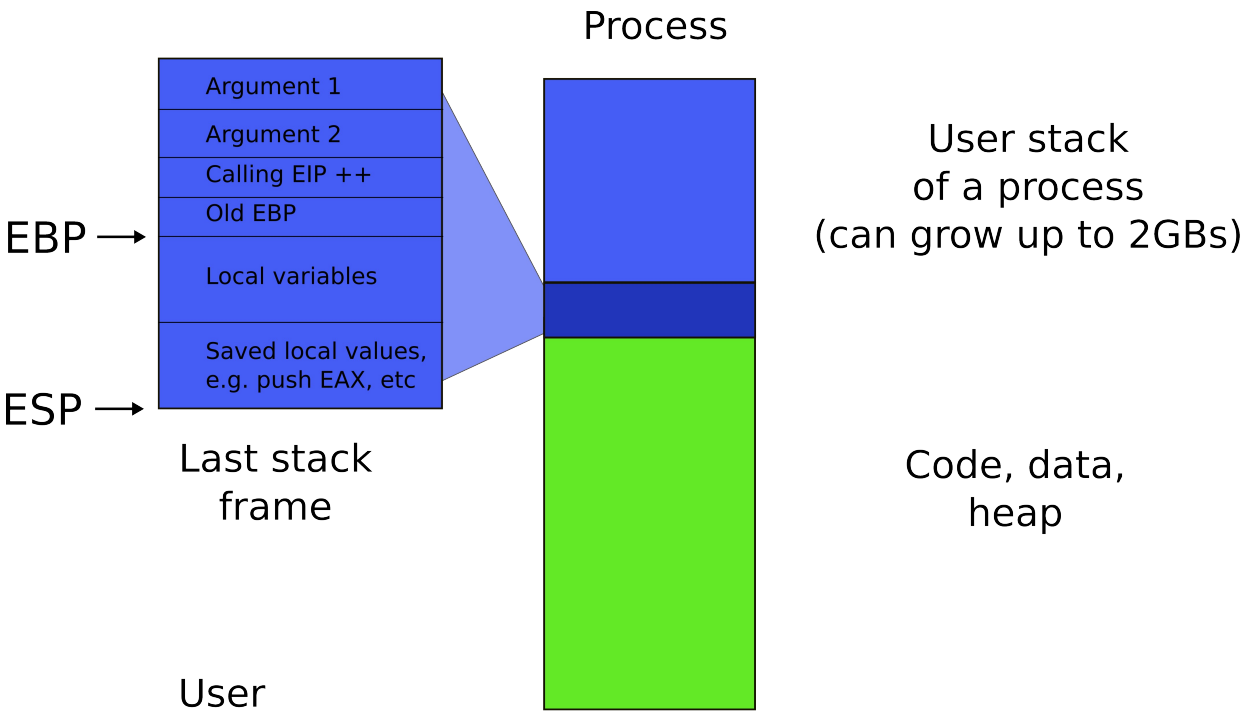
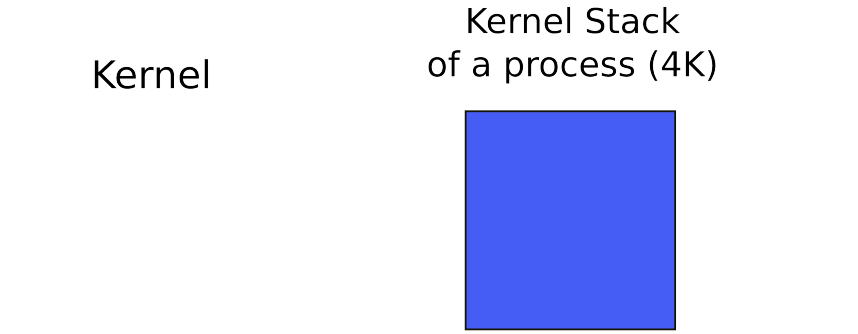
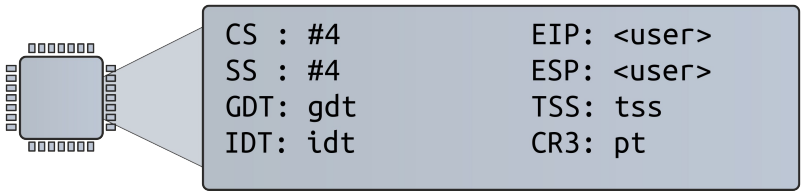
ICS143A: Principles of Operating Systems

Lecture 13: Context switching

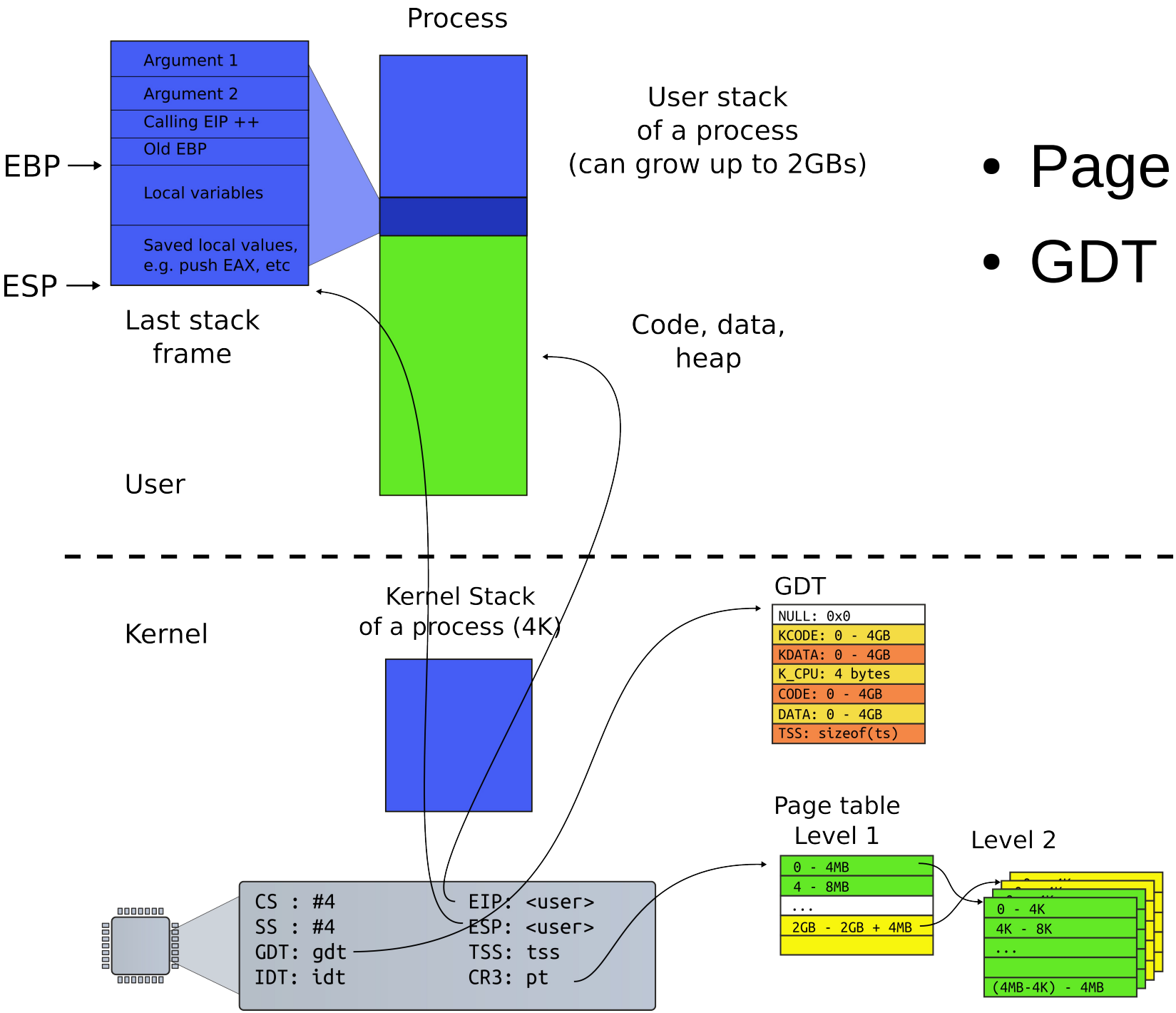
Anton Burtsev
February, 2017



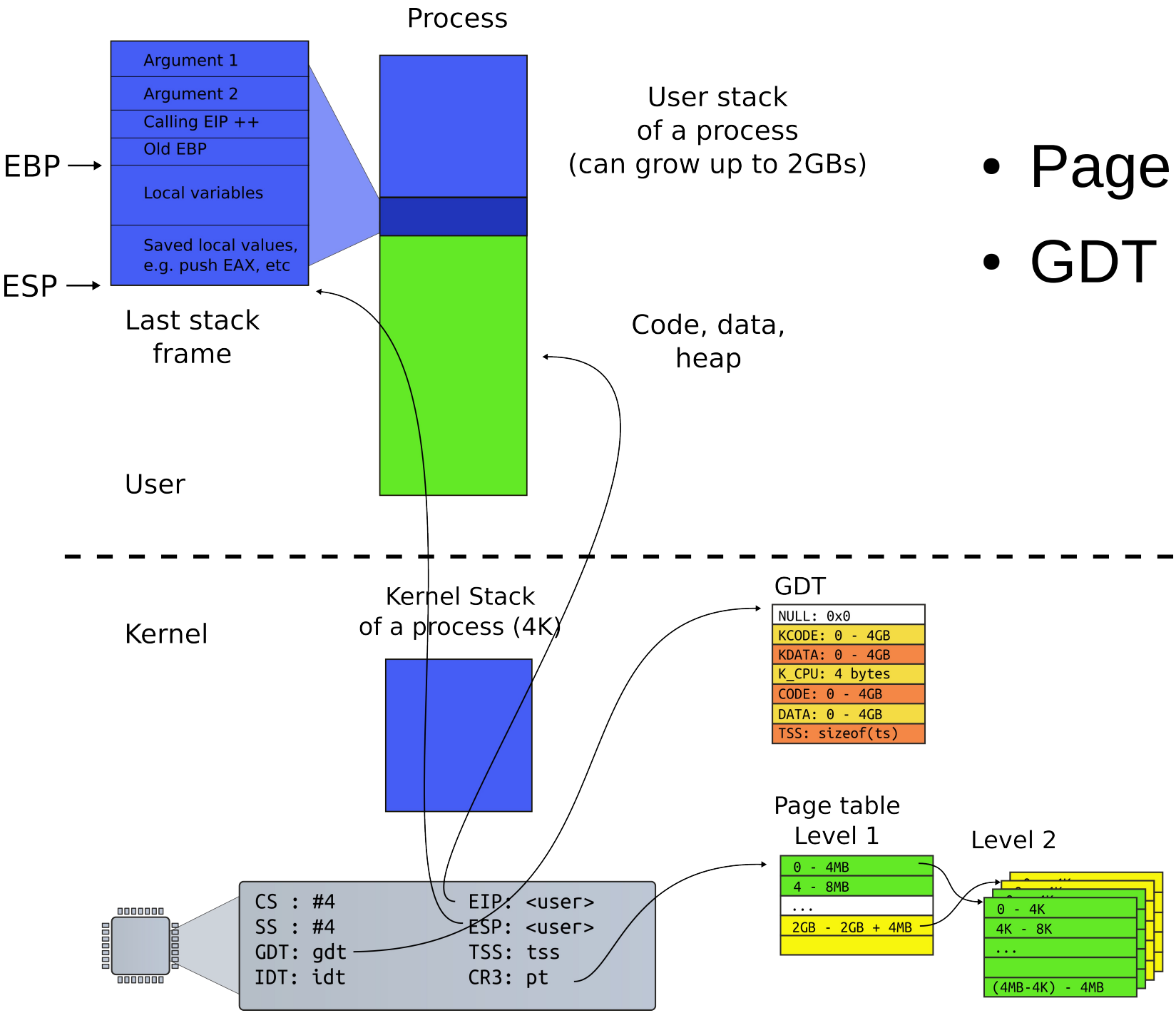




- User mode
- Two stacks
  - Kernel and user
  - Kernel stack is empty



- Page table
- GDT



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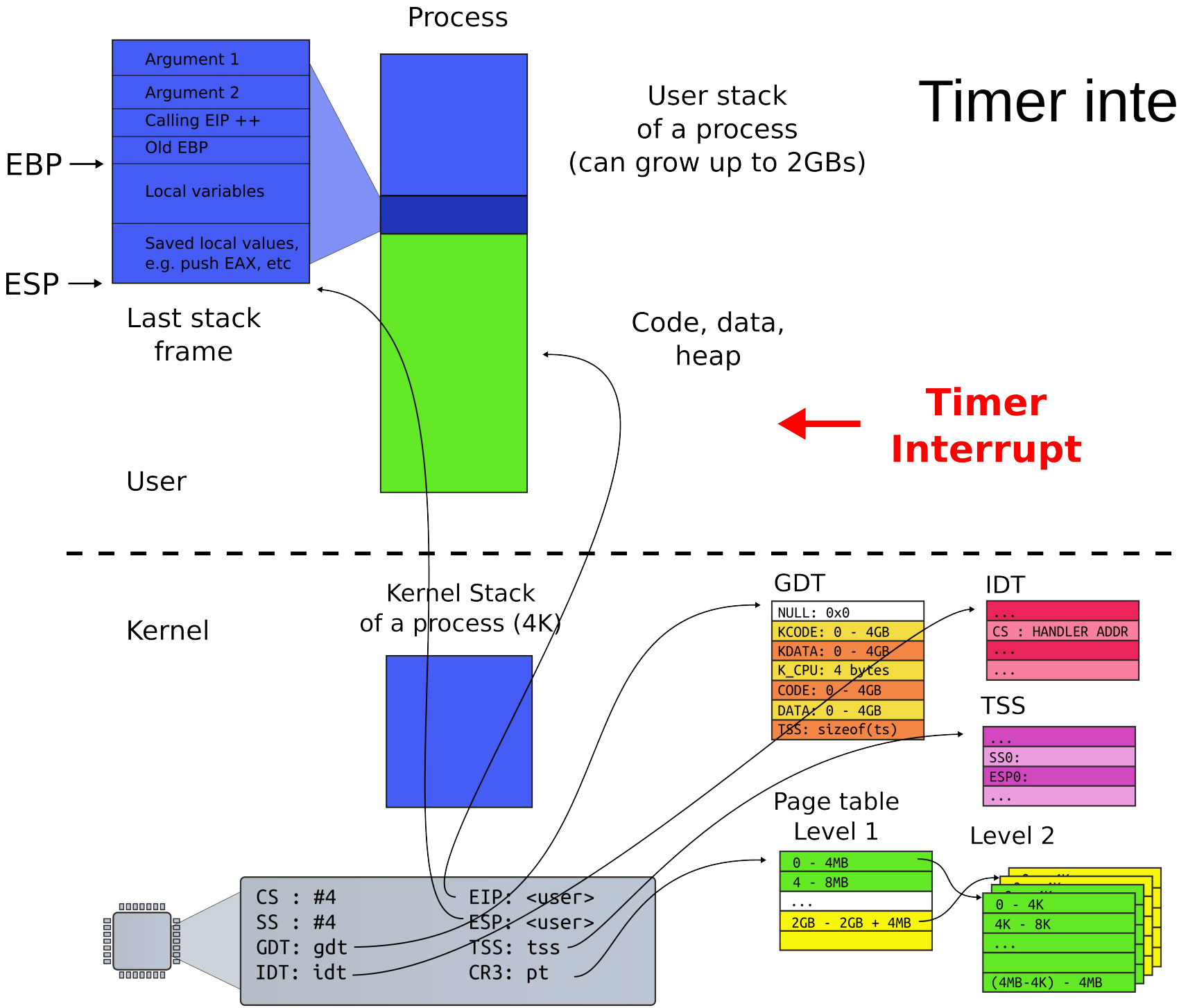
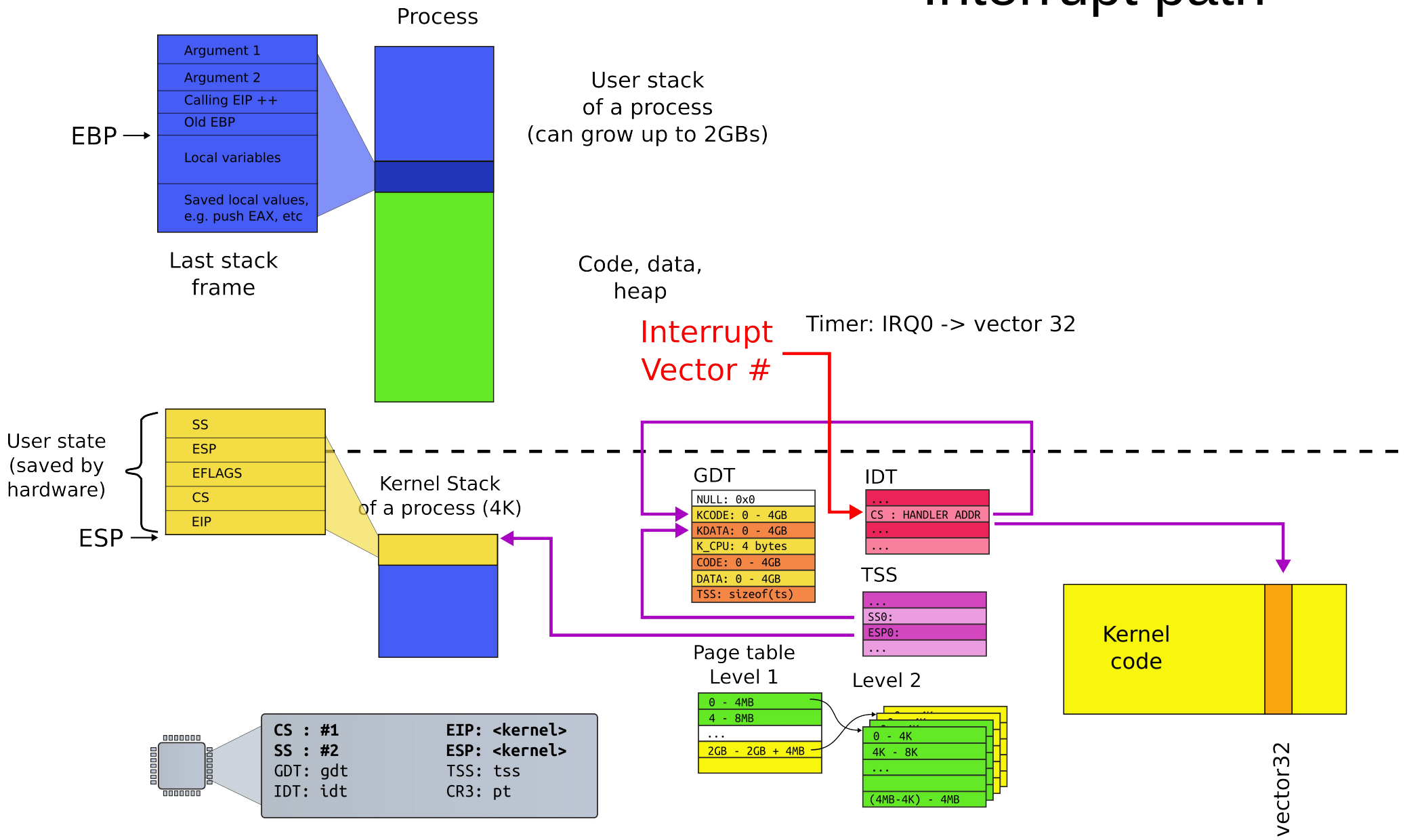

Process
Argument 1
Argument 2
Calling EIP ++
Old EBP
Local variables
Saved local values, e.g. push EAX, etc
EBP
ESP
Last stack frame
User stack of a process (can grow up to 2GBs)
Code, data, heap
User
Timer Interrupt
Kernel
Kernel Stack of a process (4K)
GDT
NULL: 0x0
KCODE: 0 - 4GB
KDATA: 0 - 4GB
K_CPU: 4 bytes
CODE: 0 - 4GB
DATA: 0 - 4GB
TSS: sizeof(ts)
IDT
...
CS : HANDLER ADDR
...
...
TSS
...
SS0:
ESP0:
...
Page table Level 1
0 - 4MB
4 - 8MB
...
2GB - 2GB + 4MB
Level 2
0 - 4K
4K - 8K
...
(4MB-4K) - 4MB
CS : #4
SS : #4
GDT: gdt
IDT: idt
EIP: <user>
ESP: <user>
TSS: tss
CR3: pt

Interrupt path

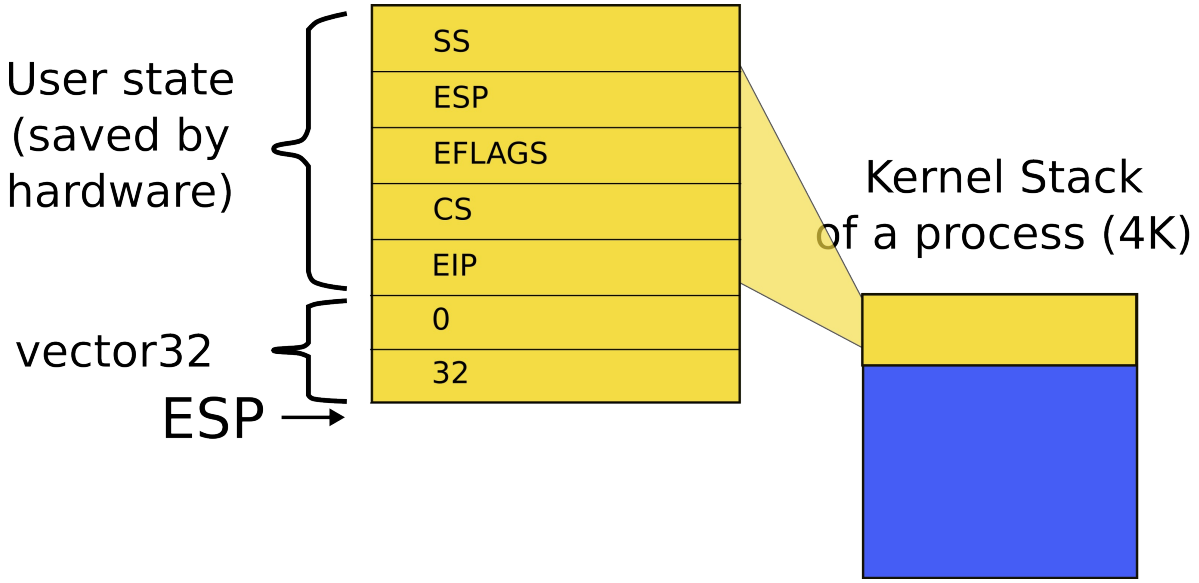


Where does IDT (entry 32) point to?

```
vector32:
  pushl $0     // error code
  pushl $32    // vector #
  jmp alltraps
```

- Automatically generated
- From vectors.pl
  - vector.S

Kernel stack after interrupt

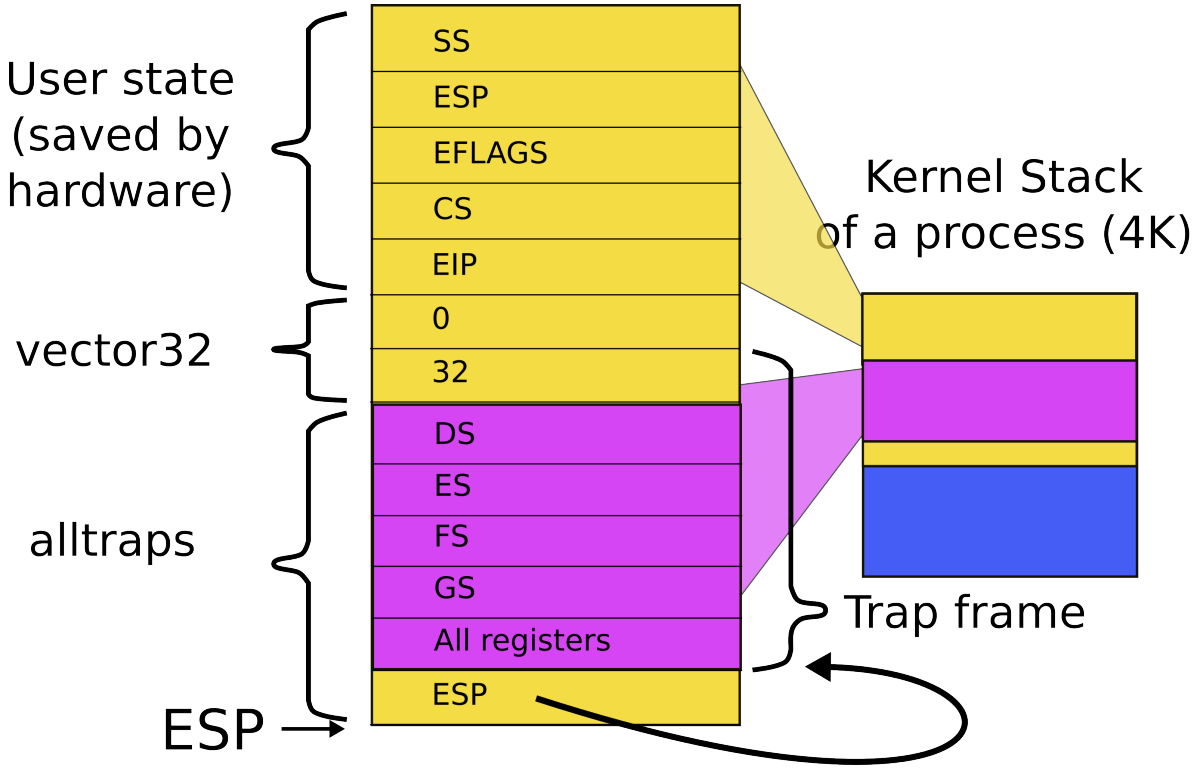


Call stack: vector32()

alltraps()

```
3254 alltraps:
3255 # Build trap frame.
3256 pushl %ds
3257 pushl %es
3258 pushl %fs
3259 pushl %gs
3260 pushal
3261
3262 # Set up data and per-cpu segments.
3263 movw $(SEG_KDATA<<3), %ax
3264 movw %ax, %ds
3265 movw %ax, %es
3266 movw $(SEG_KCPU<<3), %ax
3267 movw %ax, %fs
3268 movw %ax, %gs
3269
3270 # Call trap(tf), where tf=%esp
3271 pushl %esp
3272 call trap
```

Kernel stack after interrupt



Call stack: vector32()
alltraps()

alltraps()

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3268 movw %ax, %gs
3269
3270 # Call trap(tf), where tf=%esp
3271 pushl %esp
3272 call trap
```

trap()

```
3351 trap(struct trapframe *tf)
3352 {
...
3363   switch(tf->trapno){
3364   case T_IRQ0 + IRQ_TIMER:
3365     if(cpu->id == 0){
3366     acquire(&tickslock);
3367     ticks++;
3368     wakeup(&ticks);
3369     release(&tickslock);
3370   }
3372   break;
...
3423   if(proc && proc->state == RUNNING
          && tf->trapno == T_IRQ0+IRQ_TIMER)
3424     yield();
```

Invoke the scheduler

```
2777 yield(void)
2778 {
2779   acquire(&ptable.lock);
2780   proc->state = RUNNABLE;
2781   sched();
2782   release(&ptable.lock);
2783 }
```

Start the context switch

```
2758 sched(void)
2759 {
...
2771   swtch(&proc->context,
                cpu->scheduler);
...
2773 }
```

```
2958 swtch:
2959 movl 4(%esp), %eax
2960 movl 8(%esp), %edx
2961
2962 # Save old callee-save registers
2963 pushl %ebp
2964 pushl %ebx
2965 pushl %esi
2966 pushl %edi
2967
2968 # Switch stacksh
2969 movl %esp, (%eax)
2970 movl %edx, %esp
2971
2972 # Load new callee-save registers
2973 popl %edi
2974 popl %esi
2975 popl %ebx
2976 popl %ebp
2977 ret
```

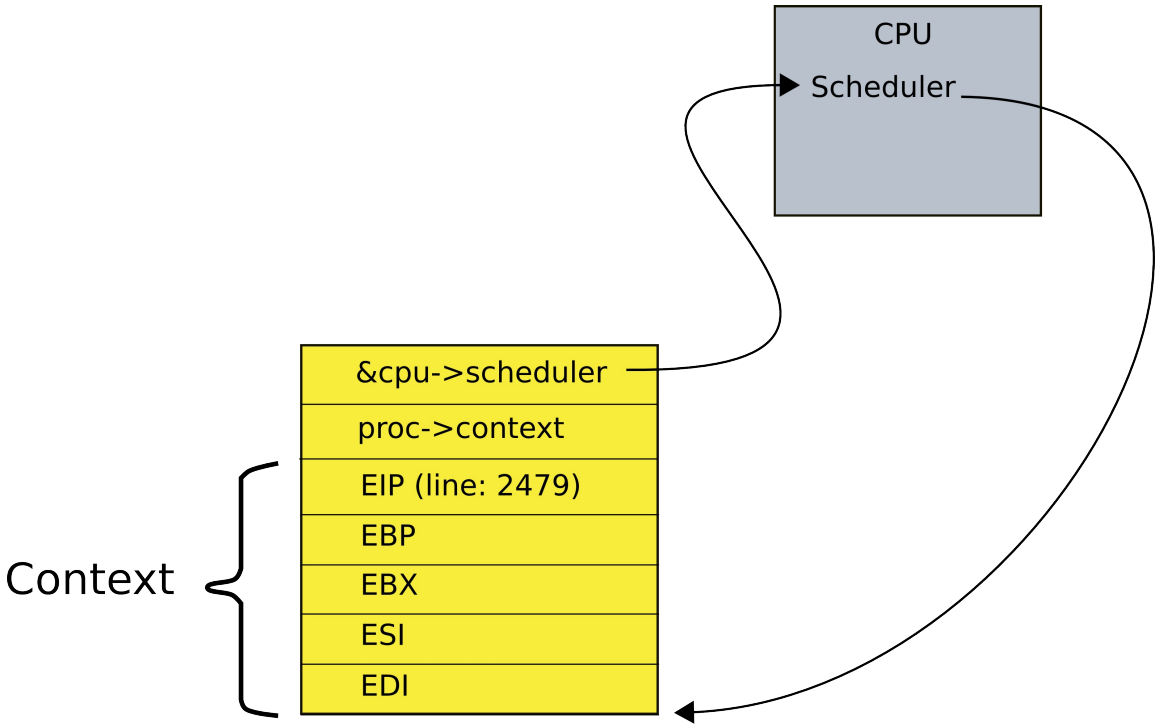
swtch()

```
void swtch(struct context **old,
           struct context *new);
```

- First argument:
  - A pointer to a pointer to a context
  - That we're going to save
- Second argument:
  - A pointer to a context
  - We're going to restore

Context data structure

```
2093 struct context {
2094   uint edi;
2095   uint esi;
2096   uint ebx;
2097   uint ebp;
2098   uint eip;
2099 };
```



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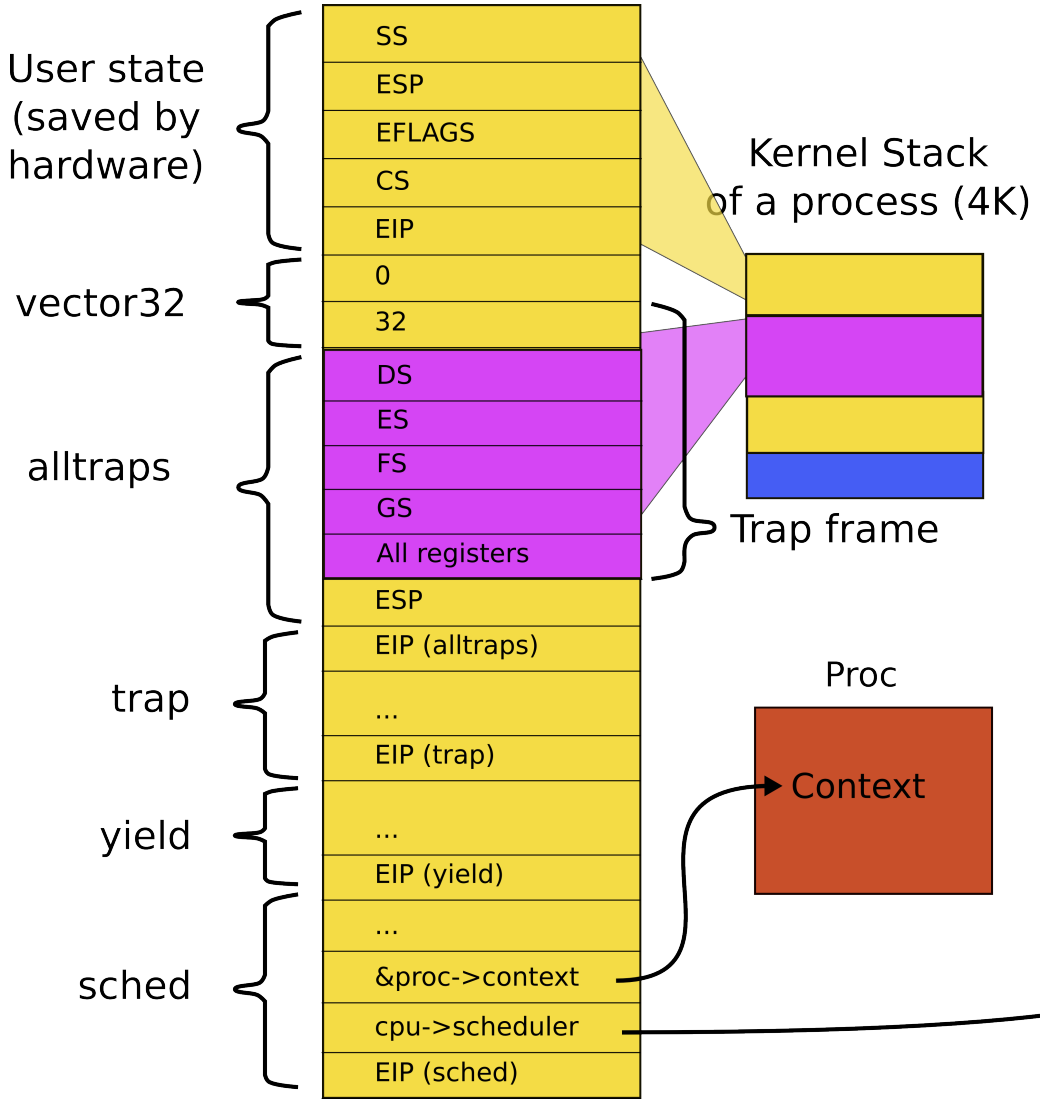
2975 popl %ebx
2976 popl %ebp
2977 ret
```

swtch()

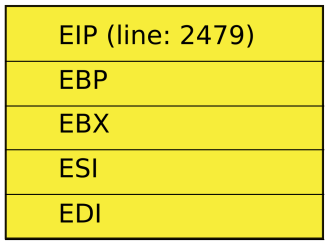
```
2093 struct context {
2094   uint edi;
2095   uint esi;
2096   uint ebx;
2097   uint ebp;
2098   uint eip;
2099 };
```

Stack inside swtch() and its two arguments (passed on the stack)

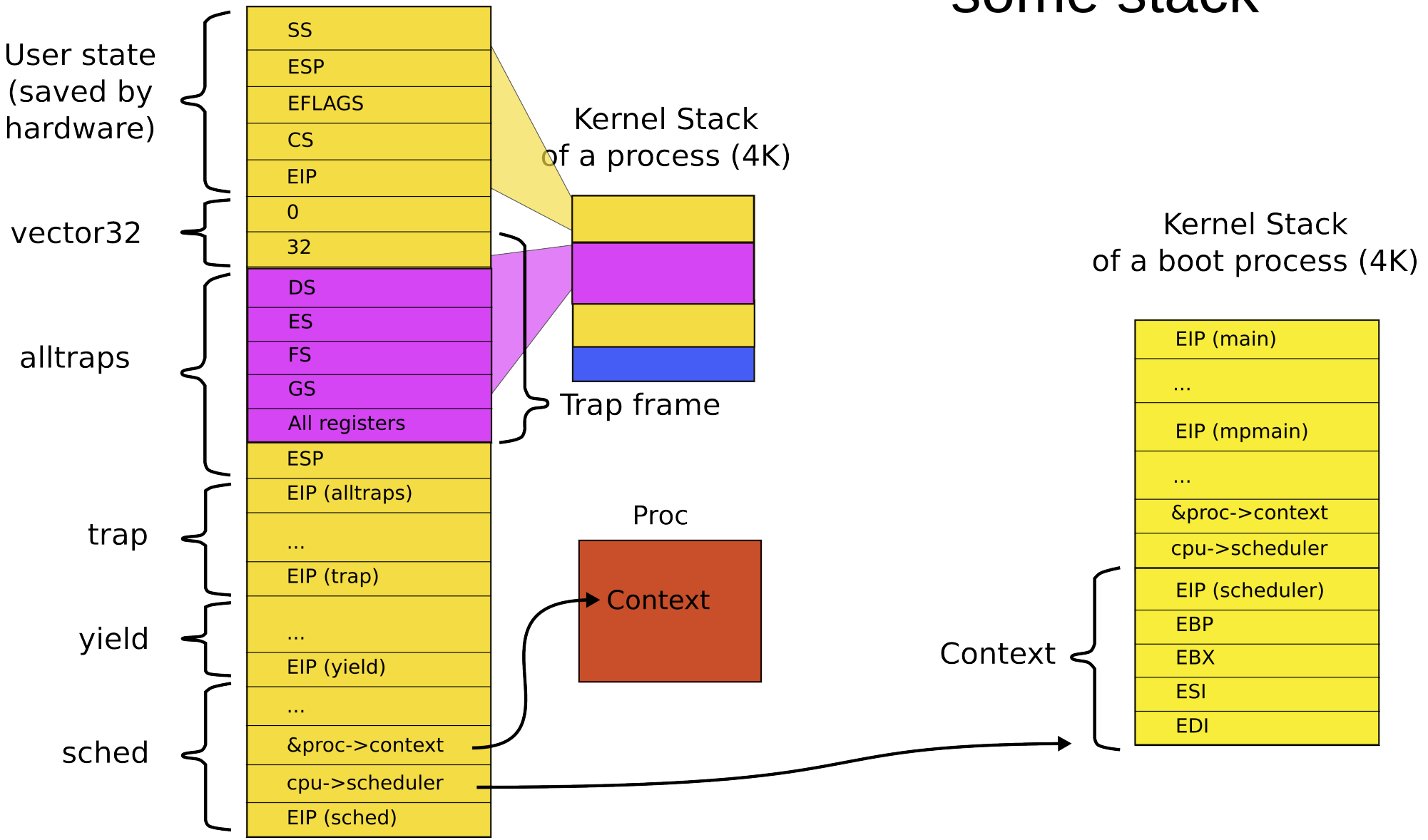


Call stack:
vector32()
alltraps()
trap()
yield()
sched()
switch(&proc->context,
cpu->scheduler)

Context



Context is always top of some stack



Context is always top of some stack, why?

- Remember how we initialized each CPU last time?

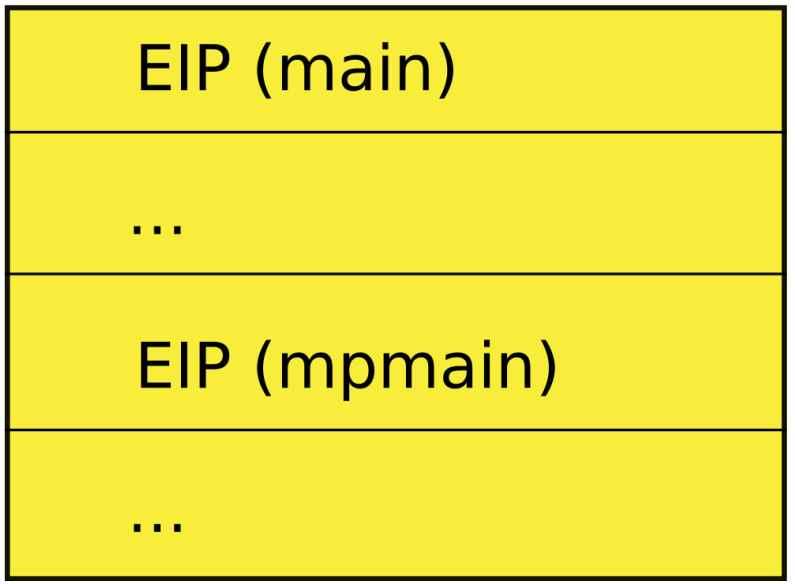
```
1251 static void
1252 mpenter(void)
1253 {
1254   switchkvm();
1255   seginit();
1256   lapicinit();
1257   mpmain();
1258 }
```

```
1260 // Common CPU setup code.
1261 static void
1262 mpmain(void)
1263 {
1264   cprintf("cpu%d: starting\n", cpu->id);
1265   idtinit(); // load idt register
1266   xchg(&cpu->started, 1);
1267   scheduler(); // start running
processes
1268 }
```

We ended boot by starting a scheduler

Remember the stack of the boot process?

Kernel Stack
of a boot process (4K)



How does scheduler start?

```
2458 scheduler(void)
2459 {
2462   for(;;){
2468     for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
2469       if(p->state != RUNNABLE)
2470         continue;
2475       proc = p;
2476       switchuvm(p);
2477       p->state = RUNNING;
2478       swtch(&cpu->scheduler, proc->context);
2479       switchkvm();
2483       proc = 0;
2484     }
2487   }
2488 }
```

- Chooses next process to run
- Switches to it
  - From the current context

- So when the scheduler context switched the first time

```
2478 swtch(&cpu->scheduler,
           proc->context);
```

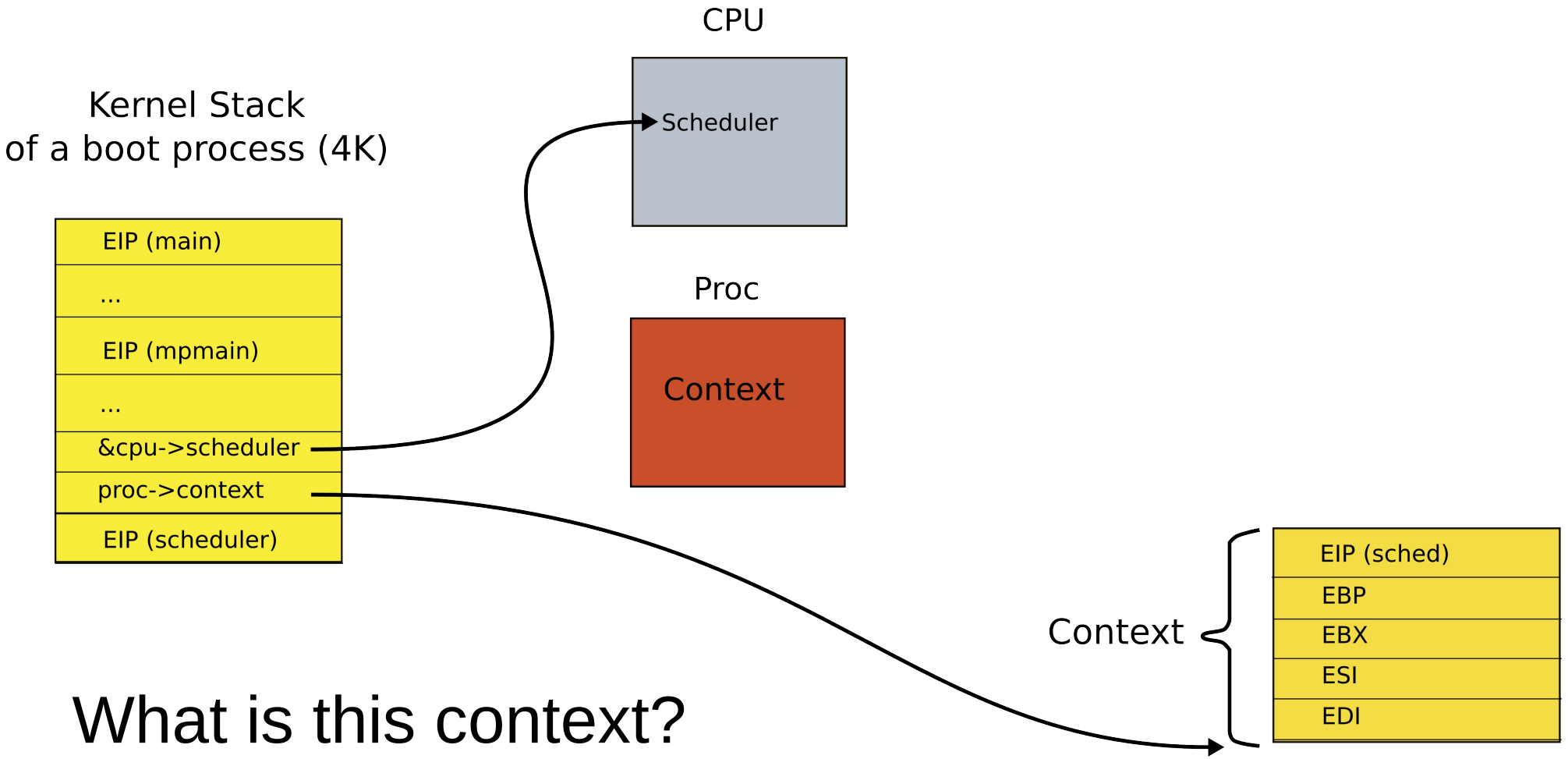
- It saved its own context

```
&cpu->scheduler
```

- And restored a context of the first process

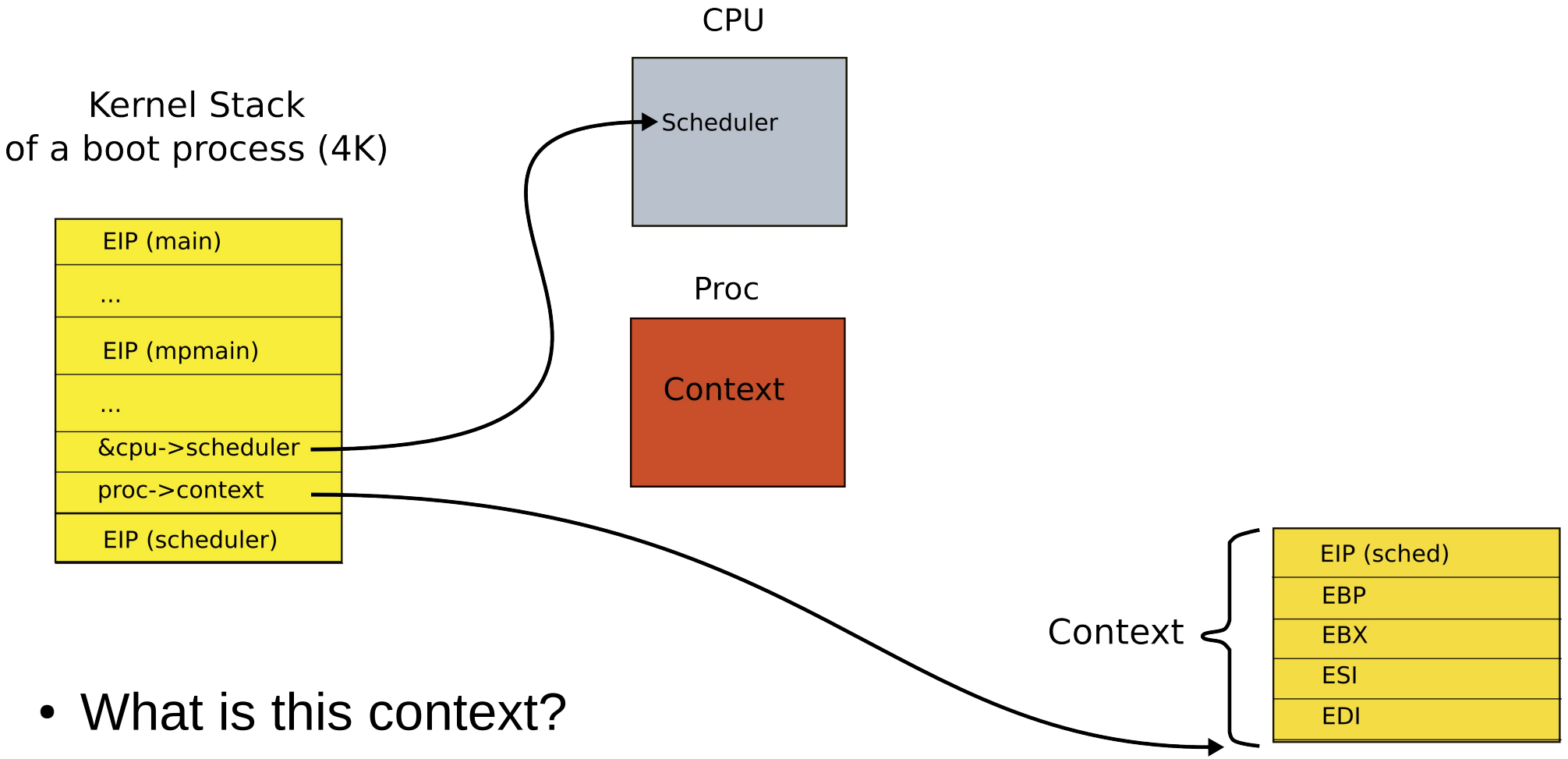
```
proc->context
```

This is how stack looked like when scheduler() invoked swtch() for the first time



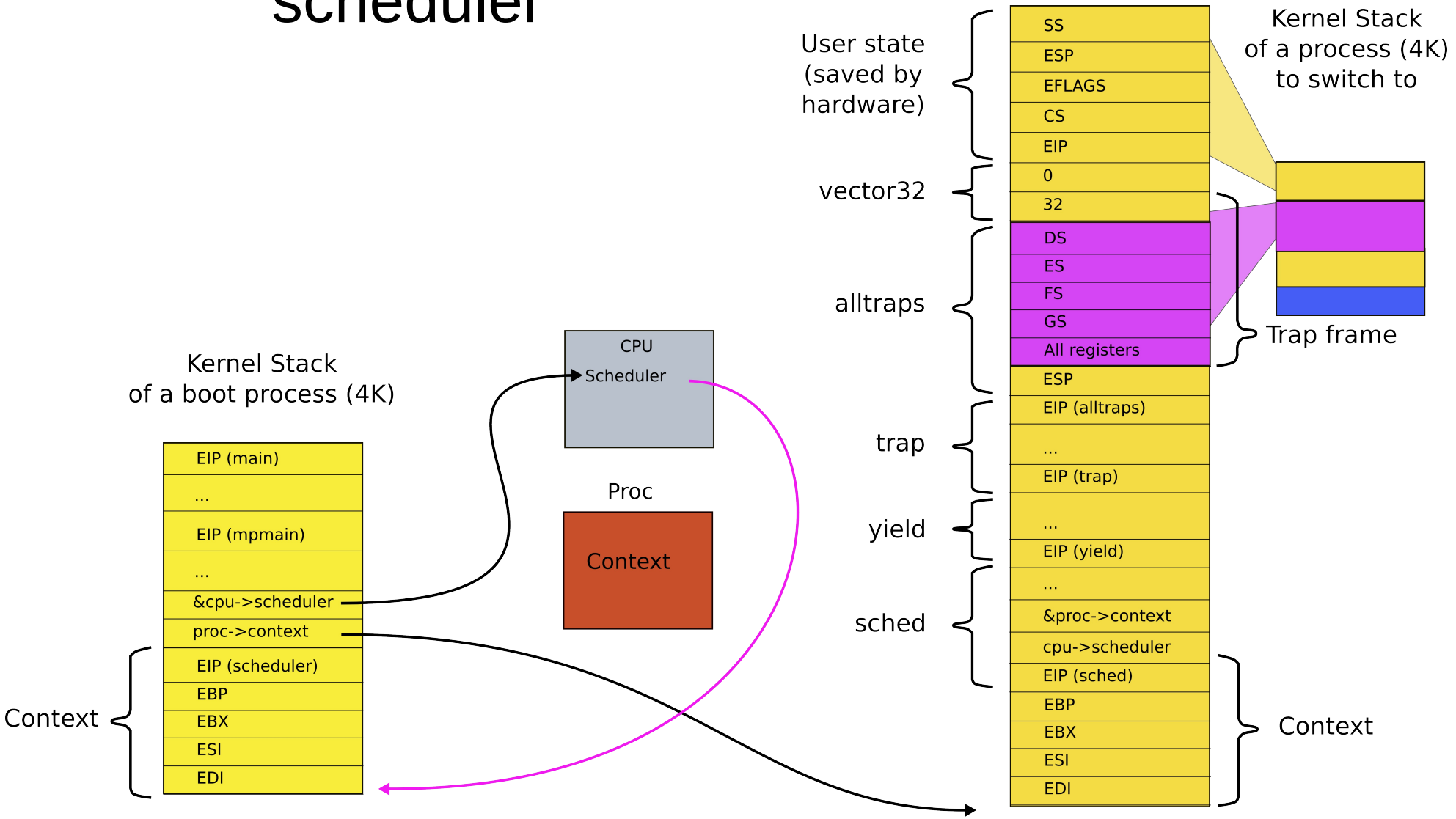
What is this context?

This is how stack looked like when scheduler() invoked swtch() for the first time



- What is this context?
- It's the context of the first process scheduler decides to run

Save context of the scheduler



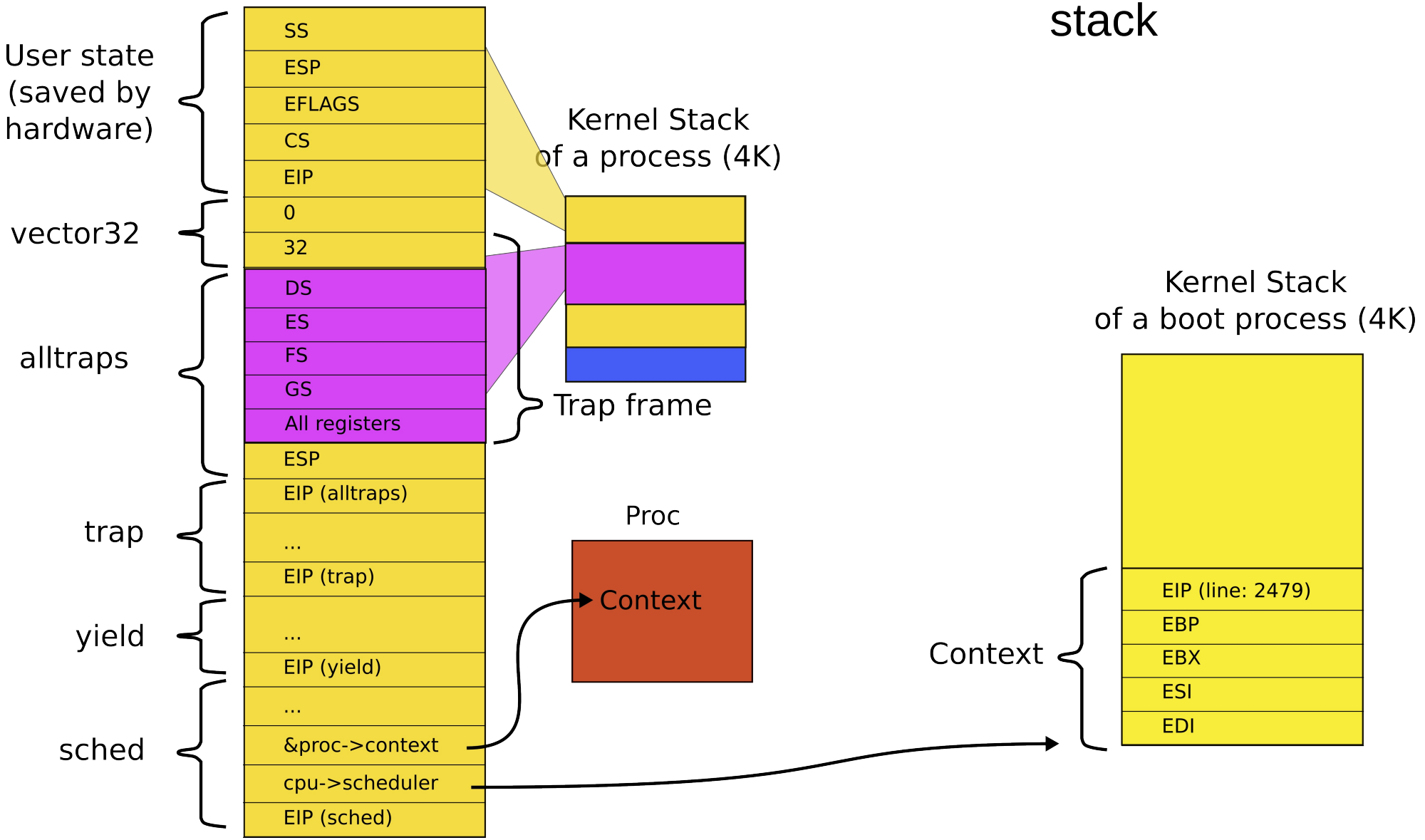
swtch()

```
2958 swtch:
2959 movl 4(%esp), %eax     // struct context **old
2960 movl 8(%esp), %edx     // struct context *new
2961
2962 # Save old callee-save registers
2963 pushl %ebp
2964 pushl %ebx
2965 pushl %esi
2966 pushl %edi
2967
2968 # Switch stacksh
2969 movl %esp, (%eax)  // load current context (top of current stack) into
                       //  the memory location pointed by *old
2970 movl %edx, %esp    // set stack to be equal to *new (the top of the new context)
2971
2972 # Load new callee-save registers
2973 popl %edi
2974 popl %esi
2975 popl %ebx
2976 popl %ebp
2977 ret
```

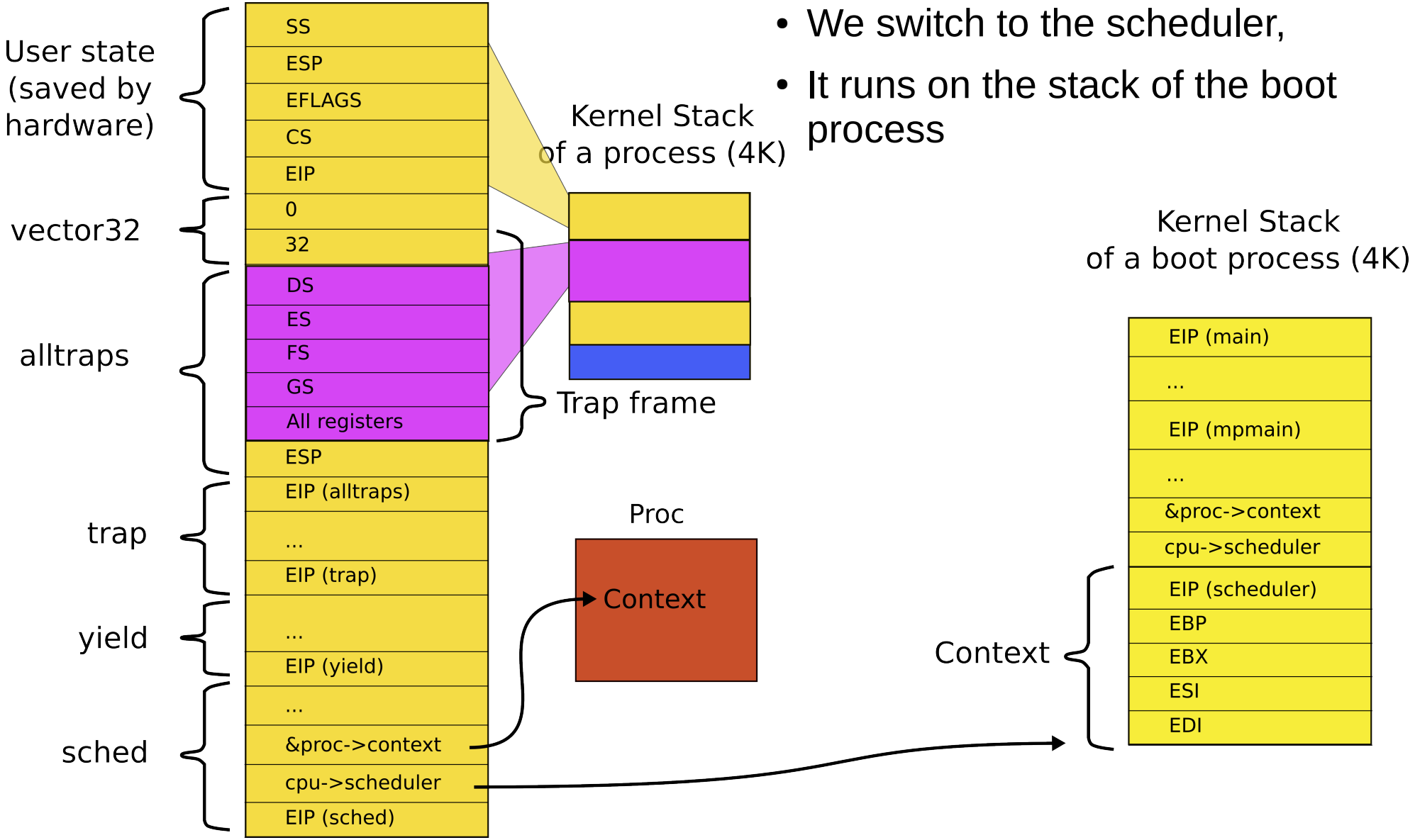
This is why the context is the top of some stack

- Initially it was the stack of mpenter()
  - On which scheduler started
- Then first process...
  - Then scheduler again
  - And the next process...

Back to main context switch: so context is always top of some stack



- Currently the ***new** context is the stack of the scheduler
- We switch to the scheduler,
- It runs on the stack of the boot process



swtch()

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2973 popl %edi
2974 popl %esi
2975 popl %ebx
2976 popl %ebp
2977 ret
```

And now: exit from swtch()

Where does this swtch() return?

Where does this swtch() return?

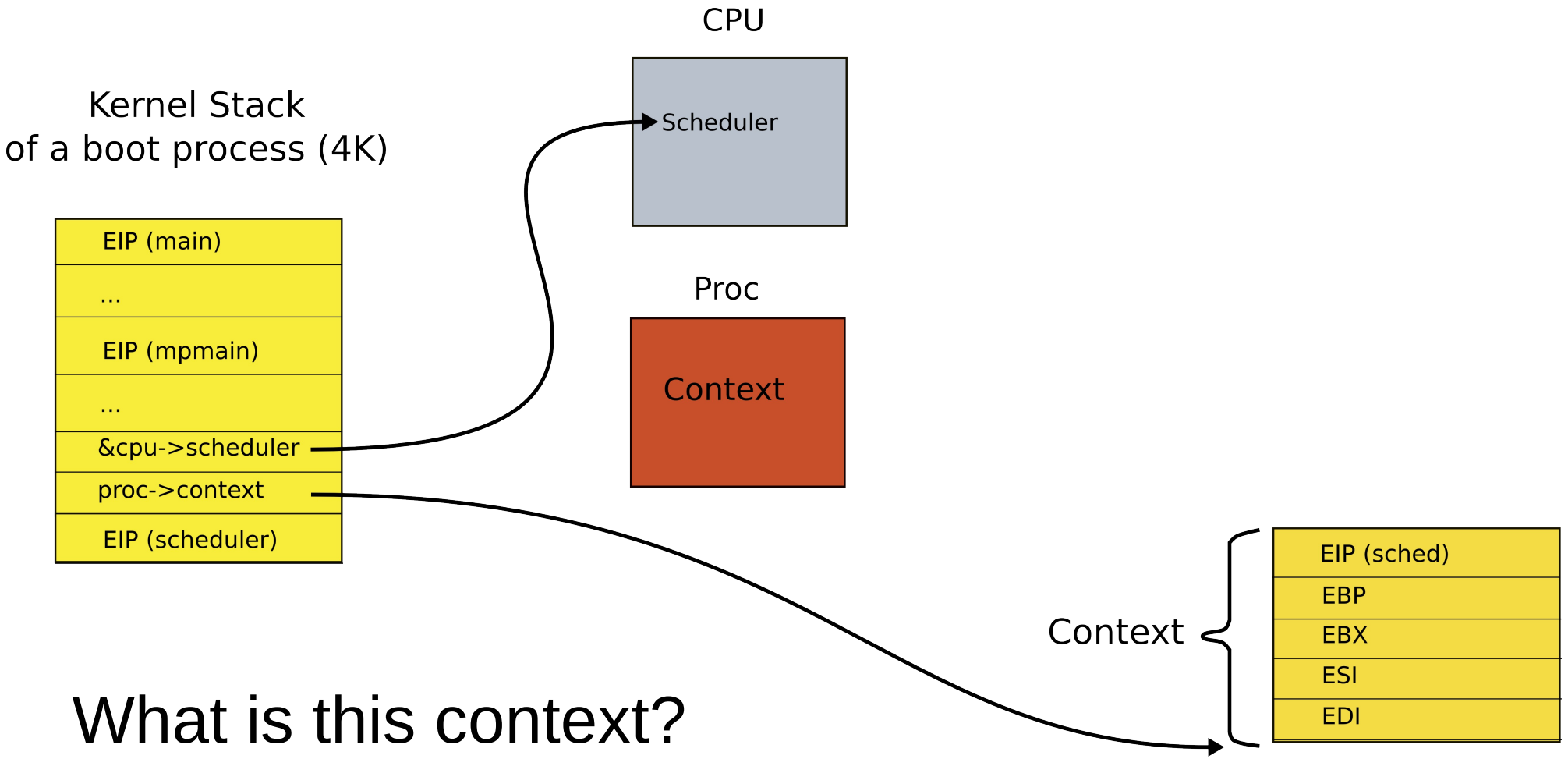
- Scheduler
- After all remember
  - We started with timer interrupt
  - Entered the kernel
  - Entered schedule()
  - Entered switch
- And are currently on our way from the process into the scheduler

What does scheduler do?

```
2458 scheduler(void)
2459 {
2462   for(;;){
2468     for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
2469       if(p->state != RUNNABLE)
2470         continue;
2475       proc = p;
2476       switchuvm(p);
2477       p->state = RUNNING;
2478       swtch(&cpu->scheduler, proc->context);
2479       switchkvm();
2483       proc = 0;
2484     }
2487   }
2488 }
```

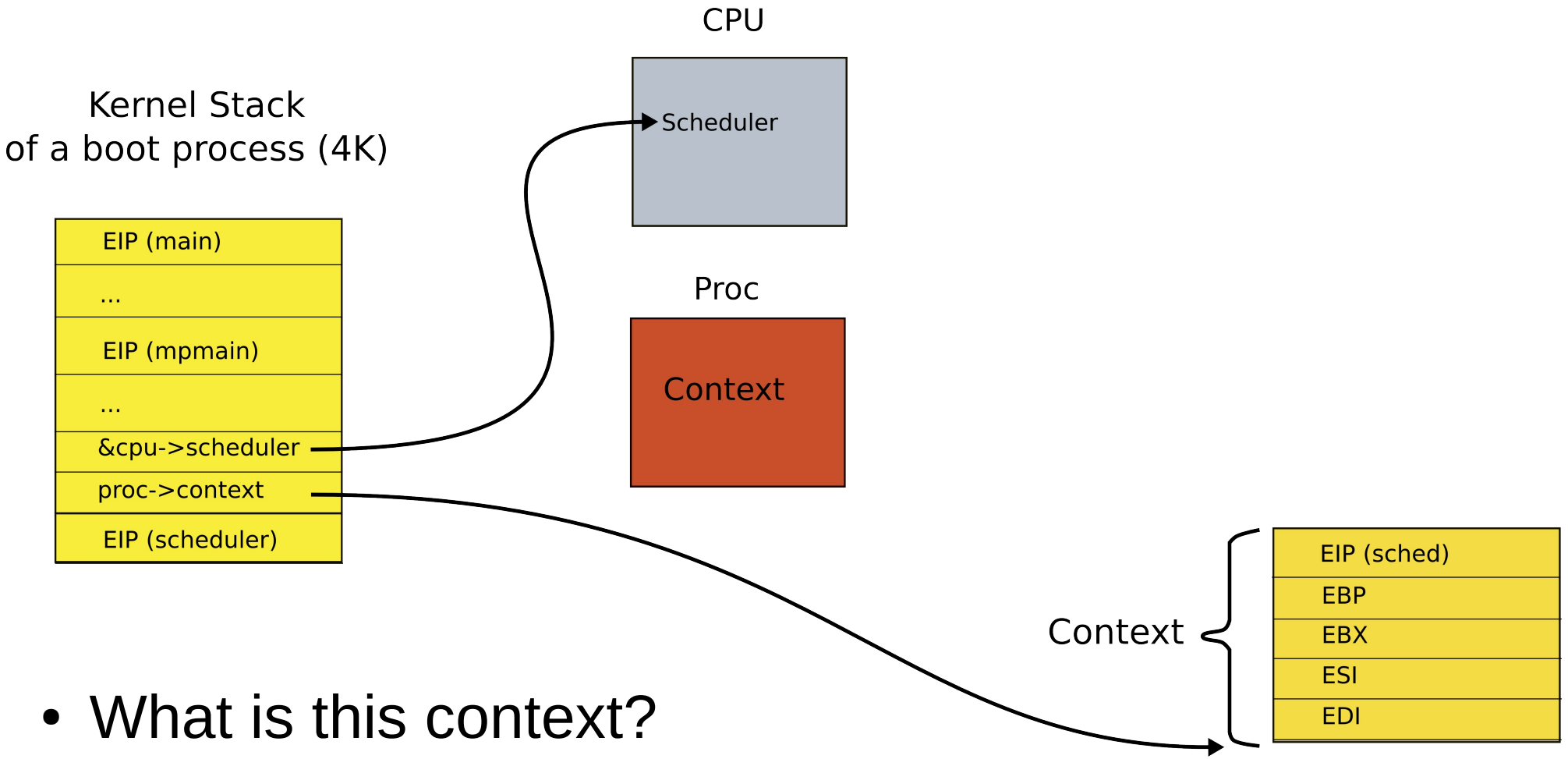
- Chooses next process to run
- Switches to it

What does stack look like when scheduler() invokes swtch()?



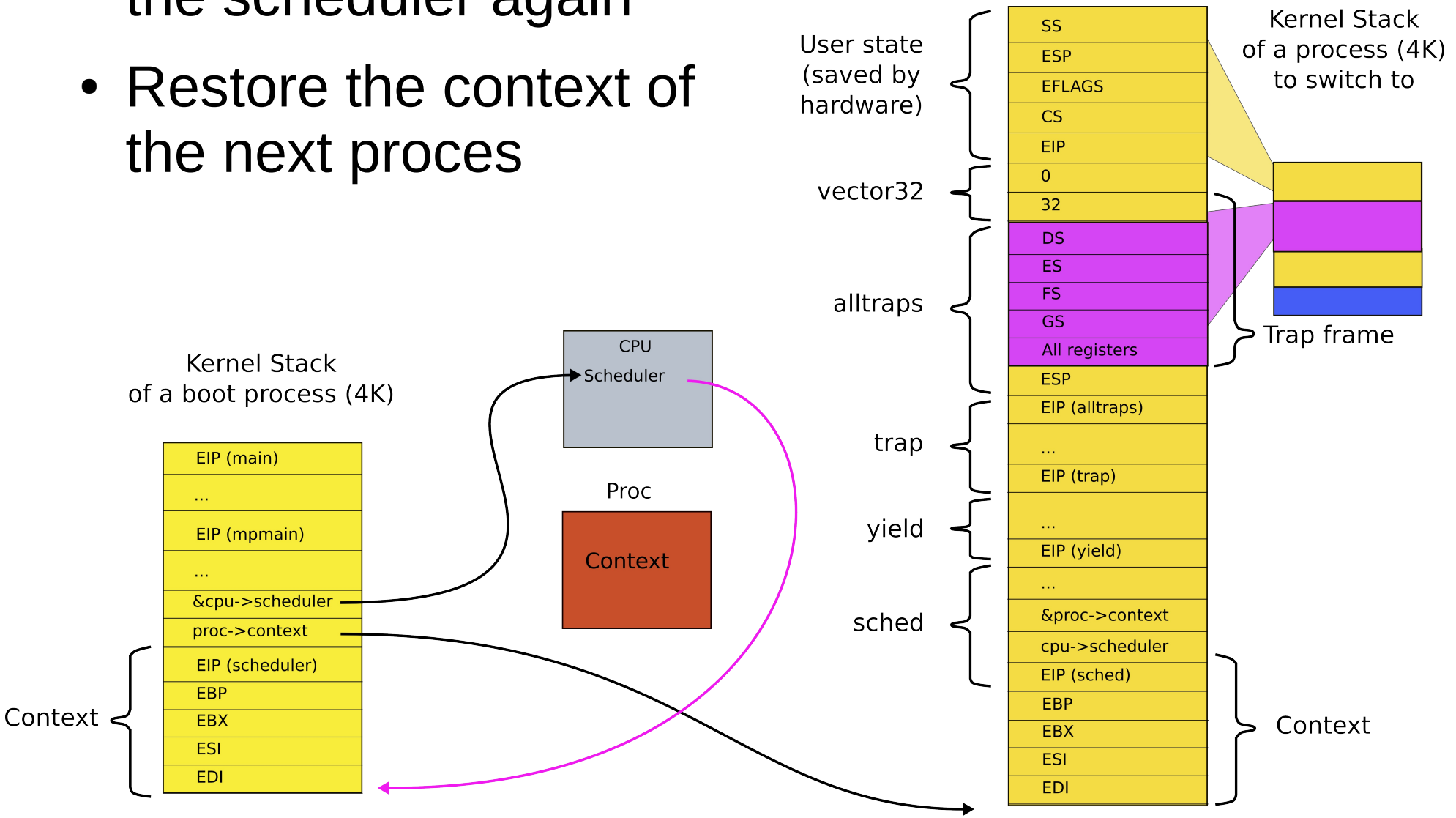
What is this context?

What does stack look like when scheduler() invokes swtch()?



- What is this context?
  - Right the context of the next process to run

- We save the context of the scheduler again
- Restore the context of the next proces



- Remember, from inside the scheduler we invoked swtch() as

```
2478 swtch(&cpu->scheduler,
             proc->context);
```

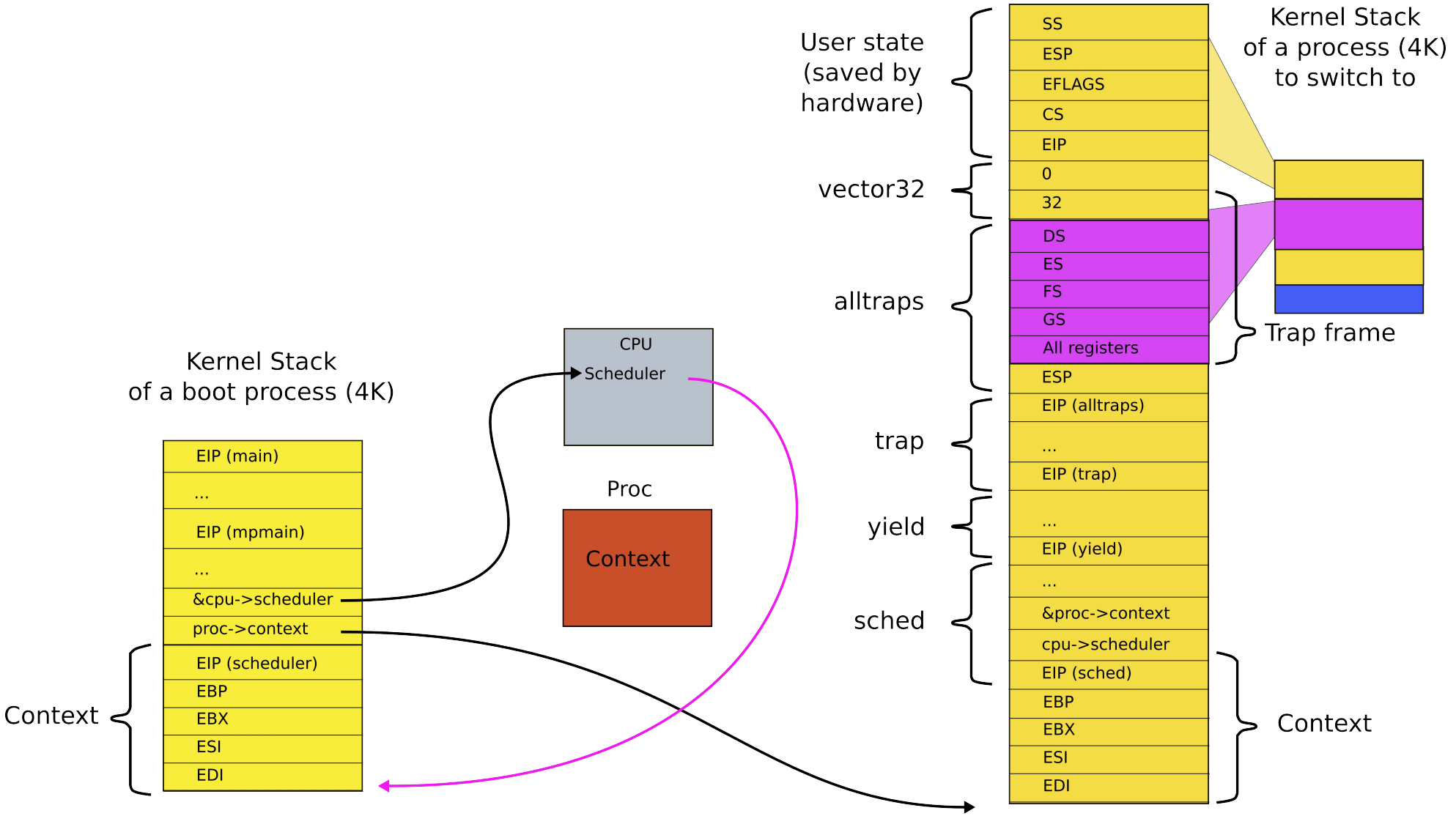
- Hence, we save context of the scheduler into

```
&cpu->scheduler
```

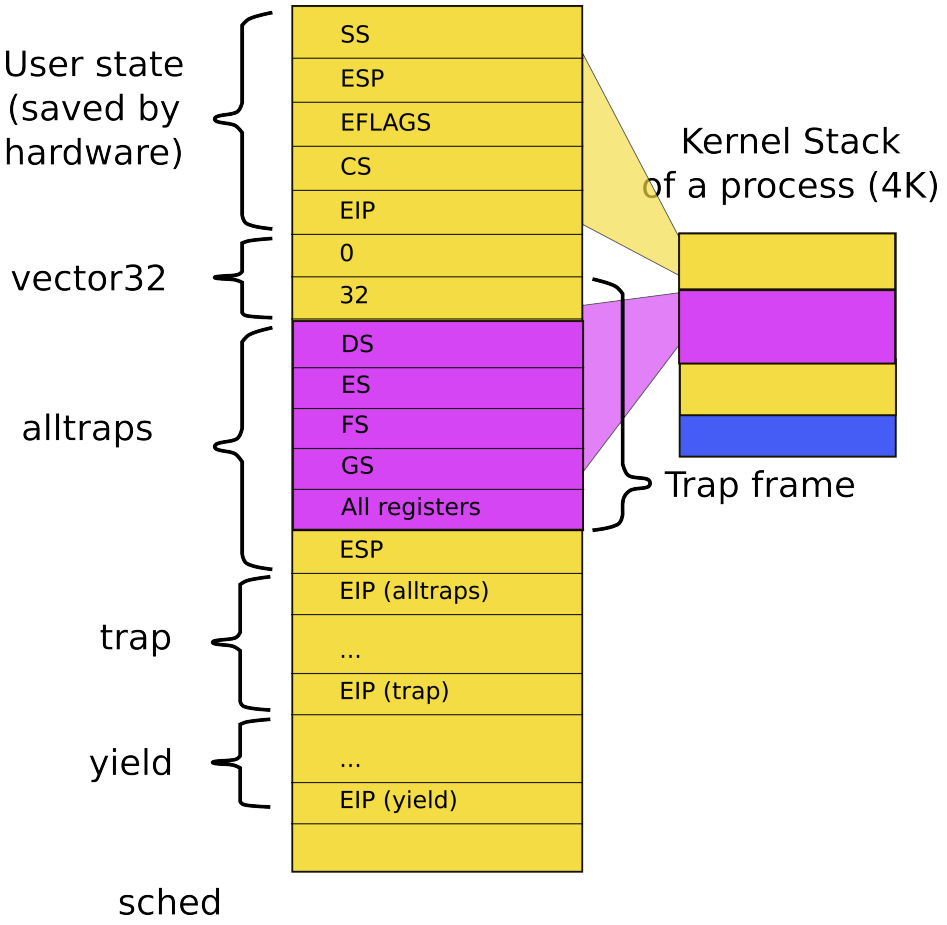
- And restore

```
proc->context
```

Stacks and context inside swtch()



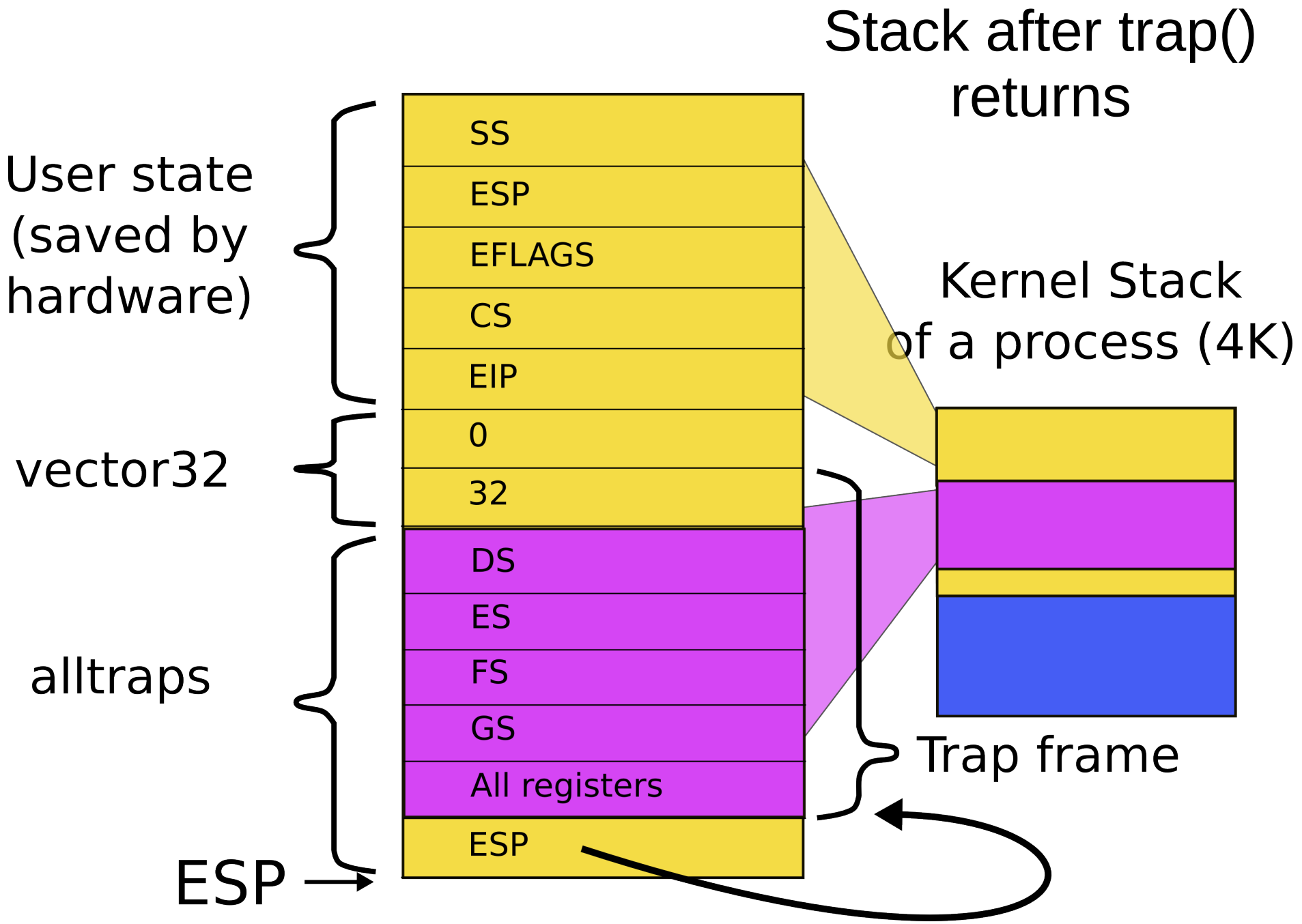
Exiting back to user-level



- Stack inside sched()
  - Normal returns until back to alltrap()

alltraps(): Exiting back into user level process

```
3004 alltraps:
...
3020 # Call trap(tf), where tf=%esp
3021 pushl %esp
3022 call trap
3023 addl $4, %esp
3024
3025 # Return falls through to trapret...
3026 .globl trapret
3027 trapret:
3028 popal
3029 popl %gs
3030 popl %fs
3031 popl %es
3032 popl %ds
3033 addl $0x8, %esp # trapno and errcode
3034 iret
```


Stack after trap() returns
User state (saved by hardware)
vector32
alltraps
ESP
SS
ESP
EFLAGS
CS
EIP
0
32
DS
ES
FS
GS
All registers
ESP
Kernel Stack of a process (4K)
Trap frame

```
3004 alltraps:
...
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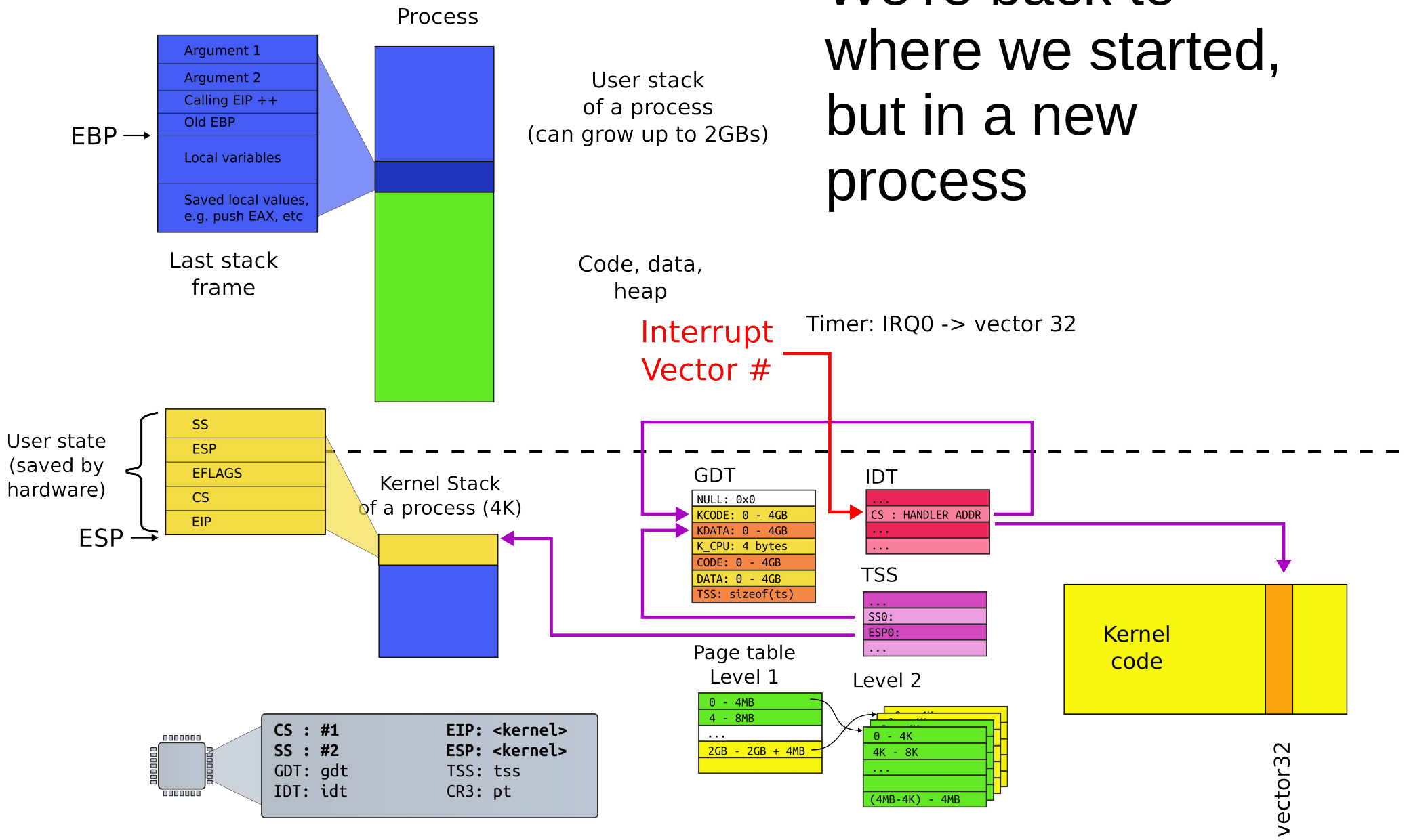
3030 popl %fs
3031 popl %es
3032 popl %ds
3033 addl $0x8, %esp # trapno and errcode
3034 iret
```

alltraps(): exiting

- Restore all registers
- Exit into user
  - iret

We're back to where we started, but in a new process



Summary

- We switch between processes now

Thank you