Concurrency

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Criteria for Evaluating Concurrent Programming Constructs

- With advanced mechanisms for **concurrency control**, we should consider the following criteria:
  - **Applicability to Centralized and Distributed System**
  - **Expressive Power**
  - **Modularity**
  - **Ease of Use**
  - **Program Structure**
  - **Real-Time Systems**
  - **Process Failure & Timeouts**
  - **Unanticipated Faults**

Criteria: Applicability

- Applicability to Centralized and Distributed System
  - Since there are times when both centralized systems and distributed systems need to interact, it is best if such constructs can work in both directions and both environments.
  - **Centralized system (the shared memory model)**
  - **Distributed system (the loosely-coupled model)**

Criteria: Expressive Power

- Exclusion constraints
  - Does the construct provide for **mutual exclusion**?
- Priority constraints
  - Is the construct able to express **priority between processes**?
- Conditions
  - Does the construct permit that **certain conditions** must be satisfied before a process can execute? Such conditions would include the following:
    - Type of request (e.g. readers versus writers)
    - Time of request (e.g. timestamps)
    - Request parameters (e.g. filename)
    - Process information (e.g. for load balancing)
    - Priority relations (static)
    - Local state of resources (e.g. to prevent overloading)
    - History information (e.g. for aging)

Criteria: Modularity

- We should consider two differing viewpoints
  - The operating system should **regulate access to all shared resources**
  - The operating system should **regulate interaction between processes** (shared memory versus message passing)
- This provides two orthogonal modularization criteria
  - **Resources** should be **separated from each other.**
    - Each may contain synchronization and scheduling information and operations.
  - **Synchronization and scheduling** should be **separated from operation and state.**
    - We may need to allow for some global control.

Criteria: Ease of Use

- How **difficult or complex** is it to **construct** a solution using the given construct?
- Can a problem be **broken into single parts**?
- Is it **easy to modify** a solution? (e.g. add or change a constraint)

Criteria: Program Structure

- Does the structure of the mechanism fit **well with the overall program structures**?
- Does the structure help the programmer avoid problems? (e.g. nested monitor calls)

Criteria: Real-Time Systems

- **Concurrent** programming techniques are not used much in real-time programming languages
  - They would need to include facilities for
    - **Time-out**
    - Time-of-day
    - Delay for a certain length of time
    - Etc
  - They would need **run-time error handling**, *even for unrecoverable errors.*

Criteria: Failures

- Process Failures and Timeouts
  - We want to keep the **failure** of one process from affecting other processes
  - We need to be able to **detect a failure** and know
    - If it was caused by a **timeout**
    - If it was caused by another **exception**
  - It would be best if we can define **exception handling** procedures as part of the structure
    - Such procedures need to leave the **state consistent**.
    - Such procedures may **cost some efficiency**.
    - Such procedures should try to avoid mutual exclusion, if only synchronization is needed – If mutual exclusion is needed, it can be done more efficiently in hardware or firmware.

Criteria: Faults

- Unanticipated Faults
  - Assuming no exception handler provided
  - We can provide a **recovery block of code**
    - That allows backtracking to a state before the error
    - That is able to detect an error
    - That could permit a retry with a different algorithm
  - This concept is fairly untried
    - It may not be feasible for complex situations
    - It may be too expensive

Semaphores (Dijkstra, 1965)

- Semaphore
  - A semaphore is "an integer variable that apart from initialization, is accessed only through two standard **atomic** operations: **wait** and **signal**"
  - "These operations were originally termed **P** (for **wait**; from the Dutch ***proberen***, to test) and **V** (for **signal**; from ***verhogen***, to increment)"
  - Dijkstra introduced these terms and used these operations in the operating system

Semaphores (Dijkstra, 1965)

- For semaphore s

```
wait(s): while s <= 0
             do no-op;
         s--;
signal(s): s++;
```

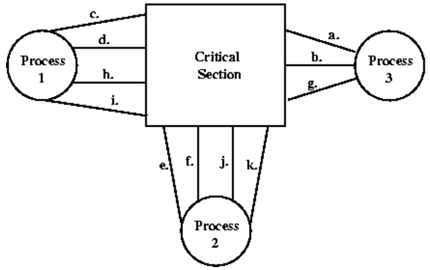
  - Where wait(s) is the same as P(s) and signal(s) is the same as V(s)
  - S can be any integer

Semaphores

- Semaphore actions
  - Must be **atomic** actions
  - Must be **indivisible**
  - Must be **uninterruptible**
- Further, both the test of the semaphore and the change of the value of the semaphore must happen together
- Note that **s** can be any integer
- There are two types of semaphores:
  - Two-valued (could be represented as **boolean** or **int**)
  - Integer (could be **multi-valued**)

Semaphore Example (SS)

- Semaphore use in a sequential system
  - Consider a sequential system with 3 running processes, **Process 1, 2, 3**
  - Each of the processes has access to a shared semaphore, **s**
  - Each process has a **critical section** controlled by **s**



Semaphore Example (SS)

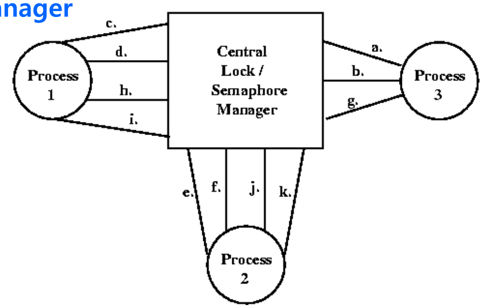
- Initially s = 1
  - With no processes in their critical section
- Steps
  a. Process3 requests its critical sections
     - Since s = 1, s <= 0, so s is decremented by 1, making s = 0
  b. Process3 is granted access to its critical section
  c. Process1 requests its critical section,
     - But s <= 0, as s = 0
  d. Process1 starts a busy wait,
     - Continually retesting s until s > 0
  e. Process2 requests its critical section
     - But s <= 0, as s = 0
  f. Process2 starts a busy wait,
     - Continually retesting s until s > 0

Semaphore Example (SS)

g. Process3 finishes its critical section,
   - So s is incremented by 1, making s = 1, releasing access to the critical section
h. Process1 checks the value of s
   - Since s = 1, s ! <= 0, So s is decremented by 1, making s = 0, and Process1 is granted access to its critical section
i. Process1 finishes its critical section
   - So s is incremented by 1, making s = 1, releasing access to the critical section
j. Process2 checks the value of s
   - Since s = 1, s ! <= 0, So s is decremented by 1, making s = 0, and Process2 is granted access to its critical section
k. Process2 finishes its critical section
   - So s is incremented by 1, making s = 1, releasing access to the critical section

Semaphore Example (DS)

- Semaphore use in a distributed system
  - Consider a distributed system with 3 running processes, **Process 1, 2, 3**
  - Each of the processes has access to a shared semaphore, **s**
  - Each process has a **critical section** controlled by **s**
  - Assume the semaphore/lock is controlled by a **centralized lock manager**



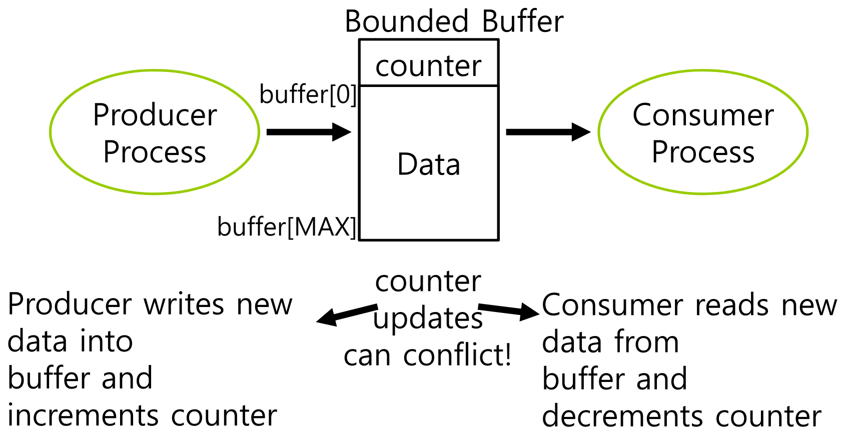
Semaphore Example (DS)

- Initially s = 1
  - With no processes in their critical section
- Steps
  a. Process3 requests its critical sections
     - Since s = 1, s <= 0, so s is decremented by 1, making s = 0
  b. Process3 is granted access to its critical section
  c. Process1 requests its critical section,
     - But s <= 0, as s = 0
  d. Process1 is placed on a **queue**,
     - Until s > 0
  e. Process2 requests its critical section
     - But s <= 0, as s = 0
  f. Process2 is **queued**,
     - Until s > 0

Semaphore Example (DS)

g. Process3 finishes its critical section,
   - So s is incremented by 1, making s = 1, releasing access to the critical section
h. The central manager checks the semaphore value s
   - Since s = 1, s ! <= 0, So s is decremented by 1, making s = 0, and Process1 is granted access to its critical section by the central manger
i. Process1 finishes its critical section
   - So s is incremented by 1, making s = 1, releasing access to the critical section
j. The central manager checks the semaphore value s
   - Since s = 1, s ! <= 0, So s is decremented by 1, making s = 0, and Process2 is granted access to its critical section by the central manager
k. Process2 finishes its critical section
   - So s is incremented by 1, making s = 1, releasing access to the critical section

Producer/Consumer Problem



Semaphore for Producer/Consumer Problem

```
sem nfull = 0;
sem nempty = N;
sem mutexP, mutexC = 1;
info buffer[N]; int in, out = 0;
producer() {
    create one unit of type info, U;
    P(mutexP); //one producer
    P(nempty); //wait for empty
    buffer[in] = U;
    in = (in++) % N;
    V(nfull); //signal full
    V(mutexP);
}
```

```
consumer() {
    P(mutexC); //one consumer
    P(nfull); //wait for full
    U= buffer[out];
    out = (out++) % N;
    V(nempty); //signal empty
    V(mutexC);
    consume one unit of type info, U;
}
```

Semaphore for Reader/Writer Problem

```
int nreaders = 0;
sem mutex, wmutex, srmutex = 1;
reader() {
    P(mutex);
    nreaders++; //#reader++
    if (nreaders == 1)
      P(wmutex) ; //wait until no writer
    V(mutex);

    ... read ... ;

    P(mutex);
    nreaders --; //#reader--
    if (nreaders == 0)
       V(wmutex); //signal
    V(mutex);
}
```

```
writer () {
    P(srmutex);
    P(wmutex);

    ... write ... ;

    V(wmutex);
    V(srmutex);
}
```

mutex protects modifications to **nreaders**
wmutex protects makes sure that only readers or just **one** writer is active
V(wmutex) should unblock a waiting reader before **V(srmutex)** can release a waiting writer

Disadvantage of Semaphores

- Simple algorithms require more than one semaphore
  - This increases the complexity of semaphore solutions to such algorithms
- Semaphore are too low level.
  - It is easy to make programming mistakes
- The programmer must keep track of all calls to wait and to signal the semaphore.
  - If this is not done in the correct order, programmer error can cause deadlock.
- Semaphores are used for both condition synchronization and mutual exclusion.
  - These are distinct and different events, and it is difficult to know which meaning any given semaphore may have.
- What happens if system crashes when one process is in the critical sections?

Monitors (Hansen 1973, Hoare 1974)

- A monitor is a high-level synchronization primitive
  - Developed by Hoare and Brinch Hansen
  - A programming language construct
  - A compiler-supported data structure with
    - Procedures
    - Variables
    - Data structures
  - Similar to today's classes and objects, e.g. Concurrent Pascal, Java
- Outside processes may
  - Call monitor procedure
  - Not access monitor data structures
- Only one process is active in monitor at once
  - Ensuring mutual exclusion
  - Blocking other processes are blocked
- It may be implemented using binary semaphores

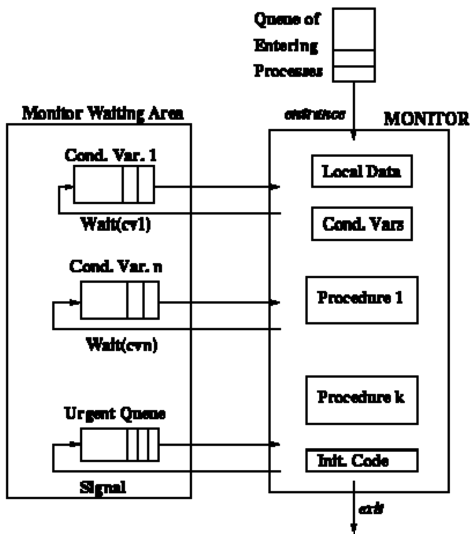
Monitor Definitions

- A monitor is an abstract mechanism which
  - Encapsulates abstract resources, and
  - Provides functions to manipulate those resources
- Can be though of as an object(or ADT) containing
  - A data structure, and operations (methods) for manipulating that data structure, where only one process can execute an operation at a time.
  - It other words, it is an object with synchronization.
- Only allows the resources to be accessed through the monitor operations:
  - Only the procedure names of the monitor operations are visible outside the monitor.
  - Monitor procedures may only access monitor variables within the monitor itself.
  - All shared variables declared within the monitor are initialized before execution begins.
- Provides mutual exclusion:
  - Only one process may be executing within a monitor at any given time.
  - Concurrent processes can use the monitor resources.

Advantages of Monitors

- A process calling a monitor procedure (or method) can ignore the actual implementation (as in any abstract data type).
- Once a monitor is correctly programmed, it remains correct, despite the number of processes executing (as in object-oriented programming).
- The implementation of a monitor can be changed without affecting the application or the user's view of the monitor resources (as in object-oriented programming).
- Monitors provide mutual exclusion on a higher level than semaphores or conditional critical regions.

Representation of a Monitor



Condition Variables

- Condition variables allow a process executing within the monitor to be put to sleep to wait for some condition to be set (signaled).
  - They are used to delay a process that cannot safely proceed until there is a change in the state of the monitor.
  - This avoids deadlock within the monitor.
- Condition variables can also awaken a sleeping process to let it be actively executing again within the monitor.
  - Condition variables wake up delayed or suspended processes within the monitor.
- A condition variable is just a data structure (or class) consisting of
  - A boolean value
  - A queue of delayed processes
- A condition variable is a shared data variable within the monitor.

Condition Variables

- Commands related to condition variables include:
  - Wait(c):
    - The process currently active in the monitor suspends execution and gives up mutual exclusion to the monitor until the condition variable c is signaled. It is placed on the end of the queue of delayed processes waiting for c to be signaled.
  - Signal(c):
    - The process at the front of the queue is awakened and resumes execution within the monitor. If the queue connected to the condition variable c is empty, nothing happens; this is equivalent to a skip operation.
- A drawback of condition variables is that compilers for monitor-supporting languages usually rely on shared memory.

Monitors vs. Semaphores

- **wait** versus **P(s)** and **signal** versus **V(s)**
  - The **signal** command has no effect if there is no suspended process. **V(s)** always increments s.
  - The **wait** command always delays until there is a **signal** command. **P(s)** only delays if **s** is not positive.
  - The process that executes the **signal** command is currently executing within the monitor. **V(s)** and **P(s)** may be used outside the critical section.

Disadvantages of Monitors

- Monitors can exhibit an absence of concurrency, when a monitor encapsulates a resource since only one process can be active at a time within the monitor.
- When using nested monitor calls, there is a possibility of deadlock.

Implementation Issues for Monitors

- Suppose process Q is waiting on the condition variable c in a monitor.
  - Further suppose that process P is active in the monitor and executes c. signal, waking up Q.
  - Now which process continues to be active in the monitor?
- This turns out to be an implementation issue
  - (i.e., how the monitors are implemented).
- When P signals Q, there are three choice of actions:
  - I. P may continue to execute in the monitor. However, if it does so, P may alter the condition that awakened Q.
  - II. P may wait (suspend) while Q executes in the monitor until Q is done or some other condition becomes true. This is the method preferred by Hoare.
  - III. P executes the signal command and immediately leaves the monitors. In other words, the signal command is the last line of the procedure P executes. This is the method preferred by Brinch Hansen.

Monitor for Producer/Consumer Problem

```
monitor ProducerConsumer {
  int itemCount;
  condition full;
  condition empty;
  procedure put(item) {
    while (itemCount == BUFFER_SIZE) {
      wait(full);
    }
    putItemIntoBuffer(item);
    itemCount = itemCount + 1;
    if (itemCount == 1) {
      notify(empty);
    }
  }
  procedure take() {
    while (itemCount == 0) {
      wait(empty);
    }
    item = removeItemFromBuffer();
    itemCount = itemCount – 1;
    if (itemCount == BUFFER_SIZE - 1) {
      notify(full);
    }
    return item;
  }
}
```

Monitor for Producer/Consumer Problem

```
procedure producer() {
  while (true) {
    item = produceItem();
    ProducerConsumer.add(item);
  }
}
procedure consumer() {
  while (true) {
    item = ProducerConsumer.remove();
    consumeItem(item);
  }
}
```

Monitor for Dining Philosopher Problem

```
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((i+4) % 5);
    test((i+1) % 5);
}
```

Pickup
-indicate that I'm hungry
-set state to eating in test() only if my left and right neighbors are not eating
-if unable to eat, wait to be signaled

Putdown
-if right neighbor R=(i+1)%5 is hungry and both of R's neighbors are not eating, set R's state to eating and wait it up by signaling R's CV

Monitor for Dining Philosopher Problem

```
void test (int i) {
    if ((state[(i+4) % 5] != EATING) &&
        (state[i] == HUNGRY) && (state[(i+1)%5] != EATING)) {
        state[i] = EATING;
        self[i].signal();
    }
}
void init() {
    for (int i=0; i<5; i++)
        state[i] = THINKING;
}
DiningPhilosopher.pickup(i);
// eat
DiningPhilosopher.putdown(i);
```

signal() has not effect during pickup(), but is important to wake up waiting hungry philosopher's during putdown()

Execution of pickup(), putdown(), test() are all mutually exclusive, i.e. only one at a time can be executing

References

- http://www.cs.colostate.edu/~cs551/CourseNotes/ConcurrentConstructs/ConcurrentTOC.html