EECS 3221:
OPERATING SYSTEM FUNDAMENTALS

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Week 5, Module 1:

Synchronization Examples

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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

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

Bounded Buffer Problem (Cont.)

- The structure of the consumer process

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


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
    - A writer and any other processes may lead to chaos
- 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 (Cont.)

- The structure of a writer process

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

- When a writer executes **signal(rw_mutex)**, we may resume the execution of either the waiting readers or a single waiting writer. The selection is made by the scheduler.

Readers-Writers Problem (Cont.)

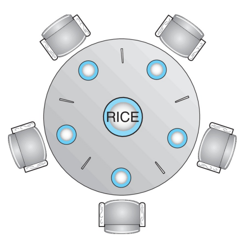
- The structure of a reader process

```
while (true){
        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);
}
```

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

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

- Semaphore Solution
- The structure of Philosopher *i*:

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

    /* eat for awhile */

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

    /* think for awhile */

}
```

- What is the problem with this algorithm?

Several Solutions

- Deadlock free solutions:
  - Allow at most four philosophers to be sitting simultaneously at the table.
  - Allow a philosopher to pick up her chopsticks only if both chopsticks are available (to do this, she must pick them up in a critical section).
  - Use an asymmetric solution—that is, an odd-numbered philosopher picks up first her left chopstick and then her right chopstick, whereas an even-numbered philosopher picks up her right chopstick and then her left chopstick.

A deadlock-free solution does not necessarily eliminate the possibility of starvation.

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
- Deadlock and starvation free solutions as exercise for you.

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

Linux Synchronization

- Atomic variables

  `atomic_t` is the type for atomic integer
- Consider the variables

```
atomic_t counter;
int value;
```

Atomic Operation	*Effect*
`atomic_set(&counter,5);`	`counter = 5`
`atomic_add(10,&counter);`	`counter = counter + 10`
`atomic_sub(4,&counter);`	`counter = counter - 4`
`atomic_inc(&counter);`	`counter = counter + 1`
`value = atomic_read(&counter);`	`value = 12`

Functional Programming Languages

- Functional programming languages offer a different paradigm than procedural languages in that they do not maintain state.
- Variables are treated as immutable and cannot change state once they have been assigned a value.
- There is increasing interest in functional languages such as Erlang and Scala for their approach in handling data races.

END OF CHAPTER 7