Monitors

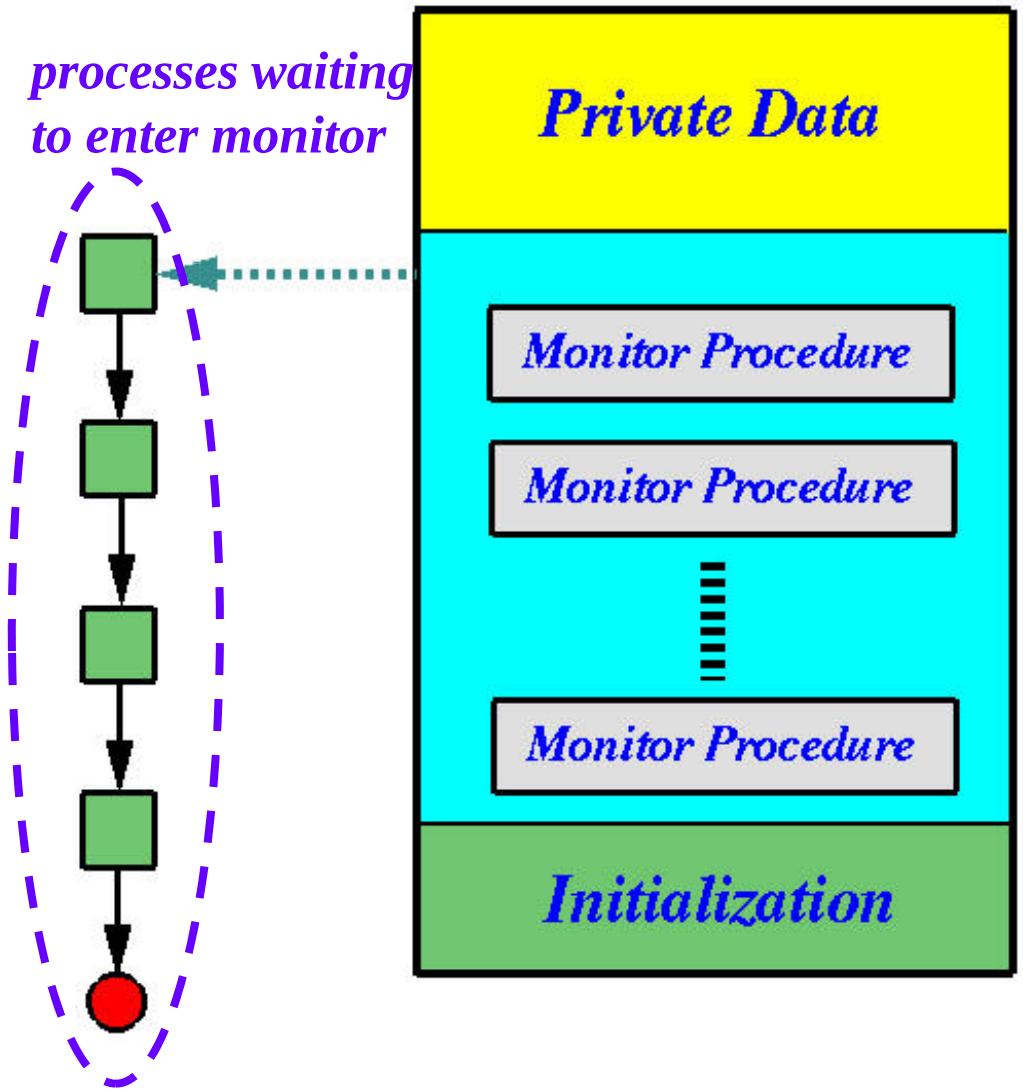
What Is a Monitor? - Basics

- **Monitor is a highly structured programming language construct. It consists of**
  - **Private variables and private procedures that can only be used within a monitor.**
  - **Constructors that initialize the monitor.**
  - **A number of (public) monitor procedures that can be invoked by users.**
- **Note that monitors have no public data.**
- **A monitor is a mini-OS with monitor procedures as system calls.**

Monitor: Mutual Exclusion 1/2

- ***No more than one process*** **can be executing *in* a monitor. Thus, *mutual exclusion* is automatically guaranteed in a monitor.**
- **When a process calls a monitor procedure and enters the monitor successfully, it is the *only* process executing in the monitor.**
- **When a process calls a monitor procedure and the monitor has a process running, the caller is blocked outside of the monitor.**

Monitor: Mutual Exclusion 2/2



- **If there is a process executing in a monitor, any process that calls a monitor procedure is blocked *outside* of the monitor.**
- **When the monitor has no executing process, one process will be let in.**

Monitor: Syntax

```
monitor Monitor-Name
{
    local variable declarations;

    Procedure1(…)
    { // statements };
    Procedure2(…)
    { // statements };
    // other procedures
    {
      // initialization
    }
}
```

- **All variables are private. *Why? Exercise!***
- ***Monitor procedures are public*; however, some procedures can be made private so that they can only be used within a monitor.**
- ***Initialization procedures* (*i.e.*, constructors) execute only once when the monitor is created.**

Monitor: A Very Simple Example

```
monitor IncDec
{
    int  count;
    void Increase(void)
    { count++; }

    void Decrease(void)
    { count--; }

    int GetData(void)
    {  return count; }

    {  count = 0; }
}
```

initialization

process Increment

```
while (1) {
    // do something
    IncDec.Increase();
    cout <<
       IncDec.GetData();
    // do something
}
```

Condition Variables

- **Mutual exclusion is an easy task with monitors.**
- **While a process is executing *in* a monitor, a process may have to wait until an event occurs.**
- **Each programmer-defined event is artificially associated with a *condition variable*.**
- **A condition variable, or a condition, has a waiting list, and two methods: `signal` and `wait`.**
- **Note that a condition variable has no value and cannot be modified**

Condition wait

- **Let `cv` be a condition variable. The use of methods `signal` and `wait` on `cv` are `cv.signal()` and `cv.wait()`.**
- **Condition wait and condition signal can only be used *in a monitor*.**
- **A process that executes a condition wait blocks immediately and is put into the waiting list of that condition variable.**
- **This means that this process is waiting for the indicated event to occur.**

Condition signal

- **Condition `signal` is used to indicate an event has occurred.**
- **If there are processes waiting on the signaled condition variable, one of them will be released.**
- **If there is no waiting process waiting on the signaled condition variable, this signal is lost as if it never occurs.**
- **Consider the released process (from the signaled condition) and the process that signals. There are two processes executing in the monitor, and mutual exclusion is violated!**

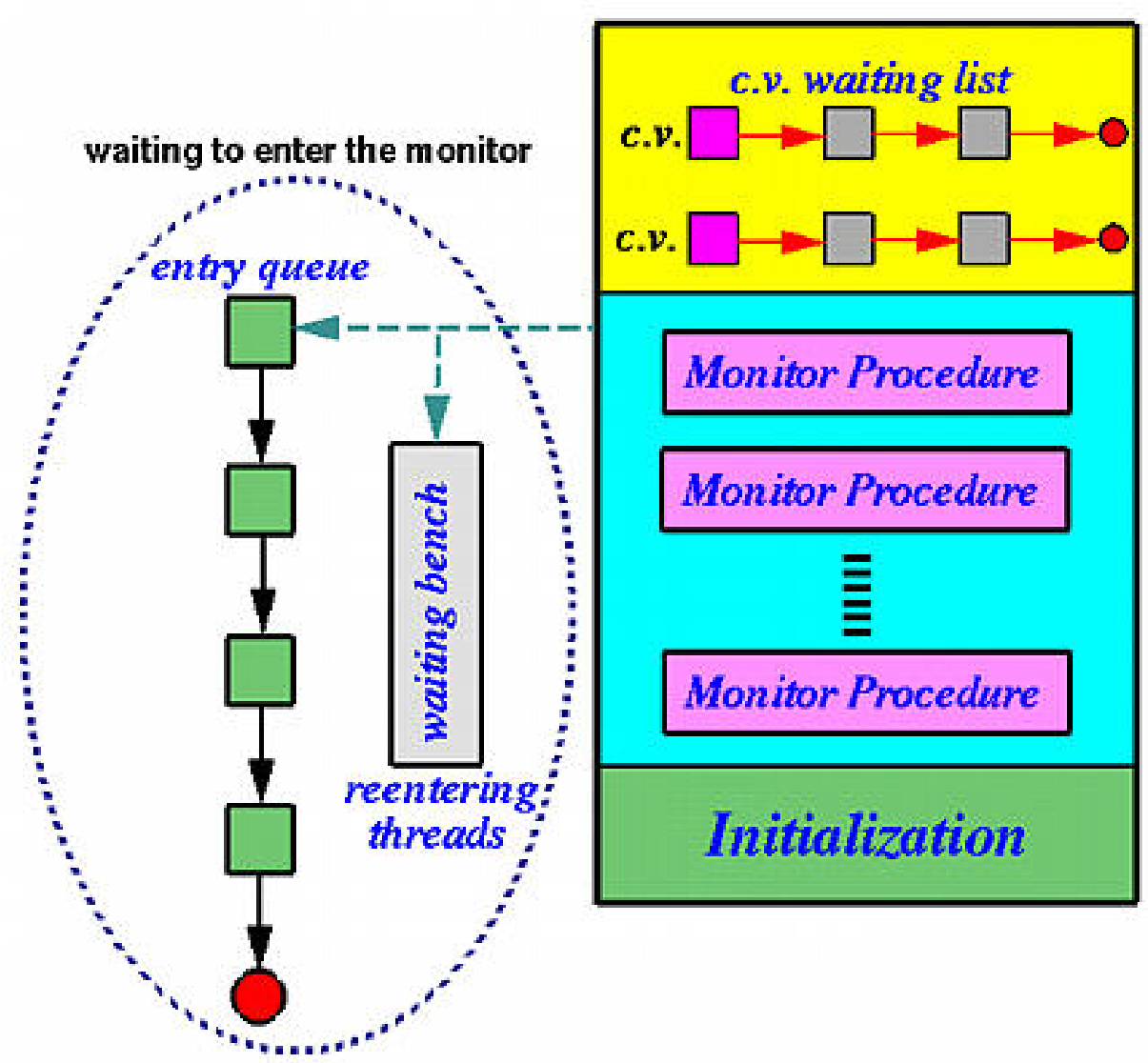
Two Types of Monitors

- **After a signal, the released process and the signaling process may be executing in the monitor.**
- **There are two common and popular approaches to address this issue:**
  - **Hoare Type (proposed by C.A.R.Hoare): The released process takes the monitor and the signaling process waits somewhere.**
  - **Mesa Type (proposed by Lampson and Redell): The released process waits somewhere and the signaling process continues to use the monitor.**

What Do You Mean by "Waiting Somewhere"?

- **The signaling process (Hoare type) or the released process (Mesa type) must wait somewhere.**
- **You could consider there is a waiting bench for these processes to wait.**
- **As a result, each process that involves in a monitor call may be in one of the four states:**
  - ***Active*: The running one**
  - ***Entering*: Those blocked by the monitor**
  - ***Waiting*: Those waiting on a condition variable**
  - ***Inactive*: Those waiting on the waiting bench**

Monitor with Condition Variables



- **Processes suspended due to signal/wait are in the *Re-entry* list (*i.e.*, waiting bench).**
- **When the monitor is free, a process is released from either *entry* or *re-entry* .**

What is the major difference?

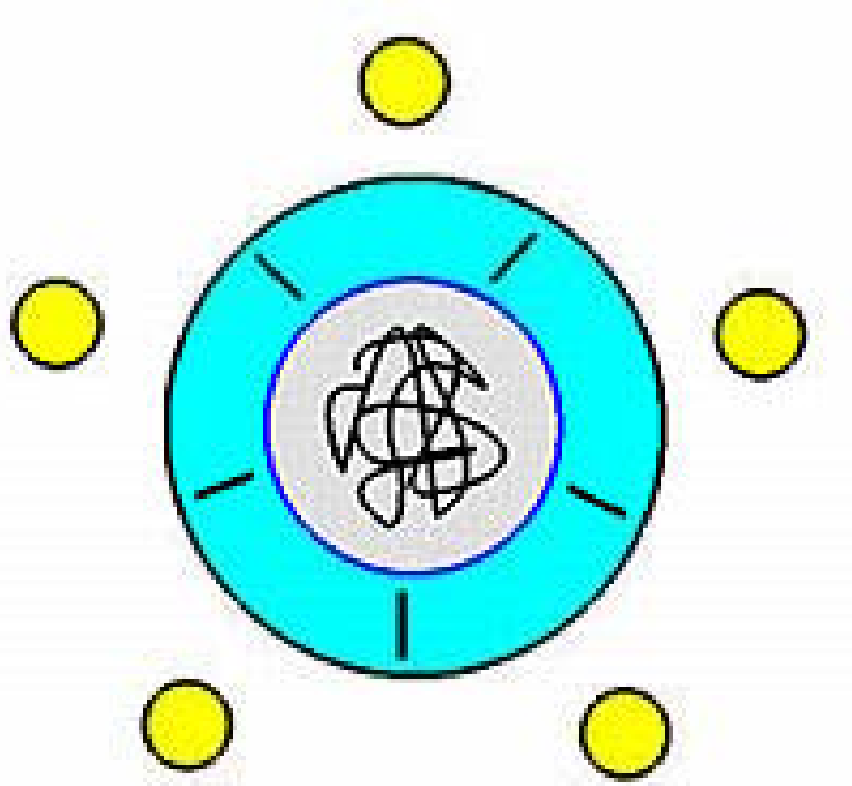
```
Condition  UntilHappen;

// Hoare Type
if (!event)
  UntilHappen.wait();

// Mesa Type
while (!event)
  UntilHappen.wait();
```

With Hoare type, once a signal arrives, the signaler yields the monitor to the released process and the condition is not changed. Thus, a `if` is sufficient.

With Mesa type, the released process may be suspended for a while before it runs. During this period, other processes may be in the monitor and change the condition. It is better to check the condition again with a `while`!

Monitor: Dining Philosophers Revisited

- **Instead of picking up chopsticks one by one, we insist that a philosopher can eat only if he can *pick up both simultaneously*.**
- **Can we use a semaphore to protect chopsticks 0 and 1, another for 1 and 2, and so on? *No, no, no*.**
- ***Race condition!!!!!***



Monitor Definition

```
monitor Control
{
    bool used[5];
    condition self[5];
    private:
        int CanEat(int);

    procedure GET(int);
    procedure PUT(int);

    { // initialization
      for (i=0;i<5;i++)
          used[i] = FALSE;
    }
}
```

```
int  CanEat(int i)
{
  if (!Used[i] &&
       !Used[(i+1)%5])
    return TRUE;
  else
    return FALSE;
}
```

Function `CanEat()` returns `TRUE` if both chops for Philosopher *i* are available.

Monitor: GET() and PUT()

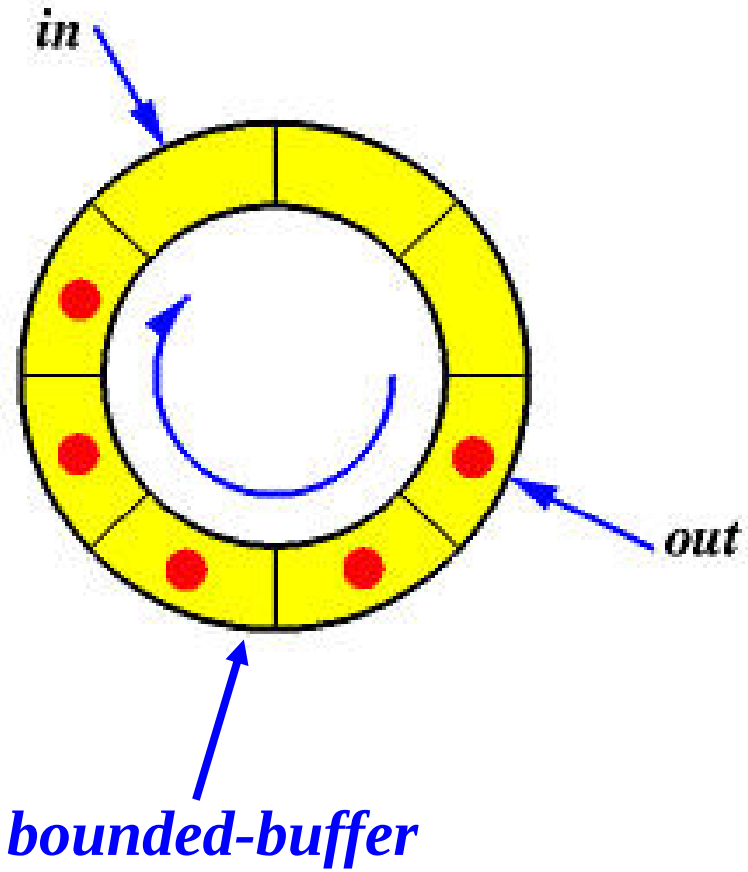
Why a `while` *rather than a* `if` `even with a Hoare monitor?`

```
void GET(int i)
{
  while (!CanEat(i))
     self[i].wait();
  Used[i] = TRUE;
  Used[(i+1)%5] = TRUE;
}
```

```
void PUT(int i)
{
  Used[i] = FALSE;
  Used[(i+1)%5]
     = FALSE;
  for (i=0;i<5;i++)
    self[i].signal();
}
```

- In fact, `PUT()` only requires to signal `self[(i+1)%5]` and `self[(i+4)%5]`, the two neighbors of philosopher *i*.
- Does it really matter? Why? How about Deadlock?

Monitor: Producer/Consumer

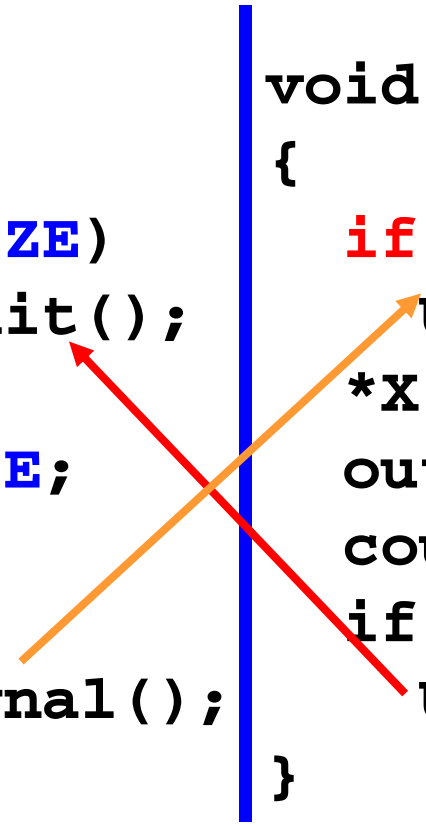



```
monitor ProdCons
{
   int count, in, out;
   int Buf[SIZE];
   condition
      UntilFull,
      UntilEmpty;

   procedure PUT(int);
   procedure GET(int *);
   { count = 0}
}
```

Monitor: PUT() and GET()

```
void PUT(int X)
{
  if (count == SIZE)
    UntilEmpty.wait();
  Buf[in] = X;
  in = (in+1)%SIZE;
  count++;
  if (count == 1)
    UntilFull.signal();
}
```

```
void GET(int *X)
{
  if (count == 0)
    UntilFull.wait();
  *X = Buf[out];
  out=(out+1)%SIZE;
  count--;
  if (count == SIZE-1)
    UntilEmpty.signal();
}
```



Dining Philosophers: Again!

- **In addition to thinking and eating, a philosopher has one more state, hungry, in which he is trying to get chops.**
- **We use an array `state[]` to keep track the state of a philosopher. Thus, philosopher *i* can eat (*i.e.*, `state[i] = EATING`) only if his neighbors are not eating (*i.e.*, `state[(i+4)%5]` and `state[(i+1)%5]` are not `EATING`).**

Monitor Definition

```
monitor philosopher
{
   enum { THINKING,HUNGRY,
          EATING} state[5];
   condition  self[5];
   private: test(int);

   procedure GET(int);
   procedure PUT(int);

   { for (i=0;i<5;i++)
        state[i] = THINKING;
   }
}
```

The test() Procedure

the left and right neighbors of philosopher k are not eating

```
void  test(int k)
{
   if ((state[(k+4)%5] != EATING) &&
       (state[k] == HUNGRY) &&
       (state[(k+1)%5] != EATING)) {
           state[k] = EATING;
           self[k].signal();
   }
}
```

philosopher k is hungry

- If the left and right neighbors of philosopher *k* are not eating and philosopher *k* is hungry, then philosopher *k* can eat. Thus, release him!

The GET() and PUT() Procedures

```
void GET(int i)
{
    state[i] = HUNGRY;
    test(i);
    if (state[i] != EATING)
        self[i].wait();
}
```

I am hungry

see if I can eat

If I could not eat, block myself

I finished eating

Let my neighbors use my chops

```
void PUT(int i)
{
    state[i] = THINKING;
    test((i+4) % 5);
    test((i+1) % 5);
}
```

Which type of monitor am I using?

How about Deadlock?

```
void test(int k)
{
  if ((state[(k+4)%5] != EATING) &&
      (state[k] == HUNGRY) &&
      (state[(k+1)%5] != EATING)) {
          state[k] = EATING;
          self[k].signal();
  }
}
```

- This solution does not have deadlock, because
  - The only place where eating permission is granted is in procedure `test()`, and …..
  - Philosopher *k* can eat only if his neighbors are not eating. Thus, no two neighboring philosophers can eat at the same time.

Hoare Type vs. Mesa Type

- **When a signal occurs, Hoare type monitor uses two context switches, one switching the signaling process out and the other switching the released in. However, Mesa type monitor uses one.**
- **Process scheduling must be very reliable with Hoare type monitors to ensure once the signaling process is switched out the next one must be the released process. Why?**
- **With Mesa type monitors, a condition may be evaluated multiple times. However, incorrect signals will do less harm because every process checks its own condition.**

Semaphore vs. Condition

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 increases the semaphore counter	`signal()` either releases a process, or the signal is lost as if it never occurs
If `signal()` releases a process, the caller and the released *both continue*	If `signal()` releases a process, either the caller or the released continues, but *not both*

The End