CSE 451: Operating Systems

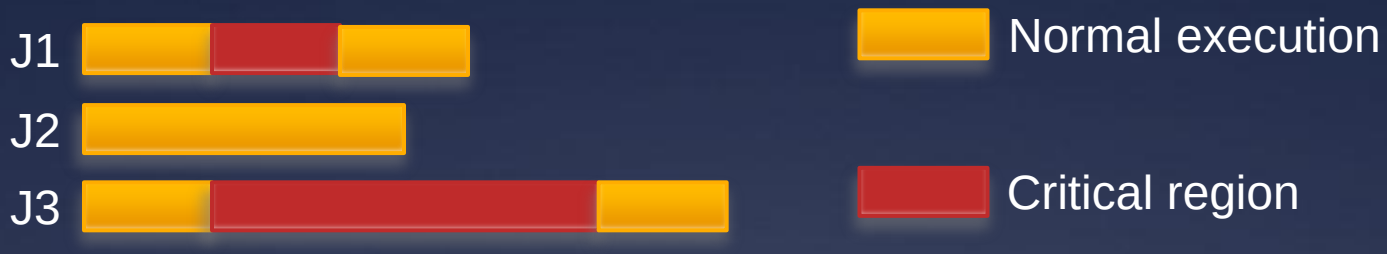
Section 4

Scheduling, Project 2 Intro, Threads

Priority Inversion

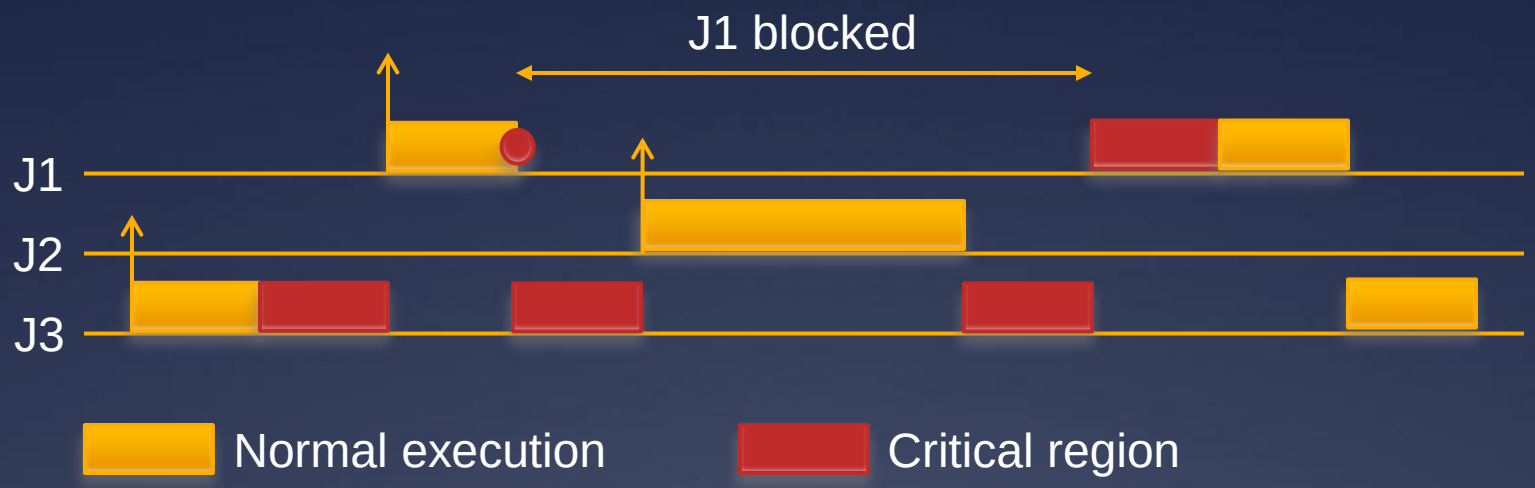
- A problem that arises when tasks (e.g. threads) have priorities and shared resource conflicts
- Typically involves tasks that operate periodically
- You won't have to worry about this in Project 2.

Priority Inversion



- Say we have 3 tasks where priority(J1) > priority(J2) > priority(J3)
- J1 and J3 each need exclusive access to the same shared resource
- When could there be problem?

Priority Inversion



- A higher priority task can interrupt a lower priority one.
- Unbounded time of priority inversion, if J3 is interrupted by tasks with priority between J1 and J3 during its critical region.

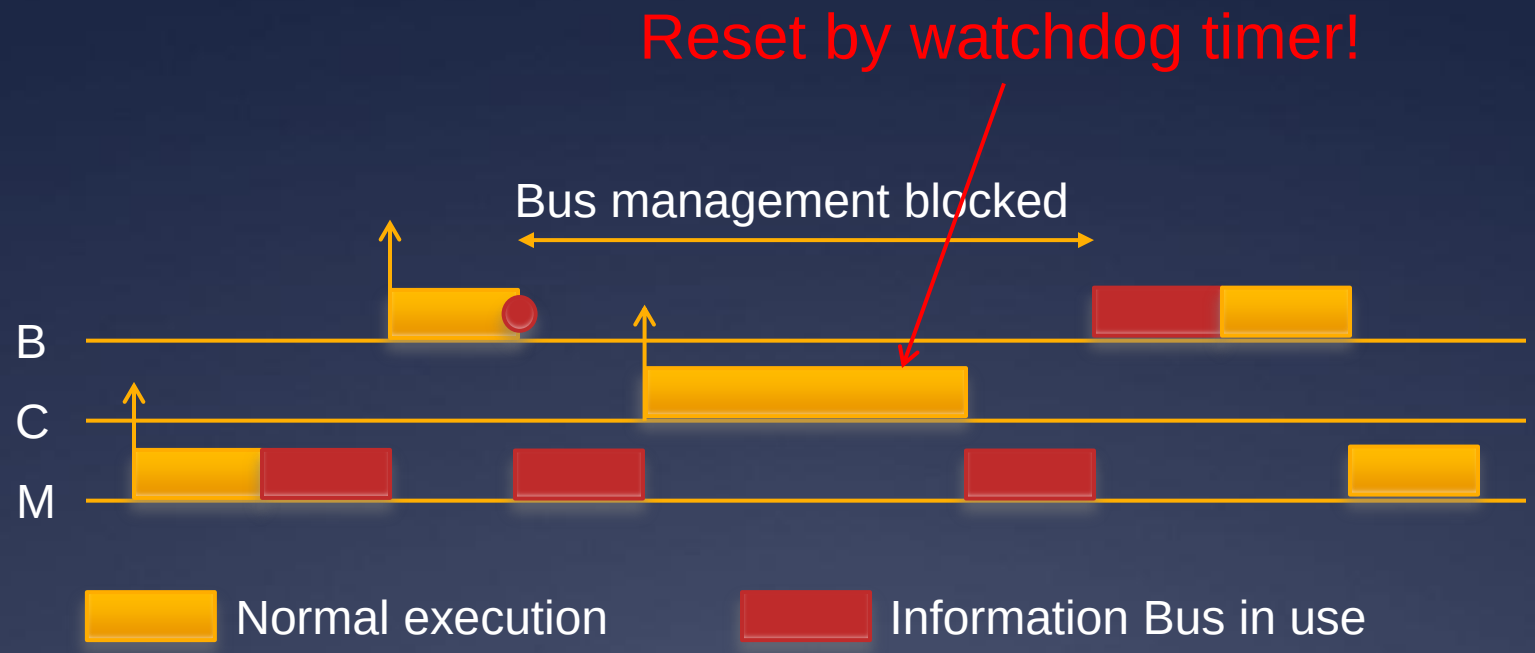
The Mars Pathfinder problem

"But a few days into the mission, not long after Pathfinder started gathering meteorological data, the spacecraft began experiencing total system resets, each resulting in losses of data. The press reported these failures in terms such as 'software glitches' and 'the computer was trying to do too many things at once'"

What happened?

- Relevant components:
  - **Information Bus** (IB)
    – a buffer for exchanging data between tasks
  - **Meteorological data gathering task** (M)
    – infrequent, low priority, locks the IB
  - **Communication task** (C)
    – medium priority, doesn't use the IB
  - **Bus management** (B)
    – frequent, high priority, locks the IB
  - **Watchdog timer** (W)
    – Resets the system if B is not activated for a certain amount of time

Pathfinder woes



- Oh noes! Is that $280M down the drain?
- What can be done?

A Solution to priority inversion

- Any thoughts?

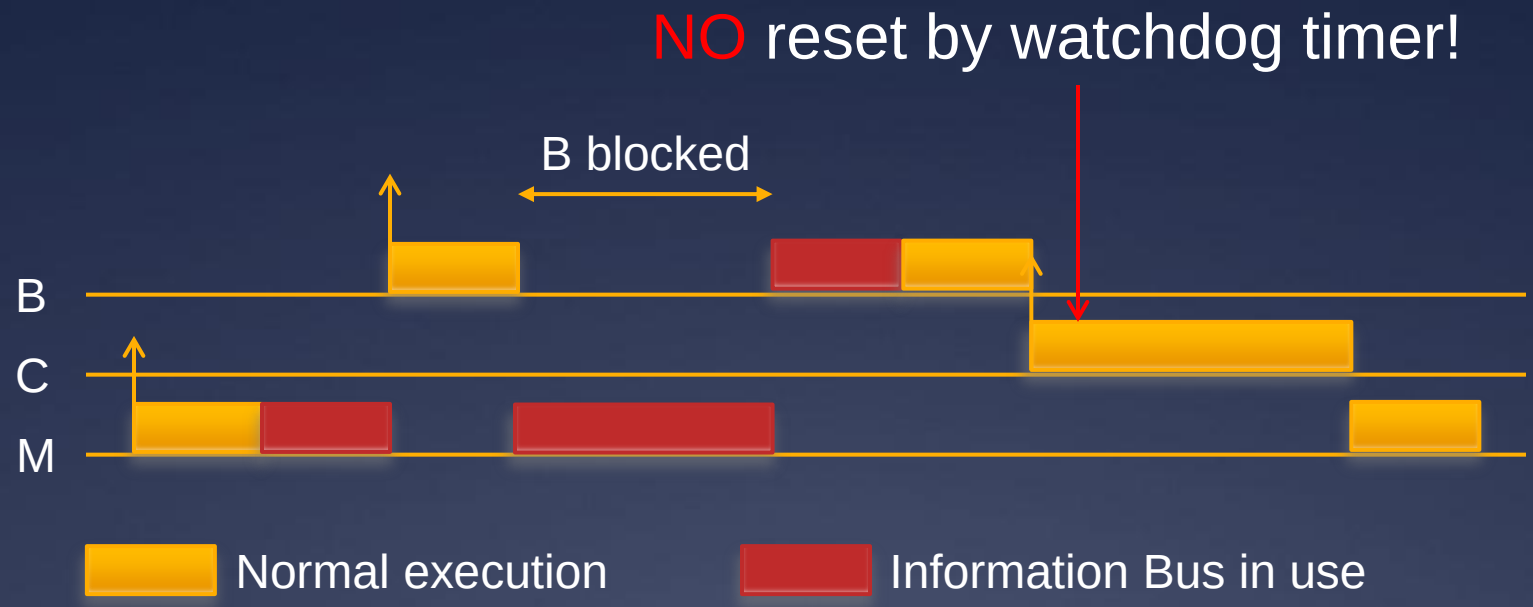
Priority Inheritance

- If a task J1 blocks because some other task J3 with lower priority owns the requested resource, the J3 temporarily inherits the priority of J1
- J3 loses its elevated priority when it releases the resource
- Rule: Tasks always inherit the highest priority of other tasks they are blocking

Mars Pathfinder solution

- The Mars Pathfinder uses a real-time OS called VxWorks
- VxWorks has a flag to set priority inheritance “on”
- How do you think this flag was set when Pathfinder was launched?

Priority Inheritance on Mars



* Luckily, that flag in VxWorks could be set remotely

Not all roses yet

- Priority inheritance solves the biggest problem, but 2 more remain:
  - Deadlock
  - Chained Blocking
- They are solved by the Priority Ceiling Protocol extension
- You can read about this on your own because now it is time for…

Project 1

- Congratulations, you're all kernel hackers now!
- We're going to give you a break and have you do some userspace work ☺

Project 2: user-level threads

- Part A: due Wednesday, May 8 at 11:59pm
  - Implement part of a user thread library
  - Add synchronization primitives
  - Solve a synchronization problem
- Part B: due Friday, May 24 at 11:59pm
  - Implement a multithreaded web server
  - Add preemption
  - Get some results and write a (small) report

Project 2 notes

- Start EARLY!
  - It's looooooooong
  - Read the assignment carefully
  - Read it again
  - Understand the skeleton code
- Use the same groups as for project 1

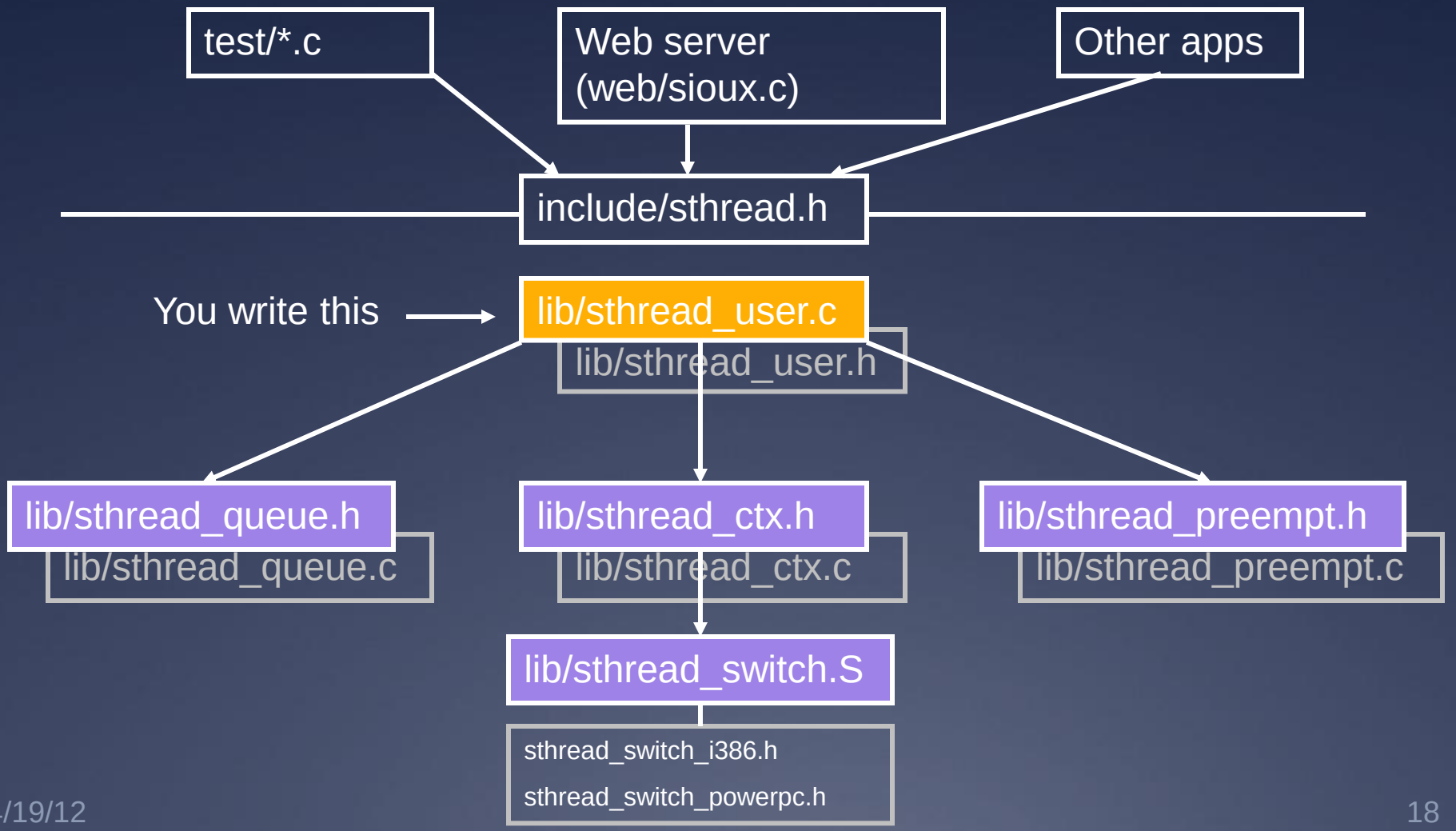
Project 2 tips

- Understand what the provided code does for you
- Division of work
  - Part 3 can be completed without parts 1 and 2
- More tools
  - ddd
  - (Or just gdb if you're not a fan of GUIs)

Simplethreads

- We give you:
  - Skeleton functions for thread interface
  - Machine-specific code (x86, i386)
    - Support for creating new stacks
    - Support for saving regs/switching stacks
  - A queue data structure (why?)
  - Very simple test programs
    - You should write more, and include them in the turnin
  - A single-threaded web server

Simplethreads code structure



Pthreads

- Pthreads (POSIX threads) is a preemptive, kernel-level thread library
- Simplethreads is similar to Pthreads
- Project 2: compare your implementation against Pthreads
  - ./configure --with-pthreads

Thread operations

- What functions do we need for a userspace thread library?

Simplethreads API

```
void sthread_init()
```

- Initialize the whole system

```
sthread_t sthread_create(func start_func,
   void *arg)
```

- Create a new thread and make it runnable

```
void sthread_yield()
```

- Give up the CPU

```
void sthread_exit(void *ret)
```

- Exit current thread

```
void* sthread_join(sthread_t t)
```

- Wait for specified thread to exit

Simplethreads internals

- Structure of the TCB:

```
struct _sthread {
    sthread_ctx_t *saved_ctx;
    /**
     * Add your fields to the thread
     * data structure here.
     */
};
```

Sample multithreaded program

* (this slide and next – see test-create.c)

```
void *thread_start(void *arg) {
   if (arg) {
      printf("in thread_start, arg = %p\n",
         arg);
   }
   return 0;
}

...
```

Sample multithreaded program

```
int main(int argc, char *argv[]) {
   sthread_init();
   for(i = 0; i < 3; i++) {
      if (sthread_create(thread_start,
                         (void *)&i) == NULL) {
         printf("sthread_create failed\n");
         exit(1);
      }
   }
   // needs to be called multiple times
   sthread_yield();
   printf("back in main\n");
   return 0;
}
```

Managing contexts

- (Provided for you in project 2)
- Thread *context* = thread stack + stack pointer

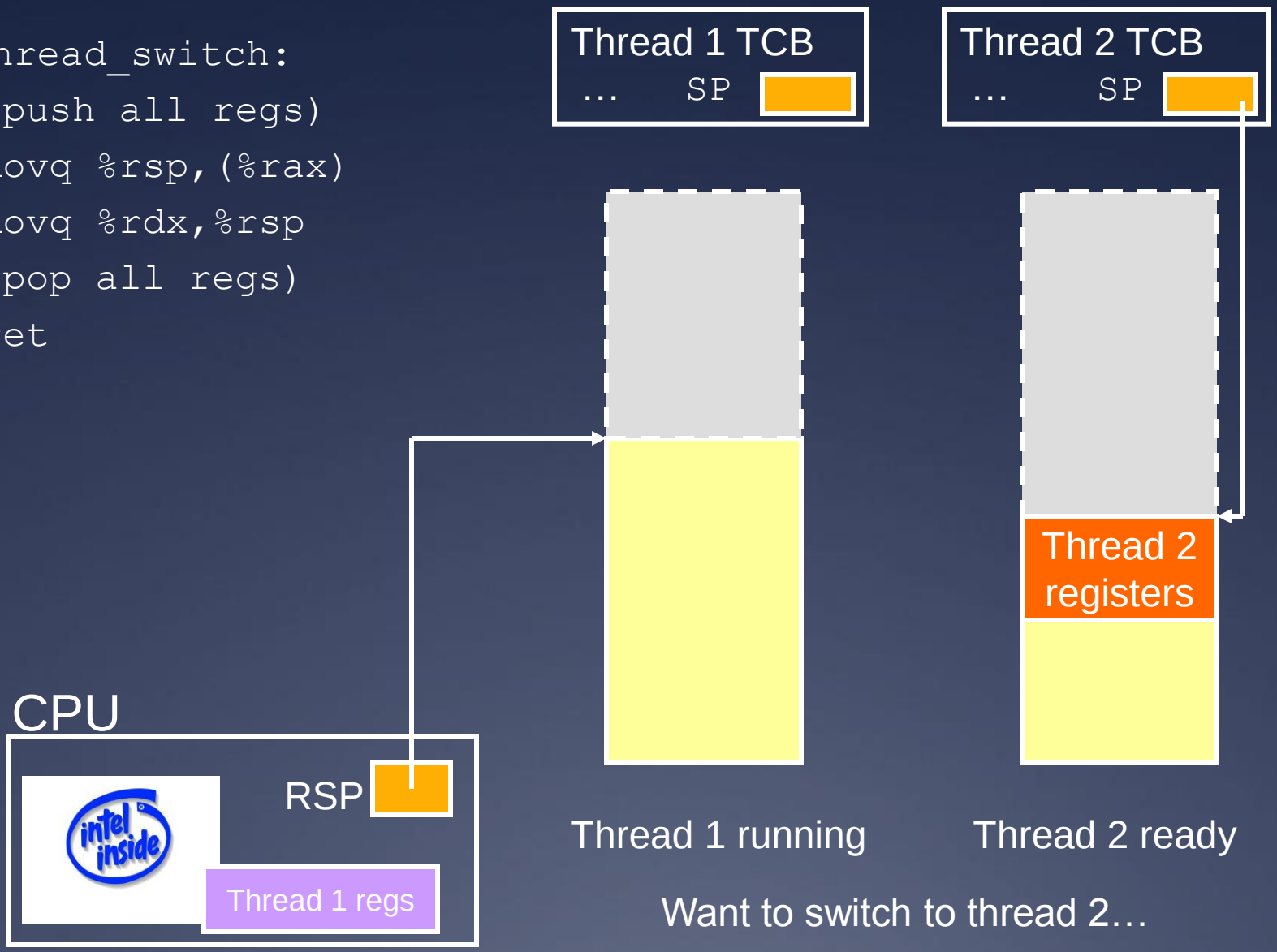
`sthread_new_ctx(func_to_run)`
  - creates a new thread context that can be switched to

`sthread_free_ctx(some_old_ctx)`
  - Deletes the supplied context

`sthread_switch(oldctx, newctx)`
  - Puts current context into oldctx
  - Takes newctx and makes it current

How sthread_switch works

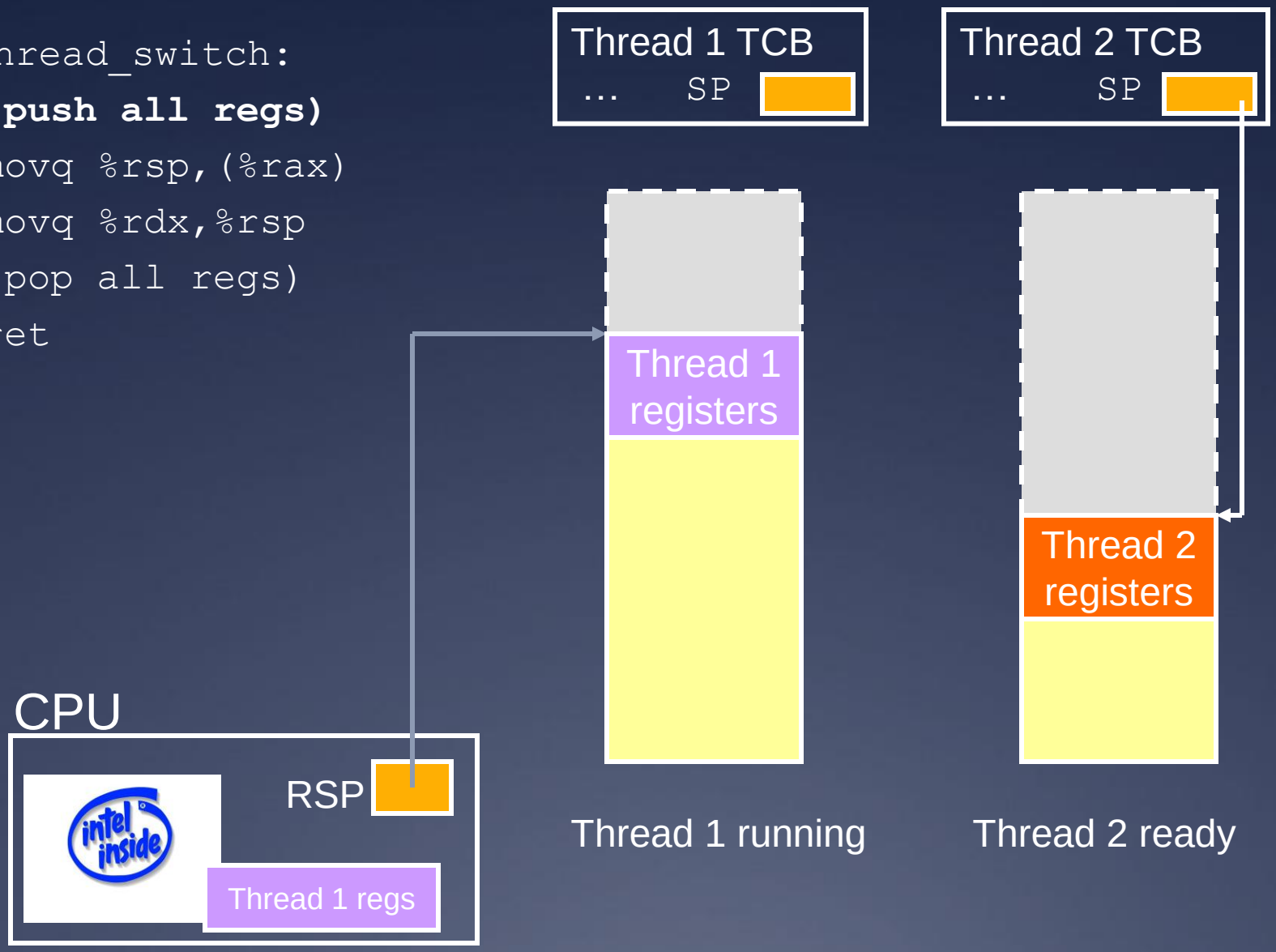
```
Xsthread_switch:
   (push all regs)
   movq %rsp,(%rax)
   movq %rdx,%rsp
   (pop all regs)
   ret
```



Want to switch to thread 2…

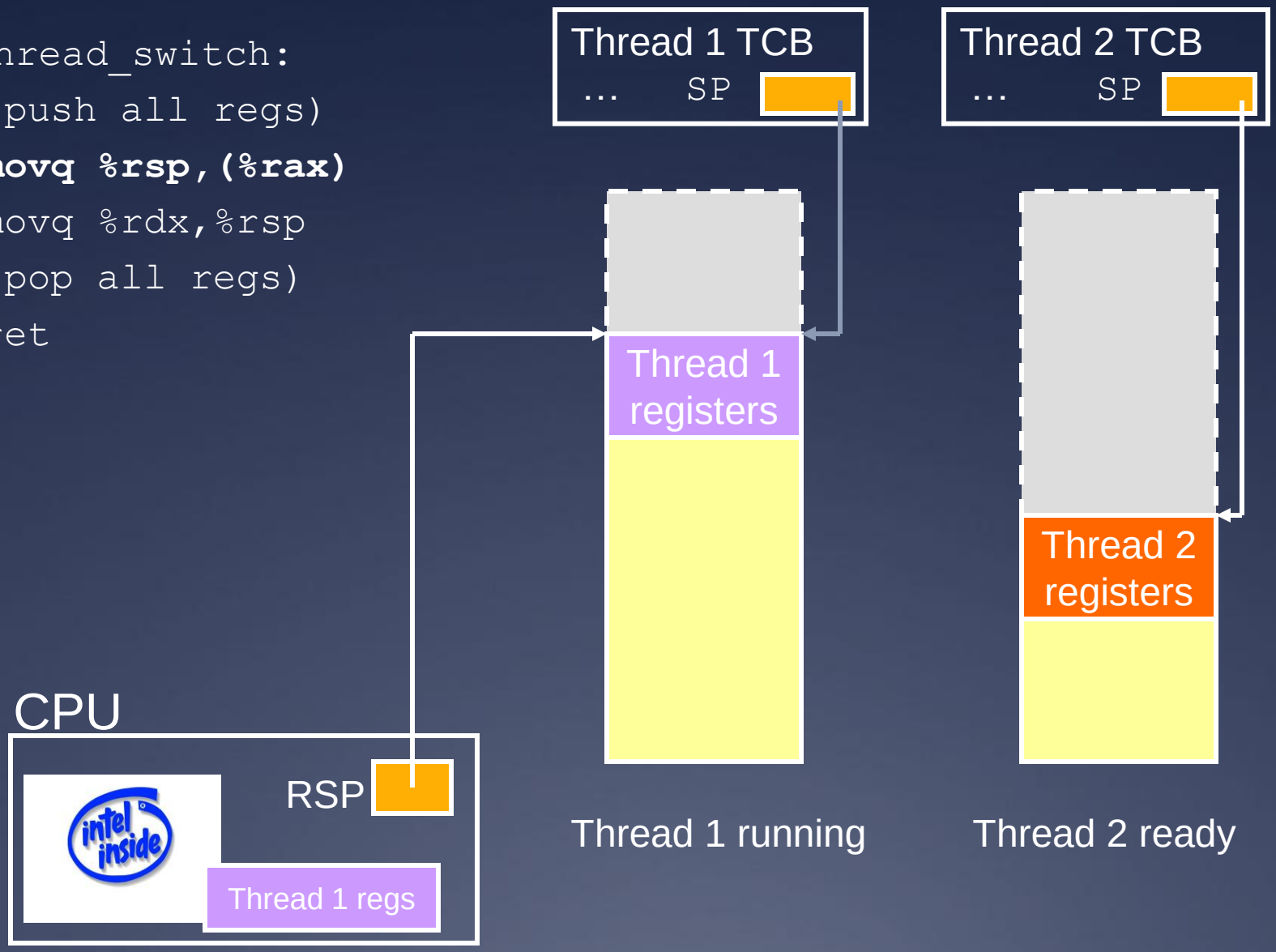
Push old context

```
Xsthread_switch:
    (push all regs)
    movq %rsp,(%rax)
    movq %rdx,%rsp
    (pop all regs)
    ret
```



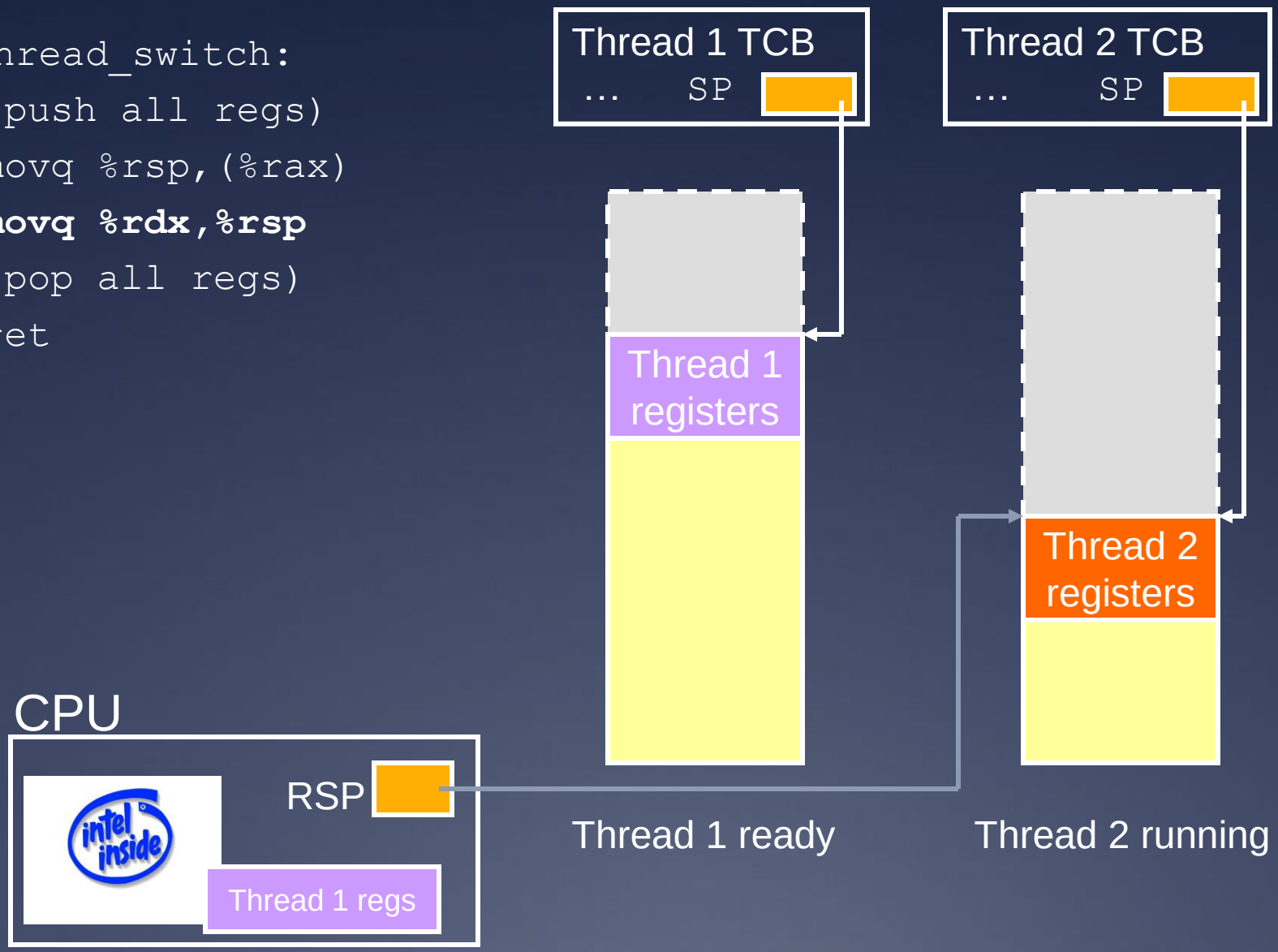
Save old stack pointer

```
Xsthread_switch:
   (push all regs)
   movq %rsp,(%rax)
   movq %rdx,%rsp
   (pop all regs)
   ret
```



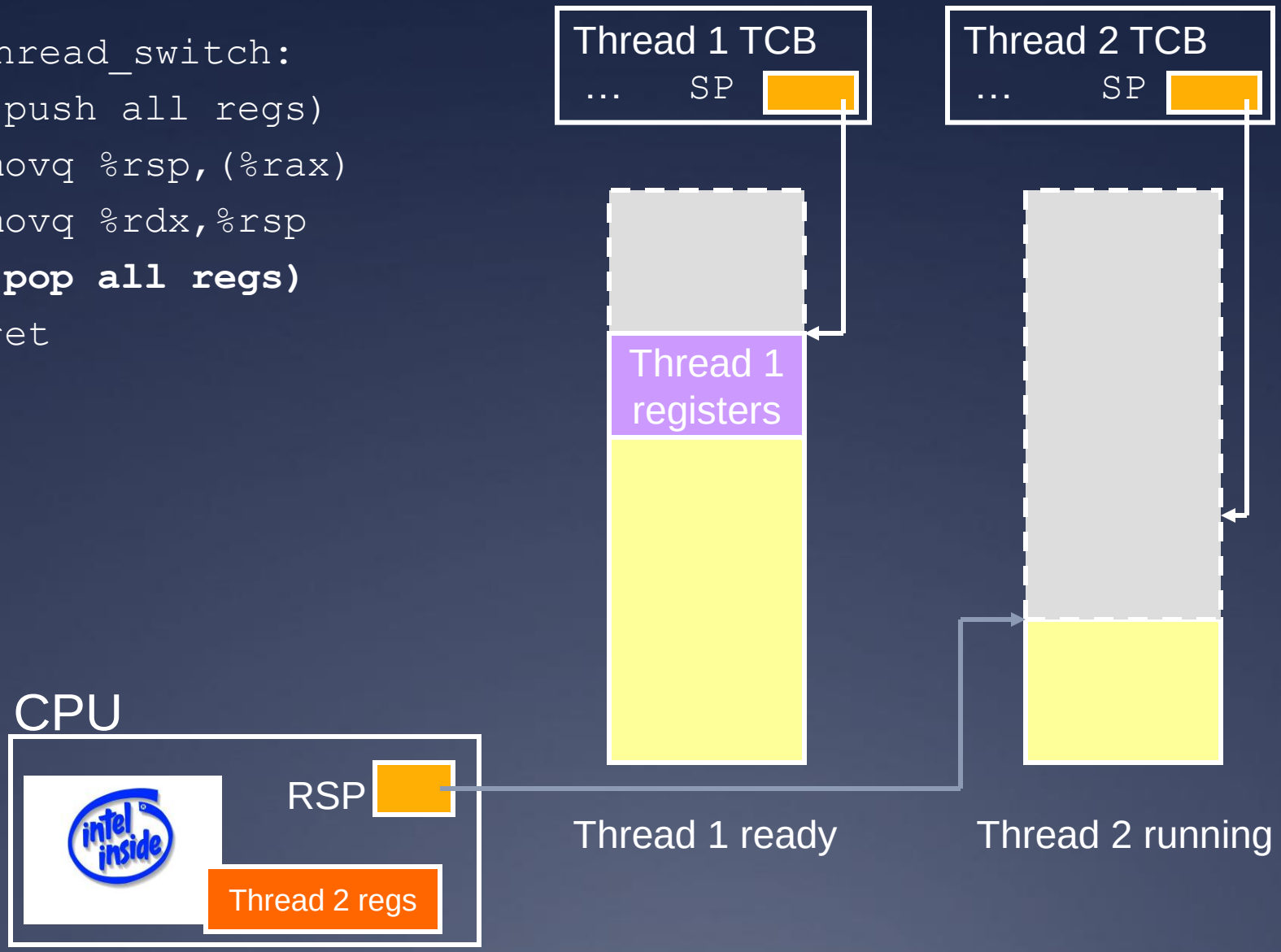
Change stack pointers

```
Xsthread_switch:
   (push all regs)
   movq %rsp,(%rax)
   movq %rdx,%rsp
   (pop all regs)
   ret
```



Pop off new context

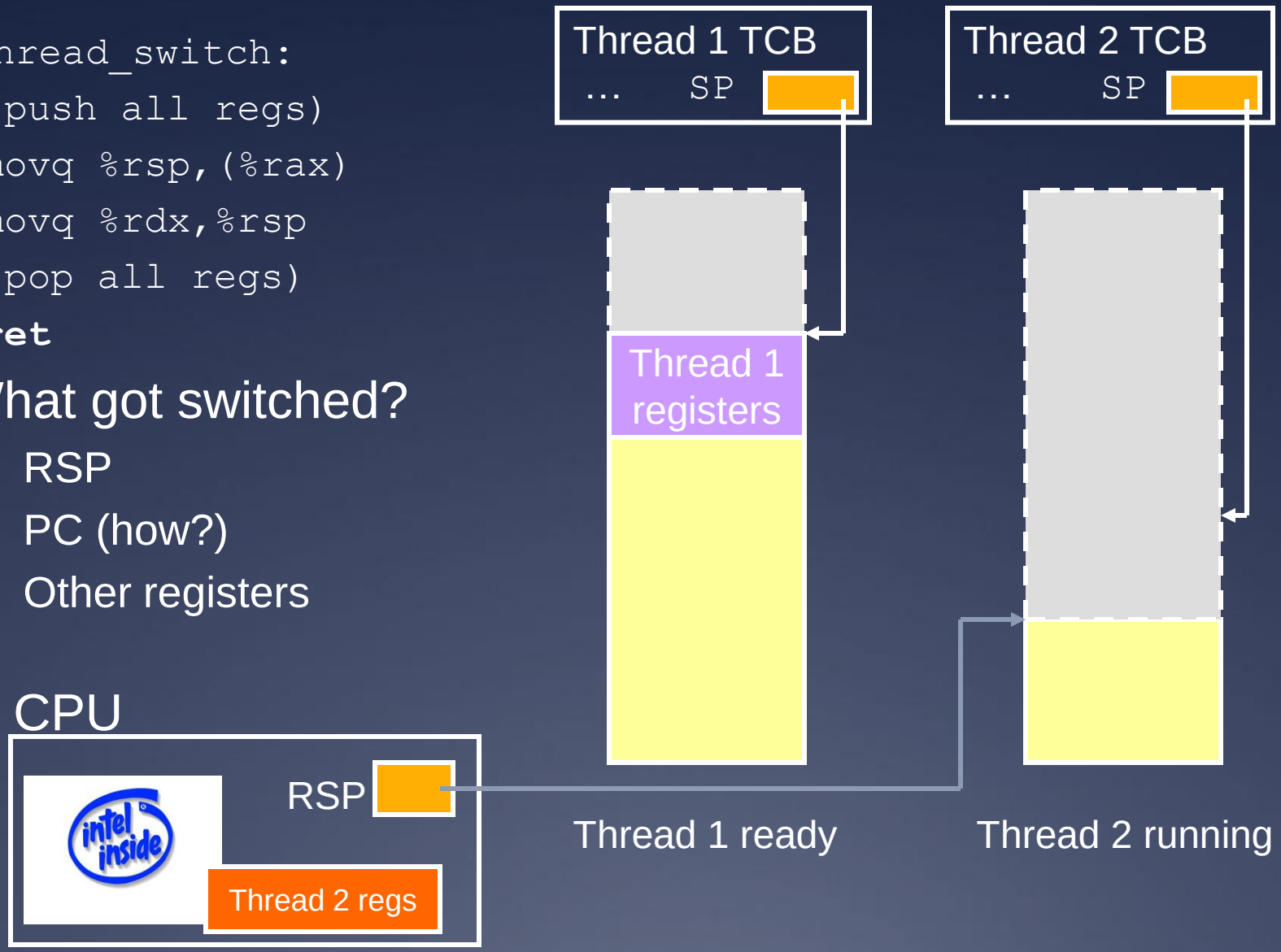
```
Xsthread_switch:
   (push all regs)
   movq %rsp,(%rax)
   movq %rdx,%rsp
   (pop all regs)
   ret
```



Done; return

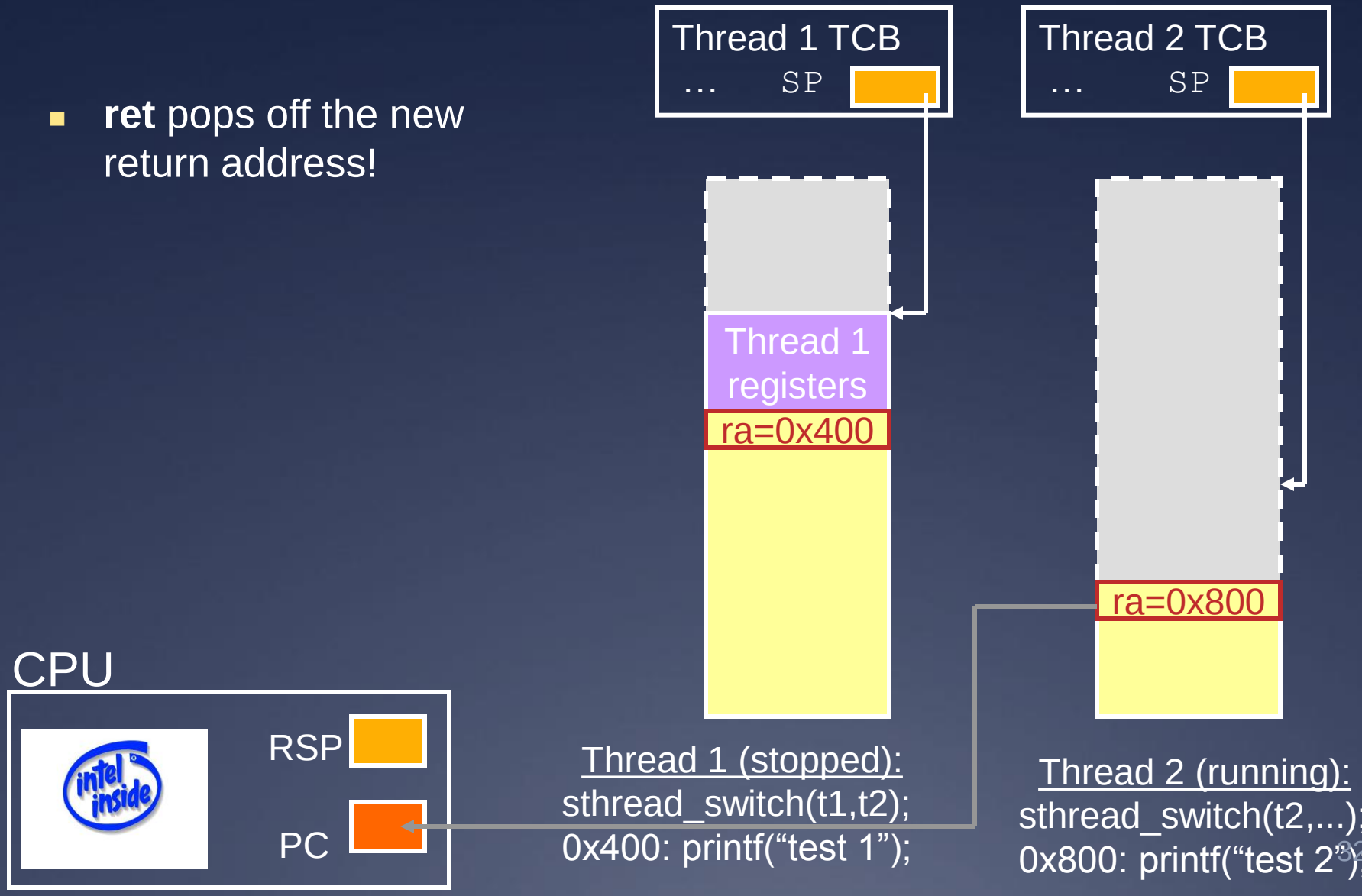
```
Xsthread_switch:
    (push all regs)
    movq %rsp,(%rax)
    movq %rdx,%rsp
    (pop all regs)
    ret
```

- What got switched?
  - RSP
  - PC (how?)
  - Other registers



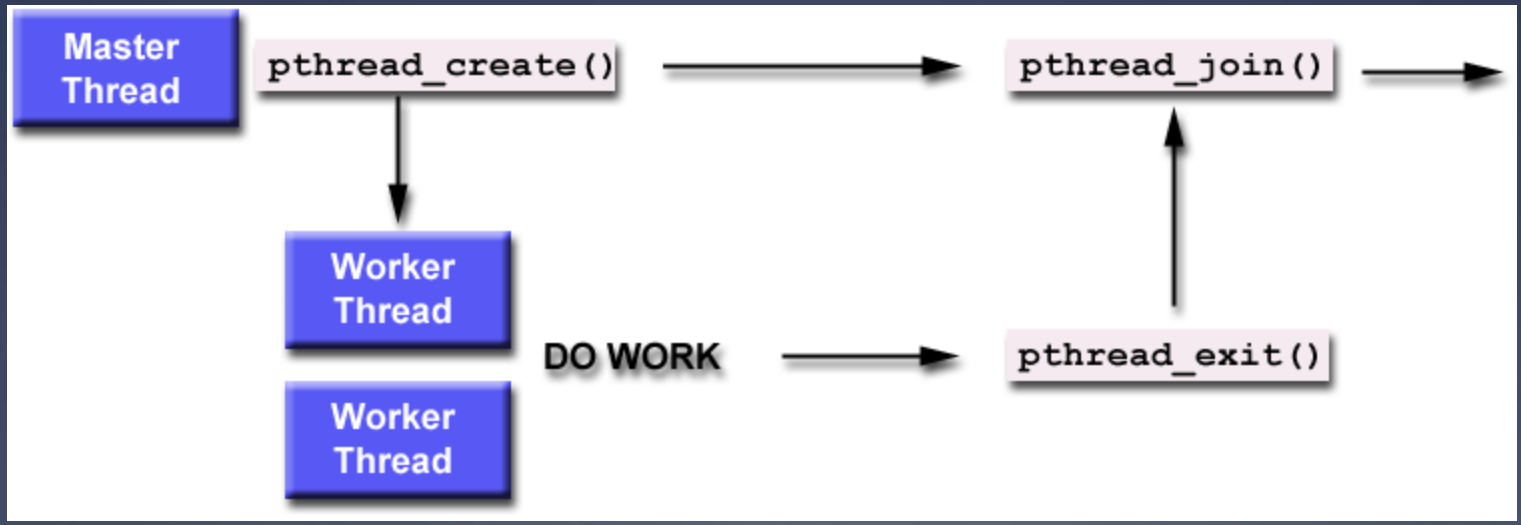
Adjusting the PC

- **ret** pops off the new return address!



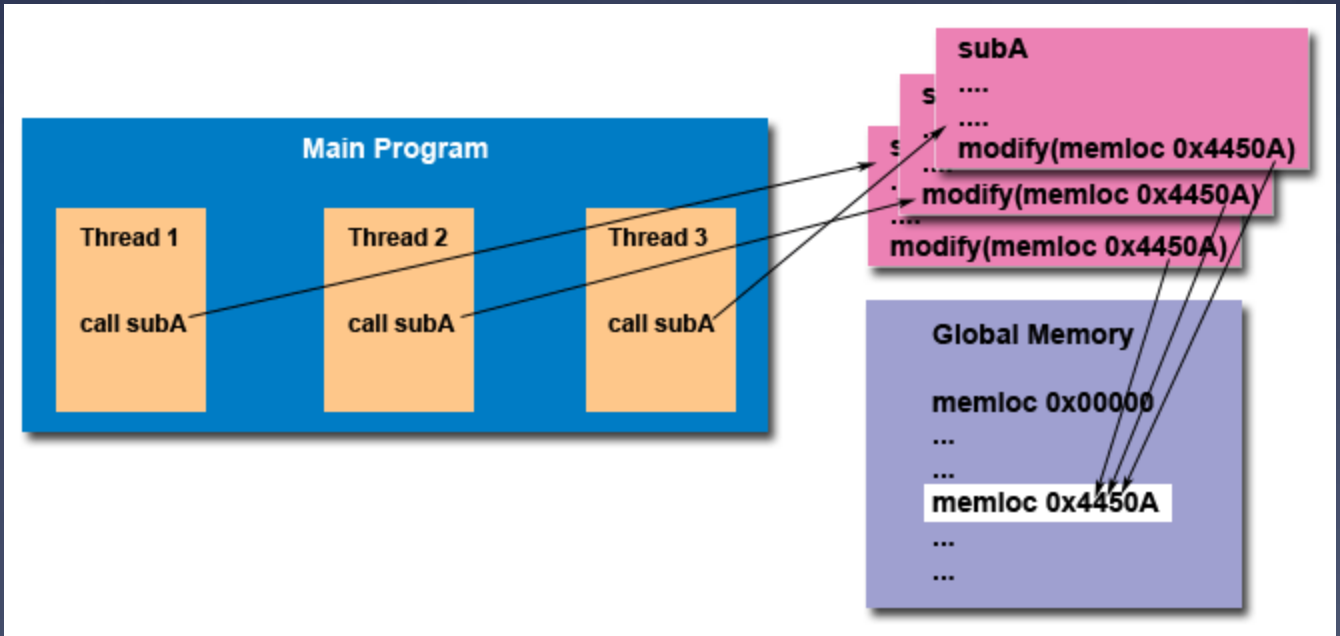
Thread joining

- With Pthreads (and Sthreads):
  - Master thread calls join on worker thread
  - Join blocks until worker thread exits.
  - Join returns the return value of the worker thread.



The need for synchronization

- Thread safety:
  - An application's ability to execute multiple threads simultaneously without "clobbering" shared data or creating "race" conditions



Synchronization primitives: mutexes

```
sthread_mutex_t sthread_mutex_init()
void sthread_mutex_free(sthread_mutex_t lock)

void sthread_mutex_lock(sthread_mutex_t lock)
```

* When returns, thread is guaranteed to acquire lock

```
void sthread_mutex_unlock(
   sthread_mutex_t lock)
```

Synchronization primitives: condition variables

```
sthread_cond_t sthread_cond_init()
void sthread_cond_free(sthread_cond_t cond)

void sthread_cond_signal(sthread_cond_t cond)
```

- Wake-up one waiting thread, if any

```
void sthread_cond_broadcast(
   sthread_cond_t cond)
```

- Wake-up all waiting threads, if any

```
void sthread_cond_wait(sthread_cond_t cond,
   sthread_mutex_t lock)
```

- Wait for given condition variable
- Returning thread is guaranteed to hold the lock

Things to think about

- How do you create a thread?
  - How do you pass arguments to the thread's start function?
    - Function pointer passed to sthread_new_ctx() doesn't take any arguments
- How do you deal with the initial (main) thread?
- How do you block a thread?

Things to think about

- When and how do you reclaim resources for a terminated thread?
  - Can a thread free its stack itself?
- Where does sthread_switch return?
- Who and when should call sthread_switch?
- What should be in struct _sthread_mutex, struct _sthread_cond?

Things to think about

- Working with synchronization: When does it make sense to disable interrupts?
  - Which actions are atomic at the application level versus at the thread level?
- When using forkbomb, run “ulimit -Su 64” to limit the number of processes/threads
  - Allows you to log in from another session even if you hit the above limit
  - Add it to your .bash_profile so it happens automatically

Final Thoughts

- Want to learn about real-time scheduling? Take CSE466