Chapter 9

High-level Synchronization

Introduction to Concurrency

- **Concurrency**
  - Execute two or more pieces of code "at the same time“
- **Why ?**
  - No choice:
    - Geographically distributed data
    - Interoperability of different machines
    - A piece of code must "serve" many other client processes
    - To achieve reliability
  - By choice:
    - To achieve speedup
    - Sometimes makes programming easier (e.g., UNIX pipes)

Possibilities for Concurrency

Architecture:	**Program Style:**
Uniprocessor with: - I/O channel - I/O processor - DMA	Multiprogramming, multiple process system programs
Multiprocessor	Parallel programming
Network of processors	Distributed Programs

Examples of Concurrency in Uniprocessors

Example 1: Unix pipes

Motivations:
- fast to write code
- fast to execute

Example 2: Buffering

Motivation:

- required when two *asynchronous* processes must communicate

Example 3: Client/Server model

Motivation:

- geographically distributed computing

Concurrency Conditions

Let *Si* denote a statement.

Read set of Si:

R (Si) = { a1, a2, ..., an }

Set of all variables referenced in Si

Write set of Si:

W (Si) = { b1, b2, ..., bm },

Set of all variables changed by Si

Concurrency Conditions…

C = A - B

R (C = A - B) = { A, B }

W (C = A - B) = { C }

cin >> A

R (cin >> A) = { }

W (cin >> A) = { A }

Bernstein's Conditions

The following conditions must hold for two statements S1 and S2 to execute concurrently with valid results:

1) R (S1) INTERSECT W (S2) = { }

2) W (S1) INTERSECT R (S2) = { }

3) W (S1) INTERSECT W (S2) = { }

These are called the **Bernstein Conditions.**

Structured Parallel Constructs

PARBEGIN / PAREND

PARBEGIN Sequential execution splits off into several concurrent sequences

PAREND Parallel computations merge

```
PARBEGIN
  Statement 1;
  Statement 2;
     ⋮
  Statement N;
PAREND;
```

```
PARBEGIN
    Q = C mod 25;
    Begin
        N = N - 1;
        T = N / 5;
    End;
    Proc1 ( X, Y );
PAREND;
```

Parbegin / Parend Examples

```
Begin
    PARBEGIN
        A = X + Y;
        B = Z + 1;
    PAREND;
    C = A - B;
    W = C + 1;
End;
```

```
Begin
    S1;
    PARBEGIN
        S3;
        BEGIN
            S2;
            S4;
            PARBEGIN
                S5;
                S6;
            PAREND;
        End;
    PAREND;
    S7;
End;
```

Monitors

- P & V are primitive operations
- Semaphore solutions are difficult to accurately express for complex synchronization problems
- Need a High-Level solution: Monitors
- A Monitor is a collection of procedures and shared data
- Mutual Exclusion is enforced at the monitor boundary by the monitor itself
- Data may be global to all procedures in the monitor or local to a particular procedure
- No access of data is allowed from outside the monitor

Condition Variables

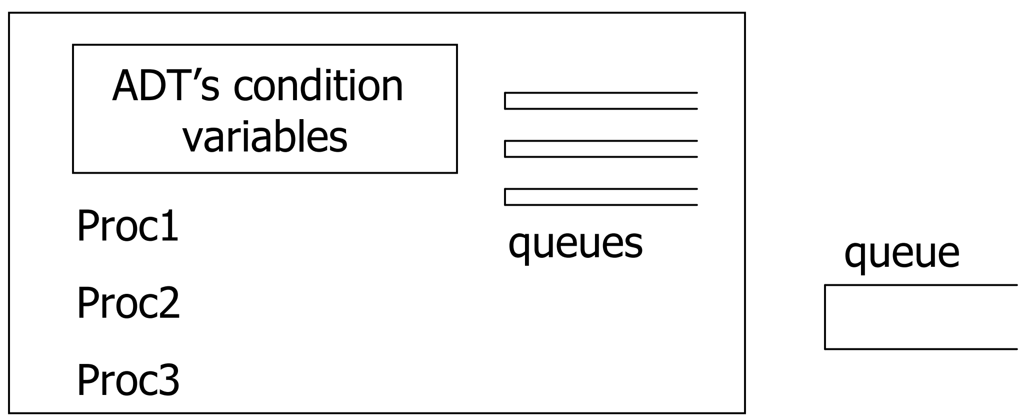
- Within the monitor, Condition Variables are declared
- A queue is associated with each condition variable
- Only two operations are allowed on a condition variable:

X.wait	The procedure performing the wait is put on the queue associated with x
X.signal	If queue is non-empty: resume *some* process at the point it was made to wait

- Note: V operations on a semaphore are "remembered," but if there are no waiting processes, the signal has no effect
- OS scheduler decides which of several waiting monitor calls to unlock upon signal

Monitor…

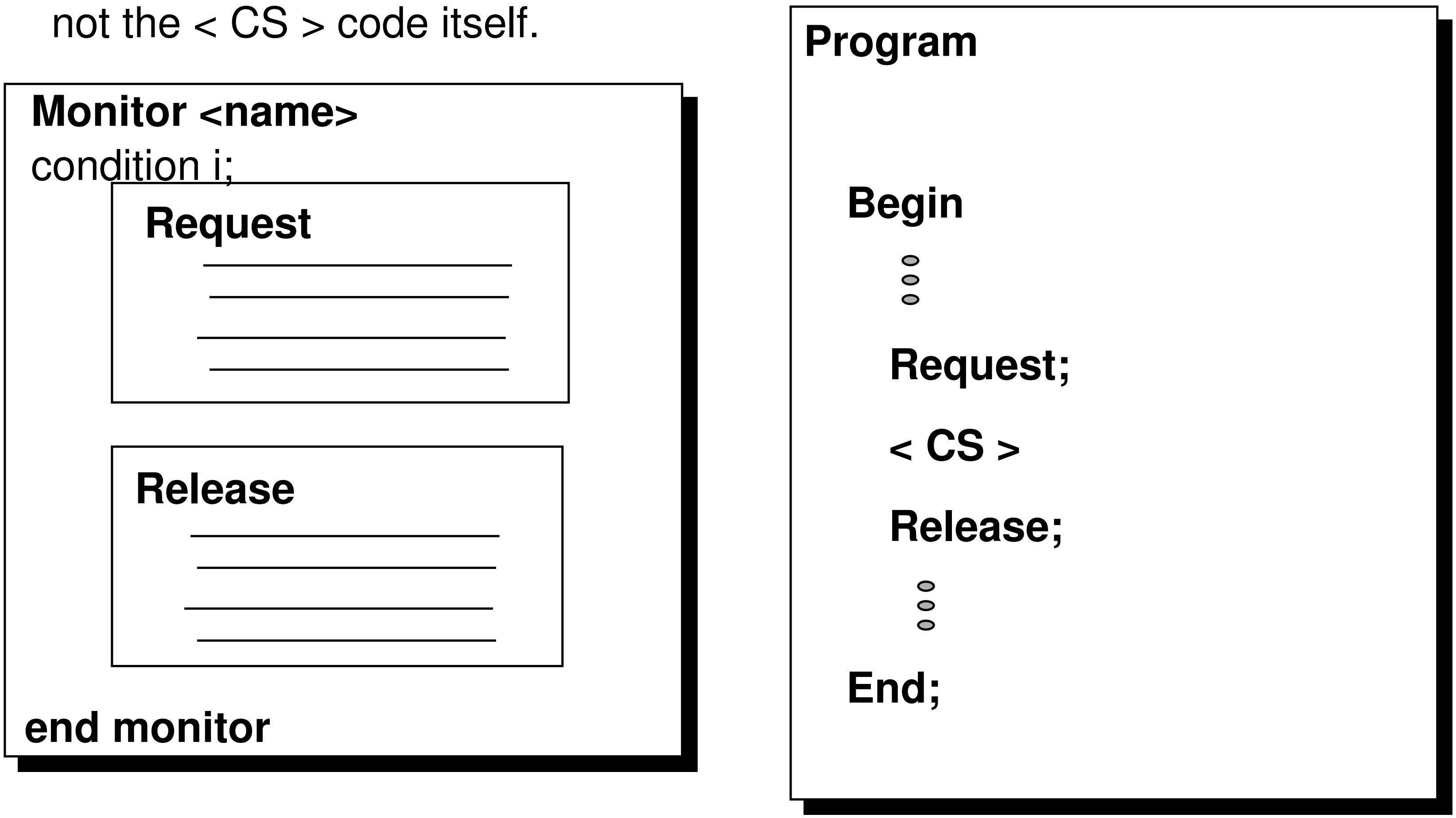
- Queue to enter monitor via calls to procedures
- Queues within the monitors via condition variables
- ADTs and condition variables only accessible via monitor procedure calls



Monitors…

Monitors contain procedures that control access to a < CS >, but

not the < CS > code itself.



N-Process Critical Section: Monitor Solution

```
Monitor NCS {
     OK: condition
     Busy: boolean <-- FALSE

    Request() {
         if (Busy) OK.wait;
         Busy = TRUE;
    }
   Release() {
         Busy = FALSE;
         OK.signal;
  }
}
```

```
Procedure P {
  NCS.Request();
  <CS>;
  NCS.Release();
}
```

```
main() {
parbegin P;P;P;P; parend }
```

Shared Variable Monitor

```
monitor sharedBalance {
      int balance;
public:
      Procedure credit(int amount)
            { balance = balance + amount;}
      Procedure debit(int amount)
            { balance = balance - amount;}
}
```

Reader & Writer Schema

```
reader() {
   while(true){
       ...
       startRead();
       <read the resource>
       finishRead();
       ...
    }
}
```

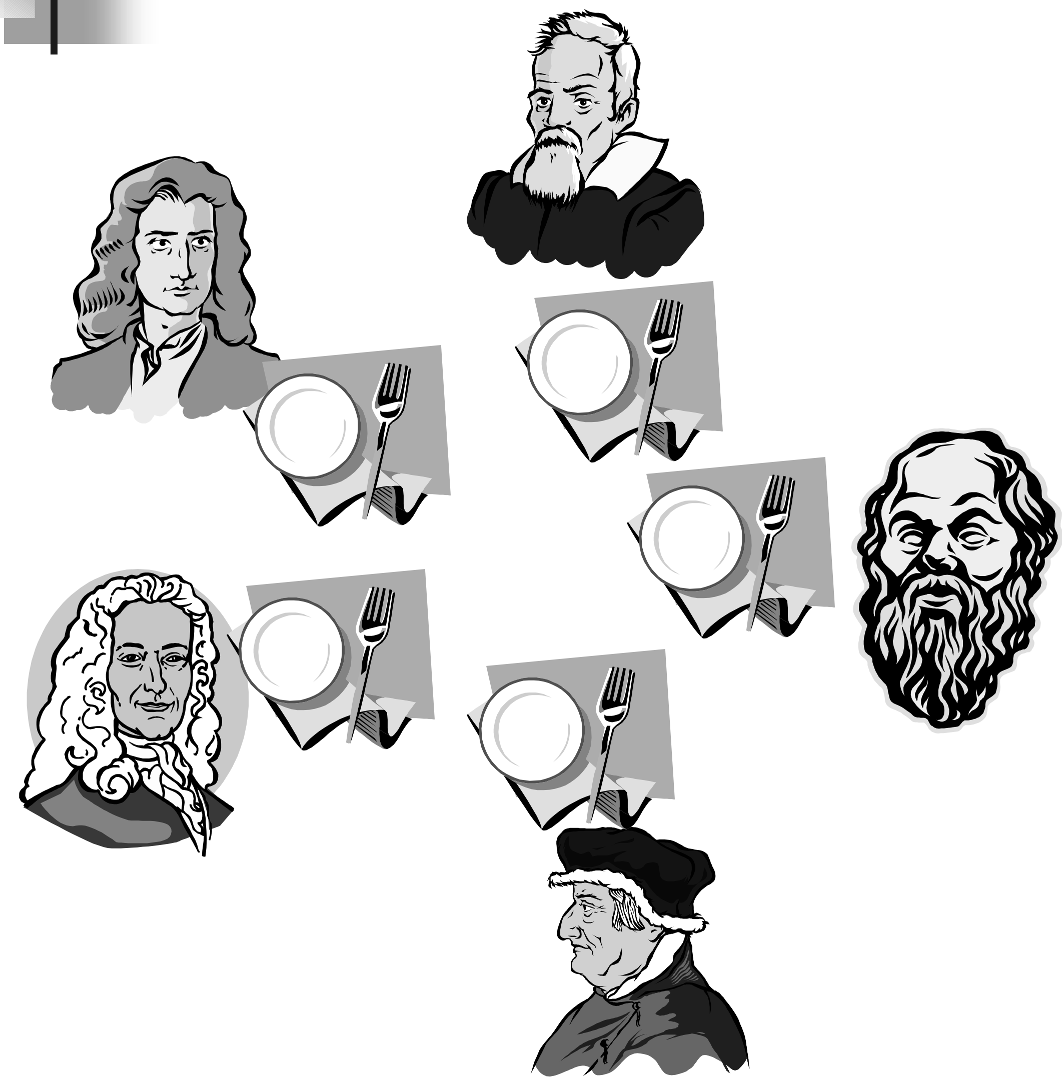
```
writer() {
   while(true){
       ...
       startWrite();
       <write resource>
       finishWrite();
       ...
    }
}
```

```
fork(reader, 0);
fork(reader, 0);
fork(writer, 0);
```

Reader & Writers Problem: The solution

```
monitor reader_writer_2{
   int numberOfReaders = 0;
   boolean busy = false;
   condition okToRead, okToWrite;
public:
   startRead(){
       if(busy || okToWrite.queue) okToRead.wait;
        numberOfReaders = numberOfReaders+1;
        okToRead.signal;
       }
   finishRead() {
        numberOfReaders = numberOfReaders-1;
        if(numberOfReaders =0) okToWrite.signal;
       }
   startWrite(){
        if(busy || numberOfReaders != 0) okToWrite.wait;
        busy = true;
       }
   finishWrite() {
        busy = false;
        if(okToWrite.queue) okToWrite.signal;
        else okToRead.signal;
       }
}
```

Dining Philosophers' Problem



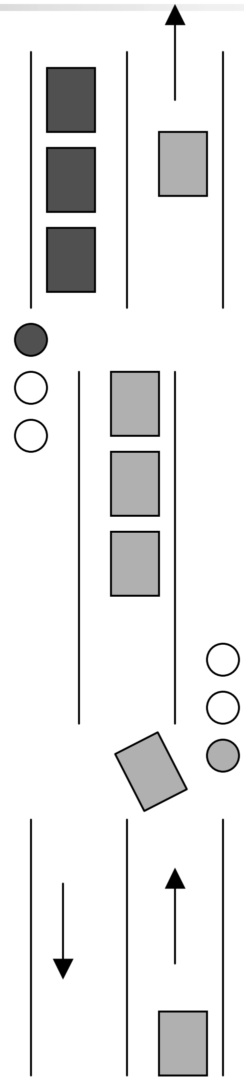
```
while(TRUE) {
  think();
  eat();
}
```

Dining Philosophers' Problem: The solution

```
enum status {eating, hungry, thinking};
monitor diningPhilosophers{
   status state[N];  condition self[N];  int j;
// This procedure can only be called from within the monitor
   test(int i) {
         if((state[i-1 MOD N] != eating) && (state[i] == hungry)
                 && (state[i+1 MOD N] != eating) ) {
            state[i] = eating;
            self[i].signal;
         }
public:
  pickUpForks(){
         state[i] = hungry;
         test(i);
         if(state[i] != eating) self[i].wait;
   }
   putDownForks(){
         state[i] = thinking;
         test(i-1 MOD N); test(i+1 MOD N);
   }
   diningPhilosophers() { // Monitor initialization code
         for(int i=0; i<N; i++) state[i] = thinking;
   }
}
```

Example: Synchronizing Traffic

- One-way tunnel
- Can only use tunnel if no oncoming traffic
- OK to use tunnel if traffic is already flowing the right way



Example: Synchronizing Traffic

```
monitor tunnel {
  int northbound = 0, southbound = 0;
  trafficSignal nbSignal = RED, sbSignal = GREEN;
  condition busy;
public:
  nbArrival() {
    if(southbound > 0) busy.wait();
    northbound++;
    nbSignal = GREEN; sbSignal = RED;
  };
  sbArrival() {
    if(northbound > 0) busy.wait();
    southbound++;
    nbSignal = RED; sbSignal = GREEN;
  };
```

Example: Synchronizing Traffic

```
depart(Direction exit) (
    if(exit = NORTH {
      northbound--;
      if(northbound == 0)
            while(busy.queue())
               busy.signal();
    else if(exit == SOUTH) {
      southbound--;
      if(southbound == 0) while(busy.queue())
  busy.signal();
    }
  }
}
```

Monitor implementation of a ring buffer

```
monitor ringBufferMonitor;
var ringBuffer: array[0..slots-1] of stuff;
    slotInUse: 0..slots;
    nextSlotToFill: 0..slots-1;
    nextSlotToEmpty: 0..slots-1;
    ringBufferHasData, ringBufferHasSpace: condition;
procedure fillASlot(slotData: stuff);
begin
        if(slotInUse = slots) then wait(ringBufferHasSpace);
        ringBuffer[nextSlotToFill] = slotData;
        slotInUse = slotInUse + 1;
        nextSlotToFill = (nextSlotToFill+1) MOD slots;
        signal(ringBufferHasData);
end;
```

Monitor implementation of a ring buffer…

```
procedure emptyASlot(var slotData: stuff);
begin
        if(slotInUse = 0) then wait(ringBufferHasData);
        slotData = ringBuffer[nextSlotToEmpty];
        slotInUse = slotInUse - 1;
        nextSlotToEmpty = (nextSlotToEmpty-1) MOD slots;
        signal(ringBufferSpace);
end;
begin
        slotInUSe = 0;
        nextSlotToFill = 0;
        nextSlotToEmpty = 0;
end.
```