1. Purpose

This assignment implements a very simple user thread library and its round-robin scheduler, say sthread (not pthread). It exercises how to capture and restore the current execution environment with setjmp( ) and longjmp( ), to retrieve stack and base pointers from the CPU register set with asm( ), and to copy the current activation record (i.e., the stack area of the current function) into a scheduler's memory space upon a context switch to a next thread. We also use signal( ) and alarm( ) to guarantee a minimum time quantum to run the current thread.

2. User Threads

Unlike kernel threads, user threads are not identified by operating systems. In other words, a process that spawns multiple user threads but not kernel threads is considered as a single-threaded process from the OS viewpoint, yet some applications can take advantage of many user threads to simulate micro-communication among many independent entities, each instantiated as a user thread.

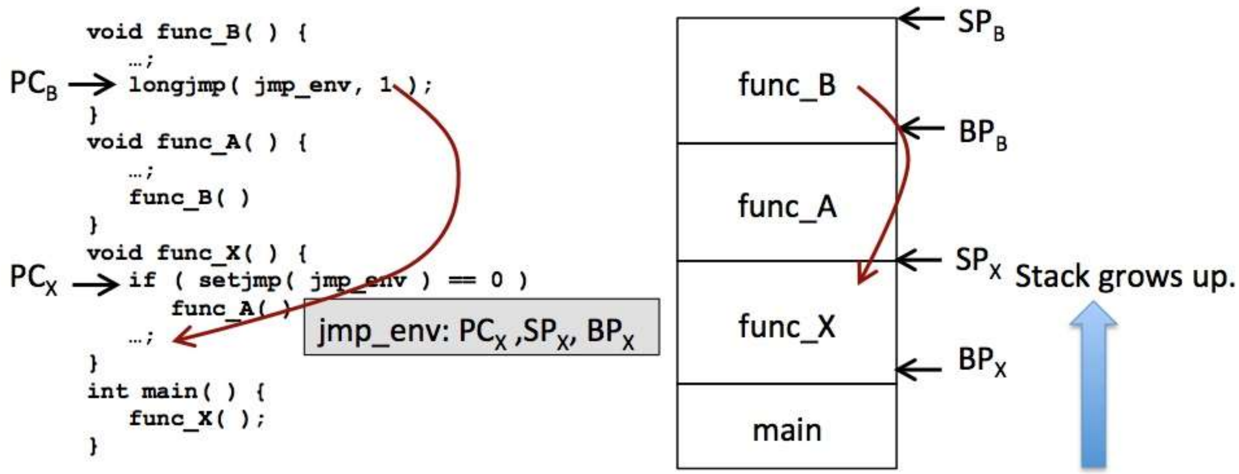
The minimum resources of each user thread are two-fold: (1) its on-going CPU register contents and (2) its stack. The former can be captured and restored as the jmp_env structure with setjmp( ) and logjmp, whereas the latter need to be identified as the current activation record that is a stack space between the current stack pointer (SP) and based pointer (BP). To manage multiple user threads, we need to allocate to each thread a thread control block (TCB) that includes its jmp_env and activation record.

3. How to Capture the Current Execution Environment

Whenever a program in execution (i.e., a process) calls a function, it creates a new activation record on top of the current stack. This activation record includes the return address to the caller function, using which the control can go back to the caller function upon a return statement.

What if the control wants to go back to the caller function or even the caller of caller without completing the current function, thus without returning from it? Assume that func_X( ) called func_A( ); func_A( ) called func_B( ); and the control wants to jump from func_B( ) back to a certain point of func_X( ) rather than a cascading return from B to A and A to X. To facilitate this long jump, Linux provides the following functions:

int setjmp(jmp_buf env)	Saves the current CPU register contents to env and returns 0. Later when longjmp is called, the control comes back to setjmp and returns a value given from longjmp.
void longjmp(jmp_buf env, int val)	Retrieves the CPU register contents from env and thus control goes back to setjmp as returning val.



If func_X( ) is a thread scheduler, it can save its execution with setmjp( ) just before launching a new thread that runs func_A( ). Without finishing func_A( ), this thread can relinquish its execution temporarily back to the scheduler with longjmp( ). Then, the scheduler can launch another thread that runs func_B( ).

Having launched all user threads, how can the scheduler resume the thread execution of func_A( ) and func_B( ) in turn? An answer is that each thread should call setjmp(env_A) or setjmp(env_B) to save its own CPU register contents including program counter (PC), SP, and BP, so that the scheduler can switch to func_A( ) by calling longjmp(env_A, 1) or to func_B( ) with longjmp(env_B, 1).

However, the remaining problem is that, when the scheduler resumes the thread func_A( ), the latest activation record in the stack has been overwritten with func_B( )'s information. Therefore, we need to capture and to save each thread's activation record in the heap. The current thread's activation record is the space between SP and BP.

For security purposes, Linux mangles jmp_env contents and makes it quite hard to locate SP and BP contents in jmp_env. (Note that MacOS can easily locate SP and BP as jmp_env[4] and [2].) We will use asm declarations that embed assembly language code in C++.

```
register void *sp asm ("sp");
register void *bp asm ("bp");
```

Including all these pieces of information, we define TCB as follows:

```
class TCB {
public:
  TCB( ) : sp( NULL ), stack( NULL ), size( 0 ) { }
  jmp_buf env;  // the execution environment captured by setjmp( )
  void* sp;     // the stack pointer (when retrieving a thread, we don't need to use bp
  void* stack;  // the temporary space to maintain the latest stack contents
  int size;     // the size of the stack contents
};
```

To save and retrieve the current thread's activation record from or into stack, we will call memcpy( ):
Saving into TCB:

```
cur_tcb->size = (int)((long long int)bp - (long long int)sp);
cur_tcb->sp = sp;
memcpy( cur_tcb->stack, sp, cur_tcb->size );
```

Retrieving from TCB:

```
memcpy( cur_tcb->sp, cur_tcb->stack, cur_tcb->size );
```

4. Signaling

This assignment's user thread library is based on non-preemptive scheduling that switches to a next thread only when the current thread voluntarily relinquishes the CPU with sthread_yield( ). However, similar to pthread_yield( ), we want to guarantee a certain amount of time quantum, say 5 seconds in Prog2A, to run the current thread. If sthread_yield( ) is called after the current 5-sec time period, we switch to a next thread, otherwise simply ignore this call and return back to the current thread. Without bothering the current thread execution, we have to check if 5 seconds have elapsed. For this purpose, we will use "signaling". The scheduler calls:

```
signal( SIGALRM, sig_alarm );
alarm( 5 );
```

These statements direct the operating system to receive an alarm interrupt upon 5 seconds and to call the user-specified sig_alarm( ) as an interrupt handler. We simply set *alarmed* true, so that sthread_yield( ) switches to a next thread as resetting *alarmed*.

```
static bool alarmed = false;
static void sig_alarm( int signo ) {
  alarmed = true;
}
```

5. The sthread library functions

Prog2A's sthread library in sthread.cpp includes the following functions to launch a new user thread, to switch to a next thread, and to terminate the current thread.

Library functions	**Actions**
#define scheduler_init( )	Initializes the sthread scheduler. It must be called before launching any sthreads.
#define scheduler_start( )	Starts the sthread scheduler. It must be called after launching all sthreads
#define sthread_create(function, arguments)	Launches a new thread that invokes a given function as passing arguments to it.
#define capture( )	Captures the current thread's jmp_env and activation record into cur_tcb. This is a helper function called from sthread_init( ) and sthread_yield( ).
#define sthread_init( )	Is called by each user thread as soon as it starts for going back to the main( ) program.
#define sthread_yield( )	Is called by each user thread to voluntarily yield the

	CPU. Only after an timer interrupt, calls capture( ) and goes back to the scheduler. When the control comes back from the scheduler, retrieve this thread activation record from cur_tcb->stack.
#define sthread_exit( )	Is called when the current thread terminates itself. It deallocates cur_tcb->stack and jumps to the scheduler.
static void sig_alarm(int signo)	Is called upon a timer interrupt and sets *alarmed* true.
static void scheduler( )	Is the logic of a simple round-robin thread scheduler. The scheduler maintains a list of TCBs in queue<TCB*> thr_queue and resumes the top thread of this queue every 5 seconds.

Note that all these library functions except sig_alarm( ) and scheduler( ) must be implemented as macro declarations with #define. This is because we do not want to insert any function calls and their activation records between the scheduler and user threads.

6. Statement of Work

Find sthread.cpp and driver.cpp on canvas. The former is the sthread library and the latter tests the library with spawning three user threads.

Complete the sthread.cpp by implementing:

(1) sthread_yield( )
(2) capture( )

The lines of code (LoC) for this implementation would be less than 20 lines. All the other functions and driver.cpp have been already implemented. The compilation and execution can be done through:

```
$ g++ driver.cpp
$ ./a.out
scheduler: initialized
func1: Bothell 0
func1: Bothell 1
...
func3: Tacoma 9
scheduler: no more threads to schedule
[css430@cssmpi1h prog2]$
```