CSCI-GA.3033-012

Multicore Processors: Architecture & Programming

Lecture 5: Threads … Pthreads

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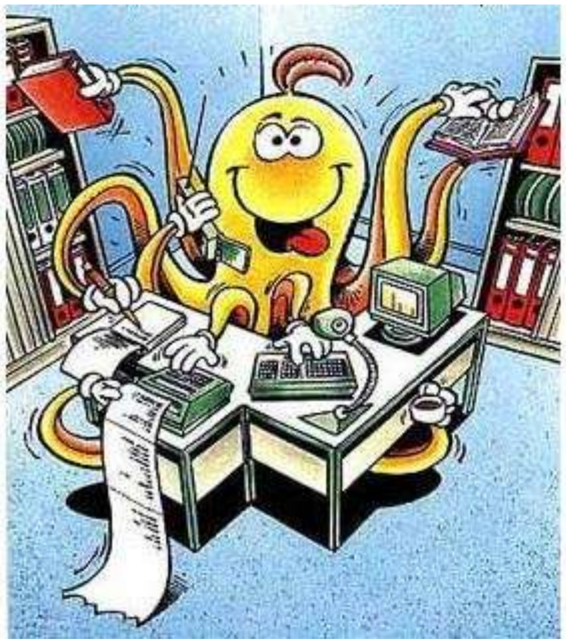
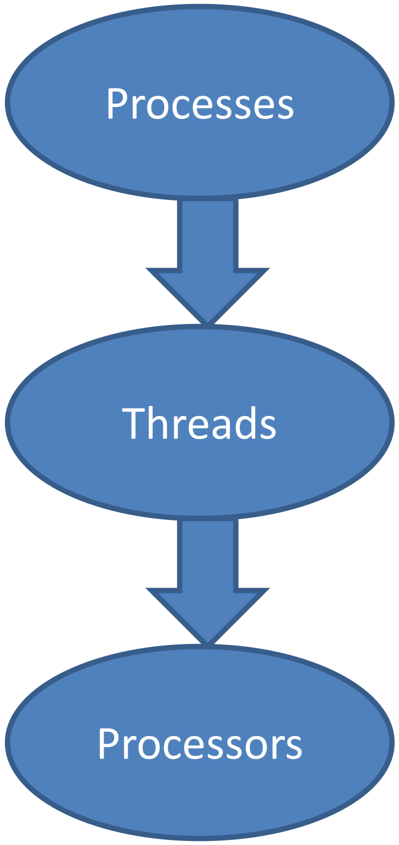
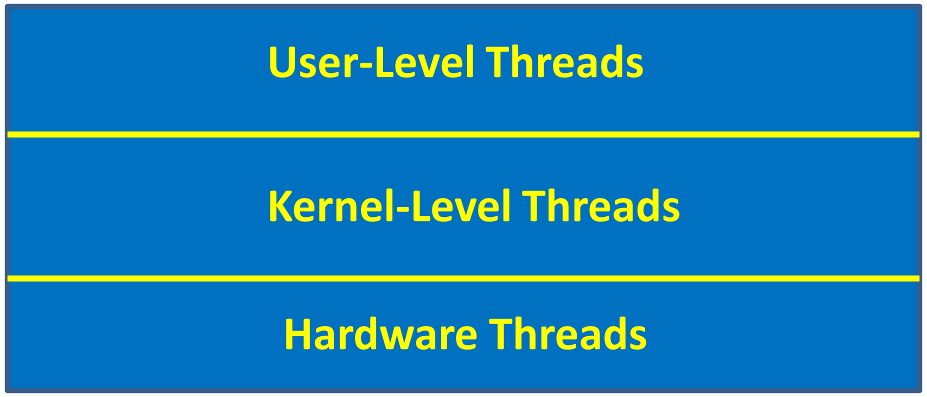
Multithreading





A Thread?

- **Definition**: sequence of related instructions executed independently of other instruction sequences
- A thread can create another thread
- Each thread maintains its current machine state



A Thread?

- Relationship between user-level and kernel-level threads
  - 1:1
    - user-level thread maps to kernel-level thread
    - e.g. win32, Linux (original C-library), windows 7, FreeBSD
  - N:1 (user-level threads)
    - Kernel is not aware of the existence of threads
    - e.g. Early version of Java, Solaris Green Thread
  - M:N
- Threads share same address space but have their own private stacks
- Thread states: ready, running, waiting (blocked), or terminated

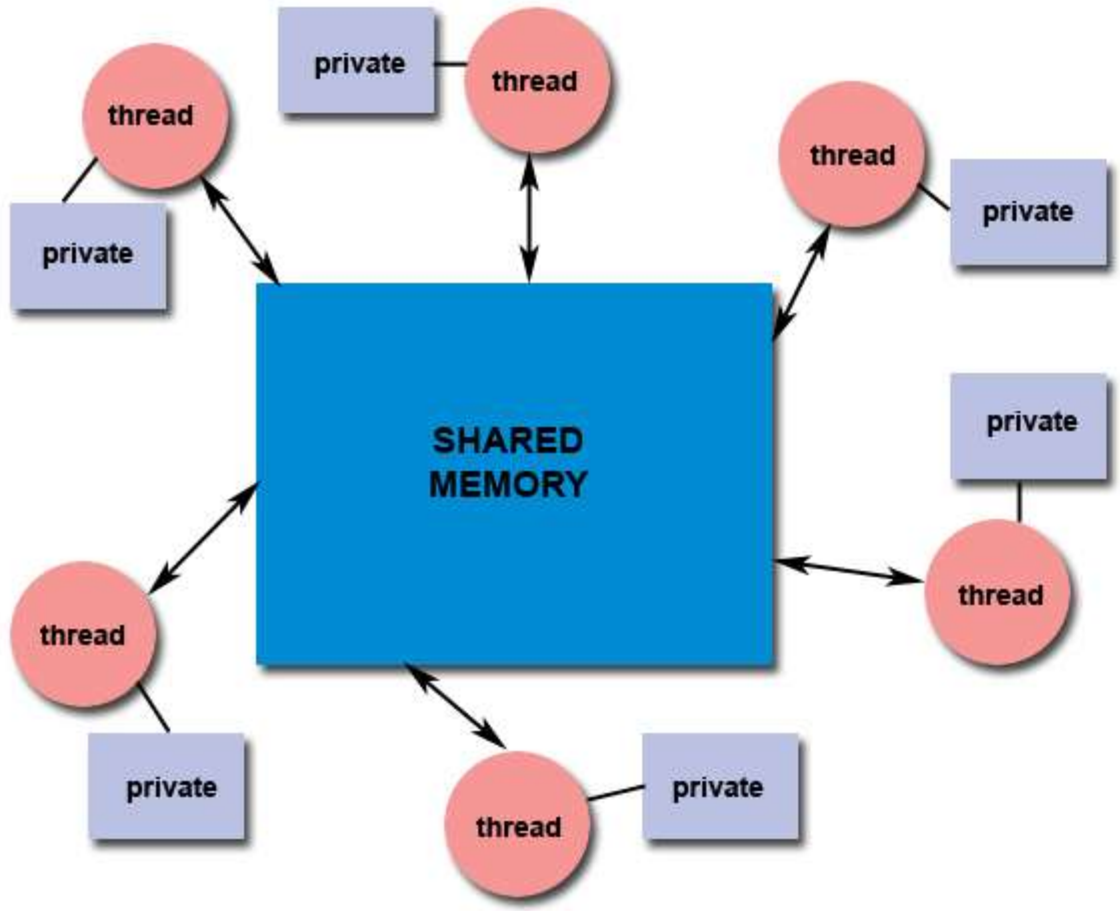
POSIX Threads (Pthreads)

- Low-level threading libraries
- Native threading interface for Linux now
- Use kernel-level thread (1:1 model)
- developed by the IEEE committees in charge of specifying a Portable Operating System Interface (POSIX)
- Shared memory

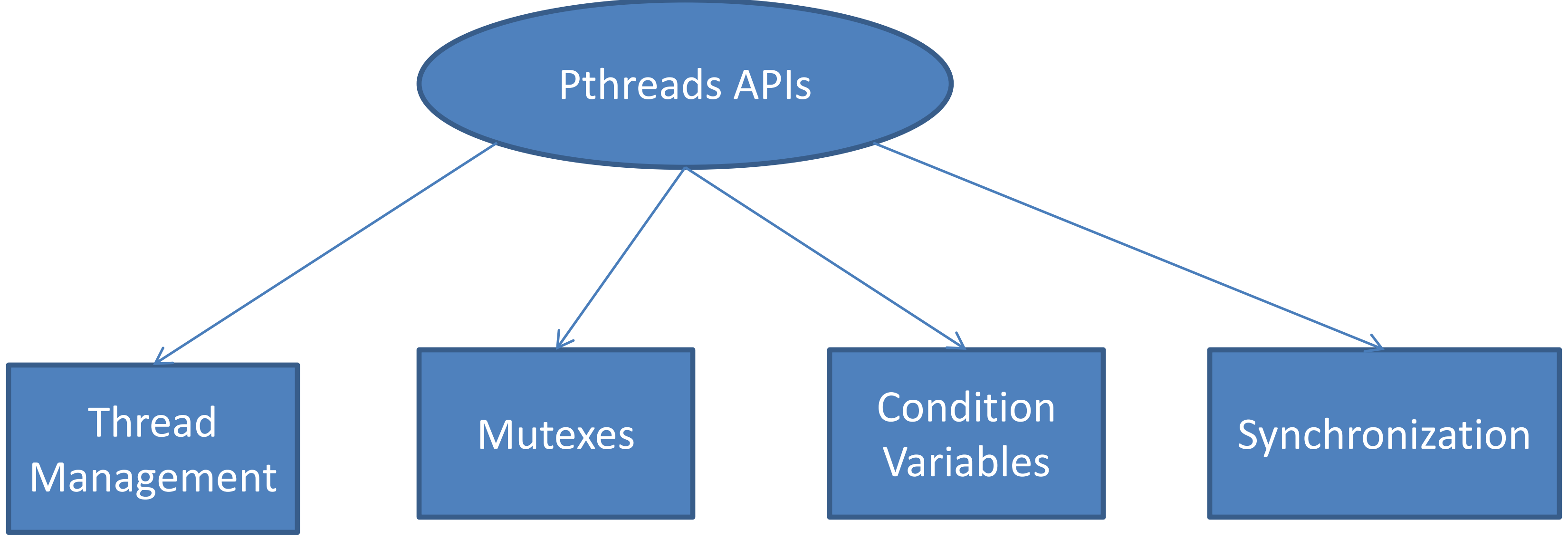
POSIX Threads (Pthreads)

- C language programming types and procedure calls
- implemented with a pthread.h header
- To compile with GNU compiler, 2 methods:
  - gcc/g++ *progname* –lpthread
  - gcc/g++ -pthread *progname*
- Programmers are responsible for synchronizing access (protecting) globally shared data.
- Capabilities like thread priority are not part of the core pthreads library.

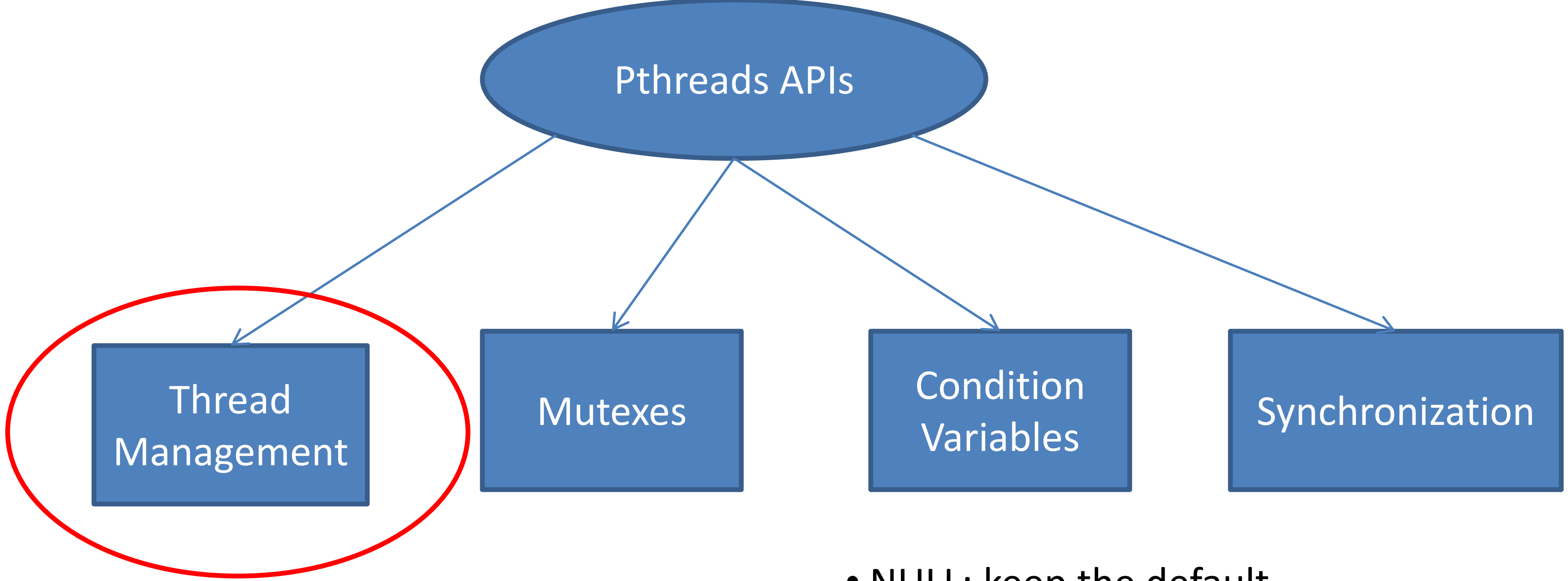
POSIX Threads (Pthreads)



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



More than 100 subroutines!



- NULL: keep the default
- specified only at thread creation time
- The main steps in setting attributes:
    - pthread_attr_t tattr
    - pthread_attr_init(&tattr)
    - pthread_attr_*(&tattr,SOME_ATRIBUTE_VALUE_PARAMETER)

```
pthread_create(pthread_t *,
               const pthread_attr_t *,
               void *(*start_routine)(void*),
               void * arg)
```

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

void *print_message_function( void *ptr );

main()
{
    pthread_t thread1, thread2;
    char *message1 = "Thread 1";
    char *message2 = "Thread 2";
    int  iret1, iret2;

    iret1 = pthread_create( &thread1, NULL, print_message_function, (void*) message1);
    iret2 = pthread_create( &thread2, NULL, print_message_function, (void*) message2);

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

    printf("Thread 1 returns: %d\n",iret1);
    printf("Thread 2 returns: %d\n",iret2);
    exit(0);
}

void *print_message_function( void *ptr )
{
    char *message;
    message = (char *) ptr;
    printf("%s \n", message);
}
```

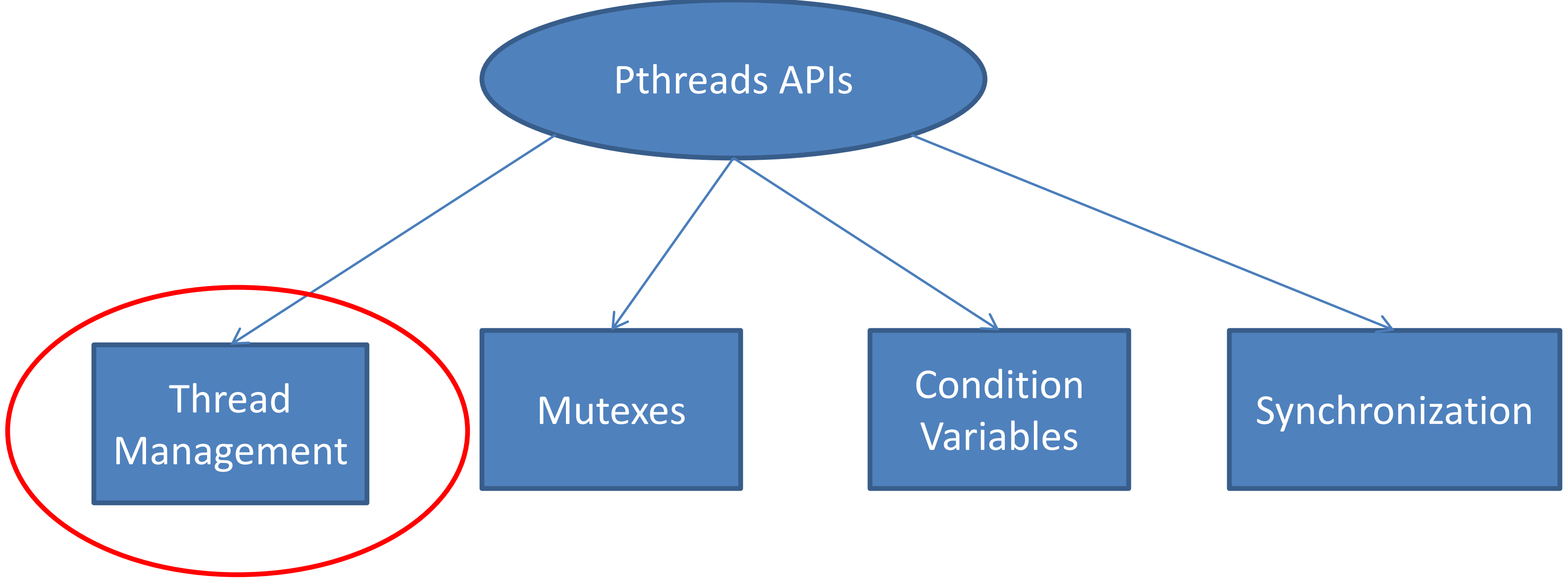
Wait until thread returns

Threads terminate by:

- explicitly calling pthread_exit
- letting the function return
- a call to the function exit which will terminate the process including any threads.
- canceled by another thread via the pthread_cancel routine

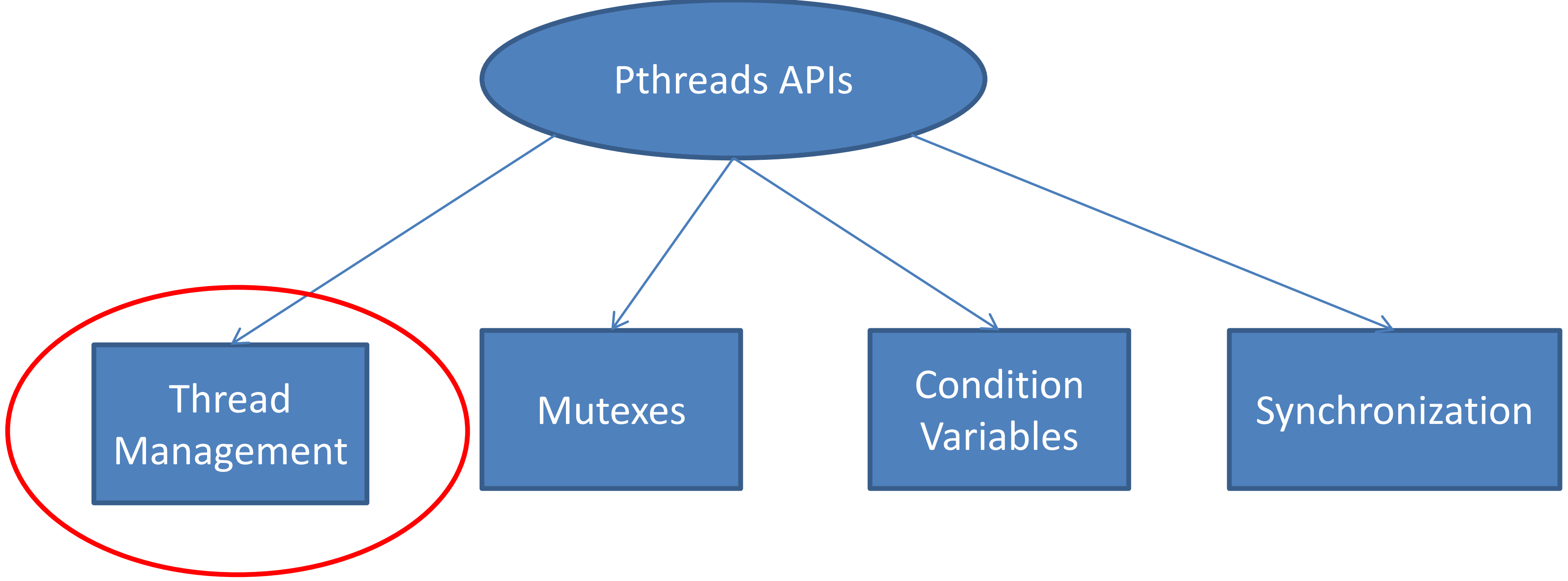
```
#include <pthread.h>
#include <stdio.h>

#define NUM_THREADS 5

void *PrintHello(void *threadid) {
         long tid;
        tid = (long)threadid;
        printf("Hello World! It's me, thread #%ld!\n", tid);
        pthread_exit(NULL);
}

int main (int argc, char *argv[]) {
        pthread_t threads[NUM_THREADS];
        int rc;
        long t;

        for(t=0; t<NUM_THREADS; t++){
                printf("In main: creating thread %ld\n", t);
                rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);

                if (rc){
                        printf("ERROR; return code from pthread_create() is %d\n", rc);
                        exit(-1);
                }
        }
        /* Last thing that main() should do */
        pthread_exit(NULL);
}
```

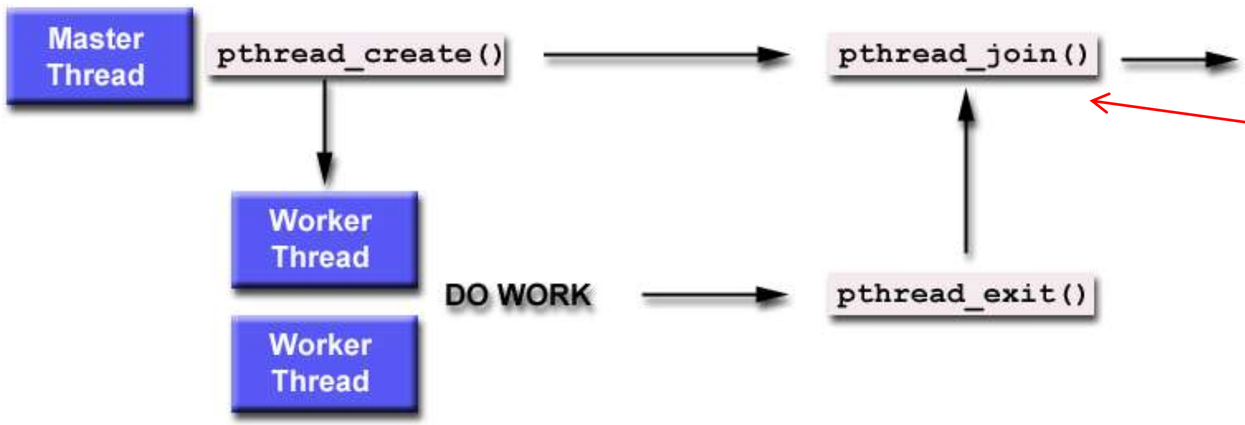
By having main() explicitly call pthread_exit() as the last thing it does, main() will block and be kept alive to support the threads it created until they are done.



What is wrong about the following code?

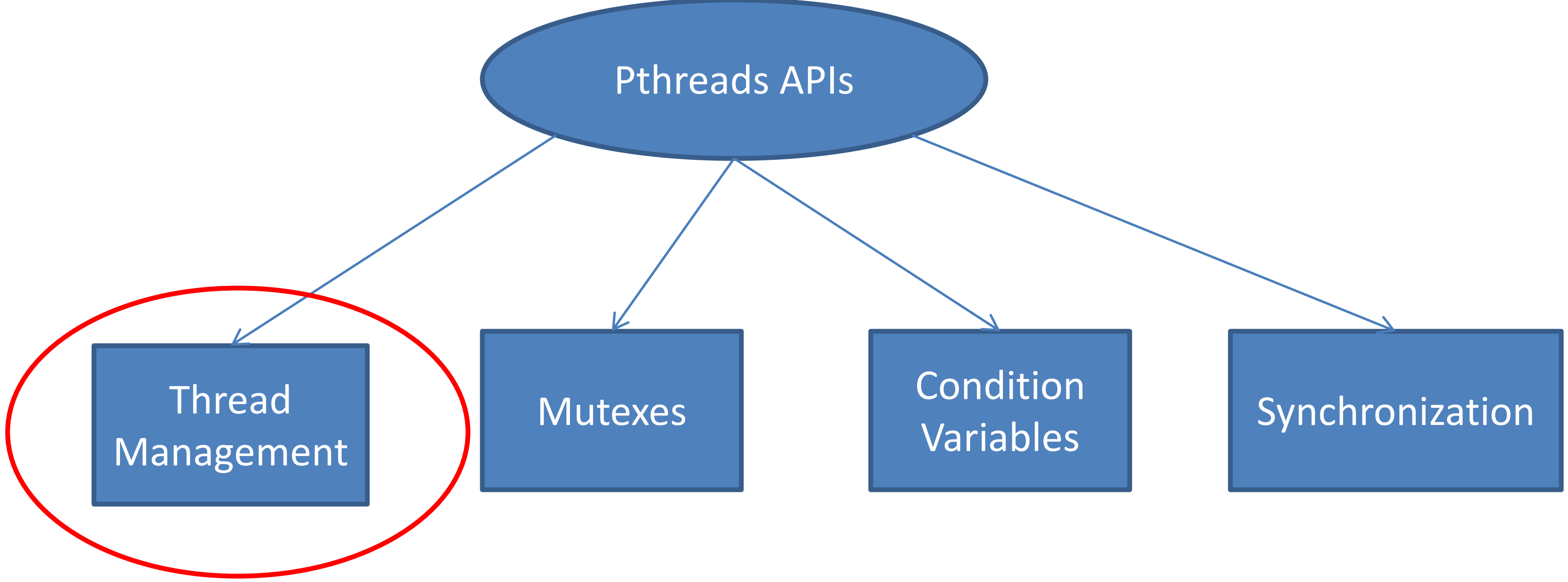
```
int rc;
long t;
for(t=0; t<NUM_THREADS; t++) {
    printf("Creating thread %ld\n", t);
    rc = pthread_create(&threads[t], NULL, PrintHello, (void *) &t);
    ... }
```





The pthread_join() subroutine blocks the calling thread until the specified threadid thread terminates.

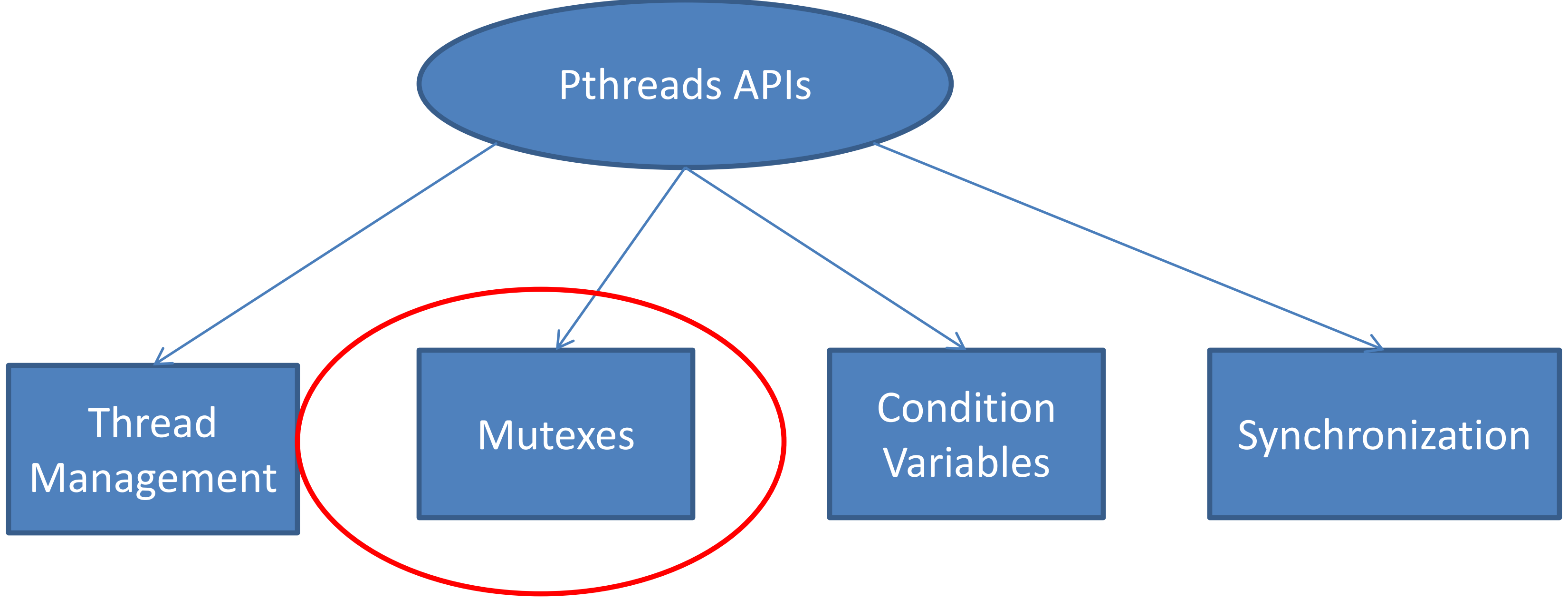
```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#define NUM_THREADS     4

void *BusyWork(void *t)
{
   int i;
   long tid;
   double result=0.0;
   tid = (long)t;
   printf("Thread %ld starting...\n",tid);
   for (i=0; i<1000000; i++)
   {
      result = result + sin(i) * tan(i);
   }
   printf("Thread %ld done. Result = %e\n",tid, result);
   pthread_exit((void*) t);
}

int main (int argc, char *argv[])
{
   pthread_t thread[NUM_THREADS];
   pthread_attr_t attr;
   int rc;
   long t;
   void *status;

   /* Initialize and set thread detached attribute */
   pthread_attr_init(&attr);
   pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_JOINABLE);

   for(t=0; t<NUM_THREADS; t++) {
      printf("Main: creating thread %ld\n", t);
      rc = pthread_create(&thread[t], &attr, BusyWork, (void *)t);
      if (rc) {
         printf("ERROR; return code from pthread_create()
                is %d\n", rc);
         exit(-1);
         }
      }

   /* Free attribute and wait for the other threads */
   pthread_attr_destroy(&attr);
   for(t=0; t<NUM_THREADS; t++) {
      rc = pthread_join(thread[t], &status);
      if (rc) {
         printf("ERROR; return code from pthread_join()
                is %d\n", rc);
         exit(-1);
         }
      printf("Main: completed join with thread %ld having a status
           of %ld\n",t,(long)status);
      }

   printf("Main: program completed. Exiting.\n");
   pthread_exit(NULL);
}
```



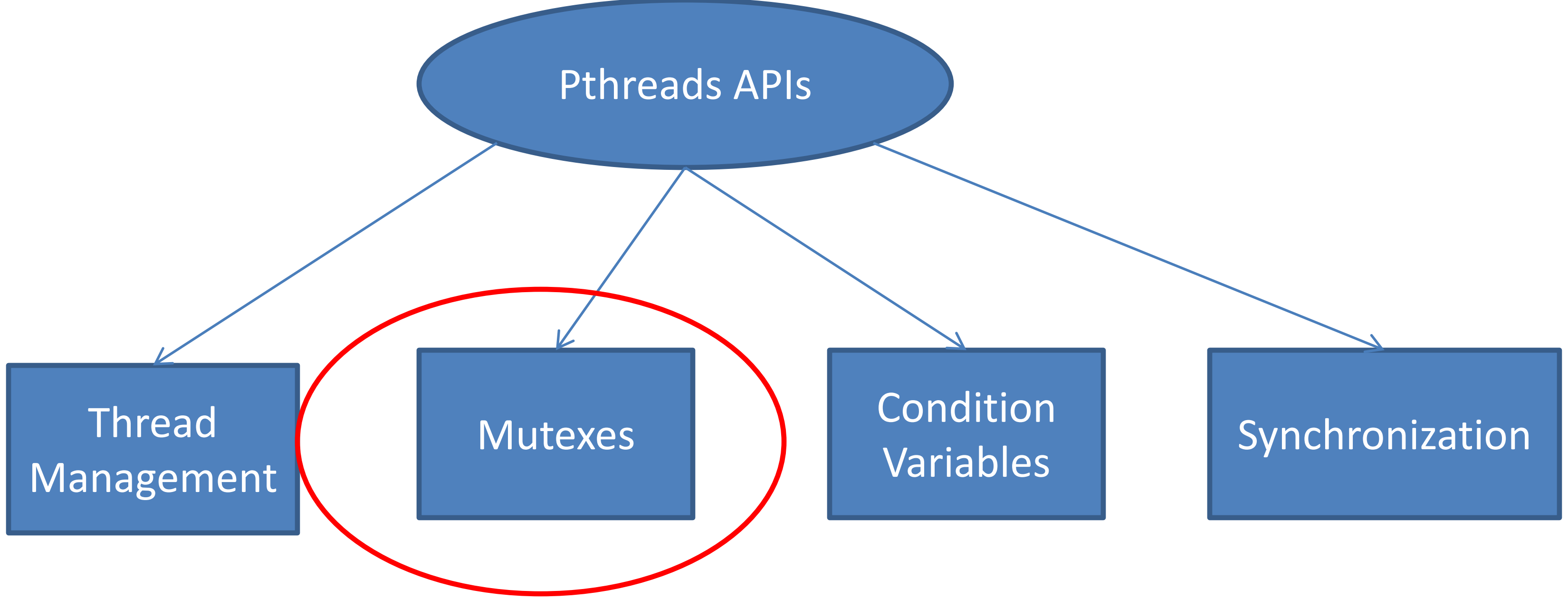
How about the stack?

- Default thread stack size varies greatly.
- Safe and portable programs do not depend upon the default stack limit

```
#include <pthread.h>
#include <stdio.h>
#define NTHREADS 4
#define N 1000
#define MEGEXTRA 1000000

pthread_attr_t attr;

void *dowork(void *threadid)
{
   double A[N][N];
   int i,j;
   long tid;
   size_t mystacksize;

   tid = (long)threadid;
   pthread_attr_getstacksize (&attr, &mystacksize);
   printf("Thread %ld: stack size = %li bytes \n", tid, mystacksize);
   for (i=0; i<N; i++)
     for (j=0; j<N; j++)
      A[i][j] = ((i*j)/3.452) + (N-i);
   pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
   pthread_t threads[NTHREADS];
   size_t stacksize;
   int rc;
   long t;

   pthread_attr_init(&attr);
   pthread_attr_getstacksize (&attr, &stacksize);
   printf("Default stack size = %li\n", stacksize);
   stacksize = sizeof(double)*N*N+MEGEXTRA;
   printf("Amount of stack needed per thread = %li\n",stacksize);
   pthread_attr_setstacksize (&attr, stacksize);
   printf("Creating threads with stack size = %li bytes\n",stacksize);
   for(t=0; t<NTHREADS; t++){
      rc = pthread_create(&threads[t], &attr, dowork, (void *)t);
      if (rc){
         printf("ERROR; return code from pthread_create() is %d\n", rc);
         exit(-1);
      }
   }
   printf("Created %ld threads.\n", t);
   pthread_exit(NULL);
}
```



- Mutex = Mutual Exclusion
- One of the primary means of implementing thread synchronization and for protecting shared data when multiple writes occur.
- acts like a lock protecting access to a shared data resource
- only one thread can lock (or own) a mutex variable at any given time.



A typical sequence in the use of a mutex is as follows:

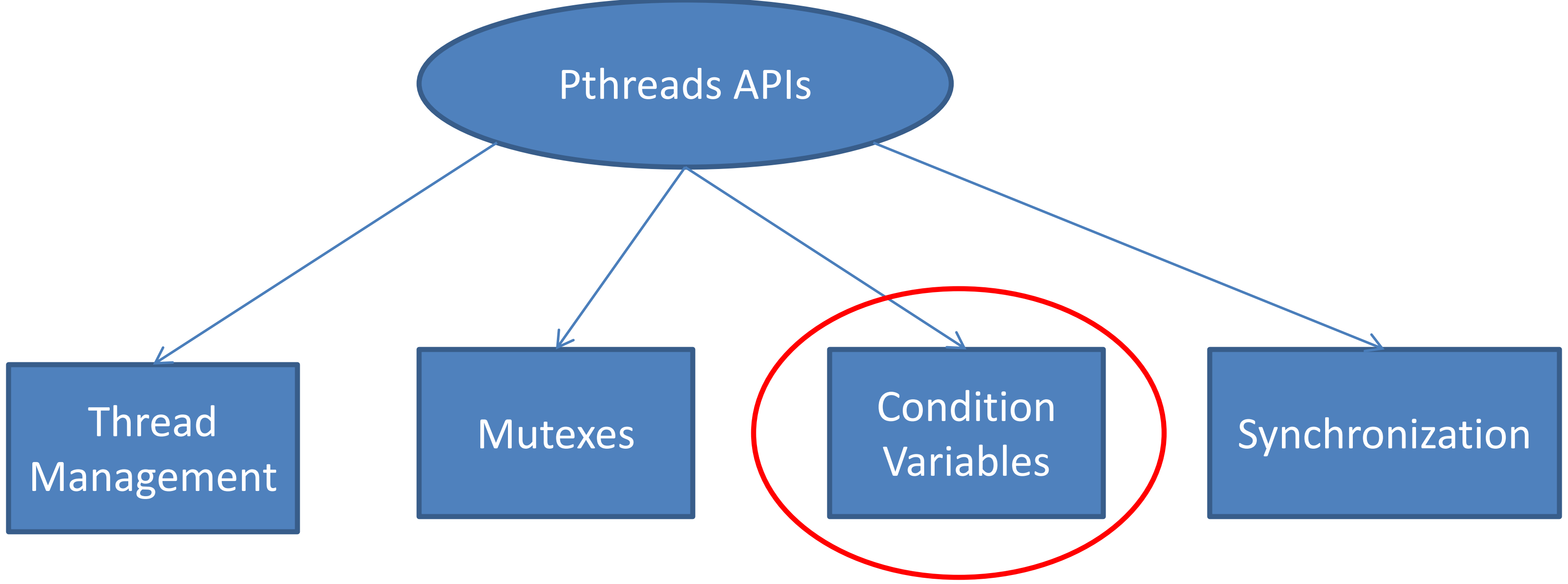
- Create and initialize a mutex variable
- Several threads attempt to lock the mutex
- Only one succeeds and that thread owns the mutex
- The owner thread performs some set of actions
- The owner unlocks the mutex
- Another thread acquires the mutex and repeats the process
- Finally the mutex is destroyed

It is up to the code writer to insure that the necessary threads all make the the mutex lock and unlock calls correctly.

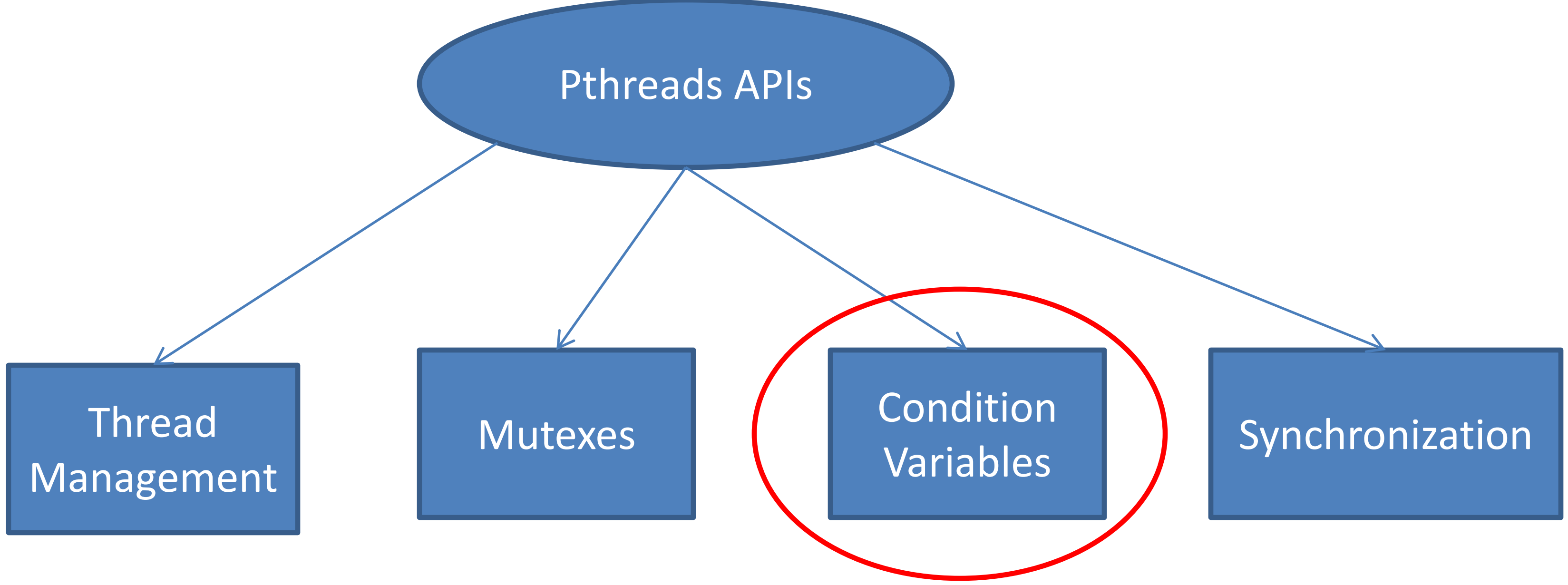
```c
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>

/*
The following structure contains the necessary information
to allow the function "dotprod" to access its input data and
place its output into the structure.
*/

typedef struct
 {
   double      *a;
   double      *b;
   double     sum;
   int     veclen;
 } DOTDATA;

/* Define globally accessible variables and a mutex */

#define NUMTHRDS 4
#define VECLEN 100
   DOTDATA dotstr;
   pthread_t callThd[NUMTHRDS];
   pthread_mutex_t mutexsum;
```

```c
void *dotprod(void *arg)
{
     ------------

  Lock a mutex prior to updating the value in the shared
  structure, and unlock it upon updating.
  */
  pthread_mutex_lock (&mutexsum);
  dotstr.sum += mysum;
  pthread_mutex_unlock (&mutexsum);

  pthread_exit((void*) 0);
}
```

```c
int main (int argc, char *argv[])
{
   long i;
   double *a, *b;
   void *status;
   pthread_attr_t attr;

   /* Assign storage and initialize values */
   a = (double*) malloc (NUMTHRDS*VECLEN*sizeof(double));
   b = (double*) malloc (NUMTHRDS*VECLEN*sizeof(double));

   for (i=0; i<VECLEN*NUMTHRDS; i++)
    {
     a[i]=1.0;
     b[i]=a[i];
    }

   dotstr.veclen = VECLEN;
   dotstr.a = a;
   dotstr.b = b;
   dotstr.sum=0;

   pthread_mutex_init(&mutexsum, NULL);

             ------------

             . . .
     pthread_mutex_destroy(&mutexsum);
     pthread_exit(NULL);
}
```



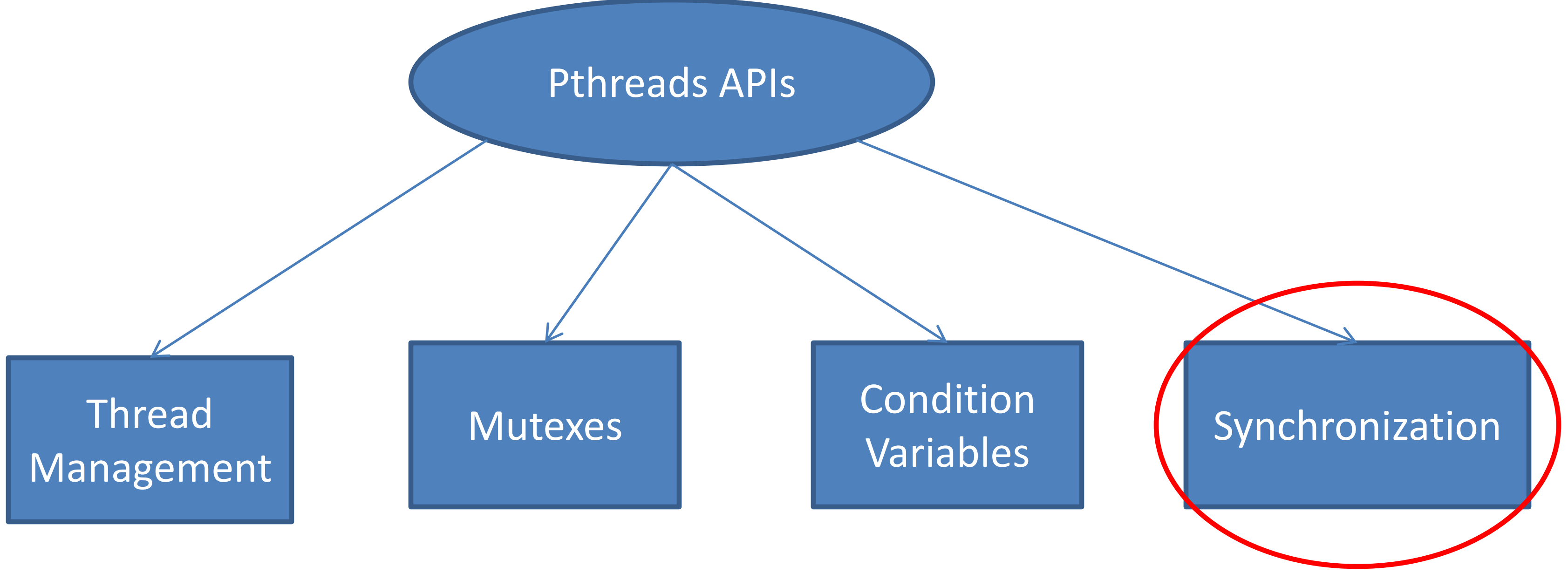
- While mutexes implement synchronization by controlling thread access to data, condition variables allow threads to synchronize based upon the actual value of data.
- A condition variable is always used in conjunction with a mutex lock.



- Condition variables must be declared with type pthread_cond_t
- must be initialized before they can be used.
- There are two ways to initialize a condition variable:
    - Statically, when it is declared. For example:

      pthread_cond_t myconvar = PTHREAD_COND_INITIALIZER;
    - Dynamically, with the pthread_cond_init() routine.
- The ID of the created condition variable is returned to the calling thread through the *condition* parameter.
- pthread_cond_destroy() should be used to free a condition variable that is no longer needed.

```
int count = 0;
int thread_ids[3] = {0,1,2};
pthread_mutex_t count_mutex;
pthread_cond_t count_threshold_cv;

void *inc_count(void *t) {
        int i;
        long my_id = (long)t;

        for (i=0; i<TCOUNT; i++) {
                pthread_mutex_lock(&count_mutex);
                count++;
                if (count == COUNT_LIMIT)
                                pthread_cond_signal(&count_threshold_cv);
                pthread_mutex_unlock(&count_mutex);

               /* Do some "work" so threads can alternate on mutex lock */
               sleep(1); }
pthread_exit(NULL);
}

void *watch_count(void *t) {
               long my_id = (long)t;
               pthread_mutex_lock(&count_mutex);

             while (count<COUNT_LIMIT) {
                                pthread_cond_wait(&count_threshold_cv, &count_mutex);
                        count += 125;
              }
              pthread_mutex_unlock(&count_mutex);
              pthread_exit(NULL);
}
```



Definition: Synchronization is an enforcing mechanism used to impose constraints on the order of execution of threads, in order to coordinate thread execution and manage shared data.

By now you must have realized that we have 3 synchronization mechanisms:

- Mutexes
- Condition variables
- joins

Semaphores

- permit a limited number of threads to execute a section of the code
- similar to mutexes
- should include the semaphore.h header file
- semaphore functions have sem_ prefixes

Basic Semaphore functions

- creating a semaphore:
  - int sem_init(sem_t *sem, int pshared, unsigned int value)
  - initializes a semaphore object pointed to by sem
  - pshared is a sharing option; a value of 0 means the semaphore is local to the calling process
  - gives an initial value value to the semaphore
- terminating a semaphore:
  - int sem_destroy(sem_t *sem)
  - frees the resources allocated to the semaphore sem
  - usually called after pthread_join()

Basic Semaphore functions

- int sem_post(sem_t *sem)
  - atomically increases the value of a semaphore by 1, i.e., when 2 threads call sem_post simultaneously, the semaphore's value will also be increased by 2 (there are 2 atoms calling)
- int sem_wait(sem_t *sem)
  - atomically decreases the value of a semaphore by 1

```c
#include <pthread.h>
#include <semaphore.h>
...
void *thread_function( void *arg );
...
sem_t semaphore;        // also a global variable just like mutexes
...
int main()
{
        int tmp;
        ...
        // initialize the semaphore
        tmp = sem_init( &semaphore, 0, 0 );
        ...
        // create threads
        pthread_create( &thread[i], NULL, thread_function, NULL );
        ...
        while ( still_has_something_to_do() )
        {
            sem_post( &semaphore );
            ...
        }
        ...
        pthread_join( thread[i], NULL );
        sem_destroy( &semaphore );
        return 0;
}
```

```c
void *thread_function( void *arg )
{
        sem_wait( &semaphore );
        perform_task_when_sem_open();
        ...
        pthread_exit( NULL );
}
```

The Problem With Threads

- Paper by Edward Lee, 2006
- The author argues:
  - "From a fundamental perspective, threads are seriously flawed as a computation model"
  - "Achieving reliability and predictability using threads is essentially impossible for many applications"
- The main points:
  - Our abstraction for concurrency does not even vaguely resemble the physical world.
  - Threads are dominating but not the best approach in every situation
  - Yet threads are suitable for embarrassingly parallel applications

The Problem With Threads

- The logic of the paper:
  - Threads are nondeterministic
  - Why shall we use nondeterministic mechanisms to achieve deterministic aims??
  - The job of the programmer is to prune this nondeterminism.
  - This leads to poor results

Do you agree or disagree with the author ?

Conclusions

- Processes → threads → processors
- User-level threads and kernel-level threads are not the same but they have direct relationship
- Pthreads assume shared memory