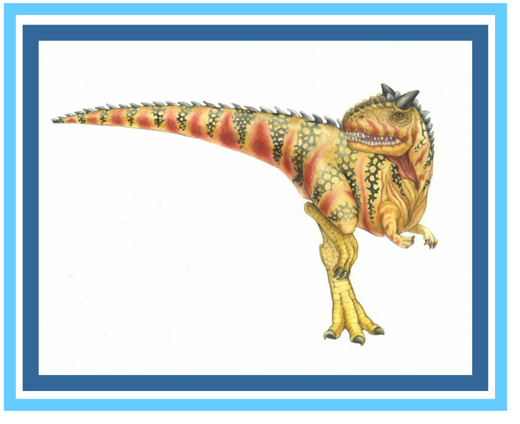
Chapter 7: Synchronization Examples



7: Model Synchronization Problems

- The bounded-buffer, readers-writers, and dining philosophers synchronization problems.
- Tools used by Linux to solve synchronization problems.
- POSIX solutions to synchronization problems.

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
- 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);
  }
```

Readers-Writers Problem (Cont.)

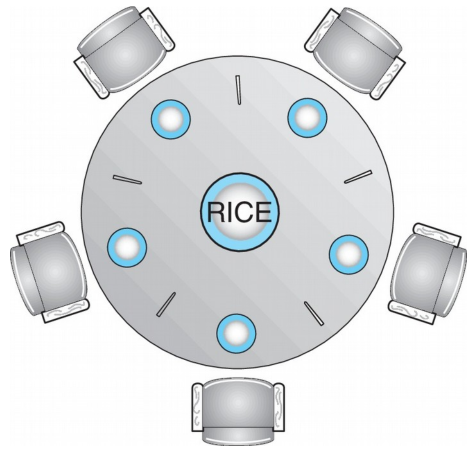
- The structure of a reader process

```
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

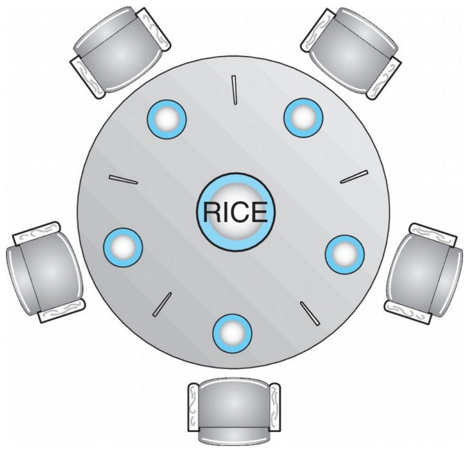
- ***First*** variation – no reader kept waiting unless writer has permission to use shared object
- ***Second*** variation – once writer is ready, it writes as soon as any existing writer finishes writing
- Both may have starvation leading to even more variations

Dining Philosophers Problem



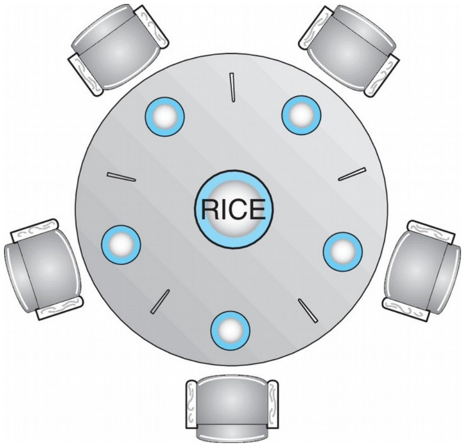
- Originally posed by Edsger Dijkstra in 1965 as a tape drive exercise for his students, and later formalized by C.A.R. Hoare.
- Five philosophers sit at a round table, and spend their lives alternating thinking and eating.
- They each have a bowl of spaghetti in front of them, and five forks are between the five bowls.
- They need two forks to eat. They cannot eat with just one.
- Problem has morphed over the years to bowls of rice and chopsticks.

Dining Philosophers Problem



- Philosophers are independent – they do not interact with their neighbors. They try to pick up 2 chopsticks one after the other to eat from bowl
  - Need both chopsticks to eat, then release both when done
- Shared data:
  - Bowl of rice (data set)
  - Semaphore chopstick [5] initialized to 1

Dining Philosophers Problem



- Formal Solution Requirements:
  - Only one philosopher can hold a chopstick at a time.
  - It must be deadlock-free
  - It must be impossible for a philosopher to starve waiting for a chopstick.
  - It must be possible for more than one philosopher to eat at the same time.

Dining Philosophers Algorithm

- Solution using semaphores
- 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?

Dining Philosophers #2

- A deadlock free solution uses an array of state variables and an array of semaphores:

```
sem_t mutex;
sem_t S[N];
int   state[N];
```

- A philosopher tries to take forks as follows

```
void take_forks(int ph_num)
{
    sem_wait(&mutex);
    state[ph_num] = HUNGRY;

    try_to_eat(ph_num);
    signal(mutex);
    wait(S[ph_num]); // wait here if could not eat
    sleep(1);
}
```

Dining Philosophers #2

- Before a philosopher picks up any chopsticks, she checks whether her neighbors are holding any with something like this:

```
if (state[i] == HUNGRY && state[(i+1)%5] != EATING
    && state[(i+4)%5] != EATING)
{
    state[i] = EATING;
    // can eat!!
    signal(S[i]);
}
```

- The putting down of forks:

```
void put_forks(int i)
{
    wait(mutex);
    state[i] = THINKING;
    try_to_eat((i+1)%5);
    try_to_eat((i+4)%5);
    signal(mutex);
}
```

Solution to Dining Philosophers (Cont.)

The code for trying to eat:

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

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

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

Synchronization in Linux

- There are several options for process and thread synchronization in Linux.
  - 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`

POSIX Synchronization

- POSIX API provides
  - mutex locks
  - semaphores
  - condition variable
- Widely used on UNIX, Linux, and macOS

POSIX Mutex Locks

- Creating and initializing the lock

```
#include <pthread.h>

pthread_mutex_t mutex;

/* create and initialize the mutex lock */
pthread_mutex_init(&mutex,NULL);
```

- Acquiring and releasing the lock

```
/* acquire the mutex lock */
pthread_mutex_lock(&mutex);

/* critical section */

/* release the mutex lock */
pthread_mutex_unlock(&mutex);
```

POSIX Semaphores

- POSIX provides two versions – **named** and **unnamed**.
- Named semaphores can be used by unrelated processes, unnamed cannot.

POSIX Named Semaphores

- Creating an initializing the semaphore:

```
#include <semaphore.h>
sem_t *sem;

/* Create the semaphore and initialize it to 1 */
sem = sem_open("SEM", O_CREAT, 0666, 1);
```

- Another process can access the semaphore by referring to its name **`SEM`**.
- Acquiring and releasing the semaphore:

```
/* acquire the semaphore */
sem_wait(sem);

/* critical section */

/* release the semaphore */
sem_post(sem);
```

POSIX Unnamed Semaphores

- Creating an initializing the semaphore:

```
#include <semaphore.h>
sem_t sem;

/* Create the semaphore and initialize it to 1 */
sem_init(&sem, 0, 1);
```

- Acquiring and releasing the semaphore:

```
/* acquire the semaphore */
sem_wait(&sem);

/* critical section */

/* release the semaphore */
sem_post(&sem);
```

POSIX Condition Variables

- Since POSIX is typically used in C/C++ and these languages do not provide a monitor, POSIX condition variables are associated with a POSIX mutex lock to provide mutual exclusion: Creating and initializing the condition variable:

```
pthread_mutex_t mutex;
pthread_cond_t cond_var;

pthread_mutex_init(&mutex,NULL);
pthread_cond_init(&cond_var,NULL);
```

POSIX Condition Variables

- Thread waiting for the condition **a == b** to become true:

```
pthread_mutex_lock(&mutex);
while (a != b)
     pthread_cond_wait(&cond_var, &mutex);

pthread_mutex_unlock(&mutex);
```

- Thread signaling another thread waiting on the condition variable:

```
pthread_mutex_lock(&mutex);
a = b;
pthread_cond_signal(&cond_var);
pthread_mutex_unlock(&mutex);
```

Alternative Approaches

- Transactional Memory
- OpenMP
- Functional Programming Languages

Transactional Memory

- Consider a function update() that must be called atomically. One option is to use mutex locks:

```
void update ()
{
   acquire();

   /* modify shared data */

   release();
}
```

- A **memory transaction** is a sequence of read-write operations to memory that are performed atomically. A transaction can be completed by adding **`atomic{S}`** which ensure statements in **`S`** are executed atomically:

```
void update ()
{
   atomic {
      /* modify shared data */
   }
}
```

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.

End of Chapter 7