CS370 Operating Systems

Colorado State University

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Fall 2016 Lecture 22

Slides based on

- Text by Silberschatz, Galvin, Gagne
- Various sources

FAQ

- Classes that follow CS370
  - CS455 Distributed Systems Spring
  - CS457 Networks Fall
  - CS470 Computer Architecture Spring
  - CS475 Parallel Programming Fall
  - CS435: Introduction to Big Data Spring

Midterm

- Scores available Friday
  - Raw -> Adjusted
    - Linear: $y = mx + c$ $m = 0.703$, $c = 35.239$
  - Adjusted scores:
    - Max 102
    - Average 80
- Tests handed back on Monday

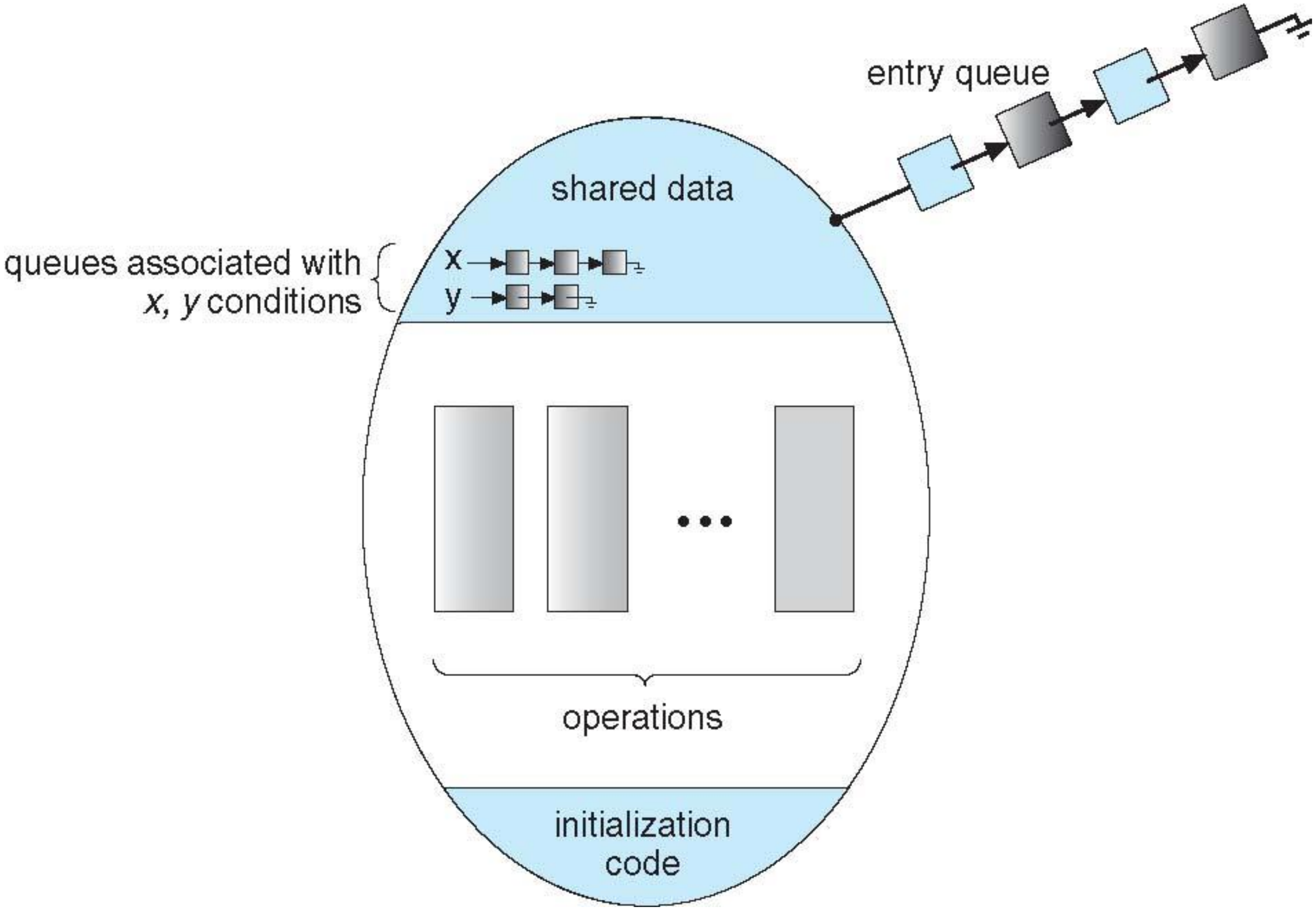
Condition Variables

Compare with semaphore

`The` **`condition`** `construct`

- **`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



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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
  - Monitors implemented in Concurrent Pascal ('75) compromise
    - P executing signal immediately leaves the monitor, Q is resumed
  - Implemented in other languages including C#, Java

Monitor Solution to Dining Philosophers: Deadlock-free

`enum {THINKING,HUNGRY,EATING} state[5];`

- `state[i] = EATING only if`
  - `state[(i+4)%5] != EATING &&   state[(i+1)%5] != EATING !`
- `condition self[5]`
  - Delay self when **HUNGRY but unable** to get chopsticks

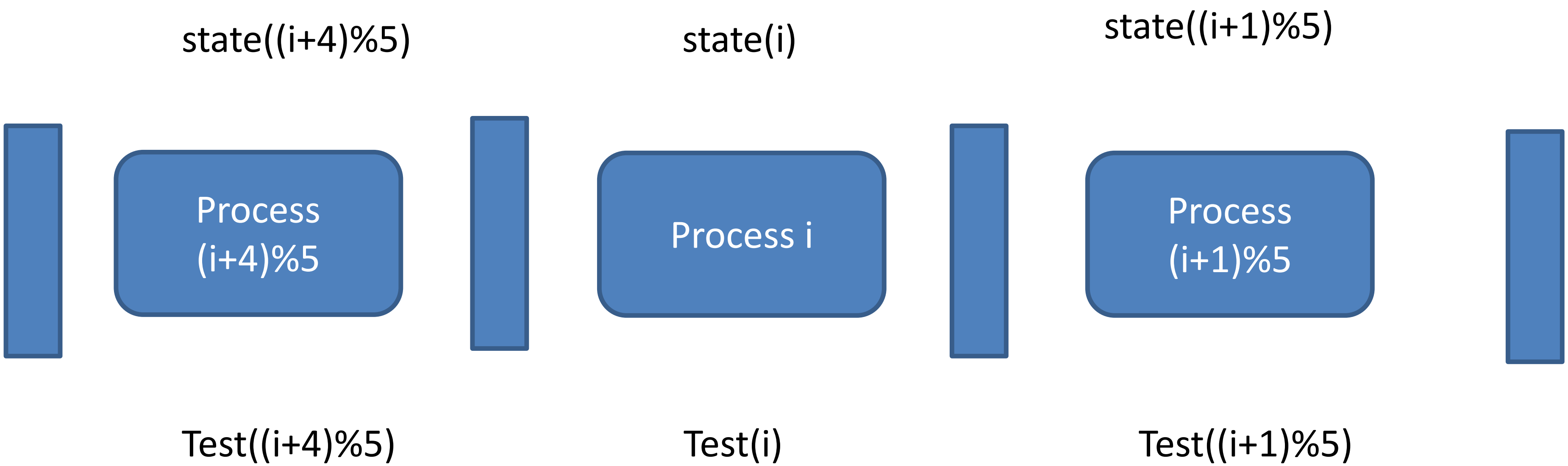
Sequence of actions

- Before eating, must invoke pickup()
  - May result in suspension of philosopher process
  - After completion of operation, philosopher may eat

```
 think
DiningPhilosophers.pickup(i);
eat
DiningPhilosophers.putdown(i);
think
```

Monitor Solution to Dining Philosophers: Deadlock-free

```
enum {THINKING,HUNGRY,EATING} state[5];
```



The pickup() and putdown() operations

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

   void pickup (int i) {
          state[i] = HUNGRY;
          test(i);    //on next slide
          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);
}
```

Suspend self if unable to acquire chopstick

Check to see if person on left or right can use the chopstick

test() to see if philosopher I can eat

```
   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;
         }
}
```

Eat only if HUNGRY and Person on Left AND Right are not eating

Signal a process that was suspended while trying to eat

Possibility of starvation

- Philosopher i can starve if eating periods of philosophers on left and right overlap
- Possible solution
  - Introduce new state: STARVING
  - Chopsticks can be picked up if no neighbor is starving
    - Effectively wait for neighbor's neighbor to stop eating
    - REDUCES concurrency!

Monitor Implementation Using Semaphores

Monitor Implementation Mutual Exclusion

For each monitor

- Semaphore mutex initialized to 1
- Process must execute
  - wait(mutex) : Before entering the monitor
  - signal(mutex): Before leaving the monitor

Monitor Implementation Using Semaphores

- Variables

```
semaphore mutex;   // (initially  = 1) allows only one process to be active
semaphore next;    // (initially  = 0) causes signaler to sleep
int next_count = 0;    num of sleepers since they signalled
```

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

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

Both mutex and next have an associated queue

- Mutual exclusion within a monitor is ensured

Monitor Implementation – Condition Variables

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

```
semaphore x_sem; // (initially  = 0) causes caller of
                                      wait to sleep
int x_count = 0;//number of sleepers on condition
```

- The operations x.wait **and x.signal** can be implemented as:

The operation x.wait can be implemented as:	The operation x.signal can be implemented as:

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

Resuming Processes within a Monitor

- If several processes queued on condition x, and x.signal() is executed, which should be resumed?
- FCFS frequently not adequate
- **conditional-wait** construct of the form x.wait(c)
  - Where c is **priority number**
  - Process with lowest number (highest priority) is scheduled next

Single Resource allocation

- Allocate a single resource among competing processes using priority numbers that specify the maximum time a process plans to use the resource

```
R.acquire(t);
          ...
 access the resource;
          ...

 R.release;
```

- Where R is an instance of type **`ResourceAllocator`**

A Monitor to Allocate Single Resource

```
monitor ResourceAllocator
{
   boolean busy;
   condition x;

   void acquire(int time) {
           if (busy)
              x.wait(time);
           busy = TRUE;
   }

   void release() {
           busy = FALSE;
           x.signal();
   }
    initialization code() {
    busy = FALSE;
   }
}
```

Sleep, Time used to prioritize waiting processes

Wakes up one of the processes

Java Synchronization

- For simple synchronization Java provides the synchronized keyword
  - synchronizing methods

```
public synchronized void increment() { c++; }
```

  - synchronizing blocks

```
synchronized(this) {
        lastName = name;
        nameCount++;
}
```

- wait() and notify() allows a thread to wait for an event. A call to notify. all() allows all threads that are on wait() with the same lock to be released

- For more sophisticated locking mechanisms, starting from Java 5, the package java.concurrent.locks provides additional locking

Synchronization Examples

- Solaris
- Windows
- Linux
- Pthreads

Solaris Synchronization

- Implements a variety of locks to support multitasking, multithreading (including real-time threads), and multiprocessing
- Uses **adaptive mutexes** for efficiency when protecting data from short code segments
  - Starts as a standard semaphore spin-lock
  - If lock held, and by a thread running on another CPU, spins
  - If lock held by non-run-state thread, block and sleep waiting for signal of lock being released
- Uses **condition variables**
- Uses **readers-writers** locks when longer sections of code need access to data
- Uses **turnstiles** to order the list of threads waiting to acquire either an adaptive mutex or reader-writer lock
  - Turnstiles are per-lock-holding-thread, not per-object
- Priority-inheritance per-turnstile gives the running thread the highest of the priorities of the threads in its turnstile

Windows Synchronization

- Uses interrupt masks to protect access to global resources on uniprocessor systems
- Uses **spinlocks** on multiprocessor systems
  - Spinlocking-thread will never be preempted
- Also provides **dispatcher objects** user-land which may act mutexes, semaphores, events, and timers
  - **Events**
    - An event acts much like a condition variable
  - Timers notify one or more thread when time expired
  - Dispatcher objects either **signaled-state** (object available) or **non-signaled state** (thread will block)

Linux Synchronization

- Linux:
  - Prior to kernel Version 2.6, disables interrupts to implement short critical sections
  - Version 2.6 and later, fully preemptive
- Linux provides:
  - Semaphores
  - atomic integers
  - spinlocks
  - reader-writer versions of both
- On single-cpu system, spinlocks replaced by enabling and disabling kernel preemption

Pthreads Synchronization

- Pthreads API is OS-independent
- It provides:
  - mutex locks
  - condition variable
- Non-portable extensions include:
  - read-write locks
  - spinlocks

Alternative Approaches

- Transactional Memory
- OpenMP
- Functional Programming Languages

Transactional Memory

- A **memory transaction** is a sequence of read-write operations to memory that are performed atomically.

```
void update()
{
    /* read/write memory */
}
```

OpenMP

- OpenMP is a set of compiler directives and API that support parallel progamming.

```
 void update(int value)
{
        #pragma omp critical
        {
          count += value
        }
}
```

The code contained within the **`#pragma omp critical`** directive is treated as a critical section and performed atomically.