OS: C Threading API (pthreads)

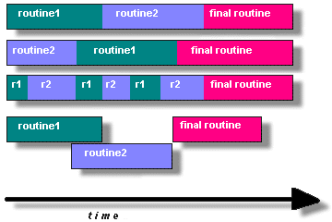
CIT 595
Spring 2010

Pthreads

- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)
- API specifies behavior of the thread library, implementation is up to development of the library
- Note: To compile program
  - gcc –lpthread filename.c
  - Must provide –lpthread flag as this library is dynamically linked (i.e. linked at runtime)

Designing Concurrent Programs with Pthreads

- Take advantage of Pthreads, the work should be organized into discrete, independent tasks which can execute concurrently
- For example, if routine1 and routine2 can be interchanged, interleaved and/or overlapped in real time, they are candidates for threading



Source: https://computing.llnl.gov/tutorials/pthreads/

Thread Creation

int pthread_create (pthread_t * thread**, pthread_attr_t ***attr**, **void *** **(***start_routine**) (void *), void *** arg**)**

- *thread*: unique identifier for the new thread returned by the subroutine
- *attr*: attribute object that may be used to set thread attribute
  - You can specify a thread attributes object, or NULL for the default values
  - Attributes such as stack size, priority, joinable or detachable
- *start_routine*: the C routine that the thread will execute once it is created
  - function that thread perform must be void * funcname (void *)
- *arg*: A single argument that may be passed to *start_routine*.
  - It must be passed by reference as a pointer cast of type void
  - NULL may be used if no argument is to be passed
  - It should be cast to its correct type in the function
- returns 0 when successful

Example thread1.c

```
struct threadData{
  int id;
};
typedef struct threadData thData;

int main(){
  pthread_t threads[NUM_THREADS];
  thData thDataArray[NUM_THREADS];
  int rc, t;
  for(t=0; t < NUM_THREADS; t++){
   thDataArray[t].id = t;
   printf("In main: creating thread %d\n", t);
 rc = pthread_create(&threads[t], NULL, PrintHello,
  (void *)&thDataArray[t]);
  if (rc){
    printf("ERROR; return code from pthread_create() is
  %d\n", rc);
    exit(-1);
 }
}
 //contd next slide
```


Example thread1.c contd ..

```
//Main contd
for (t = 0 ; t < NUM_THREADS ; t++) {
  rc = pthread_join( threads[t], NULL );
  if (rc != 0) {
   printf( "Error joining thread %d\n",
  thDataArray[t].id );
      exit(-1);
     }
 }
 return 0;
}

void *PrintHello(void *threadid){
   thData * temp = (thData *)threadid;
   printf("Hello World! It's me, thread
  #%d!\n", temp->id);
    pthread_exit(NULL);
}
```

- Sample Output

```
In main: creating thread 0
In main: creating thread 1
In main: creating thread 2
In main: creating thread 3
In main: creating thread 4
In main: creating thread 5
In main: creating thread 6
Hello World! It's me, thread #0!
Hello World! It's me, thread #1!
Hello World! It's me, thread #6!
In main: creating thread 7
In main: creating thread 8
Hello World! It's me, thread #2!
Hello World! It's me, thread #5!
Hello World! It's me, thread #4!
Hello World! It's me, thread #7!
In main: creating thread 9
Hello World! It's me, thread #3!
Hello World! It's me, thread #8!
Hello World! It's me, thread #9!
```


Incorrect argument passing

- The code below passes the *address* of variable t, which is shared memory space and visible to all threads
  - As the loop iterates, the value of this memory location changes, possibly before the created threads can access it

```
int rc; int t;
for(t=0; t<NUM_THREADS; t++) {
  printf("Creating thread %ld\n", t);
  rc = pthread_create(&threads[t], NULL, PrintHello, (void *) &t);
  ...
 }
```


Thread Termination

- void pthread_exit(void *value_ptr);
- *value_ptr* is a pointer to the object (variable, array, structure) returned by the thread
  - The value must not be of local scope otherwise it won't exist after the thread is destroyed
  - This value can available to another thread in the same process
  - Can be NULL if not returning anything

Thread join

- One way to accomplish synchronization between threads
- Causes the calling thread to wait for another thread to terminate
  - For threads it important as we run the risk of executing an exit (reach end of main) which will terminate the process and all threads before the threads have completed
- int pthread_join(pthread_t thread, void ** value_ptr)
  - *thread* is the thread to wait on
  - *value_ptr* is the value given to *pthread_exit()* by the terminating thread
  - returns 0 to indicate success
- Usuage

```
void * return_val;
....
//after code creating threads
if(pthread_join(worker_thread, &return_val)){
   printf("Error while waiting on thread\n");
   exit(1);
}
```


Mutex

- Mutex is short for mutual exclusion
- Primary means of implementing thread synchronization and for protecting shared data when multiple writes occur
  - Provides lock mechanism for shared data
- To create a mutex:

int pthread_mutex_init(pthread_mutex_t *mutex, pthread_mutexattr_t * attr)

  - *mutex* is the lock (of type pthread_mutex_t)
  - *attr* is the lock attributes
    - NULL by default
- To lock: **int pthread_mutex_lock(pthread_mutex_t *mutex)**
  - If lock is already locked the calling thread is blocked
  - If lock is not locked the calling thread acquires it
  - returns 0 on success
- To Unlock: **pthread_mutex_unlock**

Typical sequence when using a mutex

- Create and initialize a mutex variable
- Several threads attempt to lock the mutex
- Only one succeeds and that thread owns the mutex
- The owner thread performs some set of actions
- The owner unlocks the mutex
- Another thread acquires the mutex and repeats the process
- Finally the mutex is destroyed

Mutex (contd..)

- Declare variables as globals i.e. outside all methods
  - E.g. pthread_mutex_t myMutex;
- For synchronization:

```
pthread_mutex_lock(&myMutex)
 //critical section code
pthread_mutex_unlock(&myMutex)
```

- After all work is done, need to destroy them
  - pthread_mutex_destroy (&myMutex);
- See example thread2.c

Deadlock in Resource Sharing Environment

- A *deadlock* occurs when 2 or more tasks (processes/threads) permanently block each other by each having a lock on a resource which the other tasks are trying to lock
- Deadlock can occur due to
  - Locks: Waiting to acquire locks on resources, such as objects, pages etc.
  - Sharing resources such as I/O devices printer, disks etc.

Example

- 2 Threads access 2 shared variables A and B
- Variable A is protected by lock x and variable B by lock y
- Here's what Thread 1 and Thread 2 need to do:

Thread 1
A = A + 10
B = B + 20
A = A + B
A = A + 30

Thread 2
B = B + 10
A = A + 20
A = A + B
B = B + 30

- Each must acquire locks for A and B
- Lets look at one way to do this

Approach

Thread 1
Lock(x)
A = A + 10
Lock(y)
B = B + 20
A = A + B
Unlock(y)
A = A + 30
Unlock(x)

Thread 2
Lock(y)
B = B + 10
Lock(x)
A = A + 20
A = A + B
Unlock(x)
B = B + 30
Unlock(y)

- Can we see a problem with this approach?
- How can we avoid the problem?

Cond and Wait

- Another means of synchronization
- Condition variables allow threads to synchronize based upon the actual value of data
  - If we want one thread to signal an event to another we need to use Conditional variables
    - pthread_cond_t *condVariable*
- Idea is one thread wait until a certain condition is true
  - Test condition
  - If not true, calls pthread_cond_wait(..) to block until it is
- Another thread makes the condition true and call pthread_cond_signal(…) to unblock the thread waiting
- To avoid race conditions, the conditional variable must use a mutex

Example

- Signalling thread

```
pthread_mutex_lock(&mutex);
flag =1;
pthread_cond_signal(&condition);
pthread_mutex_unclock(&mutex);
```

- condition is conditional variable
  - type pthread_cond_t
- mutex is mutex variable
  - type pthread_mutex_t

- Waiting thread

```
pthread_mutex_lock(&mutex);
if(flag == 0)
    pthread_cond_wait(&condition, &mutex);
 pthread_mutex_unlock(&mutex)
```

- Wait will automatically release the mutex while it waits
- After signal is received and thread is awakened, *mutex* will be automatically locked for use by the thread.
- Programmer is then responsible for unlocking *mutex* when the thread is finished with it

Producer Consumer Example

- Single producer thread, single consumer thread
  - Single shared buffer between producer and consumer
  - E.g. A fixed-size queue of print requests
    - One thread produces information – adds a print request to the queue
    - Other thread consumes information – takes a print request and prints it
- Condition and Wait
  - Involves mutual exclusion between producer and consumer
    - Due to use of same buffer
  - After producing an item, a producer should signal the the consumer
  - After consuming, consumer should signal the producer
  - See example thread3.c for illustration

Misc.

- pthread_self() returns the unique, system assigned thread ID of the calling thread
- Thread cancelation
  - int pthread_cancel(pthread_t thread)
    - Causes the thread to be canceled (or terminated)
- Thread Attributes
  - By default, a thread is created with certain attributes
  - pthread_attr_init and pthread_attr_destroy are used to initialize/destroy the thread attribute object
  - *pthread_attr_getXXX* (..) gets the attribute and *pthread_attr_setXXX (..)* sets the attribute
- Mutex Attributes
  - Like threads, mutexes also have attributes
  - Related to thread scheduling(more details in scheduling topics)