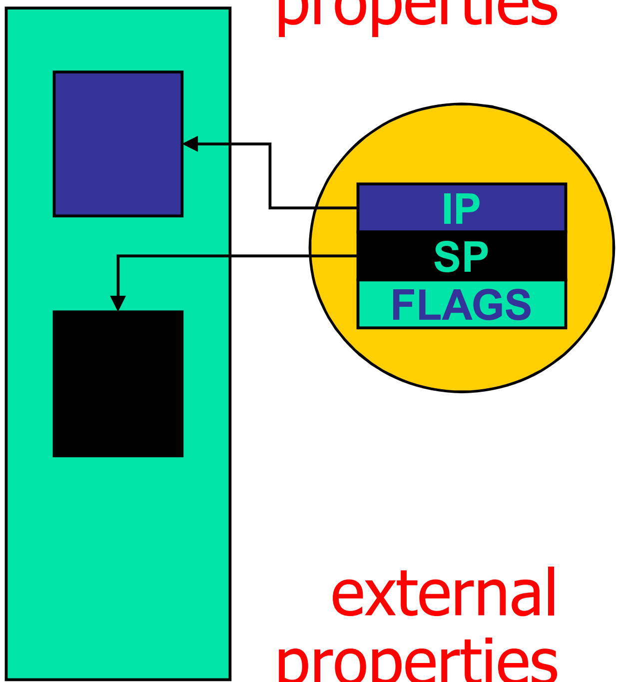
μ-Kernel Construction

Fundamental Abstractions

- Thread
- Address Space
    - What *is* a thread?
    - How to implement?

    - *What conclusions can we draw from our analysis with respect to μK construction?*

A "thread of control" has



internal properties

- register set
  - e.g. general registers, IP and SP
- stack
- status
  - e.g. FLAGs, privilege,
  - OS-specific states (prio, time…)
- address space
- unique id
- communication status

external properties

Construction Conclusions (1)

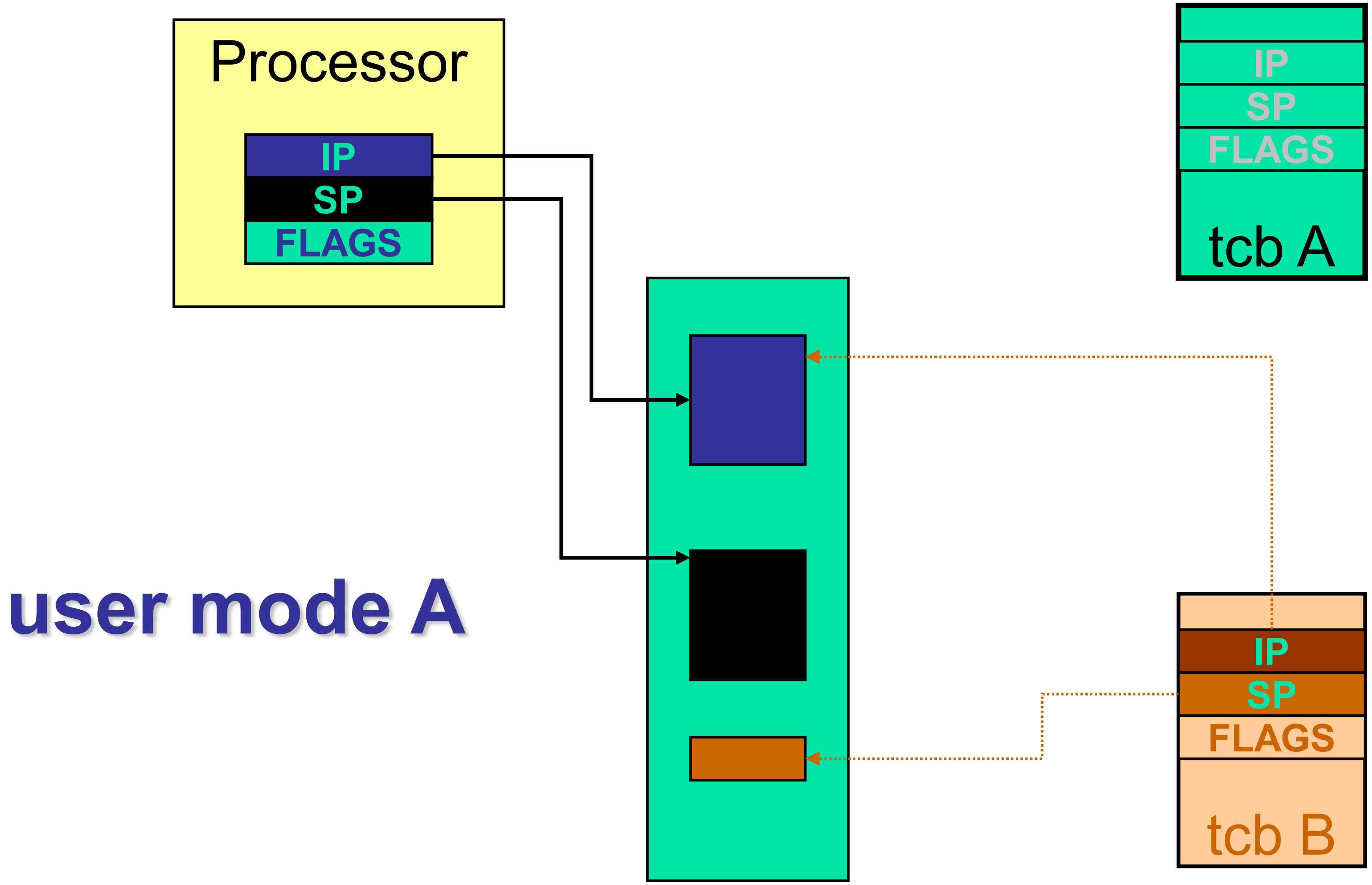
- Thread state must be saved / restored on thread switch.
- We need a thread control block (tcb) per thread.
- Tcbs must be kernel objects.

(at least partially, we found some good reasons to implement parts of the TCB in user memory.)

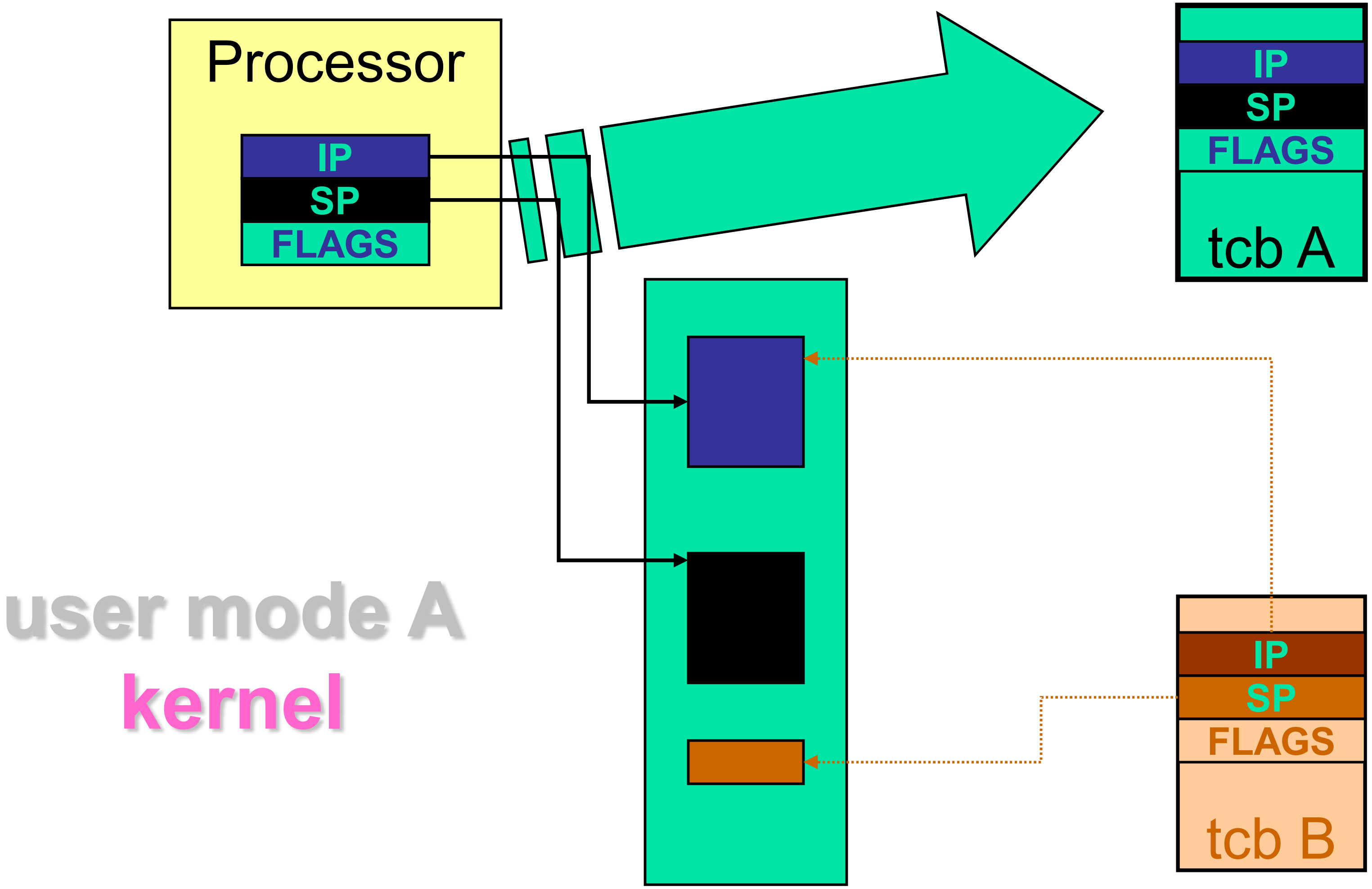
- **Tcbs implement threads.**

- We need to find
  - any thread's tcb starting from its uid
  - the currently executing thread's tcb (per processor)

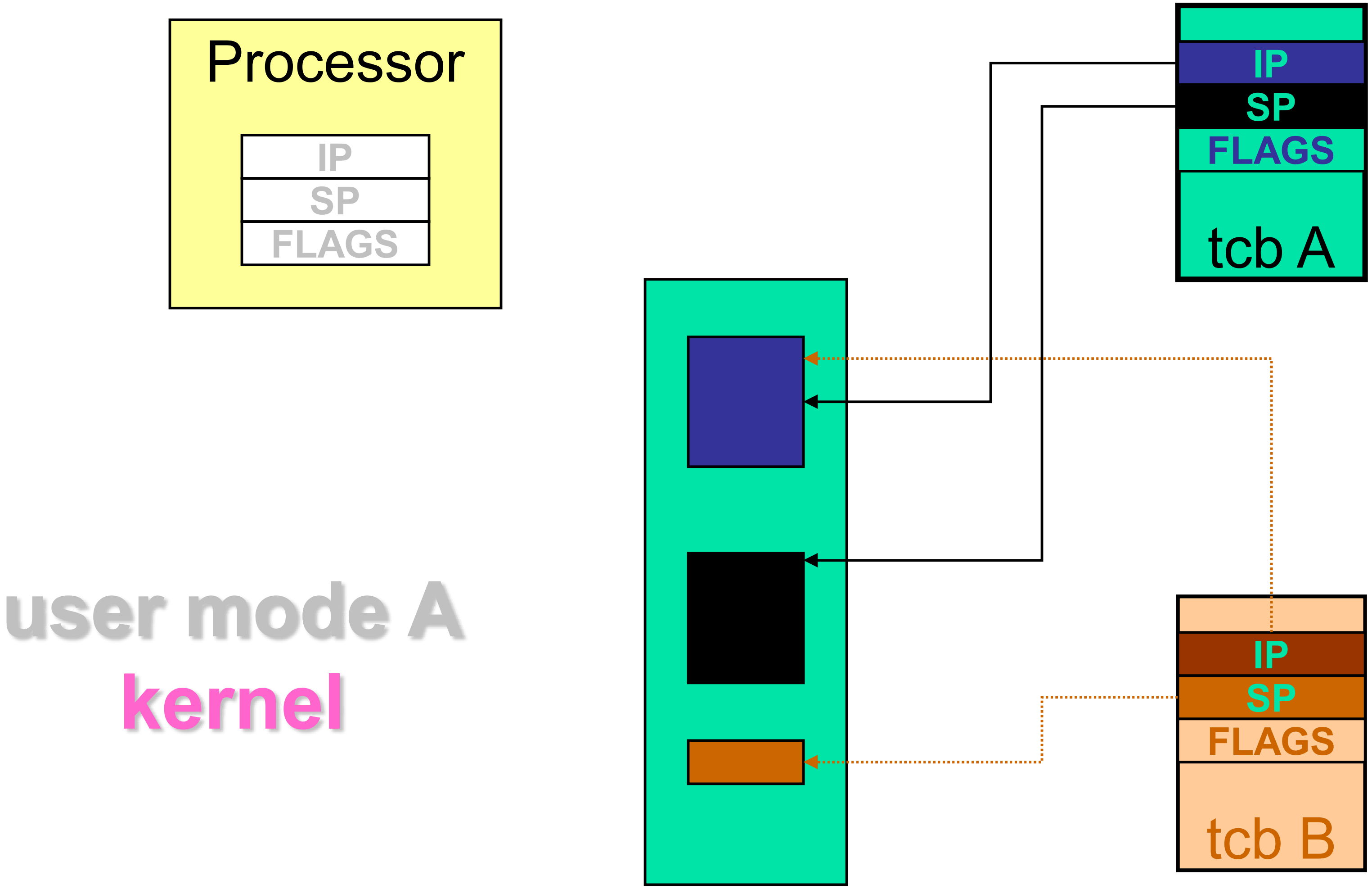
Thread Switch A → B



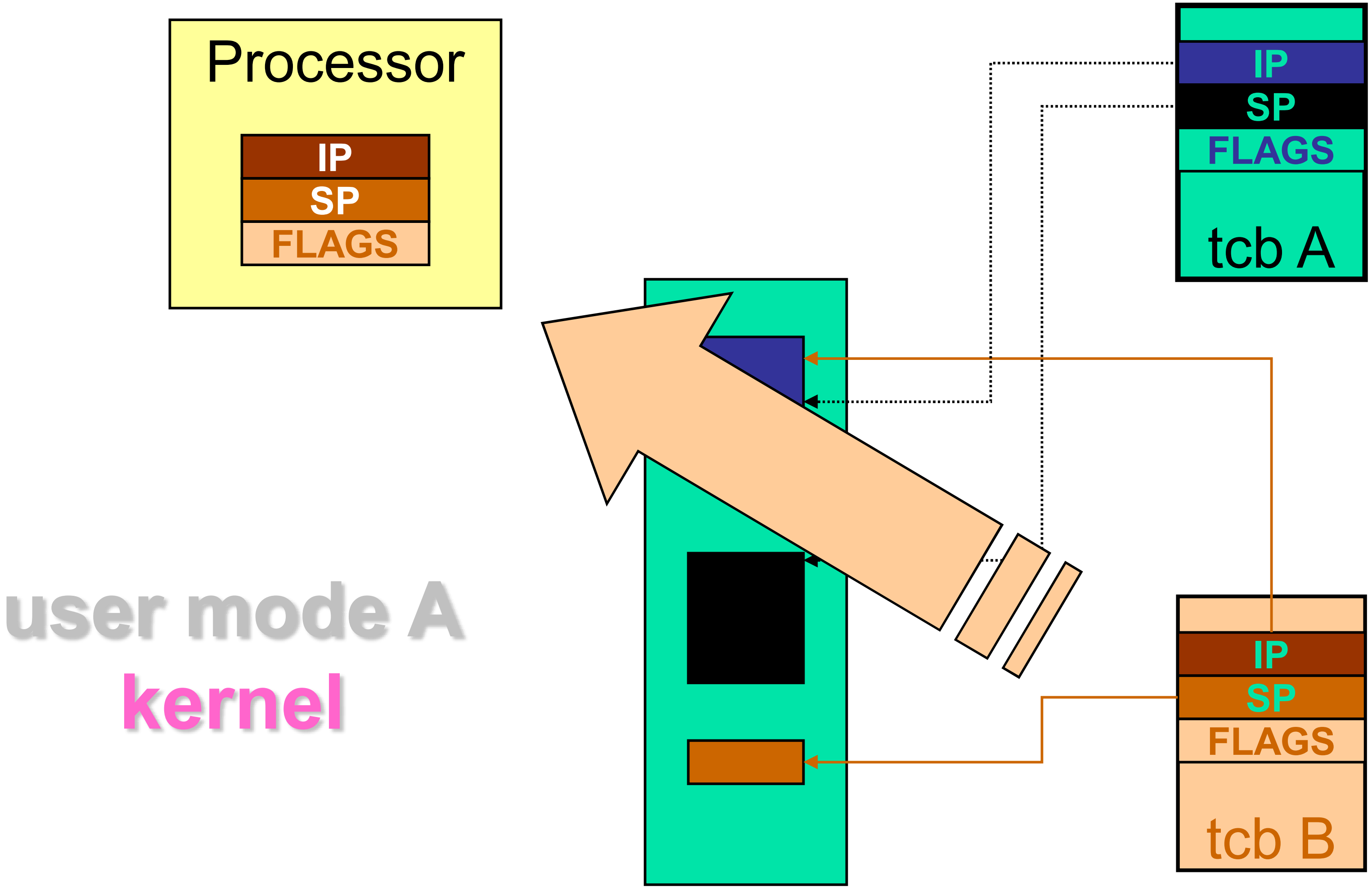
Thread Switch A → B



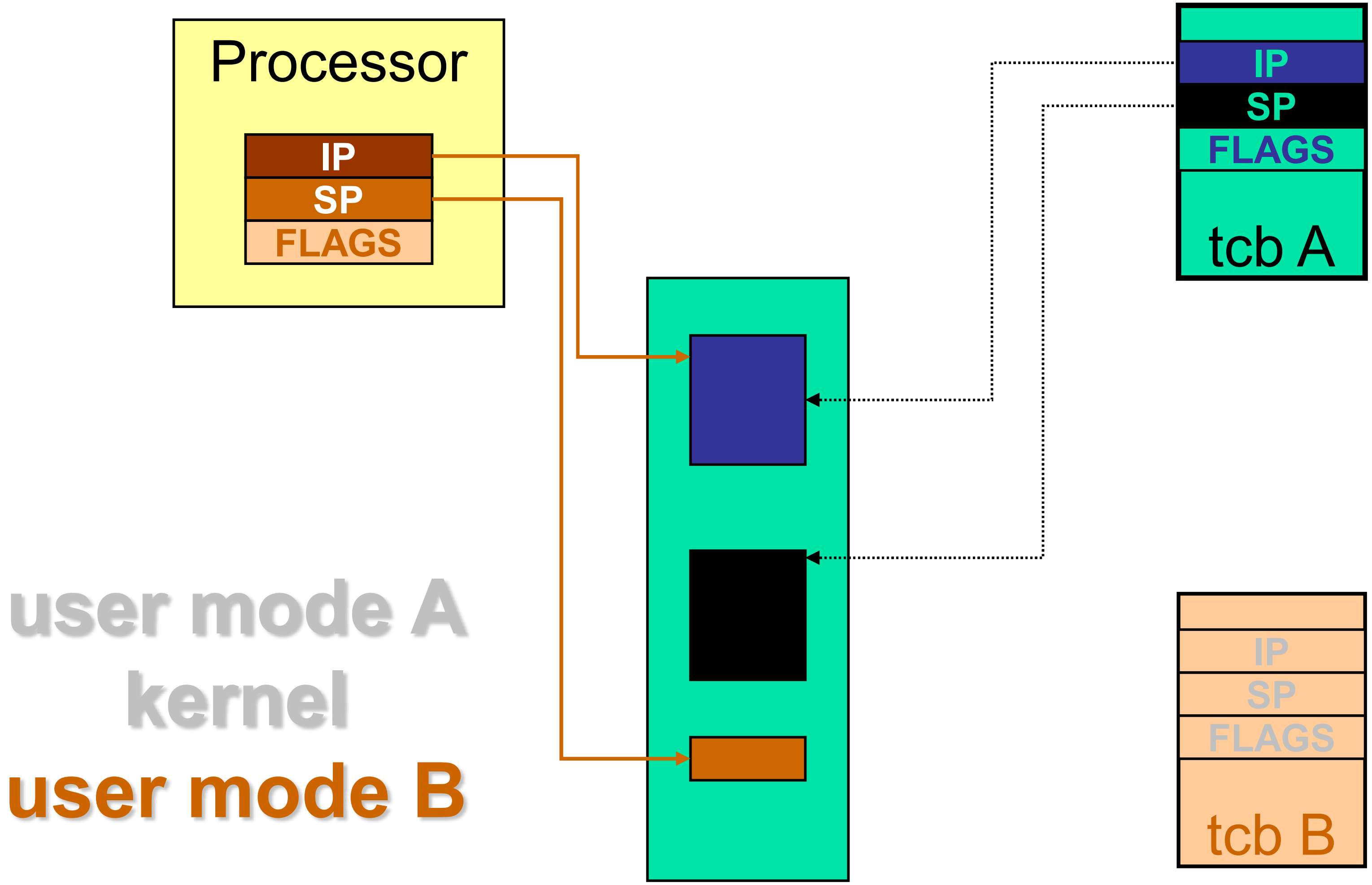
Thread Switch A → B



Thread Switch A → B



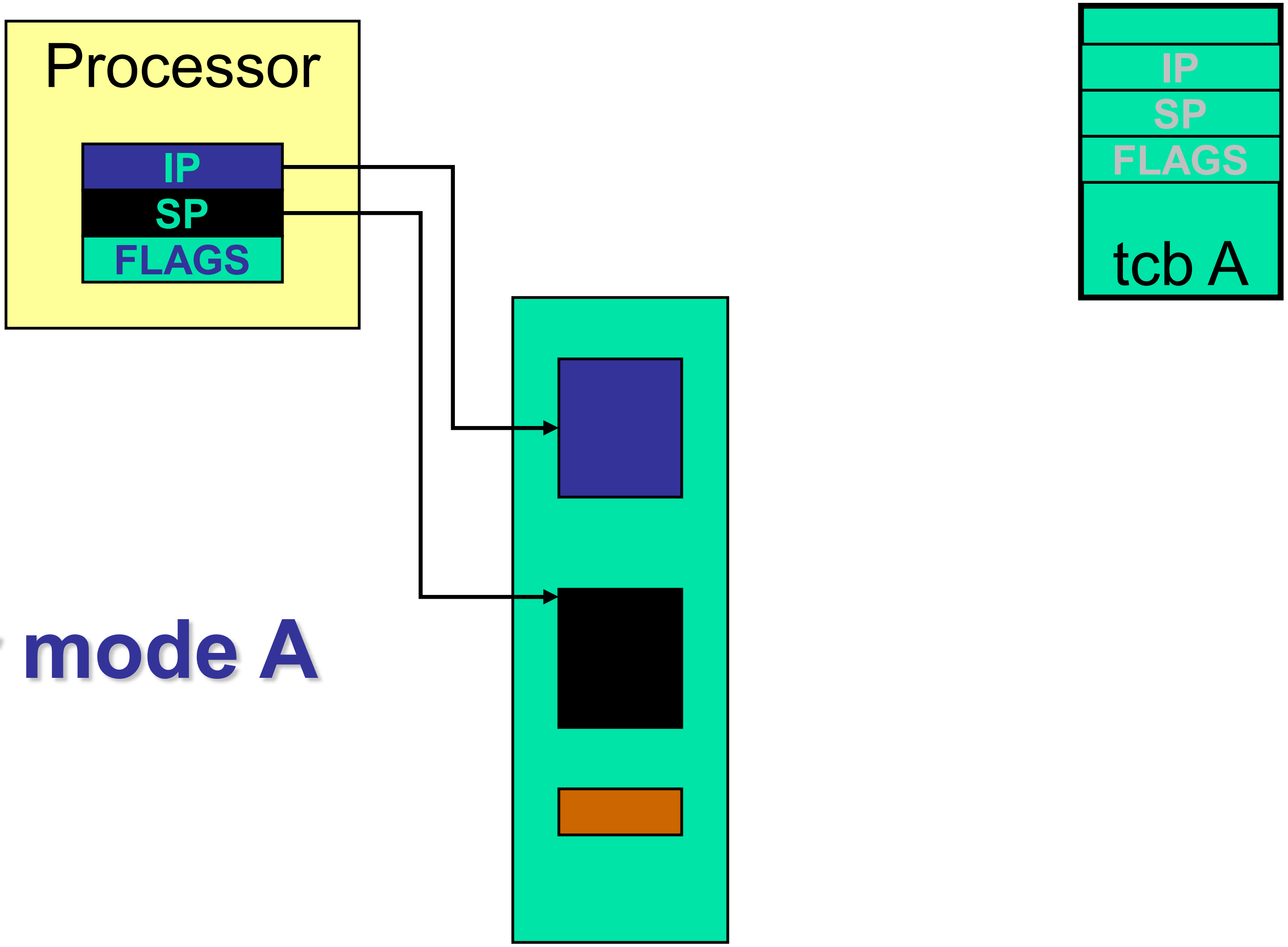
Thread Switch A → B



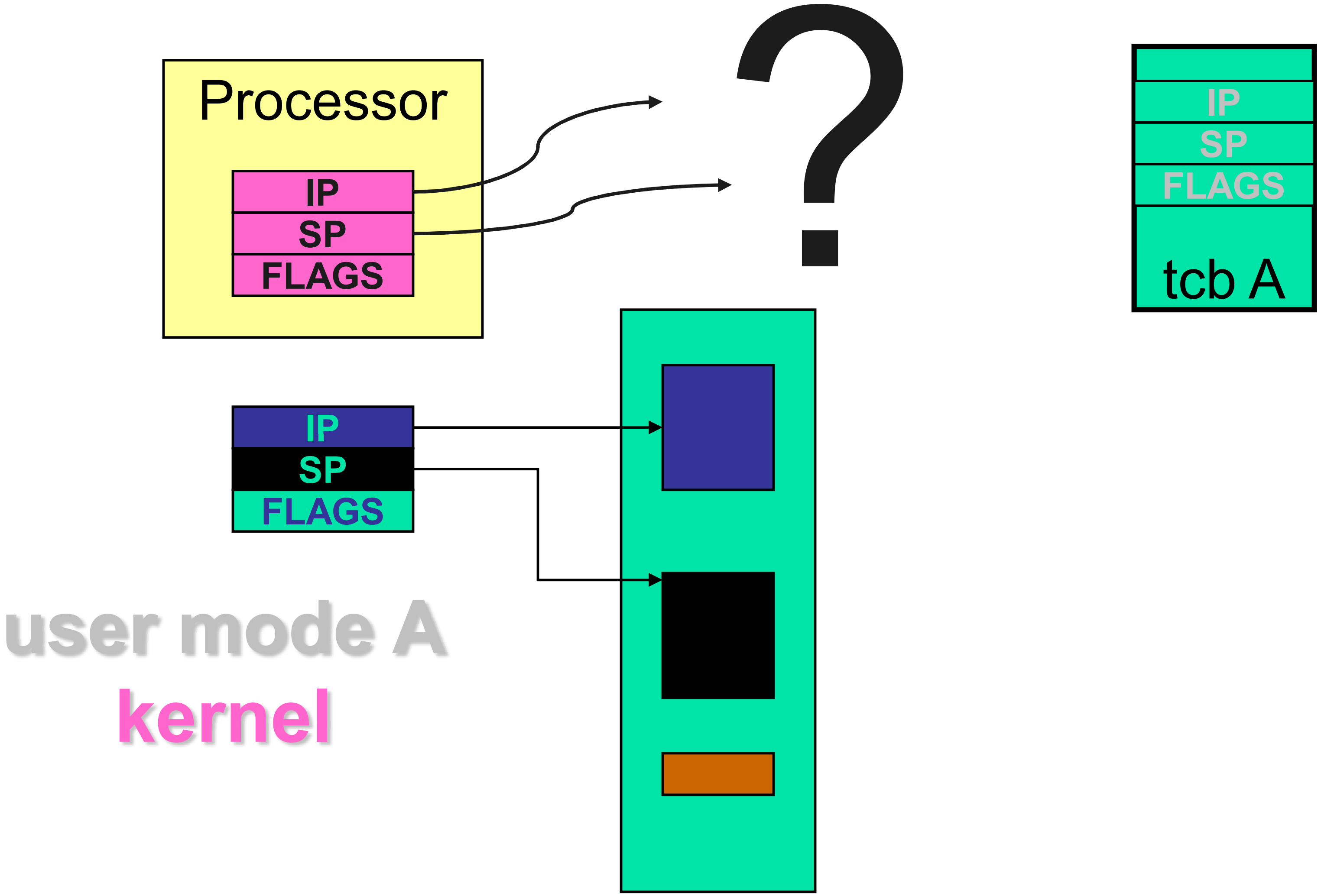
Thread Switch A → B

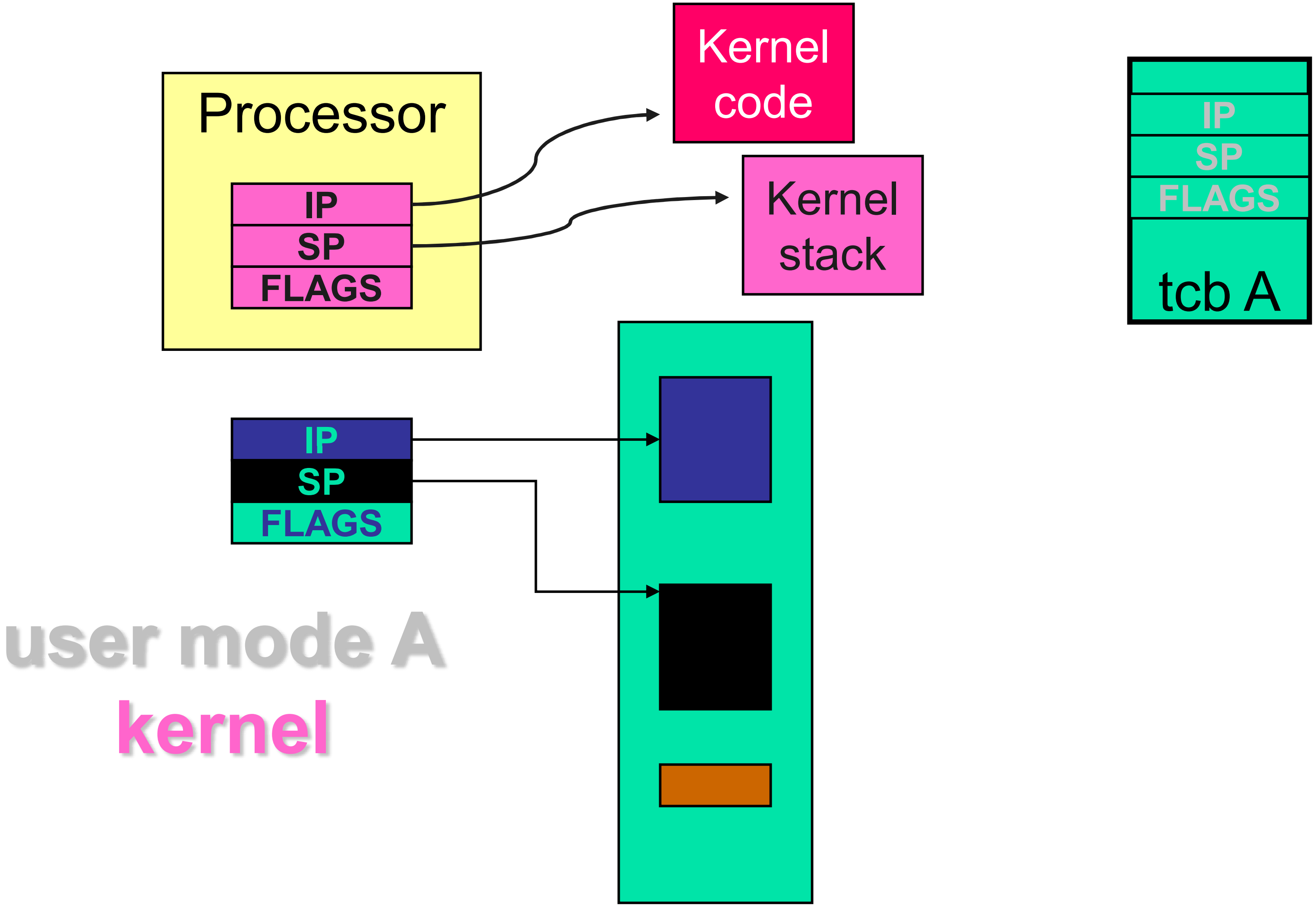
In Summary:

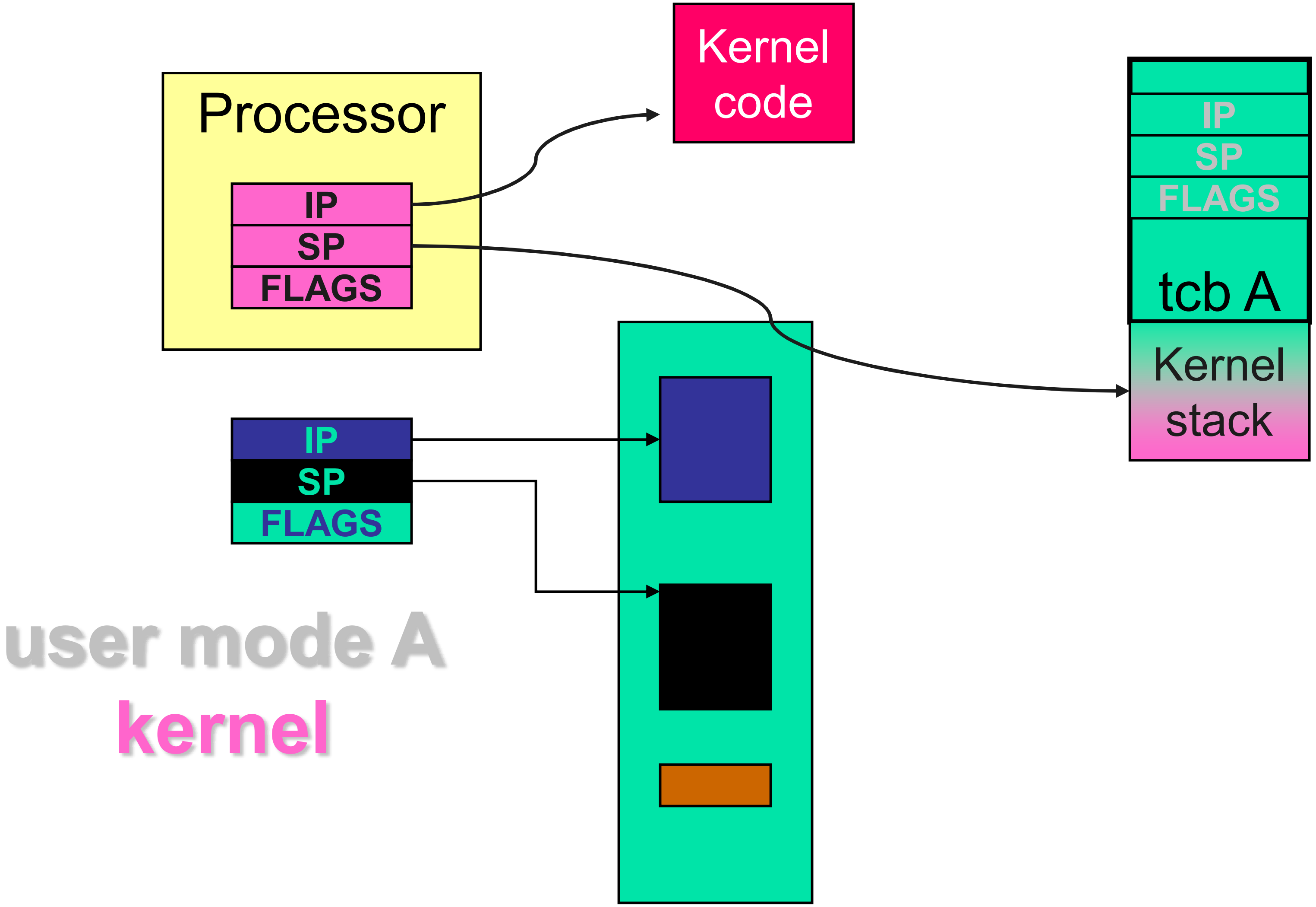
- Thread A is running in user mode
- Thread A has experiences an end-of-time-slice or is preempted by an interrupt
- We enter kernel mode
- The microkernel has to save the status of the thread A on A's TCB
- The next step is to load the status of thread B from B's TCB.
- Leave kernel mode and thread B is running in user mode.



user mode A


Processor
IP
SP
FLAGS
?
IP
SP
FLAGS
tcb A
IP
SP
FLAGS
user mode A
kernel


Kernel code
Processor
IP
SP
FLAGS
Kernel stack
IP
SP
FLAGS
tcb A
IP
SP
FLAGS
user mode A
kernel


Processor
IP
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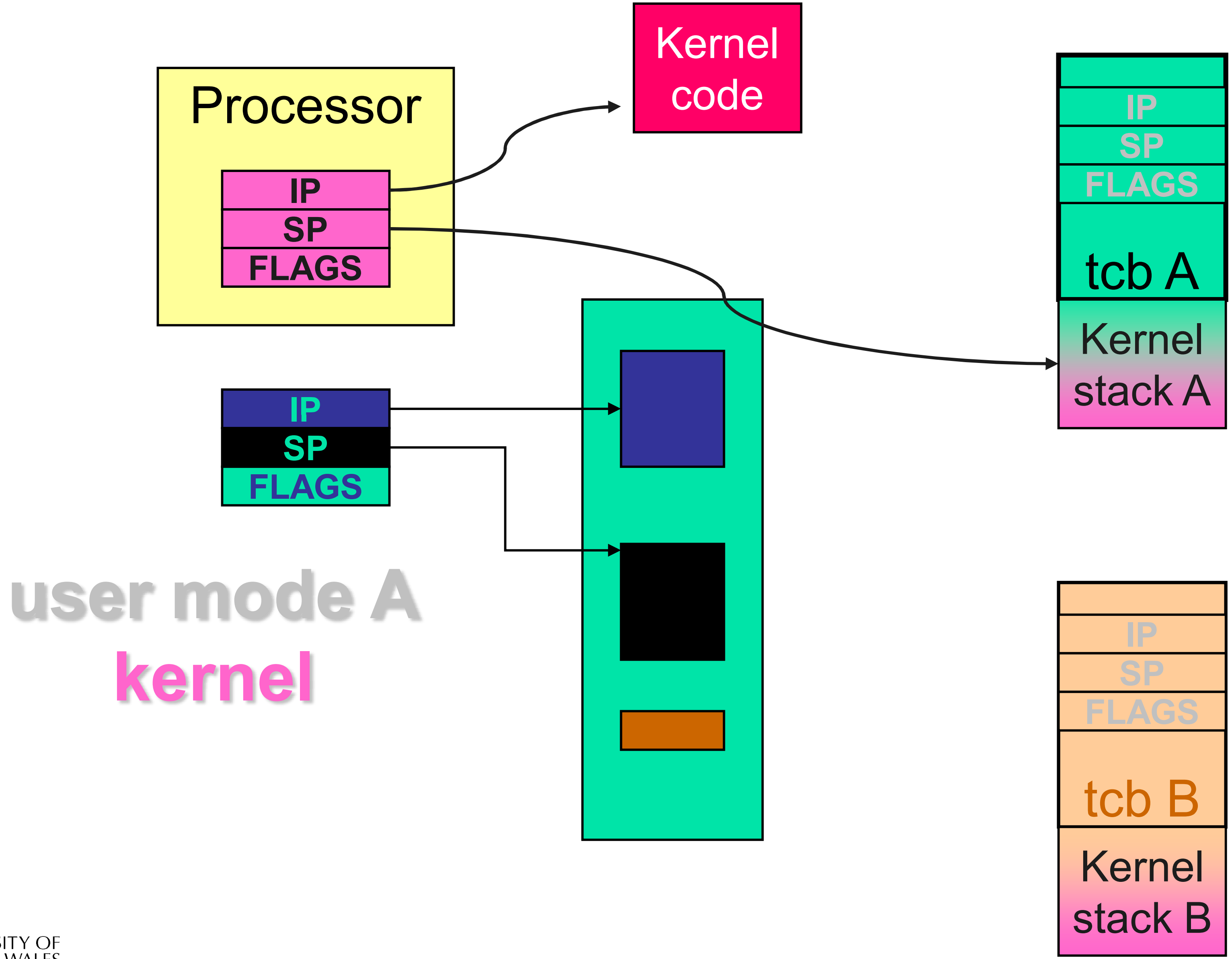
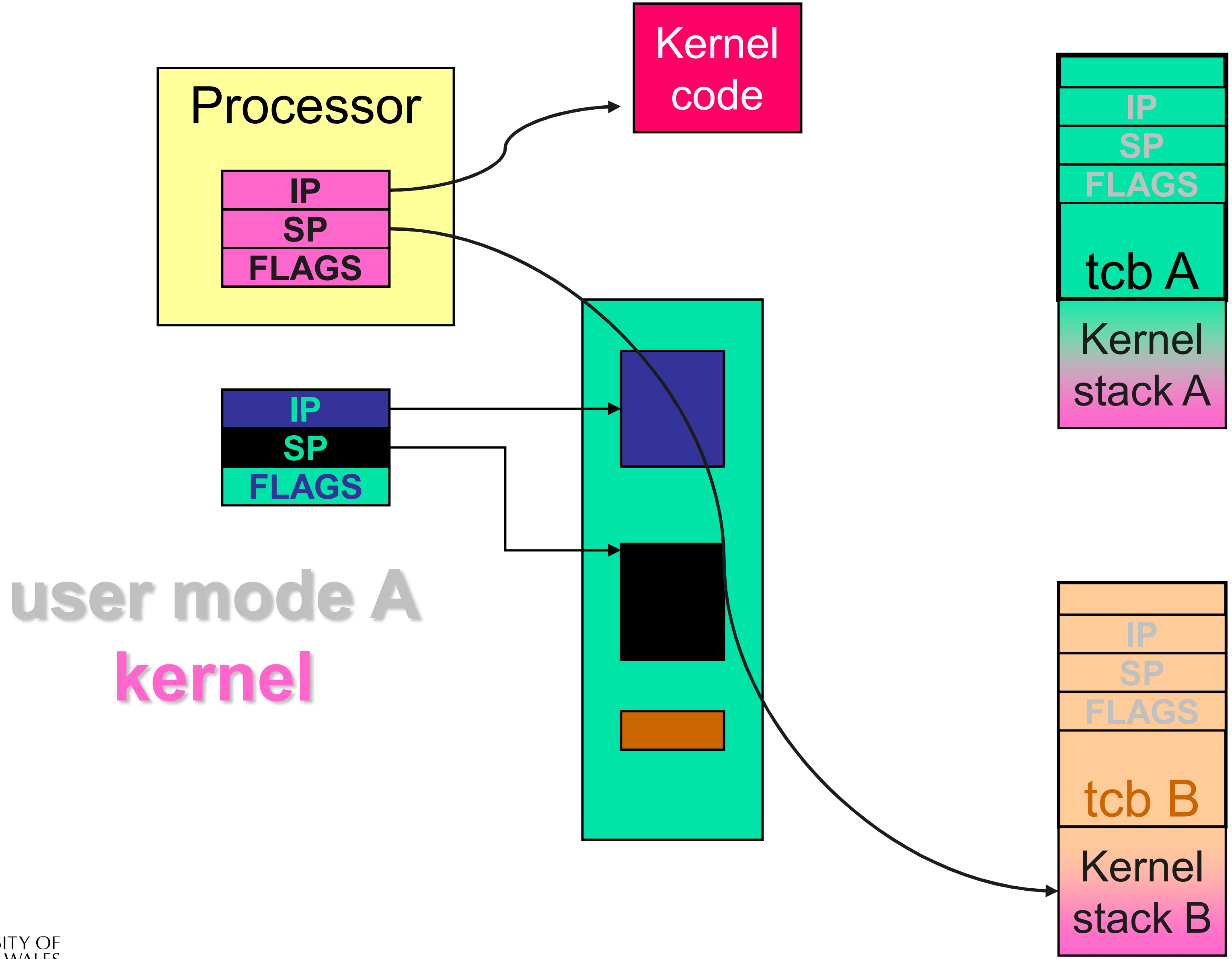
FLAGS
Kernel code
IP
SP
FLAGS
tcb A
Kernel stack
IP
SP
FLAGS
user mode A
kernel



Processor
IP
SP
FLAGS
Kernel code
IP
SP
FLAGS
tcb A
Kernel stack A
IP
SP
FLAGS
user mode A
kernel
IP
SP
FLAGS
tcb B
Kernel stack B



Kernel
code
Processor
IP
SP
FLAGS
IP
SP
FLAGS
user mode A
kernel
IP
SP
FLAGS
tcb A
Kernel
stack A
IP
SP
FLAGS
tcb B
Kernel
stack B

Construction conclusion

From the view of the designer there are two alternatives.

Single Kernel Stack

Only one stack is used all the time.

Per-Thread Kernel Stack

Every thread has a kernel stack.

Per-Thread Kernel Stack

Processes Model

- A thread's kernel state is implicitly encoded in the kernel activation stack
  - If the thread must block in-kernel, we can simply switch from the current stack, to another threads stack until thread is resumed
  - Resuming is simply switching back to the original stack
  - Preemption is easy
  - no conceptual difference between kernel mode and user mode

```
example(arg1, arg2) {
    P1(arg1, arg2);
    if (need_to_block) {
        thread_block();
        P2(arg2);
    } else {
        P3();
    }
    /* return control to user */
    return SUCCESS;
}
```

Single Kernel Stack
"Event" or "Interrupt" Model

- How do we use a single kernel stack to support many threads?
  - Issue: How are system calls that block handled?

⇒ either *continuations*

- Using Continuations to Implement Thread Management and Communication in Operating Systems. [Draves *et al.*, 1991]

⇒ or *stateless kernel* (interrupt model)

- Interface and Execution Models in the Fluke Kernel. [Ford *et al.*, 1999]

Continuations

- State required to resume a blocked thread is explicitly saved in a TCB
  - A function pointer
  - Variables
- Stack can be discarded and reused to support new thread
- Resuming involves discarding current stack, restoring the continuation, and continuing

```
example(arg1, arg2) {
   P1(arg1, arg2);
   if (need_to_block) {
        save_context_in_TCB;
        thread_block(example_continue);
        /* NOT REACHED */
   } else {
        P3();
   }
   thread_syscall_return(SUCCESS);
}
example_continue() {
   recover_context_from_TCB;
   P2(recovered arg2);
   thread_syscall_return(SUCCESS);
}
```

Stateless Kernel

- System calls can not block within the kernel
  - If syscall must block (resource unavailable)
    - Modify user-state such that syscall is restarted when resources become available
    - Stack content is discarded
- Preemption within kernel difficult to achieve.
  - ⇒ Must (partially) roll syscall back to (a) restart point
- Avoid page faults within kernel code
  - ⇒ Syscall arguments in registers
    - Page fault during roll-back to restart (due to a page fault) is fatal.

IPC examples – Per thread stack

```
msg_send_rcv(msg, option,
        send_size, rcv_size, ...) {

   rc = msg_send(msg, option,
        send_size, ...);

   if (rc != SUCCESS)
   return rc;

   rc = msg_rcv(msg, option, rcv_size, ...);
   return rc;
}
```

Send and Receive system call implemented by a non-blocking send part and a blocking receive part.

Block inside msg_rcv if no message available

IPC examples - Continuations

```
msg_send_rcv(msg, option,
        send_size, rcv_size, ...) {
   rc = msg_send(msg, option,
        send_size, ...);
   if (rc != SUCCESS)
        return rc;
   cur_thread->continuation.msg = msg;
   cur_thread->continuation.option = option;
   cur_thread->continuation.rcv_size = rcv_size;
        ...
   rc = msg_rcv(msg, option, rcv_size, ...,
        msg_rcv_continue);
   return rc;
}
msg_rcv_continue(cur_thread) {
   msg = cur_thread->continuation.msg;
   option = cur_thread->continuation.option;
   rcv_size = cur_thread->continuation.rcv_size;
        ...
   rc = msg_rcv(msg, option, rcv_size, ...,
        msg_rcv_continue);
   return rc;
}
```

IPC Examples – stateless kernel

```
msg_send_rcv(cur_thread) {
   rc = msg_send(cur_thread);
   if (rc != SUCCESS)
        return rc;
   set_pc(cur_thread, msg_rcv_entry);
   rc = msg_rcv(cur_thread);
   if (rc != SUCCESS)
        return rc;
   return SUCCESS;
}
```

Set user-level PC to restart msg_rcv only

Single Kernel Stack

per Processor, event model

- either *continuations*
  - complex to program
  - must be conservative in state saved (any state that *might* be needed)
  - Mach (Draves), L4Ka::Strawberry, NICTA Pistachio, OKL4
- or *stateless kernel*
  - no kernel threads, kernel not interruptible, difficult to program
  - request all potentially required resources prior to execution
  - blocking syscalls must always be re-startable
  - Processor-provided stack management can get in the way
  - system calls need to be kept simple "atomic".
  - e.g. the fluke kernel from Utah
- low cache footprint
  - always the same stack is used !
  - reduced memory footprint

Per-Thread Kernel Stack

- simple, flexible
  - kernel can always use threads, no special techniques required for keeping state while interrupted / blocked
  - no conceptual difference between kernel mode and user mode
  - e.g. L4
- but larger cache footprint

Conclusion:
We have to look for a solution that minimizes the kernel stack size!