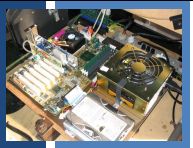
TCSS 422: OPERATING SYSTEMS



Three Easy Pieces: Thread API

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OBJECTIVES

- Linux Thread API – Ch. 27

CHAPTER 27 - LINUX THREAD API

THREAD CREATION

- pthread_create

```
#include <pthread.h>

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

- thread: thread struct
- attr: stack size, scheduling priority… (*optional*)
- start_routine: function pointer to thread routine
- arg: argument to pass to thread routine (*optional*)

PTHREAD_CREATE – PASS ANY DATA

```
#include <pthread.h>

typedef struct __myarg_t {
        int a;
        int b;
} myarg_t;

void *mythread(void *arg) {
        myarg_t *m = (myarg_t *) arg;
        printf("%d %d\n", m->a, m->b);
        return NULL;
}

int main(int argc, char *argv[]) {
        pthread_t p;
        int rc;

        myarg_t args;
        args.a = 10;
        args.b = 20;
        rc = pthread_create(&p, NULL, mythread, &args);
        …
}
```


PASSING A SINGLE VALUE

Using this approach on your Ubuntu VM, How large (in bytes) can the primitive data type be?

How large (in bytes) can the primitive data type be on a 32-bit operating system?

```
9       int rc, m;
10      pthread_create(&p, NULL, mythread, (void *) 100);
11      pthread_join(p, (void **) &m);
12      printf("returned %d\n", m);
13      return 0;
14  }
```

WAITING FOR THREADS TO FINISH

```
int pthread_join(pthread_t thread, void **value_ptr);
```

- thread: which thread?
- value_ptr: pointer to return value
  type is dynamic / agnostic
- Returned values *must* be on the heap
- Thread stacks destroyed upon thread termination (join)
- Pointers to thread stack memory addresses are invalid
  - May appear as gibberish or lead to crash (seg fault)
- Not all threads join – ***What would be Examples ??***

What will this code do?

```
struct myarg {
  int a;
  int b;
};

void *worker(void *arg)
{
  struct myarg *input = (struct myarg *) arg;
  printf("a=%d b=%d\n",input->a, input->b);
  struct myarg output;
  output.a = 1;
  output.b = 2;
  return (void *) &output;
}

int main (int argc, char * argv[])
{
  pthread_t p1;
  struct myarg args;
  struct myarg *ret_args;
  args.a = 10;
  args.b = 20;
  pthread_
  pthread_
  printf("
  return 0;
}
```

Data on thread stack

```
$ ./pthread_struct
a=10 b=20
Segmentation fault (core dumped)
```

How can this code be fixed?

How about this code?

```
struct myarg {
  int a;
  int b;
};

void *worker(void *arg)
{
  struct myarg *input = (struct myarg *) arg;
  printf("a=%d b=%d\n",input->a, input->b);
  input->a = 1;
  input->b = 2;
  return (void *) &input;
}

int main (int argc, char * argv[])
{
  pthread_t p1;
  struct myarg args;
  struct myarg *ret_args;
  args.a = 10;
  args.b = 20;
  pthread_create(&p1, NULL, worker, &args);
  pthread_join(p1, (void *)&ret_args);
  printf("returned %d %d\n", ret_args->a, ret_args->b);
  return 0;
}
```

```
$ ./pthread_struct
a=10 b=20
returned 1 2
```


ADDING CASTS

- Casting
- Suppresses compiler warnings when passing "typed" data where (void) or (void *) is called for
- Example: uncasted capture in pthread_join

```
pthread_int.c: In function 'main':
pthread_int.c:34:20: warning: passing argument 2 of 'pthread_join'
from incompatible pointer type [-Wincompatible-pointer-types]
   pthread_join(p1, &p1val);
```

- Example: uncasted return

```
In file included from pthread_int.c:3:0:
/usr/include/pthread.h:250:12: note: expected 'void **' but argument
is of type 'int **'
 extern int pthread_join (pthread_t __th, void **__thread_return);
```


ADDING CASTS - 2

- pthread_join

```
int * p1val;
int * p2val;
pthread_join(p1, (void *)&p1val);
pthread_join(p2, (void *)&p2val);
```

- return from thread function

```
int * counterval = malloc(sizeof(int));
*counterval = counter;
return (void *) counterval;
```


LOCKS

- pthread_mutex_t data type
- /usr/include/bits/pthread_types.h

```
// Global Address Space
static volatile int counter = 0;
pthread_mutex_t lock;

void *worker(void *arg)
{
  int i;
  for (i=0;i<10000000;i++)  {
    int rc = pthread_mutex_lock(&lock);
    assert(rc==0);
    counter = counter + 1;
    pthread_mutex_unlock(&lock);
  }
  return NULL;
}
```

LOCKS - 2

- Ensure critical sections are executed atomically-*as a unit*
  - Provides implementation of "***Mutual Exclusion***"
- API

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

- Example w/o initialization & error checking

```
pthread_mutex_t lock;
pthread_mutex_lock(&lock);
x = x + 1; // or whatever your critical section is
pthread_mutex_unlock(&lock);
```

  - Blocks forever until lock can be obtained
  - Enters critical section once lock is obtained
  - Releases lock

LOCK INITIALIZATION

- Assigning the constant

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
```

- API call:

```
int rc = pthread_mutex_init(&lock, NULL);
assert(rc == 0); // always check success!
```

- Initializes mutex with attributes specified by 2nd argument
- If NULL, then default attributes are used
- Upon initialization, the mutex is initialized and unlocked

LOCKS - 3

- Error checking wrapper

```
// Use this to keep your code clean but check for failures
// Only use if exiting program is OK upon failure
void Pthread_mutex_lock(pthread_mutex_t *mutex) {
    int rc = pthread_mutex_lock(mutex);
    assert(rc == 0);
}
```

- What if lock can't be obtained?

```
int pthread_mutex_trylock(pthread_mutex_t *mutex);
int pthread_mutex_timelock(pthread_mutex_t *mutex,
                           struct timespec *abs_timeout);
```

- trylock – returns immediately (fails) if lock is unavailable
- timelock – tries to obtain a lock for a specified duration

CONDITIONS AND SIGNALS

- Condition variables support "signaling" between threads

```
int pthread_cond_wait(pthread_cond_t *cond,
                      pthread_mutex_t *mutex);
int pthread_cond_signal(pthread_cond_t *cond);
```

- `pthread_cond_t` datatype
- pthread_cond_wait()
  - Puts thread to "sleep" (waits) (THREAD is BLOCKED)
  - Threads added to FIFO queue, lock is released
  - Waits ***(listens)*** for a "signal" (NON-BUSY WAITING, no polling)
  - When signal occurs, interrupt fires, wakes up first thread, (THREAD is RUNNING), lock is provided to thread

CONDITIONS AND SIGNALS - 2

```
int pthread_cond_signal(pthread_cond_t * cond);
int pthread_cond_broadcast(pthread_cond_t * cond);
```

- `pthread_cond_signal()`
  - Called to send a "signal" to wake-up first thread in FIFO "wait" queue
  - The goal is to unblock a thread to respond to the signal
- `pthread_cond_broadcast()`
  - Unblocks ***all*** threads in FIFO "wait" queue, currently blocked on the specified condition variable
  - Broadcast is used when all threads should wake-up for the signal
- Which thread is unblocked first?
  - Determined by OS scheduler (based on priority)
  - Thread(s) awoken based on placement order in FIFO wait queue
  - When awoken threads acquire lock as in `pthread_mutex_lock()`

CONDITIONS AND SIGNALS - 3

- Wait example:

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

pthread_mutex_lock(&lock);
while (initialized == 0)
    pthread_cond_wait(&cond, &lock);
// Perform work that requires lock
a = a + b;
pthread_mutex_unlock(&lock);
```

- wait puts thread to sleep, releases lock
- when awoken, lock reacquired (but then released by this code)
- When initialized, another thread signals

```
pthread_mutex_lock(&lock);
initialized = 1;
pthread_cond_signal(&init);
pthread_mutex_unlock(&lock);
```

State variable set, Enables other thread(s) to proceed above.

CONDITION AND SIGNALS - 4

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

pthread_mutex_lock(&lock);
while (initialized == 0)
    pthread_cond_wait(&cond, &lock);
// Perform work that requires lock
a = a + b;
pthread_mutex_unlock(&lock);
```

- Why do we wait inside a while loop?
- The while ensures upon awakening the condition is rechecked
  - A signal is raised, but the pre-conditions required to proceed may have not been met. **MUST CHECK STATE VARIABLE**
  - Without checking the state variable the thread may proceed to execute when it should not. (e.g. too early)

PTHREADS LIBRARY

- Compilation
  - gcc –pthread pthread.c –o pthread
  - Requires explicitly linking the library with compiler flag
  - Use makefile to provide compiler arguments
- List of pthread manpages
  - man –k pthread

SAMPLE MAKEFILE

```
CC=gcc
CFLAGS=-pthread -I. -Wall

binaries=pthread pthread_int pthread_lock_cond pthread_struct

all: $(binaries)

pthread_mult: pthread.c pthread_int.c
    $(CC) $(CFLAGS) $^ -o $@

clean:
    $(RM) -f $(binaries) *.o
```

- Example builds multiple single file programs
  - All target
- pthread_mult
  - Example if multiple source files should produce a single executable
- clean target

QUESTIONS