CSC 4304 - Systems Programming
Fall 2008

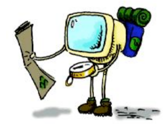
LECTURE - XVIII
CONCURRENT PROGRAMMING

Tevfik Koşar

Louisiana State University
November 11th, 2008

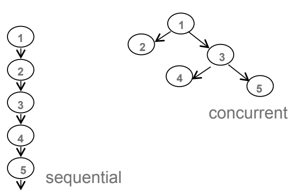
Roadmap

- Concurrent Programming
  - Shared Memory vs Message Passing
  - Divide and Compute
  - Threads vs Processes
  - POSIX Threads



Concurrent Programming

- So far, we have focused on sequential programming: all computational tasks are executed in sequence, one after the other.
- Next three lectures, we will focus on concurrent programming: multiple computational tasks are executed simultaneously, at the same time.



Concurrent Programming

- Implementation of concurrent tasks:
  - as separate programs
  - as a set of processes or threads created by a single program

- Execution of concurrent tasks:
  - on a single processor
  - ➔ Multithreaded programming
  - on several processors in close proximity
  - ➔ Parallel computing
  - on several processors distributed across a network
  - ➔ Distributed computing

Communication Between Tasks

Interaction or communication between concurrent tasks can done via:

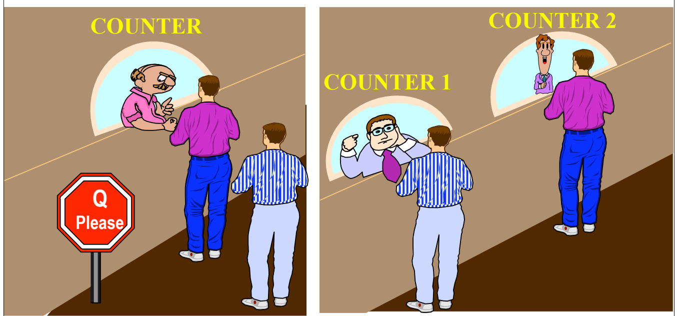
- Shared memory:
  - all tasks has access to the same physical memory
  - they can communicate by altering the contents of shared memory
- Message passing:
  - no common/shared physical memory
  - tasks communicate by exchanging messages

Motivation

- Increase the performance by running more than one tasks at a time.
  - divide the program to n smaller pieces, and run it n times faster using n processors

- To cope with independent physical devices.
  - do not wait for a blocked device, perform other operations at the background

Serial vs Parallel



Divide and Compute

x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8

How many operations with sequential programming?
7

Step 1: x1 + x2
Step 2: x1 + x2 + x3
Step 3: x1 + x2 + x3 + x4
Step 4: x1 + x2 + x3 + x4 + x5
Step 5: x1 + x2 + x3 + x4 + x5 + x6
Step 6: x1 + x2 + x3 + x4 + x5 + x6 + x7
Step 7: x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8

Divide and Compute

x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8

Step 1: parallelism = 4

Step 2: parallelism = 2

Step 3: parallelism = 1

Gain from parallelism

In theory:
- dividing a program into n smaller parts and running on n processors results in n time speedup

In practice:
- This is not true, due to
  - Communication costs
  - Dependencies between different program parts
    - Eg. the addition example can run only in log(n) time not 1/n

Prevent Blocking

- Do not wait for a blocked device, perform other operations at the background
  - During I/O perform computation
  - During continuous visualization, handle key strokes and I/O
    - Eg. video games
  - While listening to network, perform other operations
    - Listening to multiple sockets at the same time
  - Concurrent I/O, concurrent transfers
    - Eg. Web browsers

Threads vs Processes

Process Spawning:

Process creation involves the following four main actions:
- **setting up the process control block,**
- **allocation of an address space and**
- **loading the program into the allocated address space and**
- **passing on the process control block to the scheduler**

Thread Spawning:

- **Threads are created *within and belonging to* processes**
- **All the threads created within one process share the resources of the process including the address space**
- **Scheduling is performed on a per-thread basis.**
- **The thread model is a *finer grain scheduling model* than the process model**
- **Threads have a similar *lifecycle* as the processes and will be managed mainly in the same way as processes are**

Threads vs Processes

- Heavyweight Process = Process
- Lightweight Process = Thread

Advantages (Thread vs. Process):
- Much quicker to create a thread than a process
- Much quicker to switch between threads than to switch between processes
- Threads share data easily

Disadvantages (Thread vs. Process):
- Processes are more flexible
  - They don't have to run on the same processor
- No security between threads: One thread can stomp on another thread's data
- For threads which are supported by user thread package instead of the kernel:
  - If one thread blocks, all threads in task block.

Synchronization

- Mechanism that allows the programmer to control the relative order in which operations occur in different threads or processes.

Synchronization - Threads

Int sum = 0;

Thread 1:

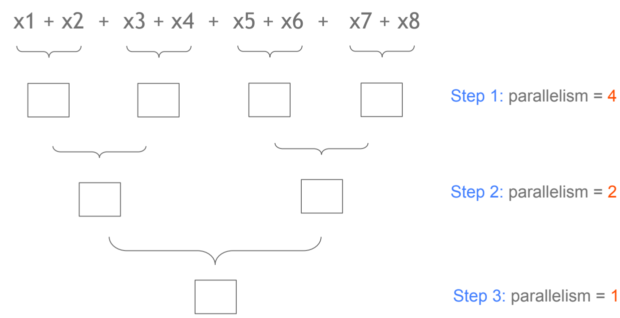
```
int t;
lock(sum);
sum = sum + x;
t = sum;
....
unlock(sum);
```

Thread 2:

```
int t;
lock(sum);
sum = sum + y;
t = sum;
...
unlock(sum);
```

Use of semaphores for thread synchronization!

Synchronization - Processes



Wait for a message from other processes before continuing processing!

On a single processor machine

- You can have multiple threads
- You can also have multiple processes and have the effect of concurrency
  - timesharing

Thread Creation

- **pthread_create**

```
// creates a new thread executing start_routine
int pthread_create(pthread_t *thread,
                   const pthread_attr_t *attr,
                   void *(*start_routine)(void*), void *arg);
```

- **pthread_join**

```
// suspends execution of the calling thread until the target
// thread terminates
int pthread_join(pthread_t thread, void **value_ptr);
```

Mutual Exclusion

- **pthread_mutex_lock**

```
// blocks until mutex is available, and then locks it
int pthread_mutex_lock(pthread_mutex_t *mutex);
```

pthread_mutex_unlock

```
// unlocks the mutex
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```


Thread Example

```
int main()
{
    pthread_t thread1, thread2;  /* thread variables */

    pthread_create (&thread1, NULL, (void *) &print_message_function,
                                                        (void*)"hello ");
    pthread_create (&thread2, NULL, (void *) &print_message_function,
                                                        (void*)"world!\n");

    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    exit(0);
}
```

Why use pthread_join?

To force main block to wait for both threads to terminate, before it exits. If main block exits, both threads exit, even if the threads have not finished their work.

Thread Example *(cont.)*

```
void print_message_function ( void *ptr )
{
    char *cp = (char*)ptr;

    for (i=0;i<NUM;i++){
        printf("%s ", cp);
        fflush(stdout);
    }

    pthread_exit(0); /* exit */
}
```


Interthread Cooperation

```
void* print_count ( void *ptr );
void* increment_count ( void *ptr );

int NUM=5;
int counter =0;

int main()
{
   pthread_t thread1, thread2;

   pthread_create (&thread1, NULL, increment_count, NULL);
   pthread_create (&thread2, NULL,  print_count, NULL);

   pthread_join(thread1, NULL);
   pthread_join(thread2, NULL);

   exit(0);
}
```


Interthread Cooperation *(cont.)*

```
void* print_count ( void *ptr )
{
   int i;
   for (i=0;i<NUM;i++){
      printf("counter = %d \n", counter);
      sleep(1);
   }
   pthread_exit(0);
}

void* increment_count ( void *ptr )
{
   int i;
   for (i=0;i<NUM;i++){
      counter++;
      sleep(1);
   }
   pthread_exit(0);
}
```


2-Thread Word Counter

```
int total_words;

main(int ac, char *av[])
{
      pthread_t t1, t2;           /* two threads */
      void      *count_words(void *);

      if ( ac != 3 ){
            printf("usage: %s file1 file2\n", av[0]);
            exit(1);
      }
      total_words = 0;

      pthread_create(&t1, NULL, count_words, (void *) av[1]);
      pthread_create(&t2, NULL, count_words, (void *) av[2]);
      pthread_join(t1, NULL);
      pthread_join(t2, NULL);
      printf("%5d: total words\n", total_words);
}
```

2-Thread Word Counter *(cont.)*

```
void *count_words(void *f)
{
    char *filename = (char *) f;
    FILE *fp;
    int  c, prevc = '\0';

    if ( (fp = fopen(filename, "r")) != NULL ){
        while( ( c = getc(fp)) != EOF ){
            if ( !isalnum(c) && isalnum(prevc) )
                total_words++;
            prevc = c;
        }
        fclose(fp);
    } else
        perror(filename);
    return NULL;
}
```


2-Thread Word Counter, Mutex

```
pthread_mutex_t counter_lock = PTHREAD_MUTEX_INITIALIZER;

int total_words ;    /* the counter and its lock */

main(int ac, char *av[])
{
    pthread_t t1, t2;     /* two threads */
    void   *count_words(void *);

    if ( ac != 3 ){
        printf("usage: %s file1 file2\n", av[0]);
        exit(1);
    }
    total_words = 0;

    pthread_create(&t1, NULL, count_words, (void *) av[1]);
    pthread_create(&t2, NULL, count_words, (void *) av[2]);
    pthread_join(t1, NULL);
    pthread_join(t2, NULL);
    printf("%5d: total words\n", total_words);
}
```


2-Thread Word Counter, Mutex *(cont.)*

```
void *count_words(void *f)
{
    char *filename = (char *) f;
    FILE *fp;
    int  c, prevc = '\0';

    if ( (fp = fopen(filename, "r")) != NULL ){
        while( ( c = getc(fp)) != EOF ){
            if ( !isalnum(c) && isalnum(prevc) ){

                pthread_mutex_lock(&counter_lock);
                total_words++;
                pthread_mutex_unlock(&counter_lock);

            }
            prevc = c;
        }
        fclose(fp);
    } else
        perror(filename);
    return NULL;
}
```


2-Thread Word Counter, Arg Pass

```
main(int ac, char *av[])
{
    pthread_t      t1, t2;        /* two threads */
    struct arg_set args1, args2;  /* two argsets */
    void        *count_words(void *);

    if ( ac != 3 ){
        printf("usage: %s file1 file2\n", av[0]);
        exit(1);
    }
    args1.fname = av[1];
    args1.count = 0;
    pthread_create(&t1, NULL, count_words, (void *) &args1);

    args2.fname = av[2];
    args2.count = 0;
    pthread_create(&t2, NULL, count_words, (void *) &args2);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);
    printf("%5d: %s\n", args1.count, av[1]);
    printf("%5d: %s\n", args2.count, av[2]);
    printf("%5d: total words\n", args1.count+args2.count);
}
```


2-Thread Word Counter, Arg Pass *(cont.)*

```
struct arg_set {      /* two values in one arg */
        char *fname; /* file to examine     */
        int  count;  /* number of words     */
};

void *count_words(void *a)
{
    struct arg_set *args = a; /* cast arg back to correct type */
    FILE *fp;
    int  c, prevc = '\0';

    if ( (fp = fopen(args->fname, "r")) != NULL ){
        while( ( c = getc(fp)) != EOF ){
            if ( !isalnum(c) && isalnum(prevc) )
                args->count++;
            prevc = c;
        }
        fclose(fp);
    } else
        perror(args->fname);
    return NULL;
}
```


Acknowledgments

- Advanced Programming in the Unix Environment by R. Stevens
- The C Programming Language by B. Kernighan and D. Ritchie
- Understanding Unix/Linux Programming by B. Molay
- Lecture notes from B. Molay (Harvard), T. Kuo (UT-Austin), G. Pierre (Vrije), M. Matthews (SC), B. Knicki (WPI), M. Shacklette (UChicago), J.Kim (KAIST), and J. Schaumann (SIT).