An introduction to the Posix Thread API

- **General introduction**
- **Creation and termination**
- **Mutex locks**
- **An example: parallel sum or inner product**

Threads

➤ Mode of programming for shared memory [shared address space or symmetric multi-processing (SMP)

➤ Very common – supported by all vendors. Part of unix standard.

➤ Low-level

➤ Helps understand issues with racing, synchronization, etc.

➤ Here: we will provide basic overview + cover an example.

Pros: simple approach –

Cons: Limited to SMPs . Gets complicated for longer codes

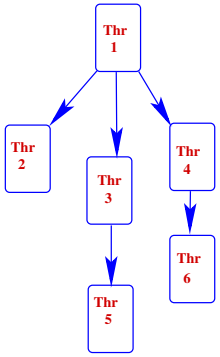
The basic commands

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

among many resources for details.

"a thread is defined as an independent stream of instructions that can be scheduled to run as such by the operating system." (source: above)

➤ Initially, main() comprises a single thread
➤ Programmer can instruct the program to start threads that execute independently.
➤ *However*: you are responsible for coordinating the concurrent accesses/ modifications of memory variables by different threads
➤ Once initiated a thread can itself create other threads



Thread creation

```
pthread_create (thread,attr,thread_fun,arg)
```

thread is of type *pthread_t* = (unique) idenfifier of thread

attr is of type *pthread_attr_t* = may be used to set thread attributes.

thread_fun is a function pointer. The thread will execute this function after creation.

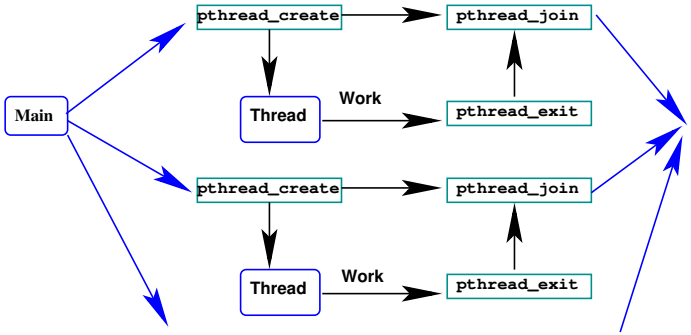
arg is of type *void. This argument is passed to the function *thread_fun*. If more than one argument use a struct

pthread_join : blocks calling thread until specified thread ends. Allows to synchronize

`pthread_join (threadid,status)`

threadid is of type `pthread_t` = idenfifier of thread

status is of type `void**`.



Use the attribute for declaring thread as *joinable*

```
  pthread_attr_t attr;          // declare
  pthread_attr_init(&attr);     // initialize
  pthread_attr_setdetachstate(&attr,
    PTHREAD_CREATE_JOINABLE); //set
  .....
/*    at end   */
pthread_attr_destroy(&attr); // Free attr
```


A common mistake

Function to be called by each thread. It will print a message that contains the thread Id.

```
void *P_hello(void *arg){
  int* thrId = (int*)arg;
  printf("\n--> Hello from thread
          number: %d \n",*thrId);
  pthread_exit(NULL);
  }
```



```
int main(int argc, char *argv[]){
  /* Adapted from llnl online tutorial. A basic
  "hello world" Pthreads program showing thread
  creation + termination --------------------*/
 #include <pthread.h>
 #include <stdio.h>
 #include <stdlib.h>
 #define NUM_THREADS 8
  pthread_t thrdNUM_THREADS];
  int rc, t;
  for(t=0;t<NUM_THREADS;t++){
    rc=pthread_create(&thrdt,NULL,P_hello,&t);
    if (rc){
      printf("ERROR: return code: %d\n",rc);
      exit(-1);
    }
  }
  pthread_exit(NULL);
}
```

➤ Pay attention to argument passed to *P_hello* – last arg. of *pthread_create*

Discussion

✍D1 Try Running this code.. What happens?

➤ Try again several times. Can you explain what happens?

✍D2 Also: run the driver without the last `pthread_exit`. Can you explain?

➤ A thread can finish on its own if parent thread (e.g., main) does not need it to join at completion.

➤ In this case: declare as 'detached'

```
/*--------- declare attribute  */
pthread_attr_t attr;
/*---------- initialize it */
pthread_attr_init(&attr);
/*---------- set as detached */
pthread_attr_setdetachstate(&attr,
             PTHREAD_CREATE_DETACHED);
/*---------- create thread with attribute */
pthread_create(threadId, attr, xfun, (void *)arg);
  .....
/*---------- instead of join issue detach   */
pthread_detach(threadId);
/*---------- do not forget:  free attribute */
pthread_attr_destroy(&attr);
```

Other functions:

pthread_attr_getdetachstate (attr,detachstate)

pthread_attr_setdetachstate (attr,detachstate)

Shared variables and mutual exclusion: Mutexes

➤ Accessing shared variables requires careful control - if data is altered by a thread: If several threads modify a shared variable, we need to make sure only one thread accesses it at a time

➤ Mechanism: Mutual Exclusion or Mutex.

```
// Declare as
pthread_mutex_t mutex1 ;
// then set as
pthread_mutex_init(mutex1, attr) ;
// or with static initialization
pthread_mutex_t mutex1 = PTHREAD_MUTEX_INITIALIZER;

//lock this critical section:
pthread_mutex_lock (mutex1);
// do the work needed in this section
// Nobody else can modify  variables in this section
// then unlock
pthread_mutex_unlock (mutex1)
// at completion free:
pthread_mutex_destroy (mutex1)
```


Example: parallel sum of n numbers

➤ We want to sum the n numbers of an array a[0:n-1] by dividing the sums into p subsums which are added in a common location in memory. Shared variable SUM will contain the final sum.

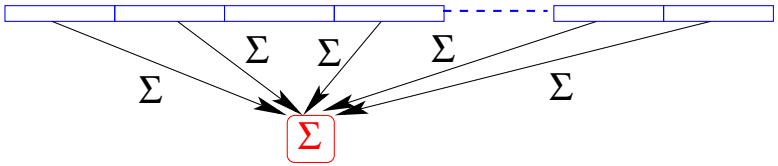
. . . Each thread computes its subsum

. . . locks the code section that updates SUM

. . . adds subsum to SUM

. . . Unlocks critical section

. . . and exit thread.



```
/*
! Main program generates data (a vector) of length n -- then
! generates threads that call the sum_mtx function to
! compute partial sums and sum them. Upon completion the
! result is printed. Main thread will wait for all threads
! to complete. This code also illustrates thread
! *attributes*. It sets the threads to be *joinable*
! (allows the main thread to join with the threads it
! creates). ------------------------------------------------*/
```

Declarations

```
/*-----------------------------------------
 * illustrates the use of mutex variables
 * in a threads program to sum n numbers
 -----------------------------------------*/
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
/*--------------------Data is passed to
  threads through the following struct */
typedef struct {
  double      *a;
  double      sum;
  int      loclen;
  int      totlen;
} sumstr, *SumPtr;
sumstr SUMST;
```


Function

sum_dat

```
#define NUMTHRDS 8
#define VECLEN 78
pthread_t callThd[NUMTHRDS];
pthread_mutex_t mutexsum;
/*-------------------- function sum -- activated when
                       thread is created. */
void *sum_mtx(void *arg){
/*-------------------- local  variables */
  int i, start, end, *blkNum, len ;
  double mysum, *x;
  blkNum = (int*)arg;
  len = SUMST.loclen;
  start = (*blkNum)*len;
  /* end = start+len > SUMST.totlen ? SUMST.totlen :
  start+len;*/
  end = (*blkNum)<NUMTHRDS? start+len:SUMST.totlen;
  x = SUMST.a;
/*-------------------- sum */
   mysum = 0;
   for (i=start; i<end ; i++)
     mysum += x[i];
/*---------------- Lock a mutex before updating
                   the value in the shared struct */
   pthread_mutex_lock (&mutexsum);
   SUMST.sum += mysum;
/*-------------------- unlock it now that update is
  done*/
   pthread_mutex_unlock (&mutexsum);
   printf(" -- Local sum in thread %d is %10.2f total
  : %10.2f\n ",
    *blkNum,mysum,SUMST.sum);
   printf("    len %d %d %d %5.2f \n",len,start,end,x
  [start]) ;
/*-------------------- done with this thread */
   pthread_exit((void*) 0);
}
```


Main

```
int main (int argc, char *argv[]){
  int i, n = VECLEN;
  int *thrNum,  *status;
  double *a;
  pthread_attr_t attr;
/*-------------------- alloc storage + initialize values */
  a = (double*) malloc (NUMTHRDS*VECLEN*sizeof(double));
  thrNum  = (int*) malloc (NUMTHRDS*sizeof(int));
  for (i=0; i<n; i++) a[i]=(double)i;
/*-------------------- have thread number in array */
  for (i=0; i<NUMTHRDS; i++)
    thrNum[i]= i;
  SUMST.totlen = n;
  SUMST.loclen = 1+(int) ((n-1)/NUMTHRDS);
  SUMST.a = a;
  SUMST.sum=0;
/*-------------------- initialize mutex */
  pthread_mutex_init(&mutexsum, NULL);
  pthread_attr_init(&attr);
  pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_JOINABLE);
  for(i=0;i<NUMTHRDS;i++) {
/*-------------------- Each thread works on a different subset */
  pthread_create(&callThd[i],&attr,sum_mtx,(void *)&thrNum[i]);
 }
 pthread_attr_destroy(&attr);
/*-------------------- Join to wait for the other threads */
 for(i=0;i<NUMTHRDS;i++) {
    status = &thrNum[i];
    pthread_join( callThd[i], (void **)status);
    printf("  join number %d -- status %d \n",i,*status);
  }
/*-------------------- Now print out the sum and cleanup */
 printf ("Total Sum in main thread =  %10.2f \n", SUMST.sum);
 free (a);  free (thrNum);
 pthread_mutex_destroy(&mutexsum);
 pthread_exit(NULL);
}
```