，要么一个也不分配。
  - 为此，在wait操作中，增加了一个“AND”条件，故称为AND同步。

2.4.5 信号量集机制

(1) AND型信号量集机制

- 实现：

```
type semaphore = record
    value: integer ;                    // 资源数量
    L: list of process ;                // 阻塞进程队列
end

function Swait ( var S1,S2,..,Sn ： Semaphore )
Begin
   if ( S1 >= 1 and ... and Sn >= 1 )
      for i := 1 to n do
         Si := Si -1 ;
   else
      Place the process in the queue associated with the first Si found with Si < 1, and
      goto the beginning of Swait.
end
function Ssignal(var S1, S2, .., Sn ： Semaphore )
Begin
   for i:=1 to n do
     Si := Si +1
     Remove all process waiting in the queue associated with Si into the ready queue.
end
```

2.4.5 信号量集机制

(1) AND型信号量集机制

- 应用示例1：生产者消费者问题

```
VAR mutex, empty, full: semaphore := 1, n, 0 ;
        in,out: integer := 0, 0 ;
        Buffer: array [0..n-1] of item ;
Parbegin
 Producer:
 begin
   repeat
      produce an item in nextp ;
      Swait( empty, mutex ) ;
      Buffer(in) := nextp ;
      in := (in + 1 ) mod n ;
      Ssignal( mutex, full ) ;
    until false
 end
 Consumer:
 begin
     repeat
        Swait( full,mutex ) ;
        nextc = Buffer(out);
        out := (out + 1 ) mod n ;
        Ssignal( mutex,empty ) ;
        consume the item nextc ;
     until false
 end
Parend
```

2.4.5 信号量集机制

(1) AND型信号量集机制

- 应用示例2：哲学家进餐问题

```
VAR chopsticks: array [0..4] of semaphore := 1,1,1,1,1 ;
Parbegin
 philosopheri:
 begin
    repeat
        Swait( chopsticks[ i ], chopsticks[ (i+1) mod 5 ] ) ;
        eat ;
        Ssignal( chopsticks[ i ], chopsticks[ (i+1) mod 5 ] ) ;
        think
     until false
 end
Parend
```

2.4 经典进程同步问题
2.4.5 信号量集机制

(2) 一般信号量集机制

- 基本思想：
  - 在AND型信号量基础上，一次可申请多个单位资源。

2.4.5 信号量集机制

(2) 一般信号量集机制

- 实现：

```
type semaphore = record
    value: integer ;                    // 资源数量
    L: list of process ;                // 阻塞进程队列
end

function Swait ( var S1,t1,d1,S2,t2,d2..,Sn,tn,dn ： Semaphore )
Begin
   if ( S1 >= t1 and ... and Sn >= tn )
      for i := 1 to n do
         Si := Si -di ;
   else
      Place the process in the queue associated with the first Si found with Si < ti, and
      goto the beginning of Swait.
end
function Ssignal(var S1, d1,S2,d2, .., Sn,dn ： Semaphore )
Begin
   for i:=1 to n do
     Si := Si +di
     Remove all process waiting in the queue associated with Si into the ready queue.
end
```

2.4.5 信号量集机制

(2) 一般信号量集机制

- 应用实例：读者写者问题

RN: 允许读者进程上限

```
VAR RN: integer  ;
        L,mutex: semaphore := RN, 1 ;
Parbegin
  Reader:
  begin
     repeat
          Swait( L,1,1,  mutex,1,0) ;
          perform read operation ;
          Ssignal( L, 1 ) ;
       until false
  end
  Writer:
  begin
      repeat
          Swait( mutex,1,1, L,RN,0 ) ;
          perform write operation;
          Ssignal( mutex,1 ) ;
       until false
  end
Parend
```

- 问题分析
  可否再简化程序？