CSE 451: Operating Systems

Section 4

Scheduling, Project 2 Intro, Threads

Project 1

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

Project 2: user-level threads

- Part A: due Sunday, February 9 at 11:59pm
  - Implement part of a user thread library
  - Add synchronization primitives
  - Solve a synchronization problem
- Part B: due Sunday, February 23 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

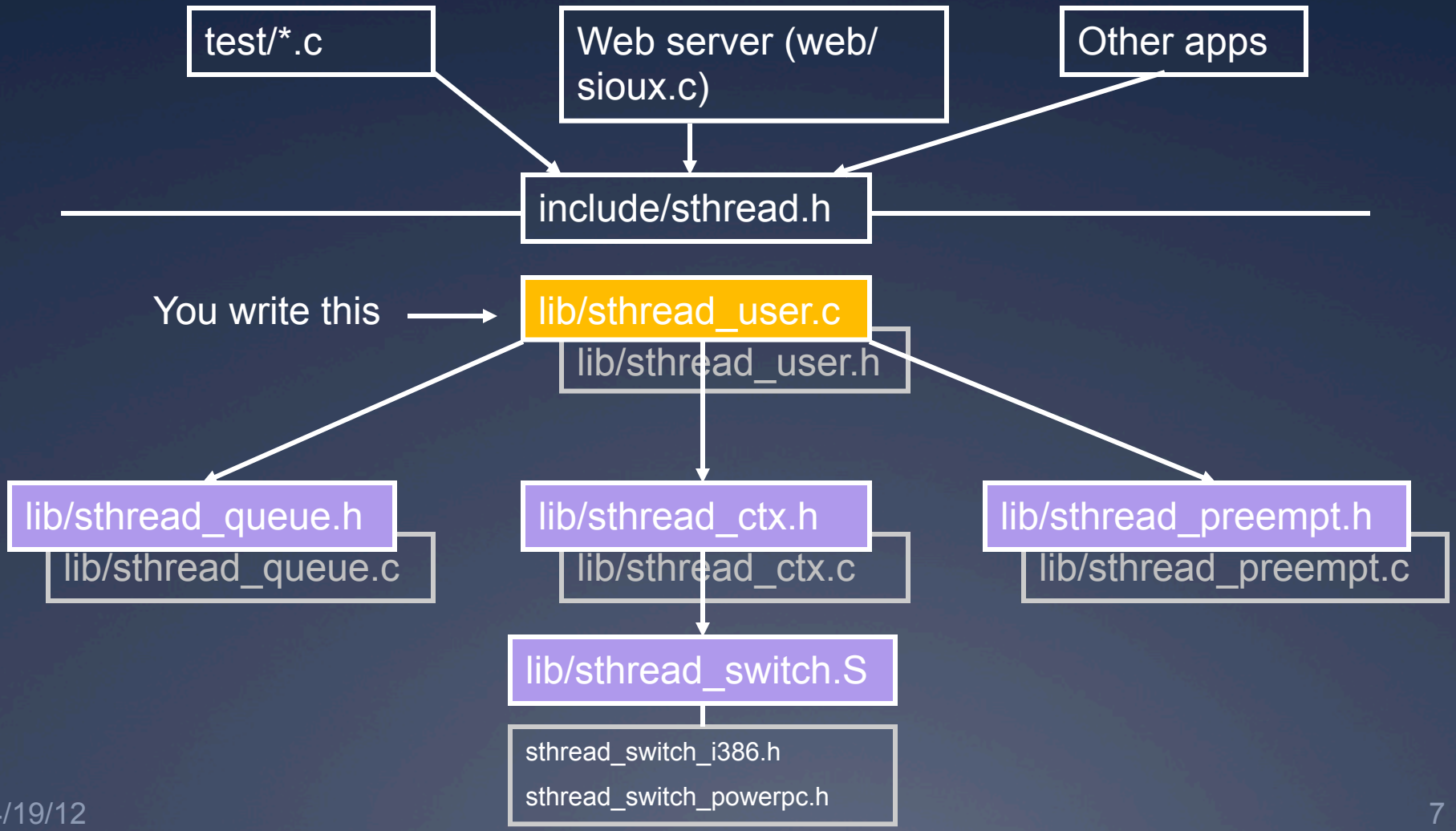
Project 2 tips

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

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)`

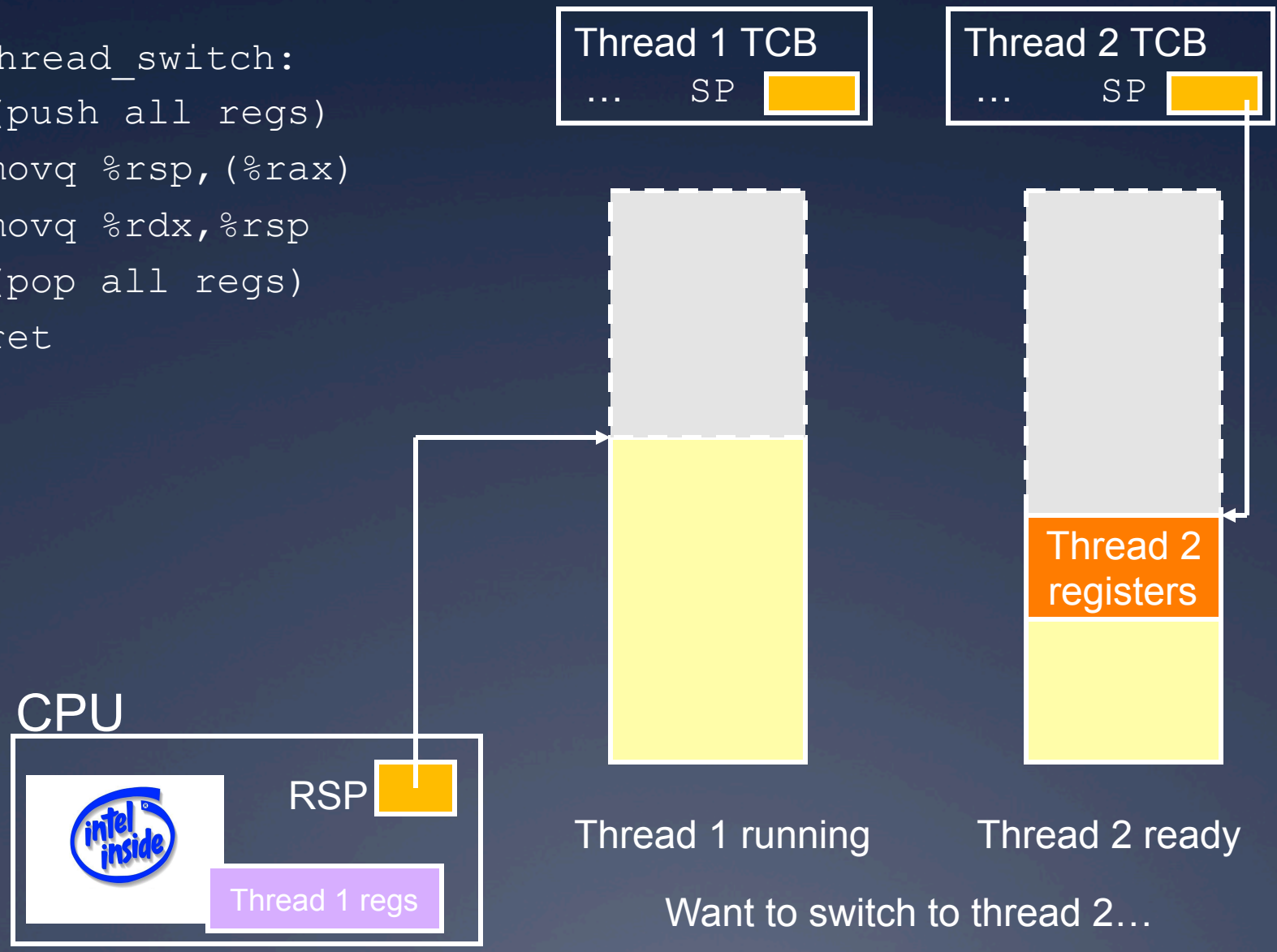
  - Deletes the supplied context

`sthread_switch(oldctx, newctx)`

  - Puts current context into oldctx
  - Takes newctx and makes it current

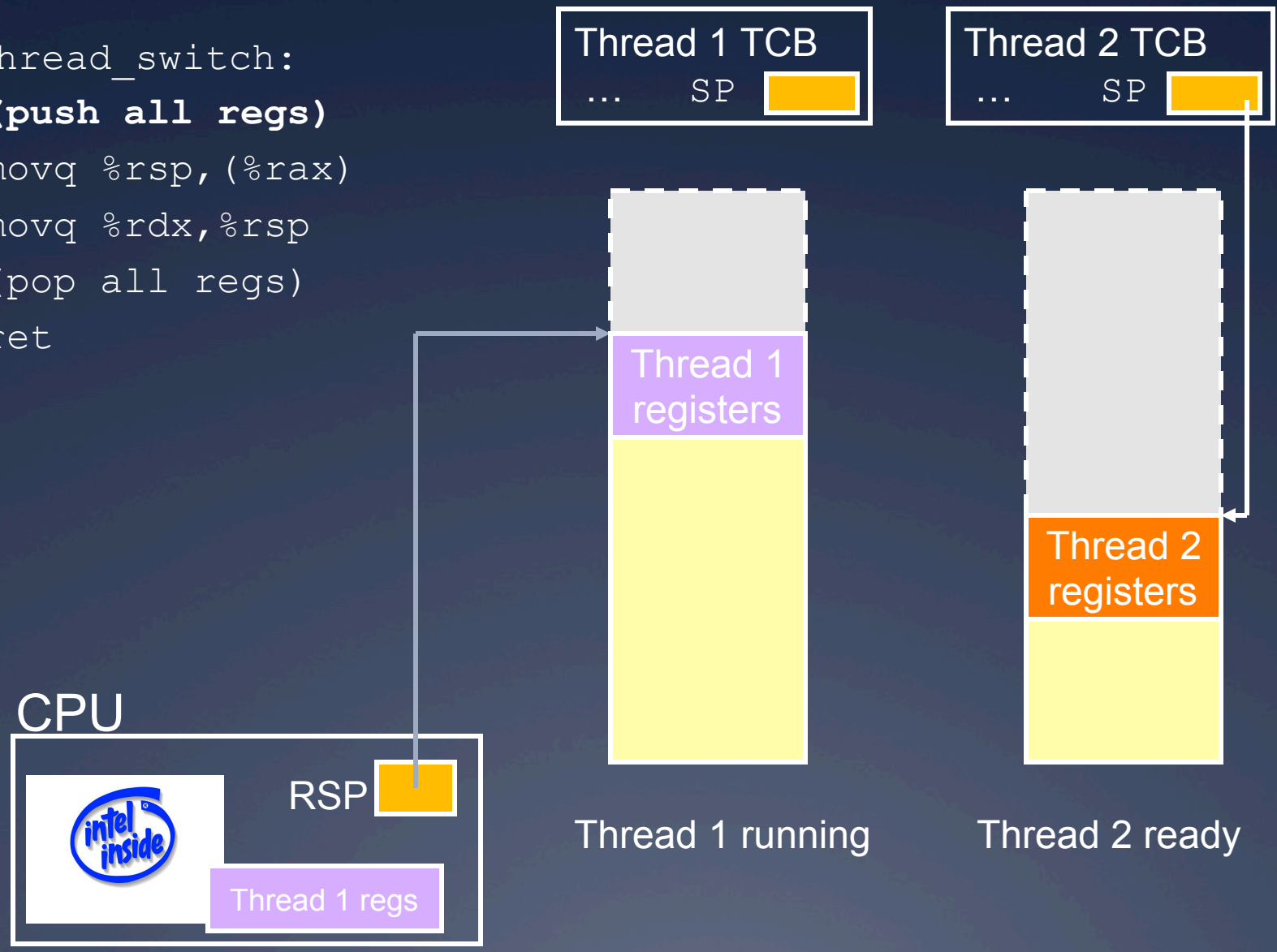
How sthread_switch works

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



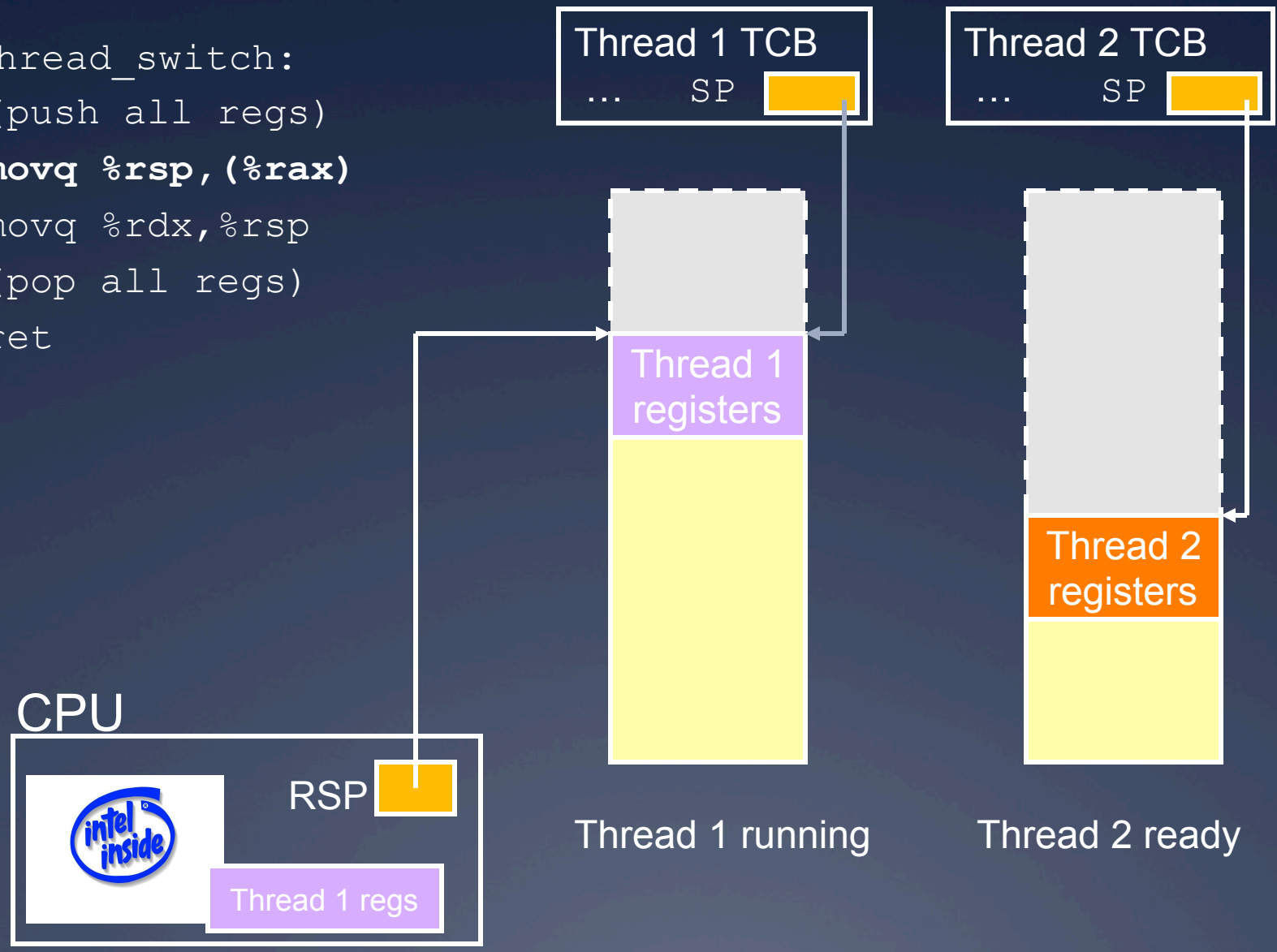
Push old context

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



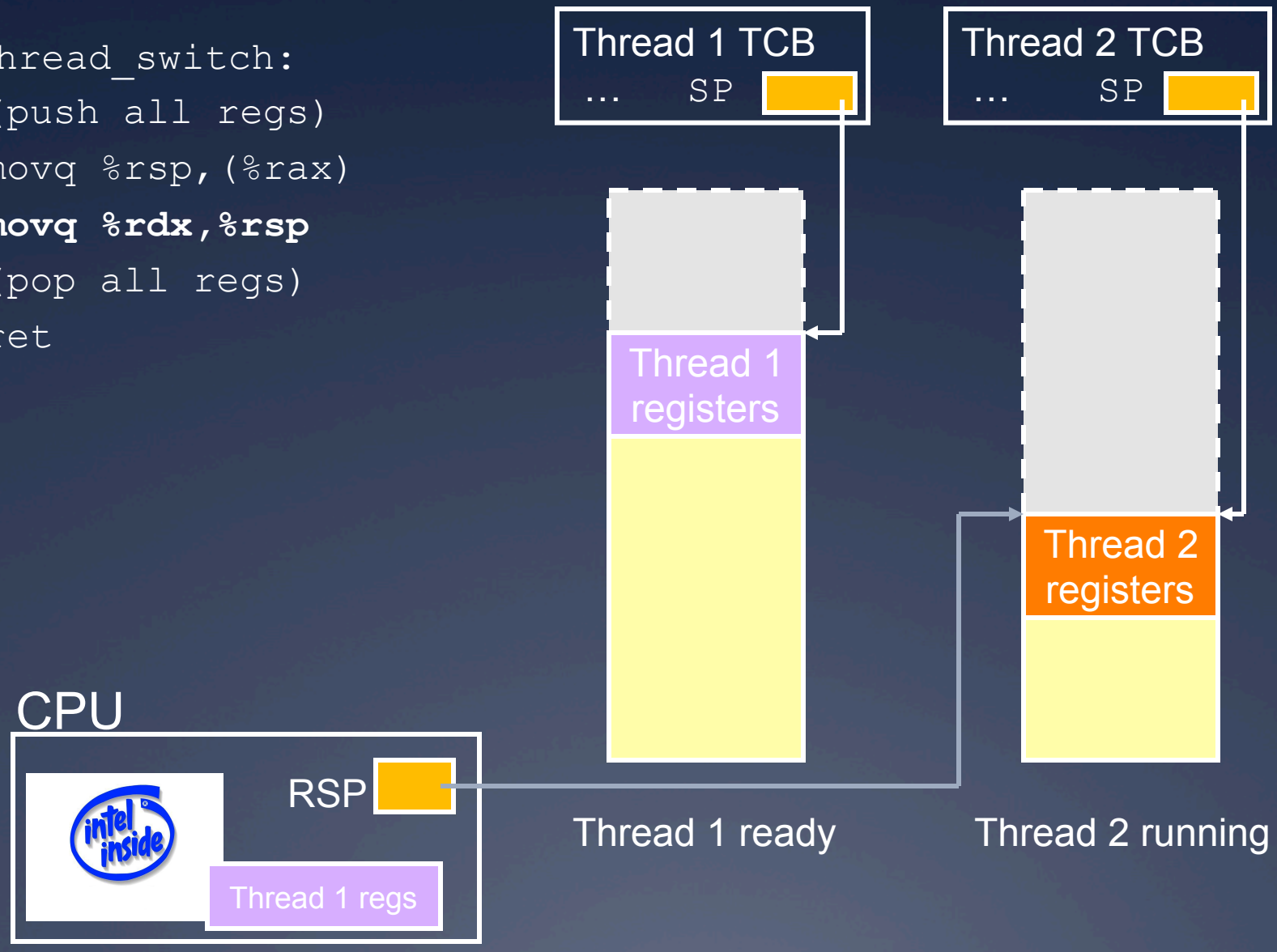
Save old stack pointer

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



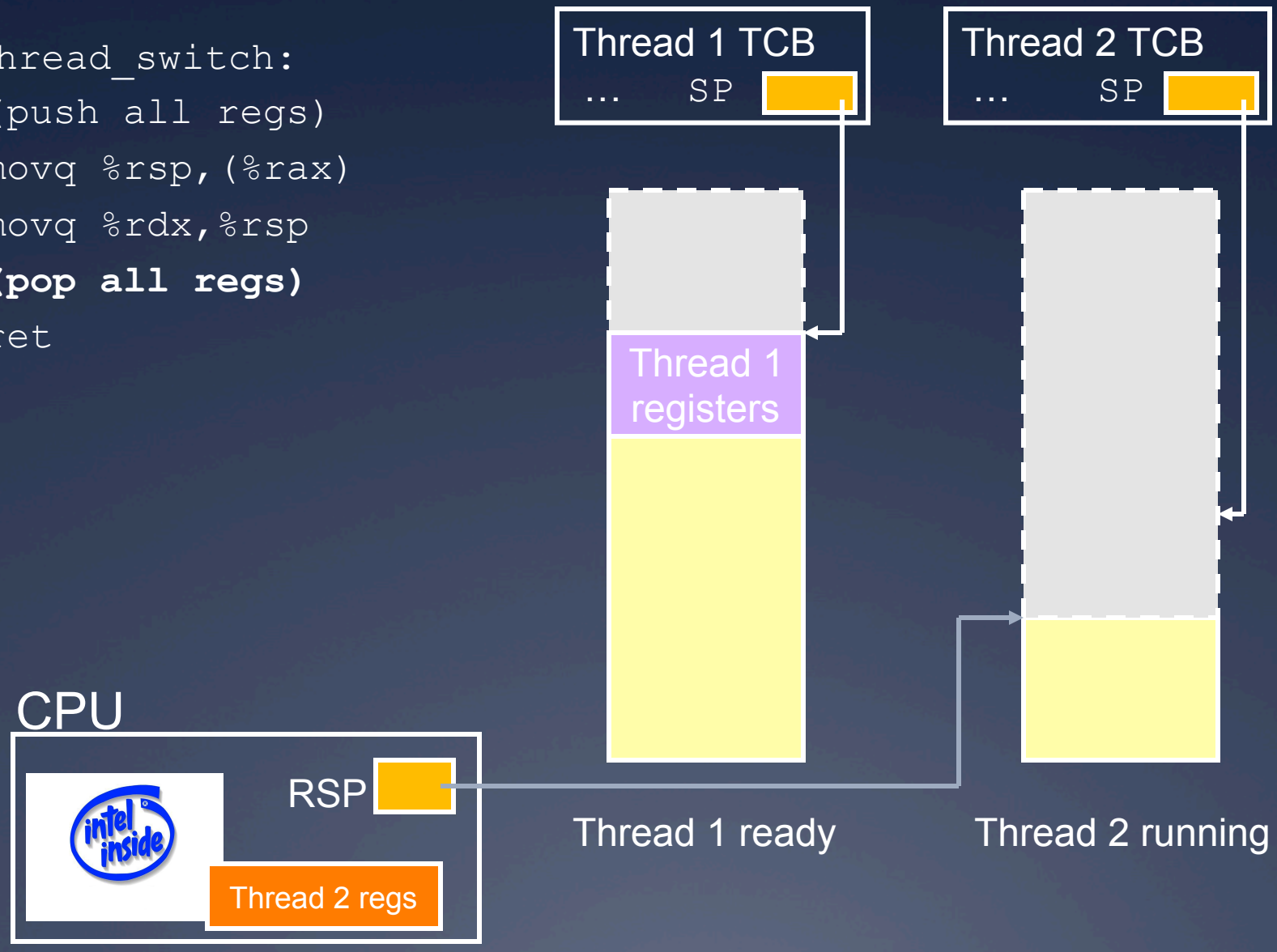
Change stack pointers

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



Pop off new context

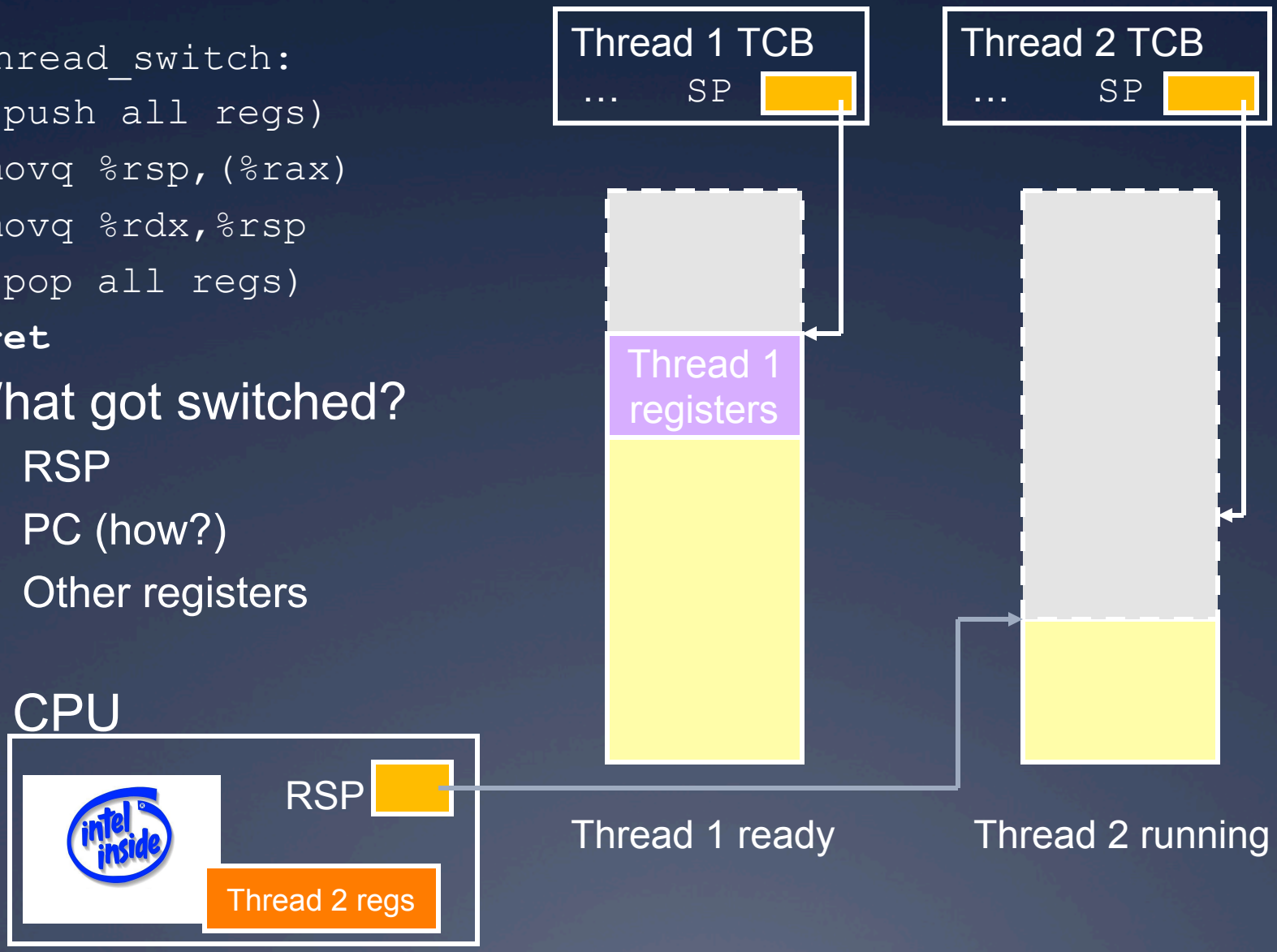
```
Xsthread_switch:
    (push all regs)
    movq %rsp,(%rax)
    movq %rdx,%rsp
    (pop all regs)
    ret
```



Done; return

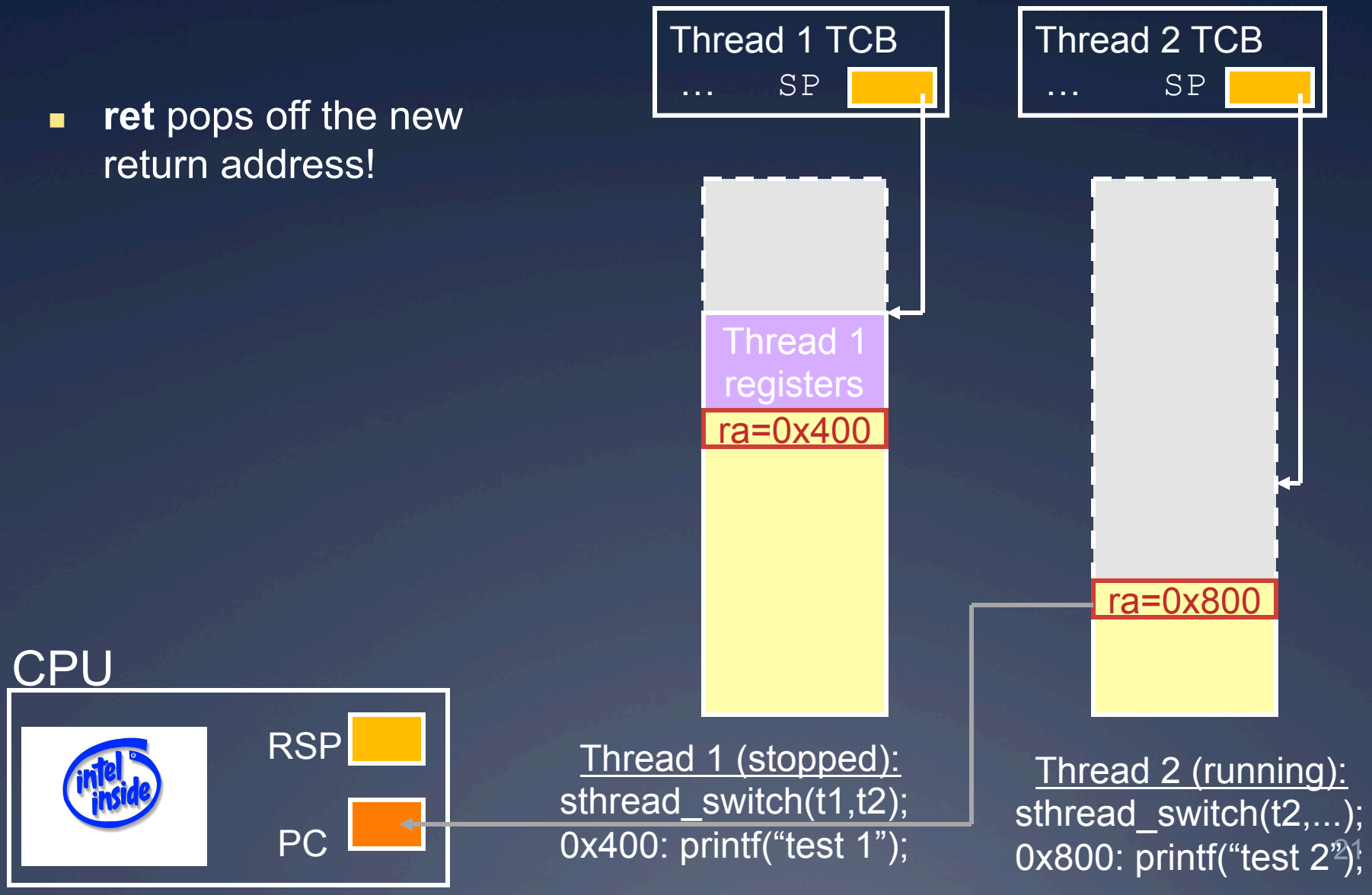
```
Xsthread_switch:
    (push all regs)
    movq %rsp,(%rax)
    movq %rdx,%rsp
    (pop all regs)
    ret
```

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



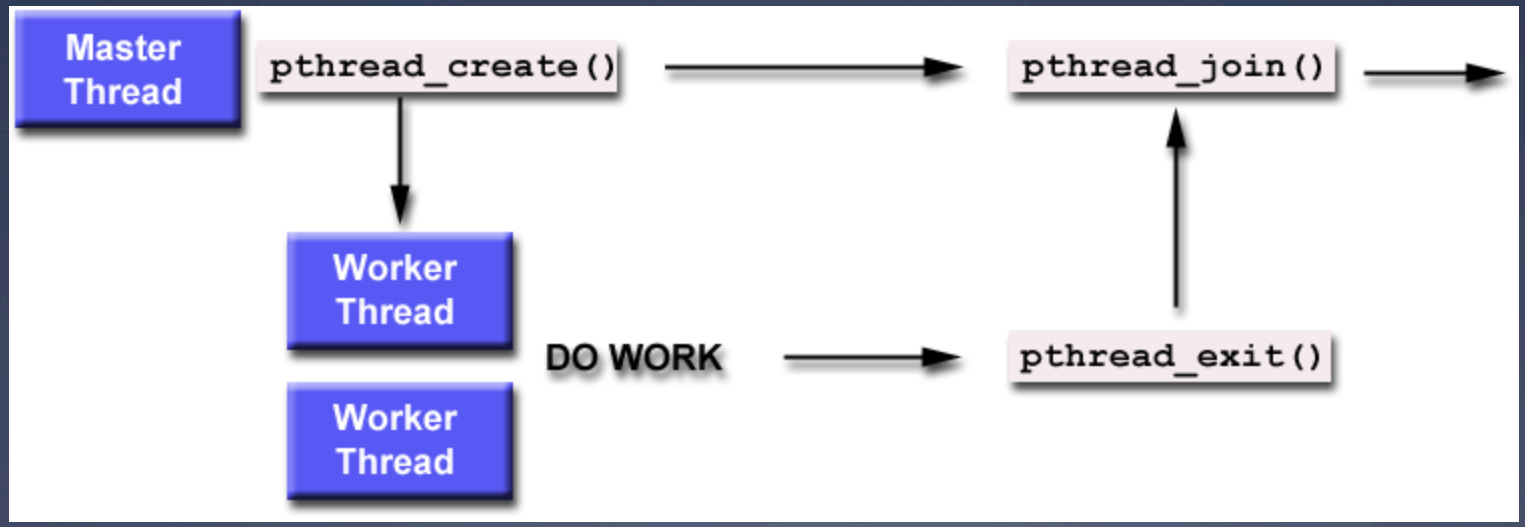
Adjusting the PC

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



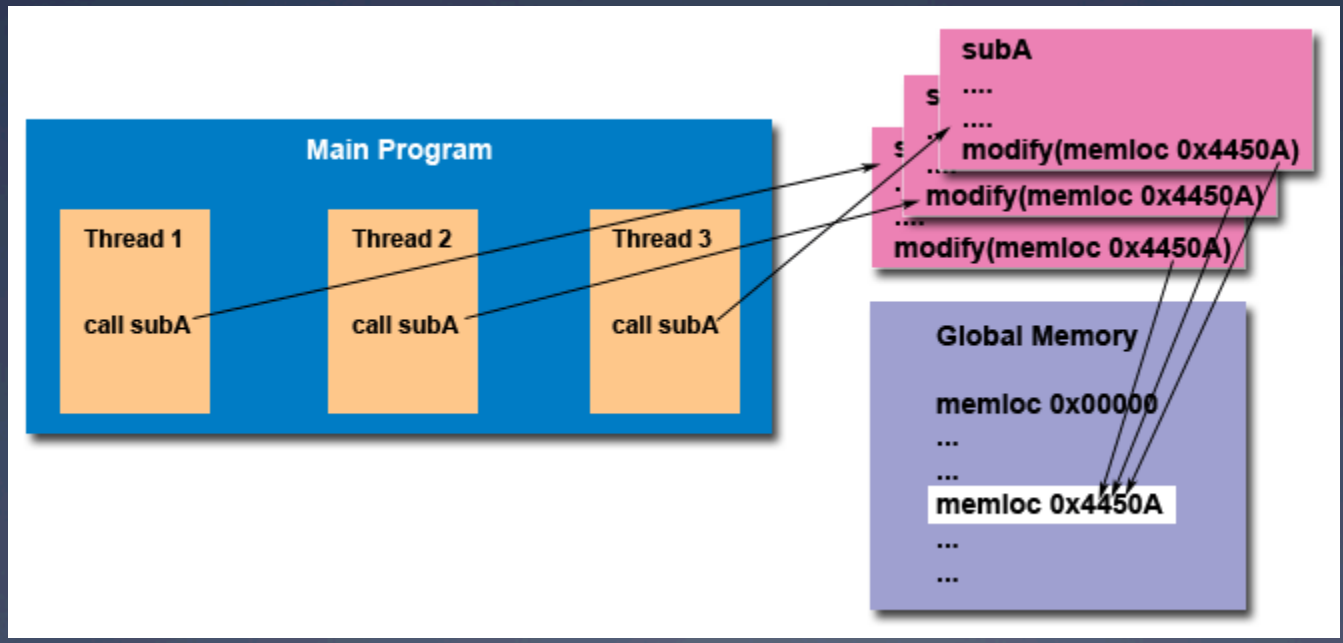
Thread joining

- 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