# Semaphore

- Synchronization tool that provides more sophisticated ways (than Mutex locks)  for process to synchronize their activities.
- Semaphore ***S*** – integer variable
- Semaphore ("apparatus for signalling," from Greek sema "sign, signal" and phoros "bearer") is the use of an apparatus to create a visual signal transmitted over distance. A semaphore can be performed with devices including: fire, lights, flags, sunlight and moving arms
- The semaphore concept was invented by Dutch computer scientist Edsger Dijkstra in 1962 or 1963, when Dijkstra and his team were developing an operating system for the Electrologica X8. That system eventually became known as THE multiprogramming system.
- Can only be accessed via two indivisible (atomic) operations
  - **`wait()`** and **`signal()`**
    - Originally wait() called **`P()Dutch proberen, ("to test");`** **`signal() was originally called V() verhogen, ("to increment")`**

# Semaphore

- Semaphore ***S*** – integer variable
- Definition of the **`wait() operation`**

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

- Definition of the **`signal() operation`**

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

# Semaphore Usage

- **Counting semaphore** – integer value can range over an unrestricted domain
- **Binary semaphore** – integer value can range only between 0 and 1
  - Same as a **mutex lock**
- Can solve various synchronization problems
- Consider $P_1$ and $P_2$ that require $S_1$ to happen before $S_2$

  Create a semaphore "**synch**" initialized to 0

```
P1:
    S1;
    signal(synch);
P2:
    wait(synch);
    S2;
```

- Can implement a counting semaphore $S$ as a binary semaphore

# Semaphore Implementation

- Must guarantee that no two processes can execute the **`wait()`** and **`signal()`** on the same semaphore at the same time
- Thus, the implementation becomes the critical section problem where the **`wait`** and **`signal`** code are placed in the critical section
  - Could now have **busy waiting** in critical section implementation
    - But implementation code is short
    - Little busy waiting if critical section rarely occupied
- Note that applications may spend lots of time in critical sections and therefore this is not a good solution

# Semaphore Implementation with no Busy waiting

- With each semaphore there is an associated waiting queue
- Each entry in a waiting queue has two data items:
  - value (of type integer)
  - pointer to next record in the list
- Two operations:
  - **block** – place the process invoking the operation on the appropriate waiting queue
  - **wakeup** – remove one of processes in the waiting queue and place it in the ready queue
-
```
typedef struct{
 int value;
 struct process *list;
 } semaphore;
```

# Implementation with no Busy waiting (Cont.)

```
wait(semaphore *S) {
    S->value--;
    if (S->value < 0) {
        add this process to S->list;
        block();
    }
}
signal(semaphore *S) {
    S->value++;
    if (S->value <= 0) {
        remove a process P from S->list;
        wakeup(P);
    }
}
```

# Deadlock and Starvation

- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes
- Let ***S*** and ***Q*** be two semaphores initialized to 1

| $P_0$ | $P_1$ |
|---|---|
| `wait(S);` | `wait(Q);` |
| `wait(Q);` | `wait(S);` |
| `...` | `...` |
| `signal(S);` | `signal(Q);` |
| `signal(Q);` | `signal(S);` |

- **Starvation** – **indefinite blocking**
  - A process may never be removed from the semaphore queue in which it is suspended
- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process
  - Solved via **priority-inheritance protocol**

# Classical Problems of Synchronization

- Classical problems used to test newly-proposed synchronization schemes
  - Bounded-Buffer Problem
  - Readers and Writers Problem
  - Dining-Philosophers Problem

# Bounded-Buffer Problem

- ***n*** buffers, each can hold one item
- Semaphore **`mutex`** initialized to the value 1
- Semaphore **`full`** initialized to the value 0
- Semaphore **`empty`** initialized to the value n

# Bounded Buffer Problem (Cont.)

- The structure of the producer process

```
do {
     ...
     /* produce an item in next_produced */
     ...
  wait(empty);
  wait(mutex);
      ...
     /* add next produced to the buffer */
      ...
  signal(mutex);
  signal(full);
} while (true);
```

# Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```
     Do {
          wait(full);
          wait(mutex);
               . . .
          /* remove an item from buffer to
next_consumed */
               . . .
          signal(mutex);
          signal(empty);
               . . .
          /* consume the item in next consumed */
               . . .
     } while (true);
```

# Readers-Writers Problem

- A data set is shared among a number of concurrent processes
  - Readers – only read the data set; they do ***not*** perform any updates
  - Writers – can both read and write
- Problem – allow multiple readers to read at the same time
  - Only one single writer can access the shared data at the same time
- Several variations of how readers and writers are considered – all involve some form of priorities
- Shared Data
  - Data set
  - Semaphore **`rw_mutex`** initialized to 1
  - Semaphore **`mutex`** initialized to 1
  - Integer **`read_count`** initialized to 0

# Readers-Writers Problem Variations

- ***First*** variation – no reader kept waiting unless writer has permission to use shared object
- ***Second*** variation – once writer is ready, it performs the write ASAP
- Both may have starvation leading to even more variations
- Problem is solved on some systems by kernel providing reader-writer locks

# Readers-Writers Problem (Cont.)

- The structure of a writer process

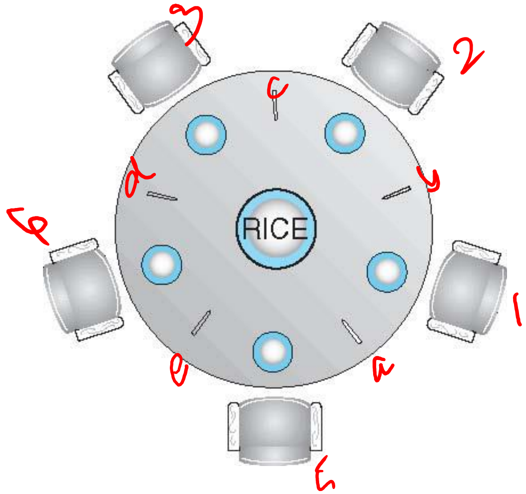
```
do {
     wait(rw_mutex);
          ...
     /* writing is performed */
          ...
   signal(rw_mutex);
} while (true);
```

# Readers-Writers Problem (Cont.)

- The structure of a reader process

```
do {
        wait(mutex);
        read_count++;
        if (read_count == 1)
           wait(rw_mutex);
        signal(mutex);
       ...
        /* reading is performed */
       ...
        wait(mutex);
        read count--;
        if (read_count == 0)
           signal(rw_mutex);
        signal(mutex);
} while (true);
```

# Dining-Philosophers Problem




- Philosophers spend their lives alternating thinking and eating
- Don’t interact with their neighbors, occasionally try to pick up 2 chopsticks (one at a time) to eat from bowl
  - Need both to eat, then release both when done
- In the case of 5 philosophers
  - Shared data
    - Bowl of rice (data set)
    - Semaphore chopstick [5] initialized to 1

# Dining-Philosophers Problem Algorithm

- The structure of Philosopher *i*:

```
do {
    wait (chopstick[i] );
    wait (chopStick[ (i + 1) % 5] );

        //  eat

    signal (chopstick[i] );
    signal (chopstick[ (i + 1) % 5] );

        //  think

} while (TRUE);
```

- What is the problem with this algorithm?

# Dining-Philosophers Problem Algorithm (Cont.)

- Deadlock handling
  - Allow at most 4 philosophers to be sitting simultaneously at  the table.
  - Allow a philosopher to pick up  the forks only if both are available (picking must be done in a critical section.
  - Use an asymmetric solution  -- an odd-numbered philosopher picks  up first the left chopstick and then the right chopstick. Even-numbered philosopher picks  up first the right chopstick and then the left chopstick.

# Problems with Semaphores

- Incorrect use of semaphore operations:
  - signal (mutex) …. wait (mutex)
  - wait (mutex) … wait (mutex)
  - Omitting of wait (mutex) or signal (mutex) (or both)
- Deadlock and starvation are possible.

# Monitors

- A high-level abstraction that provides a convenient and effective mechanism for process synchronization
- *Abstract data type*, internal variables only accessible by code within the procedure
- Only one process may be active within the monitor at a time
- But not powerful enough to model some synchronization schemes

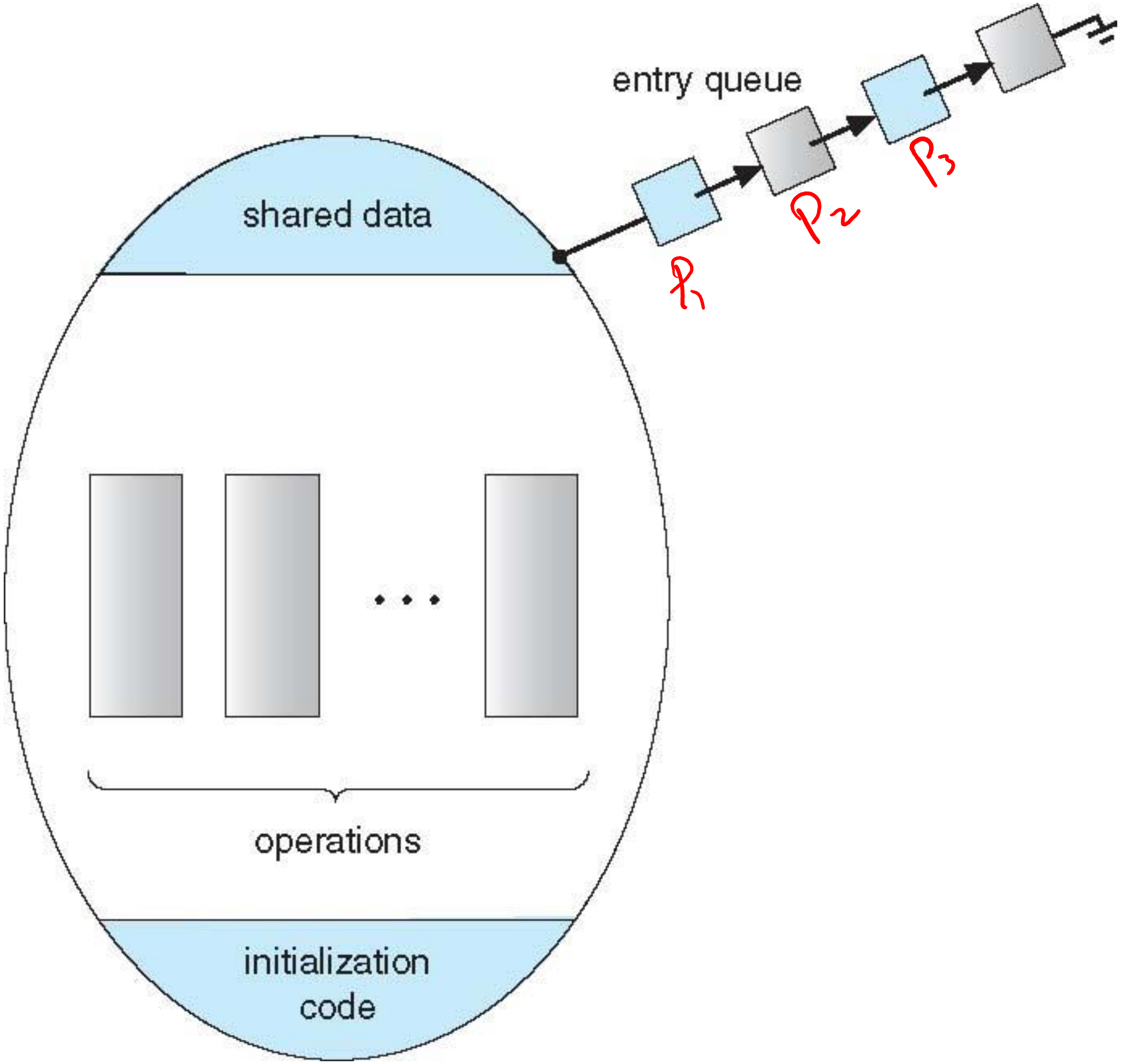
```
monitor monitor-name
{
  // shared variable declarations
  procedure P1 (…) { …. }

  procedure Pn (…) {……}

      Initialization code (…) { … }
  }
}
```

Runnable

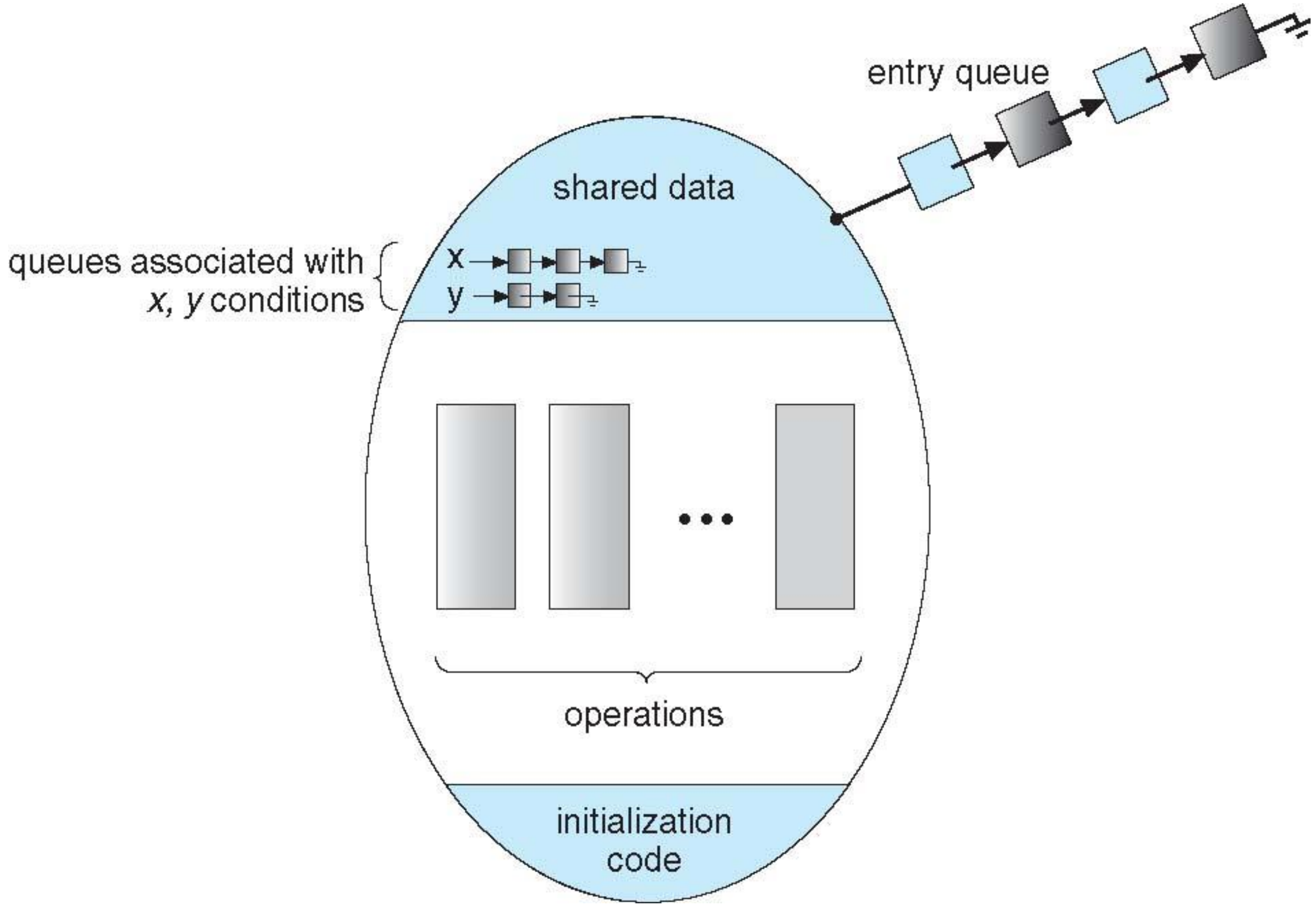
# Schematic view of a Monitor



# Condition Variables

- **`condition x, y;`**
- Two operations are allowed on a condition variable:
  - **`x.wait()`** – a process that invokes the operation is suspended until **`x.signal()`**
  - **`x.signal()`** – resumes one of processes (if any) that invoked **`x.wait()`**
    - If no **`x.wait()`** on the variable, then it has no effect on the variable

# Monitor with Condition Variables



# Condition Variables Choices

- If process P invokes **`x.signal()`**, and process Q is suspended in **`x.wait()`**, what should happen next?
  - Both Q and P cannot execute in parallel. If Q is resumed, then P must wait
- Options include
  - **Signal and wait** – P waits until Q either leaves the monitor or it waits for another condition
  - **Signal and continue** – Q waits until P either leaves the monitor or it waits for another condition
  - Both have pros and cons – language implementer can decide

# Monitor Solution to Dining Philosophers

```
monitor DiningPhilosophers
{
   enum { THINKING; HUNGRY, EATING} state [5] ;
   condition self [5];

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

    void putdown (int i) {
          state[i] = THINKING;
                   // test left and right neighbors
           test((i + 4) % 5);
           test((i + 1) % 5);
}
```

# Solution to Dining Philosophers (Cont.)

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

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

# Solution to Dining Philosophers (Cont.)

- Each philosopher *i* invokes the operations **`pickup()`** and **`putdown()`** in the following sequence:

```
DiningPhilosophers.pickup(i);

    EAT

DiningPhilosophers.putdown(i);
```

- No deadlock, but starvation is possible

# Monitor Implementation Using Semaphores

- Variables

```
semaphore mutex;  // (initially  = 1)
semaphore next;   // (initially  = 0)
int next_count = 0;
```

- Each procedure ***F*** will be replaced by

Reading Assignment

```
wait(mutex);
     …
     body of F;
     …
if (next_count > 0)
 signal(next)
else
 signal(mutex);
```

- Mutual exclusion within a monitor is ensured

# Monitor Implementation – Condition Variables

- For each condition variable ***x***, we have:

```
semaphore x_sem; // (initially  = 0)
int x_count = 0;
```

- The operation x.wait can be implemented as:

```
x_count++;
if (next_count > 0)
   signal(next);
else
   signal(mutex);
wait(x_sem);
x_count--;
```

# Monitor Implementation (Cont.)

- The operation **`x.signal`** can be implemented as:

```
if (x_count > 0) {
   next_count++;
   signal(x_sem);
   wait(next);
   next_count--;
}
```

# End of Chapter 6