Today

- Project 3
- Threads
- Mutex Locks
Project 3

• Due today
Thread-Specific Resources

• Each thread has it’s own:
  – Thread ID (integer)
  – Stack, registers, program counter
  – Errno
  – arithmetic/buffer overflow

• Threads within the same process can communicate using shared memory - *Must be done carefully!*
Posix Threads

- We will focus on Posix Threads—most widely Supported threads programming API

- Solaris - you need to link with “-lpthread”
  - For example, in the makefile we supplied
  - CC = gcc
  - LDFLAGS = -lpthread -lrt -lm
**pthread_create**

- Creating a thread is like a combination of `fork()` and `exec()`.
- `#include <pthread.h>`
  ```c
  int pthread_create(
      pthread_t *thread,
      pthread_attr_t *attr,
      void *(*function)(void *),
      void *arg);
  ```
  - Thread is the thread ID, attr is an attribute set, `function` is the function to be called with `arg`.
  - Compile/Link with `-D_REENTRANT -lpthread`
Thread IDs

• Each thread has a unique ID, a thread can find out it's ID by calling pthread_self().

• Thread IDs are of type pthread_t which is usually an unsigned int. When debugging, it's often useful to do something like this: printf("Thread %u:\n",pthread_self());
• Thread attributes can be set using attr, including detached state and scheduling policy. You can specify NULL and get the system defaults
Thread Start Routine

- The new thread starts execution by invoking `function()`

- The type of return value and parameter of `function()` must be `void *`

- When creating a process, the starting address of `function()` is passed to `pthread_create`
Thread arguments

• When **function()** is called the value **arg** specified in the call to **pthread_create()** is passed as a parameter

• A **function** can have only 1 parameter, and it can't be larger than the size of a void *

• Complex parameters can be passed by creating a structure and passing the address of the structure
Thread lifespan

- Once a thread is created, it starts executing the function `function()` specified in the call to `pthread_create()`

- If `function()` returns, the thread is terminated

- A thread can also be terminated by calling `pthread_exit()`
Detached state

- Each thread can be either joinable or detached

- **Detached**: on termination all thread resources are released by the OS. A detached thread cannot be joined
Detaching threads

• #include <pthread.h>
  int pthread_detach (pthread_t thread);

• A detached thread cannot be joined – it will just go away when it exits

• You cannot detach a thread that some other thread is joining it
Joinable Thread

• Joinable: on thread termination the thread ID and exit status are saved by the OS

• One thread can "join" another by calling `pthread_join` - which waits (blocks) until a specified thread exits
Joining threads

• Joining a thread is analogous to waiting for a child process

• #include <pthread.h>
  int pthread_join (pthread_t th, void **thread_return);

• thread_return is the exit value of the thread
Threads Cancellation

• Cancel a thread when it is a good time to “stop”
  – Done from the “outside”, e.g. parent
  – make a cancellation request

```c
#include <pthread.h>
void pthread_cancel(pthread_t thread);
```
Exercise

• Goal:
  Implement your own threads program, where two threads each open a different text file and interleave the output when printing the files to standard output:
  
  file1: line1 text here
  file2: line1 text here
  file1: line2 text here
  file2: line 2 text here
Synchronization

A section of code which works with shared resources can have unpredictable results depending on the order in which the threads execute. This is called a **critical section**.
Mutual Exclusion

A **mutex** lets you lock a code section so that only one thread at a time executes a critical section.

First, you have to identify your critical sections.

**Example:** `sum = sum + 1;` *(line 16) in race.c*

Then create a mutex for each shared resource, and lock and unlock them before and after each critical section.
POSIX Mutex

Initialize

```c
pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
```

Lock

```c
pthread_mutex_lock(&mutex);
```

Unlock

```c
pthread_mutex_unlock(&mutex);
```
Exercise

Fix race.c
Mutual Exclusion

How to fix race.c: (race_fixed.c)

//snip
int sleepFlag = 1;

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;

void *do_work() {
    int i;
    for (i=0; i<LOOPS; i++) {
        if (sleepFlag)
            usleep(rand()%100);
        pthread_mutex_lock(&mutex);
        sum = sum + 1;
        pthread_mutex_unlock(&mutex);
    }
    pthread_exit(NULL);
}
//snip
Mutual Exclusion

How is this different?

```c
int sleepFlag = 1;
pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
void *do_work() {
    pthread_mutex_lock(&mutex);
    int i;
    for (i=0; i<LOOPS; i++){
        if(sleepFlag)
            usleep(rand()%100);
        sum = sum + 1;
    }
    pthread_mutex_unlock(&mutex);
    pthread_exit(NULL);
}
```
Questions?