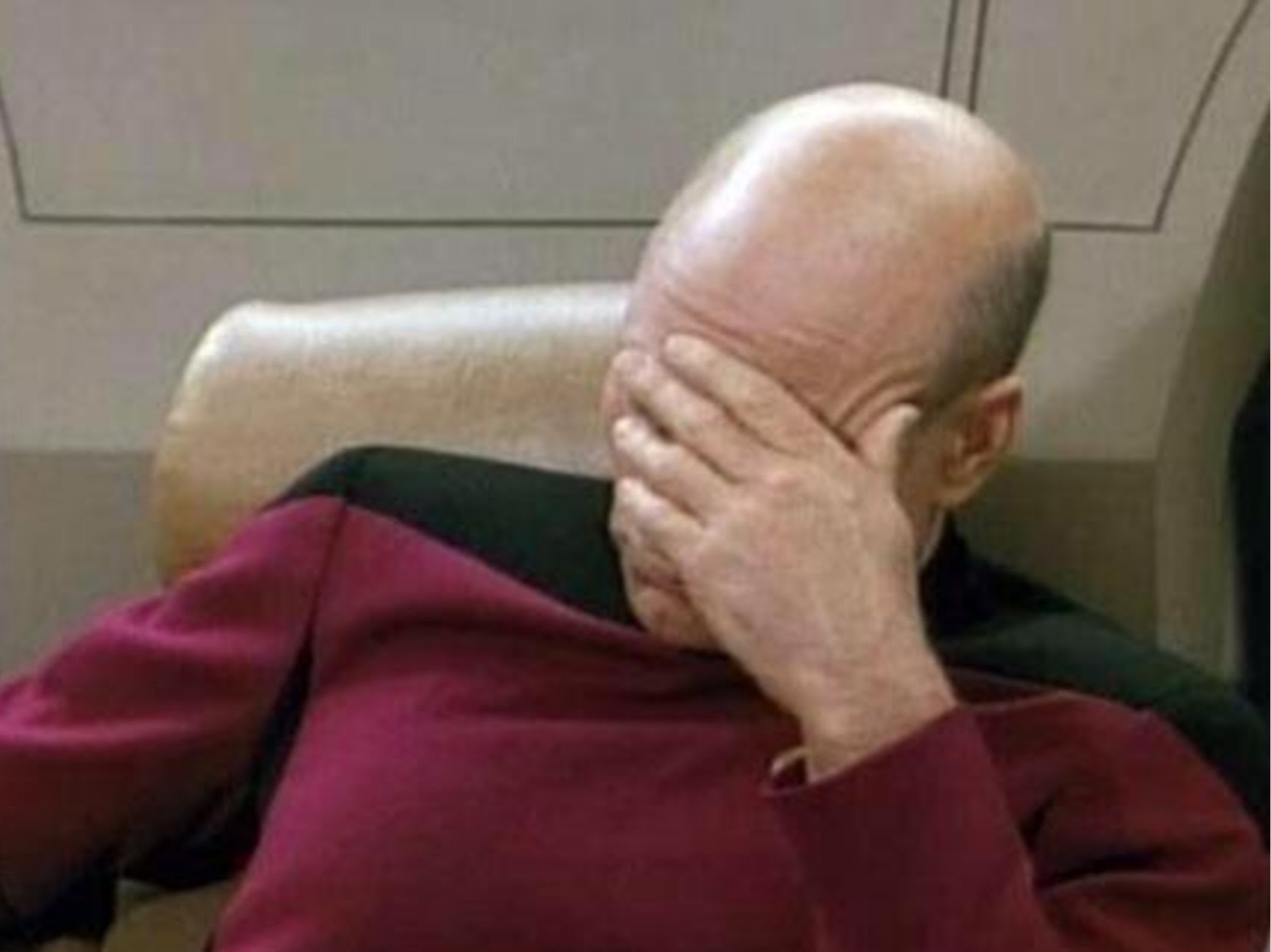
ICS143A: Principles of Operating Systems

Lecture 14: System calls & the first process (again!)

Anton Burtsev
February, 2017

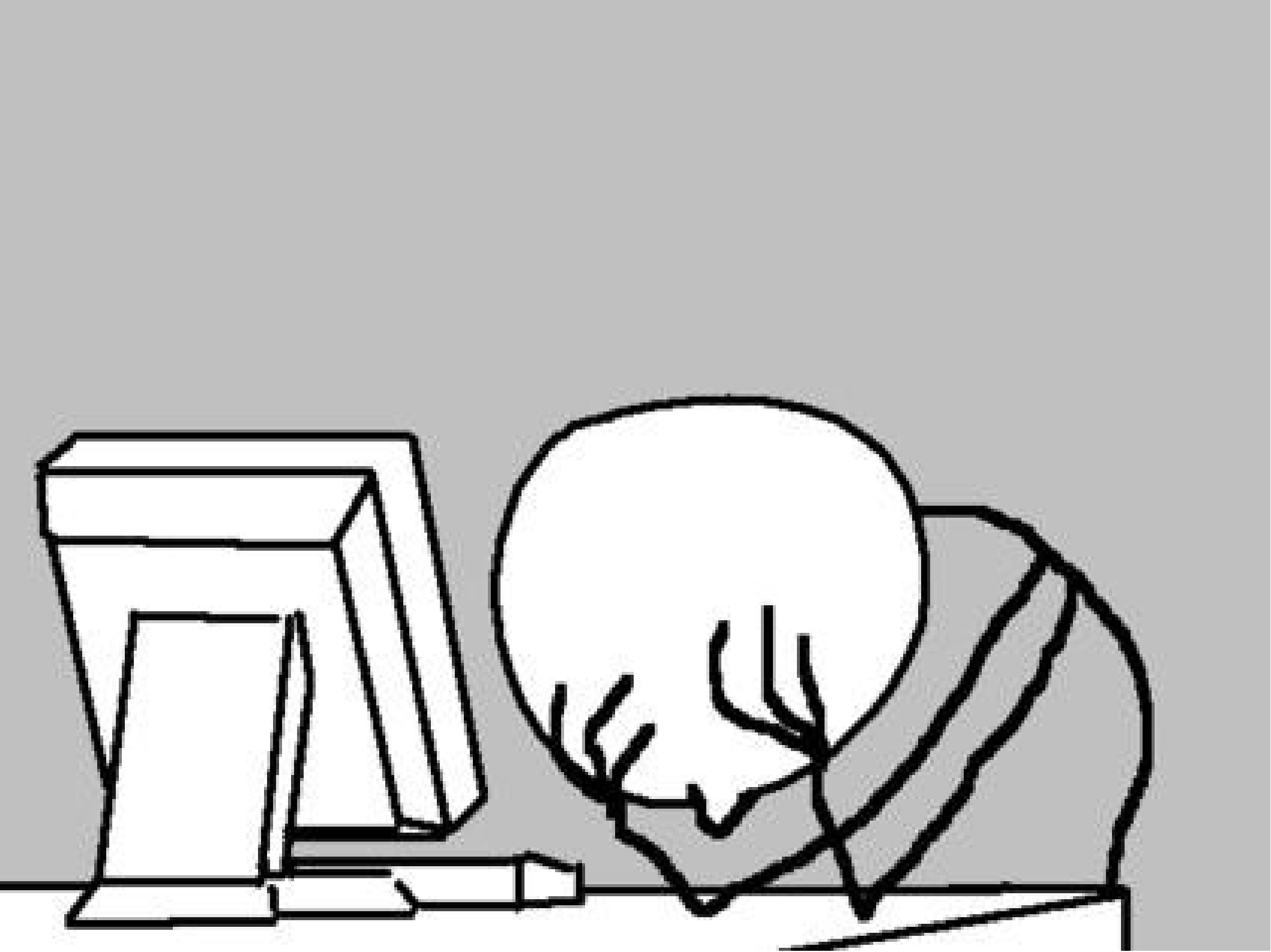
12 balls

You have 12 identical-looking balls. One of these balls has a different weight from all the others. You also have a two-pan balance for comparing weights. Using the balance in the smallest number of times possible, determine which ball has the unique weight, and also determine whether it is heavier or lighter than the others. **(Hint: 3 measurements)**



12 balls

...One of the most beautiful riddles...

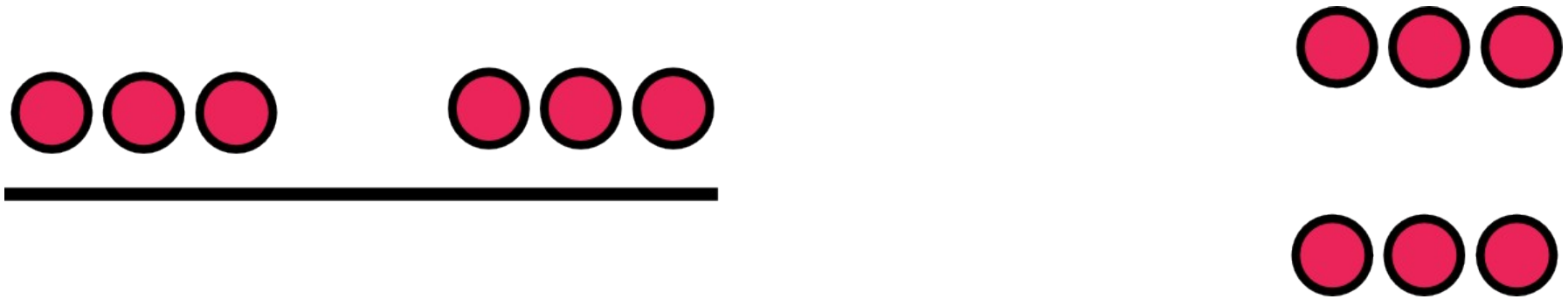


But ok... how to solve it?

Measurement #1

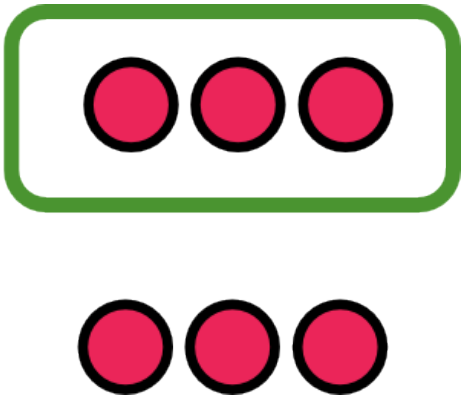
- We know symmetry is good
  - Middle of array... fast search

Measurement #2



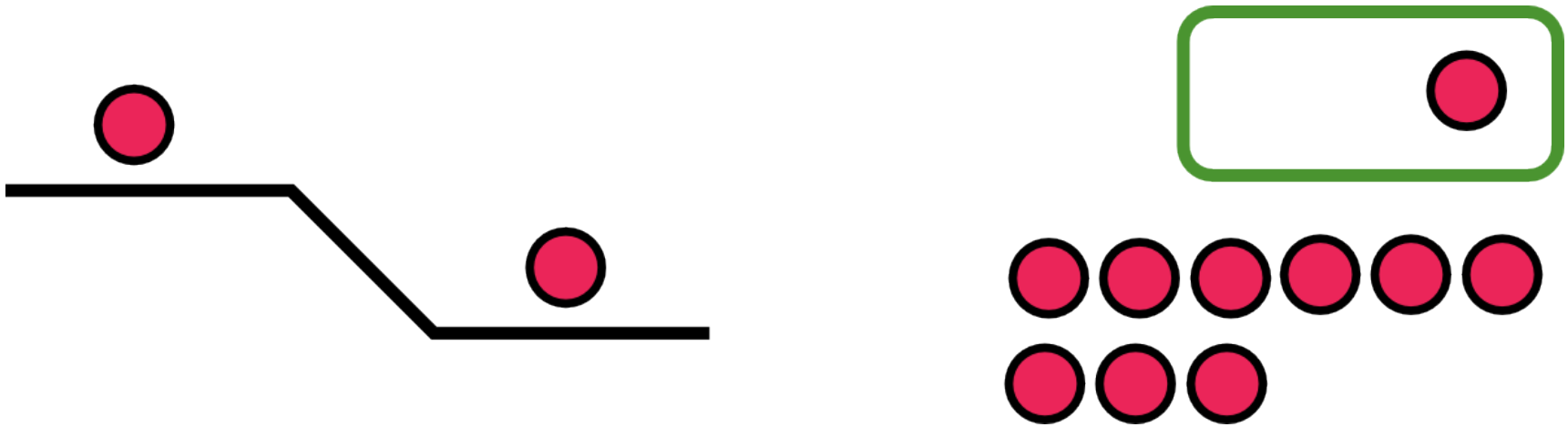
Measurement #2

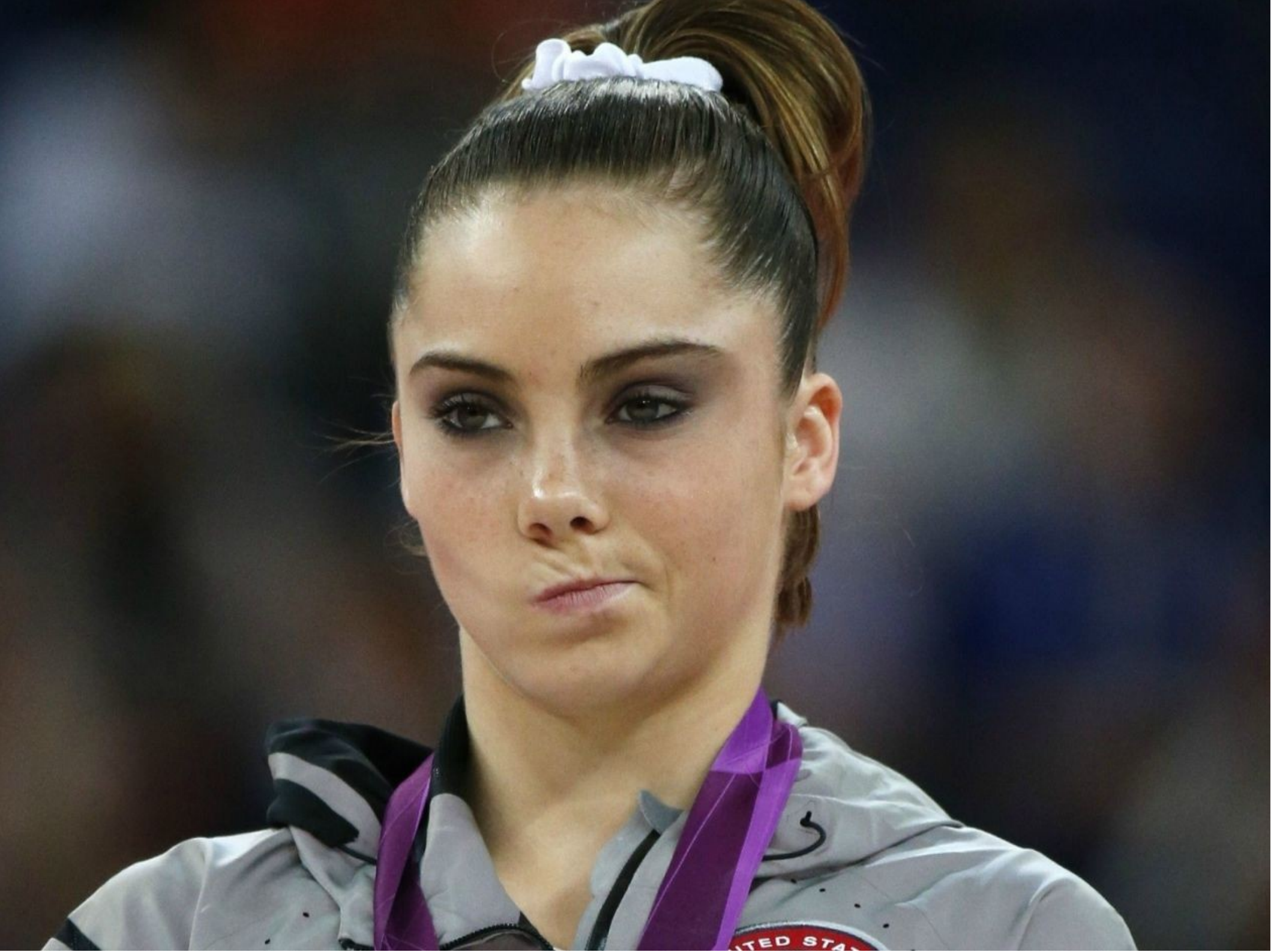
- It's one of these three



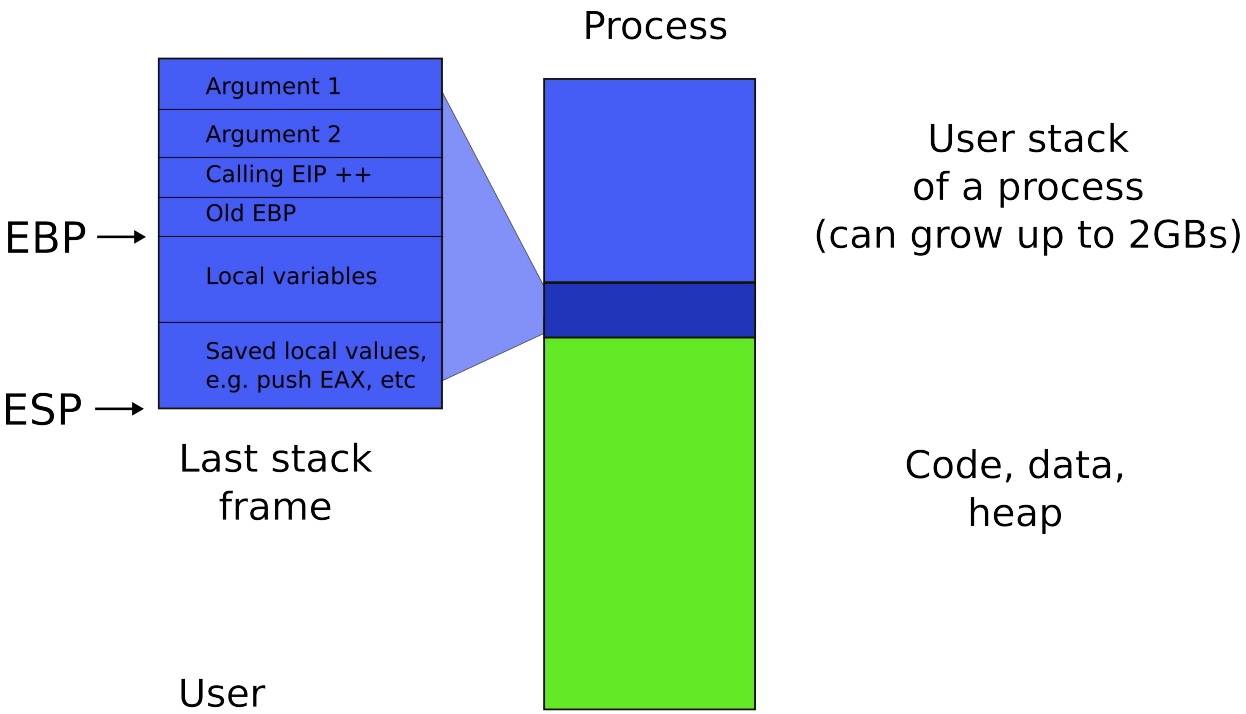
Measurement #3

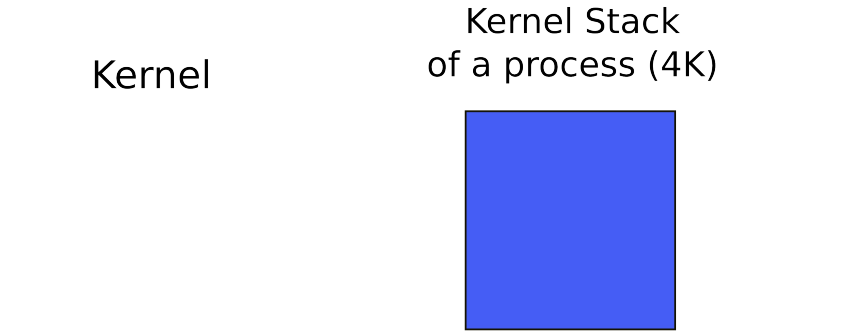
- It's one of these two... but which?

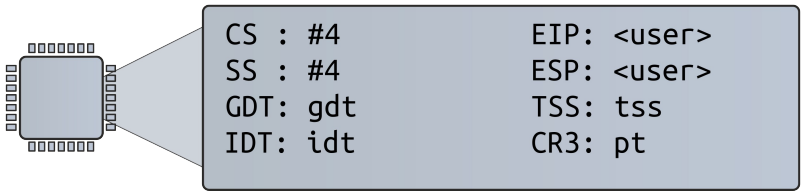




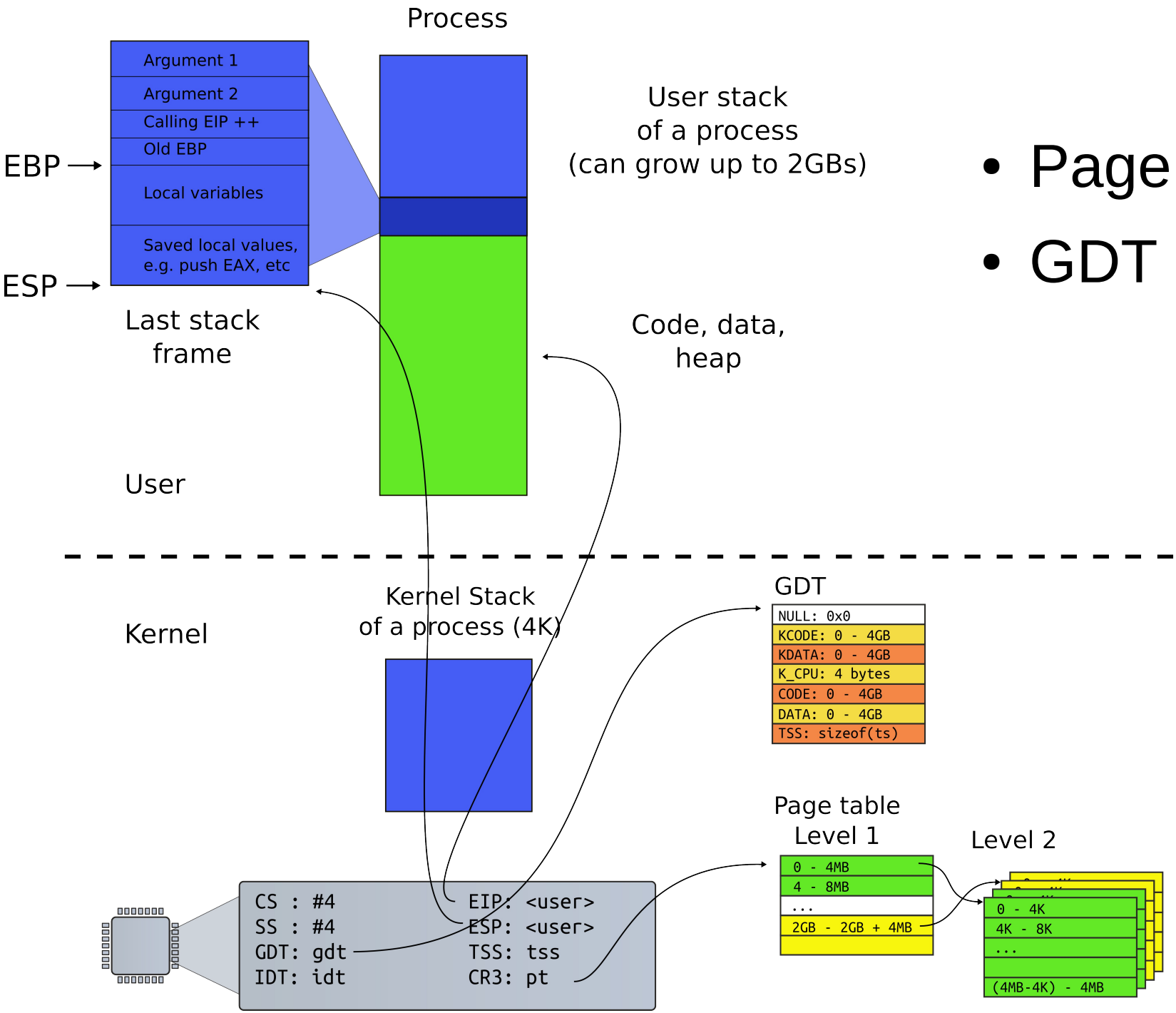
System calls



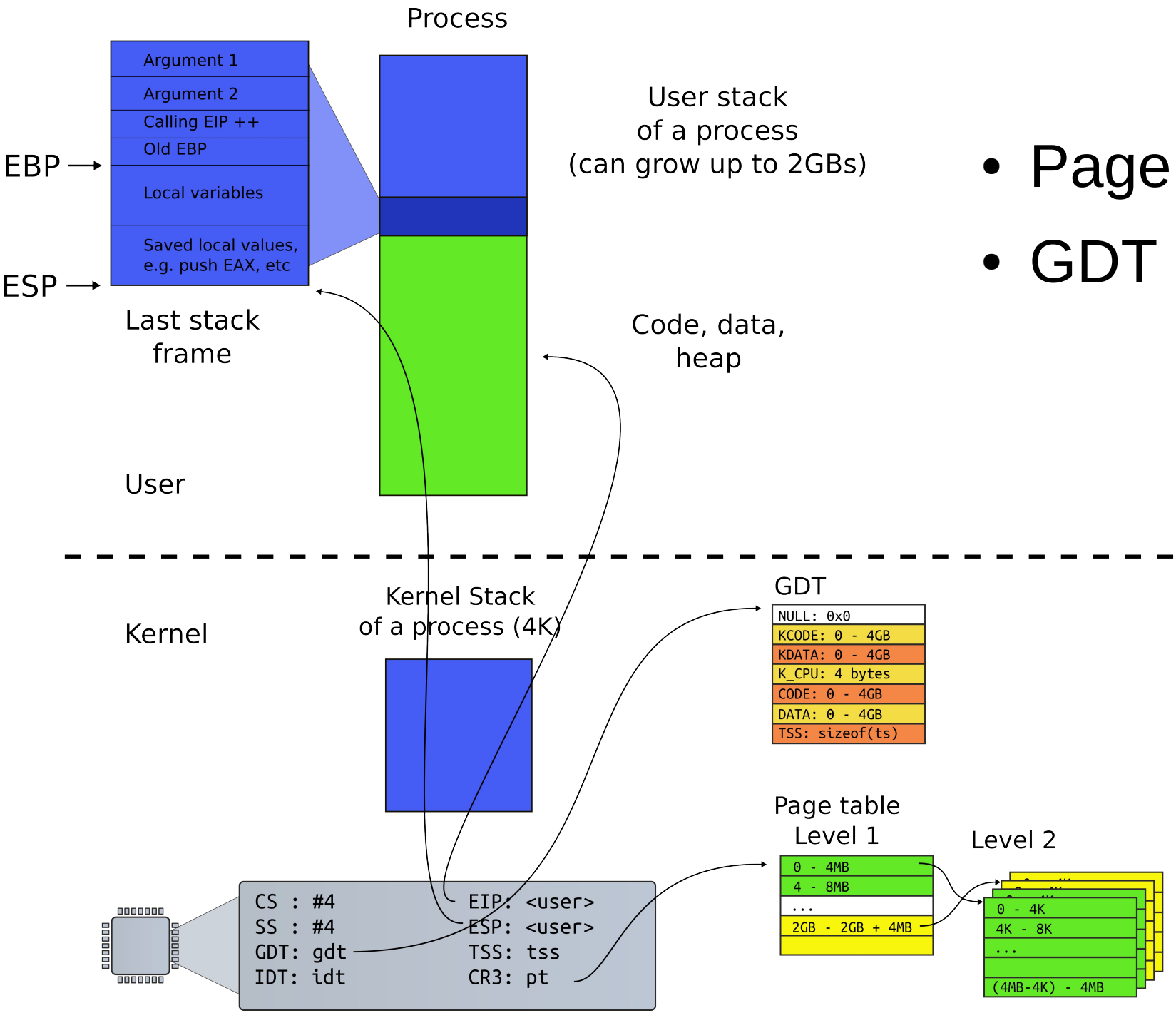




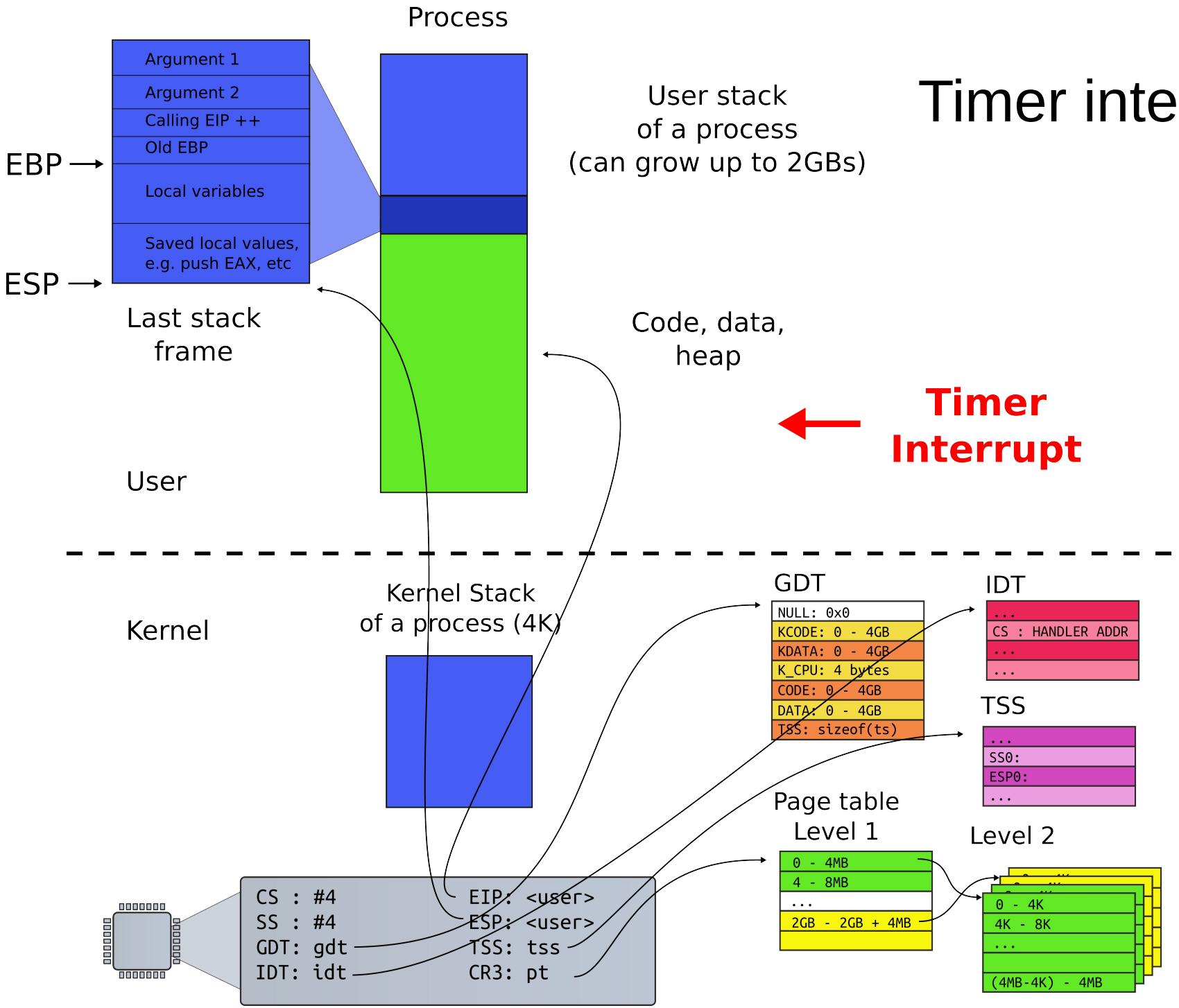
- User mode
- Two stacks
  - Kernel and user
  - Kernel stack is empty



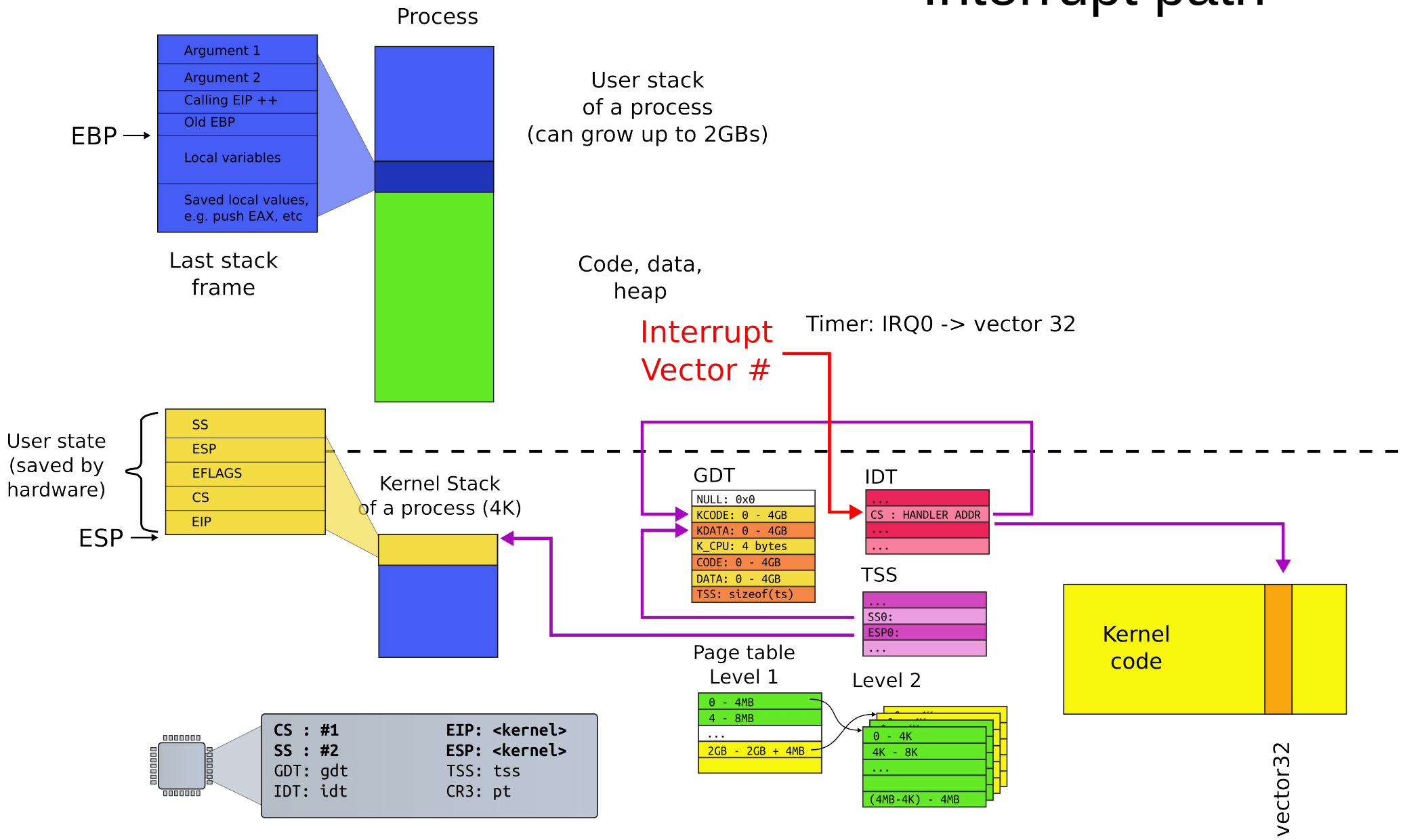
- Page table
- GDT



- Page table
- GDT


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



Initialize IDT

- tvinit() is called from main()

```
3316 void
3317 tvinit(void)
3318 {
3319   int i;
3320
3321   for(i = 0; i < 256; i++)
3322     SETGATE(idt[i], 0, SEG_KCODE<<3, vectors[i], 0);
3323   SETGATE(idt[T_SYSCALL], 1, SEG_KCODE<<3,
                vectors[T_SYSCALL], DPL_USER);
3324
3325   initlock(&tickslock, "time");
3326 }
```

Initialize IDT

- A couple of important details

```
3316 void
3317 tvinit(void)
3318 {
3319   int i;
3320
3321   for(i = 0; i < 256; i++)
3322     SETGATE(idt[i], 0, SEG_KCODE<<3, vectors[i], 0);
3323   SETGATE(idt[T_SYSCALL], 1, SEG_KCODE<<3,
                vectors[T_SYSCALL], DPL_USER);
3324
3325   initlock(&tickslock, "time");
3326 }
```

Initialize IDT

- Only int T_SYSCALL can be called from user-level

```
3316 void
3317 tvinit(void)
3318 {
3319   int i;
3320
3321   for(i = 0; i < 256; i++)
3322     SETGATE(idt[i], 0, SEG_KCODE<<3, vectors[i], 0);
3323   SETGATE(idt[T_SYSCALL], 1, SEG_KCODE<<3,
                vectors[T_SYSCALL], DPL_USER);
3324
3325   initlock(&tickslock, "time");
3326 }
```

Initialize IDT

- Syscall is a “trap”
- i.e., doesn't disable interrupts

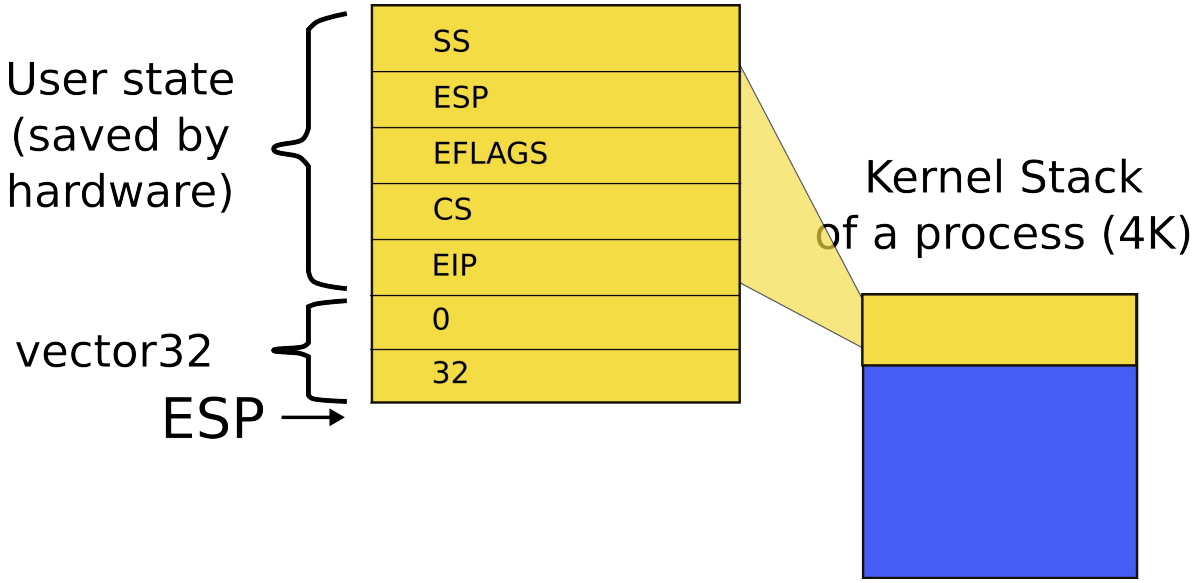
```
3316 void
3317 tvinit(void)
3318 {
3319   int i;
3320
3321   for(i = 0; i < 256; i++)
3322     SETGATE(idt[i], 0, SEG_KCODE<<3, vectors[i], 0);
3323   SETGATE(idt[T_SYSCALL], 1, SEG_KCODE<<3,
                vectors[T_SYSCALL], DPL_USER);
3324
3325   initlock(&tickslock, "time");
3326 }
```

Where does IDT (entry 64) point to?

```
vector64:
  pushl $0     // error code
  pushl $64    // vector #
  jmp alltraps
```

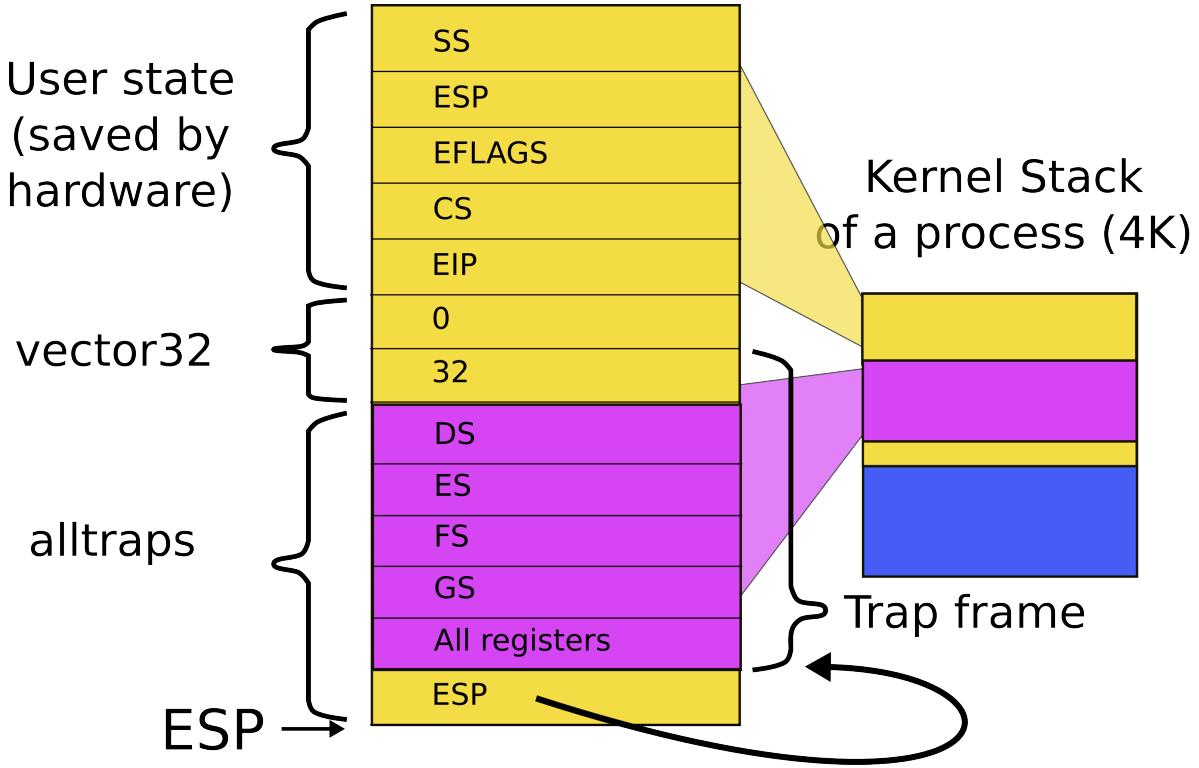
- Automatically generated
- From vectors.pl
  - vector.S

Kernel stack after interrupt



Call stack: vector32()

Kernel stack after interrupt



Call stack: vector32()
alltraps()

Syscall number

- System call number is passed in the %eax register
  - To distinguish which syscall to process, e.g., sys_read, sys_exec, etc.
- alltrap() saves it as rest of the registers

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
```

```
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();
```

Remember we went to trap() to handle timer interrup

```
3351 trap(struct trapframe *tf)
3352 {
3353   if(tf->trapno == T_SYSCALL){
3354     if(proc->killed)
3355       exit();
3356     proc->tf = tf;
3357     syscall();
3358     if(proc->killed)
3359       exit();
3360     return;
3361   }
3362
3363   switch(tf->trapno){
3364   case T_IRQ0 + IRQ_TIMER:
```

Same for syscalls

syscall(): get the number from trap frame

```
3625 syscall(void)
3626 {
3627   int num;
3628
3629   num = proc->tf->eax;
3630   if(num > 0 && num < NELEM(syscalls) && syscalls[num])
       {
3631     proc->tf->eax = syscalls[num]();
3632   } else {
3633     cprintf("%d %s: unknown sys call %d\n",
3634     proc->pid, proc->name, num);
3635     proc->tf->eax = -1;
3636   }
3637 }
```

syscall(): process a syscall from the table

```
3625 syscall(void)
3626 {
3627   int num;
3628
3629   num = proc->tf->eax;
3630   if(num > 0 && num < NELEM(syscalls) && syscalls[num])
       {
3631     proc->tf->eax = syscalls[num]();
3632   } else {
3633     cprintf("%d %s: unknown sys call %d\n",
3634     proc->pid, proc->name, num);
3635     proc->tf->eax = -1;
3636   }
3637 }
```

System call table

```
3600 static int (*syscalls[])(void) = {
3601   [SYS_fork] sys_fork,
3602   [SYS_exit] sys_exit,
3603   [SYS_wait] sys_wait,
3604   [SYS_pipe] sys_pipe,
3605   [SYS_read] sys_read,
3606   [SYS_kill] sys_kill,
3607   [SYS_exec] sys_exec,
3608   [SYS_fstat] sys_fstat,
3609   [SYS_chdir] sys_chdir,
3610   [SYS_dup] sys_dup,
3611   [SYS_getpid] sys_getpid,
3612   [SYS_sbrk] sys_sbrk,
3613   [SYS_sleep] sys_sleep,
3614   [SYS_uptime] sys_uptime,
3615   [SYS_open] sys_open,
3616   [SYS_write] sys_write,
3617   [SYS_mknod] sys_mknod,
3618   [SYS_unlink] sys_unlink,
3619   [SYS_link] sys_link,
3620   [SYS_mkdir] sys_mkdir,
3621   [SYS_close] sys_close,
3622 };
```

What do you think is the first system call xv6 executes?

```
1317 main(void)
1318 {
1319   kinit1(end, P2V(4*1024*1024)); // phys page allocator
1320   kvmalloc(); // kernel page table
1321   mpinit(); // detect other processors
...
1323   seginit(); // segment descriptors
...
1330   tvinit(); // trap vectors
...
1338   userinit(); // first user process
1339   mpmain(); // finish this processor's setup
1340 }
```

Userinit() – create first process

- Allocate process structure
  - Information about the process

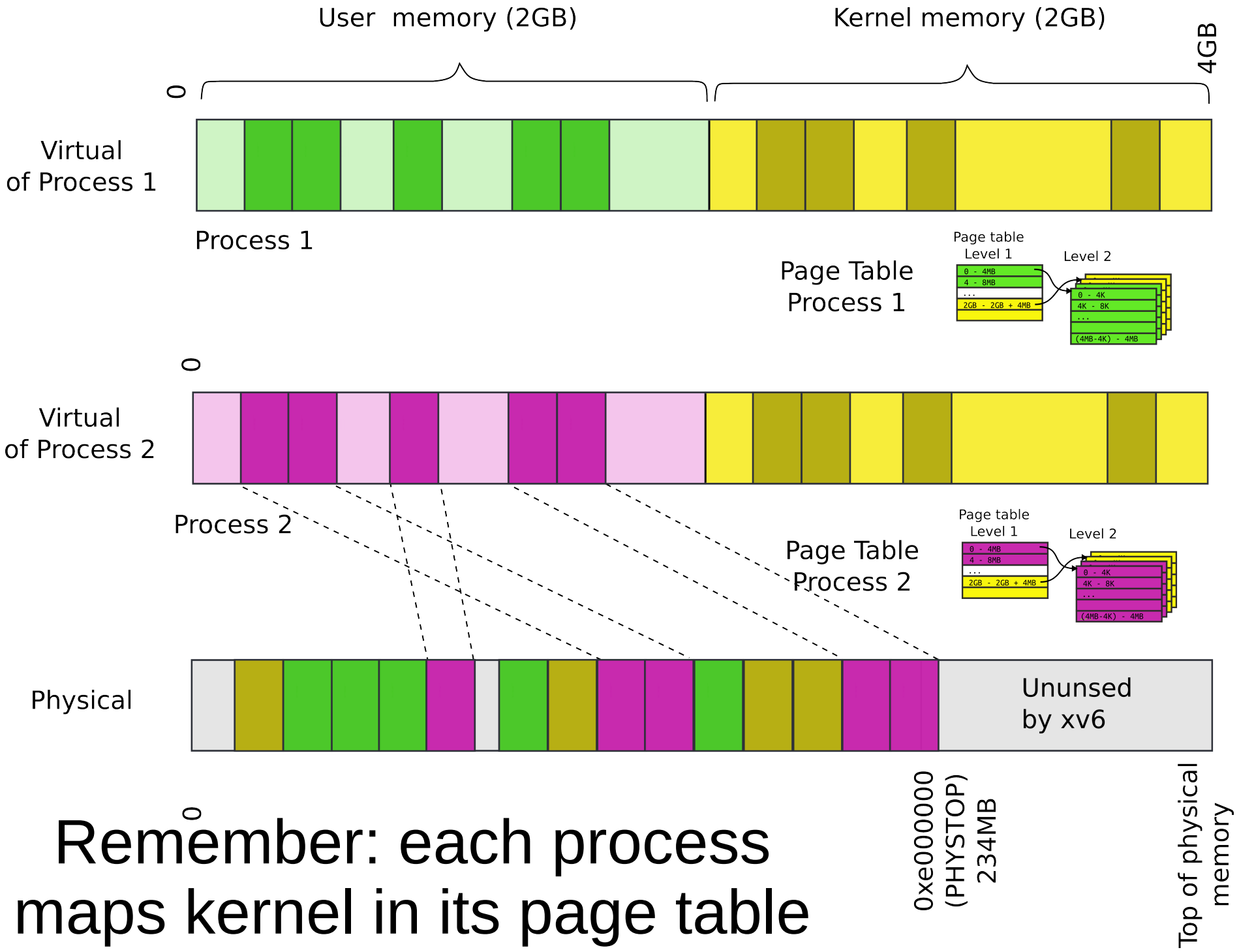
```
2502 userinit(void)
2503 {
2504   struct proc *p;
2505   extern char _binary_initcode_start[],
                  _binary_initcode_size[];
...
2509   p = allocproc();
2510   initproc = p;
2511   if((p->pgdir = setupkvm()) == 0)
2512     panic("userinit: out of memory?");
2513   inituvm(p->pgdir, _binary_initcode_start,
              (int)_binary_initcode_size);
2514   p->sz = PGSIZE;
2515   memset(p->tf, 0, sizeof(*p->tf));
...
2530 }
```

```
2103 struct proc {
2104   uint sz; // Size of process memory (bytes)
2105   pde_t* pgdir; // Page table
2106   char *kstack; // Bottom of kernel stack for this process
2107   enum procstate state; // Process state
2108   volatile int pid; // Process ID
2109   struct proc *parent; // Parent process
2110   struct trapframe *tf; // Trap frame for current syscall
2111   struct context *context; // swtch() here to run
2112   void *chan; // If non-zero, sleeping on chan
2113   int killed; // If non-zero, have been killed
2114   struct file *ofile[NOFILE]; // Open files
2115   struct inode *cwd; // Current directory
2116   char name[16]; // Process name (debugging)
2117 };
```

Userinit() – create first process

- Allocate process structure
  - Information about the process
- **Create a page table**
  - **Map only kernel space**

```
2502 userinit(void)
2503 {
2504   struct proc *p;
2505   extern char _binary_initcode_start[],
                  _binary_initcode_size[];
...
2509   p = allocproc();
2510   initproc = p;
2511    if((p->pgdir = setupkvm()) == 0)
2512      panic("userinit: out of memory?");
2513   inituvm(p->pgdir, _binary_initcode_start,
              (int)_binary_initcode_size);
2514   p->sz = PGSIZE;
2515   memset(p->tf, 0, sizeof(*p->tf));
...
2530 }
```



Remember: each process maps kernel in its page table

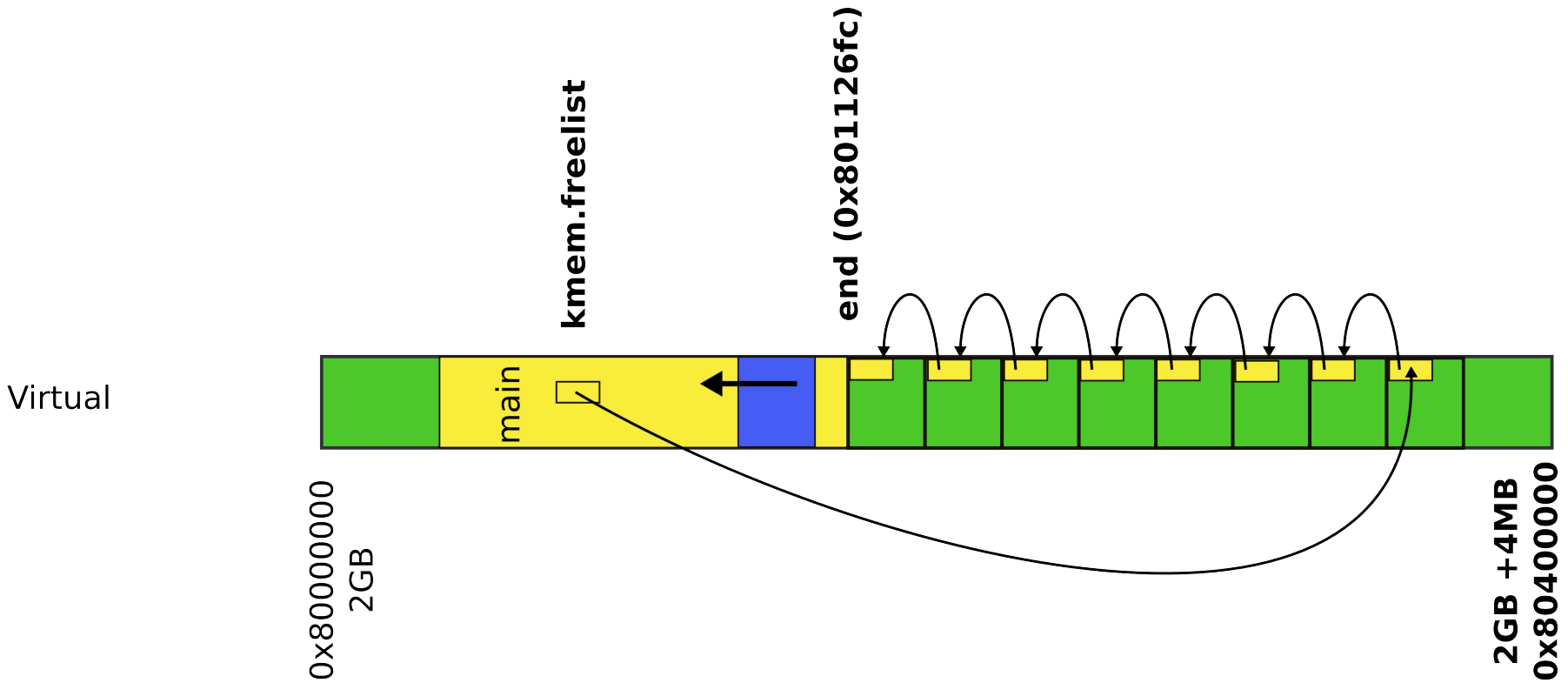
Userinit() – create first process

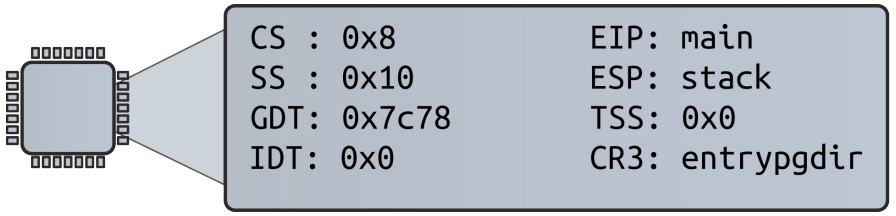
- Allocate process structure
  - Information about the process
- Create a page table
  - Map only kernel space
- **Allocate a page for the user init code**
  - **Map this page**

```
2502 userinit(void)
2503 {
2504   struct proc *p;
2505   extern char _binary_initcode_start[],
                  _binary_initcode_size[];
...
2509   p = allocproc();
2510   initproc = p;
2511   if((p->pgdir = setupkvm()) == 0)
2512     panic("userinit: out of memory?");
2513   inituvm(p->pgdir, _binary_initcode_start,
              (int)_binary_initcode_size);
2514   p->sz = PGSIZE;
2515   memset(p->tf, 0, sizeof(*p->tf));
...
2530 }
```

```
1903 inituvm(pde_t *pgdir, char *init, uint sz)
1904 {
1905   char *mem;
1906
1907   if(sz >= PGSIZE)
1908     panic("inituvm: more than a page");
1909   mem = kalloc();
1910   memset(mem, 0, PGSIZE);
1911   mappages(pgdir, 0, PGSIZE, V2P(mem),
                PTE_W|PTE_U);
1912   memmove(mem, init, sz);
1913 }
```

Recap: kalloc() – allocate page





Protected Mode

```
1903 inituvm(pde_t *pgdir, char *init, uint sz)
1904 {
1905   char *mem;
1906
1907   if(sz >= PGSIZE)
1908     panic("inituvm: more than a page");
1909   mem = kalloc();
1910   memset(mem, 0, PGSIZE);
1911   mappages(pgdir, 0, PGSIZE, V2P(mem),
                PTE_W|PTE_U);
1912   memmove(mem, init, sz);
1913 }
```

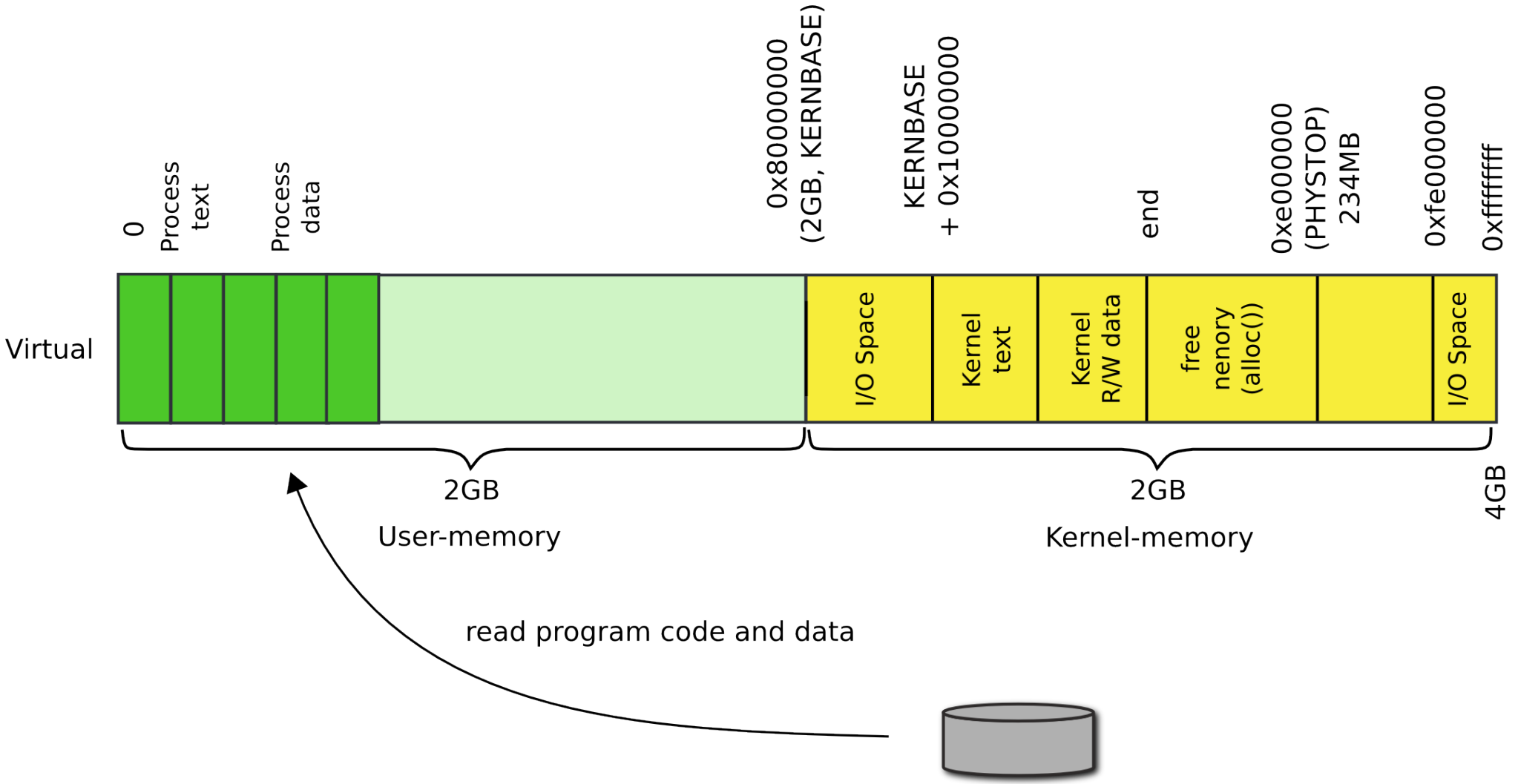
```
2502 userinit(void)
2503 {
2504   struct proc *p;
2505   extern char _binary_initcode_start[],
                  _binary_initcode_size[];
...
2509   p = allocproc();
2510   initproc = p;
2511   if((p->pgdir = setupkvm()) == 0)
2512     panic("userinit: out of memory?");
2513   inituvm(p->pgdir, _binary_initcode_start,
              (int)_binary_initcode_size);
2514   p->sz = PGSIZE;
2515   memset(p->tf, 0, sizeof(*p->tf));
...
2530 }
```

```
1903 inituvm(pde_t *pgdir, char *init, uint sz)
1904 {
1905   char *mem;
1906
1907   if(sz >= PGSIZE)
1908     panic("inituvm: more than a page");
1909   mem = kalloc();
1910   memset(mem, 0, PGSIZE);
1911   mappages(pgdir, 0, PGSIZE, V2P(mem),
                PTE_W|PTE_U);
1912   memmove(mem, init, sz);
1913 }
```

```
8409 start:
8410   pushl $argv
8411   pushl $init
8412   pushl $0 // where caller pc would be
8413   movl $SYS_exec, %eax
8414   int $T_SYSCALL
8415
...
8422 # char init[] = "/init\0";
8423 init:
8424   .string "/init\0"
8425
8426 # char *argv[] = { init, 0 };
8427 .p2align 2
8428 argv:
8429   .long init
8430   .long 0
```

Userinit.S: call exec(“/init”, argv);

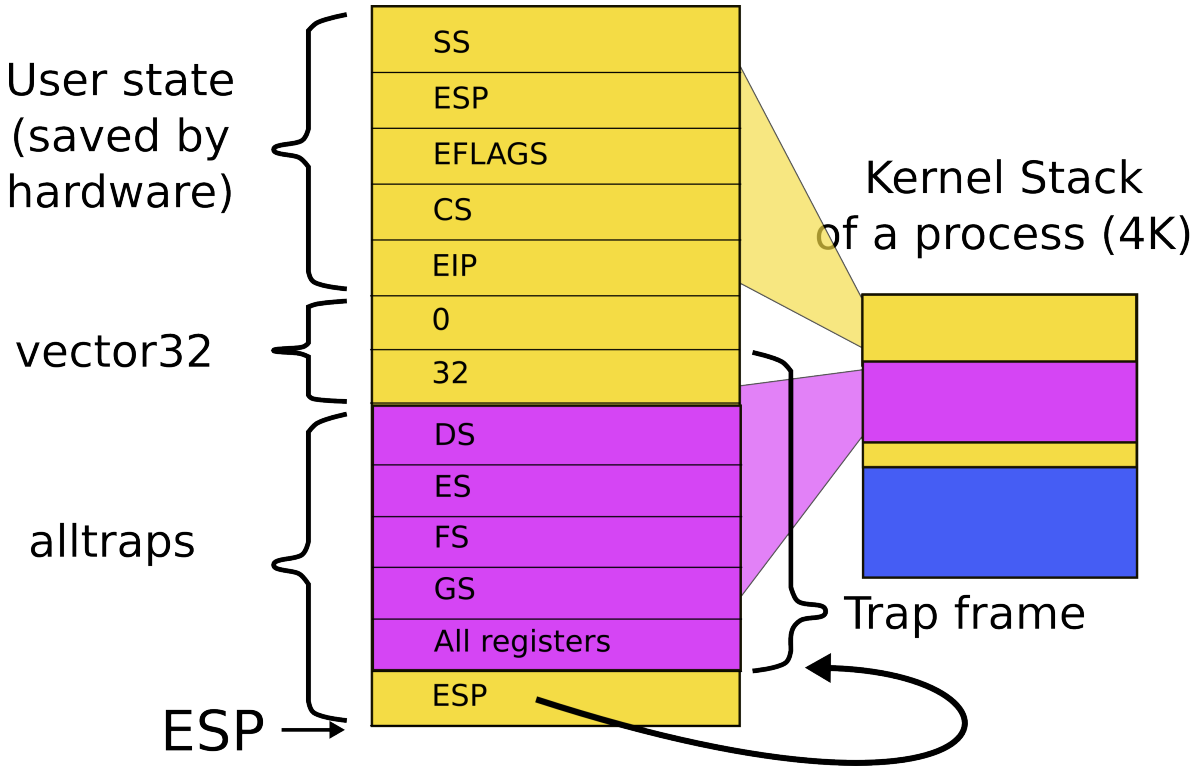
Where does userinit.S go?



Userinit() – create first process

- Allocate process structure
  - Information about the process
- Create a page table
  - Map only kernel space
- Allocate a page for the user init code
  - Map this page
- **Configure trap frame for “iret”**

Kernel stack after interrupt/syscall



Call stack: vector32()
alltraps()

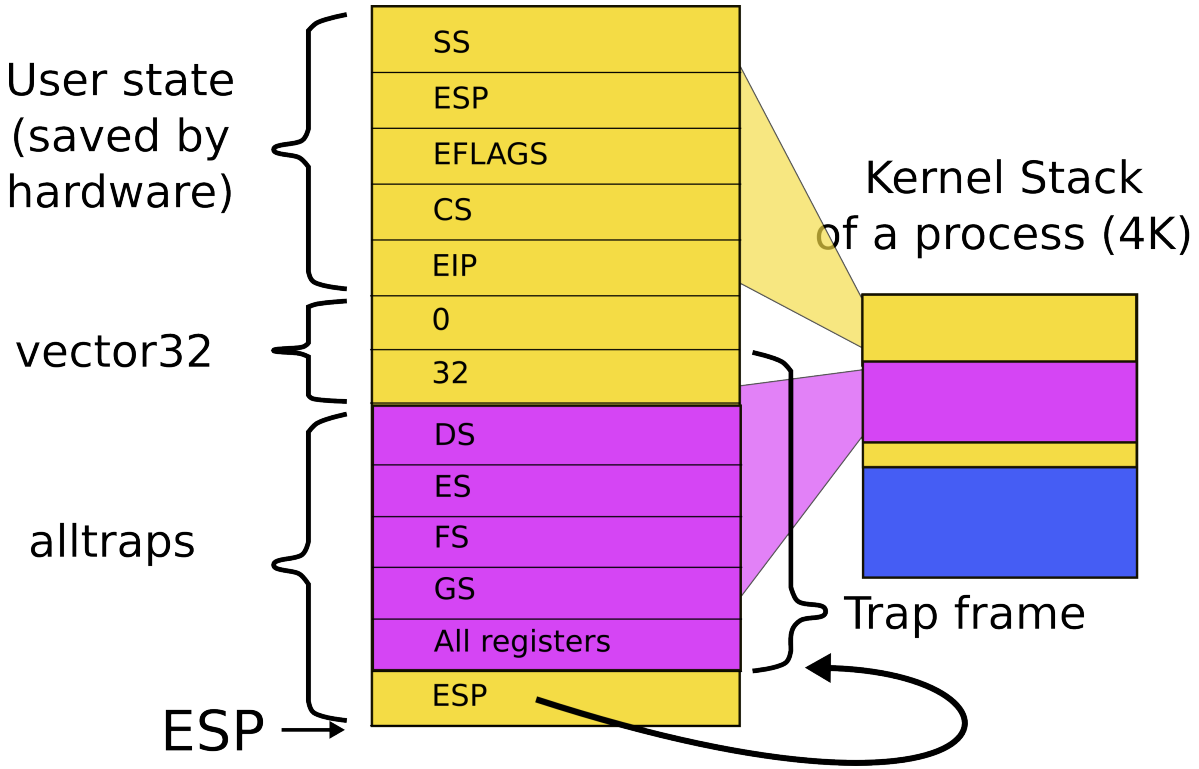
```
2103 struct proc {
2104   uint sz; // Size of process memory (bytes)
2105   pde_t* pgdir; // Page table
2106   char *kstack; // Bottom of kernel stack for this process
2107   enum procstate state; // Process state
2108   volatile int pid; // Process ID
2109   struct proc *parent; // Parent process
2110   struct trapframe *tf; // Trap frame
2111   struct context *context; // swtch() here to run
2112   void *chan; // If non-zero, sleeping on chan
2113   int killed; // If non-zero, have been killed
2114   struct file *ofile[NOFILE]; // Open files
2115   struct inode *cwd; // Current directory
2116   char name[16]; // Process name (debugging)
2117 };
```

```
2456 allocproc(void)
2457 {
...
2470   // Allocate kernel stack.
2471   if((p->kstack = kalloc()) == 0){
2472     p->state = UNUSED;
2473     return 0;
2474   }
2475   sp = p->kstack + KSTACKSIZE;
2476
2477   // Leave room for trap frame.
2478   sp -= sizeof *p->tf;
2479   p->tf = (struct trapframe*)sp;
2480
...
2492 }
```

Trap frame is on the kernel stack of the process

```
2502 userinit(void)
2503 {
...
2513   inituvm(p->pgdir, _binary_initcode_start,
                (int)_binary_initcode_size);
2514   p->sz = PGSIZE;
2515   memset(p->tf, 0, sizeof(*p->tf));
2516   p->tf->cs = (SEG_UCODE << 3) | DPL_USER;
2517   p->tf->ds = (SEG_UDATA << 3) | DPL_USER;
2518   p->tf->es = p->tf->ds;
2519   p->tf->ss = p->tf->ds;
2520   p->tf->eflags = FL_IF;
2521   p->tf->esp = PGSIZE;
2522   p->tf->eip = 0; // beginning of initcode.S
...
2530 }
```

Kernel stack after interrupt/syscall

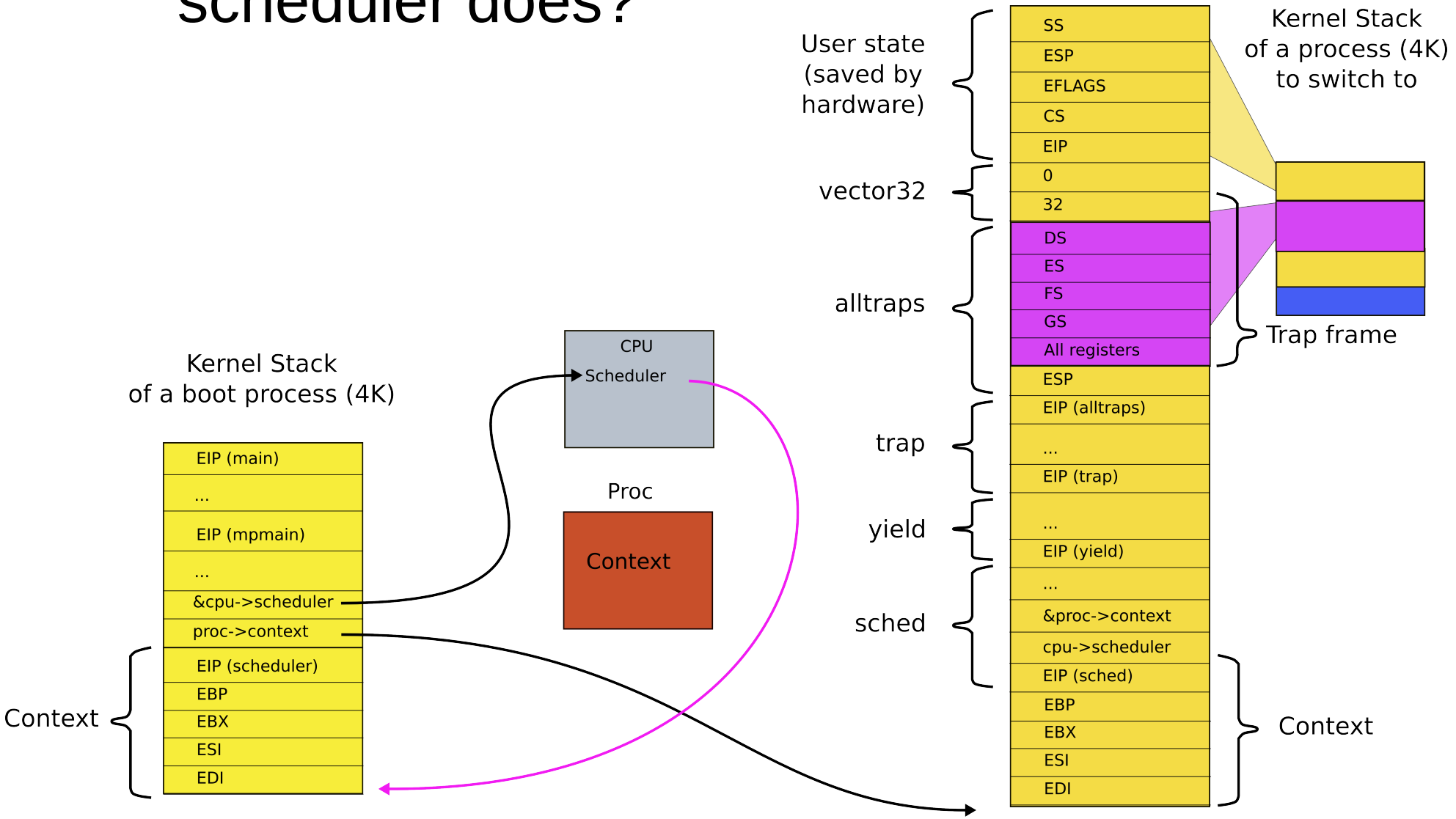


Call stack: vector32()
alltraps()

```
2502 userinit(void)
2503 {
...
2515   memset(p->tf, 0, sizeof(*p->tf));
2516   p->tf->cs = (SEG_UCODE << 3) | DPL_USER;
2517   p->tf->ds = (SEG_UDATA << 3) | DPL_USER;
2518   p->tf->es = p->tf->ds;
2519   p->tf->ss = p->tf->ds;
2520   p->tf->eflags = FL_IF;
2521   p->tf->esp = PGSIZE;
2522   p->tf->eip = 0; // beginning of initcode.S
2523
2524   safestrcpy(p->name, "initcode", sizeof(p->name));
2525   p->cwd = namei("/");
2526
2527   p->state = RUNNABLE;
...
2530 }
```

Wait, we mapped process memory, created trap frame, but it doesn't really run...

Remember what scheduler does?



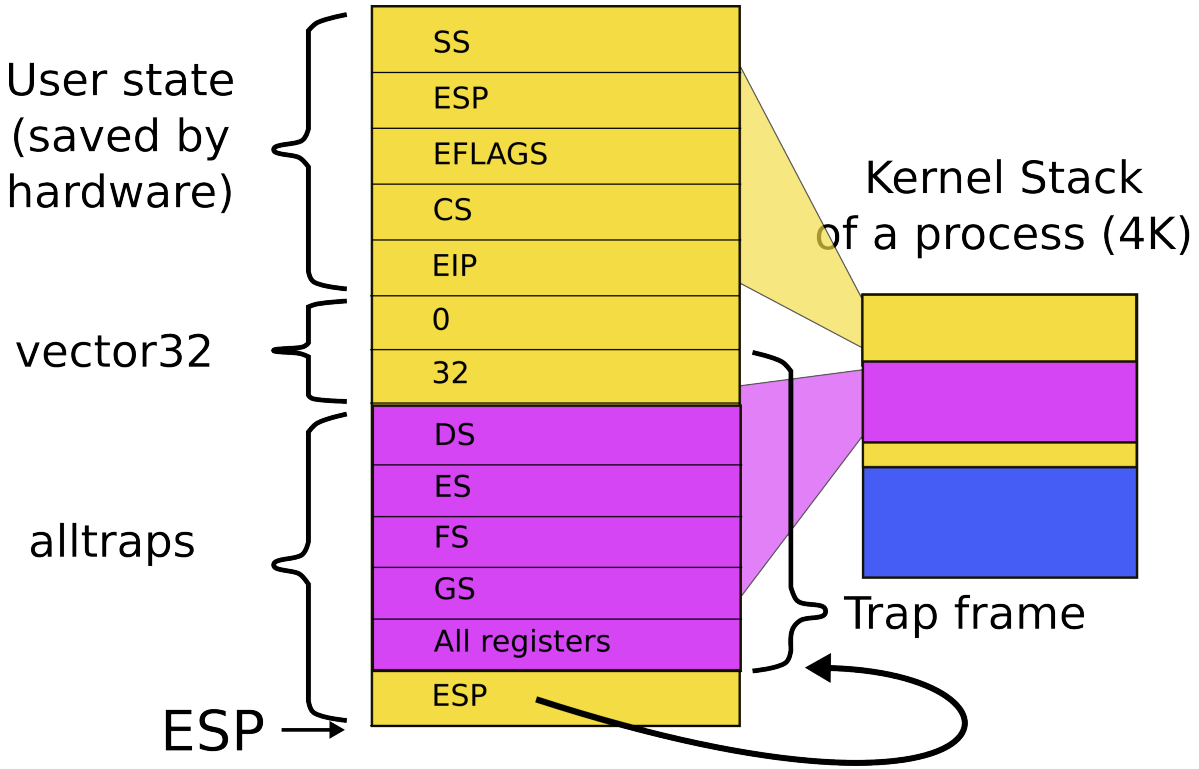
```
2456 allocproc(void)
2457 {
...
2477   // Leave room for trap frame.
2478   sp -= sizeof *p->tf;
2479   p->tf = (struct trapframe*)sp;
2480
2481   // Set up new context to start executing at forkret,
2482   // which returns to trapret.
2483   sp -= 4;
2484   *(uint*)sp = (uint)trapret;
2485
2486   sp -= sizeof *p->context;
2487   p->context = (struct context*)sp;
2488   memset(p->context, 0, sizeof *p->context);
2489   p->context->eip = (uint)forkret;
...
2492 }
```

Trap frame is on the kernel stack of the process

forkret(): just returns

```
2788 forkret(void)
2789 {
...
2803   // Return to "caller",
         actually trapret (see
         allocproc).
2804 }
```

Kernel stack after interrupt/syscall



Call stack: vector32()
alltraps()

```
3276 .globl trapret
3277 trapret:
3278   popal
3279   popl %gs
3280   popl %fs
3281   popl %es
3282   popl %ds
3283   addl $0x8, %esp # trapno and
                       errcode
3284   iret
```

forkret(): just returns

Back to the first system call: exec()

Summary

- We've finally learned how the first process came to life
- We're half way into system calls

Thank you

sys_exec()

```
6225 sys_exec(void)
6226 {
6227   char *path, *argv[MAXARG];
6228   int i;
6229   uint uargv, uarg;
6230
6231   if(argstr(0, &path) < 0 || argint(1, (int*)&uargv) < 0){
6232     return -1;
6233   }
6234   memset(argv, 0, sizeof(argv));
6235   for(i=0;; i++){
6236     if(i >= NELEM(argv))
6237       return -1;
6238     if(fetchint(uargv+4*i, (int*)&uarg) < 0)
6239       return -1;
6240     if(uarg == 0){
6241       argv[i] = 0;
6242       break;
6243     }
6244     if(fetchstr(uarg, &argv[i]) < 0)
6245       return -1;
6246   }
6247   return exec(path, argv);
6248 }
```

```
6225 sys_exec(void)
6226 {
6227   char *path, *argv[MAXARG];
6228   int i;
6229   uint uargv, uarg;
6230
6231   if(argstr(0, &path) < 0
         || argint(1, (int*)&uargv) < 0){
6232     return -1;
6233   }
...
6247   return exec(path, argv);
6248 }
```

sys_exec()