# CME 213

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# PTHREADS


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1891

# Programming using threads

- This is the most basic approach for programming in parallel.
- Pthreads: POSIX threads. This is a standard to implement threads on UNIX systems. It is based on the C programming language.
- The other approach is based on OpenMP.

# THE BASICS

- **Include the header file:**

```
<pthread.h>
```

- **Compile using:**

```
gcc -o pth_hello pth_hello.c -lpthread
```

# LET'S DIVE IN

```
…
#include <pthread.h>
#define NUM_THREADS    5

void *PrintHello(void *threadid){
   long 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);
}
```

# Output

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

# THREAD CREATION

```
int pthread_create(
    pthread_t *thread,
    const pthread_attr_t *attr,
    void *(*routine)(void*),
    void *arg)
```

- **`thread`** thread identifier
- **`routine`** function that will be executed by the generated thread
- **`arg`** pointer to the argument value with which the thread function **`routine()`** will be executed
- **`attr`** use **`NULL`** for the time being

# THREAD TERMINATION

**A thread terminates when:**

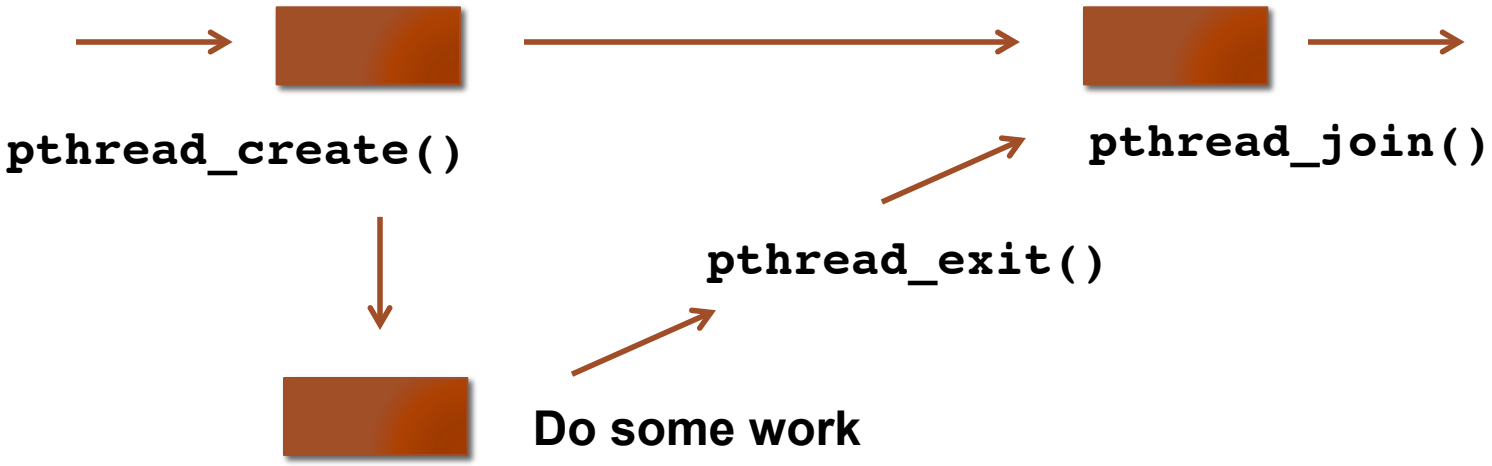
1. **Thread reaches the end of its thread function, i.e., returns.**
2. **Thread calls**

```
void pthread_exit(void *valuep)
```

**Note:**

- **Upon termination, a thread releases its runtime stack.**
- **Therefore the pointer should point to: 1) a global variable, or 2) a dynamically allocated variable.**

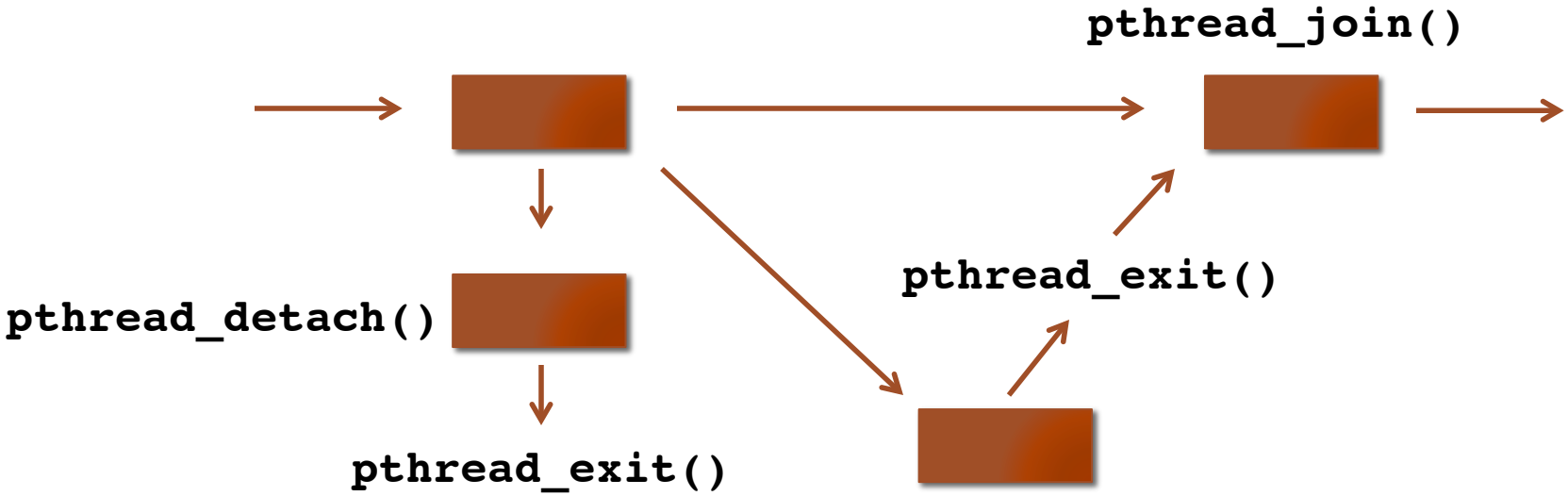
# JOINING THREADS




```
int pthread_join( pthread_t thread, void **valuep )
```

- Calling thread waits for thread to terminate.
- `pthread_join` is used to synchronize threads.
- `valuep` memory address where the return value of thread is stored.

# DETACHING A THREAD



# DETACHING THREADS

- **A thread that terminates needs to hold some internal data structure until `pthread_join()` is called.**
- **What happens if `pthread_join()` is never called?**
  - Basically, synchronization is not needed. We launched a thread; it does its work but we don't need to know when it terminates.
- **In that case, the internal data structure is never released. This can be a problem in programs that create and terminate a lot of threads.**

**Solution:**

```
int pthread_detach(pthread_t thread)
```

- **This function notifies the runtime system that the internal data structure of this thread can be freed as soon as the thread terminates.**
- **`pthread_join()` returns an error in that case.**

# EXAMPLE: MATRIX MATRIX PRODUCT

**MC = MA * MB**

```
#include <pthread.h>

typedef struct {
  int size, row, column;
  double (*MA)[8], (*MB)[8], (*MC)[8];
} matrix_type_t;

void *thread_mult (void *w) {
  matrix_type_t *work = (matrix_type_t *) w;
  int i, row = work->row, column = work->column;
  work -> MC[row][column] = 0;
  for (i=0; i < work->size; i++)
    work->MC[row][column] += work->MA[row][i] * work->MB[i][column];
  return NULL;
}

int main() {
  int row, column, size = 8, i;
  double MA[8][8], MB[8][8], MC[8][8];
  matrix_type_t *work;
  pthread_t thread[8*8];
  for (row=0; row<size; row++)
    for (column=0; column<size; column++) {
      work = (matrix_type_t *) malloc (sizeof (matrix_type_t));
      work->size = size;
      work->row = row;
      work->column = column;
      work->MA = MA; work->MB = MB; work->MC = MC;
      pthread_create (&(thread[column + row*8]), NULL,
                      thread_mult, (void *) work);
    }

  for (i=0; i<size*size; i++)
    pthread_join (thread[i], NULL);
}
```

# THREAD COORDINATION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# MUTEXES

# The risks of multi-threaded programming

- Let us assume that a well-known bank company has asked you to implement a multi-threaded code to perform bank transactions.
- You start with the modest goal of allowing deposits.
- Clients deposit money and the amount gets credited to their accounts.
- As a result of having multiple threads running concurrently the following can happen:

# A PARALLEL BANK DEPOSIT

| Thread 0 | Thread 1 | Balance |
|---|---|---|
| Client requests a deposit | Client requests a deposit | $1000 |
| Check current balance = $1000 | | |
| | Check current balance = $1000 | |
| Ask for deposit amount = $100 | Ask for deposit amount = $300 | |
| | Compute new balance = $1300 | |
| Compute new balance = $1100 | Write new balance to account | $1300 |
| Write new balance to account | | $1100 |

# RACE CONDITION

- Although the correct balance should be $1,400, it is $1,100.
- The problem is that many operations “take time” and can be “interrupted” by other threads attempting to modify the same data.
- This is called a race condition: the final result depends on the precise order in which the instructions are executed.
- Unless thread 0 completes its update before thread 1 (or vice versa) we get an incorrect result.
- This issue is addressed using mutexes (mutex): mutual exclusion.
- They ensure that certain common pieces of data are accessed and modified by a single thread.

# MUTEX

- **A mutex can only be in two states: locked or unlocked.**
- **Once a thread locks a mutex:**
  - Other threads attempting to lock the same mutex are blocked
  - Only the thread that initially locked the mutex has the ability to unlock it.
- **This allows to protect regions of code.**

# TYPICAL USAGE

**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**

# Performing a dot product in parallel

- This is the simplest example that uses mutexes.
- All threads calculate a portion of the dot product using local variables.
- A final reduction (+) is made to a shared variable.
- This update is protected using a mutex.

# HEAD OF FILE

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

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

/* Define globally accessible variables and a mutex */
DOTDATA dotstr;
pthread_mutex_t mutexsum;
```

```
int main (int argc, char *argv[]) {
      int numthrds = 4;
      int veclen = 100000;
      long i;
      double *a, *b;
      pthread_t *thread;

      /* Assign storage and initialize values */
      thread = (pthread_t*) malloc(numthrds*sizeof(pthread_t));

      a = (double*) malloc (numthrds*veclen*sizeof(double));
      b = (double*) malloc (numthrds*veclen*sizeof(double));
      …

      dotstr.veclen = veclen;
      dotstr.a = a; dotstr.b = b;
      dotstr.sum = 0.0;

      pthread_mutex_init(&mutexsum, NULL);

      /* Create threads to perform the dotproduct */
      for (i=0; i<numthrds; i++)
            pthread_create(&thread[i], NULL, dotprod, (void *)i);

      /* Wait on the other threads */
      for (i=0; i<numthrds; i++) pthread_join(thread[i], NULL);

      printf("Sum =  %f \n", dotstr.sum);
      free(a); free(b);
      pthread_mutex_destroy(&mutexsum);
      pthread_exit(NULL);
}
```

```
void *dotprod(void *arg) {
     int i, start, end, len;
     long offset;
     double mysum, *x, *y;
     offset = (long) arg;

     len = dotstr.veclen;
     start = offset*len;
     end   = start + len;
     x = dotstr.a;
     y = dotstr.b;

     mysum = 0;
     for (i=start; i<end; i++) mysum += x[i] * y[i];

     /*
      Lock a mutex prior to updating the value in the shared
      structure, and unlock it upon updating.
      */
     pthread_mutex_lock(&mutexsum);
     dotstr.sum += mysum;
     printf("Thread %d did %8d to %8d: mysum = %7.3f global sum = %7.3f\n",
             (int)offset,start,end,mysum,dotstr.sum);
     pthread_mutex_unlock(&mutexsum);

     pthread_exit(NULL);
}
```

# OUTPUT

```
Thread 2 did   200000 to   300000: mysum =   0.405 global sum =   0.405
Thread 1 did   100000 to   200000: mysum =   0.693 global sum =   1.099
Thread 3 did   300000 to   400000: mysum =   0.288 global sum =   1.386
Thread 0 did        0 to   100000: mysum =  12.090 global sum =  13.476
Sum =  13.476437
```

```
int pthread_mutex init (pthread_mutex t *mutex,
                        const pthread_mutexattr_t *attr)
```

Initialization of mutex; choose `NULL` for `attr`.

```
int pthread_mutex_destroy (pthread_mutex_t *mutex)
```

Destruction of mutex

```
int pthread_mutex_lock (pthread_mutex_t *mutex)
```

Locks a mutex; blocks if another thread has locked this mutex and owns it.

```
int pthread_mutex_unlock (pthread_mutex_t *mutex)
```

Unlocks mutex; after unlocking, other threads get a chance to lock the mutex.